

**Transcript of the
Joint FAA/Industry Symposium
on
Level B Airplane Simulator
Motion Requirements**

Part 1 of 9

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**Washington Dulles Airport Hilton
June 19 - 20, 1996**

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Part 2 of 9

Preface

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Preface

This is the transcript of the *Joint FAA/Industry Symposium on Level B Airplane Simulator Motion Requirements* held on June 19 - 20, 1996, at the Washington Dulles Airport Hilton. The purpose of the meeting was to discuss the motion considerations associated with updating FAA qualification requirements for Level B flight simulators. It is available to the public on 3.5" high density drive diskettes in Adobe Acrobat Portable Document File (PDF) format from Dr. Thomas Longridge, Advanced Qualification Program Manager, AFS-230, Tel. 703-661-0275. The document is platform, application, and font independent and may be viewed and printed using Adobe Acrobat Reader, V. 3.0 for PC, UNIX, or Macintosh. The Reader is available from the Internet at <http://www.acrobat.com> or, upon request, on a second diskette.

Flight simulator technology has advanced significantly during the past decade, one result of which is that device capability has increased while cost has declined. However, for commuter airlines, cost continues to be an obstacle to flight simulator access, particularly for recurrent training. We believe that it may be possible to revise Level B simulator qualification procedures and requirements to enhance affordability, without degrading the standards or quality of performance for such equipment. The first step in this endeavor is a comprehensive review, which began with aeromodeling and flight data considerations and continues with the discussion of motion requirements reported in this transcript. The overall project is described in Longridge, T., Ray, P., Boothe, E., & Bürki-Cohen, J. (1996): Initiative towards more affordable flight simulators for U.S. commuter airline training, *Royal Aeronautical Society Conference on Training - Lowering the Cost, Maintaining the Fidelity* (pp. 2.1-2.17), London, UK, in *07Apx1.pdf*. *08Apx2.pdf* contains the conclusions from both workshops. The pertinent literature from the past two decades, including broad guidelines for an appropriate research design, is discussed in Bürki-Cohen, J., Soja, N., & Longridge, T.: Simulator Platform Motion—The Need Revisited, submitted to the *International Journal of Aviation Psychology*, in *09Apx3.pdf*.

Attendance at the symposium was by invitation only and included experts from industry, academia, and government in the disciplines of simulator motion, simulator qualification, aircraft certification, air carrier pilot training, and human factors (*03Partic.pdf*). The meeting was chaired by Dr. Thomas Longridge, with the participation and cooperation of Mr. Paul Ray, Manager of the FAA's National Simulator Program. The technical discussions were led by Mr. Edward Boothe. Mr. Donald Eldredge of Battelle was responsible for the meeting logistics. The discussions were recorded live by Mr. Dave and Ms. Allison Hoyman of RealTime Reporters. Dr. Nancy Soja incorporated the participants' comments. Ms. Mary Townsend and Ms. Julie Guinn applied the final editing touches to the transcript. The overall project is managed for Dr. Eleana Edens of the FAA's Office of the Chief Scientist for Human Factors by Dr. Judith Bürki-Cohen of the Department of Transportation's Volpe Center. We extend our highest appreciation and gratitude to all.

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Participants

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Participants

Sunjoo Advani	SIMONA International Centre for Research in Simulation, Motion and Navigation Technologies , Delft University of Technology
Bruce Baker	Servos and Simulation, Inc.
Normand Bluteau	CAE Electronics, Ltd.
Edward Boothe	Consultant, Flight Simulation and Training
Judith Bürki-Cohen	United States Department of Transportation, Volpe National Transportation Systems Center
Frank Cardullo	State University of New York at Binghamton
Donald Eldredge	Battelle
Robert Foster	USAirways
Geoffrey Harris	Thomson Training & Simulation, Ltd.
Robert Heffley	Robert Heffley Engineering
Donald Irving	United Kingdom Civil Aviation Authority
Thomas Longridge	United States Federal Aviation Administration, Advanced Qualification Program
Edward Martin	United States Air Force, Armstrong Laboratories
Paul Ray	United States Federal Aviation Administration, National Simulator Program
Lloyd Reid	University of Toronto
Hilton Smith	United States Federal Aviation Administration, National Simulator Program
Charles Stocking	Hughes Training, Inc.
Donald Sussman	United States Department of Transportation, Volpe National Transportation Systems Center
Stuart Willmott	SimuFlite Training International

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Abbreviations

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Abbreviations

727	Boeing 727; 3-engine jet transport airplane
737	Boeing 737; 2-engine jet transport airplane
747(-400)	Boeing 747(-400); 4-engine wide-body jet transport airplane
757	Boeing 757; 2-engine jet transport airplane
767	Boeing 767; 2-engine wide-body jet transport airplane
777	Boeing 777; 2-engine wide-body long-range jet transport airplane
AC	Advisory Circular
ADI	Attitude Director Indicator
AGARD	North Atlantic Treaty Organization Advisory Group for Aerospace Research and Development
AH-1(W)	Bell Huey Cobra 1(2)-engine attack helicopter
AQP	Advanced Qualification Program
A to D	Analog to Digital
B-2	Northrop Spirit 4-engine stealth bomber airplane
B-1900	Beechcraft 1900 2-engine turboprop airplane
C-5	Lockheed Galaxy 4-engine military cargo/transport airplane
C-17	McDonnell Douglas 4-engine military cargo/transport airplane
C-130	Lockheed Hercules 4-engine military cargo/transport turboprop airplane
CAA	Civil Aviation Authority (United Kingdom)
CAE	CAE Electronics Limited; Canadian simulator designer and manufacturer
CEN	Comité Européen de Normalisation (European Committee for Standardization)
CG	Center of Gravity
CH-46	Boeing-Vertol Sea Knight 2-engine tandem-rotor transport helicopter
Chinook	Boeing-Vertol CH-47 2-engine tandem-rotor transport helicopter
CNN	Cable News Network
CRT	Cathode Ray Tube,
DASH 8	Bombardier (De Havilland) 2-engine turboprop airplane
DC-9(-80)	McDonnell Douglas 2-engine jet transport airplane
DC-10	McDonnell Douglas 3-engine wide-body jet transport airplane

DOF	Degrees Of Freedom
D to A	Digital to Analog
EFIS	Electronic Flight Instrument System
F-4	McDonnell Douglas Phantom II 2-engine multi-role fighter
F-14	Grumman Tomcat 2-engine multi-role fighter
F-15	McDonnell Douglas Eagle 2-engine fighter
F-16	Lockheed Martin Fighting Falcon 1-engine multi-role fighter
F-18	McDonnell Douglas Hornet 2-engine multi-role fighter
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
FSAA	Flight Simulator for Advanced Aircraft
FTD	Flight Training Device
g	acceleration due to gravity, 9.8 meters per second squared (m/sec ²)
GP-4	General Purpose computer used in flight simulators
heli	helicopter
IATA	International Air Transport Association
IFR	Instrument Flight Rules
IG	Image Generator
JAA	Joint Aviation Authorities (Europe)
KLM	Koninklijke Luchtvaart Maatschappij voor Nederland en Koloniën (Royal Dutch Airlines)
LOE	Line Oriented Evaluation
LOFT	Line Oriented Flight Training
m	mass
mil	milliseconds
MIL-STD	Military Standard
NADS	National Advanced Driving Simulator
NASA	National Aeronautics & Space Administration
NASA-Ames	NASA Ames Research Center, Moffett Field, California
NLR	National Lucht- en Ruimvaartlaboratorium (National Aerospace Laboratory, The Netherlands)
NT-33	Airforce variable stability airplane (modified T-33 trainer)

P-51	North American Mustang 1-engine World War II fighter
PC	Personal Computer
PDP-11	Programmable Data Processor (Digital Equipment Corporation)
PIO	Pilot Induced Oscillation
prop	propeller
PSD	Power Spectral Density
psi	pounds per square inch
RAA	Regional Airlines Association
RATS	Roll Axis Tracking Simulator
R&D	Research and Development
reg(s)	regulation
RLD	Rijksluchtvaartdienst (Dutch department of civil aviation)
RTO	Rejected Takeoff
SAS	Stability Augmentation System
sim(s)	simulators(s)
SIMONA	International Centre for Research in Simulation, Motion and Navigation Technologies, Delft, The Netherlands
SME	Subject Matter Expert
spec	specification
TDI	Training Devices Inc.
UK	United Kingdom
v	velocity (speed in a specified direction)
V₁	takeoff decision speed (formerly denoted as critical engine failure speed)
V-22	Bell/Boeing-Vertol Osprey 2-engine tilt-rotor vertical/short takeoff & landing aircraft
VGA	Video Graphics Array
V_{MCA}	minimum control speed with the critical engine inoperative ¹
VMS	Vertical Motion Simulator at NASA-Ames
x double-dot	the second derivative of x; denotes acceleration
x	longitudinal body axis
y	lateral body axis
z	vertical body axis

¹ The sub a indicates in the air in take-off configuration

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Transcript of Day 1

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Transcript of Day 1

MR. LONGRIDGE: Let's get started. I believe everybody has taken name tags. If you have not done so, please do so, as the transcriber will need to refer to these in order to record who is talking. So please put these in a position where our transcriber can read your name.

Welcome to this distinguished group, my name is Tom Longridge. I'm going to give you a very brief overview of why we are having this meeting and in general what we are looking for to come out of it. For those of you that were at our last meeting I apologize, this is repetitious, but a number of you weren't. So I will simply say in terms of background, the FAA has a problem. We issued a commuter rule around the first of this year, that commuter rule was intended to establish one standard of safety for regional airlines, for commuter airlines, as well as major air carriers. One of the requirements for one standard of safety, of course, is the quality of training and the use of training devices.

The problem is that for the commuter airlines we don't have the availability of simulators that we have for the major airlines. The reason that we don't, as you all know, I'm sure, has principally to do with the cost of these devices for commuter airlines. The cost of a full flight simulator may actually exceed that of the aircraft, certainly the cost of conducting training is arguably more expensive in a flight simulator for some of these regional airlines as it may be in an aircraft. And yet the FAA is committed to get commuter airlines into training equipment and full flight simulators.

So that's the essence of this particular project, we are viewing the considerations that have to do with the cost of full flight simulators and trying to come up with recommendations that will make the costs of those devices more accessible to that community.

I'm the manager of the Advanced Qualification Program. The Advanced Qualification Program is an alternative to the traditional requirements for training and checking pilots. It does offer considerably more flexibility than do the standard Part 121 rules with regard to the use of training equipment, but even in the Advanced Qualification Program, which is focused on the use of scenario based full crew training and checking, even in that program we require a full flight simulator. We require a full flight simulator in order to execute the types of scenarios that are appropriate for checking the full range of operations for that community.

The Regional Airline Association, which is a lobbying group that represents commuter airlines, has come to the FAA with a proposal, that proposal is "well, because of the cost considerations associated with full flight simulators, what we would like to do is be able to take a flight training device and equip it with a visual system, and maybe some type of motion system." There are different proposals, some of them are based on the entertainment industry, and they are saying to us, "look FAA, if you want us to use training equipment you have to make some compromises, you are going to have to change the requirements to make this equipment accessible to us." We have looked at this proposal, we have certainly given it serious consideration, but we have determined at least at this point that agreeing to that type of proposal is not consistent with the original goal of one standard of safety for the major airlines and for the commuter airlines. We feel that the types of enhancements that would have to be made to flight training devices in order to permit their use for these purposes, those types of considerations could also be applied to a full flight simulator. So what we would like to do is to review the existing requirements for Level B full flight simulators with the idea in mind of trying to achieve the cost goals that these commuter airlines have for the use of flight training devices.

The FAA has settled on what we call a Level B simulator in this country, for those of you that are from overseas, and that is because our existing rules permit a Level B simulator to be employed for 100 percent of the recurrent training and checking requirements for airlines. So that to the extent that we can review the existing qualifications standards for Level B simulators and

achieve the cost goals that the regionals have for enhanced FTDs, we can achieve both their goals and the FAA's goals, enhanced quality of training for that community and also more affordable training equipment.

One of the advantages of this approach from our perspective as well is that it would not require any change to the existing regulatory language as pertains to the use of devices whereas the use of flight training devices, the use of simulators I should have said, whereas the use for flight training devices, that would require changes in language. For the FAA changes in regulatory language can take years.

So the bottom line is what we are trying to achieve is an increase in affordability without degrading the standards or quality of a Level B full flight simulator.

This is the second such meeting that we have had. What we are doing, our strategy, which has both a short-term component and a long-term component, is to convene the best experts that we can find in the various domains that pertain to reviewing the qualification standard for devices and the cost considerations, to come up with their recommendations on how we might achieve our goals, and for that matter whether those goals even in fact are achievable. We recognize that what we are proposing to do may not be achievable, or may not have a significant enough impact to achieve the desired goals.

So the focus of today's meeting is on motion cuing, the focus of the first meeting that we had a number of months ago was on aeromodeling. It was a very productive meeting, I think we did achieve recommendations that will result in cost savings without degrading quality. So we wanted to conduct a similar type of review as pertains to what I have called whole body motion cuing, which could be interpreted to mean platform motion. But we would, I think, entertain other approaches to whole body motion if any such approaches indeed exist or might be feasible. We already have, of course, a great body of knowledge in this area, we already have qualifications standards that speak to the motion cuing requirements of a full flight simulator, Level B. We know that, we recognize that. But we also know that we have now got 20 or 30 years of experience in the use of these devices; what we would like to do is to take a second look at those qualifications standards with the idea in mind of updating those standards to identify what might be considered to be the essential motion cues to the extent that modifications might be made in the cuing capabilities of motion systems that would also reduce cost.

And in view of what we have learned in the past 20 or 30 years, to make updated recommendations concerning the limits, tolerance and dynamics of motion cuing, what can be done in that regard to reduce costs without compromising that essential motion cuing.

Now, I need to add a caveat right now. It may be that some day the FAA will delete the requirement for platform motion from some level of device. We are not going to do that at the present time. And so it is not our purpose in meeting today to decide whether or not we need to retain or not retain platform motion for Level B simulators, we have made an arbitrary decision in the FAA that we are going to retain motion cuing for Level B simulators. But we are interested in the extent to which the costs associated with doing so can be reduced. We will in the future, I think, entertain the question of motion, no motion, but we are only going to do that when we have solemn empirical evidence that will enable the FAA to make that kind of change while still assuring the flying public that there has been no degradation in the quality or safety of training that is provided to air carrier pilots.

So we have both a short-term strategy, that short-term strategy is embodied in this meeting, that is to come up with the best expert recommendations that we can come up with regarding the changes that might be appropriate and to make those changes in our advisory materials that define what the qualification standards are for devices, for Level B.

And we have a long-term strategy, we would also like to seek input from you regarding having to do with future research that might be done to resolve still unresolved questions, I mean this is an area that we all know has been the subject of research for many, many years, decades.

And still we don't have the resolution of some of these issues. The FAA is prepared once again, after I guess a long hiatus of research in this arena, to initiate a systematic program of research addressing motion issues, and as we finish up tomorrow I think what we would like to do is to get the recommendations of this group on, given the limited resources that we have, what might be the highest priority for the research areas that might be addressed in motion.

Okay. I will just mention some session ground rules. As you can see, we have a transcriber present. I can tell you that this transcriber is very, very accurate. She doesn't miss a thing. If you burp, it will be in the proceeding. So based on our last experience, the transcript of the discussion that's going to take place today and tomorrow will be very accurately captured in writing. And each of you will be provided with the original drafts of these transcripts so you can make any corrections to your comments that you feel might be necessary. Based on our last experience, very few such corrections were in fact required.

Because we are transcribing, we need to abide by certain rules. One of them is of course one person speaks at a time. Our transcribers will quickly, I think, learn your names, however, during the, I think the first hour or so, you might want to identify yourself to facilitate transcribing the correct speaker.

The only problem that we had last time was occasionally people would mumble, she is not at all bashful, she will stop the proceedings and ask to you speak up, so I will ask you right now, please speak up so she can hear you.

We would like to stay focused on the session goals and agenda. All of you will have received a straw man set of tables¹ that was prepared by Ed Boothe that will provide the basis for most of the discussion. However, I'd like to say that we can by mutual agreement divert from our agenda, for example those of you that might have come prepared to make presentations that are pertinent to our goals today, I think that those presentations might be helpful, you are certainly encouraged and welcome to do so. I believe Sunjoo [Advani] has one such presentation.

MR. ADVANI: At some point I do. I have to take care of the technical difficulties in printing it out.

MR. LONGRIDGE: Okay. Also, I'd like to say, you know, we are not here to rubber stamp the FAA's opinions about anything, we really want an independent expression of thought, so that while consensus is always desirable, if it makes it easier, because it makes it easier to make decisions, alternative viewpoints, disagreeing points of view are certainly encouraged. That was our experience last time, we would also welcome those kinds of divergent viewpoints today. Time permitting, everyone's point of view will be heard and documented.

Everyone should have picked up an agenda as you walked in. If you don't have a copy of the agenda, I believe the pile was originally over where Sunjoo [Advani] is seated. We will more or less abide by this agenda. Our first break is at 10:00, we are going to have lunch, catered lunch at 12:00. There is a discussion—discussion will end approximately 4:30, we will have a cash bar, because the government is not permitted to pay for your liquor, we will buy your meals. Actually we can buy your wine.

MR. BAKER: Time for a revolution.

MR. LONGRIDGE: We will have wine tonight. But we can't pay for the drinks at the cash bar. So that's from 6:00 to 7:00, and the dinner will be from 7:00 to 9:00. Both of these will take place in Grand Ballroom 3, right through those doors, this evening. We will have a continental breakfast again tomorrow from 8:00 to 8:30. And as you depart tomorrow, this is for your information if you don't already know, the buses leave for the airport on the hour and half hour.

The materials you have in front of you can be left in this room overnight. So you don't have to bundle up all your stuff. Leave it here and it will be safe.

¹ The final set of tables resulting from the Symposium can be found in Appendix 2, 08apndx2.pdf.

Any questions pertaining to housekeeping or to the goals that we have for today and tomorrow? This discussion will be moderated by the distinguished Mr. Boothe. However, before doing so, I would like to give Paul Ray the opportunity to make a few comments.

MR. RAY: Thanks, Tom [Longridge].

Really my thoughts are few, not nearly as eloquent as Tom's [Longridge]. Primarily it's an offer of thanks to everyone that's shown up. The invitations, your presence here, is not taken lightly. We went through a rather lengthy list of potential participants in this effort. What we were looking for is an objectivity that we think each and every one of you bring to the table to discuss what can be a very, how should I phrase it tactfully, difficult subject, discussion of motion, its use or nonuse.

The point I would like to reinforce and put up at the pinnacle of our discussion is the fact that the device we are talking about is used for pilot assessment, maintaining that level of safety in regular flight of the airlines, whether it be a regional airline, commuter, or a typical air carrier. We are using simulators to not only train, as Tom [Longridge] accurately had on his slide, but also the checking of those pilots in devices that are fixed to the ground as opposed to going out and flying the airplane. We all know the value of what that simulation can do for us, but some discussions tend to waiver when you get into the area of what is training. If we keep our focus on the fact that simulators are used for pilot assessment, I think such a focus could or may keep us on track. What's valuable for training? There is a plethora of devices used for training. However, these devices are used for pilot assessment. My personal thoughts on how or why discussions on motion have become so heated in the past is that we tend to look at the entire motion envelope of an airplane. Airplanes can fly upside down well for some short period of time in some cases. However, is that characteristic reasonable to look at from the standpoint of motion for devices that are used in checking in an IFR environment?

Personal opinion, we may need to put an envelope around what motion we are talking about. Typically, in any training or checking environment you are talking about, generally speaking, plus or minus 45 degrees of bank. And somewhere in the neighborhood of plus or minus 30 degrees of pitch.

To address motion from the standpoint of inverted flight, or high g maneuvers, people typically want to take a fighter aircraft, an F-16 or F-15, and try their best through implementation of various motion cuing techniques, simulate that complete envelope. That just doesn't work very well in the commercial world, or the practical application of simulation.

I offer those thoughts as a potential for looking at the practical motion simulation envelope as opposed to the full flight envelope of an aircraft.

Again, thank you for taking time out of your very busy schedules to come in. We look forward to the interaction that's going to occur. I hope some very heated discussions occur. If they don't, then we did something wrong.

And thanks again to Ed Boothe for the outstanding work that he has done in preparing a program, the agenda worked extremely well for our look at aerodynamic data requirements, I'm sure it will again. Thanks again for your participation. We look forward to a very productive two days.

MR. BOOTHE: Mr. Toula is not here?

MR. LONGRIDGE: Yes, he is not here.

MR. BOOTHE: I would like to add my thanks to you all being here. I know this is a disruption to your schedule, a donation of your time that certainly could be more productive doing what you normally do. So I think it's quite a sacrifice on your part to come and join in a group like this to offer your expertise to the government, as Bruce [Baker] likes to say. I thought Tom's

[Longridge] comment about the FAA having a problem was a bit of an understatement in today's environment. I probably won't discuss that.

One administrative thing I would like to do before going on is that we have promised to pay your transportation cost. In order to do that I will need to know the total amounts so that I can request that amount and, in turn, when you invoice me, pay you. So if you would be kind enough to have your ticket receipt available after lunch so that we can just copy all the ticket receipts and later I can add them up and invoice for that amount, I'd appreciate it. That doesn't mean that you are covered, what that means is we simply know how much it is. Then it is still up to you to send me the original ticket receipt and some sort of company letterhead or company invoice so that frankly when I get audited I have an excuse for having had this cash flow. So if you would bring the tickets after lunch and let us copy them, I would appreciate it, and some people from the first meeting have never collected, I don't know whether that means they are not going to or what, but I've got money to get rid of.

MR. SMITH: We can help.

MR. BOOTHE: I think the people present here are from a variety of representations, that was purposely intended so that we have a good input from different points of view. I think what we don't have is any people who are adamantly opposed to motion. Of course, there are such people. But I suppose we could have included people like that. At every place where I have ever been where motion was discussed in any serious nature, those people always seemed to be there. And they have some legitimate points of view and some points of view worth listening to, I just happen to disagree with most of them because I guess I can tell you up front I'm a pro-motion person and I think motion cues are important to pilot certification.

So that is something to keep in mind as we do, we don't have that kind of distracter, if you will, in the discussion, I don't think any of you are adamantly "no motion" people. But keep in mind that those people are there and whatever we do, whatever we conclude, I think we have to certainly be in a position to defend what we conclude and the FAA has to be in a position to defend our conclusions by being able to say, particularly in this case, to regional airline operators, that this is what you need, here is the minimum you need and here are the reasons that you need it. So just to say "you need motion because you need motion is not good enough." We have to be able to justify why we need motion and what does it do, what does it accomplish, and I think that's the thoughts to keep in mind.

Of course, I gave you this picture². If I were king I would probably say there is the solution, if you want a Level B motion system, go with that. But that wasn't really the purpose. This particular system has some unusual features that we don't normally see. It's a bit reminiscent of the old FSAA at NASA-Ames. But I only point this out to ask you to think beyond what we normally think about in motion systems. We normally think of a synergistic six degree of freedom system and seem to go from there. But there are other ways of doing the job. Perhaps those other ways would be appropriate to conclusions that we might draw from our two days here. I took this out of Jane's [Defense & Aerospace Information], I'm not sure what it is, I think Don [Irving] said it's a Mercedes car simulator.

MR. IRVING: Yes.

MR. BOOTHE: I think it does say "get full lateral cues in a driving simulator." Anyway, that's not necessarily a starting point, it's a starting point for thinking in terms of perhaps something other than what we normally see on a commercial flight simulator.

² Figure caption: A sophisticated hydraulic system with six degrees of freedom moves the projection dome to and fro, thus reproducing the subjective impression of accelerating, braking or cornering. Following the latest developments, the impression of lateral acceleration - for instance during lane-changing or evasive manoeuvres - can be created with 100 per cent accuracy. This extra realism is achieved by a new cylinder with long 5.7 m stroke, which imparts lateral movement to the 18 tonne simulator.

Now, about the table,³ actually the table begins with this page which addresses transport delay, drive equations and so on. I want to emphasize that this is only one person's idea. And certainly nothing more than that. I took the advisory circular for simulator qualification, I looked at the subjective test area [AC120-40B, Appendix 3], because that is the area that really identifies tasks that will be done in a simulator that closely relate to training and certification tasks. I looked at each of those and said if I were the sole person deciding this, what would I think, what cues would I think would be necessary to stimulate a pilot in this task? And I want to tell you up front, I could be totally wrong. It's just my idea, this is just a—just like the picture, just a starting point.

You may look at this and say “boy, he is crazy.” So that's all right. But what I have done is simply list an area of operation, if you will, and some tasks associated with that, and then the degrees of freedom of motion that I thought would be pertinent to that task. I have an acceleration velocity and displacement column that has no numbers because I certainly don't know what those numbers should be, and in fact without feedback from people like you I would be reluctant to put a number in because sometimes if you see a number you might decide that's good enough and discussion ended.

So, I don't know what the numbers should be, I don't know whether there should be numbers for all of those things. It may be that if acceleration were the number, then the rest of it to have something within the physical limits of possibility, the rest of them would automatically be decided. Or we may find out the acceleration we would like is not possible. So those are things that hopefully we can think about in these two days.

I have also tried to write some kind of objective as to why I think or what I think motion accomplishes in that particular task.

Now if you look at the first one, which is surface operation pushback/powerback, I have listed four degrees of freedom, there is acceleration, velocity and displacement column and the task, our motion objective column fits all of that one block. But if you go to the next block, I have written for those four events or tasks, ground handling and nose wheel scuffing and brake operation and brake fade, the same four degrees of freedom I thought applied to all of them in that block. But the motion objective is slightly different for each of them, so if as we go through this table it makes sense to only me, please ask me and we will clarify as we go. It's simply a way of having something to somewhat guide the discussion, and really I didn't intend it to be anything more than that. My thoughts were that the recommended solution from us could be anywhere from nothing to full six degrees of freedom. Tom [Longridge] has changed that in his presentation saying that nothing is not an acceptable solution now, so we think Level B needs some motion cuing.

MR. LONGRIDGE: Yes, that's true. But let me clarify that. I recognize that the issue is really task specific, so for a given task the group may decide that motion is not essential, and I did mention recurrent training but let me reemphasize, what we are talking about here is the use of a device for training pilots who are already qualified in the aircraft, we are strictly dealing with the requirements that would be necessary and relevant for recurrent training.

MR. RAY: There is a supplementary part of that in that the devices we are addressing could likewise be used for what is generally referred to as 85 percent of initial flight training requirements. Pilots would still be required to go to the airplane to complete the initial training. However, Tom [Longridge] is absolutely correct, the recurrent training issue is the foundation of what we looked at, but the device look-wise could, and would be used for initial training.

MR. LONGRIDGE: Yes, but that's not relevant to this discussion, you are talking about the aircraft, supplemental device with the aircraft. Our concern is what would be the minimum requirements that would satisfy us for the use of the device to satisfy all of the requirements for recurrent training.

³ The final set of tables resulting from the Symposium can be found in Appendix 2, 08apndx2.pdf.

MR. BOOTHE: Thank you. I was getting to that point as well. I think that's an important point. So I will just perhaps add to it just a little bit. I want to reemphasize if you have something you would like to present, and even if you need help in getting that ready, I think that help is available here. If you decide this morning that you want to make some handwritten slides and go get transparencies, that opportunity is available and Don Eldredge can assist you—not to put you on the spot prematurely, is that correct, Don [Eldredge]?

MR. ELDREDGE: Yes.

MR. BOOTHE: —in doing that. So if you in the discussion come up with an issue that you feel strongly about and would like to make some transparencies and use the overhead and make a presentation on that issue, I would invite you to do that because I think it's important for us to hear your point of view. That's really why we are here. If you feel that's the way you want to do it, by all means just let Don [Eldredge] know and let me know and we will certainly do that.

Sunjoo [Advani] is doing that and it's up to Sunjoo or any of the others of you who want to do that to let me know when you want to do it. Perhaps an appropriate place in the table, or if you want to do it at some particular time of day, like after lunch or now, just let me know and I think we can accommodate that.

And back to the events, I know I'm bouncing back and forth here a little bit, I just want to reemphasize what Tom [Longridge] and Paul [Ray] have said, we are interested from the regional airline perspective, and from the AQP perspective, primarily in a simulator to support pilot recurrent check. So we are thinking primarily of pilots who have been initially qualified, either in a high level simulator, or perhaps they completed their certification and their qualification in an airplane, and now they are facing recurrent qualification. So these are people who we have to consider to be certified for the airplane they are flying. But the recurrent qualification check, it could either be, correct me if I'm wrong here, but it could be in a conventional FAR [Part] 121 program, which now all regionals who fly airplanes of ten or more seats I believe will have to phase in to the FAR [Part] 121 training and qualification requirements, or it could be in an Advanced Qualification Program where recurrent is often associated with a Line Oriented Evaluation, which is an in-context evaluation and may not—well, it's not always the same, and so it could include any of the maneuvers or tasks that we are talking about here but not necessarily all of them.

So we are talking about certified pilots for the most part, but as Paul [Ray] aptly points out, someone could use a Level B simulator in an initial training program and complete that training in a real airplane. So we can't dismiss the idea of such a device being used in an initial, and when I say initial I would include those other things like transition and upgrade, but the primary emphasis I think for us is the recurrent training. But it's pilot certification or recurrent certification, it's not, and I say just, it's not just training transfer.

When we speak of pilot certification we have to think as the total package this person is being totally requalified in the simulator without having to be validated following that simulator session, without having to be validated in an airplane. So Level B could end up in a pretty wide spectrum. As I said, our policy is for recurrent, it is the end of the line vehicle, there will be no further validation in the airplane, so the person then goes, having passed this recurrent qualification check, goes back to flying the line.

Those are just some thoughts to keep in mind as we talk about what this device should do. So before we go into this specifically, I would like to have, if none of you object to you introducing yourself to others, I know most of you have met but we haven't had a chance to discuss who you are by profession and what you do, and I think that's important for us to know. So perhaps if we could start over there with you Don [Eldredge], and go around the room, because it's important to bring out the variation of experience and expertise and background that we have in the room. And it's quite a variation and I think that variation is important.

So if we could, Don [Eldredge].

MR. ELDREDGE: I'm Don Eldredge from Battelle, we are sort of managing the logistics for this meeting. So if you need help on anything, let me know.

MR. CARDULLO: I'm Frank Cardullo, Department of Mechanical Engineering at the State University of New York in Binghamton. And I guess what I do is I teach mechanical engineering and do my research in the area of man-machine systems and flight and ground vehicle simulation. And I do a little bit of consulting in that area as well.

MR. REID: I'm Lloyd Reid, at the University of Toronto. I'm with the Institute for Aerospace Studies. We are the aerospace engineering arm of the University of Toronto. I run a lab, flight simulation lab there, in which we have a flight simulator based on a six degrees of freedom hexapod system, and we do studies into flight simulation technologies and also we use the flight simulator in human performance and operational problem investigations. And as with Frank [Cardullo], I do some consulting to various organizations. I guess one that relates to what we are doing here today, I'm working on the NADS driving simulator motion base system with the prime contractors, so I have been involved in the simulator business a bit.

Originally we did a lot of work on motion simulation, in the last few years we have been working on helicopter simulations and using the motion system but not necessarily studying the motion.

MR. SUSSMAN: I'm Don Sussman, Chief of the Operator Performance and Safety Division of Volpe that supports Tom [Longridge] in this project. Our division does a lot of research using motion simulation, mostly for the evaluation of proposed high speed ground systems. For about 15 years I have served on the Technical Advisory Group for the United States on human exposure to shock and vibration for the International Organization for Standardization.

MR. BAKER: Bruce Baker, President of Servos and Simulation, Inc. I've been in the simulator business mostly on the engineering sides for about 30 years. I've been—I've had the opportunity over the years to program a number of motion bases and had some relatively good experience with that.

We also make a product line of low cost electric motion platforms and they start at fifteen thousand dollars, so low cost is low cost. We can do six axes up to fairly large payload, up to eight thousand, ten thousand payloads. Those don't cost a few thousand dollars, however, nevertheless there is an opportunity for us to get our oar in the water in terms of some sales, possibly. And I have programmed a number of motion platforms for people and always had, I think, some good pilot reaction and I'm willing to tell everybody what I know about that. Or what I think know about it. It may not be the same thing.

MR. SMITH: Hilton Smith, aerospace engineer, FAA, seven years. Retired, Lockheed Georgia Company, 30 years, stability and control engineer, conducted design analyses as to stability and control and performance of business jets, prop jets and large transports.

MR. IRVING: Donald Irving, CAA and part of the great European dream or nightmare JAA. I've been with CAA for about eight years, and what's of greatest interest to me recently is low cost simulation, what we think is a low cost Level A standard. Prior to the CAA, I worked for Rediffusion, and was involved in the flight modeling and certification with Mr. Boothe and other people like that. I convinced them that the simulation was good enough.

MR. WILLMOTT: Stu Willmott, I currently work with SimuFlite Training International in Dallas. For about 19 years I was with the Link Commercial Organization. And of course worked with motion systems and the aerodynamics involved with those simulators.

MR. HEFFLEY: I'm Bob Heffley, I'm an independent consultant. I work with a fairly broad range of flight simulator topics. A fair amount of my work is simulator math modeling development, some flight tests from time to time, and simulator research, predominantly concerned with handling qualities. This covers fixed wing, helicopters, and from time to time some automotive simulation.

Most of my experience has been in using the simulator facility at NASA-Ames, and these days that center uses the very large amplitude motion simulator, the Ames VMS (Vertical Motion Simulator), and in fact my most recent experience is last month doing cargo helicopter handling qualities research involving sling loads and motion was an important aspect of that. That's it.

MR. BOOTHE: Thanks Bob [Heffley].

MS. BÜRKI-COHEN: I'm Judith Burki-Cohen, I work at the Department of Transportation Volpe Center in Don Sussman's division, I'm an engineering psychologist. I'm the overall Project Manager for the FAA of this project which is supported by the FAA's Office of the Chief Scientist for Human Factors and the person responsible is Dr. Eleana Edens, we are serving Tom Longridge's research needs.

MR. STOCKING: Charles Stocking, I'm in engineering in vehicle dynamics for Hughes Training, I worked for Stu [Willmott] there for a while in the commercial division, I was there for 18 years. I work in primarily aerodynamics and motion, equations of motion, ground reactions. I did the most of the motion software we used in the commercial division, and I just recently finished the motion cuing system for the B-2.

MR. ADVANI: My name is Sunjoo Advani, I'm the Director of SIMONA International Centre for research and simulator motion and activities. I gained my simulation experience in the beginning working with Dr. Lloyd Reid. And then I moved to Holland and established SIMONA and its facilities. I was the prime founder of that. SIMONA is mainly dedicated towards developing simulation technology, establishing new standards and looking at things such as what we are talking about at this meeting. We have high performance research simulators, a generic reconfiguring device. But moreover it uses the latest in all of the technologies that have been selectively addressed to bring together a system with the highest possible performance for the physical cues, the visual and motion and so on. It features all composite flight deck, a new motion system approach using fairly standard equipment but using the latest possible technology in the motion system. So we consider that we have a Level E motion cuing device. We work in close cooperation with industry as well. We also operate a Cessna Citation II aircraft for in-flight evaluations. I'm currently completing my Ph.D. on motion system design.

MR. HARRIS: I'm Geoff Harris, I work for Thomson Training and Simulation Limited. I currently hold the role of product specialist for control and motion systems. I am responsible for the control and motion systems within Thomson. I normally do design and development on these systems for civil aircraft typically 30 thousand pound payload. We do single seaters and helicopters, but most of my experience is heavy payload systems. This is a new departure for me.

MR. BLUTEAU: My name is Normand Bluteau from CAE Electronics. I'm the senior group leader of the motion system engineering group. For the past ten years I've been involved in design of cuing algorithms for motion systems, control schemes for actuators, motion system geometry design, and I've been involved in many customer acceptance and certifications of simulators.

MR. MARTIN: I'm Ed Martin, I'm an engineer with the Air Force Armstrong Laboratories, Human Engineering Division. This is a job that I have jumped into a little over a month ago. Prior to that time I was with the Aeronautical Systems Center acquisition office as an engineer. From the early '70s to the late '80s I was involved in various types of simulator technology research, including dynamic seat benefits that might be derivable for both performance in the simulator and training transfer, as well as some time delay work that we did using the Wright Laboratory's NT-33 variable stability aircraft. Some of that might be germane to this discussion.

Prior to that I had about ten years' experience working at the Link University up at Binghamton.

MR. FOSTER: I'm Bob Foster with USAir. I'm manager of Simulator Development Engineering, which is one group in our whole simulator support group. My department, or my group, is responsible for all modifications to existing simulators, either to reflect changes in

airplane configuration or training requirements, and in addition to that we have a big role in the procurement of new equipment. We are currently supporting one simulator, a Dash 8 for the USAir Express carriers, and looking at developing programs to support the other regional carriers that are affiliated with us or owned by us.

I'm also very sensitive to representing our maintenance department, who looks at the, primarily the long-term costs of maintaining simulators from the standpoint of maintenance and utility costs and those types of things, which are significant. And of course in today's environment, with all the airlines we are all very cost sensitive and are looking more at life cycle costs rather than just the initial capital costs of simulators.

MR. BOOTHE: Thank you, Bob [Foster]. Bob, I didn't mean to add to what you said, but Bob's is the user's perspective, which I think is important to the rest of us as we talk about what we think it ought to be. He is the guy at the end of the line that has to keep it working and afford it or afford it and keep it working.

I'm Ed Boothe, consultant these days and some mornings I ask myself how did I drift into simulation. I think it had something to do with that NT-33 that Ed [Martin] mentioned, but I'm basically an engineer who worked in handling quality research and a pilot. Paul [Ray]?

MR. RAY: Paul Ray with the National Simulator Program. We will have the ultimate responsibility of incorporating the product of this effort into changes to the advisory material and potentially the regulatory material that applies to training and checking of U.S. airmen. It may necessitate, as Tom [Longridge] alluded to earlier, depending on what the outcome of this meeting will be, potential regulatory changes. For example, if there is a consensus of something more than three degrees of freedom required for a Level B simulator. That question is certainly open and on the table.

But the position I would like to take in this meeting is that of the ultimate user, which is a pilot. We were, and I think Stu [Willmott] would confirm this, offered some level of criticism when Tom [Longridge] and I briefed the product of our aero efforts in Orlando with the RAA and took some, I hope it was fun, poking at the fact that a bunch of engineers sat around a room and designed something for a pilot. In defense of the ultimate user I hold the hat high at this meeting of that of a pilot. I'm going to be the person receiving the benefits of this effort. I know there are other pilots in the room and I trust all will provide a user's perspective.

MR. BOOTHE: We will keep that benefit in mind.

MR. LONGRIDGE: As I mentioned, I'm Tom Longridge, I'm the manager of the Advanced Qualification Program, which is an alternative to the traditional Federal Aviation Regulation requirements for pilot training qualification, certification, it does have considerably more flexibility. It's almost a blank check compared to the traditional FARs, we have used the AQP to enable carriers to reduce the full flight footprint requirements by the use of lower level devices like FTD.

On the other hand, what AQP does that's different is it replaces the maneuver oriented proficiency check with a line operational evaluation. This is a scenario based evaluation, so that the pilot is required to exercise the maneuvers for evaluation purposes in the full context of decision making, workload prioritization, communication, so on and so forth. We feel it's a much better screen than a traditional program is with regard to a pilot's readiness for line operations.

Nearly all major carriers, certainly all the large ones are currently participants in the Advanced Qualification Program and many of the larger commuter airlines are also participants, it's a growing program. That's it.

MR. BOOTHE: Allison [The Reporter]?

THE REPORTER: I'm Allison Hoyman. I'm with RealTime Reporters in California, and we have the honor of reporting you ladies and gentlemen today.

MR. BOOTHE: Are we clear? I don't know if we have enough time before the first break to really discuss transport delay or latency or lags, but perhaps we could get started on that and just say well, at 10:00 we will stop where we are and pick up after the break. That may be putting the toughest problem first, or an easiest problem first, I really don't know. But I've listed here or written here what is the current latency or delay permitted for Level B simulators. It's 300 milliseconds, that 300 milliseconds applies to both the Level A and Level B, but we are primarily concerned with Level B. But I have a feeling that some of this is going to drift into other areas, like Level A, because it just seems to work that way. I don't think that most modern Level B simulators have delays of this magnitude.

MR. REID: We better hope not.

MR. BOOTHE: So Bob [Heffley] is ready to start the discussion. I'm ready for you.

MR. HEFFLEY: The 300 milliseconds certainly does jump out to any of us who have done much simulation. Where does this come from and how does it fit into the scheme of things right now?

MR. BAKER: I think I know where it came from. I was going to make a comment that says this is—these delay numbers basically to a large degree are based on what the available technology would do at the time the reg was written.

If you watch, for example in the military, they keep trying to squash these numbers down. They are talking about 100 milliseconds right now because the visual system needs about 60, okay? And everybody else needs a little bit. Now I don't know that there has been any serious psychological work or testing work to say 300 is a good or bad number, it just goes back to historically what the devices were capable of when the reg was written. I personally believe 300 is a bit on the high side for anything you would call a real high fidelity simulator. Maybe they are getting by with it on 300 or maybe the fact is they are much better than 300 millisecond time, that's why the trainers are working. But I think 300 milliseconds is big enough to adversely affect the handling of the airplane. And to some degree I can prove that analytically. Although we would have to agree on what the model of everything looks like. Certainly in the context of a one hertz control loop or even a half hertz control loop, 300 milliseconds is a long time.

For example, I would be very surprised in a Level B sim if the motion cues are lagging anywhere near 300 milliseconds, I would suggest they are probably lagging on the order of 100 milliseconds, or something like that. The visual cues are driving that 300 millisecond number.

MR. BOOTHE: I think this number is a holdover from the past. I think you are right about that.

MR. WILLMOTT: I think that this is a holdover from the past. When these latency numbers were first put in there, there were visual systems that had latencies up to one second.

MR. BAKER: It's easy to do to get one second.

MR. WILLMOTT: And of course the problems that were encountered were pilot-induced oscillations. I think the gentleman that was principally involved with getting that number put into the performance was Jim Copeland, and at the time I think what he used for that was the studies that were done on the space shuttle where they had found, when they first flew that aircraft, if you call it that, that there were pilot-induced oscillations on approach.

They did simulator studies of that and found in fact that the problem was delays in the control system and at the time I think it was around 300 milliseconds. In simulator studies where they introduced increasing delays in this control system, they found that they started getting pilot-induced oscillations when they were around 300. I think that type of motion where you are controlling the shuttle on approach is a much tighter type of control than would be used in simulation, although of course you have to fly accurately on approach, but it was felt I think at the time that that was adequate.

But I don't think in current simulators that there are any pilot-induced oscillations involved with the simulator even if it has a latency of 300 milliseconds.

MR. MARTIN: Yes. The work we did with the NT-33, indicated that performance started degrading—that is, the handling quality ratings went from Level 1 to Level 2—at about 150 milliseconds delay. So you will probably start seeing performance degradation with that much delay.

The delay in the NT-33 work was defined differently from the way the FAA defines delay. That delay was defined in terms of phase lag. It included the equivalent delay introduced by the aircraft beyond the classical lateral and longitudinal modes.

MR. BOOTHE: Was it a time constant?

MR. MARTIN: No, it was a pure time delay that was injected into the control system.

MR. ADVANI: May I comment on that? As I understand from your reports, any delay above the aircraft time delays in excess of 50 milliseconds, if I understand you correctly, was judged as degrading the handling quality. So I think the criteria is in fact 50 milliseconds above the aircraft—

MR. MARTIN: No, the 50 milliseconds came from the fact that if you interpret the FAA requirements for the amount of delay that's permitted in an aircraft, you can have up to 100 milliseconds equivalent delay in the aircraft. If you allow for an aircraft equivalent delay of 100 milliseconds, then you can allow another 50 milliseconds for the simulator.

MR. BOOTHE: Perhaps I could say a word by way of interpretation here. In the FAA measurement if you use the latency measurement, which is difficult because you are looking for small changes in long analog traces, the 300 milliseconds is additional to the airplane's natural lag or latency. So if you were to include the airplane's natural delay, you could have something considerably more than 300 milliseconds from pilot input to response using this number. If my memory is correct, human response time is something on the order of 200 to 300 milliseconds.

MR. HEFFLEY: One hundred.

MR. BOOTHE: Is it 100?

MR. CARDULLO: Depends on what you measure.

MR. BOOTHE: So if the task is such that the transport delay or phase lag falls into the human response time, you are likely to end up with pilot-induced oscillations, which I think simulators are somewhat notorious for. So perhaps 300 is the wrong number. But I don't think most simulators have this much delay these days.

MR. BAKER: Let me make a comment about that, also. First of all, there is an area which is—to sort this thing out, there is a test on the simulator which will probably sort this out before the simulator is certificated. That is, somebody who is a qualified pilot will get into it and fly it and say yes, it flies like the airplane. And I guess my concern is that if 300 milliseconds stays in the advisory circular and somebody says well, gee, these guys are supposed to know what they are doing, they have told me 300 milliseconds is an acceptable number, he designs to that and turns on the simulator and the pilot comes in and says “blah,” then we kind of led the guy down the primrose path. I would suggest that we probably ought not to do that, we probably need to give the guy a little better guidance.

And secondly, I would also suggest that pilots will learn how to fly these things, given a little bit of simulator time they will change the control laws they have inside of them to account for the time delay and put some artificial lead in there which they wouldn't do in the airplane. Neither one of those situations is desirable. We are trying to avoid retraining a pilot between the simulator and the airplane. I think everybody would agree on that.

MR. BOOTHE: Bob [Heffley]? Did your comment go away, Bob?

MR. HEFFLEY: Yes, it did. Everybody said the right things.

MR. BOOTHE: Let me catch Frank [Cardullo] here.

MR. CARDULLO: I was talking with Bob [Heffley] about this before we sat down. It was in the first line of the thing. And it just floored me. I don't think it ever hit me as hard when I had seen this before as it did in preparing for today. But my opinion is that if the simulator has 300 milliseconds delay in the motion, it doesn't matter what you do in the motion system. The motion is going to be useless.

MR. ADVANI: You can turn it off.

MR. CARDULLO: So the rest of the discussion is moot with that long of a delay. I think if we look at some of the higher bandwidth piloting tasks, that start to push up around one to two hertz, at two hertz, you are looking at 220 degrees of phase lag, clearly the system is unstable if you just look at it as a system.

MR. BOOTHE: Right.

MR. CARDULLO: It's going to be unstable. So even at one hertz you are not going to have very much phase margin. So anything, anything else that you do in the motion system is not going to make any difference. You might as well have a shake table under the guy to give him some vibration, because the lead that you want to get out of the motion system just isn't going to be there.

So I would strongly recommend altering this number if we are going to seriously address this problem.

MR. BOOTHE: I think Frank [Cardullo] makes a good point. If we leave it at 300 maybe our job is finished.

MR. CARDULLO: We can go drink beer for the rest of the time. But we will have to pay for it ourselves.

MR. SMITH: I just wanted to make the comment that the last six or seven years, with the computer capacity and speed increases we have experienced, that my observation of the simulators that we have been evaluating, that the motion latency on Levels C and D is typically now, you know, anywhere from 70 to 80—most often less than a 100 milliseconds. And I don't see that Level B is going to increase that because computers aren't that expensive. You are not going to get a less capable computer for, I don't think, for a Level B than you would for a [Level] C or D, because there is not that much of a cost savings.

But the visual systems, because of that increased computer speed and capability, haven't reduced latency because they add scene features and they are still pushing 150 milliseconds which I brought up to all the operators and sim manufacturers, a question—do we need to look at—we say the motion should be before the visual, but now we are getting differences between the motion and visual of, you know, 60, 70 milliseconds. Should we be concerned about that? If we have a limit of 300, it might be that we would have motion latency on the order still of, I would suspect, 70 to 80. Now you could go with a lesser expensive, you know, IG, and come up with latencies of 250 or so. If there is no phase requirement, then I think perhaps, does that constitute a problem, is the question?

MR. BOOTHE: Can I ask you to rephrase the question?

MR. SMITH: Okay. If we left the requirement at 300, possibly would we not wind up with motion latencies on the order of 80 to 90 and visual latencies of say up to 250, or it could be up to 300 and still be acceptable if that's the requirement? Would that be a problem?

MR. BOOTHE: I don't know, but I don't know whether we want to address—if we do, we do have motion and visual phase relationships, I guess that's a legitimate question. I don't know the answer.

Bob [Heffley]?

MR. HEFFLEY: Well, just maybe to complete the thought there, one important aspect of quality of simulator cuing, of course, is the reasonably simultaneous occurrence of motion cues and visual cues, they need to be pretty well synchronized. If there is much of a phase distortion there you really start to destroy the quality. I think one crucial question here is specifically what flight tasks are we really considering? And there will be probably two or three critical flight tasks that really force the level of motion and visual fidelity that if you have a flight task where the pilot is having to close a very tight precise loop on something, that's what designs the motion. And that's what designs the visual, that's what designs the amount of transport delay, that's acceptable.

And possibly one thing to do is go directly to what those critical tasks really are for the application that we are talking about today.

MR. BOOTHE: I think you have to consider for this the most demanding task. If you are suggesting that perhaps we should leave this and go through the task list and let that—consider that as we go, and when we identify what we might perceive as the most demanding task then address it at that point?

I do agree it has to be the most demanding task that the pilot would be doing, which is usually some high gain close—let's see some—Bruce [Baker]?

MR. BAKER: I wanted to make another comment with respect to the history of this thing as the best I understand it. Let me say I'm not a good historian on flight training simulators. But I would suggest that perhaps that the 300 millisecond number, besides being historical from a hardware technology standpoint, is also historical from the standpoint when the Level B simulators, most of them that exist were built, most of them were large aircraft. We are talking about smaller aircraft now which are more responsive. And that may, you know, if we had the time to investigate it thoroughly we would probably come to the conclusion we need to drive that number down quite a bit just because we made the airplane smaller.

MR. MARTIN: Let me just make a comment on that. In the NT-33 studies we looked at representative dynamics for a range of aircraft. The delay tolerance seems to be a U shaped function. For the very heavy transports, it's less forgiving of delays than it is for some of the smaller aircraft in between, then as you get to the very agile fighter type aircraft it becomes less forgiving of delays again.

MR. BOOTHE: So there is an in between area.

MR. MARTIN: That's a little more forgiving, yes.

MR. BOOTHE: I would have not have predicted that, that's interesting.

MR. MARTIN: For transports you probably don't have a less restricted requirement simply because you have a large aircraft.

MR. REID: Ed [Martin], when we are talking about the control loop with the pilot in it and worrying about the delays, time delays in the motion feedback loop, we have got to remember that the washout algorithms are filtering the signals being put through the motion system, thereby creating phase lead at the lower frequencies and maybe frequencies up to the frequency of the critical control frequency bandwidth of the control loop. So that's one thing we should think about a bit, I guess, at the same time.

And the other thing is that it is possible to put in lead compensation software to try to compensate for time delays, so again those software routines will also be influencing what the pilot is feeling in his closed loop control.

Just so I have a chance to say this, I have always had a little problem with the simple step input electronically generated measurement of pure time delay to qualify the systems, because in actual fact as we have been talking, the tasks that seem to be most critical are high bandwidth

continuous control tasks that may be less than three hertz in bandwidth and it's quite possible that the phase lags that the pilot is experiencing at these frequencies when doing normal control activities can be assisted by lead compensation and maybe even inadvertently by what the washout filter is putting in in the way of leads.

In some sense I have always felt that this simple time delay measurement, though it's simple to do, was putting the simulator manufacturer or the people trying to qualify the simulator at a bit of a disadvantage in that it may be saying the simulator is worse than it really is to the operator as far as the human pilot is concerned.

MR. BOOTHE: Frank [Cardullo]?

MR. CARDULLO: I'm inclined to agree with a lot of what Lloyd [Reid] just said. You and I have talked about this before, that the U.S. Navy has gone to a broader definition of this issue in qualifying their simulators. In that they do both a time domain and frequency domain specification of this problem. And so in the frequency domain you measure the phase lag, and that of course is really what Lloyd's [Reid] point is. And I agree with that. Of course if you do have 300 milliseconds, that's going to add quite a bit of phase lag that you are going to be stuck with, and it's possible to compensate the phase but you are still going to have the pure delay left with you. But the phase is what really affects the pilot performance. So, yes, I would say that Lloyd's [Reid] recommendation here, as I interpreted it, is to broaden this definition and to at least include, if not solely make it a frequency domain specification.

MR. BAKER: Let me make another comment.

MR. BOOTHE: Two more before—

MR. BAKER: Before the break?

MR. BOOTHE: —before the break.

MR. BAKER: Let me say I agree with what Frank [Cardullo] and Lloyd [Reid] have said about the motion platform getting an advantage from the washout filtering in terms of lead compensation. If the computer doesn't add too much delay to it then the motion may be exactly following the airplane simulation model at around one hertz, which is a good number. I think most of the delay that you would measure if you looked in the frequency domain would become, if any existed, they would be coming from the time delay and probably the reason we are getting by with that is the fact that the motion cues are, I think, what the pilot uses primarily to close his fast loops and the visual cues is what he uses to close the maneuvering loops. How does he line the airplane up on the runway and that sort of thing.

The maneuvering power spectrum density, from the little information I have, is down around a sixth of a hertz. At a sixth of a hertz even 300 milliseconds isn't going to be too bad of a problem. I'm just throwing this out as a suggestion as to how we are getting by with systems the way they are and the visual lag, which I believe is always the greatest lag in the system, is not totally destroying the handling qualities of the simulators.

MR. BLUTEAU: I would like to add my experience with the small aircraft simulation. Our experience has shown that on smaller aircraft for maneuvers such as landing with heavy turbulence, the pilot input was actually very lively, so was the aircraft response. As a result we experienced that high performance throughput delay was actually a requirement to produce the reality of the aircraft. We have had problems with pretty good models not being found to be flyable by pilots just because, as has been said before, we are dealing with a smaller aircraft, the loop response being what it is, the throughput delay is actually a fairly important criteria for reality.

The other point I would like to make, since the whole idea of the session is cost driven, how to make—how to reduce cost, how to address cost issues, I think we should consider the ratio of training value of something versus the cost of that feature. In the case of throughput delay, it may turn out the training value associated with high performance throughput delay does not

actually cost a lot of money because the technology, it has been said already, technology is almost there worldwide, very good performance. If you look at the ratio of the training value versus the cost, it's actually very good, it's very advantageous, I think, from a money point of view, to get that additional training value that good throughput delay would bring us.

I think possibly we would have to look at issues from the point of view of cost as well what the money can buy us in terms of performance.

MR. BOOTHE: I said two more before break, if I could hold you till after break, Geoff [Harris], I would appreciate if you could keep that thought. As they say on commercial TV, it's hold it till after the break.

(Break taken.)

MR. BOOTHE: If we could get going again, I'm in a different location because I was apparently ignoring some folks over here who had their hands up and I couldn't see them. They asked me to take a more central position so I could get questions from this side of the room as well as the other side. So the advantage you have over here is gone.

MR. BAKER: That didn't take long, did it?

MR. BOOTHE: So Hilton [Smith], you wanted to reintroduce that question that you had, and then Geoff [Harris] was holding a thought for after the break.

MR. SMITH: Well, I'm just, I guess due to my experience in evaluating simulators, Levels C and D, in the last six, seven years I have noticed the motion has been running 70 to 80 milliseconds and visual still pushes 150. As a matter of fact, we evaluated one recently and I'm not sure it met 150. But I'm just asking, is that a problem? Especially in light of leaving this at 300, I suspect we might get motion systems with latencies of 80 and visual systems, I suspect you could design a cheaper visual system if you only had to meet 300 and it probably would just meet 300. Is that delay a problem? That's the question now.

I wanted to just make another point of interest on airplane responses. Back in the late '60s when jumbo jets came on the scene, 747, C-5, DC-10, engineers were looking at those things, the size of these airplanes based on wing area, which says the inertia goes up as the cube of the wing area ratio. The C-5 compared to the C-141 has twice the wing area and the inertia came out about ten times. Everyone was concerned about response, especially on the flight path. We actually added a longitude stability augmentation system (SAS), that had lead functions, that added elevator as a function of stick position, in other words if you wanted one degree of elevator it would put in two, for the landing configuration. And the first thing they did, in the preliminary flight test, they decided they didn't need that. As a matter of fact, the only thing that's in the C-5 pitch SAS now is a half degree of elevator per degree per second of pitch rate damping, and it was really determined in the most critical maneuver, which is air refueling, they ran a bunch of pilots through in the airplane, they couldn't tell when the pitch SAS was on or off. But they had to leave it on the airplane because they had designed the autopilot around it.

But anyway, on the instrument panel in the cockpit it says if you engage the autopilot the pitch SAS has to be on. That's just a point of interest, in aircraft response, you can move those aircraft if you put high enough rate actuators in the control system you can move the control surfaces and obtain the desired aircraft response.

MR. BOOTHE: Thanks, Hilton [Smith]. Let me ask Geoff [Harris], do you still have that thought?

MR. HARRIS: Yes, I do. A number of things, first in terms of pilot input versus the aircraft response. In small aircraft, private aircraft, there are papers that say there should be less than 100 milliseconds delay between the pilot input and the aircraft response. We are talking about an additional delay of 30 milliseconds. With small feeders, which are more lively than the big

aircraft, the 30 milliseconds response is obviously far more important than for a jumbo jet, the delay should be less than a jumbo jet, 150 mil is not good enough, it should be 100.

The third point is that typically these days the computer power minimizes the delay between the pilot input and the math model out to the motion system, they can be very small, 150 is way in excess of what we can achieve, we get better than 100 on all the jobs. On high performance take it down to 50.

This doesn't correspond to the visual system, of course, it typically takes 150. It takes time for visual to paint the picture, it's worse on lag time because you have to paint more stuff. The critical thing is phasing between motion and visual cues. If the motion leads by a lot you get—pilots get simulator sickness, nausea, headaches, occasionally vomiting, this sort of thing. So the phasing between motion and visual cue is important. The latency between the pilot input and motion cue should not be a problem these days. We have the technical abilities to do this.

MR. BOOTHE: Okay. Thank you, Geoff [Harris], I wanted to—Paul [Ray]?

MR. RAY: Just one point. I believe I'm hearing 150 milliseconds is reasonably achievable as a no cost driver, essentially a no cost driver, to a Level A or Level B, or simulation in general. If that's the case, I see no reason for anyone to interpret 300 milliseconds as the holy grail. If that response should be changed to some lesser figure without driving cost, then it's certainly reasonable to do that. If there is a similar addition of language that needs to be embedded to address the issues of phase lag between motion and visual, then certainly we should do that. We have an obligation, I think, as a user, if you want to phrase it that way, to do that. If we can write more effective words to address the issue of transport delay, then we have an obligation to do it. If we need to change it, let's change it. Particularly if it's not, if I hear correctly, not a cost driver.

MR. BOOTHE: Well, I will be right there. I think cost is important, we are looking for lower cost Level B simulators, in fact. So I guess it's yours and Tom's [Longridge] prerogative in this proceeding, whether or not in the process we say we can make it technically more acceptable without affecting cost, and that's an okay solution, or whether we have to keep lower cost in mind, say we can only make it technically more acceptable if the cost is lower. That's not a question that I think you can answer. So that's just a thought to keep in mind.

MR. SUSSMAN: Don Sussman, Volpe. What you are hearing though is two things. It depends on the flexibility of what you can do with the guidelines. You can accept that the motion simulation is no lag, is no longer a cost item. You can think about establishing the guidelines as a proportion of the plane's response that you are simulating. Perhaps when you look at the question of visual simulation, which is, to a large extent is how complex the simulation is, maybe in terms of proportion with the response to the aircraft and the phase lag of the slowest input, which is the visual, maybe those are the guidelines we should look at.

MR. RAY: We have an item on the agenda that may be pertinent to our discussion here. We plan to start an effort this fall to completely address, among other parts of Part 121, Appendix H, which contains simulator technical standards for Level B through D. The issue we are discussing would necessitate a change there.

MR. SMITH: I just wanted to add I may have misunderstood what you said, but I think you are correct in saying to go with 150 for motion or even lower is not a cost factor. However, the phase shift between the two might be a cost driver on vision, from what I've heard.

Just another point of interest, I was talking to Ed [Boothe] on the break and he said I might bring it up, a point to keep in mind when we are talking about the Level B as a recurrent trainer, it won't support, or the visual system will not support a LOFT scenario. Currently the standards—

MR. RAY: It will.

MR. SMITH: That's the difference in the visual requirement on a Level B and Level C, Level B is not required to have gates.

MR. RAY: It depends—pardon me for butting in. A Level B or Level A simulator is capable of supporting a LOFT scenario, at least certain LOFT scenarios. Does it support the Level C or Level D LOFT requirements in Appendix H? The answer obviously is no. But you can accomplish, as we have been accomplishing under Part 121 for years, LOFT scenarios with a single channel visual in a Level A simulator.

MR. SMITH: I may be wrong. I thought you had to have a gate. You don't?

MR. BOOTHE: Bob [Foster]?

MR. FOSTER: I would like to say that one of the things we should be careful doing here is to say anything we do say or recommend is a cost driver. Because what we are asking people to do is to step back and look at designing simulators in the future, not taking today's current simulator and downgrading it to a Level B. We have tried that for flight training devices and for those types of things and in general that's not an economical method of doing it. And it's going to be this combination of what comes out of—what came out of the data and the fidelity of the aero requirements with the visual requirements and the motion requirements that's going to set the basis for asking various manufacturers to design a new simulator whose top end is going to be Level B. It's not going to be a Level B that can be made into a Level D, or a chopped down Level D, so consequently it's going to enable them, the innovative manufacturers, to step back and look and say with a fresh look at this, what kind of a simulator can I design as Level B, and it's all it's ever going to be.

The other thing, and Hilton [Smith] brought it out a little bit, I think to be honest about this, we have to look and say it's not just going to be regional carriers that are going to use these. In today's world everybody stands back, the [Part] 121 carrier stands back and says, especially for a new airplane type, not necessarily a new airplane or introducing a new airplane in your fleet, you stand back now and you say, especially in light of AQP, you stand back and say what is the best training program? How can I best put a training program together, to bring my pilots up to speed and keep them trained?

Now you would have be able to look at this full range of saying "okay, maybe I will do my initial training in a Level D sim, if I'm going to have 60 or 70 of these airplanes I have now a certain initial requirement and I also have a recurring requirement." I will say "geez, maybe I'll buy a Level D and buy Level Bs to do recurrent training [and] checking." It's not just for the regional carriers, over the years it's going to grow and the major carriers will use them as well. I guess my biggest point is what we say here is going to set targets for a new type of simulator.

MR. LONGRIDGE: Yes.

MR. BOOTHE: It's an important point, thank you, Bob [Foster]. I think Geoff [Harris] was vying for time here just ahead of you.

MR. HARRIS: Two small points. Assume that the 300 milliseconds we might grandfather in existing simulators, no argument there. Something we haven't touched on so far which is important in our local community is sound cues. It's not anything we mentioned nor is it part of the comments, but it might be worth bearing in mind for future, particularly touchdown, where you get the bump of the motion, the cockpit rattles and later on you get a pop through sound system and the pilots say what the hell is that? So synchronized issue of sound as well as the other cues.

MR. BAKER: I think, first of all I think we don't want to beat this to death, and I really feel that the 300 millisecond number is historically—today is being driven by the visual system and not the motion platform. It's not that hard to get the motion platform delay down. I think I would suggest again that we might want to put some more words in here to advise the reader that 300 milliseconds may not be satisfactory. He is going to have a problem if he designed to 300 milliseconds in some applications. And give him a heads up. Because I have run across some extremely naive simulator

builders in the last several months and I would hope that we would give them advice here that would be useful and pertinent to achieving a satisfactory result with a simulator.

This is not a spec, most of this is not a spec, most of it is an advisory that says if you do it this way, it's probably going to work. So I think we have an obligation to tell the guy maybe not everything we know, but enough of what we know that he can achieve a good result with a simulator. The CAE guys and the Thomson guys, I don't think we have to teach them how to do this. There are some folks out there that are somewhat more naive than the big guys are. And I think it's important that we try and give them advice in this advisory circular that says, you know, the present requirement is you can't do any worse than 300 milliseconds, but we think to achieve a good result you ought to look at numbers more like 100.

MR. BOOTHE: Thank you, Bruce [Baker]. We, I think, or let me say I don't think the FAA wants to give design advice, but simply lay out a performance standard and however one meets the performance standard is up to them. I think that's proper. But to set a reasonable performance standard that does the job and does it in context of the correct parameters I think is an important consideration.

Let me just ask, Paul [Ray] brought up Appendix H, I don't know if all here are familiar with Appendix H, which is the appendix to regulation 121 that describes the advanced simulation program. If you are not familiar with that, I think I have a copy upstairs and I can have it copied and available to you after lunch. And it may be worthwhile. I will do that if—I think I have one.

MR. LONGRIDGE: Is this the new one? The latest?

MR. BOOTHE: I have the one that's in the rule. Is there an amendment to that?

MR. LONGRIDGE: Yes.

MR. RAY: We finally have Levels A, B, C, D, nothing else did that.

MR. BOOTHE: The one I have still says Phase 1, 2, 3. Do you have a copy?

MR. LONGRIDGE: I have nearby, but not with me.

MR. HARRIS: I have one here.

MR. BOOTHE: Is there a significant enough thing, we can all say Phase 1, 2, 3 translates to [Level] B, C, D, it's either here or it's not. Let me check and see if I have it first. If you want to go to the office—

MR. LONGRIDGE: I don't think it's necessary.

MR. BOOTHE: I will grab that at lunchtime and we will copy it so you can see where the regulatory basis for advanced simulation is and then additionally to that there is an Advisory Circular 120-40B, which is still current.

MR. RAY: Unfortunately.

MR. BOOTHE: That would be a lot to copy for everybody, but I do have one here if there is a question about it. So I will get that for you at lunchtime.

I think what I'm hearing is that Geoff [Harris] and Norm [Bluteau] and others have said what's the big deal, we can meet 150 milliseconds at no additional cost. Is that a correct statement?

MR. BLUTEAU: Yes.

MR. HARRIS: Yes, I think so.

MR. BOOTHE: Ed [Martin]?

MR. MARTIN: I think we may be talking about different time delay definitions without being real explicit about it. I mentioned that in some of the studies we have done time delay is measured in the frequency domain. The point at which we started to see handling quality degradation, that is

150 milliseconds, included the aircraft equivalent delay. That could get you down to about a 50 millisecond budget for the simulator—which might be a cost driver. I'm not saying that we need to necessarily get down to that level for training devices or training simulators, but we probably ought to make sure everybody is clear on how delay is defined in a given context.

MR. BOOTHE: Very good point. Whether or not that's within—whether or not the airplane response is within that 150 millisecond or whether it's additional. Traditionally it has been additional to the airplane response. And when we have measured transport delay it has been just a pure time delay that one could practically take a worst case calculation and get the same answer.

But what I'm hearing that I would like to follow up some, is first of all, it's not a cost driver in terms of additional cost to get from the current spec of 300 milliseconds in addition to airplane response down to 150 milliseconds. But I hear Lloyd [Reid] and Frank [Cardullo] and some others saying we need to talk some more about frequency domain, and phase lags, and important parameters in that terminology and how we might apply that. And I'm interested in hearing more about that. Because if you here as the experts on the subject say that the FAA, just specifying this transport delay is really not a proper thing to be doing and it really doesn't tell you anything, and I can put in a lead network to take care of that and maybe ignore the real phase lag or the real frequency domain important parameters, but I think we need to hear that and hear how would we implement those kinds of performance specifications in a simulator requirement. Bob [Heffley]?

MR. HEFFLEY: I think that the frequency domain definition is really crucial to approaching all of this. There are things that fall out of a frequency domain that are easy to miss in the time domain. But in order to apply frequency domain you have to be thinking in terms of, well, what frequencies here are really relevant to be looking at? If you are going to apply some sort of a phase mismatch as a standard, that has to be set at some frequency.

Well, there is a relevant frequency and it depends on the task. Some tasks are inherently high bandwidth, some are inherently low bandwidth. And one thing that is missing, and I think needs to be kind of put on somebody's list to pin down in the future, is some array of training needs and flight tasks for regional transports. How do we get to these task bandwidths that we ought to be using in the standards? We are really starting to talk, I think, about three basic characteristics.

One is the basic simulator versus aircraft match, and that can be expressed as some match in terms of a phase mismatch at a particular task bandwidth. I'm using this term task bandwidth for, I don't know, for want of maybe a better term. But we have the basic match between aircraft and simulator. You like those to be pretty much one-to-one because then the simulator is behaving like the airplane.

Another important one here that Geoff [Harris] and I think others have just mentioned, is the motion-visual mismatch. Again that can be expressed very conveniently as a phase mismatch. But again that has to be specified at a particular frequency and that frequency again depends on the task, this so-called task bandwidth.

The third crucial element I think has been mentioned here, something maybe we can talk about in terms of some added transport delay, you know, what we are really talking about here in terms of transport delays is some amount of really undesirable, unwanted transport delay that we just have to live with. And the significance of this transport delay is that transport delay is a really nasty sort of response characteristic to be present in something that a pilot is trying to control. It takes five times the amount of first order lag to have the same effect as the same amount of transport delay. In other words, for 100 milliseconds of transport delay, you could basically tolerate a half a second first order lag and the pilot would have to contend with about the same amount of difficulty there. It's a very important and a very insidious thing, and transport delay you generally can't see. But it's got to be pulled in here because we have to live with that in the world of digital computers.

And finally, this matter of transport delay again is expressed in terms of some sort of a phase lag, and that phase lag does have to be tied to a frequency, and again it comes back to what the task is and what that relevant frequency is for a particular task. And there is going to be two or three crucial tasks and they are going to have the highest frequency. You have to pin down the task, you have got to relate that to a particular frequency regime and then these other things I think tend to fall out. We can't just really talk about these things without the context of a task.

MR. BOOTHE: I don't know who won the contest.

MR. BAKER: We need buttons, don't we?

MR. BOOTHE: We will get you both.

MR. BAKER: I have a short one, I think. Basically I agree with everything Bob [Heffley] has had to say about this. Let me add one I think important point to it. The thing you would really like to know to evaluate the effect of transport delay on the sim is what the pilot's phase margin is. I was hoping that Frank [Cardullo] or Lloyd [Reid] or somebody could illuminate that question a little bit. Because I'm not aware, but I'm not the guy that would be aware of measured data on pilots in high bandwidth requirements. You know, in terms of a low bandwidth requirement, it's reasonable—it's a reasonable supposition that the phase margin of the control loop is fairly large and therefore if we disturb it somewhat we are not going to make a fat lot of difference on a pilot's response, the response of his tracking task if he has 30 degrees of phase margin, which I think is not unusual in a high bandwidth task and we add another 30 degrees of phase lag to it one could assume you are in a lot of trouble.

MR. CARDULLO: Yes. It's all going to—

MR. HEFFLEY: What you are talking about is I guess what I was trying to get at with this idea of this task bandwidth or however you want to express it. That is the place where you have to have 30 degrees of phase margin.

MR. BAKER: PIO is the place where the phase margin goes to zero. I would like to know if any of these guys that are more research oriented than I am have numbers that say we have measured this thing, it's around 30 or 60 degrees for this task.

MR. BOOTHE: Ed [Martin] is burning over here.

MR. MARTIN: To make a comment, I agree with this idea of task bandwidth and the frequency at which you really want to measure this delay. Frequency domain measurements capture the effects of transport delay, so that's really rolled up into it. When we talk about aircraft dynamics being included in this 150 milliseconds, or whatever number we talk about, we are only talking about what looks like a pure time delay, the equivalent transport delay of those aircraft dynamics. We are not talking about the classical roll dynamics or pitch dynamics, rather it's the dynamics due to higher order effects that appear as a pure time delay when you are down in the zero to two hertz manual-control range. I just wanted to make that point.

MR. BOOTHE: Stu [Willmott]?

MR. WILLMOTT: The purpose of this test in the first place, why it was first put into the requirements, was that the pilot-induced oscillations were occurring because there were inherent delays in the architecture of the simulator. There were dead times between the pilot doing something and getting the required response out of it. And it was involved with visuals and to some extent motions. But the purpose of the test was to try and find out what the dead time in the simulation was due to the architecture of the simulation. When it first came out like that, there were a certain body of people that had simulators that could not meet those requirements, and I guess the test was then changed to make that additional dead time on top of the airplane response. In that way certain simulators could still be qualified.

Now the FAA allows us to do just a response and compare that with the airplane within the given latency time, or to go back to the original purpose, which is to see what the dead time was in

the simulator. And, you know, I'm not sure what talking about all these phase things and putting frequencies of responses really into the system do us. But I remember working on a visual system and the proof of it meeting its particular requirements was by putting in a sine wave, and indeed they had lag compensations in that and they could show that the visual system matched the airplane beautifully. But in fact when we did a simple test input on it, it took 400 milliseconds for the thing to respond. And that was on a commercial simulator, and I found out later that our military group had the same visual system on an F-4 and it could roll 360 degrees before the visual responded.

And, you know, you could put lead lag networks in there up the kazoo and you will never solve the problem. You are really trying to find what the dead time is in the simulation. If you do anything more than that, I think you are getting into the airplane responses and things like that. I'm not really sure what it is you are going to do with a frequency input. What is it that you are going to compare it with? Do you have airplane results for different frequencies that you could compare the simulator to as far as the responses?

MR. MARTIN: The bulk of the research literature that talks about the effects of delays on the pilot in these closed loop situations is based on frequency domain data. It's probably easier to relate frequency domain measurements to the effect of delay on vehicle operator control than it is for time domain transient measurements.

MR. BOOTHE: Thank you. I'm going to take this side in order in just a second.

Are you suggesting that maybe transport delay is an improper measurement and we should look at—

MR. MARTIN: I'm not sure how you interpret the results of time-domain measurements in the context of the available literature.

MR. BOOTHE: Let me start with Frank [Cardullo] and work the way down the side.

MR. CARDULLO: I have a few comments here, one with regard to Stu's [Willmott] comment. Folks oriented themselves towards this pure delay initially because they didn't understand the system implications. I don't think that the complete man-machine system idea was ever thoroughly understood. And they knew that going from analog computers to digital computers was adding some pure delay to the system. So folks concentrated on that and it's really subsequent research that started looking at the total human-machine system and the frequency domain implications of phase lag. I'm an advocate of really measuring both from the standpoint of when you measure the pure delays, you find out what the digital system is adding, and that's an important parameter to measure.

But from a human-machine system standpoint in terms of performance it's phase lag that really determines whether the system is going to be stable or unstable. Ed [Martin] is correct when he says that if you do a frequency domain measurement everything is in there. But if you do both, and that's really what the Navy is advocating these days, you get a better idea, I believe, of where to apportion the differences. And that's why I advocate doing both.

And to add in Bob Foster's comment or a reference to his comment about cost drivers, the pure delay issue doesn't add much in terms of cost because most of that is coming from the digital computer and how fast you are executing the programs. But if you look at a motion system, from the standpoint of the frequency domain and phase lag, you can be talking about a significant cost driver.

Most of the motion systems I think that have been out in the field for some period of time now are, you know, one and a half to two hertz bandwidth motion systems, so at the pilot operating frequency they are going to be adding a substantial amount of phase lag. Newer motion systems that have bandwidth of four, five hertz, are obviously adding less. The cost driver there is really in the size of the motion system, because if you can get away with a smaller stroke motion system, then it's a lot easier to meet the requirement to have higher bandwidth. Because of the effects of actuator stiffness, basically, that enters into that.

So to just sort of summarize that, the transport delay issue is not a cost driver. The bandwidth, the frequency domain or phase lag issue, can be a cost driver when coupled with the size of the motion system. So if we want to try to reduce the cost, we ought to be looking at whether we can reduce the stroke of the motion system. Then that will reduce the cost. And by the way, I think we can.

MR. BOOTHE: Thank you, Frank [Cardullo]. Let's see.

MR. BAKER: I'm the last guy to put my hand up.

MR. BOOTHE: Did I miss somebody over here?

MR. SMITH: I have a question for Norm [Bluteau], it may be dumb, but you know we do three other tests on the sim and we check response of the hardware motion system, we check frequency lag and phase lag and we do this with sinusoidal input and three frequencies, I don't remember what they are, it seems like they are one, two up to eight hertz. When we do transport delay that's included. It's usually done at the high frequency end because it's a real fast step input. Do we not get that included in there at the most critical, what we consider the most critical condition of the high frequency?

MR. BLUTEAU: That's a point I wanted to make. The FAA's AC120-63 includes both transport delay requirement on top of high frequency response for phase lag tolerances, that Circular actually including both concerns of addressing phase lag on top of pure delays in the computing system.

MR. SMITH: We don't specify the tolerance, we say whatever the customer has defined as his design requirements. Right?

MR. FOSTER: Yes.

MR. RAY: That's [AC120-]40B, not [AC120-]63.

MR. SMITH: We are not covered? Maybe Frank [Cardullo] can—

MR. BOOTHE: Maybe we ought to copy the [AC120-]40B motion requirements when we copy Appendix H. I don't know that you are—most of the frequency response stuff that I have seen is, excuse me, Bob [Foster], but it's useless that I've gotten from operators when I was there because quite often it was at one frequency and it was not a frequency response. In fact there are only a very small number of manufacturers I have ever seen that really produced a frequency response of a motion system in the context of a Bode plot or something that one would be used to seeing. I don't think a couple of jolts at different frequencies does the job.

Anyway, let me see, was Sunjoo [Advani] next?

MR. ADVANI: I just wanted to add to a few comments. I do agree with Frank [Cardullo] totally. We should recognize [that the] motion system is after all an acceleration cuing device. But we also have to address the issue of the good cues versus the false cues, that's also where the time delay issue comes in. The only way to address that is to then split it up into time and frequency domain because again, like Frank [Cardullo] says, it's the phase which affects the man-machine interface. I think we all do agree on that. But how do we go further? I think there is some major holes that are open for research.

MR. BOOTHE: That seems to be the case. I think Bruce [Baker] is next.

MR. BAKER: I want to make one comment on something Frank [Cardullo] said a minute ago about cost of motion platforms. I have taken old Link cascaded systems and old Reflectone six axis systems and pushed them up above five hertz, and it's very cheap, you just have to know how to do it. I do it by subterfuge and smoke and mirrors as opposed to brute force. But there are ways, and I've got measured body response data on the two platforms from like a tenth hertz up to ten hertz. I can show you what I'm talking about. I made the measurements from essentially putting an input into the host computer motion drive equations at that point, which include the

washout and the leg drive equations and measure with an accelerometer on the platform and you can fairly easily discern from the Bode plots that response to motion basis is quite good and you can see the effects of the oil spring and so on, which really is the limitation which does get better if you get down to a shorter actuator, but goes the other direction if you go to a smaller diameter.

MR. CARDULLO: Sure.

MR. BAKER: I don't believe it's necessary to go to a ten hertz position loop or five hertz position loop on a six axis motion platform to get very good performance. You can leave the bandwidth of the servos down even under a hertz and get incredibly good performance out of the motion platform. Essentially it's just a matter of doing some algebra on the equations and putting the poles and zeros where you want them.

MR. BOOTHE: Thank you. I'm going to get to you. I think Don [Irving] has a comment.

MR. IRVING: I like the smoke and mirrors comment. That seems to me to encapsulate what I was thinking. The improvement, I have noticed as a doer of these things and trying to fiddle the results past Mr. Boothe and his colleagues in order to be one of these people trying to understand what's going on. The improvement is due to the ingenuity of mankind as much as it is technique. Mr. Boothe was kind enough to say most of the response was rubbish. The regulations for the frequency was just the motion frequency response, it's not a system response.

One of the delays we used to have was in controls going to anywhere, maybe that delay is now gone, I don't know, Geoff [Harris] and Normand [Bluteau] might comment. Whatever we do has to be simple. I'm still deeply suspicious. The ingenuity of mankind is what confused me rather than technical facts whether we get 80 milliseconds or 100 milliseconds or 300 milliseconds, I don't think that's always a measure of the system, that's a measure of the ingenuity of mankind, whatever we do has to be simple when it goes in the regulations.

It may be as a result of a complex and clever research, but we have to try and capture a test or a measure or something which is simple and unambiguous, otherwise we are going to confuse the industry. I'm getting confused.

MR. BOOTHE: Very good point. I agree. I see we go from here to there and back. Bob [Heffley]?

MR. HEFFLEY: Okay. On this subject of frequency response, I guess in hearing some of the remarks it's important to maybe keep in mind that frequency response is a way to—is a way to get at system response in an overall way, that it pulls in a lot of individual little components, but you are trying to crunch things down to just a very few very relevant parameters.

And as kind of a historical note here, the use of looking at these kinds of things in the frequency domain was very painfully adopted in the past few years by the handling qualities community and has found its way into the basic handling qualities specifications for aircraft. In particular for helicopters, that's where the—where this way of looking at things has really been most successful. But in order to do it, there really are some kind of new tools that have to be used to get a frequency domain measurement. It is not a matter of putting in discrete frequencies, that's one way to do it, but it's a tough way to do it.

If we are to be measuring a system in terms of frequency response, typically what's done these days is to drive the system with some sort of a range of inputs, you can actually have a pilot sit in the cockpit and start to drive the system through a range of frequencies and actually it's as simple as starting with a very slow oscillation of the control and then more and more rapidly until you really kind of span the frequency range. Then you take that time response and run it through a Fourier transform computer program that winds up giving you a classical Bode plot, frequency response plot, amplitude and phase versus frequency. The end result is a fairly easy straightforward way of looking at how a system responds.

What falls out are these things that we are talking about like transport delay and basic aircraft response. They are all mixed up together. The one crucial element here in this I think that's fairly new, in order to handle this, is the ability to take the time domain responses that are generated and translate those into the frequency domain. But that's a matter of software and it's reasonably straightforward. But it's a different way of looking at it.

And as I said, the handling qualities community got to this very painfully because it required a lot of new ways of thinking and looking at things. But in the end it's a way that is really quite successful in handling a lot of different kinds of systems and a lot of different kinds of components and we have the issues of motion, visual, aircraft response, they all, you know, in the end they all get pulled together, the pilot doesn't see these individual components, the pilot is just some sort of a processing system that takes the overall. And so you don't need to break things down into components, especially in the end. That's what the frequency domain way of looking at it gives you.

MR. HARRIS: A small point first, we are talking about column stiffness, all column stiffness in motion systems depends on the length of the stroke, most critically depends on the mass of the payload of the platform that you are moving.

The second thing has to do with Bode plots of aircraft and motion systems. We can track demanded acceleration of the aircraft and the response acceleration of the platform, it's very straightforward, you can model acceleration with the model of the aircraft. What we can't do is the frequency sweep of the aircraft itself. To put a frequency sweep on the control column of the aircraft is very difficult and probably fairly unsafe, so we can't put half hertz, one hertz, two hertz in the control column and model the aircraft.

MR. BAKER: It's been done, by the way, on helicopters.

MR. HEFFLEY: Disagree.

MR. BAKER: On actual aircraft it's been done.

MR. STOCKING: It's been done in the commercial.

MR. BOOTHE: I'm sort of losing track here. There was somebody I missed over here, maybe you gave up.

MR. WILLMOTT: I'm looking back to the ground rules of the meeting which were—we were to identify motion cuing considered essential for specific recurring training and checking tasks. To my knowledge, there are a lot of Level B simulators out in the industry right now that are perfectly satisfactory that have used 300 milliseconds as the latency test. And one comment is if it ain't broke, why fix it? For the higher level of simulators we have already got 150 milliseconds, and now we are talking about, you know, doing other types of tests that aren't even being considered for Level C and D devices.

And the ultimate purpose, I think, of this get-together is to try and reduce the cost of the simulators, which right now are in the range of ten to 15 million dollars, down to even less than half that. And I'm not sure that the CAE and Thomson organizations are capable of going downhill from the [Level] C and D devices. There are a lot of other people out there currently trying to get involved with simulation. There is one organization that is currently producing a Beech 1900 simulator to Level B standards, and you know they believe they can do it for around 2.5 million dollars. And I think to consider, you know, tightening up the requirements for people that are trying to get into the business, if you like, using standards that have been accepted over the last ten, 15 years, is something that we don't really want to do right here and now. And I would like to recommend that we stick with the 300 milliseconds that is currently in the requirement.

MR. BOOTHE: Thank you, Stu [Willmott]. I think Sunjoo [Advani] had a comment.

MR. ADVANI: I simply disagree.

MR. MARTIN: I would like to make a statement that supports the idea of both the time and the frequency domain characterization. Tom [Longridge] had earlier said he is interested not only in defining the immediate cost reduction requirements, but also identifying research issues. Frequency domain measures do not capture transient response. You are going to get different delay values from the frequency domain measurements than you will with step input measurements. You may want both—and you may want different tolerances for both.

MR. BOOTHE: Bob [Heffley]?

MR. HEFFLEY: That's an important point that Ed [Martin] makes. At the same time, look, to me the reason for bringing up the frequency domain aspects here is that it's a way to look at that high frequency end of things. Where you have these issues of transport delay and the match in the phasing between motion and visual. Those are things that are of concern in the very, very short term. And certainly still have to have things correct in terms of the basic, let's say, response of the aircraft, short periods, load weights and all that good stuff. That's got to be in there.

One other short point is back to what Stu [Willmott] just said. I think it's terribly valid to say, you know, if it isn't broke, then why should we be trying to fix it? But look, if we are really trying to get down to the matter of reduced costs on some of these crucial components, particularly motion, you have got to know how to make the trade-offs, you have to have some ways of saying well, look, if I do back off on motion amplitude, how does that—how does that balance out with any of these other basic characteristics in the simulator? And that's what I think does force you to start thinking in terms of some of these different approaches to how you look at systems.

MR. BOOTHE: Okay. Let me get these two questions. Thanks, Bob [Heffley]. Then I think we have to discuss where we are going from here. I don't know which of you was first, but Sunjoo [Advani], then you and Frank [Cardullo].

MR. ADVANI: I would like to quote Paul Ray's comments last year at the Making It Real conference, where he said we should also consider the cost of not doing these things and the cost of not making these kinds of revisions. To address the bidirectional behavior of the pilot. I think we should keep that as also a primary guideline in this discussion.

MR. BOOTHE: Agree. Frank [Cardullo]?

MR. CARDULLO: Well, in response to Stu's [Willmott] comment, I go back to the first comment I made. If the simulators out there actually do have 300 milliseconds of delay, then we can cut the cost of the simulator by forgetting about the motion system and that's going to cut it substantially. We can just put a vibration system out there. I don't know that we know that they are perfectly okay. Just because they pass certification requirements doesn't mean they are okay.

MR. BOOTHE: It doesn't. Not to butt in, I'm sorry.

MR. CARDULLO: That's okay. You are the chair, you can do whatever you want. If you have a pertinent comment, go ahead.

MR. BOOTHE: I was just agreeing.

MR. CARDULLO: So, you know, putting Bob's [Heffley] most recent comment into the context of all this, if we are looking at this problem, we have to look at the whole problem and we know that 300 milliseconds is going to cause problems. It may be that there are no simulators out there with 300 milliseconds, but if someone all of a sudden wants to come along now and try to design something that's really cheap and gets in there, we might find that we do have problems. So I think we really have got to address this problem.

And one additional comment I would like to make. I have made reference a couple of times to what the Navy is doing. I really wish I'd brought some documentation on that, because they have really done quite a bit in terms of test methods, trying to define criteria, in terms of relative phase between motion and visual as well as just overall delays in both time domain and frequency domain, and one of the interesting things that they do in measuring transport delay in the time

domain that purely gets at what the computer is adding is that they actually take the vehicle dynamics out of the loop when they make that measurement. They keep the integrations in, essentially they keep the equations of motion in there, of course, depending on what kind of integration algorithm you choose, you can really screw up the problem, right? So they leave the integration algorithms in but they take out the aircraft dynamics. So they really get just a pure delay. So I think it would be instructive, really, to look at what they have done, rather than try to repeat work that's already been done. I wish I'd brought that stuff, I didn't think of it.

MR. BOOTHE: Maybe we could get it at a later time.

MR. CARDULLO: I could certainly send you the stuff and you could distribute it to people when we review the proceedings, maybe it can be integrated.

MR. BOOTHE: Okay.

MR. BAKER: Let me make one quick comment. I looked at the stuff Frank [Cardullo] is talking about and I think it is a good piece of work. I think it bears looking at.

MR. BOOTHE: I would like to see it. Let's give Stu [Willmott] one chance to reply here and we need to—

MR. WILLMOTT: I was going to comment that of course when you have one of these tolerances in the requirements it doesn't mean people are going to design their systems so they back right up onto the maximum values, they are still trying to do better than that. I think many of the systems out there are considerably better than that. I think if those latencies give a problem from a piloting standpoint, that is one of the things that the FAA subjectively evaluates as part of their flying evaluation of a simulator at initial acceptance. And if it's found, if the simulator is found, to be unacceptable in doing the tasks, then they can raise the flag on that and something has to be done about it.

And I don't know if you want to continue talking about frequency response, I'm still not sure what you are going to do, but I have listed a number of variables involved with doing frequency response. Of course it depends on the axis that you want to do this in, you have six axes, of course you have the stroke that you want to use, and that gives variability on the response that you get. What attitude of the simulator that you are going to use for doing that, whether it's just zero pitch or whether you are going to have it up at some pitch attitude where perhaps you want the response to be better, like engine failure after takeoff, where you want the real quick response. The frequency and then other things like the oil temperature, and the filter standards, and all sorts of things like that. And as far as I know, what you are aiming to get out of this is some sort of a, I guess a phase, either a delay in time, or a delay turned into phase lag using the input frequency, versus the frequency.

So here is this picture and you have a whole family of these things and now you have got them, what are you going to do with them?

MR. BOOTHE: One more comment.

MR. HEFFLEY: That's why it has to be done in the context of a specific task. And that task dictates how you look at that frequency response because you are right, you can generate an awful lot of stuff that, you know, you don't want to bother with. But there are a few relevant things and it's going to depend on that, especially that critical task, that's the design elements.

MR. BOOTHE: I think you keep leading us in a direction, Bob [Heffley], that's probably proper. There are a couple of comments I would like to make. I don't know if we got the point across about frequency sweeps in airplanes, I think they have been done and they are possible, so I just want to clarify that point that even in large airplanes frequency sweeps can be done.

In terms of the 300 milliseconds being "if it ain't broke, don't fix it," I think perhaps it has been getting fixed through subjective or other types of evaluations. I think it's pretty much a rather ignored specification because it gets measured but because of subjective measurement and

subjective tuning, if you will, of motion systems, I think it's—I'm not sure, but I think it's more or less meaningless in the qualification of a simulator these days.

Of course it's measured, but does that really mean anything? I think we are at a point here where, as I said in the beginning, we could either—the easiest or the hardest of the whole book and it turns out that it's not the easiest. So I think we could spend the rest of our today and tomorrow on it, and of course we can't do that.

Bob [Heffley] has made the suggestion several times as we discuss these things unrelated to a task we really are not zeroing in on the problem, I guess I could say. So maybe what I can suggest is that we agree that, or at least I think we have a majority consensus that 300 milliseconds is not satisfactory, I think Frank [Cardullo] put it in context if that's what we are going to do, maybe we could go drink beer for the next day and a half and not have to worry about the rest of it. So we have also, I think, had suggestions that 150 milliseconds, if we are going to measure transport delay and latency in the manner that we have measured in the past, 150 milliseconds is at no additional cost in today's technology. Is that a fair statement?

MR. HARRIS: Yes.

MR. WILLMOTT: It's the major manufacturers.

MR. BOOTHE: Well, today's technology, I think, applies to whomever. I don't think that's restricted to major manufacturers.

A third suggestion is that we should look at frequency domain and measure phase lags, that certainly sounds like a reasonable thing to me. However, as Don [Irving] has pointed out, we still have to keep it simple. And I think that's important to a performance specification and that's a very important point that Don [Irving] made, we do have to keep it simple. So we have got all those things to consider.

And so my suggestion would be let's at least in the interim of the two days accept 150 milliseconds as a starting point, assuming that we are going to continue to measure transport delay, let's keep frequency domain measurements on the table, we don't know how to, at this point to keep it simple or how it might be done, but I think we cannot discard that, and proceed through the table and as we proceed perhaps we can identify that critical task and at that point perhaps then we can say well, here is the one we really have to look at in terms of addressing a performance specification, if you will, for motion. And we might want to at the same time consider the motion and visual system relationship and a phase difference of those two systems.

But I think if we continue to talk about only motion transport delay, phase lag and frequency domain in sort of open loop, without having a task to close that loop, I think we are going to be here two days and still talking about it.

So is that an acceptable progression to move on with keeping those thoughts and try to address them at the appropriate time? And I should, I guess, ask, is 150 milliseconds acceptable to you from the FAA, that we could go on on that premise?

MR. RAY: I see no reason not to. What I would put on the table with your list of notes there, Ed [Boothe], is the potential of a number, the one I have in my mind is 50 milliseconds, but visual cannot lag motion. It's a synchronization issue of visual lagging motion and the number that comes to mind is 50. If, for example if you have motion that occurs and you have got a high fidelity system, high quality system and you are getting let's say 50 milliseconds on motion, you may end up imposing on yourself, and rightfully so, a 100 milliseconds tolerance on that delay if you have a number that links motion and visual together.

MR. BOOTHE: Well, I have a problem with that number but I can't defend it, either. I don't know—

MR. RAY: It just appears that 50 milliseconds is defensible from some of the studies I've seen, Ed [Boothe], and others I hear Ed [Martin] and Frank [Cardullo] talking about.

MR. BOOTHE: That falls into the same thing we have been hearing, maybe a number is not the correct approach.

MR. RAY: It may not be. But in the context if we are going to embed a relationship between motion and visual within 150.

MR. BOOTHE: We will start at the end.

MR. CARDULLO: I'm a little bit concerned about that from the following standpoint: Obviously we must be concerned about the relationship between motion and visual. But for [a] purely time domain characterization of it, I don't know if any number is really defensible. What we want to be concerned about is what really is the phase relationship. And you want to make sure that the whole system does not drive you into a point where your phase margin is too small and renders the whole system uncontrollable. And why I'm a little bit reluctant to put a time domain specification on this synchronization issue is that the motion information is what provides you generally a lead, and if you get the sense of motion, I'm not sure how much missynchronization is tolerable and I don't know how much you can really allow the visual to lag. It depends somewhat on how long you can sustain the motion cue. So we are in a really touchy area and I'd rather say nothing than say something that's wrong.

MR. RAY: I agree. If there is a better way of phrasing it—

MR. CARDULLO: I don't know what everybody else thinks about that, but I'm really kind of uncomfortable with that. Because we simply don't know.

MR. RAY: It's certainly an issue to lay on the table now.

MR. BAKER: The other thing I would like to suggest in that area is, as Frank [Cardullo] said, the motion provides you with very fast cue compared to the visual. And it would be a mistake to drive somebody into the position where they have delayed the motion cues so that the synchronization is better because you are going to have more problems with the phase margin of that fast control loop, which I believe is almost 100 percent from the motion cue and not from the visual at all. So I wouldn't want us to put anything in here that even suggests that it's a good thing to delay the motion so it more matches the visual delay, okay?

MR. RAY: That's exactly the reason I mentioned the 50. Because I know there are systems out there that are capable of less than 50 milliseconds and you are going to find people playing games. I appreciate your comments, because that was the reason I said—you don't want to see people taking a high quality system and playing with it just to accommodate the visual.

MR. BAKER: Or just to accommodate a spec and perhaps degrading the actual performance and flyability of the system just to meet a spec requirement.

MR. BOOTHE: Very good point.

MR. SMITH: I hate to bring this up, but I'm more concerned about the phase lag after the discussion this morning than I was before because there is some indication that we are not getting a true indication of the latency of the visual system because we are just measuring the line on it rather than waiting till the whole scene is computed. And the video system delay may be much greater than what we were getting. And so—

MR. RAY: It's true.

MR. CARDULLO: We don't understand a lot of the psychophysics that is involved here and most of the knowledge that we have from the literature has not been derived from simulator literature. The experiments involving the relationship between vestibular stimulation and visual stimulation that Young and Dichgans and those other folks did were not done in simulators, and that's the only place that I know about that that information exists. Another factor is that they were not task loaded, they were not doing something, it was just a purely psychophysical experiment. So we are really at a loss for supportable data.

MR. ADVANI: I would just like to add that we recognized there was a lack of data five years ago and that's why we put so much effort into designing a system which allows us to go into that kind of study. If we had begun with an existing system we are already infiltrated with those kind of phenomena of the time delays and phase lag and so on. So we put all the efforts into reducing the inherent lag of the system so we can simulate all the various types of situations and introduce lags, introduce discrepancies in visual and motion. So I think there exists an opportunity here to do research.

MR. BOOTHE: Geoff [Harris]?

MR. HARRIS: Going on at the moment there is a European research directive, it's under a Euclid title, it covers all aspects of simulation, visual, motion, the various aspects, the phase and the timing. It is still in draft, due out in three, four months' time. If it is available, then I will bring it to the session and we can distribute it. It does cover all aspects. There is about 300 papers referenced at the end, including the psychological aspects.

MR. CARDULLO: Psychophysics. Who did this work? The group?

MR. HARRIS: Dassault Aviation and IMASSA-CERMA in France. Roke Manor Research and Thomson in the UK, NLR Netherlands. With references outside to U.S. papers, European papers.

MR. CARDULLO: So is it a literature review or experiments?

MR. HARRIS: It's a literature review. They were not experiments as such.

MR. SUSSMAN: Is this to form the basis of a CEN standard? What's the purpose of the review?

MR. HARRIS: I don't know at the moment.

MR. HEFFLEY: I guess I just wanted to mention also along the same lines there is some ongoing work right now that's really relevant to what we are trying to talk about today. At NASA-Ames, I guess NASA is the one that's doing it, but basically looking at what are the motion cuing requirements for simulators. Right now it's really centered on perceptual as opposed to training. They are not really looking at training right now. But they are looking at what is required to successfully fly certain flight tasks. Jeff Schroeder is the main contact there, but this is being done on the VMS, so there basically is, at least in comparison to the typical airline training simulator with VMS there is pretty much unlimited motion, so you are kind of working back into smaller amplitudes. But all of this really hinges on getting down to specific flight tasks, that's the only way, really, you can start to get a handle on these things.

And number two, the frequency domain approach is very heavy because of that being the most successful tool for how to look at and how to define the sorts of things we are talking about.

MR. BOOTHE: Paul [Ray]?

MR. RAY: If I could add to that. We have had one of the members of our staff participate in the effort at NASA-Ames. And if memory serves me correctly, he indicated that they use the entire envelope of that system and then work downward to specific degrees of motion that are available.

MR. HEFFLEY: They start out one-to-one; yes.

MR. RAY: He has the results in his desk from his effort and he said it was so clear, the need for motion to do a task, the removal of motion and the task became basically non-doable.

MR. BAKER: Somebody should tell the Air Force.

MR. RAY: Regardless of what was done. Contrary to some of the blue suit reports out there.

MR. BAKER: Exactly.

MR. RAY: So we have had someone working on it.

MR. HEFFLEY: I have a copy of one of the papers I think that is currently out there on the—I think it's mainly looking at yaw axis isolated, and if you want to make a copy of that for anybody—

MR. BLUTEAU: One last comment on the frequency domain approach. There may be value in that method, I'm not sure whether we are all ready to agree with that today, because of time constraints we may decide to postpone the final decision. It is interesting.

I think the delay is in two parts, the delay due to transport delay and the delay due to motion response. The way many people have approached this problem in the past is to check those two elements separately, the transport delay first, the motion frequency response and the phase lag checks second, and separately makes it easier for the manufacturers to identify the source of the problem, to pinpoint whether it's a computer architecture problem or whether a motion servo controller phase problem.

So we addressed the problems separately. But in effect I guess we achieved the same result, we ensured the phase information is proper, that the overall system as seen as a complete system actually has a proper phase shift.

So this new method may sound new but it may actually be already in the circular, at least in AC120-63, where I think phase tolerances are specified, I believe. So this may seem like a new one, but it may in fact already be used.

MR. BOOTHE: Have we experience yet using the helicopter advisory circular and those motion requirements that we established there several years ago?

MR. SMITH: We have looked at a couple, I don't know if we evaluated one since it's been published but we did a couple under XX and I don't remember the motion test results.

MR. BOOTHE: Draft XX did not contain motion requirements. Well, it's getting close to lunchtime, actually it might be best to break a little early for lunch rather than trying to start this task-by-task thing, and then come back a little early because I do think we need to progress on to the task-by-task discussion, and keeping in mind that we have tentatively accepted that we will look at 150 milliseconds if we are going to retrain a transport delay.

We will entertain frequency domain measurements, but as Don [Irving] said, we have to keep them simple. So as we go through I think it would be proper at each task we address to ask the question, is this critical? And we may not know that until we get to the end because you might look ahead and see what's in there and perhaps can make some decisions about where you think it's going to be critical as we go. It's not a very long list. I think that's my recommended approach. If you have a different idea of how we should proceed, I would like to hear it.

MR. BLUTEAU: I think it's a good idea to keep in perspective the cost of the simulator. I think we should possibly identify what are the parameters that are cost drivers in a motion system. And when we look at the elements on the table, determine whether—how critical those maneuvers are and what effect do they have on those motion features that are costly, to possibly be able to reduce those motion features that cost a lot of money.

We have talked about, obviously, frequency response as being a cost driver and we covered that one. But there may be other cost drivers, the length of the actuator would be one of them. Maybe length of the actuator. How long an actuator we need. There are other cost drivers in motion systems, smoothness is one of them, turn around bump, maybe we should have a list of cost drivers and really ensure that we actually need those features.

When we get to the end of the session we will find out some of the cost driver issues can be simplified while meeting the essence of those requirements so they do address the costs and we know how those issues actually correspond to the training value.

MR. CARDULLO: I was going to suggest something along those lines. I agree that that's a good idea. But along with that, identifying what we think are the most critical parameters of

motion cuing. What are the critical parameters in a motion system design, those parameters that are critical to motion cuing. You mentioned smoothness, it turns out it's not only costly but it's also critical. But there are some other things maybe that aren't so critical, like how critical is static accuracy which we often impose as a requirement. I suggest we look at what are the critical motion system design parameters and then also determine whether they are costly. Therefore, I would just add a dimension to what you are suggesting.

MR. BAKER: I would also like to hear from you guys that make simulators, what are the big cost drivers in the total simulator? So we can put the motion based costs in perspective. Because I'm going to get the feeling before we are done with this session tomorrow that we are going to figure out a way to get the motion based costs down to a relatively small number compared to some things like EFIS instruments and visual displays. Because I know what those things cost, they are quite dear. So I think you guys can probably give us a pretty good indication of what's driving the cost of simulators right now so we can put the problem in perspective. In other words, I don't think we ought to worry about taking one thousand dollars out of the motion platform, we are not going to get the simulator down ten million dollars by doing that.

MR. CARDULLO: I quote the results of a Rand study done a few years ago for the Air Force where they calculated the 25 year life cycle cost of adding motion systems to the C-17 simulators, and it added four percent to the total life cycle cost, which included building cost, heating and air conditioning costs because of a larger building and all of that. For cost purposes they were looking at a synergistic six degree of freedom motion system. So four percent of life cycle cost is probably a small number, it seems to me though, I guess four percent of a big number is a big number.

MR. BOOTHE: That's true that they did come up with four percent.

MR. BLUTEAU: I'm not sure how long ago the research was done, do you remember the year it was done?

MR. CARDULLO: It's probably getting close to ten years now. Whenever the Air Force was contemplating the C-17 simulator, maybe Ed [Martin] recalls when the Air Force was seriously considering the configuration of the C-17 simulator. So it's probably ten years.

MR. BLUTEAU: Why I'm asking is because technology has changed a lot since then. And when we look at smaller devices, like commuter aircraft simulators, and because we are looking at really providing the industry with something very cheap, then maybe those figures do not apply as well as we would think.

MR. BOOTHE: You are saying it could be even less life cycle cost?

MR. CARDULLO: More. I think he is implying more.

MR. BLUTEAU: More, yes.

MR. MARTIN: For example, you may have a rudimentary simulator having a TV set in front of some sort of cockpit.

MR. BOOTHE: In that case, yes.

MR. CARDULLO: You are talking about a wide field of view visual display with relatively high resolution. That certainly drives the cost very rapidly. If you are talking about narrow field of view visual, a TV monitor, it could be less impact.

MR. BOOTHE: Any other—

MR. HARRIS: Just is there a clear definition of what the simulator will be used for?

MR. BOOTHE: We are going to talk about that after lunch. That's what these tasks are all about.

MR. HARRIS: I was thinking will it always be a commuter? Will it have windshear? Will it only be used for landing and takeoff?

MR. BOOTHE: Well, yes. We said earlier that the simulator we are addressing is primarily or our considerations are addressed primarily to recurrent pilot certification. Which includes all of the pilot certification maneuvers and procedures. Windshear I have put here with a question mark because I don't know whether or not we need to consider windshear. Paul [Ray] is saying yes. But right now I think the rule permits operators of turbo propeller airplanes to do windshear training in the classroom environment and not have to do it in a simulator. But we cannot assume that our conclusions will apply only to turbo propeller airplanes because there should be one standard and one level of safety and if somebody wants to make a Level B 777 simulator, they are certainly permitted to do so, and in that case windshear would of course be a requirement.

MR. HARRIS: Okay. Windshear certainly effects the geometry of the motion system.

MR. BOOTHE: I know. That's why I had the question mark. That's a question I think we need to ask, does every simulator have to do windshear or does the operator simply have to find a simulator in which to do their windshear training? I think the latter is true, but in our consideration of a Level B and the thoughts of trying to lower cost, do we want to include that? Because that could be a significant driver as to what kind of motion geometry.

MR. LONGRIDGE: You should probably address both. The turbo prop operators do not have to address windshear in a simulator. Clearly the focus of this meeting is on commuters, nearly all of whom at present fly turbo prop aircraft although that is changing. But you might want to consider having two versions of the table, you know, one for turbo prop, which is our majority concern here, and the other for those that are operating regional jets.

MR. HARRIS: Do the aircraft incidents that we are concerned about—aircraft safety, is it more predominant in windshear situations?

MR. BOOTHE: I don't think I understood the question.

MR. HARRIS: If a turbo prop or any other aircraft is flying through windshear, is that where incidents occur? Is it more windshear or more aircraft that causes the fault?

MR. LONGRIDGE: I'm not sure I even want to address that question. It's from a regulatory perspective, for those operators operating turbo prop aircraft, we don't have to provide a simulator capability for training windshear.

MR. HEFFLEY: Why is that? Why that distinction?

MR. LONGRIDGE: Well, there again I didn't make the rule but I think the thinking—

MR. CARDULLO: Because it's tough.

MR. LONGRIDGE: You don't have a spool up problem, you have got positive thrust, quick response. You can fly out of it. It's not an issue.

MR. SMITH: You have power to lift that, you don't have—

MR. RAY: There was an assumption made, does that tell you anything?

MR. BOOTHE: Bob [Foster] had one comment there, did you still have a comment?

MR. FOSTER: Just about windshear, turbo prop people are not required to have windshear detection and avoidance equipment in the airplanes either, whereas all turbo jets have to have it.

MR. BOOTHE: I ten minutes ago said we were going to break for lunch. Now we are late.

MR. WILLMOTT: I just wondered if there was one general consideration we will give to motion when we are going into each of the items. That is, it seems to me there are three purposes of motion, one is something like an engine failure where a motion happens and a pilot must respond to it.

The second thing is where he does something and expects a response from it, and the third thing is whether there are things in the motion system that are nice to have for realism, like flap buffet, and I wonder whether we ought to address these items when we are going into each of the items here.

MR. BOOTHE: I think we do indirectly through those, what did I call them, motion objectives that I have written I think do address those issues but if you find they don't then by all means bring them up and we will do that. So let's plan to—if I can find the agenda, I think we have an hour for lunch, we will reconvene at 1:00. I will try to have a copy of Appendix H and some other stuff.

(Lunch break taken.)

MR. BOOTHE: I think we can get started again. Back to the administrative duties, first. Did you remember to bring your ticket receipts so we can copy them?

MR. BAKER: I did, but I still didn't go get it even though I remembered. Can I get it right now?

MR. BOOTHE: Or at break. We would like to get them today. Those who have them can give them to me.

Some of these are not just receipts but they are tickets, so we do have to be careful about getting them back. If you don't have it now, just get them during a break. If you do have them now, if you would pass them to me then I will in turn get them to Don [Eldredge] and we can copy them.

There have been a couple of reconsiderations during the lunch period and people have ideas of things that we might do to improve our understanding. And what I would like to do is, Sunjoo Advani had a brief presentation that he wanted to make. And following that there has been—there was some discussion before lunch and then during lunch in terms of before we proceed to identify some critical design parameters and major cost drivers and Frank [Cardullo] will speak to that in a few minutes. I think we might want to stop and do that so we can keep those as considerations as we proceed through the table. So let me ask Sunjoo [Advani] to do his presentation and we will proceed after that.

MR. ADVANI: Thanks, Ed [Boothe]. I will keep this quick. I didn't know how this workshop would go, but I just made some view graphs to express our concerns and our viewpoints on the issue of motion, our viewpoints being SIMONA, just very quickly what SIMONA is all about. You should have a copy of a recent Flight International article in front of you.

The goal of this program is to develop simulation technology and look at the standard with the new technology in a research environment. The focus being on the physical cues of motion, and visual as well as audio. With the utility of the high performance modular research simulator as well as a Citation II laboratory aircraft. It's a multi-disciplinary project in which we work together with a lot of industries as well. In fact through this type of collaboration we are also a sort of simulator developer on our own. So we are quite aware of the reality issues and with constraints of university budgets we have to think of low cost approaches to things without compromising the quality. And as I said earlier, our goal is to develop a system which exceeds performance levels so that we can address all of the performance issues. This is a view of the device synergistic motion system. One interesting thing is we have looked at not just purchasing an off-the-shelf system, but looked at issues such as the optimization of the motion envelope by changing the geometry of the system.

There is in fact a lot to be gained by changing, say, the gimbal spacing, change the arranging of the motion system to give the cuing in a particular degree of freedom more emphasis.

One of the interesting conclusions about our research is that in order to improve the motion system performance, you have to put a lot of effort in reducing the inertia of the visual display system because that contributes to the coupling dynamics, contributes to the lag of the motion

system response. So the flight deck and the visual are built from advanced composites to keep their contribution to the inertia as low as possible.

Now about this meeting, I just wanted to reiterate a few points. We should be looking at the criteria from the point of view of the specific forces and angular accelerations. There may be some discrepancy here about angular accelerations or rates at the pilot head position, the detection of false cues, so the detectable false cues should be thrown out as much as possible. And the fact that you should not be considering the positions, in fact it's not the roll position or pitch attitude but in fact the forces which drive those and drive what we are going to talk about now, the envelopes of the motion system. And we should have a very clear understanding of the time delays and phase lags.

And by the way, I know that we have discussed a lot of these issues, I made these slides on my way over here, so please excuse me if some of this is repetitive, but I will go through it quickly.

If you look at an aircraft motion in roll you see the simulator reaches its maximum very quickly in position. In velocity as well. But acceleration can very closely follow it. And we should be then looking at something between velocity and acceleration. Just a point to keep in mind for the coming instructions review about the Level B motion requirements is that you cannot address this alone. If we want to simulate the pilot-vehicle interaction we have to look at the interaction and not say it should be based on just the standard, the way we have been going about it, that's our feeling. The value of training and the transferability is something else and we should address all the issues simultaneously in that respect. And the costs of training devices, as we have heard now, is driven not only by the motion system, but by many other factors. And we also discussed the fact that if we were addressing the commuter market it may require the highest motion quality, in fact inversion motion qualities for the size or the cost of the aircraft, which means we are—we have to do some very interesting work in the future.

Now, I just wanted to reiterate some of the issues about the time delay to make it clear that we have two things, the pure time delay and the phase lag. Pure time delay being something for example from digital computation independent of the frequency and the phase lag being dependent on the system dynamics. And the total sum of these at a given frequency is what we should be considering. I just made a rough sketch of these two factors, the pure time delay being a simple phase shift while the phase lag of course is dependent on the function. Now, we have talked something about the delays and effects on pilot performance, I won't go over that again, but just to reiterate some things, motion system delays can be caused by the motion controller hardware, the controller software, including all of the transfer functions in the software, we also have to consider the effects of the washout filters because that's not an independent article in the total system delay. It's part of that system. The servo valve also has a transfer function which should not be forgotten.

One thing we have done in our approach is to use a new type of feedback that is velocity feedback and closes the outside loop with pressure in the actuator control. And we are finding that the robustness of the actuator, the robustness of the motion system in various attitudes can also significantly affect the performance. If you double the load or change the position of the platform, you can have a totally different response. So we should be very careful in how we define these requirements. The platform itself also has a transfer function dependent on its own inertia. That has been one of our major efforts. Some of the sources of the delays can be, and this is for time and frequency domain, the sampling, if you miss the sampling period you can have up to one over that frequency in delay. You have the computation in the model itself, the integration scheme which is applied as in Tustin and as in Adams-Bashfort. These can also have an impact on delay and prediction of the algorithms and the testing methods for those. The D[igital] to A[nalog] conversion and the cuing device of course follow.

So I think we have all come to one conclusion so far, and that is we need to do research. So we need to understand variations in these parameters with the pilot, with the pilot in the loop,

evaluations because we are talking about a man-machine system here. And it's a matter of understanding the synchronization of a multiple cue environment. And this is in fact what we have set ourselves up for to do in the future. This type of research. Are there any questions?

MR. ELDREDGE: Do you need a break?

THE REPORTER: No.

MR. BOOTHE: Thank you, Sunjoo [Advani].

MR. WILLMOTT: I had one question on that, Sunjoo [Advani], you said the criteria you are looking at is acceleration and not velocity or position. When you are considering longitudinal acceleration, for example, the position of pitch attitude is one of the keys to the acceleration, is that included in your acceleration?

MR. ADVANI: Yes. Well, it's simply the total sum of the forces and the rates or accelerations which you are driving your system with. Of course you have to accept some false cues but we should try to keep those within the threshold of perception. Those are what we feel are the important criteria.

MR. BOOTHE: Thank you. We have added to the weight of your briefcase for the trip home by giving you a copy of Appendix H. Tom [Longridge] has pointed out it is not the most current copy, so if you can mentally change Phase 1, Phase 2 and Phase 3 to Level B, Level C and Level D, I think that's the major change. But I think it's important for you to see where Level B simulator requirements are now recorded in the regulatory sense and those are here under Phase 1.

I have also given you a couple of pages from the Advisory Circular [A120-40B] Appendix 2 and on the page that is numbered 14 you can see the current motion system specification, or the lack thereof. And on the page numbered 16 are the 150 to 300 millisecond requirements, and interestingly enough sound is on that page. And either Normand [Bluteau] or Geoff [Harris] said that this morning, that we should consider sound because it certainly ought to be properly synchronized, I guess is a good enough word, with the other sensory input. So I just thought that was interesting that came out on that page. So those are for your reference as we proceed.

Rather than going directly to the table, I've had, as I said earlier, a suggestion that as we do that table we ought to know what the critical parameters are and what the cost drivers are. I think Frank [Cardullo] can explain that much better than I. And more importantly, or not more importantly, but also he has said that he would be happy to record these parameters on that easel there as we identify them so that we can keep them in consideration.

So Frank [Cardullo], could I ask you to explain that particular task?

MR. CARDULLO: Okay. Norm [Bluteau] started the idea with saying we ought to identify the cost drivers. And in connection with that, I think it's really—first identifying the critical design characteristics of a motion system and then specifying which ones of those are in fact cost drivers. So it's sort of a two-step process to get at what Norm [Bluteau] was suggesting.

And so what I thought we could do is if everybody just hollers out what they think the critical design parameters are, we can list them all without comment and then get a consensus from the group as to which are indeed the critical ones and then get a consensus which are the cost drivers. So we should be able to do that relatively quickly.

Do we want to do that?

MR. BOOTHE: Yes.

MR. ELDREDGE: If it's done neatly I will take the pages back and get them put in tables and submit them.

MR. CARDULLO: That's another constraint you are placing on me.

MR. BOOTHE: I'm not the one writing this.

MR. CARDULLO: Do we take off points for neatness?

MR. ELDREDGE: Of course not.

MR. BOOTHE: While we are doing that I might remind you the current Level B simply says a three degree motion system—three degrees of freedom motion system as you find in Appendix H. It does not say which degrees of freedom. Traditionally those have not been the correct ones in my opinion. But traditionally they have been heave, pitch, roll. I think there is more critical ones but whether or not you can have the others without having those, but that's really our starting point.

MR. CARDULLO: So I guess degrees of freedom is one design parameter.

MR. BOOTHE: Right. I got my piece in, now it's up to you.

MR. CARDULLO: Smoothness was one that we mentioned, right?

MR. MARTIN: Probably bandwidth with emphasis on the phase lag.

MR. CARDULLO: Phase bandwidth.

MR. WILLMOTT: What does that actually mean? Is that the servo or the electronic drive—

MR. MARTIN: System. I would tend to exclude washout from that. Normally you treat the washout independent of the hardware system.

MR. CARDULLO: We are talking about hardware first. And we might want to mention cuing algorithms separately.

MR. BAKER: Time out. The problem with leaving the washout out of this discussion is that the washout, part of the washout can be put into the servos of the motion platform and it works perfectly well, okay? And I don't know how to handle this exactly, but—

MR. MARTIN: That's the way it used to be.

MR. BAKER: Try and separate those two, then you are going to drive the thing to a point do you need a five or six or seven hertz servo on the motion platform, which I don't believe that's true. If the motion servo response is sufficiently linear, that is, it's the same response over large variations in amplitude, and it could be represented by an analytic function, then I submit to you I can compensate that in software and make it a five hertz or seven hertz system even though the servo itself is only a couple of hertz in bandwidth. Maybe even a half a hertz in bandwidth.

MR. CARDULLO: I don't think so, Bruce [Baker], for the purposes of what we are doing here, all we want to do is decide what the critical design parameters are. If you are talking about bandwidth being a critical design parameter, I don't know that we have got to get into where or how the motion cuing algorithm is split between hardware and software, right?

MR. BAKER: I don't want to say a five hertz motion is inherently better than a one hertz motion platform. Right now—admittedly, I haven't talked to all you guys in great detail on that. Right now I don't happen to believe that.

MR. CARDULLO: We can treat it as a total system.

MR. MARTIN: He makes a good point, that's the way we used to do it.

MR. CARDULLO: We used to do it that way. We found out that wasn't the best. Sunjoo [Advani]?

MR. ADVANI: Cross-talk is something. Cross-talk.

MR. REID: Do you bump—

MR. CARDULLO: Smoothness includes all that kind of stuff.

MR. WILLMOTT: Stroke length.

MR. CARDULLO: Excursion? Why don't we classify it as excursion and it will be included in each degree of freedom. It certainly ends up being ultimately stroke length—

MR. STOCKING: Payload weight.

MR. ADVANI: That relates to the maximum acceleration.

MR. BLUTEAU: Acceleration is the real factor.

MR. CARDULLO: Acceleration, then?

MR. ADVANI: Yes. You are going to—you can use brute force to overcome the payload weight but in fact what you are looking for is acceleration.

MR. CARDULLO: We have velocity, we have excursion—

MR. MARTIN: Cue duration.

MR. ELDREDGE: Is that the same as washout time?

MR. MARTIN: No.

MR. CARDULLO: How about, one thing that's often specified is accuracy, position accuracy. Personally I don't think it's very important but it's often specified.

MR. BAKER: It's often specified very tightly, too, as a matter of fact. It's something you can measure and the guy says it's ten percent, it's good, one percent is obviously better, and ten percent is better even, though I can't perceive ten percent.

MR. CARDULLO: That's exactly my problem. The [MIL-STD-]1558 spec specified a relatively tight excursion accuracy.

MR. FOSTER: How about platform size? Physical size.

MR. REID: Position accuracy doesn't matter much anymore, probably, but hysteresis.

MR. ADVANI: I think we shouldn't forget the criteria for motion system design that are specified in AGARD report AR-144 because they do cover a lot, the response to half hertz, whatever.

MR. CARDULLO: So you want me to put time to half amplitude?

MR. ADVANI: I'm not saying just one of the parameters but there are a number of parameters specified.

MR. CARDULLO: We have many of them here already.

MR. REID: Signal to noise was one of them, also time to 69 percent on a step response.

MR. ADVANI: Right. That's important.

MR. CARDULLO: But when we talk about bandwidth, those end up being included.

MR. REID: They are all intermixed.

MR. CARDULLO: You want me to put some of those?

MR. REID: Not me. I was just stating what they were.

MR. CARDULLO: I think they are included more or less in this category. You fix one of them, you basically fix them all. Any other suggestions?

MR. HARRIS: Do you want to consider external standards, AGARD[-AR-]144, MIL-STD-1558, the more recent 2714 that came through? Is that a requirement for our—

MR. CARDULLO: No, it's not, all we are trying to do is get specific parameters. So if there is some parameter in any one of those specs that you don't think we have on the list already, we want to add it.

MR. REID: Is stiffness a parameter like the actuator structural stiffness, the design of your actuator, it costs you more to make a stiffer actuator.

MR. CARDULLO: But it's not usually a specified design parameter. Of course it greatly affects the bandwidth.

MR. ADVANI: Stiffness is also dependent on the way you feed back your—

MR. REID: I was thinking of actual mechanical stiffness, you take your long rod and it affects how big your actuators are physically in diameter.

MR. CARDULLO: Right.

MR. REID: I can make a little spindly one that is flexible.

MR. BOOTHE: You don't mean stiffness from a frequency perspective.

MR. REID: No, structural.

MR. CARDULLO: We are talking about structural stiffness.

MR. BLUTEAU: We go for performance, we want to go for something that is going to meet certain requirements. I think bandwidth covers in terms of stiffness, in terms of structural design.

MR. CARDULLO: I just want to put a list up and then we will go through and reduce it to the most critical ones.

MR. HEFFLEY: Going just a little bit beyond the platform size, it's really the total real estate or physical size of the enclosure that costs money. I mean, size of the room or however you want to look at that, you are forced into by not only platform size but the excursion of the motion base plus cab.

MR. CARDULLO: This gets at that, right?

MR. HEFFLEY: Okay. Yes, I guess, yes.

MR. CARDULLO: Yes?

MR. SUSSMAN: There are also the environmental requirements, cooling, heating, air flow, all of the things that you buy into when you buy a system.

MR. CARDULLO: Might as well go over to another page.

MR. BOOTHE: I was hoping for a one-pager.

MR. CARDULLO: I should have written smaller, I didn't plan ahead.

MR. REID: What about safety factor? When you build a system you put in a safety factor, one, three, four, the bigger it gets the more expensive it gets, I assume. Should we talk about it?

MR. CARDULLO: It's a parameter in the military specifications, it's always subject to interpretation, do you test it one leg run-away, two leg run-away?

MR. ADVANI: One of the safety factors in SIMONA was the maximum acceleration in the buffers.

MR. CARDULLO: That's usually where you generate the highest forces going into the buffers at maximum velocity.

MR. HARRIS: The worst I have ever seen is running full velocity and shutting off the servo.

MR. BLUTEAU: The cushion or the buffers can be designed to be very smooth so servo reversal is typically the worst case.

MR. HARRIS: Also add to your list possibly the floor load of the building.

MR. LONGRIDGE: That's part of environmental.

MR. CARDULLO: It could be considered part of environmental. I think it's significant enough that maybe we want to identify it because this ends up being affected by both the payload and the acceleration and excursion, all of them because it moves the mass around, et cetera.

So any other ones?

MS. BÜRKI-COHEN: Maintenance and life cycle.

MR. CARDULLO: Pardon me?

MS. BÜRKI-COHEN: Life cycle cost, maintenance, is that part of it?

MR. CARDULLO: Well, life cycle cost isn't a design parameter, although I guess maintainability is a design parameter. Right?

MR. FOSTER: I would say it is because if you design, for instance, a type that uses three different types of actuators, just for lack of a better example, that is a much different case when you go to provide spares. If you have to spare three actuators rather than one common actuator, for instance if you use different servo valves on different actuators, those all become real issues and can come close to doubling the price of a motion simulator.

MR. CARDULLO: Would that come under life cycle cost?

MR. FOSTER: I think so. I'm trying to support her.

MR. ELDREDGE: Do you want to include computation and conversion?

MR. CARDULLO: What's conversion?

MR. ELDREDGE: Analog to Digital conversion. Or D to A in this case.

MR. CARDULLO: Okay, I guess we can just say computation includes that, that's pretty straightforward nowadays. Anything else?

MR. BOOTHE: How about the size of the building as the thing grows? The simulator bay may have to grow, too. Is that included in environment?

MR. CARDULLO: I think that's included in excursion.

MR. RAY: Environmental, I think you picked it up.

MR. CARDULLO: Well, environment is affected by that because you need more air conditioning and that sort of thing. And that ultimately affects life cycle cost.

MR. SUSSMAN: That environment would also include power supplies?

MR. CARDULLO: Yes. The amount of power that you use to drive the compressors. Sunjoo [Advani]?

MR. ADVANI: Just a very quick one. One interesting thing that we have found, one factor which determines much of the cost and the performance is the distance between the upper gimbal plate and the design height reference point. It's a strange parameter it may seem, but it's the most important parameter in the simulator.

MR. CARDULLO: That affects moment of inertia? I mean, moment of inertia then affects everything else but that difference between the centroid and the center of gravity affects the moment of inertia which affects acceleration and floor loading and everything else. So what if we just put up mass properties?

MR. ADVANI: Sure.

MR. CARDULLO: Which is CG location. Moments of inertia and payload?

MR. ADVANI: Fine.

MR. REID: What we are talking about mostly is hydraulically actuated systems, I guess, in the back of our minds, people are coming up with electrically driven hexapod systems. Why don't you put down motor source or power source, in other words you may have a choice, if it's a smaller system you may have a choice between hydraulic or electric. I don't know what else, pneumatic, who knows what you could come up with. But certainly electric. I mean, you can buy them now, right?

MR. ADVANI: Sure.

MR. CARDULLO: You might even buy one from Bruce [Baker]. He's got one outside just waiting to bring it in.

MR. BAKER: Actually, just a side note, we built a six axis electric motion seat for a training system, we built two of them, it's eight inches high and it sits in a 14-inch diameter circle and it will carry 300 pounds. We are not sure it works yet, we haven't had a chance to integrate it because their sim isn't ready, but they have some Apache simulators that have to be transportable, deployable. And the SMEs wanted to have some motion, and we said well, we can move the seat, that's about all we can do. I don't know if we are going to get good motion cues because of the relatively small amplitude of the stroke. It's a two and a quarter, two and a half inch stroke on the base. We will find out where the low end of things are one of these days. That will be sometime August, September of this year we will integrate those.

MR. REID: Will it take a Level B cab?

MR. BAKER: Not quite.

MR. BOOTHE: Delay, is that what you wrote?

MR. CARDULLO: I wrote delay because we mentioned phase bandwidth and I thought we should probably have delay up there, too.

MR. BOOTHE: You think we should start mission critical?

MR. CARDULLO: Unless somebody has some other parameters—yes?

MR. FOSTER: One question that comes up, does the instructor station have to be on board? That has a big effect on the amount of hardware on board and all that sort of stuff.

MR. BOOTHE: How would you give—

MR. FOSTER: If somebody could come up with an alternative method, video, an enhanced instructor station type of thing and enough audio, the audio is a difficult issue to address. Could it be done that way?

MR. BOOTHE: I have been told the Russians do it that way.

MR. CARDULLO: The military fighters do it that way.

MR. BOOTHE: So if the question is can it be done, I guess the answer is yes. If the question is would the FAA permit it to be done—

MR. FOSTER: That's really the question.

MR. BOOTHE: It's a different question. You are looking at the wrong guy.

MR. FOSTER: That's the question, really. Do you—if somebody could demonstrate a satisfactory off-board instructor station, would that be acceptable?

MR. ADVANI: We are going to demonstrate that.

MR. REID: He said FAA.

MR. IRVING: Paul [Ray], I find the answer is probably no. Probably.

MR. RAY: That's the tendency I've got right now, is probably no. I wouldn't close the door forever.

MR. IRVING: That's right. You need the instructor on board, but perhaps the question is do you need an instructor station or would a little VGA screen be sufficient?

MR. SUSSMAN: So the question is location and nature of the instructor station.

MR. RAY: I think right now my tendency is to say you need an instructor station. Maybe in the future—the immediacy of the feedback on the session. You jump back into the how good is the training program as far as the feedback of the pilot in the seat? All he or she may receive in the case of an external instructor station would be audio feedback as opposed to visual feedback from an instructor. I can't answer that.

MR. BOOTHE: Let me clarify something. Bob [Foster] said instructor station, did he not? And I assume that he did not include necessarily an observer. It could still be an observer on board if one were doing a pilot proficiency check, just as we do it today, but somebody else might have been operating the instructor station off board in that case. So you could still have an observer to do the things, in fact it wouldn't be much different than you would do in an airplane. After all, there is no instructor station there, most of the time. So that's a thought to add to that consideration. You could still have the observer there.

MR. RAY: My concern and focus on the instructor station is not the station itself as much as it is the instructor. The station could be a PC, a laptop sitting in front of you.

MR. FOSTER: The ultimate thing would be to take the whole back end of the simulator off so that from the cockpit door back there was nothing. But on the other hand, you know, the intermediate positions, like Ed [Boothe] was saying, do you really need to have a full-blown console mounted instructor station or could something less, perhaps as long as it provided the functionality, would that be acceptable?

MR. RAY: Sure.

MS. BÜRKI-COHEN: You can do more and more with telepresence technology, audio is not a problem and visual is not that much of a problem.

MR. LONGRIDGE: I think for the purposes of this discussion we want to assume that the instructor or check airman is on board and he does have sufficient facilities available to him at that station to control the direction of the scenario if it's a LOFT or LOE. There may be some possibility with respect to miniaturization of the technology for that purpose, but for all intents and purposes I think the answer to your question is yes, we want the operator station to be on board.

MR. RAY: Although it could be miniaturized or whatever. It's a weight consideration, is what you are looking for.

MR. CARDULLO: That's about really all that affects the mass properties.

MR. BOOTHE: One more comment.

MR. BLUTEAU: Many military simulators have no on-board instructors. But I would like to add that may not be a big driver for the weight, currently the big driver for simulator weight and mass property are the visual projectors and the support structure we have to build to hold those huge projectors, it's a big impact.

MR. CARDULLO: That's true. And not only weight but because of their location it gives you very high moments of inertia.

MR. BAKER: One of the things I wanted to bring up, I just wanted to mention so we get it mentally on our agenda, is the possibility of taking the visual system off the motion platform, particularly for motion platforms that have much less stroke than 60 inches, it may be a very reasonable thing to do that. I think there is development work that would have to be done, but you can certainly take a lot of money out of the problem if you get that weight and inertia off of there. And do it with a visual system that is on the floor.

MR. ADVANI: Or do some things to the visual system that bring the mass and the cost down.

MR. CARDULLO: Putting it on the floor, it's actually been done a few times. One of the first ones I knew about was done in England by Arthur Barnes. He did it with a small motion system. Boeing helicopter has done it with their V-22 tilt rotor simulator in Philadelphia, they have used a small stroke motion system and the big problem that everybody is concerned about is the necessity to do dynamic distortion correction, because as you are moving the eye-point relative to the screen distortion of the image theoretically results. However, my observation, purely anecdotal sort of thing, is that for small stroke motion systems, that distortion is not noticeable when you are looking at a typical visual scene.

If you put an orthogonal grid pattern up, we did this in England at Arthur Barnes's facility, you sure see it. You see the distortion. But with a visual scene for aircraft it was not noticeable. Maybe for a driving simulator where you are driving down the street and you have a lot of vertical edges, it might be a problem. I think for an airplane simulator where a lot of the scene is amorphous, it probably works, if you can use a small stroke motion system.

MR. BAKER: I would think some 24-inch stroke or something less than that would be appropriate. I believe that there are things that you can do to take some of that distortion out of the visual scene.

MR. CARDULLO: Oh, yes, you can do dynamic distortion correction, all it takes is a computer.

MR. BOOTHE: Maybe mass properties is one of the critical design parameters.

MR. CARDULLO: It is.

MR. BOOTHE: Why don't we start marking that.

MR. CARDULLO: We already defined that. I will put a C, okay? Do we have consensus that's a critical parameter?

MR. STOCKING: Yes.

MR. CARDULLO: Let's go down the ones on here and define which ones are critical. And maybe we ought to define what critical means. Critical to the performance of the system. And then, you know, critical to the performance of the system as a training simulator. Like we said before, accuracy, static accuracy is a design parameter, but it's not critical for this kind of a servo system. It may be for a robot, I don't think that is the definition we want to use for a flight simulator.

MR. HEFFLEY: Are we putting down cost drivers critical to operation?

MR. CARDULLO: Critical design parameters, if they are not critical then we can forget about them in terms of cost drivers. Once we define the critical ones we are going to define the cost drivers.

MR. LONGRIDGE: Are you saying it's possible to have something that would not be critical to performance and is therefore not a cost driver?

MR. CARDULLO: Well, if it's not critical to performance, then you can reduce the requirement on it so it does not become a cost driver. For example, there is the issue of accuracy, position accuracy. If the position accuracy must be maintained within one percent, it's going to cost a lot.

But if you say I don't really worry about it because I can't tell the difference between one percent, ten percent, 20 percent, then it's not a cost driver.

MR. LONGRIDGE: I still question whether or not that may be true. Let's see how it develops.

MR. CARDULLO: Maybe we can find a case where it's not.

MR. STOCKING: You can correct positional problems, too. We have got feedback programs that tell us where the platform actually is. And you correct for it.

MR. CARDULLO: Sure. You can't tell the difference, can you, between ten degrees of pitch and 15 degrees of pitch when you are sitting in a vehicle or in an airplane?

MR. STOCKING: In a gravity aligned system it's important to sustain cue. So yes.

MR. CARDULLO: Since you can't get all the way up it's all scaled down anyway.

MR. STOCKING: Well, in some cases, yes. Well, I will get into variable gain later.

MR. SUSSMAN: Before you do it do you want to limit yourself to two levels, critical, noncritical, or do you want to give a third level, without getting too fancy?

MR. CARDULLO: Ed [Boothe] says two.

MR. BOOTHE: We only have two days.

MR. SUSSMAN: Good point.

MR. CARDULLO: What else? Let's go down the list. Is delay critical?

MR. REID: It has to be critical but not a big problem.

MR. CARDULLO: We have to define—

MR. REID: I would say it would be critical.

MR. CARDULLO: It's a critical design parameter. It doesn't cost anything.

MR. REID: Fortunately it won't cost as much.

MR. CARDULLO: Environmental factors?

MR. FOSTER: If you are counting facility size, it is.

MR. CARDULLO: Pardon me?

MR. FOSTER: If you are counting facility requirements in there it becomes a critical design factor from a user standpoint.

MR. LONGRIDGE: But is it critical to performance? That's the problem with your logic.

MR. CARDULLO: As soon as I got to that one it becomes your counter example.

MR. BOOTHE: In our issue here, since we need to consider overall cost to a regional airline of having a Level B simulator, I think it is critical and probably a major cost driver. So we do need to mark that. Because if we can have a motion system with one-foot cylinders instead of eight-foot cylinders, that's going to be a big difference in what it costs to house it.

MR. LONGRIDGE: Clearly it affects cost.

MR. CARDULLO: Safety factor is critical, I think we can agree safety factor is critical.

Floor loading.

MR. BOOTHE: That backs into the environmental factor.

MR. CARDULLO: And mass?

MR. LONGRIDGE: Wait a minute. Your criterion is performance of the device, is the safety factor critical to the performance of the device? Are you mixing costs and performance again?

MR. CARDULLO: Well, no. Maybe the definition of—it's a good thing I have you checking me, Tom [Longridge]. Safety factor is an important design parameter, but because it affects the safety of the device.

MR. LONGRIDGE: Yes.

MR. CARDULLO: But it's not—in general a performance issue but it is a design issue. So we have to redefine—

MR. LONGRIDGE: Critical, what do you mean by critical? That's all I'm saying.

MR. REID: Because we have environmental factors in there, that's certainly not performance.

MR. CARDULLO: I guess maybe critical to anything. I can think of some safety issues that end up affecting design system performance, that's the redundant legs that were originally on some of the hexapod systems. They had added so much inertia—

MR. REID: The springs, yes.

MR. CARDULLO: They were actually hydraulic springs.

MR. MARTIN: More like shock absorbers.

MR. BOOTHE: I think safety factor is still a cost driver.

MR. CARDULLO: We haven't got to cost drivers yet.

MR. BOOTHE: I'm still hung up on what Tom [Longridge] was saying, are we considering cost drivers or performance? If we have to have them it's a cost driver we are concerned about.

MR. LONGRIDGE: Yes, both.

MR. CARDULLO: We have expanded the definition of critical. Critical doesn't mean just critical to performance but it means it's a significant factor in design. Whether it's performance or safety or other issues. But whoever is doing the design has got to be concerned with it.

MR. HEFFLEY: I have a question, Frank [Cardullo].

MR. CARDULLO: You know what, everything is going to come up critical.

MR. HEFFLEY: Everything will have a C.

MR. CARDULLO: When you expand the definition of critical beyond performance, everything—

MR. LONGRIDGE: Let's do cost drivers, then. You can keep the C.

MR. SUSSMAN: C is cost.

MR. CARDULLO: I will leave Norm [Bluteau] alone with his original idea. I think if we have constrained this to performance parameters, then that would have worked. But now that we have expanded the definition of critical, it no longer has any meaning. Very good. Okay.

So in terms of cost drivers, we don't think delay is a cost driver. We define delay as really being the computational architecture, et cetera, right? That's not a cost driver.

Environmental factors, we will use the C for cost driver. Environmental factors is a cost driver.

Safety factor, that would be a cost driver. Say a safety factor of eight as opposed to two. You have to take eight times stress.

MR. BAKER: I don't think that drives the cost very fast. We are going to have to try to separate the things that are not terribly sensitive to cost from things that are, because—

MR. CARDULLO: Okay. Is there a consensus on that? Does not drive it fast? Does environmental factors drive it fast?

MR. HARRIS: The building does.

MR. CARDULLO: Okay.

MR. HARRIS: If it's a new building.

MR. CARDULLO: Floor loading. That really is contained in this mass properties, right? And mass properties is a fast cost driver?

MR. BLUTEAU: Yes.

MR. CARDULLO: It affects—

MR. BLUTEAU: Everything.

MR. BAKER: Well, let's talk about fast and slow cost drivers for just a minute. What I had in mind when I said the safety factor doesn't drive it very fast, if I double the safety factor requirement I'm not going to double the cost. I'm going to increase the cost but I think some relatively small percentage. Now, mass properties I think drive it faster than safety factor does. If I double the payload I don't think I'm going to double the cost of motion base, although it's probably something more like a 50 percent increase in the cost of motion because if I double the payload size—

MR. CARDULLO: It's a significant cost driver because it affects frequency response, acceleration, et cetera.

MR. BAKER: It is a significant cost driver in that respect. I would like to throw some sort of qualitative criterion like that out on the table and say everything will drive cost, some things don't drive cost very hard and some do.

MR. CARDULLO: We are concerned about hard cost drivers.

MR. BAKER: If you start increasing the stroke of the actuators you will find costs go up very fast.

MR. CARDULLO: That's right. Power, I think, is a really a secondary factor because power is determined by mass properties. If we talk about hydraulic power, it's determined by mass properties, and if you talk about electrical power that's in the environmental factors, that are really driven by excursion and things like that.

MR. REID: If I specify I want an electric system as opposed to a hydraulic system, then I don't know what that does.

MR. BAKER: The power situation gets a lot better because the electric system is essentially conservative.

I want to get Bob's [Foster] comment on that because he is an end user, about how sensitive USAir is to power consumption. Is that something that the bean counters get excited about, or is that something they kind of ignore?

MR. FOSTER: No, it's become a hot issue, actually. We went back and retrofitted our existing machines with shutdown circuitry, automatic shutdowns and stuff, but it's still more like you said, it's not an essentially conservative system like we envision electric would be. If you are not driving the machine you are essentially consuming almost no power. Where even the big hydraulic systems when you are sitting there with three 50 horsepower motors running, you affect the power factor, you are killing yourself.

MR. BAKER: The electric system does better than that, it actually takes the kinetic energy out of the motion platform and puts it back in the power supply. So the regenerative breaking of the power amplifiers do that for you, all you basically have to get out of the wall socket is the power required to overcome friction and other dissipative type losses. But in a hydraulic system every time you run hydraulic oil under pressure through an orifice you are burning up power.

MR. CARDULLO: Let me suggest something here. Instead of saying power, what if we say electric versus hydraulic and then make an assessment, if that's a cost driver. Because that's really where this discussion is going, right?

MR. SUSSMAN: Does that go to maintainability, also?

MR. FOSTER: Yes.

MS. BÜRKI-COHEN: Yes.

MR. BAKER: Might affect that somewhat.

MR. FOSTER: Utilities in our facility, it's very sensitive to what you pay for electricity, but for a six axis motion simulator, the entire simulator, it's about 25 thousand dollars a year for electrical power.

MR. BAKER: I can see where the bean counters might pay attention to that.

MR. FOSTER: You get to the point where you start investing some money to save money, get some payback on auto shutdown features and stuff like that.

MR. CARDULLO: Is the difference a cost driver?

MR. SUSSMAN: Yes.

MR. REID: Is it a feasible technical alternative for a Level B simulator? Or are we dreaming something?

MR. CARDULLO: With today's visual systems and all and instructors on board, it may not even be feasible. So I don't know. I would kind of leave that out. And location and nature of instructor station comes under mass properties.

Maintainability, is that a cost driver? In the design? Yes?

MR. HARRIS: One extension to that is the life cycle expectancy, it's not just maintainability but how long do you expect that thing to last? 15 years, 20 years?

MR. LONGRIDGE: Is that a big cost driver?

MR. HARRIS: It is if you have to choose electronics that would last 20 years.

MR. BAKER: I think one of the things that—on a related issue, I think one of the things that surprised all of us over the last 20, 25 years, is how long some of these simulators are in service. And there was a conference in Atlanta a few months ago that addressed the problem with simulator maintainability. Frankly, there was more than a little bit of whining from folks who said we can't get parts for simulators built 25 years ago. I thought, you better get used to the problem, because it's not going to get better. Power supply technology has changed, computer technology has changed, it's not changing at the same rate it did 20 years ago, it's changing very fast. So I don't know that it's possible at this point to design a simulator that's going to have a 20-year life and expect to be able to buy the parts for it 20 years from now.

MR. HARRIS: You can choose a protocol that will last five years, at least five years instead of one year.

MR. BAKER: On the computer side of the market I'm not sure that's even true.

MR. CARDULLO: Can we agree, if we include all the "ilities" under this thing, reliability, maintainability, life cycleability—

MR. BOOTHE: I think it is a cost driver. If I understood correctly, the concept that Rediffusion did, had lots of considerations for maintainability strictly for that purpose, to reduce the life cycle cost. So it could easily get to various components and at least repair, replace them and so on. I don't think a manufacturer would have gone to that extent if it weren't a cost driver, so I think we should probably mark that.

MR. CARDULLO: Unless the customer was pushing in that direction.

MR. HARRIS: It's customer driven.

MR. BOOTHE: Why would the customer drive that?

MR. CARDULLO: Because some bean counter thinks it is necessary.

MR. HARRIS: It's important for maintenance.

MR. CARDULLO: I don't deny it's important.

MR. MARTIN: Is it sensitive?

MR. CARDULLO: Is it a cost sensitive parameter? If you double the life cycle of this thing, does it half the cost or something?

MR. HARRIS: If you can't make it maintainable, then it's—

MR. BOOTHE: That's a different consideration. Forget what I said. I think he put his finger on it, it's ease of maintainability rather than a cost driver that you have described. So maybe we could press on to the next page.

MR. CARDULLO: Computation. We didn't do computation. Computation includes the computational architectures, software, software development is included. Would you consider software development included in computation?

MR. REID: Is this for the washout and the control loops, or is this just the inner loops of a digital control loader—or a digital controller?

MR. CARDULLO: I guess it's everything. All the computation associated with the motion system. That would include the servo controller.

MR. REID: Sometimes it's part of the host.

MR. CARDULLO: Sometimes it's part of the host.

MR. REID: So where do you place it?

MR. CARDULLO: I don't know.

MR. BAKER: The servo guides who does it.

MR. HARRIS: The hardware is cost per unit. The software, you buy it once, you have got it forever.

MR. CARDULLO: For this application it's not a cost driver.

MR. HARRIS: I wouldn't say computation itself is a cost driver.

MR. CARDULLO: So we have two items here, mass properties, and environmental factors. Number of degrees of freedom. I think this is certainly a cost driver.

MR. BAKER: Is any degree of freedom—

MR. CARDULLO: It may not be cheap, but it is inexpensive.

Smoothness, is smoothness really a cost driver those days?

MR. BLUTEAU: Yes, it is.

MR. LONGRIDGE: Is it true that there is that much of a cost difference, let's say between a four and a six DOF system, do we say there is a big cost in degrees of freedom granted zero versus something, how about three, four, six?

MR. BAKER: We looked at that problem on the small motion platforms recently, we concluded an analysis to go from three to four is like 30, 35 percent increase in cost. So it's probably almost linear.

MR. LONGRIDGE: Really?

MR. BAKER: Most of the money is in actuators. The mechanical structures, are really not that expensive. Their costs don't change very much. When you add another actuator and all the stuff that goes with it, you are adding quite a bit of cost.

MS. BÜRKI-COHEN: What you are saying applies, however, to an electric small system?

MR. BAKER: I think if you talk to the guys that build hydraulic stuff they will tell you the actuators are a fair amount of the cost. Cylinders, the Weldment structure for the top and bottom platforms, they change the way they look but they don't really change the cost that much because they are not going to change in weight. You can almost buy those per pound, but let's hear from Geoff [Harris], he knows more about it.

MR. HARRIS: If you have a six degree of freedom platform, you have six legs. If you make less degrees of freedom you need to restrain the others. So you do away with two motion legs but you now have to add extra structure and pivots. You don't save that much money. But assuming you use the same category of actuators on a four DOF as you do a six DOF, you don't save that much money.

MR. CARDULLO: I understand your point. And I agree with your point.

MR. STOCKING: The other thing you want to think about, when you start talking about degrees of freedom, as a manufacturer if you can build one device that fits all your products, you begin to reduce the cost of that. And if you have two, three, and four degrees of freedom, five degrees of freedom systems, and you make two of these, three of these, they start costing more than a single synergistic system that falls across three or four lines, even though you may not use one or two of the degrees of freedom. It's actually cheaper to use a single synergistic system.

MR. BAKER: We don't recommend, for example, people build a five axis system, because you can build a six just as cheap. Because of the constraint problem. When you go from six down to three, I guarantee there is a cost savings. It's significant.

MR. STOCKING: Again it depends on what you are manufacturing. If you are looking just at the, we will say the commuter market where you are looking at a whole bunch of different aircraft, probably the minimum you could come up with on a commuter training requirement may be four. And I would be skeptical. I would go for six.

MR. CARDULLO: So basically what you are saying is, I think, the consensus at least between you two is that adding degrees of freedom is not a cost driver, in fact it may even be a cost saver?

MR. STOCKING: That is correct.

MR. CARDULLO: For overall—

MR. STOCKING: That's the way I view it.

MR. CARDULLO: The other thing is for something like a Stewart platform you have six identical actuators, whereas for a three degree of freedom system the actuators may be different if they are standard actuators. I guess that would make it cheaper. Do we have a consensus?

MR. SUSSMAN: Before the consensus there is one comment. Right now we are specifying three degrees of freedom, if you move beyond three, there is a cost—is that right, Tom [Longridge]?

MR. LONGRIDGE: For Level B, that's correct.

MR. RAY: That's what is there now. That's not to say it would be there tomorrow.

MR. CARDULLO: Except, Don [Sussman], that Geoff [Harris] is saying that it really doesn't cost any more to build a six degree of freedom than it does to build a three.

MR. HARRIS: If it's a comparable system, yes.

MR. BAKER: Time out.

MR. CARDULLO: Let's get Norm's [Bluteau] comment.

MR. BLUTEAU: I want to talk about a CAE experience. We had an experience where we had to replace the degrees of freedom by constraint, the constraint turned out to be just as costly as degrees of freedom. But our experience was very heavy simulators where the constraints themselves became very complex, I suspect if you go with lighter weight payloads possibly the constraints become easier to design. Easier to build.

MR. ELDREDGE: Let's take a break.

MR. BOOTHE: Let's take a break.

(Break taken.)

MR. CARDULLO: Where are we on degrees of freedom?

MR. BOOTHE: I don't know where our missing parties are, I guess they will be back.

I was hearing two things here. On this side I'm hearing that we are reducing degrees of freedom from a six degrees of freedom system. And it's no cheaper because of imposing constraints on a six degree of freedom system and you wind up with the same cost. But over here I'm hearing we are adding degrees of freedom by adding hardware and therefore it costs more. So I think if we are looking at progressing to some additional degrees of freedom that might be needed on a Level B simulator beyond the three that are now required, I think we are talking about increasing cost. Now if it comes out that we do need more than three degrees of freedom because that's what this group establishes, then that's what we need to do and in that sense it is definitely going to be an additional cost driver. But we don't necessarily need to do that by starting, I mean we may end up wanting to use a six degree of freedom system because it's the cheapest way to go, but for right now I think it is a cost driver and cost increaser, the degrees of freedom, so I think that's probably quite true.

MR. CARDULLO: I think what you are saying is if you are starting from scratch, it's a cost driver. If you are not starting from scratch it might not be, but is anybody starting from scratch?

MR. BOOTHE: Yes, I think they are.

MR. WILLMOTT: What about people like this gentleman right here that currently makes three degree systems that are going to be a hell of a lot cheaper than the CAE and Thomson six degree system and making it into a three?

MR. BOOTHE: I think we will find out when we go through the tables.

MR. CARDULLO: You are supporting what Ed [Boothe] is saying, Stu [Willmott]?

MR. WILLMOTT: I think it is a cost item.

MR. BLUTEAU: I want to say we had a similar experience where it was not a significant cost driver to add or remove degrees of freedom but I must say it was in the case where the payload was extremely large then the cost of constraint was possibly a factor. I'm hearing conflicting response from us and from Bruce [Baker]. He may be dealing with smaller payloads.

MR. CARDULLO: He is. Are there Level B systems now that use three degree of freedom systems, so there are systems out there currently being used on Level B certified devices?

MR. LONGRIDGE: Yes.

MR. CARDULLO: So I guess then it is a cost driver.

MR. BOOTHE: I think we need to, keeping in mind the calendar and the clock, we need to move right along here.

MR. CARDULLO: I'm sorry, were you saying?

MR. BOOTHE: No, just—

MR. CARDULLO: Is smoothness a cost driver?

MR. STOCKING: Before you get back to that I want to say one thing. On a three degree of freedom system, there are certain types of motion cues you cannot give and you want to make sure that those meet the training requirements.

MR. CARDULLO: That's right. When we get to the table we will deal with those. Smoothness. Today's state of the art, is this a cost driver?

MR. MARTIN: It might be the difference between using an entertainment quality electric system versus a hydraulic system with a hydrostatic bearings.

MR. BLUTEAU: The answer is yes.

MR. CARDULLO: Would smoothness alone drive that?

MR. MARTIN: Smoothness would be a consideration.

MR. CARDULLO: For example, you can buy a motion system from McFadden with either hydrostatic actuators or production actuators, standard actuators. Is there a significant cost in the difference of the two actuators? I don't know.

MR. BOOTHE: If we meet bandwidth, you don't think—

MR. CARDULLO: No, no, no. This is smoothness like turn-around bump and that sort of stuff. It's not a bandwidth thing. How about Norm [Bluteau], do you have an idea in terms of relative costs?

MR. BLUTEAU: Not precisely, but I know hydrostatic technology costs a lot more because of the accuracy required to achieve hydrostatic cushioning.

MR. CARDULLO: So you are supporting Ed [Martin]'s position?

MR. ADVANI: It also requires a higher flow volume because of leakage in flow.

MR. HARRIS: If you are talking about smoothness, you must consider also the servo valve, you need a higher performance servo valve.

MR. STOCKING: It's been my experience, I have seen good systems that were not hydrostatic that produced good smooth systems, but I have no relationship as to whether it was a cost driver or not.

MR. HEFFLEY: It depends on where you have a problem to begin with. If you have to spend a lot of money to smooth out what you got, then that can really be a cost, a lot of engineering.

MR. BOOTHE: Could I ask you, is smoothness a cost driver?

MR. BAKER: I would say it is. You can get by, as Geoff [Harris] mentioned, you can get by with some awfully grubby parts if you don't have to worry about smoothness aspects of it.

MR. HARRIS: Is it a requirement for the flight regime? When flying in an aircraft there is always turbulence.

MR. CARDULLO: That's right. But what is included in smoothness is any kind of spurious acceleration. What you really don't want to happen is, during a maneuver, to get a cue that may destroy any vection that you have been able to build or something like that.

MR. HARRIS: Turn-around bump in particular.

MR. CARDULLO: Turn-around bump is one of them, but cross-coupling can lead to that.

MR. ADVANI: You don't want pilot-induced turbulence.

MR. BOOTHE: I think we concluded that is a cost driver.

MR. CARDULLO: Right. Phase bandwidth.

MR. WILLMOTT: Turn-around bump requirements you have to meet at Level B anyway. You can't have turn-around bumps.

MR. IRVING: If you have a test you have to specify criteria to be achieved.

MR. WILLMOTT: If you define it—

MR. BOOTHE: It's in the Advisory Circular but it says as specified by the operator for simulator acceptance, which means we really have no—

MR. CARDULLO: No criterion.

MR. BOOTHE: No criterion, right. Bandwidth? I will throw out a yes and see if anybody agrees.

MR. CARDULLO: Or disagrees.

MR. MARTIN: See if anybody disagrees.

MR. REID: You are saying if someone demands more bandwidth it will cost more money? I have to agree with that.

MR. BOOTHE: So somebody agreed.

MR. CARDULLO: Bob [Heffley]?

MR. HEFFLEY: The thing is the bandwidth, that's—that can very likely, I think, be driven by the mass properties. You have got to solve that, you know.

MR. CARDULLO: If you are stuck with certain mass properties, you may not have an alternative to the mass properties, so you have got to do something, you have to use larger diameter actuators or higher pressure hydraulics, or whatever, in order to get the bandwidth.

MR. SUSSMAN: Mass properties are going to drive everything in the end, or almost everything.

MR. CARDULLO: But if you need the bandwidth, and if you increase the mass properties, it's going to reduce the bandwidth. If you specify a certain bandwidth then you, in spite of the mass properties, have to achieve it. By specifying five hertz as opposed to two hertz is it going to be a cost driver, is the question?

MR. HEFFLEY: It takes expensive components to fix it. So I guess that becomes a cost driver.

MR. BAKER: Let me stir the pot a little more.

MR. CARDULLO: I know exactly what you're going to say. More smoke and mirrors stuff.

MR. BAKER: Absolutely. If you can do it with smoke and mirrors, it's a lot cheaper than doing it with money.

I've made some comments today about doing some phase compensation or pole-zero, in some cases I have also used the motion base servo as one of the washout filters. And I think you

all are thinking some things you haven't said yet. I'd be interested in your comments because you may have had different experiences than I have. You have more data than I have. I'm not in the business of running psychological test in motion platforms, sometimes I wish I were, it's an exciting business. Is that too deep a discussion for right now?

MR. CARDULLO: I think the only thing to respond quickly to that is there are things that can be done in control system design to get around that problem, basically the problem is the resonant frequency of the system. And getting around the resonant frequency of the system you have, and if you are going to try to solve it in the mechanical part of the system, you have got to make the system stiffer.

MR. BAKER: Actually—

MR. CARDULLO: But there are some control things that you can do to get around that. But I don't know what people are doing in the industry as a matter of course in production. I mean, most of what I see people doing is try to get bigger valves, larger diameter actuators, things like that. They don't try to solve the problem in the control system, they try to solve it in the mechanical design.

MR. BOOTHE: But in general we can say we have increased mass, we have to spend more money to get the desired bandwidth. So I think they are definitely cost drivers, whether Bruce [Baker] does it with smoke and mirrors instead of money.

MR. CARDULLO: His point is it's a small amount of money if you do it in the control system. It's a large amount of money if you do it in the mechanical apparatus.

MR. BOOTHE: What's the more general solution?

MR. CARDULLO: The more general solution is doing it, what I just said was my experience is most people do it in the mechanical design.

MR. BOOTHE: Then the more general case is a cost driver, then, and if Bruce [Baker] can do it cheaper, then by gosh he ought to do that.

MR. CARDULLO: Do you guys agree with that?

MR. HARRIS: I almost agree with Bruce [Baker]. The way we have improved the bandwidth is with mass—

MR. CARDULLO: That's what we are saying here. You have mass, you need to increase bandwidth to get up to five hertz to get a good motion system.

MR. HARRIS: That would normally be a server loop control, unless you run out of power, which might be transducers or valves—

MR. BAKER: Back up a minute. I have done a lot of analysis and some significant amount of testing on hexapod systems. And if you try and treat the servos on motion platforms—six axes motion platform—as conventional single axle servos, what you will discover is they don't work like that. There is an interaction between the servos that cause an instability as you start to turn up the gain and try to push the bandwidth. Typically above two and a half hertz you start to see resonance show up in the servo that is coming from the other axes, and it's essentially driven by the oil spring frequency. If you could push the oil spring frequency up, the problem would move up with it.

I worked on a project some years ago that Contraves in Pittsburgh did, the tank command wanted something like ten hertz position bandwidth out of these servos. And I've got a theoretical analysis at home that shows you can do that in theory but in actual practice it's not quite so easy. I don't think the motion platform ever achieved that performance in actual practice. Nor do I really believe it's necessary. But I think there are other ways you can achieve effectively the same thing. That was a fair sized platform, had seven and a half inch diameter actuators and you could put a seven thousand pound turret on it and shake it at two g. Three thousand horsepower pumps, that

sort of thing. It was a larger system than we are normally concerned with. Yes, indeed, it cost a lot of money.

MR. BOOTHE: I think for our purposes here we can move on. It is definitely a cost driver.

MR. CARDULLO: How about hysteresis?

MR. REID: Not anymore. I think you avoid it automatically with the hexapod. If you go to some ganged systems, systems within systems, then it may be a problem.

MR. CARDULLO: You might get some position hysteresis because it's a nonlinear system, but who cares, so I wouldn't think it's a cost driver on that basis.

MR. BAKER: The hysteresis will disappear if you resolve the smoothness problem because they are closely related.

MR. CARDULLO: How about cross-talk, cross-coupling between degrees of freedom, so if you command a pure pitch, do you get a pure pitch or do you get some other degrees of freedom cross-coupled into that? The old military specification [MIL-STD-]1558 measured it on a position basis from actuator to actuator. I think the AGARD[-AR-]144 does it in degree of freedom space, which is really the way, in my opinion, it should be done. And it should be acceleration, not position, because the pilot doesn't feel position, he feels acceleration. So it's a very important parameter because it can destroy a cue, but is it a cost driver?

MR. BOOTHE: Does that fall out if we do the other things right?

MR. BAKER: No, not necessarily.

MR. CARDULLO: Not necessarily.

MR. HEFFLEY: If you have dissimilar actuators.

MR. CARDULLO: That exacerbates the problem.

MR. BLUTEAU: It's not a cost driver right now because we are not building to that spec, it's not an FAA requirement, cross-talk, so right now it's not a cost driver.

MR. CARDULLO: If we were, would it be?

MR. BLUTEAU: I don't see how that translates to any training value.

MR. CARDULLO: There is a lot—I disagree. It translates into lots of training value. Because if the pilot pulls back on the stick and expects the airplane to just to be pitching and he feels a little bit of yaw while he is doing it, he thinks he has lost an engine or something. I believe there is a lot of training.

MR. BAKER: I believe if you try and squash that number down, more than what you—well, let me back up a minute. It's an expensive thing to drive that number down real small. The main reason is that most of the cross-talk, at least in the systems that I have measured, is coming from the oil spring. Okay? You start putting high frequency large amplitude inputs in, say in a lateral on an hexapod system you will see it also gives you some roll. And it's because of the elasticity of the oil.

MR. HARRIS: But is that a problem?

MR. CARDULLO: There is another factor, the dynamic effects of the mass.

MR. BAKER: I did some tests a few years ago on an AH-1W sim for the Marines. It has a big dome on it so the CG is pretty high when you run the thing back and forth, low frequency nice and level, as you go up it starts to make a figure eight for you. It's because the CG is up so high.

MR. CARDULLO: It's the moments of inertia.

MR. BAKER: It's the moments of inertia.

MR. CARDULLO: So it's the dynamic effects of the mass.

MR. BAKER: If you want to fix that you have to stiffen the actuator. Well, putting pressure gain in there is the wrong direction, you want to take the pressure gain out. Then you have other problems that show up.

And so the only real way to stiffen the actuator that I know of that works is to make it bigger in diameter. That doesn't get you good results very fast. Flow rates go way up and servo valve sizes.

MR. CARDULLO: So on that basis it's a cost driver.

MR. BAKER: If somebody really wanted to drive that parameter down small, it gets to be expensive in a hurry.

MR. BLUTEAU: The model of the mass, it can be done.

MR. CARDULLO: That's what you can do but that's expensive the first time you do it.

MR. BLUTEAU: Still is.

MR. STOCKING: I will sell it to you.

MR. BAKER: You can achieve some performance improvement but it's a matter of degree, you may get it down by a factor of five but if you get it down by a factor of ten it's expensive.

MR. CARDULLO: I think we have agreed, so we should continue the discussion.

Platform size, this really is a mass properties issue.

Excursion.

MR. REID: Cost driver.

MR. CARDULLO: Do we all agree, excursion is a cost driver? I think that's pretty straightforward.

Payload weight, this is really a mass property, we have already defined it.

Acceleration. Cost driver, right?

Velocity.

MR. HARRIS: It is, but indirectly to achieve velocity in itself—

MR. CARDULLO: I'm sorry.

MR. HARRIS: To restrain velocity in the snubbers is expensive if you have a lot of velocity: $-mv^2$.

MR. CARDULLO: Just being able to achieve a high velocity?

MR. BLUTEAU: You need bigger valves.

MR. CARDULLO: So it's a cost driver.

MR. BOOTHE: We have already said acceleration is and we have already said excursion is, so velocity is already included. I think it's a secondary—

MR. CARDULLO: You think?

MR. BAKER: Time out.

MR. BOOTHE: I wouldn't have even marked it. Time out over here.

MR. REID: It's a different process that's causing it, though. This is a restriction like the problem of getting fluid down a pipe or through the servo valve, it's a different physical problem, so your solution has to be achieved differently from the acceleration and excursion one.

MR. BOOTHE: Okay.

MR. CARDULLO: It's a different problem.

MR. BAKER: If you run the velocity requirement up in addition to the problem with the snubbers that's been mentioned, you also have to put a larger servo valve on it and a larger pump for more flow. The downside is the larger servo valves are not going to work at low speed, the turn-around bump performance is not going to be as good. What you would like to do is have a real small valve on there because you can make it work through zero. The problem is people will object if the motion takes a week to go through a full excursion. The whiners and snivelers they are.

MR. CARDULLO: The next one is cue duration, two issues; one is excursion, on the other hand if you don't have excursion there is some things you can go do in the cuing algorithms, so whatever cost there is with cue duration personally I think is here (*indicating*). Does anybody disagree with that?

MR. HEFFLEY: Yes, it's cue duration that kind of drives excursion more than anything, more than the inverse, isn't it?

MR. CARDULLO: Well, a couple things drive excursion. Cue duration is one thing, another thing is how large of a pitch amplitude do you need, for example, to take care of the gravity alignment?

Were you going to say something, Ed [Martin]?

MR. MARTIN: No, I was going to agree with him.

MR. BLUTEAU: Actually velocity also affects cue duration, you saturate your velocity much quicker than you saturate position.

MR. CARDULLO: So are we saying that cue duration is taken care of by excursion and velocity requirements so we don't have to consider it independently?

MR. HEFFLEY: The reason that you might really want to consider it independently is the fact that that's one of those things you can almost relate very directly to a given task. I mean if you are really forced to a cue duration.

MR. CARDULLO: For example, a large side force?

MR. HEFFLEY: Yes.

MR. CARDULLO: A long duration side force to either cancel out roll or to take care of an engine out or something like that.

MR. HEFFLEY: Yes, yes.

MR. CARDULLO: Let's say in those kind of cases, then it would be an independent cost driver is what we are saying.

MR. BLUTEAU: Yes. There may be other examples of that.

MR. CARDULLO: Pardon me?

MR. BLUTEAU: There may be other examples as well.

MR. CARDULLO: Position accuracy, it would be a cost driver but I don't think it's important, so it's not. Everybody agree with that?

MR. BAKER: I agree with that exactly.

MR. CARDULLO: Structural stiffness.

MR. REID: Is there a spec anybody has to meet on that?

MR. BAKER: The structural stiffness requirement basically gets driven by the bandwidth requirement, does it not?

MR. CARDULLO: Not completely. You have these banjo stringing modes, right?

MR. BAKER: Yes, I know.

MR. CARDULLO: That's an independent issue.

MR. REID: The only thing I remember on that was watching an Air Canada simulator that was doing a, what was it now, it was an engine failure combined with a tire burst on takeoff. And I could see the strut on the—

MR. CARDULLO: Boeing.

MR. REID: —boing on the actuator.

MR. CARDULLO: I've seen them, you guys probably have the old Link systems where you can observe out of plane motion during heave at certain frequencies.

MR. BAKER: You know what, I have put accelerometers on systems and I can't measure if that gets in the platform.

MR. BLUTEAU: It does.

MR. CARDULLO: It's a fatigue issue.

MR. BAKER: I don't know. I don't think you are going to excite that mode hard enough to cause it to be a fatigue issue.

MR. CARDULLO: As far as I know no one has ever done analysis of that.

MR. STOCKING: If you are doing PSD plots in the testing phase of a motion system, the lack of structural stiffness of your platform may induce or you can end up with resonance frequencies that show up everywhere, and you want to avoid those.

MR. CARDULLO: Speaking of Mercedes Benz, they were popping rivets on the dome because they didn't have sufficient structural stiffness.

MR. ADVANI: There are two structural stiffness issues that we have discovered. One is lateral natural frequency of the actuator in its maximum extended mode, and that affects the interloop to the motion control; and secondly, the structural natural frequency of the payload structure and we have—that in our case is a big cost driver because we have put a tremendous effort into keeping those natural frequencies above 15 hertz. So my answer is yes.

MR. CARDULLO: Yes, it's a cost driver? Does anybody object to our calling it a cost driver? Okay.

Finally, so we have got degrees of freedom, smoothness, bandwidth, particularly phase bandwidth, cross-talk, excursion, acceleration, velocity, cue duration, structural stiffness, mass properties, and environmental factors.

MR. BOOTHE: Now are those factors that we want to refer to as we address these tasks in the table directly or are they simply to have understood at this point and know that as we address these, I'm not quite sure how we are going to use these now that we have done it. I thought I knew when we started.

MR. CARDULLO: I don't know that as we go through each one of these tasks, that we then address each one of these because we would be here for an awful long time. But I think we have got to keep these things in mind when we are addressing those tasks.

MR. BOOTHE: Okay.

MR. CARDULLO: Not explicitly referencing them, but maybe implicitly.

MR. BOOTHE: On occasion—

MR. CARDULLO: You may want to raise some of these things.

MR. BOOTHE: Thank you, Frank [Cardullo], for taking that on and getting us through it.

MR. CARDULLO: No problem.

MR. LONGRIDGE: To reiterate what was said earlier, it was suggested that we identify the two or three most critical tasks that are likely to be impacted by these cost drivers. If you want to delay the discussion until we go through the table, that's fine. I think at some point you have to identify what the tasks most likely to be impacted are.

MR. BOOTHE: Yes.

MR. LONGRIDGE: Do you want to defer the discussion till the appropriate point in the tables, then?

MR. BOOTHE: What I had thought we might do is simply leaf through the tables to see what is there with the thought of working our way towards the most critical task, but if we don't already know what's there, then we can't anticipate what would be most critical. So I don't know if that makes sense, but if I know that there are takeoffs with failures in this table, then I would know that pushback and powerback are not critical. So I need to know that those other tasks are here so I don't get hung up on lesser tasks as being critical. So I think we need to leaf through the table to see what's here first.

MR. FOSTER: I think one of the things that's critical in going through the table is determining how many degrees of freedom are required. It varies in your initial estimate of—from two up to six.

MR. BOOTHE: Right. So if we—that's a good point, Bob [Foster]. You notice they are not all the same as I had listed them. Again, those are only my ideas. And not necessarily the results, probably not the result that we would come up with. Keeping in mind that currently there are only three degrees of freedom required, keeping in mind that I have said before I think that's not sufficient, but you may think that's sufficient. So I think that's up to our discussion to resolve that issue as we go.

But just to leaf through the table, we start with surface operations just as it starts in the advisory circular and I think as it is similarly stated in the practical test standards for pilot certification. And so I have just listed the task under surface operations, pushing it back from the gate or power back from the gate. Whichever the operator might do. Then taxiing, then takeoffs with various events in the takeoff, a normal one, a crosswind, and other factors associated with that. Including a windshear. Events that may occur in cruise, then there is descent, approaches, and landings.

In terms of what's critical, probably something in the takeoffs and landings is the most critical and probably also the highest gain task will come somewhere in takeoffs and landings, so I would think that's likely where we would find application for these critical parameters. But not necessarily. So we have to keep them in mind as we go through.

MR. CARDULLO: I think on ground taxiing, that's a high bandwidth task. It's a high frequency domain and that's where motion cues are critical.

MR. LONGRIDGE: That's true, but this is recurrent training and these are people that already know how to taxi and taxi on a routine basis.

MR. CARDULLO: How does that impact—

MR. RAY: There is a problem, an issue there in that they are assessed on their taxiing in a Level B. Because Level B requires a ground handling package be embedded in it. So taxiing would be an issue, I agree.

MR. ADVANI: What about landing and taxiing on contaminated runways? I would consider that important even in recurrent training.

MR. RAY: Is it important? Yes. Is it important on a Level B simulator? Probably not to the degree it is on a Level C and/or D. Not—

MR. BOOTHE: Would it be a requirement on a Level B—

MR. LONGRIDGE: Normally what we rely on is abnormal or unusual situations they don't see all the time.

MR. BOOTHE: Which points up we need to make additions to this table as we go. Bob [Foster]?

MR. FOSTER: The biggest thing we see in operation, the biggest limitation is visual for pushback and taxiing, not the motion system.

MR. CARDULLO: How do you know?

MR. FOSTER: That's where all the complaints are. "I can't find my way around the airport." The instructors are saying "can't we preset to the end of the runway." Like I said—started to say, taxiing is a nonissue to these guys.

MR. RAY: Not taxiing around the full airport environment. Because you just don't have enough peripheral vision with a 45 degrees field of view.

MR. FOSTER: Pushback is strictly procedural. What you are looking for are the people making the right calls. You don't have marshalers on a Level B sim, it's all done by the instructor saying you are clear to push back, anyhow, and making sure he sets the brakes, there you need a little cue saying the brakes are set.

MR. CARDULLO: Those aren't critical.

MR. FOSTER: They are not critical at all.

MR. BOOTHE: We have a comment over here.

MR. ADVANI: What I think you are referring to, Frank [Cardullo], what I'm saying, any time the wheels are in contact with the ground, single engine operation, crosswind operation, those are demanding situations.

MR. CARDULLO: They are. But if they are not part of the training requirement, or the recertification requirement, then they are not necessary.

MR. RAY: But in fact they are.

MR. CARDULLO: Well, if they are—

MR. RAY: Is it limited in view as far as what you can do, as far as how much taxiing you can do? Certainly. But you could not exclude taxiing from that, you have to control the aircraft on the runway, which is a taxiing maneuver, to exit the runway, et cetera.

MR. LONGRIDGE: That's true.

MR. CARDULLO: Is it mainly, as Bob [Foster] says, a visual task? Is it a navigation task or is it a handling quality task?

MR. RAY: There is a handling quality task. There are complaints about the visual from a user's perspective.

MR. CARDULLO: If it's a handling quality task, then the motion cues are extremely important because it's high frequency regime.

MR. FOSTER: In Level B? I have to question that in Level B.

MR. RAY: A lot of the complaints, the skidding on the ice complaints that you get from Level A or Level B, take your choice, is relevant to a Level B sim. The complaints you get from the pilots are about the unrealistic nature of the simulation relative to the aircraft in taxiing, whether you are decelerating after a landing or whether it's the initial acceleration, or taxiing off the runway. It is a major complaint that the pilots throw at the Level A and Level B simulators. I think to exclude that would be a mistake.

MR. BOOTHE: Bob [Heffley]?

MR. HEFFLEY: In taxiing, and ground handling, you know the dynamics, the response required is pretty high if you are going to have reasonably high fidelity. In fact higher probably than flight.

MR. CARDULLO: Yes.

MR. RAY: That's true.

MR. HEFFLEY: It seems to me this is especially a case you would like to make some sort of trade-off in terms of quality of that motion. Because that could design things very fast and I guess I would be interested in knowing how that's really handled now in terms of quality of the ground handling.

MR. FOSTER: If you don't have wide angle visual, you are wasting your time. It takes something beyond Level B to do any sort of really meaningful taxiing training and checking. I'm sorry, I think that's the truth.

MR. RAY: But I would add, it depends on what your definition of taxiing is. From a pilot's perspective it's the feedback of those controls, whether it's the brake pedals, rudder pedals, or nose wheel steering. The pilot focus is on whether the visual and motion cues are correct. It's just not there in many devices. If it's an exercise and it's not in just navigating around the airport, agreed, you can't do it in a Level B sim. The feedback to the pilot sitting in the seat from the brake pedals, the motion feedback you are going to get with a lurching of an aircraft, the sensitivity of the brakes in stopping the aircraft, the pitching moment that occurs, both in break-away and stopping, and the visual cuing is critical to the realism that you are trying to portray in that device.

MR. CARDULLO: I think more than the realism, it's the controllability, the handling quality.

MR. RAY: Absolutely. I got a call yesterday in the office from an operator who had received a number of complaints about his, believe it or not, Level B simulator. They discovered a major problem they had and asked "can we please fix it?" I said "by all means." They said the feedback from the pilots, even using a single channel visual, that major improvements were made in the acceptance of that device as representative of the aircraft. Was it motion directed? Probably not, according to the operator. But the key was they didn't like the way it taxied on the ground at all. It didn't feel like the airplane.

MR. HARRIS: Do you know which axes those were in?

MR. RAY: The truth of the matter was they had previously played with the main gear. The main gear positioned was too far forward. They didn't say which, where the feedback was.

MR. BOOTHE: Let's proceed under the first entry in this table, assuming it's the right position.

MR. CARDULLO: I thought that's where we were.

MR. BOOTHE: Let's look at pushback and powerback from the gate and look at the degrees of freedom listed and see if they are more or less than are needed and see if we can proceed on through here in determining what's needed for a Level B motion system to satisfy the requirements that we described earlier today. So I've listed four degrees of freedom here. As I listen to you talk I can easily change that. I'm not going to tell you which way.

MR. CARDULLO: Is powerback when they use thrust reverses to back away from the gate?

MR. BOOTHE: Yes.

MR. RAY: Yes.

MR. CARDULLO: That's really a handling quality problem, whereas pushback, the pilot is not in the loop.

MR. BOOTHE: Pushback is very procedural, but a tractor is hooked up—

MR. CARDULLO: The pilot is not driving.

MR. BOOTHE: Right.

MR. CARDULLO: So really what we are concerned about is powerback.

MR. BOOTHE: But even on a pushback there are things that happen that I think are cues to pilot.

MR. CARDULLO: They are easy.

MR. BOOTHE: But they jerk the airplane around and that sort of thing. So I think there are still motion cues to be considered. Whether or not we determine they are important to Level B is another issue, but if you sit there and feel that jerking and in fact there is some interesting sounds that go with that, there are cues. How important they are, I don't want to pass judgment on. That's you guy's job.

But I've left out pitch and I've left out roll. I left out roll because both main wheels are, or whatever number of main wheels the airplane has, are firmly planted on the pavement, so I would think roll excursions would be extremely small. But the rest of these you can't have bumps in the pavement and feelings of the airplane taxiing without some heave in the motion system.

MR. CARDULLO: Pitch for braking?

MR. BOOTHE: I was afraid you would want to add that.

MR. ADVANI: I don't know why you need yaw.

MR. IRVING: You don't need yaw. You may not need yaw.

MR. BOOTHE: Well, let's go down to this. Is there concurrence on surge?

MR. WILLMOTT: No. I would think, as Frank [Cardullo] said, pitch is better. The surge is the short-term effect, you can't do much in a motion system, anyway. The tilt that the motion has for the acceleration or deceleration I would think would be more important than that.

MR. ADVANI: On the other hand, during the pushback the acceleration levels are not very high so you just feel the sharp onset, and not the—you are not concerned with the amount because you know it will be quite small. Have we started pushback or not?

MR. BAKER: This should be one of the areas where you can do a virtually perfect job of simulating what the airplane does. He is on the ground, he is not in flight, the acceleration levels are low. If you give him the bumps and the little surge when the tractor starts, that should be almost perfect.

MR. BOOTHE: It was that tractor bump that caused me to select surge. If the tractor starts and stops the airplane and brakes are not applied, there should be no pitch. So that's why I selected surge.

MR. BAKER: There is no long-term acceleration because the acceleration is over in a matter of a second or less, probably.

MR. BOOTHE: But if there is powerback, then pitch is probably important, and it would be a trade-off, so—

MR. BAKER: I think we are going to end up with six axes before we end anyway.

MR. STOCKING: This is a six axes cue. The surge cue, if you watch the pilots during pushback you will see his head nod like this when he starts, right? You will see his head move. And that's the longitudinal axis of the motion system.

MR. HARRIS: It's an onset cue.

MR. BLUTEAU: On motion systems with six degrees of freedom we don't use very many axes, it's almost a pure surge, very brief and pure surge, for the onset at least.

MR. STOCKING: As a matter of fact, for a six axes system I would replace yaw with roll, even though it's very small, when you push back and turn, you will get a gravity line cue.

MR. HARRIS: But it is very small.

MR. STOCKING: Yes, very small, but it's there.

MR. IRVING: It's there.

MR. BOOTHE: Bob [Heffley]?

MR. HEFFLEY: I think that we have a situation developing here where we really need to maybe start to make some basic distinctions between things that the pilot is doing where he is using cues in a closed loop sense to do something that involves a basic piloting skill. And we have other things going on where the pilot is using cues only to alert the pilot. And for example, in this case here where you have got a pushback. Well, isn't this a place where you can start to talk about substitute cues? I mean, all you are really trying to do maybe is to let the pilot know what the sequence of events are and where you are in that sequence of events. And if you try to carry something as simple as what we are talking about here in this ground handling to the same point that you know you need the fidelity for a basic flight maneuver, then you might as well decide on six degrees of freedom right off the bat. No question about it. Let's go have some beer.

MR. BAKER: Two votes for beer so far.

MR. CARDULLO: I was going to say with regards to degree of freedom, maybe rather than going through every maneuver and going through this torturous thing we could abbreviate that and get to the beer sooner. We could abbreviate that by just asking a general question. Does anybody think that you can get by with fewer than six degrees of freedom and—in any maneuvers for a Level B simulator, and if so, which degrees of freedom can we get away without?

MR. HARRIS: You can get away without—

MR. FOSTER: We are doing it. We are doing it right now. We have Level B simulators with roll, pitch and heave. And they are being used only as Level B simulators. And the results to this point are very satisfactory.

MR. CARDULLO: Well, then that's the answer to the question. But on the other hand it depends on how you define satisfactory.

MR. SUSSMAN: Bob [Heffley] put the question better. We can think of two considerations, one is what do you need for a cue to alert you to an event, and the other one was what do you need for a maneuver which requires feedback to maintain control.

MR. CARDULLO: I whole-heartedly agree with that. That's why I said ground handling is important because it's a high frequency domain and not when you are being pushed but when you are actually driving the airplane on the ground, those are important. But what I was just trying to do is say, okay, we got those important tasks, can we simplify the process by saying which degrees of freedom we don't think we need or we think we do need overall rather than going through each individual task?

MR. SUSSMAN: The reason I asked is, I think he is implying that you don't need the same degree of fidelity for all cues in all degrees of freedom; am I right?

MR. HEFFLEY: Yes. But the other little step in this is that for these tasks where you don't really need the pilot in the loop, so to speak, if it's a matter of the bumps on the ramp, there are cheaper ways to get that with a cheap seat shaker or something.

MR. CARDULLO: I agree.

MR. HEFFLEY: Something artificial then to necessarily try to get that through the large amplitude motion system.

MR. RAY: Isn't that part of the bigger issue of the cost? If you dissect it too far you can drive your cost up. Let's assume that you elect a six degree system as the minimum because of the maneuvers required. With that six degree system—six degree of freedom system, I can get those same runway bumps without adding to that seat shaker. If I look at that maneuver in isolation it may be that the seat shaker could satisfy the runway bump cue. If you focus on it too long you drive the cost of your simulation up because you are embedding, or adding, that device in isolation.

That's why I think the correct thing to do is look at the most important maneuver, that maneuver which requires the most significant pilot control feedback. In my opinion, you are looking at takeoff and landing maneuvers. You focus on those and your answer becomes clear and everything else falls out.

MR. BOOTHE: Shall we proceed to takeoff and landing?

MR. RAY: My basic instincts say that's the most critical maneuvers as far as cuing requirements, everything else falls out.

MR. IRVING: If you decide that you need pushback and you say hang on, you only do this once and it really is a fairly small event, it doesn't actually add up on a cost benefit basis, so out it goes. You are looking at the asymmetric business and the axis required for those maneuvers must surely be sufficient to cover less important, less repeated maneuvers.

MR. BOOTHE: Shall we proceed to the next table, which is takeoff? I have listed normal takeoffs and abnormal/emergency takeoffs. Under normal there is the acceleration, the airplane acceleration, if you will, to takeoff speed. And of course there is steering, there is crosswind compensation, there is probably other things. But those are the three things I have listed.

Under abnormal, there are rejected takeoffs, there are takeoffs with an engine failure, possibly takeoffs with a windshear, so that's really a lumped group of considerations there and as you can see—I guess I can ask the question that Frank [Cardullo] prompted, do we need any less than what's listed there? So I pose that question to you.

MR. RAY: I'm reluctant to raise my hand.

MR. CARDULLO: So you raised a finger.

MR. RAY: I think there is a logical case that can be made to say historically we have done it with pitch, heave and roll, correct? It's only because that's what, let's face it, Link produced back when, 1960 sometime for the Level A motion systems. It doesn't—I'm sorry.

MR. WILLMOTT: Probably 1929 when he patented the simulator.

MR. RAY: Yes, for his original simulator. I think it's very easy to come to the conclusion that that's what we have done, therefore it's correct, therefore that's what we will do in the future. I think we might cut off our nose to spite our face if we approach it that way. The reality is the pilot experience base we know that's come along through the airline history has been quite high. From military sources primarily. What's likely going to happen over the next 20, if not ten years, is the experience base is going to drop dramatically. We are probably going to end up with pilots we are required to train that have less experience than we have had in the past. We have an obligation to ensure the training of those pilots is as effective as we can reasonably make it. From what I'm hearing here from the sim manufacturers it's not going to cost any more to provide better training.

Would we be correct in the future, since [a] six degree of freedom is apparently as inexpensive as a three or four degree, should we simply continue what we did in the past? We would naturally grandfather the existing devices, we would be wrong to kill them.

MR. CARDULLO: Bob [Foster] makes a compelling argument when he says that it's been fine. And we can say well, that's all anecdotal, but nevertheless we don't have any counter-argument, any research that says anything different than what Bob [Foster] is saying. Other than the fact what we know theoretically. And what we know theoretically says that, really shouldn't be working fine. And that perhaps maybe the metrics just aren't there to identify the fact that it really isn't working. I mean, anecdotally we all hear all sorts of things, this is great, that's fine, but is it really, since we don't do transfer of training studies, we don't do much even in the way of performance studies, how do we really know it's fine? So we are stuck here. Do we just say that it appears to be fine so we do it that way? Or do we rely on our theoretical understanding of the problem to say what it should be, or do we go ahead and try to do some research to determine what really is fine. These are questions I don't know the answer to.

MR. LONGRIDGE: We are going to do both. We are going to make some decisions based on our best expert judgment. We will do some in the immediate future. We will also define promising areas of research.

MR. BOOTHE: I think we are here, you are here as a group of subject matter experts to tell us how it ought to be.

MR. CARDULLO: So theoretically I say you need six degrees of freedom. There is no question in my mind from a theoretical standpoint that you need six degrees of freedom. You get things like center of gravity movements, so you have to change the center of rotation, and in order to get different centers of rotation you need those additional degrees of freedom. You need side force cues, for engine out sorts of things, there is no question in my mind that you need six degrees of freedom.

MR. BAKER: I was going to ask if Bob [Foster] or anyone else has any anecdotal information that might shed some light on this from the standpoint of pilots that have been recertified in Level B simulator without yaw and lateral motion. And did it ever show up that they had a problem with an engine out condition, for example? Do we have any data at all that even if it's one or two cases that says, gee, this guy didn't handle an engine out situation very well and it may have been because he was getting all of his recurrent training in a Level B sim that didn't have the ability to give him a good cue for the situation?

MR. FOSTER: I'm not aware of anything. On the other hand, most of our airplanes are tail mounted engines, so there is not a—

MR. BAKER: You fly a lot of [7]37s.

MR. FOSTER: Yes, but we have all six axes simulators for the B-737 equipment. But on the other hand, look at this situation right now with the commuters, we take a relatively inexperienced pilot who has had virtually all his training in fixed base simulators or other airplanes, and now a commuter hires him and puts him through ground school and now they take him out in the airplane and do it and give him engine out conditions. They generally live through it, but that's a terrible thing to do compared to giving him a decent simulator where he can properly practice emergency procedures. There may be some limits imposed due to lack of motion in a couple axes, but I would submit I think with a good three axis simulator he is far ahead and a far safer and a far better trained pilot than the guy that that does not have the simulator at all.

MR. BOOTHE: I would agree with that. No pilots get exposure to things like engine failures in airplanes these days for training. The only people who get that exposure are the company test pilots and perhaps an FAA test pilot in the certification process. Therefore, I think it's a heavy responsibility of the simulation industry to provide the proper cues for that kind of training and that kind of pilot certification because that is the only exposure a pilot gets. And I have said that before

in terms of data requirements, in terms of simulator motion cues, and even in terms of other cues a pilot receives, and I think it's, I don't want to sound too altruistic here, it's not fair to the flying public to put a guy up there who has not had the exposure to what might happen. I think Bob [Foster] probably agrees with that. But I also would have to say that a simulator that doesn't provide all the cues may be better than no simulation at all, but I don't know how to say that. Bob [Heffley]?

MR. HEFFLEY: Two points here. I guess we are really kind of talking three degrees of freedom versus six. I guess I concur with what Frank [Cardullo] says and what you just said and kind of trying to make a case for going all the way, in building a low cost simulator. If I were doing it I would still like to have the option of just going three degrees of freedom. It seems to me I could make it cheaper. But moreover, I think you all are maybe assuming that maybe you have a tacit quality, level of goodness that you are going to get with six degrees of freedom that are somehow going to give you really good engine out cues. I don't know. Given that this six degrees of freedom simulator is very expensive, one still doesn't have a very long stroke. You don't get very sustained cues, the basic quality of the motion is still pretty ragged compared to the real world. Are you really going to improve things that much more?

The bottom line is you still don't have a good solid basis for saying, well, six is really going to do the job a whole lot better. Especially in the light of people who use this three degree of freedom Level B trainer here for presumably a long time and getting what appears to be good results.

MR. RAY: I would like to add to Bob's [Heffley] comment along those lines. Looking at what's really going on, getting back to my pilot experience base again, those that are using the Level B sims, I think Bob [Heffley] would agree, are fairly highly experienced pilots. We are talking about pilots with several thousand hours of flying time. Let's look at who we are talking about if we focus on the commuter world. The vast majority of commuter pilots possess significantly less experience. Co-pilots may only possess 200 hours of actual flight time before being hired, including minimal multi-engine time or training. Are we correct in limiting motion to pitch, roll and heave only for that 200 hour pilot? Can we have the faith necessary in that the assessment of those pilots in that device is as good as the airplane? I don't think you can get there yet.

Pilots with the typical major air carriers have been through multiple engine failures both in the aircraft and [in] high fidelity simulation. The experience base that major air carriers typically have now is not going to exist in the future. Are we willing to make that step at this point to have that comfort level of proficiency assessment in simulation with three degrees versus six?

MR. HEFFLEY: Again you are assuming, though, that six sounds better than three. But those six degrees of freedom may still be just as distorted as the three except in a different way. Neither one is necessarily any closer, you know, to the real world. So it's one of those things without having something to really look at—

MR. BOOTHE: Good point. I think Frank [Cardullo] was first.

MR. CARDULLO: For the first time today I disagree with you, Bob [Heffley]. I think, you know, for example to use Ed [Boothe]'s example of the engine out on takeoff. You can't sustain that side force cue for very long, that's true. Well, but if you give a roll onset the guy is going to think the airplane is rolling, that's not going to cue him to the fact that he has an engine out. Now if you can at least provide him an onset in lateral side force and then roll it to try to sustain it for a while, I have to believe that's better than just trying to roll it. Because rolling it alone is going to give him the wrong cue. So you are right, [a] six degree of freedom system is not a perfect system because as we know it's constrained in all those degrees of freedom by its excursion.

But most of the psychophysical research with regard to how the visual system picks up after the motion, indicates that you hasten this onset of vection as long as the vestibular and somato-sensory stimulation is in the right direction. And it doesn't even have to be very long. Right? As long as it's in the right direction. And so I think that's the basis for the argument.

MR. BOOTHE: I think we are going to hopefully have time to address some of those issues about how long it has to be and what magnitude, I don't know—

MR. CARDULLO: I can't answer that one.

MR. BOOTHE: Okay.

MR. HARRIS: I will try and keep it short.

THE REPORTER: And louder.

MR. HARRIS: You are talking about cues, acceleration is obviously a prompt cue that comes from rotation. Onset is also a series of cues that comes from the linears. So if you are going to have onset with some sort of sustaining you need six axes. If you run a six axes system you can put in additional cues, like the Appendix H windshear we talked on before. The pilot may perceive a six DOF simulator as being a higher fidelity machine than a three DOF simulator. Higher fidelity. I don't know about this, but it's possible.

MR. WILLMOTT: Ed [Boothe]? Am I not right in saying that the simulator is used for training and checking? When the task of a V_1 cut or any of the tasks are done in the simulator for which the person is being checked, the check—a check airman is with him and certifies that he has done that maneuver correctly or incorrectly. Whatever the motion system is, if he does the maneuver satisfactorily, is that really what it is that you are looking for? And if it is, you know, why are you looking for other degrees of freedom in the simulator? And if by chance it's tougher to do it in the simulator, without these extra degrees of freedom, is it better for the person to be trained to do that and be more easily able to control the airplane where he has these total degrees of freedom? I mean, the argument that we are making here I think is “the closer you could make the simulator to the aircraft, the better it is.” But we are looking at a device downgraded from a [Level] C and a [Level] D. We already have seven levels of flight training devices which can be used for all sorts of training for which there is no motion at all. So why do you need six degrees of freedom for motion in a Level B simulator?

MR. RAY: I would answer the question with a question, Stu [Willmott]. In that maneuver you are talking about, why do you need a visual system with it? Why do I need any motion system at all if my purpose is to see that the pilot successfully completes a maneuver? That's in essence what an examiner or check airman will be doing. They will be asked to see if a pilot can successfully control that device. If that device doesn't replicate the airplane, then how can the check airman's assessment be accurate? There's the old adage, the old Air Force adage, which was to make simulation tougher than the airplane. That was, as someone I think within this room accurately mentioned, that was the coverup for the fact that simulation at the time in the '60s could not replicate the aircraft. It was a known fact, so the Air Force accepted the adage “it's tougher, therefore it's better.” But in fact what you do with improperly cuing a pilot in simulation is you include pilots who would otherwise be unsuccessful in the airplane. Similarly, we exclude some who would otherwise be successful in the aircraft. And that is, I would submit, improper.

MR. WILLMOTT: I am not suggesting that you do away with visual. I think that is a prime requirement for takeoffs and landings. But I'm not so sure that the motion is.

MR. RAY: Well, if motion is not a key player there, where would motion be a key player?

MR. WILLMOTT: For higher level devices for doing initial training.

MR. RAY: From a regulatory perspective of assessing pilot performance in flight, I'm sorry, you can't get there from here.

MR. LONGRIDGE: I think the logical conclusion, Paul [Ray], from your arguments, is we should do away with Level B simulators immediately.

MR. RAY: I disagree. I think the potential is there for designing a Level B simulation that may have in fact less excursion than a Level C or D, reduced excursion and whatever else needs to be

modified within that, you end up with a smaller motion system. You probably don't end up with a 60-inch throw system, it may be that 30 inches is satisfactory. You get a smaller building, you reduce environmental costs, as we pointed out on the board. There are all sorts of things that can be done to improve Level B without driving costs. Let's not forget Level B's origins and that they were conceived as an accommodation and bridge to Phase II and III, or [Level] C and D. We should be able to have Level B simulation that perfectly satisfactorily meets the needs of a user whose final level of simulation is Level B.

MR. SUSSMAN: At this point you get into philosophical considerations.

MR. RAY: Oh, sure.

MR. SUSSMAN: What we usually do is establish a level of safety. Then in the future when we want to buy a piece of equipment which is important to maintaining that level of safety we must ensure that it is at least as "good as" the existing equipment. That is, new equipment must at the least provide the current level of safety. There are exceptions. For instance if you expect some external change to drive safety down, for instance a change in the demography of the pilots which results in lower initial skill levels. In this case you might have to go to equipment that is "better" than the existing equipment. The question is do we want a Level B simulator which is "as good as" the current simulators but cheaper? Or do we want better Level B simulators because we expect external forces to impact safety negatively?

MR. SMITH: At the same time, and I hate to say this, I mentioned this a couple times but really that Level B simulator is going to fill the role of what the Level C is doing, a lot of Level Cs are doing now.

MR. SUSSMAN: You need a better requirement then.

MR. SMITH: I'm not saying that, but like Paul [Ray] says, in order to provide a simulator that can reasonably be used for recurrent training we have to come up with a cheaper Level B, you can't cut corners everywhere.

MR. RAY: The Level B only requires a single channel visual. That keeps costs down. Expanding the visual should be an operator's choice. You are talking substantial cost differences between a Level C and a Level B simulator.

MR. LONGRIDGE: We are getting into the issue of trade-offs here. I think we need to kind of leave it up to the group to define the discussion and not define what the trade-offs would be. It may be that a three DOF system, with a wider field of view visual system would be another alternative trade-off that we might want to make that might meet our requirements. I have to think we have to keep the discussion open to all possibilities.

MR. RAY: I think defining what three DOF is. It's not necessarily the old Link system. It may have worked fine for its intended use, but three DOF may be pitch, roll, yaw, sway, pick another one, not necessarily the original three. That's the paradigm we are carrying around on our shoulders now, that three DOF means old systems.

MR. HEFFLEY: We are still with three versus six, the only argument so far here to depart from three to go to six is the initial onset of an engine out until residual tilt takes over. And that may be a big price to pay for that.

MR. CARDULLO: I don't think that's the only one. That's one example. I think handling on the ground is another. I don't know how much handling on the ground you have to do, but not navigation sorts of things, but hitting the ground and high speed control of the airplane on the ground, the side force is important. And you can't sustain it very long, true, but at least to have that onset cue and then maybe the gravity align will help. I mean, there are two camps on the gravity align issue, too. But at least you get the onset. So that's another place where side force is important.

I'm not sure in windshear, I mean a lot of things can happen to the airplane in windshear. I'm just not sure how important side force cue is in trying to fly out of windshear. And I don't know how much training you do in a Level B simulator for flying out of windshear.

MR. RAY: Quite a bit. For non-turbo prop, the regulatory structure does not presently require simulator windshear training. If you have a turbojet aircraft, yes, you are required to accomplish simulator windshear training. It can be accomplished in as low as a Level A simulator.

MR. MARTIN: If you could do without the gravity align, there is the alternative of using a dynamic seat for some of the roll and pitch cuing. I don't know that it's much good in other degrees of freedom. Of course, you could include a vibration system. We have seen that dynamic seats can be very effective for roll and pitch cuing.

MR. CARDULLO: I agree they are most effective and the work that you did points that out. But even the work that was done at NASA-Ames with the old pneumatic seat showed some value. They did some engine out things with the dynamic seat and showed some performance benefit. I am referring [to] the work of Parris and Showalter out there. And it all goes back to some of the things we stated previously, as long as you are providing some cue in the right direction, as long as it's not in the wrong direction, as long as it's not a false cue, there is going to be some performance benefit. I don't know about training benefit, but there is definitely performance benefit from that.

MR. BAKER: I wanted to mention a couple things. Degrees of freedom and the necessity for them. The phenomena that occurs in the cockpit from engine out is primarily a lateral motion as opposed to yaw. Most of the effect a pilot feels is CG, the same thing is true with pitch, that the limitation that I always had was a six axes base has to do with vertical translations caused by pitching of the aircraft. That's on an A-10 aircraft that's only got 20 feet between the CG and the pilot. So I wanted to emphasize the fact that if you leave out—if you add yaw but don't add sway, for example, you really haven't bought yourself a whole lot because the yaw motion isn't what the guy primarily feels.

MR. CARDULLO: Right.

MR. BAKER: You can buy a lot by building a motion platform that's got three axes where the pivot point is well back behind the pilot. And giving roll, pitch and yaw, put the pivot point ten feet behind him and he is a lot happier than with the pivot point beneath his feet. The degrees of freedom come up pretty well when the pivot point is behind him as opposed to underneath him.

I had another point I was going to make, and like Ed [Boothe], I forgot.

MR. CARDULLO: Two things happen when you get old, you know.

MR. BAKER: You can't remember the other one, either?

MR. CARDULLO: I have the same problem.

MR. BOOTHE: Are you suggesting, then, that if we could say use a three degree of freedom system simply by redesigning the system, forgetting about convention and perhaps having a system that's unconventional with three degrees of freedom but emulates other degrees such as sway because of design factors.

MR. BAKER: Let me say I talked to Marty Henderson at Frasca about this a couple weeks ago. They designed a motion platform like that. They are putting it under FTDs basically but they said it gives quite a good result. There is no longitudinal acceleration, no surge on it, but the other degrees of freedom seem to come in pretty well. And you know, that unfortunately increases the dimensionality of the parameters paperwork by quite a bit, so we have a whole lot of other considerations in terms of defining how the motion base might be designed.

But, you know, it's back to the question of how do you skin the cat? And, you know, back to the question about how many degrees of freedom do you have and what's the trade-off? Is

six axes with a 24-inch stroke better than three axes with a larger stroke? And does it cost about the same? Once again, I don't know the answer to that. I would have to go off and do a preliminary design. There are trade-offs like that which will be very hard to get a handle on in this discussion. And, you know, would something with a foot stroke be better, six axis base with a foot stroke be better than a three axis base with a three-foot stroke? I don't know.

MR. BOOTHE: That was the question I was going to ask. If you have a small displacement, six degree of freedom synergistic system, in which you could create small pulses in the right direction, small onsets in the right direction, but yet that would limit the gravity alignment rather severely, is that something we should consider for Level B or should we consider that only with a wide angle visual system? There is so many variables that we can put in the problem it's hard. But if we for the moment confine ourselves to a single channel visual system, and look at a synergistic motion system that's capable of six degrees of freedom but only for small onset cues, is that sufficient for recurrent training in a Level B simulator?

MR. CARDULLO: How wide a field of view is that?

MR. BOOTHE: Generally 40—is it 45?

MR. RAY: Forty-five.

MR. BOOTHE: Thirty-five, 45 per pilot.

MR. CARDULLO: To get circular vection, ideally you need about 60 degrees. But all the research that I know about, that supports the fact that you need 60 degrees to get circular vection, doesn't have any motion onset with it. My guess is that with 45 degrees and a motion onset you can develop circular vection. And as far as linear vection, most of that comes from optical flow, anyway. Recent work has shown that you don't really need to stimulate the periphery, given a narrow field with sufficient optical flow, you can develop linear vection but we are mostly concerned, I think, with circular vection, anyway. So my vote would be for shortening the stroke and keeping the six degrees of freedom and you can almost shorten it to whatever you want.

MR. BAKER: One of the things, let me say—

MR. CARDULLO: To make it cheap.

MR. BAKER: To shorten the stroke you don't necessarily lose angular motion, you essentially lose linear motion. 23 degrees, right now it's not a big hexapod, you can maintain that, so the gravity vector alignment question really isn't an issue.

The other point I wanted to make a minute ago, if I could sneak that in while I have got the floor, one of the things that strikes me is that we have been searching as an industry for 20 or 30 years to try and determine what we can get by with and what we can't get by with in terms of motion cues and visual cues and so on. And there isn't a whole lot of hard data that you can hang your hat on that says this is what's enough, and anything less than this isn't enough. And you know, Bob [Foster] has been training pilots on three axis bases and as far as we know it's been satisfactory. The consensus amongst a lot of us is that "gee, you could do better if you had more degrees of freedom," we almost all intuitively believe that's true. We know if we go back to zero degrees of freedom we can create problems with training. And so we are trying to make, I would say, a judgment call here between three axes and six axes, and the concern I've got is that after a lot of years and a lot of study we still don't have any really good data that says yes, three would be good enough for all these particular types of training scenarios, and you know, I think we are in a position where it's almost not a bad idea to err on the side of conservatism and say Levels C and D are running six axes bases and we are almost convinced it's pretty good. Maybe we ought to impose that on the Level Bs. Just on the basis of consistency and the fact that, you know, to some extent the same argument holds true with motion and it holds through with a 300 millisecond time delay. That's what was available back historically when a lot of these devices were built. We had to find a way to fit them into the program.

But we are talking about new simulators now and you know, we could get into a long discussion about how much this three additional degrees of freedom cost, these guys who build the simulators think it's not a really expensive item. So if that's true, then, maybe we ought to go for it and say hey, put it in there because it's not going to drive your costs that hard.

MR. CARDULLO: I'd like to make one comment about what you can train with. Ed Link trained thousand of pilots in World War II with a blue box and trained them, as everyone would say at that time, trained them successfully, and that blue box was a relatively low fidelity simulator. So you can accomplish a certain amount of training with any kind of a training device. But when we want to talk about some of these more sophisticated maneuvers, and actually training them in some of the things we have been talking about here, that's when I think we need the additional fidelity or the additional capability. So you can get by with very little, but trying to do as much as possible with as little as possible I think there are trade-offs and I think, as I said before, I would err in the direction of six.

MR. BOOTHE: Ed Link didn't certify pilots to go and fly in revenue service. He prepared them to go and train in airplanes.

MR. CARDULLO: But they got some training, that was my only point.

MR. ELDREDGE: Can we take a five or ten minute break for Allison [The Reporter]? We are expected to go another half hour.

MR. STOCKING: Just one quickie I wanted to bring up. Signs of the times. There is also product liability that's going to come in the future. We need to think about that, also, in terms of cost of this device.

MR. BAKER: Would you elaborate on that?

MR. STOCKING: Somebody suing us after an accident saying our training equipment was not satisfactory.

MR. BAKER: You would like to face the situation and say we did the best we possibly could.

MR. BOOTHE: No, what they will say is the FAA approved it.

MR. BAKER: You guys will pay the bill?

MR. BOOTHE: That is a good thought. I think a few minutes break, five to ten minutes is a wonderful idea, and I had been waiting for an opportunity.

(Break taken.)

MR. BOOTHE: Did everybody that gave me a ticket get it back?

If anybody did not give me a copy of their ticket, would you please remember to do that tomorrow?

I think the consensus was that if we all had what's best, we would have six degrees of freedom for the takeoff task or various takeoff tasks. The question that I have, is that the minimum we can have and still meet the requirements for Level B simulator which are, which you heard before the break are now being met with three degrees of freedom. Or should we try to define a system of less than six degrees of freedom and decide what are the most important ones and can we build a lesser system reasonably or cheaper to satisfy those requirements, or should we say we need the six degrees of freedom and start working on how small can we make it in terms of those critical parameters?

MR. ADVANI: As far as I'm concerned, it all comes down to the acceleration and the amounts of false cues that are presented. The elimination of false cues and the negative effects on training of those, as far as I'm concerned, are the most critical parameters.

MR. BOOTHE: Do we introduce more false cues by reducing the size of the system?

MR. BAKER: Yes. It's a trade-off between washout rate and level of input cue. If I wanted to have the same level of acceleration cue in a small system versus a large system, then I've got to wash it out faster to keep from bottoming out the actuator.

MR. BOOTHE: But if we accept a smaller system, can we accept less acceleration cue as long as it's in the right direction? Assuming that we then generate, more quickly generatevection in the correct direction?

MR. BAKER: I think Frank's [Cardullo] position is we can do that, if we have a cue in the right direction even though it's reduced amplitude, that's a very good thing. I've got data that says the same thing. We ran a sim at 20 percent gain and got very good motion acceptance by the pilots. They were getting a fifth of what they would have gotten in the airplane with the same maneuvers, yet they were happy with the result.

MR. BOOTHE: They were happy in what respect?

MR. BAKER: They were happy in the sense they could do a rather difficult task, they had very complimentary things to say about the motion cues and its effect on flying. The tasks they were doing was manual terrain avoidance on a simulated night vision system which had a very restricted field of view. And at the same time they were asked to do a task of looking at a head down display on a missile guidance system, they were busy. They were busier than just about anybody would ever get in an aircraft. They had very good things to say about, for example, looking at the head down display, how fast it took them to mentally figure out what the airplane was doing when they went back out the window, for example.

Basically the problem is, one of the problems that you get into with that particular environment, the guy has been looking at the head down display for maybe as long as a few seconds, he wants to check that the airplane is still airborne and isn't about to run into the mountain or getting too low to the ground. He wants to be able to acquire in the essentially out the window visual or his flying visual scene, he wants to acquire very quickly what the airplane is doing. And the comments from the pilots were that it's much easier to do with motion on them than no motion. We didn't try it with three degrees of freedom as opposed to six, just the point was that even the 20 percent cues they were getting were a huge advantage for the problem of acquiring, rapidly acquiring what the airplane was actually doing.

MR. BOOTHE: This was strictly pilot opinion, you didn't measure performance or workload?

MR. BAKER: The only measurements on workload was 29 out of 30 pilots said they couldn't fly the mission without the motion on it. The other guy was some anomalous character that said it didn't matter. He can do it with motion or without motion. 29 out of 30, the most frequent comment was "gee, now I can fly it," when we turned the motion base on for it. We instruct him by a guy sitting by the side of the cockpit with the motion off, we instructed them on exactly what the task was and they would try to do it with the motion off, generally not do it very well. As soon as we turned the motion base on every one did well. So that's my anecdotal story about motion. It's an intense task, okay, it's like a carrier landing in bad weather, very, very intense.

MR. CARDULLO: I think we should ask Ed [Martin] to tell the group about the experiments that they did with very little motion system and the very favorable results they got.

MR. MARTIN: You are speaking about the dynamic seat stuff?

MR. CARDULLO: Right.

MR. MARTIN: We were looking only at roll axis, that was supposed to be just an initial look into the effectiveness of seat cuing. We had plus or minus 12 degrees capability in roll. Of that, we used just a couple degrees. But we were able to elicit operator performance with just seat cues that was indistinguishable from operator performance observed in a one-to-one full body motion device.

In addition, we measured frequency domain characteristics that allowed us to essentially characterize the pilot as a filter—and in this way look at operator control strategy. We were able to elicit the same operator control strategy as observed in the full-motion environment, with just a small amount of seat motion. This was accomplished with essentially plus or minus two degrees or so of platform motion that was providing tactual cues. There wasn't any vestibular information that we could detect coming through. We did some tests with a bite board to check this out.

MR. BOOTHE: You mean the motion drive was just on the seat itself?

MR. MARTIN: Just on the seat. The information was just coming through the seat of the pants.

MR. BOOTHE: So you had roll—just roll.

MR. MARTIN: Roll was all I looked at initially. Some follow-on stuff was done with pitch. They seemed to be getting similar results in pitch.

MR. CARDULLO: It's a single axis tracking task he was doing. With a very narrow field of view visual that was really nothing more than an instrument display, an artificial horizon.

MR. MARTIN: The visual display mimicked an ADI. As I recall it subtended a visual angle of about 12 degrees.

MR. CARDULLO: You weren't really getting a lot of motion information out of the visual.

MR. BOOTHE: All I need is a little six degree kick in the pants?

MR. CARDULLO: The question you asked was how small can you get?

MR. BOOTHE: Right.

MR. CARDULLO: So this indicated that you could get quite small. No washouts, you've just got to be careful as Sunjoo [Advani] has said several times, not to give any false cues. Now, this was a limited experiment, but nevertheless I think it's quite encouraging, the results were all published so you can read them.

MR. SUSSMAN: Ed [Martin], you said one thing, you were sure they were having no vestibular cues, the head was fixed basically?

MR. MARTIN: Pardon?

MR. SUSSMAN: The head was fixed?

MR. MARTIN: Yes.

MR. SUSSMAN: Just seat of the pants.

MR. MARTIN: But still with tactual seat motion.

MR. SUSSMAN: Yes.

MR. ADVANI: We have done work in our group also using a very limited display, artificial horizon in a tracking task where the only, let's say motion cues, are coming through an active side stick, so you can see that the very high frequency proprioceptive feedback gets you a lead [and] that you can stabilize a highly unstable task just through that cue only. Which tells you something about the muscle, joint and proprioceptive sensors as opposed to the full vestibular system.

MR. CARDULLO: I'm not advocating we go to a dynamic seat at this point. I think it would be problematic from a pilot acceptance standpoint, and maybe probably from the FAA. But nevertheless, it does give you some idea that you can get performance equivalent to the criterion device. That was key, I don't know if everybody caught that but they actually transferred and measured in a full motion simulator—they didn't transfer to an airplane, but they transferred to the RATS, the roll axis tracking simulator, which gave full roll motion.

Do you have pictures?

MR. MARTIN: Yes, I think I do. Yes.

MR. CARDULLO: So that's a quasi transfer study, so it's essentially the same thing as transferring to the airplane. You get as much motion out of that in that roll axis as you would out of the airplane.

MR. MARTIN: Basically what we had for a criterion device was a roll axis tracking simulator that was capable of full 360 degree roll. We included the dynamics of this device in the simulation for the dynamic seat. For training we used this dynamic seat in the enclosure shown here, with the same ADI-like display as in the full motion device, and performing the same task—but with just the limited amount of seat roll motion. We trained subjects in this device, then transitioned them to the full-motion device. We actually had four groups of subjects. One group started off in the full motion device as the control group. One group trained with no motion cuing. Two groups trained with two different dynamic seat drive laws.

MR. SUSSMAN: Let me ask a question, you are saying people who trained in this device did as well in the RATS as people who trained in a full motion device?

MR. CARDULLO: No, we didn't say that. That's the other shoe.

MR. MARTIN: No. Once subjects were trained to proficiency, task performance using the dynamic seat cues was indistinguishable from task performance in the full motion environment.

MR. SUSSMAN: Okay. That doesn't demonstrate that this was good training for flying airplanes. It means that you can get the same cues. That's different.

MR. MARTIN: Training transfer was disappointing, because when we took groups that trained on the seat and put them into the full-motion device, they regressed and required a few sessions to get back to previous performance levels. However, they didn't start out as badly as the control group starting out in the full motion device with no previous training.

MR. SUSSMAN: That's very important, though.

MR. MARTIN: Oh, yes.

MR. CARDULLO: The point is that you can elicit the same performance, whether that transfers or not is another question. And that is a very difficult question to answer.

MR. SUSSMAN: Isn't that the most important question?

MR. CARDULLO: It may be.

MR. MARTIN: In the case for the Level B simulator, we have got people that already know how to fly the airplane. We did look at reverse transfer with pilots (rather than naive college-student subjects) where the pilots were trained in the full-motion device and then transitioned to the dynamic seat. That turned out to be pretty straight transfer. Forward transfer (from the seat to the full-motion device) showed statistically significant benefit of seat training when experienced pilots were used as subjects. However, naive college-student subjects that were trained in the seat and then transitioned into the full-motion environment still had a lot to learn about that motion environment. There was a lot of difference in the motion environment with whole-body motion versus just having tactual stimulation. Naive subjects just weren't able to learn how to use that motion information with the seat cues alone.

MR. CARDULLO: There is probably only one study out there that shows significant transfer of training of motion to the airplane. And that's that helicopter study that was done by—

MR. HEFFLEY: Jeff Schroeder?

MR. CARDULLO: No. Who was the guy? I think it was a Navy guy, wasn't it?

MR. MARTIN: Galloway, are you talking about somebody down at the Naval Air Warfare Center's Training System Division?

MR. CARDULLO: I don't remember. Grant often quotes that work. Other than that, any transfer of training studies that have been done with motion show virtually no transfer. But almost all the transfer of training studies, if not all, were done with inferior motion systems. And recently with the stuff that's been done with good motion systems there haven't been transfer of training studies, they have been performance studies. And does performance in the simulator improve with motion? And the answer to that question is always yes. Does that mean anything? It means something, but it's not clear whether it means it transfers training. But if you compare behavior or performance, it seems to me if you are getting the same behavior in the simulator as you would get in the airplane, then that should be indicative of transfer. Because what are you trying to train? Well, you may be shaking your head no, but what are you trying to do in a simulator? You are trying to teach behavior. And so if you are getting the same behavior, I don't know why it doesn't seem to transfer.

MR. SUSSMAN: I would argue in a simulator you are trying to teach appropriate responses to cues which indicate emergencies or flying difficult situations, you are not trying to teach how to fly a simulator.

MR. BOOTHE: The question I have, you said you are getting—you are studying performance and performance improves if you have motion. And then you switched to behavior. Now, my question is—

MR. CARDULLO: What's the difference between performance and behavior?

MR. BOOTHE: My question is, which are we really getting? You can get the same performance with a lot of pilot compensation.

MR. CARDULLO: That's right.

MR. BOOTHE: That's different than—

MR. CARDULLO: Depends on how you measure performance. That's why performance and behavior sort of overlap.

During the break I was talking about some things that we did just fooling around where you saw, when you turned the motion system off, that the pilot went from very small control in station keeping for air refueling, to after the motion system was turned off really jerking the stick all over the place. But nevertheless maintaining the same error, so behavior changed but the performance, as measured by the error with respect to the tanker aircraft, remained the same.

MR. BOOTHE: My whole point.

MR. CARDULLO: That's your point?

MR. BOOTHE: Exactly. Performance alone—

MR. CARDULLO: It depends. If you call performance in a general sense behavior, where workload goes up or down, so it depends on how you define it.

MR. BAKER: I think from a scientific/analytical perspective what we are trying to accomplish with training, at least in a lot of the situations, is that the man's mental controller that he uses for the particular task is the same in a simulator that it is in an airplane.

MR. BOOTHE: That's close.

MR. BAKER: If we had a way to measure that, we would be home free.

MR. BOOTHE: You never know how hard I'm working.

MR. BAKER: You can measure how hard somebody is working a lot of times by looking at amplitude of motions.

MR. BOOTHE: You can get indicators, I think. But we are interested in more than training. We are interested in pilot certification. What we want a device to do for pilot certification is to permit

that pilot using the behavior he would use in the airplane to achieve the same performance he would achieve in an airplane. And in fact there is only one set of performance standards and it doesn't matter whether you take a check in an airplane or a simulator, you still get graded on the same performance standards. So if the device doesn't stimulate the same behavior for any given task that the airplane would, then we aren't really certifying the person for the same airplane.

MR. BAKER: That's basically what I was trying to say.

MR. BOOTHE: So when we talk about small motion systems, that's the question that I'm concerned about, will they stimulate their behavior that the airplane will stimulate? And how can we decide that here? Has somebody got an answer?

MR. CARDULLO: You can do experiments. Not here.

MR. ADVANI: We need to do research.

MR. SUSSMAN: The research is transfer of training research.

MR. CARDULLO: I don't think you can do transfer of training research. I think it's impossible to do transfer of training research.

MS. BÜRKI-COHEN: Perhaps you can do quasi.

MR. CARDULLO: Perhaps you can do quasi transfer of training. For example, how do you do transfer of training for negotiating windshear? Are you going to take the guy up and fly around and look for some windshear and try to fly through it?

MR. MARTIN: You could probably do that in a variable stability aircraft.

MR. REID: I can simulate windshear.

MR. LONGRIDGE: Certainly we can do transfer performance from a redefined Level B to a Level D sim.

MR. CARDULLO: Sure. Those kinds of things you could do quite easily.

MR. LONGRIDGE: We could do some transfer to aircraft for tasks that routinely occur in aircraft.

MR. CARDULLO: That's still tough and expensive to get.

MR. LONGRIDGE: Money is no object.

MR. CARDULLO: Performance studies are easy, performance studies are more reasonable to do than transfer of training.

MR. LONGRIDGE: Of course. Yes. I mean we are concerned really with transfer performance, we are not concerned so much with transfer of training in that we want the same level of performance whether we are talking about the aircraft or a simulator, we are talking about terminal performance.

MR. BOOTHE: But as I understand it, you have two objectives here: A very short-term objective of trying to define a Level B simulator that's lower cost and can do the job, and a longer term objective with some research—

MR. LONGRIDGE: Right.

MR. BOOTHE: —involved to maybe validate what we do in the short term, I don't know.

MR. LONGRIDGE: Yes, by all means.

MR. BOOTHE: So I think it's our job here in the day remaining to see if we can identify something for the short term that we think—I mean, we have the data that you know about, but we are still stuck with our expert opinion to identify a device that we think will satisfy the short-term purpose of certifying pilots, recurrent certification in a Level B device, and what's that minimum

device? And would motion be in the pertinent subject for this group? I think we have already come to two preliminary conclusions, I say preliminary because we have another day and what we say today may change by tomorrow. And that is we seem to agree that six degrees of freedom is necessary. And we also seem to agree that six degrees of freedom with very limited envelope is acceptable. Is there any—am I wrong on that?

MR. LONGRIDGE: Can we take a show of hands how many people concur with that position?

MR. BAKER: I agree with that conclusion.

MR. BOOTHE: I certainly do. I shouldn't be able to vote. Well, let me just ask, who does not think six degrees of freedom are necessary for the critical tasks that we identified in takeoff and landing, is there anybody that thinks we do not need six degrees? We have—

MR. HEFFLEY: About the question, I guess you are just asking for an opinion.

MR. BOOTHE: Expert opinion, that's what I'm asking. So we have Bob [Foster] and Stu [Willmott] and you [Heffley] and Tom [Longridge]. We have four people who say that we do not need six degrees of freedom.

MR. LONGRIDGE: Maybe a better way of phrasing it is at least I'm not convinced, I'm not convinced that we need six degrees of freedom for a Level B device.

MR. HEFFLEY: It seems like there must be some burden of proof here to make the step that we are talking about. It seems reasonable, seems nice. But there is this fundamental trade-off between cost and effectiveness that maybe is a flip of the coin. And we have got this basic experience of existing simulators that keeps bothering me.

MR. RAY: I just pose a question to you, Bob [Heffley]. I'm not trying to convince you. I guess my answer would be do I agree that more than three is required, and that's a yes. The options were three or six. I think more than three certainly are required. But would you agree or disagree that some standard should be applied to what those three degrees should be capable of doing?

MR. HEFFLEY: Yes.

MR. LONGRIDGE: Of course.

MR. HEFFLEY: Yes. And likewise with six, you know. Six doesn't buy you the world. You can have six really poor degrees of freedom.

MR. CARDULLO: Which six are the poor six?

MR. HEFFLEY: The other thing that bothers me about it is the same question is going to maybe pop up here with some of these other characteristics. Seems nice to eliminate all cross-talk, but it's a matter of degree, and engineering time alone to handle some of these questions can be horrendous. And it's trying to make these kinds of judgments or decisions simply based on—well, not casual, this isn't casual discussion, but I understand we are all coming from a lot of different places and experiences here. But ultimately it's not having any real good rational basis other than just some kind of logic that sounds, you know, sounds about right. Six sounds better than three.

But it troubles me that there is still, still might be some very good reasons for allowing some latitude as to stick with three here.

MR. IRVING: I just want to make a point, I think six is a comfortable decision. I don't think that it's necessarily a valid or logical decision. I think we might be doing a disservice to the community if we say six. Three or four, four and a half, four and a quarter, I don't know. Remember, Ed [Boothe] and I worked on the Level A working group and we agreed that counting the level of axes was too difficult, so we didn't count them.

The industry hasn't taken up the issue because we don't have Level A simulators. I think there is a disservice in saying [that] six is comfortable, and [that] six must be better than four axes.

How you quantify or define as good or not so good in a regulatory document I think is probably nearly impossible.

MR. LONGRIDGE: Did you include any specifications regarding what would be sufficient for the task?

MR. IRVING: No.

MR. LONGRIDGE: You left that wide open.

MR. IRVING: We said it had to be sufficient.

MR. LONGRIDGE: This is kind of a subjective decision on CAA's part.

MR. IRVING: The FAA was present. But I think the point there is that we couldn't sensibly conclude what was or was not necessary and we felt that there are wiser people and we shouldn't constrain their creativity. Remember the ultimate—the less you specify, the more risk you are passing on to the doers and owners downstream.

MR. LONGRIDGE: That's great. How does the regulatory body qualify the device in the absence of qualifications?

MR. IRVING: Because three axis and six axis doesn't help to qualify the device. The subjective tests are really the arbiter in our view.

MR. LONGRIDGE: The six.

MR. IRVING: The six. I remember sitting there being told you can't have at Level C, why not, it can't move forward and backwards, it only has five, not six. Ridiculous observation. Well, make it move back and forward. I think it has to be left subjective. I think we are bright enough to define collectively how good or bad motion must be when it's totally integrated with the training device, simulator.

MR. BAKER: I think the danger of doing that is you get quite a variety of reactions from pilots. One guy will say "well, I can't fly this thing in this particular maneuver because the cues are missing." And another guy will do it just fine, he won't even care. And, you know—

MR. BOOTHE: That's a good point. But you see, Bruce [Baker], I think it's even more serious than that in terms of a recurrent check. Maybe Bob [Foster] can help me out here, but in an airline where you have pilots whose career is at jeopardy when they take a check, and should they fail that check, and that the device is in their opinion insufficient to support the task they failed, there are—that there are means for them to get checks in other devices, even airplanes and all sorts of things. I say you might have to help me out including union policies to save their jobs. So we can't be in a position of specifying something that won't support the task, in fact rather than minimize a specification and have some fears of it not supporting the task I would, as I did, go with Don's [Irving] position of something sufficient for the task. Not knowing what that is. And so we are back where we started from. But we can't afford to specify something that sets a guy up or a woman up for failure. So that's a tough problem. Right?

MR. CARDULLO: If you go through this taxonomy of tasks that you have listed here, if you say which tasks can be done with a three degree of freedom of motion system, the standard I think which is pitch, roll and heave, it's none.

MR. BAKER: That's the cues missing. You have missing cues in every one of those tasks.

MR. CARDULLO: Right. And the only ones, the only maneuvers that include pitch, roll and heave are the ones that include all six. So—

MR. BOOTHE: My guess is—

MR. CARDULLO: So what that says, if you are going to have less than six, presuming this is reasonably accurate and you certainly have as good a sense as any one of us as to what the

dynamics are and what information you need to do the various tasks, what that says is if you are going to do with fewer than six degrees of freedom, you have to design a new three degree of freedom or four degree of freedom motion system.

MR. LONGRIDGE: There is nothing that says we can't do that.

MR. CARDULLO: No. But I'm just making that point.

MR. BAKER: Let me say something about that.

MR. CARDULLO: Is that really cost effective? I think the sense I got was that the people who were favoring the three degree of freedom were favoring from the standpoint something already exists, and we can work with what already exists. That may not have been your point of view but I think it was Bob's and Bob's [Foster and Heffley].

MR. BOOTHE: No, I think that's not the case.

MR. CARDULLO: Is that not the case?

MR. BOOTHE: We think there are four important degrees of freedom that will support this task. I think we ought to say what they are.

MR. CARDULLO: Oh, yes.

MR. BOOTHE: And then, as Don [Irving] so aptly points out, it's the industry's problem to figure out how to get them.

MR. BAKER: Let me make a comment about making motion platforms that have less than six axes and other than roll, pitch and yaw. Roll, pitch and heave I mean. Roll, pitch and heave are probably the three easiest to get and it's easiest to constrain x, y and yaw. All right? There have been motion platforms built in the entertainment industry that I'm aware of that do x, y and z. And there is a lot of iron in there to keep the thing from doing roll, pitch and yaw when you don't want it to. And I think for most of those configurations, with the possible exception of one that I mentioned that did roll, pitch and yaw, it's probably true that you are not going to save a lot of money by taking degrees of freedom out. Because the constraint mechanism gets to be very, very hard to build. And believe me, we have looked at a lot of different situations where guys have asked funny questions about two axis or three axis, like an x, y motion platform. It's a hard thing to build, okay? Compared to pitch and roll. Pitch and roll is very easy to build.

So I think that if we are going to constrain—if we are going to allow or constrain the thing to three degrees of freedom we better have a reasonably good idea of how we are going to—what three degrees of freedom we are going to use and exactly how a guy might build that.

MR. LONGRIDGE: I think there is an improper phrasing, there was never an intent or suggestion to constrain it to three. All you are doing is specifying a minimum requirement. That doesn't preclude people from using six.

MR. BAKER: The guy can go beyond the requirement, yes.

MR. FOSTER: One thing I would like to say, I don't think you can judge a three axis motion system that would be built today with the experience that most of us have had with three axis motion systems that were built in the late '60s, early '70s. I think if we were to allow, still allow use of the three axis level motion for the Level B, there has to be performance specifications, serious ones about turn-around bumps, smoothness and that kind of thing. I don't think you would find a lot of comparison about the pilot sensed end performance in a hydrostatic three axis motion system that had some serious analysis done of proper drive algorithms to it. If you remember, most of those were attached to PDP-11s and GP-4s, the motion drives in them were so simple, it's hard to believe. There is no compensation for hardly anything. And the servo valves were very bad on them by today's standards. If somebody was to start from scratch to build a three axis system with roll, pitch, heave and had minimum performance specifications to meet, I

think you would end up with a much different three axis motion system than what people were used to in the old 727, DC-9 and that kind of thing.

MR. CARDULLO: It would still be missing degrees of freedom.

MR. FOSTER: But I think it would take a lot more advantage of the ones that are there. Most of the three axis systems out there now are so toned down, a lot of them have a frequency range of one cycle every two hours, you turn it on, it goes up, two hours later you turn it off and it comes down. And it wiggles.

MR. CARDULLO: That's true of some of the old six, too.

MR. FOSTER: We have to tie some performance specifications to it. Particularly, the friction on those cylinders was so high, and so variable depending on, you know, whether it was first thing in the morning or you overhauled the o-rings, the seals last week or last month. So consequently they were all severely detuned and in fact most of the time people turned on servo—

MR. CARDULLO: I think what we are talking is equivalent servo performance and actuator design and all of that whether it's three or six degrees of freedom, the question that's germane is can you get away without some of these degrees of freedom?

MR. FOSTER: And I think—

MR. CARDULLO: And which ones?

MR. FOSTER: Right. What drives that for me as a user is the overall size of the device. I wouldn't probably have—if there wasn't a lot of economic or cost difference between the three axis and a six axis and it fit in the same envelope, and I could put it in the same building.

MR. CARDULLO: You could do that.

MR. FOSTER: Nobody has proposed it and I haven't seen any. Nobody proposed it when we looked at some of the regional people trying to go for—to try in the last few years trying to set up regional carriers with it. Maybe somebody can do that. But the problem you get into is the life cycle cost of the simulator. If you now all of a sudden have to go to something with a 32-foot ceiling or a 24-foot ceiling instead of a 19-foot ceiling, it's a huge difference in initial cost which you have got to fund out over ten, 15 years, and it becomes a prohibitive cost rather than possible.

MR. CARDULLO: I agree.

MR. STOCKING: I was going to say there is a fellow in Binghamton that makes a good three degree system. It's about the same size and stroke as the old ones. He still ends up with cues subdued, part of the reason is you are not getting all the cues. They have to subdue the cues, you do have to hide or mask the false cues. So you still end up with the same problem.

MR. HEFFLEY: Well, so, you know, it's sounding more appealing to me to focus on the cues that you want as opposed to how you get them. And the idea here that, I think Don [Irving] was really right on, you lay out the task, you lay out the relevant cuing, and whether that cuing comes as a result of a direct axis of actual motion or whether maybe it's substituted very cleverly by something in your seat, if in the end it does the job, that's what you want. And it's kind of like the problem over the years that airplane designers had versus the people who were specifying airplane designs, you know? In the end you really wanted to lay out what you wanted the airplane to do, then you let the designer do it and do it to design the aircraft, to do this job in whatever way really made sense. And you didn't say “well, we have got to have spoilers and flaps and all kinds of augmentation systems,” you do what's required to get the end result. So you lay out what you want first.

MR. BOOTHE: If you are lucky you get a P-51. So seriously, that's the kind of thing I think you are talking about. I think we have got a set of directions for tomorrow and I appreciate Bob [Heffley] bringing to the day a bit of humor near the end on a one cycle system. But I think we have done lots of discussing of what we know about motion systems or what we don't know

about motion systems, as the case may be. I would like to leave here tomorrow, though, with something tangible that we can use to pose to the FAA to propose to regional airlines and I don't know whether at this point it should go through this table and try to forget what I have written here, just look at the task and say what are the minimum degrees of freedom or whether we should abandon the table and do what Bob [Heffley] has said and look at these tasks and say what are the cues you need? And is there a big difference?

MR. HEFFLEY: I don't think there is any difference, that's what I was thinking.

MR. CARDULLO: The table has the cues.

MR. HEFFLEY: It has the cues.

MR. BOOTHE: So is that a direction for tomorrow morning, to go to the table and minimize those cues to get a minimum system to serve our purpose, and not be concerned about whether it's a six degree of freedom system or whether it's a four degree of freedom system? Let's just look at the task and try to minimize the requirement. Is that a possibility for a starting point tomorrow? I can't think of another direction to go.

MR. WILLMOTT: I was going to say if you have one maneuver in there that required all six degrees of freedom, then why do you go to the rest of them?

MR. BOOTHE: I don't know which one that is.

MR. HEFFLEY: You might think of other ways.

MR. BOOTHE: Maybe we can start with what we think are the more complex ones and work our way down to the less complex. That might be a good approach.

MR. CARDULLO: Maybe we could give everybody a homework assignment tonight to go through the list and check off the degrees of freedom that you think you need for each of these maneuvers. And see how that comes out tomorrow. It won't take very long for each of us to do that this evening. And then we come prepared with that tomorrow morning and I think everyone will have a good idea of what they think they can eliminate, which degree of freedom they think they can eliminate.

MR. BOOTHE: I would be delighted if you would take that assignment. So we can proceed in that direction in the morning. For the rest of today, there is, what little bit is left, there is the cash bar that was supposed, does begin at 6:00. And—

MR. LONGRIDGE: That's in the grand ballroom number three right through the double doors.

MR. BOOTHE: And dinner will also be there at 7:00.

MR. LONGRIDGE: Yes.

MR. BOOTHE: So hope to see you all there. We will start here again in the morning at 8:00 for the continental breakfast. Thank you for today. It was interesting and I look forward to tomorrow.

**Transcript of the
Joint FAA/Industry Symposium
on
Level B Airplane Simulator
Motion Requirements**

Part 6 of 9

Transcript of Day 2

**Washington Dulles Airport Hilton
June 19 - 20, 1996**

Transcript of Day 2

MR. BOOTHE: Good morning. I hope everybody had a restful evening. Secondly, as Frank [Cardullo] reminded me, I hope you did your homework. Frank [Cardullo] did his.

MR. CARDULLO: I wouldn't dare not.

MR. BOOTHE: Yesterday as we wound up we made some plans for today and part of that included the homework and I think we had more or less already said that we were going to look at the takeoff and landing where we think the most critical tasks would occur. But in order to really narrow our direction, I think Tom [Longridge] has had some thoughts about whether we could set a more defined objective; and rather than trying to relay that, I'm going to ask Tom [Longridge] if he could give us his need again and express that so that we can work towards that objective today and see if we can come up with some positive results in that direction. So, Tom?

MR. LONGRIDGE: Okay, thanks, Ed [Boothe]. First of all, I agree we should proceed to look at the motion requirements, map those against a certain subset of what we consider to be critical takeoff and landing tasks. We should continue to do that. My big fear is that at the end of the day we will not have defined a direction that will enable the FAA to achieve its cost objectives and we really are under the gun to do this, so this meeting that we are having is not simply an academic exercise, we are going to have to make some decisions. And those decisions will be targeted at doing something that will increase the accessibility of full flight simulators Level B for the community that I described yesterday.

I certainly enjoyed yesterday's discussion, it sheds a lot of light on why maybe we don't have motion standards to the level of specificity that we would all like to have today, because I think we could continue to talk about these issues for several more days.

One of the critical things that came out of yesterday's discussion in my mind was, well, with regard to critical design parameters, three DOF versus six DOF. It's my perception that the consensus is, if we really want to achieve a significant cost savings for motion platforms, what we ought to do is talk about how we could perhaps come up with a redesign for a six DOF system that is substantially cheaper. That is to say, we could come up with a six DOF system that provides what this group would consider to be the essential motion cues and reduce costs by perhaps reducing the mass on the platform, coming up with ideas on how to do that.

The suggestion has been made that perhaps if we get it small enough and get the weight off the platform, we could actually enable the use of electrics rather than hydraulics and achieve a very significant savings thereby.

What I think I'd like to suggest we do is focus on the notion of a six DOF system in terms of the critical design characteristics that were listed yesterday and get suggestions on how we might proceed to specify the performance characteristics of such a redesigned six DOF system. Particularly in view of the performance characteristics that we feel are essential for the critical takeoff and landing tasks.

Anybody have any thoughts on that?

MR. SMITH: I'd like to comment on that because I've had some discussions with some of the guys and basically I think that's the right direction. But I think inherently the cabin of these regionals is smaller than [of] the large aircraft. By design it's going to be smaller. If you go with innovative designs and material, maybe not just use aircraft parts for the cabin structure and everything, then you are going to wind up with a much lighter weight.

MR. LONGRIDGE: Yes.

MR. ADVANI: As I pointed out yesterday, a major contributor of the inertia is the displaced system, a general rule of thumb for smaller commuter type aircraft where the pilot head position is

quite close together, is that you can get away with, say, a nine-foot displaced system that's one indicator but the whole vision system can be smaller if you choose to go that way.

MR. BAKER: You are talking about if you use a dome as opposed to a collimated image?

MR. ADVANI: Beg your pardon?

MR. BAKER: Talking about using a dome as opposed to a collimated [image].

MR. ADVANI: A wide angle collimated [image]?

MR. BAKER: One of the things I think we need to keep in mind, that's not a requirement for this level of simulator. That the requirement for the visual display on this simulator, unless I'm messed up, is relatively simple.

MR. BOOTHE: That's a good point.

MR. LONGRIDGE: That is a good point. But on the other hand, the requirement for this level of simulator at the present time also is three DOF. And here we are talking about six DOF. I personally—the objective is cost. And balanced against effectiveness. It may very well be that because the cost of these visual image generation and display hardware items have come down, that we could also specify a wider field of view. In fact a wider field of view may very well serve our purposes.

MR. BOOTHE: That's exactly what I was going to follow up with. Before a group like this could, I think, be serious about, like he said, design parameters for a motion system, I think they need to know what are going to be the other simulator requirements. If indeed we were going to say that a Level B need have only the current 30 by 45 degree system, then that makes quite a difference to one of our critical parameters, namely mass properties. Well, I think the others would be secondary.

So if we have a notion that we may decide that a wider field of view is going to be necessary, we need to make that known. Because that will make a difference to whether, for example, we could use a hydraulic powered system or possibly an electric powered system simply because of the mass that those systems are capable of handling. So I guess it's the typical design trade-off problem.

MR. BAKER: We are really at this point kind of run up against system design problems, when we try to constrain this to a motion based problem, but we just discovered it's not really just a motion based problem.

MR. BOOTHE: I think we would have to make some design assumptions about the rest of the system before we could really pin down or stick strictly to motion. I think we have to do that.

MR. LONGRIDGE: I think it's reasonable to make a design assumption that we are going to have a wider field of view than the minimally required display system for a Level B. But I don't think it's necessary for us to come to a decision today what the size of the field of vision might be.

MR. BOOTHE: I think to at least know we are discussing the possibility of a larger system, which may introduce the possibility of more mass, I don't think we could accept a dome because I think most of us believe that the separation of the pilots is great enough that we need a virtual image rather than a real image. So that leaves us with some possible comments up there, I think.

MR. LONGRIDGE: We could leave that open because Level B right now does not require a virtual image. That's not a specification, it's a functional specification, not a hardware specification. It may be wise to leave it that way and let industry employ its ingenuity to come up with ways of meeting that functional spec.

MR. BAKER: Well, let me say one thing about that, Tom [Longridge], for just a minute.

One of the things that's going to drive these poor system designers crazy is that they have got more technology than they are sort of allowed to use. You know, if we can't in some way

constrain the problem, then they are not going to know when to quit, I mean clearly a large collimated display is better than two CRTs stuck in the window, there is no question about that from a performance standpoint, from a training standpoint, I don't think anybody would argue with that.

But from a cost standpoint two CRTs stuck in the window is a lot cheaper than a large collimated display. It's also got a lower operating cost because the projectors are in some way a little bit of a challenge to keep running all the time. They don't run nearly as long as a CRT. I'm not suggesting that we back off from perhaps changing the requirement to a large collimated display or some other display that has a much wider field of view, but it's going to be hard to—well, first of all, the other comment is that's a very large cost driver, two collimated displays in front of two pilots are relatively expensive, it drives the motion based requirements and it drives the room requirements and all sorts of things. So maybe we need to come to grips with that problem first.

MR. LONGRIDGE: It would be a good idea to do that if we could, but I don't think it's feasible. I would say that, you know, we are having, our strategy is to have a series of these meetings. This is the second one and the next planned meeting will address the visual display and image generation considerations.

So all we can do today is make some general assumptions and perhaps those need to focus on what would be the maximum mass of whatever system is up there that could be tolerated in view of the alternative design that we are talking about for a six DOF system.

MR. BOOTHE: I think to follow up on Bruce's [Baker] comments a bit, the person designing the simulator of course is designing with the objective of getting it qualified for use by a carrier, otherwise they don't have a customer. And it's up to them to work out these trade-offs. If we were to say we have identified some tasks which we think are critical, we think those require this many degrees of freedom, we think those require a certain amount of cuing capability, however we would describe that. Then I think that would serve our purpose and then if the designer decides he wants an extremely large visual system that has massive projectors and other equipment, I think it's then up to the design company—the simulator company and the customer to work those things out and still meet standards that are put forth.

So I know those are all considerations in design of the system, but I think we need to direct our attention to what's the end product in terms of certifying pilots, and if we say it's three, four, five, six degrees of freedom, then we need to write that down. If we say we need a sway acceleration capability of x feet per second squared or centimeters per second squared—

MR. BAKER: Feet per second squared.

MR. BOOTHE: —then if that's possible for us to do, I think that's the only way I would know how to approach this task.

So I'm looking, I think Tom [Longridge], too, on your input there, and I don't know if the homework assignment last night heads us in this direction. But I think those are the things that I would like to see us making some decisions about. If we decide that you only need, let's say we did think you needed a six degree of freedom system but you only needed a plus or minus six-inch stroke, and Thomson comes along and says "yes, but I want to put this huge system on it." Then it's their problem. I prefer to leave it that way. Because I think they would prefer to leave it that way.

MR. HARRIS: I always tend towards not the technology we can use, but the price the customer is capable of paying. The customer wants a certain type of simulator, goes out in the market, what does it cost?

MR. BAKER: Let me ask you a question at this point. Would it be helpful if we could get one of the guys from the major builder companies to put up on the paper over there the cost drivers, the big cost drivers for the system and about what they cost? There are some cost drivers in there—

MR. LONGRIDGE: Didn't we do that yesterday?

MR. BAKER: That's for the motion platform. I'm talking about the whole system. So we can put this problem in perspective in terms—is that useful at all? I'm appalled, for example, what an EFIS system costs.

MR. BOOTHE: I don't know if they want to write down their costs.

MR. LONGRIDGE: We could do percentage, relative percentage of total cost of system, we could do that.

MR. BAKER: I don't think the hardware costs are too big a secret. If you go to Collins and want to buy an EFIS system—

MR. BOOTHE: There are some things happening in that arena. Maybe Don [Irving] can help us a bit, but I keep hearing numbers quoted that aircraft parts are 40 to 50 percent of the total simulator costs. And the latest figure having been 40 percent, and the reason for that is because avionics costs are high and because vendors of the avionics will not support software emulation of their equipment and won't release the data. I think—and there are some changes coming in that area. And something is being addressed.

Now whether or not something will actually get done and the software vendors will actually release that data is another question.

Don [Irving], could you—that's a major cost driver, not one we can fix here.

MR. BAKER: The only reason I was bringing it up was to put the motion based cost into perspective. There is some hard costs in there like the cost of the aircraft parts that were—no matter how we slice this thing up, we are not going to have any impact on that. Unless we work probably with the avionics manufacturers.

MR. BOOTHE: That's true. As Tom [Longridge] said, he is having a series of these discussions and perhaps that will be in one. But this one happens to be addressing just motion. I think motion is not a major cost of the overall simulator, except as how when it gets large enough you have to have a 34-foot bay to put it in. It does become expensive.

MR. BLUTEAU: The cost of simulation—there is a trend in replacing expensive avionics by the use of simulated display, simulated panels, there is definitely a trend. And I think that in the coming years we will see dramatic changes in the cost structure of the simulator.

Secondly, CAE hasn't built small devices, we have done cost studies. The only thing is it's a dramatically different approach design-wise. We don't have the exact figures, it may be a difficult task for us to put on paper what the cost breakdown of a potential Level B simulator would be if we designed it. So it may be difficult to assess that right now. Based on similar estimates that have been done in the past, it turned out that the motion system was a significant part of the overall cost. Especially because in those lower level simulators we tend to save on various things, much cheaper visual systems, structure being simplified, flight control being simplified, display systems, everything else.

One thing that was difficult to make cheaper was the motion system. So I still believe it would be a significant contribution to the overall simulator cost if we could simplify the motion system requirements.

MR. BOOTHE: Do you have an idea of percentage of total simulator cost that would be attributed to the motion system?

MR. BLUTEAU: It varies. I would hate to quote any numbers. Especially because I suspect in the case of a Level B simulator a brand new design would probably be used, so you have that—whatever number I can mention here would probably turn out to be inaccurate.

MR. BOOTHE: I don't mean a raw number but some approximate percentage of the total cost, is it 20 percent or ten percent or 50 percent?

MR. BLUTEAU: I would say in excess of 20 percent.

MR. BOOTHE: Excess of 20 percent. Do you have any comment on that, Geoff [Harris]?

MR. HARRIS: I don't have the figures for small simulators. But for the full flight systems it's way down below that. The small simulators you have a different approach, build different fidelity, individual controls, presumably different instructor stations as well. If all these other factors are coming down in price, then the motion system percentage rises accordingly. It depends a lot on what you compare it against. For a full flight simulator, very small percentage. The smaller system, the price of the motion remains the same.

MR. BOOTHE: For a full Level C or D sim are we talking about five percent, ten percent, fifteen?

MR. HARRIS: I guess between five and ten percent.

MR. BOOTHE: Does that sort of put it in some perspective?

MR. BAKER: Yes. I would certainly agree that as you start to make the rest of the simulator cheaper, if you stick with the traditional six axis 60 inch stroke motion platform, it starts to become a very large percentage of the total cost. If you are trying to get this whole thing down to five million or six million dollars, then have a one million dollar piece of equipment in there, which is somewhere around the right number for the motion platform, is a little absurd.

You don't think it's that much? You think it's more than that?

MR. HARRIS: I think it's less than that.

MR. BAKER: Well, you can buy from McFadden a machine for about 650 thousand dollars. But that's the box of parts. So I was going to include some of the costs of installation and the problem of site, that sort of thing, in the cost.

MR. BOOTHE: Frank [Cardullo]?

MR. CARDULLO: Perhaps a useful estimate to make here is if we reduce the six degrees of freedom, considering the standard hexapod type configuration. But reduce the stroke to on the order of 30 to 36 inches; what impact would that have on cost? Would it cut costs in half or would it cut them more or less? Does anybody have a sense? What is the opinion of you folks that build them.

MR. BOOTHE: I found out that's already been done in some cases that we weren't really aware of because we didn't have any motion standard other than to say you needed six degrees of freedom, people did go to 36-inch systems and we found out after the fact, so I guess the answer is there is no cost impact at this point of going to a 36-inch system because people have already done it. Of course that's a cheaper system than if somebody puts on a 60-inch system. I don't know that differential.

MR. REID: I know what it was 12 years ago. When we bought our three-foot system, it was two-thirds of the price of the 60-inch system. So it wasn't half.

MR. BOOTHE: Six foot or 72-inch system?

MR. REID: Yes. That was 1983, '84. The price costing may have changed since then, it wasn't half.

MR. BOOTHE: So here is one of our SMEs with experience with a 36-inch system.

MR. REID: Yes, we have a 36-inch system.

MR. BOOTHE: Maybe that helps us in deciding whether—what your experience has been with the 36-inch system and whether or not a little bit less would work.

MR. REID: Well, I guess, first of all, we don't train people in it, we use it as a research tool. We have looked at how much degradation we have over a larger system. In particular we have looked at cue duration, acceleration cue duration effects and this sort of thing. And we came to the conclusion that to make a significant improvement in the cues that we were getting for the kind of work that we were doing we would have to go to a large six-foot system because stroke requirement to increase the acceleration cue duration tends to go as Phase squared, with t as length of time duration, and t is so small anyhow you are talking about small absolute number changes, maybe large percentage changes, but small absolute changes.

So we have been using our system really as what we have been saying all along, namely as an onset cue device. And we are under the impression that to make really significant advances in say reducing false lateral cues during turn entry and this sort of thing, you have to get things almost bigger than the VMS to make a real impact.

So we backed off, I guess I didn't have a choice since we are stuck with our particular system, we were fairly happy with the way it's working. And we have had a number of airline personnel through our system who are used to using the full six-foot stroke systems. And we get very favorable responses. We asked them for objective comparison data when they fly our system, both with other simulators they fly normally in their training and the aircraft they fly. And we haven't seen any really big complaints relative to other training simulators with larger strokes. However, we don't do the full gamut of maneuvers that you have been doing here. So we are very restricted.

MR. BOOTHE: What sort of maneuvers were you doing?

MR. REID: Normal takeoff and landings, climb, descent, flight through turbulence, flight through wind shear, what else did we do, Sunjoo [Advani]? Did I miss anything?

MR. ADVANI: Side-step maneuvers, you should mention, usually for a large transport.

MR. REID: Yes. All that experience I'm talking about was basically 747. That's pertinent to this. A lot of our recent work has been on helicopters, so it doesn't really relate too much to regional aircraft.

MR. ADVANI: What about the difference between the washout algorithms which you were comparing, was it similar in both cases?

MR. REID: You never know.

MR. ADVANI: What you did versus what the pilots were used to in their training environments.

MR. REID: We don't know what the algorithms are. I can guess what they are on the training simulators, and I think they are using classical washout.

MR. ADVANI: I think so, too.

MR. REID: We used classical washout during a lot of these trials, too.

MR. BOOTHE: That's interesting. There are people with in-service training simulators, as we call them, that do use or have used 36-inch systems. I don't know that I have ever found one less than that. But if I could put you on the spot.

MR. REID: Just one point. It's a 19-foot ceiling we are working in.

MR. BOOTHE: That's important.

But if the FAA were to say "all right, we have looked at these tasks, we understand the history," and Bob [Foster] has been clear about that. There has been these older systems that have worked but I'm not sure they are really doing anything. As you said yesterday, one cycle per

period or something. If the FAA were to say “okay, we are going to look at a six degree of freedom system for Level B, and we are going to say it must have a minimum stroke of plus or minus 12 inches,” which would be a 24-inch system, what, in your opinion, would that give us in terms of onset cues that we think are important for critical maneuvers that we really haven’t talked about yet but we know are there? Do you think it would be a significant reduction from what you have experienced with a 36-inch system?

MR. REID: It would be a reduction. You can’t say there won’t be.

MR. BOOTHE: Well, I agree.

MR. REID: But I think we get the onset cue all right. It would be reduced in duration. And we would have a harder time reducing any false cuing that’s being generated in the simulator. They make it harder for us to tune the simulator to get the same subjective pilot assessment of the motion quality. We might get around that by reducing the scale factor overall. We tend to run at a scale factor of 0.5, if we can. We might have to back off on that to something lower. Someone yesterday was saying they were using 0.2.

MR. BAKER: Point two we used on a high performance.

MR. REID: So you can obviously get away with lower than 0.5. Point five has never been an official number although it’s been used a lot.

MR. BOOTHE: Suppose we don’t say anything about the stroke? I, in fact, have suggested this and been shot down before. So it’s a familiar position.

MR. BAKER: I think that you may have to require—I’d hate to see this argument go to its logical conclusion, which is you only need a half inch.

MR. BOOTHE: That’s right. You get down to vibration.

MR. BAKER: You can certainly say “well, gee, if 36 is good enough, it was only a small reduction from 60, then 24 is probably okay, too. Then maybe 18, then 12.”

MR. REID: There is a logical place to stop as you go down. You get to the level of cue you can provide which is below what are called the threshold levels, not really a threshold but down in the region you can’t sense it.

MR. LONGRIDGE: We have people proposing 12 and 18 inches right now. I think your point is well taken.

MR. BAKER: I think someone is building one with 24. They can’t get anything bigger in the trailer they want to put it in.

MR. RAY: There’s been a number of efforts done like that before. Well, selection of the motion base was not done analytically. It was based on what room was available. Can it fit in a room?

MR. BOOTHE: That’s because all you say is you have to have a motion system with six DOF.

MR. LONGRIDGE: Maybe we need to specify the minimally required for FAA purposes.

MR. BAKER: The other thing is historically the requirements for motion platforms have been based on essentially what you can do. Lloyd’s [Reid] comment really says what you would like to have is something with about 600 feet of travel, okay? Seriously. That’s what you would really like to have.

MR. BOOTHE: Sunjoo [Advani] is burning.

MR. ADVANI: Sorry. What it comes down to is how much false cuing are we willing to accept?

MR. BAKER: There is a trade-off in false cuing, it says if I reduce the stroke of the motion platform, I can accommodate that two ways. One is I can reduce the gain. Or I can increase the

washout rate or increase the—move the pole for the washout, the zero for the washout, however you want to look at it, up higher in frequency so it washes out faster. And I wish we had a lot of data on the effects of doing that, but I don't think we do. I know I don't have any. I always set mine at one a second. That's a good number. Nobody whined.

MR. BOOTHE: Let me ask a different question. Suppose we were to not say anything about the stroke and say you need to provide accelerations in each of these degrees of freedom for t duration? Is that something that we could do? I mean, is anybody willing to put a number on paper?

MR. CARDULLO: I was going to suggest just that. I think you are better off trying to specify cue duration than to specify stroke length. Because we would be guessing at stroke length. To a certain extent we are going to guess at cue duration. I think we have a better idea of cue magnitude and cue duration, from that you can derive stroke length.

MR. LONGRIDGE: You are going to have to specify the tasks for these.

MR. BAKER: If he specifies the magnitude of acceleration at a time, you can calculate the displacement.

MR. REID: Right.

MR. BAKER: And—

MR. CARDULLO: So from that you could infer displacement. But—you might say “well, why not just define displacement?” But my view is that if the simulator motion system designer has some creative way of providing the cue and the washout, you enable him to do that by this functional specification as opposed to a performance specification.

MR. BOOTHE: Excuse me, I have two down here. But what you also do when you specify stroke is almost lock a design in, and we don't want to do that. Because that—some innovative person might come along and have a completely new and better idea and we would be ruling that out if we specify stroke.

MR. CARDULLO: The other way, just a brief comment, the other way is specifying excursion by degree of freedom as opposed to stroke length. The least desirable is to specify stroke length. The next best would be excursion per degree of freedom. I think a functional specification on cue magnitude and duration is best.

MR. BOOTHE: Bob [Heffley] had a comment.

MR. HEFFLEY: Yes. If we come up with a number for cue duration—yes, for cue duration, we better have a pretty good basis for it, because you know if we say arbitrarily one second cue duration then that could maybe mean a horrendous stroke.

MR. CARDULLO: Oh, yes.

MR. HEFFLEY: That's the sort of thing you really need to think about and do some real analysis on before you come up with a number. In fact, probably it's safer at this point if you want to walk out of here today with a number, let's just say 36-inch stroke or actually, you know, go right—that's at least safer, that at least bounds it to something that's a reasonable cost. Cue duration might wind up costing far too much.

MR. BAKER: Let me comment about that also. When Ed [Martin] talked about his experiment yesterday with that roll machine, and he found that the guys could do the tasks equally well with a large cue or a small cue, but when he took the guys that trained on the small cue and put them in the large cue machine, the training didn't transfer 100 percent. I think that comes from the fact they had the gain in their controller set wrong. They get a little bump in the large amplitude machine and they would over-react to it. The same thing can happen in a simulator if you start to reduce the gain too far on the motion cues, the guy will learn to fly the simulator but the training won't transfer directly. I think in the case of a simulator like this for this application where it's a recurrent qualification simulator rather than training raw recruits, that's not as big a hazard,

because I believe—I mean, I’m way out on a limb now, but I really believe that the pilots will very quickly accommodate the change in gain in motion cues in a simulator and equally quickly accommodate when they go back in the real airplane.

MR. ADVANI: But still in recurrent training you are going to go through maneuvers you normally wouldn’t encounter, so you are doing training.

MR. BAKER: That’s true. That’s the argument that says we ought to go to 100 percent gain all the time.

MR. ADVANI: I’m not saying that.

MR. BAKER: But, you know, we are kind of stuck in a lot of cases without being able to do 100 percent gain no matter what size motion platform you are talking about.

MR. STOCKING: I work almost exclusively with a 60-inch system and our entire motivation for the last 20 years has been trying to optimize the cue envelope, to use as much of it as possible for any particular cuing. And there is a bottom limit when you are performing any maneuver that is acceptable to the pilot. When you drop below that level, you are producing a cue to the pilot that tells him to adapt to the machine that he is flying. It is no longer transferable to the aircraft.

And my opinion on this on the three degree system, is that you are supplying to the pilot a system that helps him learn to fly the simulator. Not the aircraft. It’s not transferable.

I tend to look at different cue envelopes. When we start reducing the size of the envelope, we are going to come up with some boundary where we are no longer successfully performing that task. And to say that we are transferring that to the aircraft, I think is subjective. Very subjective. I just don’t believe that anything less than a six DOF of a certain magnitude is going to accomplish that task.

MR. MARTIN: I think basically that this is what I was finding with that dynamic seat study.

MR. BAKER: If you went down to a two-inch stroke, for example, like our old motion seat, I think all we are going to get is—we are certainly not going to get the cues of the caliber and the accuracy that you get with 60 inch stroke with a two-inch stroke, you can’t do it. I think what we are going to get is a situation where the pilots like it as an improvement over no motion at all.

MR. STOCKING: Right. You are helping him learn to fly the device. For that particular part there won’t be a transfer of training to the aircraft.

MR. BAKER: Our objective on this one really is recurrent training of qualified Apache pilots. We are not trying to teach him how to fly the bird. We are trying to help him fly the simulator better than he can do with no motion at all. I’m still skeptical we are going to be able to do as well as we think with that small a platform.

MR. BOOTHE: That’s not the issue for us. Our issue is we bring a pilot out of revenue service, we are going to relicense him, we are going to relicense him to go back into revenue service. We are asking the pilot to demonstrate in this device the behavior that we expect to be able to observe in the airplane. And that’s really, as best as I can describe it, our objective. And if it’s not possible, then we need to say that. But we are doing something like that, at least we are assuming we are accomplishing that, you know, maybe airplane accidents are very much at a low level because of other reasons. I’d like to think some of it is because of good training. But we don’t want to—we don’t want to relicense a guy to fly the simulator, we want to relicense him to fly the airplane. That’s the cues we need to try to provide while at the same time trying to get the cost down to something that smaller carriers can play with. Frank [Cardullo]?

MR. CARDULLO: I think we should refrain from talking about transfer of training because all we know about transfer of training concretely is that there may be none, from a motion system. We have no real basis to say that any motion cues transfer. We all have opinions about it, but all the experiments that have been done, or a very large percentage of the experiments that have been

done say there is none. And albeit that most of those experiments were done on inferior motion systems for one reason or another. The data is really inconclusive. However, we have no proof to the contrary.

So I think we should say nothing about transfer, and since we don't have that, what we have got is that feel that because of intuition and other things that we need a motion system, we should base our sizing or specification on our best engineering analysis of the problem.

And what I think that comes down to is, since you can't provide a full motion cue in a simulator, you have got to provide enough of a cue to advance thevection that you get from the visual system. Since thevection research shows that as long as you don't do anything wrong with the motion, that even a very short duration onset cue provides an advancement of the induction ofvection. So now I don't think we can risk taking that to the extreme of just providing a jolt because there is a little bit of research on jolt simulation that jolts just don't seem to work, but nevertheless, I think we can look at things like cue duration.

There are several of us here who have software that could go and say "well, for these—this particular set of maneuvers, what kind of cue duration would you be able to get out of a 30-inch stroke, 24-inch stroke, et cetera?" And you could come up with some bounds analytically by doing something like that relatively quickly. Do you agree?

MR. REID: Yes. The tricky part would be to correlate those numbers with what a human is going to experience. Right? If you wanted to say what percent of the time is a human going to detect some of the lower values, you would have to make some extrapolations on the literature or do some investigative project.

MR. CARDULLO: I think what we know is we need to produce a cue for a couple tenths to three tenths of a second in order to advance the induction ofvection.

MR. BAKER: What's the trade-off on cue duration versus cue level? I can trade those two off and I don't have any experience with that at all.

MR. CARDULLO: Well, cue level largely is determined by, I think, the range. By the maximum. You were talking about a fighter, you set it at about—

MR. BAKER: Two-tenths.

MR. CARDULLO: —two-tenths. With transport you are setting it at five-tenths. The reason for that if you set it higher because of the dynamics of the airplane—

MR. BAKER: You run out of stroke.

MR. CARDULLO: —you run out of stroke. That's really set by the dynamics.

MR. BAKER: But see, I could have changed the washout, I could have washed it out faster and I could have also solved the stroke problem that way. I had the washout set at one radian a second. So I never changed it. I never went and—we weren't chartered to run the experiment that says suppose I change the washout to two radians a second. What happens to the false cues? I did query the pilots about false cues and they said well, the only way they could notice them is if they concentrated on looking for them. If they concentrated on their task, which was a high level task, they never noticed the false cues from the motion platform. We don't have a charter to mess with it, we were building avionics equipment.

MR. STOCKING: I wanted to say I didn't disagree with Frank's [Cardullo] premise about transfer of training to the aircraft. But I have been able to observe how quickly a pilot adapts to the simulator. And in my way of thinking that's where we should concentrate. If we are talking about the number of degrees of freedom or the size of the envelope or anything else, that's within the capability of a six DOF system to program it so it restricts its cue to a smaller and smaller envelope. As a matter of fact, it's going to be fairly easy to do. And you can determine subjectively just from

taking line pilots into the simulator and observing how quickly they adapt to the simulator, you can determine the quality of that cue.

MR. LONGRIDGE: Yes.

MR. BAKER: I would think so.

MR. CARDULLO: I don't completely understand what you mean by adapting to the simulator.

MR. LONGRIDGE: Backward transfer. So you take somebody that's totally adapted to the aircraft, put him in the simulator and measure the performance in the simulator.

MR. CARDULLO: Until he comes to asymptote in the simulator.

MR. LONGRIDGE: That's a pretty good technique, actually.

MR. STOCKING: Everything we are talking about at this level is just that.

MR. CARDULLO: You could do that in a simulator that has 72-inch or 60-inch stroke, then just gradually reduce it, and that's not a difficult experiment to do.

MR. STOCKING: And the same thing with eliminating degrees of freedom. If you want to find out what the minimum degree of freedom set is to give the pilot an alerting cue and what would be the best situation, you could do the same thing in a six DOF system.

MR. CARDULLO: That would take longer.

MR. ADVANI: You could also have temporal fidelity in that sense.

MR. BOOTHE: I'm just—let me ask Geoff [Harris], go ahead.

MR. HARRIS: Considering the cost of small short stroke actuators, to achieve the same angulation, the same rotational displacements with a smaller actuator, you move the motion feet in on the floor and the pads in on the structure. Obviously you get less translation of cues. If the simulator adopts, what's the word, a nose down or extreme attitude, like 30 degrees of the platform, to recover from that displacement you actually need to put a larger force into the actuators, so for a given mass of simulator you suddenly need larger diameter cylinders. That doesn't mean the cylinders cost more, but your hydraulic requirements go up. The apparent savings are not quite as good as they seem.

MR. BAKER: It also depends on the CG height, which is a function of cabin size and how much stuff you put above your cabin. So it's very CG height dependent.

MR. HARRIS: It comes back down to mass properties again.

MR. BAKER: Funny thing about that.

MR. CARDULLO: But you do save in building size, even if you don't save in the cost of motion system you save in building size, which is probably a more significant cost for the operator because he has to air condition and heat that building.

MR. HARRIS: You mean the physical size of the room?

MR. SUSSMAN: Yes, or the number of simulators you can put in a room.

MR. HARRIS: That's true. Invariably these days we put simulators in existing rooms. Very rarely do people build a new room for us.

MR. BOOTHE: Bob [Foster], help me out, I don't know if the regionals have ever gotten that far into their thinking. I think they are hung up on initial cost and I really don't think they have looked at life cycle costs or buildings. It seems to me they are hung up right now on initial costs.

MR. BOOTHE: Well, you have to get past the first step before you can think of the next step in some cases.

MR. FOSTER: Actually we have gone past that with some of the ones we own.

MR. BOOTHE: But excuse me for saying so, but you are different because you have a different experience from some regionals. So for the ones that you are concerned with, but there are others out there who I think have not—

MR. FOSTER: I agree. There are those operators who don't have simulators and don't have a parent company that does, that haven't looked at that, but that was one of the reasons in fact why with what's now Piedmont, which used to be Henson, that USAir group said we want the USAir simulator department to look at providing simulation because they have the expertise. And immediately the question came up from Henson saying we would like to put this simulator in Salisbury, Maryland, but there is no facility there in Salisbury.

When you start looking at the cost of putting them in new buildings, Geoff [Harris], we are looking at new installations here now, not installing necessarily in the—in an older facility. And the cost of new buildings is extremely expensive. And again then you start looking at life cycle costs and how many people it takes to maintain them. Do they have to add staff? How much staff has to be added? What are the spares requirements? All that sort of stuff.

MR. HARRIS: This touched on something I mentioned last night with Hilton [Smith], does it have to be a building? Suppose the simulator is a portable device.

MR. BOOTHE: Suppose it was what?

MR. HARRIS: A portable device.

MR. BOOTHE: That I can't answer.

MR. BAKER: We are looking at one of those right now. I could make a comment about that. It's a B-1900 that TDI is in the process of building. And space requirements in the van restricted to a 24-inch stroke on the motion base, you can't get anything bigger in there.

MR. HARRIS: Right. What about the certification issues?

MR. BAKER: That fortunately is not my problem. We may have to get our controller certified for it but the motion platform is not our piece of equipment. We are not on the hook for that one.

MR. BOOTHE: Let's follow this one more step. Paul [Ray]?

MR. RAY: We have had some discussions with those folks, it's not going to be an easy hurdle to jump.

MR. BAKER: Right.

MR. RAY: Their incorrect assumption is that systems are certified in the classic sense. In fact, they are not. We have to look at that system every time it moves.

MR. BAKER: Every time it moves?

MR. RAY: From one location to another.

MR. BAKER: You want to recertify every time it's moved?

MR. RAY: Because we don't certify simulators. That term is misapplied. Ed [Boothe] has accurately pointed out before, if we certified simulators, nobody could afford them.

MR. BAKER: I think the concern that I would have prior to that one is the concern about is the 24-inch stroke motion platform going to pass muster? Because they have made an assumption that it will, based on the fact that's the biggest one they can get in the truck. And—

MR. RAY: If their truck was smaller would a six-inch system be acceptable?

MR. BAKER: MIL-STD-1558, if you lay it on the desk, and you get the data off a Link 60-inch motion base, it's surprising how close the numbers match. So MIL[-STD-]1558 I think came after the motion base design and not prior to it.

MR. MARTIN: Actually the Link motion base was designed around those numbers.

MR. BAKER: It's awful close.

MR. CARDULLO: There was a back and forth.

MR. BAKER: It's an awful good match. And I'm not saying there is anything wrong with that. But if I were the guy building that sim, my first concern would be will you guys sign off on the thing with a short stroke motion platform considering there doesn't seem to be a whole lot of data in the industry that says it's all right?

MR. BOOTHE: Paul [Ray] and his staff are in the process, once they do that, perhaps that's—the solution to this whole issue of motion may be your decision on that 24-inch system. And that may set the precedent for Level B. Which is to say maybe what we say here could be overridden by what you do on this particular system.

MR. RAY: I hope not. We're not necessarily looking forward to it, either. It points to another issue. The fact is that we don't currently have any substantive Level C or Level D standards which encompass the issue we are talking about here. We simply say a six DOF system.

Is there any disagreement in this room that the drafted international standards for a Level I or II motion system are acceptable? They unfortunately were not incorporated in the final ICAO standards. I don't have a copy with me, but I believe they require—Bob [Foster], you may know better than I—a 60-inch system?

MR. FOSTER: I honestly don't remember.

MR. RAY: Does anybody have any problem with what the international group came up with for [Levels] C and D, and we can set that aside. That should allow us to address Level B more comfortably.

MR. BOOTHE: I haven't seen the international proposals except in a handbook.

MR. RAY: That's the only place I have seen them.

MR. IRVING: They were done after the work was actually formally finished, it was an extra meeting of a motion working subgroup, I'm not sure that the results were fully incorporated in the final document.

MR. RAY: They were not fully incorporated in the international document, correct.

MR. IRVING: It was to try and handle Ralph Lugent's motion critical airplane maneuvers plus some other metrics for the motion system. The idea of specifying the critical maneuvers was thrown out, the metrics were broadly agreed, I think it was fairly conservative, no manufacturer or regulator or operator was prepared to demand high levels of performance, just minimum standards.

MR. RAY: I'm sorry, Don [Irving], I apologize for interrupting. I want to make the comment there has to be an assumption that in order to address Level[s] A and B we must also establish standards for Level[s] C and D.

MR. IRVING: We must resurrect that work. It's a good starting point.

MR. RAY: Back to the issue. I apologize, I had to get that thought out.

A lot of the discussion we are having here has application to Level[s] C and D systems.

MR. IRVING: I think they were minimum standards to protect us from the crazy man, the two-inch six degrees of freedom, I think we didn't expect people to design down to that level, it was just a floor. I think that's all we can do here, whether we get hung up on whether it's 36 or 37 or

38, perhaps we can say it's 36 or equivalent. That puts the ball back in Paul's [Ray] court when it comes to qualification. Somebody could perhaps design a system which is better than somebody's 36-inch, which has 36 inches in one direction and three inches in another direction, I don't know.

MR. BOOTHE: That's exactly what Appendix H says now for [Levels] C and D, it must provide cues equivalent to those provided by a six degrees of freedom system but it doesn't say what six degree of freedom system. Frank [Cardullo]?

MR. CARDULLO: I think in order to come to some kind of closure here, we need to do something. If we refer to Tom's [Longridge] keynote to us yesterday, the sense I got was that what he is looking for is some interim recommendation, both a short-term and maybe a long-term plan. And so in the long-term we could look at some of the potential research that can be done in order to quantify these various parameters. But in the near term, I think we are faced with, at least without interminable discussion about which we have no concrete data, we are faced with either one of two alternatives, either no standards, and having no protection against the crazy man, as you said, or making some reasonable estimate of a floor as was pointed out. And say for the interim, let's go with that floor. And my opinion is, and it would sort of recant something I said earlier, if you put it somewhere around 36 inches you would probably have a reasonable floor. You would have something that you know would not be a disaster. And perhaps it could be optimized a little bit less or maybe a little bit more. But my opinion is we would be in the ballpark. Maybe we could just get a consensus from people.

MR. BAKER: If I may make another comment, and this is the one I made to you on the phone when you called me up about the meeting, and that is can we potentially scale this problem based on aircraft physical parameters, like the size of the aircraft, one is a 747 or 737, the other is a smaller aircraft, and therefore—in some cases you can say “well, if it's a smaller aircraft, then the problem gets easier.” In other cases you say maybe it gets harder. But can we arrive at some set of numbers starting with a 737 or 727 on a 60-inch stroke base and work our way back to a smaller base?

MR. LONGRIDGE: You have to consider the size of the aircraft and the task. We have to go back to critical tasks that we are designing these specifications to as well.

MR. RAY: That's true. Bruce [Baker], we have addressed that with one operator. Their proposal was “an analytical comparison between airplanes and motion base requirements.” They tried to equate the size of the aircraft and takeoff pitch attitude to motion excursion requirements, totally discounting aircraft acceleration characteristics. If you compare aircraft you will find, I suspect, that the acceleration characteristics and potentially the motion requirements for a Beech 1900 or a Lear Jet may be significantly greater than that of a 747-400.

MR. ADVANI: Absolutely.

MR. RAY: Perhaps the characteristics of an aircraft in acceleration could be in that matrix, that being more appropriate than the physical size of a system. As this one individual tried.

MR. BAKER: I'm not suggesting you do it based on tape measure data.

MR. CARDULLO: But I think any attempt in trying to do that here is not possible. I just don't think we have time—

MR. BAKER: We don't have time.

MR. CARDULLO: —in the couple hours remaining to do something like that.

MR. RAY: I agree.

MR. CARDULLO: Whereas I think we could come to some consensus on what the floor should be.

MR. BOOTHE: Could we possibly come to a consensus on an interim cuing floor, if you will, in terms of those parameters we mentioned earlier? Acceleration and duration, rather than stroke,

do some of us know enough to have some numbers that we would—we know we can't support the data maybe, but just like we have done the rest of simulation to this point in time, it's all been expert opinion, there is no data base, that's well-known. The aerodynamics falls into the same realm, it's based on expert opinion. So why can't we base minimal motion cuing on expert opinion as an interim standard to be followed with research to improve that? And of course those simulators that might be qualified to the interim standard would have to have some strong assurances that grandfather is alive and well and not be subject to requalification with new standards.

MR. ADVANI: What do you do if your final standards are quite different from your interim standards?

MR. BOOTHE: That's why grandfather has to be invoked here.

MR. SUSSMAN: You should look at each function, is this a cuing or alerting function, or does this motion provide direct feedback in a control loop that includes the pilot? We could take a crack at this mentally, but it would be better if we subsequently developed a list of motions and then tested to determine whether a given motion was required simply as an alerting cue or was also required as part of a feedback loop.

MR. ADVANI: We have gone through the whole exercise of motion base design. It turns out that stroke is not really the most relevant factor. It's in fact the maximum length and the minimum length, and the ratio of the two is one. The size is one. The size of the upper gimbal circle, the lower gimbal circle, the space between the gimbals in both cases. You see tremendous variations in the maximum angles and lateral displacements for a given stroke, so you have to be very careful.

MR. SUSSMAN: But what the pilot is seeing or feeling is acceleration and duration.

MR. BOOTHE: Go ahead.

MR. ADVANI: But for a reduced stroke you can still have the same angular parameters, but not at the lateral. So my feeling is it should be based on the lateral displacement, if you want to use displacement and not acceleration, and the maximum angle.

MR. BOOTHE: I think what Sunjoo [Advani] told us, if I interpreted him correctly, if you specify stroke, you almost have to specify system design to go with it.

MR. ADVANI: Correct. That's what I'm saying.

MR. SUSSMAN: What I heard is talking about rotational motion stroke doesn't make much difference. You put a different actuator. If you are talking about lateral it does make a difference.

MR. ADVANI: No, what I'm saying is very small changes in design parameters can have a very large effect—

MR. SUSSMAN: That's why like Frank [Cardullo] said, take a straw man, see how it fits.

MR. BOOTHE: Bob [Heffley] had a comment.

MR. HEFFLEY: I think the point here is that, let's take stroke, it's perhaps just too simplistic. Yes, you can sit down here and on the back of an envelope compute accelerations, displacement, durations, but it winds up not being quite that simple. And I think for a given stroke actuator, there are a lot of different ways to come up with a final solution.

And one other point, I think we are really on thin ice if we want to come up with some numbers on something today, it seems to me we ought to come up with some numbers that at least some of us have had a chance to really think about. It's not the time to invent a new parameter here for getting at simulator amplitude or whatever we are talking about. I think that if numbers are to come out of this, they ought to be numbers that are coming from some previous thought. That's why I guess again it's probably safer to be talking in terms of 24-inch, 36-inch, whatever numbers

people have really been accustomed to thinking about here, rather than to try to go off and devise another metric.

MR. BOOTHE: What metric, are you suggesting that we might—

MR. HEFFLEY: Frankly, I guess I've been in recent discussions similar to this and with similar issues being discussed with reference to a 720-inch actuator (the Ames VMS). And so I'm not sure how relevant it is to really pin that down beyond just going back to this idea of just starting to enumerate just exactly what we really want in terms of cuing. I think that's the one thing that probably most of us are most comfortable with, is what are the cuing needs task by task.? It's almost going back to the old list here that you had.

MR. BOOTHE: Maybe we should go to that list.

Frank [Cardullo]? You had a comment?

MR. CARDULLO: I was just going to say that Sunjoo [Advani] is exactly right in what he said. There is no question. If you just specify stroke there are a lot of different configurations that come with a wide range of capabilities.

All I'm saying is that to come up with something within a couple of hours I only think we have two choices, which runs counter to what I said, really, before. In trying to specify cue duration and amplitude and I just don't think we have time to do any of that.

So we have two choices, either just say it's six degrees of freedom with no standards and be unprotected from the so-called crazies, or to come up with some stroke length, which is about the only thing that we could do in a relatively short time, we feel somewhat comfortable with. And that is what drives me to that. I feel uncomfortable with that. And the only reason I'm willing to propose it is we are thinking about it in terms of short-term solution, not a permanent recommendation.

MR. REID: Just a brief addendum. Instead of specifying a stroke, why don't we specify simulator displacement both angular and linear, don't talk about the stroke. You can produce it any way you want. We know a three-foot stroke on a typical hexapod produces plus or minus two feet in this or that direction. Then you aren't nailing them down or creating the problem that Sunjoo [Advani] was describing where a given stroke can produce a whole range of different simulator displacements.

MR. CARDULLO: I would like to be able to do that, I'm not sure we can. I'm having a lot of trouble, I don't have a lot of trouble with angular degrees of freedom but I have a problem—

MR. REID: In the back of your mind when you say three-foot stroke you know the simulators you are used to seeing, typical hexapod setups have plus or minus two feet from a linear degree of freedom from a three-foot actuator.

MR. BAKER: It's actually closer to 40 inches.

MR. REID: Okay. But you know roughly what it is.

MR. BAKER: Sixty-inch stroke size has typically got about 68 inches of stroke on x, y and z.

MR. BOOTHE: But you couldn't take a direct proportion to 36, I don't think it works that way.

MR. BAKER: It can. It just depends on the geometry.

MR. ADVANI: Without unnecessarily complicating the matter, yesterday we talked about the temporal fidelity in phase lag. In fact in the SIMONA simulator our stroke was determined by the natural frequency of the actuators, simply that. That of course determines the total of system fidelity. You shouldn't exclude that. Keep that in mind, please.

MR. BAKER: Let me take Frank's [Cardullo] thoughts and wander off with them just a minute. I suggest that we take a look, see if we can scale the motion base problem somehow and Frank's

[Cardullo] comment was we don't have time to do that. I think I agree with that on a purely analytical basis. Could we take the critical maneuvers, decide what they are in a qualitative way, go through and say "well, I think in the small airplane this is going to get worse, in a small airplane this problem is little better," and at least bound the problem that way?

MR. BOOTHE: Yes, that was the whole purpose here of the table¹ and maybe we ought to do that. Because I want to try to leave here with at least some interim number. I don't think it's possible to leave here with a permanent standard. But because one thing I'm going to leave with is—I'm glad I studied aerodynamics, because it's a lot easier. But I think we need to leave here with at least a recommendation for an interim standard that Tom [Longridge] can use to solve an immediate problem. Understanding that that's to be confirmed or revised by future work. And I don't think it's defined yet how that future work will be accomplished, but certainly there is every intent to do such work. So if we could go to the tables now and look at those critical things or identify what we would say is critical, and maybe we could get something from there.

MR. SUSSMAN: I just had one question. Is it possible when you make the entries in the table to consider the amplitude of the acceleration and the duration for each critical degree of freedom? That will tell you an awful lot about them.

MR. BOOTHE: Well, I don't know, because you notice that I put a_x , v_x and x , because I don't have a number and I think that's the crux of the whole thing here. I don't think anybody here so far has a number to fill in, the suggestions I made are that they have confidence in a safe number that's neither penalizing nor too lenient.

MR. SUSSMAN: I wasn't suggesting you nail it to the ground but at least get an opinion as to what's a reasonable number.

MR. BAKER: Let me ask a question of the guys that build simulators for a living. Is it possible to go through these, what we think are the critical maneuvers, and have you guys tell us where the motion base is a severe limitation? For example, on a normal takeoff I would assume that the lateral acceleration is not a big deal, you are not generating normally enough lateral acceleration cues to limit the travel of the acceleration.

MR. HARRIS: There is also a cue, the pilot goes down the runway you can—

MR. BAKER: There is a little bit of cue there. What I'm thinking of is which particular DOFs in these critical maneuvers are limited by the motion base limitations, by the stroke length limit, or the angular rate, angular position load? I'm thinking during climb-out you normally have the nose of the motion base, the nose of the airplane up, to give a longitudinal acceleration cue. That's going to limit the motion of the motion platform in the other degrees of freedom. Now, you would probably like to have more nose up attitude capability than you can. I'm guessing that you would, not knowing for sure. What I'm trying to do is get a qualitative feel for where is the motion, where are the critical limitations of the motion base in an existing sim right now so we can address those with respect to the new Level B requirements?

MR. STOCKING: Go ahead.

MR. HARRIS: The limitations that I see from outside the simulator; if I watch a training session, it would normally be a fairly clean training session without turbulence or whatever, the strong pitch nose up for takeoff, strong pitch nose down for braking, a bit of heave, not too much, minimum roll, very rarely do I see a significant roll. And yaw in fact only on ground accompanied by sway.

The limitation, if any, would be in the rotational axis. I see very little translation on the simulators. Maybe a touch of surge when you put the brakes on, release brakes. So sustained acceleration, a simulator very gently will surge, really not too much. So the linears I think we can cut back on. The rotational I think we need.

¹ The final set of tables resulting from the Symposium can be found in Appendix 2, 08apndx2.pdf.

MR. BAKER: That's a valuable piece of data.

MR. STOCKING: I also disagree with it.

MR. LONGRIDGE: Of course.

MR. BAKER: I think we need to get more than one person's opinion.

MR. BOOTHE: We are coming up on break time. I have seen some indications that we need that. So if we could take one more comment, I'd like to suggest we take our break and come back. And you had a comment?

MR. HEFFLEY: I guess I just wanted to ask Geoff [Harris], it seems to me that you are seeing all of that because number one, you have very limited motion to begin with; and number two, it's been scaled down far enough for the so-called maximum maneuvers that in ordinary operations you really are going to see these fairly mild motions.

MR. HARRIS: It is true they are normal operations. It's on acceleration, it's not wind shear—

MR. IRVING: Bob [Heffley] is right, reverse cuing is devastating to the pilot, so during rotation and takeoff you need all the pitch and heave you can get. With 50 degrees of pitch and 60 inches of heave you can't have both so you scale down heave because you need pitch. It's a major trade-off.

MR. HARRIS: Yes.

MR. IRVING: From the outside looking in you think "oh, that's the way it is." It's not the way it is, it's the way it has to be.

MR. HARRIS: I still don't see the heave from the outside.

MR. IRVING: Because it's not available because you are pitching.

MR. BLUTEAU: It's one of the toughest cues, the rotation cue you have it's a matter of fully pitch up, you want to, on top of maintaining pitch you want to create heave but you don't have—

MR. STOCKING: To optimize the envelope what we have done is, sustaining a longitudinal acceleration is to slowly squat the system so you have more rotation and wash it out once airborne.

MR. BLUTEAU: So heave is critical, we need enough heave to do rotation.

MR. BOOTHE: Let me suggest a 15-minute break. And please hold your thoughts.

(Break taken.)

MR. BOOTHE: I think there must be something to the theory of relativity after all, because it seems like whenever there is a break, time slows. I never have quite figured it out but everybody's watch slows down during a break.

MR. CARDULLO: Ed Martin had a good suggestion, I think, during the break. Where we were talking about perhaps a 36-inch stroke system, if we didn't want to specify it in terms of stroke, but rather in terms of excursions, we could use the numbers from Lloyd's [Reid] system. Because he has been using that. You know that, if we are adopting this defensive posture for the interim. We know that would be a viable system. And it's been manufactured, so you know it's manufactureable and all that sort of thing. I mean, Lloyd [Reid] says he doesn't have the numbers on top of his head. He could give you a call tomorrow or next week.

MR. REID: Norm [Bluteau] may have them. It's a series 300.

MR. BLUTEAU: I was just on the phone to get the numbers.

MR. CARDULLO: Let me offer that as a suggestion. We use those numbers, then we don't specify stroke, we specify excursions, we may be more comfortable with that.

MR. BOOTHE: I think excursion is a good start. If somebody has the numbers we can write them down.

MR. BLUTEAU: I've got numbers, they are rounded out but I can always follow up with more accurate numbers.

MR. BOOTHE: I will give you my fax machine number.

MR. BLUTEAU: They are roughly in the x axis plus 27 and minus 31 inches. In y plus/minus 26 inches. In z plus 22, minus 25 inches. In pitch plus 25 degrees, minus 23 degrees. In roll, plus/minus 24 degrees. And yaw plus/minus 27.

MR. REID: Just one comment on the last three numbers. Those numbers are the numbers for the absolute angular displacement. If you drive it to those numbers, the CG moves. If you want the numbers that represent pure rotation, I was about to say the centroid of the platform, they are slightly reduced from those angular numbers.

MR. BLUTEAU: Yes. Those numbers are maximum numbers. Also they are nonpure axis. So you are driving each actuator to its mechanical limit and see how much displacement you get.

MR. BOOTHE: But this is single degree of freedom numbers.

MR. BLUTEAU: No, they are not.

MR. BOOTHE: They are not. We have to say what they are.

MR. REID: You can get the numbers. They are approximately plus or minus 21, 22 degrees. The pure motion about the centroid. You can get the exact numbers. Or I can look them up.

MR. BOOTHE: What I'm trying to get at is, how would I say under what conditions these numbers are attainable?

MR. MARTIN: I would suggest, number one, rather than plus or minus just specify total excursions so they can optimize the plus and minuses for the specific design.

Number two, specify that those total excursions may be about one neutral point so they don't play games moving the neutral point around. That way at least you have got some consistency.

Number three, that it's not required that these motions be simultaneous.

MR. BAKER: You better believe that.

MR. HARRIS: Zero cross-coupling between the axes? Is that implicit?

MR. MARTIN: I'm not sure what you mean by zero cross-coupling.

MR. HARRIS: It's sway without any—

MR. REID: Yes, I think that's what it was.

MR. MARTIN: I think that's what I meant by saying establish a single neutral point from which you make the measurements.

MR. BOOTHE: So that's redundant to say—

MR. MARTIN: That should be redundant.

MR. BOOTHE: So Ed [Martin], should we say x of 30 inches? Would that—

MR. MARTIN: I'm saying that you should specify a total excursion in x of 60 inches, or whatever. The 60 inches may be plus and minus 30, or it may be plus 33 and minus 27, but leave that up to the specific designer.

MR. BOOTHE: What size system are these taken from?

MR. BLUTEAU: It's a 36-inch.

MR. BOOTHE: It is a 36-inch.

MR. REID: It's the one I've got.

MR. BOOTHE: How can we get an x of 60 inches?

MR. STOCKING: That would be a unique single degree of freedom number. These are not single, right?

MR. BLUTEAU: No, those are coupled. The figures were derived, derived from the platform, move it as far back as you can, including pitching it over.

MR. BOOTHE: That really amounts to all legs extended in one direction and essentially laying them down as flat as they will go.

MR. BLUTEAU: Absolutely. Then go the other direction would be the same. Those are extreme numbers. I'm not sure they are really meaningful for training purposes. Because for training scenarios you only use a fraction of the whole stroke, you tend to drive using pure x.

MR. MARTIN: This is beyond the operational limits.

MR. BLUTEAU: Oh, yes.

MR. REID: I've got the numbers which are the pure motions for the same system. We use the real numbers, the ones that are pure motions.

MR. BLUTEAU: Do you subscribe cushion legs as well?

MR. REID: We use the stroke just to before the microswitching and we use pure motion. In other words, we don't allow any coupling of the motion when we specify what performance we are getting. These are smaller than what you are quoting.

MR. STOCKING: These are from mid stroke.

MR. REID: Yes, from mid stroke.

MR. BLUTEAU: Perhaps those numbers should go in a final version as being pure.

MR. REID: These are a little bit larger than the numbers I would quote.

MR. BOOTHE: Can you round them down to a—

MR. REID: I can send you a fax with the page with all the data on it tomorrow.

MR. BOOTHE: Okay.

MR. ADVANI: I can do the same.

MR. BOOTHE: Okay.

MR. STOCKING: What you are doing is reverse specifying a 36-inch system.

MR. REID: In effect. That may not be what you want to do.

MR. CARDULLO: The only reason I suggested this approach is that it gives us an ability to specify excursions rather than stroke. And that gives the potential manufacturers a little bit more flexibility.

MR. BOOTHE: Okay. Before Bob [Heffley] breaks his arm here, give him a chance.

MR. HEFFLEY: I guess this appeals to me because, number one, we bring in some experience base here that's attached to some numbers.

Number two, if you are going to express these numbers in terms of this pure axis by axis motion you are talking about, Lloyd [Reid], then that makes it not explicit in terms of how you

may achieve these and I think that's neat, because it doesn't say you have to use a hexapod, it doesn't say you have to use anything, it leaves it up to the designer to satisfy this. So, you know, if you have everything that's gone on here, and all of the circles that we have been around, you know, it seems to me this really starts to get to something. If you really need a number today, this really comes close.

MR. STOCKING: You do want to specify in here you want to do it in neutral. You can optimize the envelope by setting your operational point to different positions.

MR. REID: Oh, yes. You can cheat.

MR. BOOTHE: Well, Lloyd [Reid], in the fax you will send me, will it specify also the basis for measurement that—

MR. REID: I will make sure it's in there.

MR. ADVANI: Ed [Boothe], my colleague from Thomson had a paper of mine which specifies our system, if you are interested in that.

MR. BOOTHE: Of course I'm interested. Thank you very much.

MR. ADVANI: That's for a 1.25 meter stroke.

MR. BOOTHE: Can we get this copied? Don [Eldredge] is not here.

MR. ADVANI: As I mentioned earlier, I should warn you it doesn't state—oh, yes, it does state the gimbal circle diameters.

MR. BOOTHE: I'll get this copied and back to you, Sunjoo [Advani].

MR. ADVANI: To him.

MR. BOOTHE: Thank you.

MR. WILLMOTT: There are six more pages there, Ed [Boothe].

MR. BOOTHE: I also have here a copy of a table from Jane's, is it called "All The World's Simulators?"

MR. IRVING: Simulation and Training Systems.

MR. BOOTHE: By our good friend I. W. Strachan, who is now the editor of Jane's Simulation Documents, which is quite an impressive document. But this lists various motion platforms around the world and who made them, what country they are in, but it does give pitch, roll, yaw, heave, sway and surge, throws he calls them here, or excursions, as we call them, for each of those systems. I don't know that that's of any particular help, it's just a document that has the world's motion systems in it. But unless I could find out which is a 24- or 36-inch system, I don't know that I can use it. But I would—I will take a look and see if I can get some useful information from it.

But now having put—thank you, Stu [Willmott], for bringing this along, I appreciate it.

Having put some numbers now on the paper in terms of excursion, my next concern is the one Bob [Foster] brought up yesterday, we could do this at one cycle a training period. So we have to say something, I believe, about one more parameter, like an acceleration.

MR. CARDULLO: I was going to suggest, I talked with Ed [Martin] during a break about this, I was going to suggest for acceleration we adopt the [MIL-STD-]1558 standards for acceleration. They have been around for a long time, people have built motion systems to them, we know it works reasonably well, as well as anything else. We know manufacturers can meet them, so for an interim standard it seems to be a very reasonable set of numbers.

Now, Ed [Martin] suggested a modification. The heave number in [MIL-STD-]1558 is, I think eight-tenths of a g, and the other translational degrees of freedom are six-tenths of a g. He is

suggesting make them all six-tenths of a g. While everybody can make larger numbers with hydraulic systems, making them all six-tenths of a g in translation will open the door for some electric systems to meet this standard.

MR. BAKER: The reason they are the way they are has to do with geometry of the base. You are going to get more acceleration vertically than laterally. You have more actuators working for you.

MR. CARDULLO: You have a mechanical advantage. I guess all I'm suggesting is if we have to come up with some numbers, these are numbers that have worked in the past, they are achievable for an interim standard, why not go with it? I think we can defend the position.

MR. BOOTHE: All right. I don't happen to have a copy of [MIL-STD-]1558, I'm sure—

MR. CARDULLO: The translation numbers are plus or minus six-tenths of a g. And Ed [Martin] is recommending that for all three translation degrees of freedom. Do you remember the angular numbers?

MR. MARTIN: I think they were something like a hundred radians per second squared.

MR. BAKER: Degrees per second squared.

MR. MARTIN: Degrees per second squared.

MR. BOOTHE: Slight difference.

MR. BAKER: I could get a copy faxed up here.

MR. STOCKING: They are a function of the—

MR. MARTIN: If you could meet the translation—

MR. CARDULLO: You can do a lot more. The systems are capable of much more than 100 degrees per second squared.

MR. BAKER: It's not that much more. I have run tests on them.

MR. CARDULLO: We can argue about them but we are trying to set numbers.

MR. STOCKING: In a regulatory environment every number we put down is going to add hours and hours of testing requirements to certify the simulator. That's engineering hours. We are talking cost drivers every time we put a number down.

MR. CARDULLO: The other thing is, don't put any numbers and let them do what they want to do.

MR. BOOTHE: That seems to be the choices.

MR. STOCKING: You can achieve a compromise, you can put one thing down like 0.6 g for translational, that way you don't have to test rotational.

MR. BAKER: The only thing is you need to test the—specify the translational velocity. You basically constrain the rotational velocity and acceleration by specifying the rotational angles and by specifying the linear velocities and accelerations.

MR. BOOTHE: Let me ask one question. Are you saying rather than acceleration we use translational velocity?

MR. BAKER: You also have to specify velocity, the velocity and acceleration are essentially independent of each other. I can get you a momentary acceleration with a very low velocity and you will be—based on cue duration, you will be relatively disappointed with the motion platform performance. You know, I think [MIL-STD-]1558 has about 20 inches per second.

MR. MARTIN: I think it's about 20 inches per second.

MR. BAKER: Somebody's comment yesterday was that actually on sustained cues you run out of velocity before you run out of position. But in terms of cost, raising that 20 inches per second number up raises the price up in a hurry. It's all related to oil flow. Valves get bigger, oil lines get bigger, and the pump is going to get a whole lot bigger if you want to start raising that number.

MR. BOOTHE: Let Bob [Heffley] make his statement and then I have a question for you.

MR. HEFFLEY: Well, I guess I have a question. So far the numbers that we are talking about are only system potential and we have not even come close to getting to the point of what do you have to provide relative to the aircraft and pilot and task that you happen to be doing? And somebody could in effect turn down the gain to nearly nothing on this thing that we have come up with thus far and make it real easy to engineer and have totally inadequate cuing. I mean, we haven't come that close to getting to the task-related stuff.

MR. BOOTHE: Well, I hope to do that. I think what we have now is an engineering envelope in which to contain ourselves and then we can look at these tasks and try to make some decisions within that envelope. But if we were to just go down the task and say what we need, then we might come up with a system that's totally unacceptable in terms of size and expense, so I think we have contained it. Now we should perhaps look at task.

MR. CARDULLO: Let me suggest, to satisfy Bob's [Heffley] concern, [MIL-STD-]1558 and other specs have sort of addressed that problem without actually going and specifying a specific cue for each maneuver. It lists a number of maneuvers which are necessary and states that the system must be capable of providing a perceptible cue for all of these maneuvers.

MR. HEFFLEY: Does it say how much you must exploit that?

MR. CARDULLO: No. It just says it has to be perceptible. Since we don't know how much you should exploit it, it seems something like that would be a reasonable compromise.

MR. FOSTER: The last IATA group that worked on this came to the conclusion, they were talking about conventional six degrees of freedom, that the best thing to do was still require what we were saying was the manufacturers' specifications for acceptance. Then the concern was, how do we then ensure that this system continues to operate the way it was approved?

So the approach they took was to say "well, each maneuver should be subjectively evaluated and tuned during an initial evaluation by the regulators and the—working along with the operator. And at the conclusion of that, then the operator must provide a method to, in the computer, inject aircraft accelerations into each axis prior to coming out of the equations of motion, prior to the motion drive algorithms, and record the output of the motion platform accelerations that were produced by that." And then that became the standard that you retested to for recurrent evaluations. And that was felt, at least all the operators that participated in that, felt that that left their pilots that were responsible for the training, the ability to subjectively evaluate a system that had some given performance capabilities. It was either going to be a Thomson or CAE six degree of freedom, 60-inch stroke, so they could tune the motion system to match their training requirement and their airplane type but still give the regulators something in addition to that to make sure that now in recurring evaluations, we can show the simulator hardware and software is still performing the way it did when it was evaluated.

MR. BLUTEAU: Something that isn't in AC120-63 but it is a cost driver.

MR. BOOTHE: It is in [AC]120-63. And I think the person that designed that is right over there. But we felt we needed something like that to assure continuing performance to the original acceptance. And I think that's a good idea, but there is still nothing to say that initially providing the cues other than the subjective—

MR. FOSTER: Subjective, right.

MR. BOOTHE: —evaluation.

MR. MARTIN: In my experience, if you try to nail things down too much objectively you find you tune the simulator to satisfy the objective specifications and then you retune it to satisfy the subjective evaluations. It might be better not to say too much objectively.

MR. CARDULLO: I think Bob's [Foster] suggestion is a reasonable one. It's a little more comprehensive than what I suggested. The only negative thing would be from Norm's [Bluteau] perspective of the engineering time required to run that test. And I'm not sure it would be any more than what I was suggesting. So probably they are equal cost drivers. But I think your language specifies things much better than what I was suggesting.

MR. STOCKING: It's an accepted process, too, using [AC120-]45A to establish what the criteria was when it was accepted.

MR. CARDULLO: I have a question. Did we have a consensus on a velocity of 20 inches per second in translation?

MR. REID: It's all part of the same standard.

MR. STOCKING: As long as that's what's in [MIL-STD-]1558, I'm comfortable with that.

MR. CARDULLO: I agree, it's in [MIL-STD-]1558. Did we come to consensus?

MR. BOOTHE: I don't think so. I think I might have written it down if we did, and I didn't. I have written down a lot of numbers.

MR. CARDULLO: I would suggest that we adopt that. Unless some folks could think why we shouldn't.

MR. MARTIN: As long as you just specify the velocity in terms of translational degrees of freedom. You start getting into some—

MR. CARDULLO: Right.

MR. MARTIN: —geometric considerations when you start talking about pitch and some interactions.

MR. BAKER: The spec in [MIL-STD-]1558 is for actuator velocity. So with that in mind the actual x, y, z velocity will be a little bit higher, okay? Because the actuator velocity is less than platform velocity in every case that I'm aware of. Due to geometry.

MR. BOOTHE: What was the number, Frank [Cardullo]?

MR. CARDULLO: Twenty inches per second.

MR. BAKER: Twenty.

MR. MARTIN: Actually in [MIL-STD-]1558, we had to do some tuning for pitch. We had to back off on the pitch velocity requirement because—with the geometry used—pitch velocity was driving actuator velocity requirements.

MR. BAKER: Right now based on—I just looked at this test data a few days ago. I ran some tests on an AH-1W motion platform a couple years ago and compared that with spec requirement [MIL-STD-]1558, and with a couple of exceptions meeting the spec was not too much of a challenge. There wasn't a lot of margin but there was I think quite a bit more roll, pitch and yaw velocity than the spec required. That came from the fact you had translational velocity requirements. There was more pitch, roll and acceleration than the spec requirement. The requirement in x, y and z drove you to that position. You know, I don't know the history of that spec, so I don't know if it got backed off a little bit in the process, it may have.

MR. MARTIN: We didn't typically stick by all the numbers in MIL-STD-1558. We had some modifications in the Air Force that we typically used. Unfortunately, we were never able to complete an update for the standard before it eventually was canceled.

MR. BOOTHE: Okay. Let me record a couple of IOUs here. Lloyd [Reid] has said he will fax me your system performance.

MR. REID: Right.

MR. BOOTHE: And was somebody going to provide some pages from [MIL-STD-]1558?

MR. BAKER: I can supply you with [MIL-STD-]1558, I have a copy of it.

MR. ADVANI: I can provide you my latest paper where I show these trade-offs.

MR. BOOTHE: That's not this, that's Geoff's [Harris] paper. I will run a copy of that. I think that covers the IOUs. Frank [Cardullo]?

MR. CARDULLO: Yes. I suggest we might want to specify bandwidth. And as Ed [Martin] recommended yesterday, we should do it in terms of phase angle. And I would offer 45 degrees of phase lag at four hertz.

MR. BAKER: That's a lot more than [MIL-STD-]1558 requires.

MR. CARDULLO: Yes indeed, it's a lot more than [MIL-STD-]1558. But I think that's one area, that's probably one of the most important areas in my opinion, and [MIL-STD-]1558 was written against what the state of the art was in 1968 or so. Also, these numbers are relatively easily achievable, especially with a lighter payload.

So if 45 degrees at four hertz, and if you are talking about 150 milliseconds of transport delay, which was mentioned yesterday, that's going to give you about 110 degrees of phase lag, so you add the 110 and the 45 and you are up to 155 degrees of phase lag, which is not giving you too much phase margin. So I don't think we can do much less.

Now, it is true, most of the operating we are doing is going to be down under four hertz, it's going to be around two to three hertz. And some even below that. But in the extreme maneuvers it's going to be around two to three. So we could fudge these numbers a little bit, but it's something to shoot for, anyway.

MR. BOOTHE: If we use 45 degrees at four hertz, do we forget about the 150 millisecond transport delay?

MR. CARDULLO: That's for the whole simulator, 150 ms. Well, and also it includes the motion. But it's from when you get a stick input until the end.

MR. ADVANI: Is that above the aircraft dynamics?

MR. CARDULLO: Yes.

MR. BAKER: The thing about the motion base that's a little peculiar is the motion base time delay, if you measure with a step function, doesn't depend very much on the bandwidth of the servo because essentially what you are doing is putting a step command in the valve, and the valve is essentially at that point running an open loop.

MR. CARDULLO: Right.

MR. BAKER: Those are a lot—let me make another comment about the four hertz number.

First of all, I think it's imperative that we constrain or somehow encourage the manufacturers to push the motion base bandwidth up above what it in some cases may have classically been. I've seen them down around a hertz and a half, and that's a little bit slow. But you don't have to get there by pushing the position bandwidth up. Okay? The actuators are very good integrators. And you can set the bandwidth as low as a sixth of a hertz and still gets ten hertz equivalent bandwidth out of the system. I have test data to show that off of several different motion platforms.

Recently I took an old Link base that the Coast Guard owned that has about 2.7 hertz actuators on it, as I recall. And we pushed that up well above five hertz in most axes, on all the axes and I think some of them were closer to ten, so you don't necessarily have to do it by forcing the designer or the builder to position the loop bandwidth of the hardware. Maybe Frank [Cardullo] wants to comment on that, he may have different data than I have got. I admittedly don't have a totally thorough set of test data on this stuff. I would be interested to know people's comments.

MR. CARDULLO: Well, how would you suggest specifying it, then?

MR. BAKER: Well, when we talked about this for the helicopter Advisory Circular, we suggested one way to do it was to measure from the acceleration input to the motion and washout equations to acceleration measured over on the platform on the accelerometer. And actually, if that, you know, if you run a Bode plot of that, you get a very clear picture of exactly what the motion base is going to do when the aircraft does some maneuver. And I don't think we came around to specify what that had to be, but I think we did suggest in the circular that people use that measurement technique to determine what the motion platform was doing. We didn't get to the point of telling the guy how good it had to be, we just got to the point of suggesting that was a valid measurement technique and he probably ought to look at it.

MR. BOOTHE: Maybe Paul [Ray] has that. That's been so long, Bruce [Baker], I don't remember. We put in a method and it seems to me an alternative would be acceptable.

MR. RAY: I don't have it with me.

MR. BAKER: There was two alternatives, the older one said to basically make it acceptable to the operator or to the pilot. And I didn't think that was quite analytical enough or scientific enough.

MR. BOOTHE: Okay. Are there any other numbers we should consider in a general way on the engineering aspects or engineering envelope of the motion system independent of any specific cuing that we might want to look at?

MR. CARDULLO: Have we come to closure on this one?

MR. BOOTHE: I don't know. Which one?

MR. CARDULLO: You are asking for additional ones and I don't know if we have come to closure on bandwidth.

MR. BOOTHE: I'm still thinking of phase lag, I'm sorry.

MR. CARDULLO: Bandwidth based on phase lag. I don't think we have come to a consensus, necessarily. One thing about it, I was just asking Lloyd [Reid] what his system is capable of and it's a little bit less, he thinks, than what I was suggesting. And I think we can live with that. He was also saying it is considered in terms of acceleration transfer function, which is really what's important, I think. And he thinks that maybe it's about 60 degrees phase lag at four hertz.

MR. REID: Don't quote me. What do you think, Norm [Bluteau]?

MR. BLUTEAU: It all depends on the controller. The controller can be made to match or exceed those numbers. Even with a 45 thousand pound payload. It depends. Frank [Cardullo]?

MR. CARDULLO: So if we were in that ballpark that shouldn't be a problem.

MR. BLUTEAU: This 45 degree phase lag at four hertz, would it be tested on all six axes?

MR. CARDULLO: Yes. In terms of acceleration transfer function.

MR. BAKER: You want to test it in x, y, z space, not leg space.

MR. CARDULLO: That's correct. It's meaningless in leg space, in my view.

MR. BAKER: It's harder to make it work in x, y, z space.

MR. CARDULLO: It's harder to drive the simulator.

MR. BOOTHE: Are you suggesting 60 degrees?

MR. BAKER: I have measured data on it, I could send it to you on several different motion bases.

MR. CARDULLO: What I'm saying, 45 degrees, degrees, it doesn't matter much. Norm [Bluteau] seems confident that their system with a lower payload would have no trouble meeting 45 degrees. And I think most people don't have any problems now with these kinds of numbers. So 45, 60 is not that much, as far as I'm concerned, for an interim spec.

MR. BOOTHE: Well 60 appears more relieving whether it is or not.

MR. CARDULLO: Yes.

MR. BOOTHE: So if it appears more relieving we probably should use it.

MR. CARDULLO: It's all right with me if everybody else agrees.

MR. ADVANI: I don't see 45 as being any problem, from my experience.

MR. STOCKING: Yes, that's wide open.

MR. MARTIN: I would like to make sure it's clear as to what transfer function you are talking about. Are you talking about from the input to the motion drive laws to—? I'm wondering.

MR. CARDULLO: Exclusive of the drive.

MR. ADVANI: To the servo valve, input to the servo valve, correct?

MR. CARDULLO: No, because we are going to do it in degree of freedom space, it has to be input to the kinematic transformations. So that's just one step before. And the only additional problem there since—the only additional problem there is D[igital] to A[nalog].

MR. MARTIN: Yes. If you start bringing the D to A into it, that changes the picture.

MR. CARDULLO: It's going to change the picture.

MR. MARTIN: You might have some filtering hung out there.

MR. STOCKING: You want to find those, too.

MR. CARDULLO: Good point. So I think from the input to the kinematic transformations to the acceleration of the platform.

MR. BAKER: You are not going to include the washout now?

MR. CARDULLO: No.

MR. REID: No.

MR. HEFFLEY: Just to clarify, so we are talking about like an x double-dot to x double-dot command transfer function. Right?

MR. CARDULLO: Yes.

MR. BOOTHE: I feel like an auctioneer here. 45 once? Should we say 45 sold? I don't have a problem with 60, and apparently you don't think it's that important, that that's an acceptable range, actually. But I think we would like to use a number that appears to be less stringent if it doesn't make, especially if it doesn't make any difference.

MR. HARRIS: If the number is less stringent you may find other manufacturers are now capable of achieving it. This may be a good thing.

MR. BOOTHE: So should we say 60 once?

MR. CARDULLO: I don't object to 60.

MR. RAY: Sold.

MR. REID: Sold.

MR. BOOTHE: We use 60 degrees at four hertz.

MR. CARDULLO: And when someone says "where did the 60 degrees come from?"

MR. ADVANI: And four hertz.

MR. CARDULLO: We cast dice.

MR. BOOTHE: About the same place where plus or minus three pounds came from.

MR. HEFFLEY: To maybe state this slightly different, if we are talking about 45 degrees, you know, you are in effect saying normally that's going to determine a bandwidth, so you would say "this has a four hertz bandwidth." If you take an effective time constant to that 45 degrees, four hertz, that's about 40 milliseconds for a time constant. 60 degrees you come along, fine, that will give you some slightly different numbers there, but it's kind of—it's a slightly nonconventional way of stating bandwidth.

MR. CARDULLO: Yes, it is.

MR. HEFFLEY: So 45 degrees from the standpoint of being a universal way of—

MR. BAKER: Some of us use 90 degrees, too.

MR. BOOTHE: Okay, 45 makes it appear that we know a little bit more about what we are doing.

MR. SMITH: I like the word "appear."

MR. REID: If you want to use 45 and keep the same characteristic, you could always back off on four hertz. You could say 45 and whatever it works out to be, three and a half hertz.

MR. HEFFLEY: True.

MR. BOOTHE: So Bob [Heffley] says a more conventional way of specifying, 45, 90, 135, 180. So maybe we should stick with 45 for that appearance.

MR. CARDULLO: Yes, I agree.

MR. BOOTHE: And maybe, I don't know what the frequency would be for an equivalent, but three and a half hertz?

MR. HEFFLEY: You can figure that out.

MR. CARDULLO: Why don't we just stay with 45 degrees and four hertz?

MR. ADVANI: It's a very easy computation.

MR. BOOTHE: 45 degrees and four hertz. And that's measured from an input to the kinematic transformation equations—transformations to platform—

MR. CARDULLO: Acceleration. In each degree of freedom.

MR. BOOTHE: Any further comment on that?

MR. BAKER: One of the interesting things about this is the method of measurements, which I think is a very proper way to do it. It's going to include some of the transport delay in the computer. In the output of the computer. And I think that's good, I think that part of that should be in that measurement.

MR. CARDULLO: Do we want to specify looking at our list of critical parameters, cost drivers, do we want to specify a cross-talk or smoothness?

MR. BLUTEAU: Before we go to that, I would like to possibly finish with displacement, velocity and acceleration.

MR. CARDULLO: I thought we did.

MR. BLUTEAU: I want to make sure. Have we specified rotational velocity at all?

MR. CARDULLO: No. We specified actuator velocity. Right?

MR. MARTIN: No, translational.

MR. CARDULLO: Okay. We are saying the rotational falls out from that?

MR. BLUTEAU: I'm not sure.

MR. MARTIN: Rotational becomes somewhat complicated by the specific geometry of the design.

MR. REID: It may be true of a hexapod system. What you are saying here will hold. Specifying linear may specify angular. It may not.

MR. BLUTEAU: To be sure, we should specify linear and rotational displacements, velocity and accelerations.

MR. BOOTHE: We only have translational velocity and accelerations, we have six-tenths g for translation. We have one—wait a minute. We have angular of 100 degrees per second, we don't have a velocity.

MR. CARDULLO: We don't have angular velocity.

MR. MARTIN: I think the mind set was "synergistic." You could come in with a cascaded system, so that's a good point.

MR. BOOTHE: Well, Norm [Bluteau], now that you have put yourself on the spot.

MR. CARDULLO: Give us some numbers.

MR. BLUTEAU: AC120-63 for Level C and D, I think, has plus or minus 20 degrees per second for pitch and roll. I think it has 25 for yaw. I'm not sure whether we should back off a little bit from those numbers.

MR. BAKER: Those numbers are small. Those numbers are quite small. And probably something above that, I think [MIL-STD-]1558 has them as 30 degrees per second. And I think the bases are actually achieving something closer to 50.

MR. BLUTEAU: Do we have to be consistent with Level C and D? Should Level B be below Level C and D in terms of performance requirements?

MR. BOOTHE: Well, should it be? The perception is yes, it should be, Level B should be a lesser—a less stringent requirement than [Level] C or D. But since at the present moment there are no such specifications as these for [Levels] C and D, I guess we just pick something that we can propose for a Level B, and Paul [Ray] has to worry about [Levels] C and D some other time.

MR. BLUTEAU: There is something—

MR. BOOTHE: Pardon?

MR. BLUTEAU: There is something specified for helicopter performance in AC120-63 on both Levels C and D.

MR. BOOTHE: We didn't do anything on [Level] B, did we?

MR. BLUTEAU: No. There is a concern to be consistent between what we do now and what is presented with helicopter. But I agree those numbers are not unreasonable, I'm just addressing the consistency.

MR. BOOTHE: Yes.

MR. BAKER: Well, let me say first of all I don't think the numbers in [MIL-STD-]1558 are that hard to achieve.

And secondly, let me say if somebody comes in with a cascaded system, what you expect goes out the window. In a cascaded system if you are forced to go to plus or minus 20 degrees of pitch, roll, yaw. Most of the cascaded systems I see do that simultaneously. You do that in all three axes at once. Which you can't do with the synergistic systems.

It's not a bad assumption to press on and assume that we are talking about a synergistic system, and if somebody wants to design something else they can come back to Paul [Ray] and say "hey, here is a rationale why this is an equivalent system, we would like to do it this way because of these engineering reasons." And he will call this body back together again and we will have a few days of nice meetings and say "yes, that's okay." Maybe it will be simpler than that. I don't know.

MR. BOOTHE: Let me get that number written down that you were proposing.

MR. BLUTEAU: I was proposing possibly the same numbers as being used, presently used on AC120-63 Levels C and D, and the numbers are, for pitch and roll, plus minus 20 degrees per second.

MR. BOOTHE: Okay.

MR. BLUTEAU: For yaw it's 25, I think.

MR. MARTIN: MIL-STD-1558, at least what I have written down here, specified 20 degrees for roll, pitch and yaw. For the geometry that [MIL-STD-]1558 was written around, I recall we had to back off to about 18 and a half degrees per second pitch to be consistent with the two feet per second translational velocity. This was due to the geometry.

If a vendor doesn't come in with a cascaded system you may be driving it with some of the angular rates. It all doesn't scale down very neatly.

MR. BAKER: I wish I had a calculator. That would—wish I had a copy of that, that would eliminate a lot of discussion.

MR. STOCKING: I was going to say for [MIL-STD-]1558 testing we segregate the testing in two areas. One is testing the capability of the hardware, and we do those tests without the platform being populated, we do a dummy load on it. And once the maximums are tested, we never test them again. We only have maintenance testing from that point on. But once it's populated, both with expensive electronics and people, with expensive visual systems, these accelerations can be potentially damaging.

You have visual systems that are located a long way from the CG and whatnot that are starting to magnify things considerably. We are approaching these problems with this type of regulation.

MR. IRVING: So why bother with them?

MR. STOCKING: Instinctively I feel we are maybe doing something that we want to specify when it's a manufacturer's type of motion system. And in another place have it tested when it's fully populated with some other type of test system then indeed we've got a system, right? That has that capability but not test explicitly once that platform is populated.

MR. BOOTHE: I'm not sure I followed all that, Chuck [Stocking]. There's silence in the room.

MR. STOCKING: Once you populate the platform, a lot of the numbers we are talking about are potentially damaging or reduce the life cycle of the equipment on the platform.

MR. IRVING: Therefore we shouldn't specify something we can't use. Or am I missing something?

MR. BAKER: I think the biggest problem is you kill the projector for the visual system.

MR. STOCKING: Tear off screws and bolts and all kinds of things.

MR. BLUTEAU: What number are you concerned with?

MR. STOCKING: The acceleration testing. As soon as we get into acceleration testing for translational, it isn't too bad. Rotational stuff really starts taking off when you start testing.

MR. BLUTEAU: So the 100 degrees per second or 20 degrees per second that you take, which number is a threat to simulator integrity?

MR. STOCKING: I don't have a good feel for that.

MR. BAKER: You know, I basically agree with what Chuck [Stocking] said. When I ran a test on an AH-1 they put a projection dome and a bunch of high quality projectors in it. I said "are you sure you want me to do this? Because it's going to thump the equipment pretty hard." They said "go ahead."

But we also did damage some projectors on a CH-46 sim by having the computer program overflow and wrap around once and give a full scale, full amplitude motion input into the platform. We didn't get cursed real bad, but the guys weren't real pleased with that.

MR. BLUTEAU: [MIL-STD-]1558 requires that the simulator can sustain—well, the simulator typically can sustain up to 2.5 g or something along those lines.

MR. STOCKING: That's an unpopulated platform.

MR. HARRIS: No.

MR. MARTIN: No, that the worst case emergency shutdown is 2.5 g.

MR. HARRIS: Under no circumstances must it exceed. It's not shutdown.

MR. MARTIN: That's a "not to exceed number."

MR. BAKER: I think very few people test to that number. Particularly with it populated, you would be foolish.

MR. CARDULLO: If we are talking about 100 degrees per second squared and if the equipment is about 15 feet from the center of rotation, you are only talking about 26 feet per second squared tangentially. It's less than a g. This stuff ought to be able to hack a g.

MR. BAKER: It doesn't always hack a g real good.

MR. CARDULLO: Well, then I have to agree with Don [Irving]. Why are we specifying it if you can't use it? It seems to me it ought to handle a g.

MR. BOOTHE: That brings up a question. We are talking about what [MIL-STD-]1558 says and what other specifications say, what we have done in Advisory Circular 120-63. Those are system specifications. The question is, is anybody using a motion base that even approaches that performance level?

MR. MARTIN: Yes.

MR. BAKER: The motion bases do, the performance that's in [MIL-STD-]1558, some do a lot more than that.

MR. BOOTHE: They get tested to that but in daily operation are they doing that, is my question?

MR. HARRIS: Certainly we achieve [MIL-STD-]1558. One of the requirements, one of our customers in this country wants to take the simulator ready for acceptance and drive it as hard as he can till it stops.

MR. BOOTHE: Drive it until it stops?

MR. HARRIS: Drive it worst case and check that the simulator itself is safe and what are the g[-value]s, and this we have to do.

MR. BOOTHE: That's testing. My question is now, what's going on in operations? Do military simulators actually use the values to which the motion base was tested in flight training operations? Or do they decide we don't want to damage our equipment and for a number of other reasons attenuate it subjectively and we are hitting ourselves with these numbers?

MR. MARTIN: Let me make a couple comments. Based on what I have on the table here from the short-course notes—and I think I have copied this accurately out of [MIL-STD-]1558—what we specified for peak acceleration in rotation was 60 degrees per second squared. Not 100. I have tested the systems to these limits with the operational equipment on board. I have done it with sine waves, not steps. That may make a difference.

Now, whether we use it, whether the washout ever commands this size acceleration, I don't know. I've never monitored for that—only whether the capability was there in the basic equipment.

MR. HEFFLEY: Seems to me that's an awful relevant question, though. I mean, if we are designing something that is far in excess of what is really being used—

MR. BAKER: Well, it turns out that the—

MR. BOOTHE: Frank [Cardullo] has been up here raising his hand.

MR. BAKER: I'm sorry.

MR. BOOTHE: Sorry.

MR. CARDULLO: Part of the reason I don't think it is used, at least not in all cases, but part of the reason for that is the types of cuing algorithms that are being used. If you use a linear cuing algorithm, you scale so that the washout is imperceptible. And in a linear cuing algorithm, the washout is proportional to the onset. So this drives you to scale factors like 50 percent or 20 percent.

If you use nonlinear cuing algorithms, then you can take advantage of that capability and you really want to be able to do that. I don't think the capability that we are specifying is anything less than what we could use and should use, but it isn't often used because of the types of cuing algorithms. But cuing algorithms are getting better, people are improving them, they are using nonlinear adaptive algorithms, and so in that case I think you will find that they are using much more of the capability of the hardware.

MR. STOCKING: On a case-by-case basis, right? You will find uses to use the things that we are testing to. And somebody is going to make a decision. I've got this expensive electronics in there, and it's more important to me that I don't break the electronics every six months than it is for whatever training it achieves. And you have that potential to make that decision at any time down the road if you have these limits. But you don't have to test for them all the time if it's a design criteria and not maintenance criteria.

MR. BAKER: One thing I was going to say, if you design a 60-inch stroke base with the payloads they are designed for, you are going to end up with three kinds of acceleration numbers based on the way the rest of the engineering comes out. You are not going to want to reduce the system pressure much below 1200 psi because of problems with the valves if you do that. You are not going to want to make the actuator smaller in diameter, because of the problems of holding a static load and problems of stiffness of the actuators in the bending direction. So I don't think we

have put an unnecessary burden on anybody by keeping those numbers, those g acceleration numbers where they are in [MIL-STD-]1558.

MR. BOOTHE: Well, another question I would have about these numbers, then, is whether or not they could be met by an electrically driven system, within its own payload capability, of course. I guess Fokker says they can handle seven thousand or eight thousand pounds, which really simulator-wise is not a lot. But are we out—are we overruling electrically driven systems with these numbers?

MR. BAKER: I don't think so.

MR. MARTIN: I don't think so.

MR. CARDULLO: One of the reasons I reduced the eight-tenths accelerations to six-tenths, was to accommodate electric motion systems.

MR. BOOTHE: I do want to make sure we are not just ignoring that capability. Because I think that's a system very much of interest to people in this environment.

MR. WILLMOTT: I'm not familiar with [MIL-STD-]1558. I would take it to be a military specification?

MR. MARTIN: Military standard.

MR. WILLMOTT: What was it designed for, what was it produced for? Was it for F-14s? F-18s? Or was it for—

MR. MARTIN: It was produced around the 1974, '75 time frame. Back then it was to be a generic six degree of freedom six post standard for the motion simulators that we would require for the Air Force.

MR. WILLMOTT: So it applies equally to these fast little fighters that need very, very high rates of—

MR. STOCKING: It's an all product spec.

MR. MARTIN: That was the intent. In fact after it got published we found that the frequency response numbers didn't really make a whole lot of sense in some areas. We backed off on the pitch velocity requirement because that turned out to be driving actuator velocity, which in turn starts driving the cushions and devices that are needed to absorb the kinetic energy in the event of a failure, and became a cost driver.

These modifications wound up just being an addendum that we put in specific specifications. So [MIL-STD-]1558 was generally what we used, but there were a few amendments to it that we always applied.

MR. WILLMOTT: The point I'm getting at, I wonder if that is relevant to passenger carrying aircraft.

MR. CARDULLO: This was used for transports, C-130s and B-2s.

MR. WILLMOTT: But it's really designed for all military aircraft and much, much more responsive ones than what we are talking about for regional aircraft.

MR. STOCKING: In the commercial division we used the military hardware but we used it without the specs. In other words, we did not test those specs because they were design specs. That saved us money.

MR. BLUTEAU: Also I would like to say that this spec, being over 20 years old, it is generally accepted that this spec is now very easily met and it's not seen as being a high performance spec to meet at all.

MR. WILLMOTT: But there are quite definitely some systems out there now that do not meet it.

MR. BLUTEAU: They may not meet the safety part of it, which is the toughest part.

MR. WILLMOTT: In terms of performance.

MR. BLUTEAU: Performance is generally recognized to be fairly easily met.

MR. WILLMOTT: There are systems out there that don't.

MR. BLUTEAU: I'm sure there are, yes.

MR. BOOTHE: That brings up the next subject I would like to introduce. We are talking here about a segment of the industry which would much prefer a fixed base device, they would like to get all the credits. So I don't mean that facetiously, but in perspective, we are going with this segment of the aviation industry from nothing to what appears to be a rather stringent specification of performance here. Tom [Longridge] is going to hear about this. So I think the next step we have to do is still look at these tasks and say what cues are necessary to check pilots in these tasks, and put them in the perspective of this engineering envelope that we have now designed. Because I don't think the industry that we are dealing with is going to be very receptive to us, to the FAA just saying here is your motion spec, live with it. There is going to have to be some rationale to convince them why this is an important thing to do.

MR. LONGRIDGE: I think that's certainly true. But I would hope by virtue of some of the decisions we made today we are coming up with a more affordable six degree of freedom motion platform.

MR. BOOTHE: Well, I guess that's the question.

MR. SUSSMAN: I was just going to say the whole concept was to bring the simulators used by the Part 135 airlines to a higher level. What you have done is come up with a meaningful spec, which is more consistent with the "state of the art." I don't think you can say "yes, it's possible that it will be more expensive but the only way you are going to enhance the simulation capabilities available to Part 135 airlines is to make use of the advanced technologies which represent the current state of the art." The goal of this activity, as I understand it, is to elevate safety by providing improved simulation. So you are suggesting what appears to be a reasonable level of improvement.

MR. LONGRIDGE: Yes, that's true. But we have to be pragmatic, we absolutely must come up with a system that is accessible from a cost perspective.

MR. SUSSMAN: I think you are getting there, though.

MR. CARDULLO: I had a question about your question. I didn't really understand what you meant by matching these maneuvers to cues. What did you really mean? Do you want to go and specify what acceleration is necessary for each one of these maneuvers? Is that's what you want? I don't think we can do that.

MR. BOOTHE: Then that's what I want, but your feedback is what I want to find out, too. So if that's not something that's possible for this group to do, we need to know that. Maybe that's one of the longer term things we need to think about.

MR. CARDULLO: I think what we sense, what we kind of know, is that given the engineering specification that we have laid out so far, that we could accomplish all of these maneuvers at a reasonable level of fidelity. I think that's what we are implying in what we are doing.

But to go into each maneuver and specify a cue for each maneuver and magnitude of acceleration or whatever, I don't think we can do that.

MR. BOOTHE: Okay. I think Lloyd [Reid] had his hand up.

MR. REID: What we can do, Frank [Cardullo] and Ed [Boothe], is go over to the next column, motion objective, and go over these items, and say these are the things that must be produced with sufficient fidelity to allow training in the judgment of whoever it is we are going to say has to make

these judgments. I assume it's FAA certification pilots or whatever their titles are. I think we could go over that list and see if we are happy with the things that you have listed initially.

MR. CARDULLO: I agree with that.

MR. REID: And modify those based on our experience.

MR. BOOTHE: I would like to look at them because, I mean those are just one person sitting at the computer saying "why do we want to do this?" And there you have it. I think I do need some input there, very much so.

MR. CARDULLO: Before we depart from the engineering specifications to go to this, let me reiterate the question that I asked before. Do we want to have any specifications concerning cross-talk and smoothness? Because I think if we don't, all the rest of the spec kind of becomes meaningless because those can add a lot of false cues.

MR. BOOTHE: Well, I think if we are going to do this we ought to do it completely or else we are wasting our time. I don't mean we should overdo it, but I certainly think we should include all of those things that are important to the appropriate result. And exclude everything that we don't need. Stu [Willmott]?

MR. WILLMOTT: I'd like to suggest that we include a check for the balancing of the lags dynamically. If you say you accept 45 degrees lag at four hertz, I would recommend that each of the six legs be within—I beg your pardon. You are not—I'm off on the wrong tack. You wanted to do that on each axis. I was thinking in terms of the legs.

MR. CARDULLO: What you are suggesting is cross-talk in degree of freedom space.

MR. WILLMOTT: We recently accepted a simulator with a motion system that didn't meet these dynamic characteristics, and you could do a heave motion just checking the system out and you would find a lot of lateral and other spurious movements, and it got down to the characteristics of the individual valves on the legs not being closely matched.

And we had to get those checked.

MR. CARDULLO: You do want cross-talk and spurious movement to be below the level of perception. So you want to specify in terms of acceleration. But what that threshold is varies depending on what the pilot is doing. If he is heavily task loaded, it's much higher. If he is just sitting there testing the simulator, that threshold is much lower. You can feel a lot more.

MR. BAKER: Let me make another comment on that, Frank [Cardullo]. The problem with the synergistic base is that the cross-talk is not a simple thing to specify or test to. And if we, I think—not that I think we should back away from it, if you make some simple tasks, for example running the thing in the lateral direction and measuring cross-talk in roll, then if you change the attitude of the base or you change something about the base, then the cross-talk is going to change. And I think we need to at least be aware of the fact that people may try and design a simplified controller to take some of the cross-talk out, which will work for the test but won't work in general.

MR. CARDULLO: Well, that's a problem. Although I think that if you run these tests out of neutral, which is where you would probably do it most of the time, or a high percentage of the time, you are operating the simulator out of neutral. So you may run into some situations where you get into that problem. But it's usually the dynamic effect of the mass that causes that problem in unusual attitudes. Since we are talking about a smaller payload with smaller mass properties, that problem will not be as great as it is in a Level C or D device.

MR. BAKER: That's an assumption, I think, be careful with that. Because you know if you go back to the specs that we have got for acceleration, for example, that's going to size the actuators for the payloads on there. The real question is not—the real question is driven by the—determination of cross-talk is driven by the natural frequency of the actuators, the natural frequency

of the oil spring, that's what causes the phenomena. If the oil spring wasn't there you wouldn't have cross-talk.

MR. CARDULLO: Right, that's a function of the virtual mass that exists at various attitudes.

MR. BAKER: It's dependent on that, it's also dependent on that if you reduce the acceleration requirement, then the designer can reduce the diameter of the cylinder, which makes the spring softer, so I think the whole thing washes out. If he designs to a particular acceleration level.

MR. CARDULLO: Well, would we be comfortable in specifying cross-talk and smoothness simply as in terms of, rather than numbers, words, to the effect that cross-talk should be imperceptible as opposed to saying it should be less than 0.01 g or something like that? The problem is that it leaves it sort of open, but it leaves it up to the examiner to say—well, I'm not sure that's the right term for the person doing the checking.

MR. RAY: Right.

MR. CARDULLO: But it leaves it up to them to say “yes, it's acceptable” or “it's not acceptable.” You have to remember this is an interim specification that we are talking about. And if we get more knowledge later on, we can change it.

MR. WILLMOTT: The sort of test that I was envisioning to check that out, in fact, goes to drive all six legs, so it's essentially moving up and down, which I guess is the z axis test at zero pitch, and to put an accelerometer on board that measures the lateral and the longitudinal accelerations, and those should be below certain threshold levels. I thought the threshold value was about 0.05 g.

MR. CARDULLO: If I may answer that. That's sort of the absolute threshold. But it's higher if you are task loaded. So when you are flying the airplane that threshold moves up. We don't want to be too stringent because the guy is going to be flying the airplane, or flying the simulator. I mean, since we don't really know what those numbers are, I'm not comfortable with putting one in.

MR. MARTIN: Well—

MR. HARRIS: Go ahead. Okay. Currently in [AC]120-40 we have frequency response, which we normally take as being platform response. [Item] 3.b. is leg balance. Now, here you are talking about driving the platform, either all legs together or else in heave, which are similar but not the same. And checking the symmetry of the legs to each other. Any asymmetry and the thing will rotate as opposed to—

MR. WILLMOTT: But it is done at a relatively low frequency. When you do things faster depending on the frequency response of your system, you get something totally different.

MR. HARRIS: It will buck and twist.

MR. WILLMOTT: I think we did ours, I forget the frequency, at half a hertz or something like that, but still when you were doing this sort of thing (*indicating a fast push/pull control column motion*) you get all this lateral movement.

MR. HARRIS: Are you expecting that a Level B simulator will have a tighter specification than [Levels] C and D?

MR. WILLMOTT: I think what we are specifying here is a requirement for a Level D sim, but I'm going along with the general consensus which is to make the system as complicated and sophisticated as we possibly can. This is something that I have found and experienced but there is no requirement to test that, I think it should be included.

MR. BAKER: Let me comment on that a minute. First of all, it's my opinion—

MR. BOOTHE: Go ahead. We had a couple other comments.

MR. BAKER: Getting the leg servos to balance pretty well is not hard to do. I'm more concerned about the dynamics of the oil spring. And the effect of putting a large input, a fast input in x or y than having the base react in pitch or roll. Those things are inherent in the design of a base and they are somewhat difficult to correct. I don't think making the leg servos match is as difficult as that problem is.

MR. HARRIS: It's inherent. The specification is in [Levels] C and D.

MR. BOOTHE: Ed [Martin] is trying his best.

MR. MARTIN: Just some comments. One of the first problems that I got involved with in motion simulation was a problem where an Air Force pilot in an F-4 simulator complained about a problem involving cross-talk. It was pretty subjective, he said "when I roll it feels like I bump my wing on a cloud." I don't believe there was any cross-talk spec on the simulator at that time. Nonetheless, there was an intensive effort to try to correct the problem. I think it was due to the oil spring problem. It never did get corrected satisfactorily, to my knowledge, in that particular simulator. Link developed another motion simulator to supercede it. It was a major change.

What I'm thinking for purposes here, is that the FAA has a much larger hammer than the Air Force does—and the Air Force was able to get the vendor to address the problem. Leg balance is one critical parameter. If you don't get that right you have a lot of problems. It's a fairly straightforward test.

If we start getting into trying to test other aspects of cross-talk, we might start driving cost just on the basis of some of these complicated tests. It might be best just to have some words in there about subjective evaluation of cross-talk.

MR. CARDULLO: That's what I was going to suggest, I was going to suggest some straw man wording.

MR. MARTIN: By the way, since the question came up earlier, the magnitude of this cross-talk was about a tenth of a g.

MR. BAKER: I would like to get an input from—

MR. BOOTHE: You said to say it's imperceptible, which sounds okay to me.

MR. CARDULLO: I was going to say imperceptible during normal flight maneuvers or imperceptible while flying a simulator during normal flight maneuvers. I don't think you should simply say imperceptible because someone can then sit in the simulator and concentrate on the motion cues and they will be subject to this 0.015 or 0.008 g threshold if he or she has a really fine-tuned otolith.

MR. BOOTHE: Like staring at a visual system.

MR. CARDULLO: Exactly. I would put it in the context of normal maneuvering.

MR. RAY: Could I suggest operational use as opposed to normal maneuvering.

MR. CARDULLO: That's fine.

MR. SUSSMAN: If I could suggest modifying that slightly I think it is right to do it in the performance of routine maneuvers or however. I think one way of framing it, cross-talk shall not be objectionable and then that leaves it open to the—

MR. CARDULLO: Maybe "objectionable" is better than "imperceptible."

MR. HEFFLEY: You know, that's going to get you—

MR. CARDULLO: That's sort of a number.

MR. HEFFLEY: That's a number.

MR. CARDULLO: People look for numbers.

MR. HEFFLEY: What you really want is something that's not going to get in the way of doing the job.

MR. WILLMOTT: But how do you check for it? What is it that you do to check for your cross-talk?

MR. BOOTHE: You don't notice it. Then it's not there. Right?

MR. HARRIS: Intrusive.

MR. BOOTHE: Seriously, that's what we are saying.

MR. WILLMOTT: Subjective evaluation, that I thought was what we were trying to get away from.

MR. RAY: I personally prefer, everyone has a different word they like to use in the English language, I prefer the word "imperceptible." To me that's an objective term, "objectionable" is a subjective term. That being different to any two pilots. However, they should be able to clearly identify whether or not they can perceive that cross-talk.

MR. HEFFLEY: I understand, you are certainly right about that. But not perceptible can be awfully small. And awfully tough.

MR. SUSSMAN: What we do when we have to work with a basically subjective judgment, we tend to specify the maneuver and the conditions and the people who certify it need to develop a repertoire of what they think is perceptible within that maneuver, that's the only way you can do it, you can't get away from subjective all the time. After a while the guys develop a repertoire of what they expect.

MR. BAKER: One of the things that has probably kept us out of trouble in this area is the fact when a guy is doing a normal maneuver, he is not pushing the motion base too hard and the cross-talk levels are very, very small. And when you get a wind shear situation where you expect higher frequency inputs into the platform, the cross-talk levels come up. But the guy doesn't really know what to expect anyway, so he doesn't know if that's a real computer generated cue or it's a false cue, and furthermore, it doesn't make any difference because you are basically trying to let him know he is in a turbulent situation, how the turbulence got there is kind of subjective anyway. So I don't think the problem is a real issue except to keep the legs balanced. I don't think we are going to force people to change the design of the motion platforms to reduce the cross-talk that's inherent due to the oil spring. Okay?

MR. BOOTHE: Well, if we use words like not objectionable or imperceptible, I think we could come up with something that satisfies the group.

MR. SUSSMAN: You know what you want to use the simulator for, concentrating on the following maneuvers it should be imperceptible, not objectionable, and specify the maneuver.

MR. CARDULLO: We specify this list of maneuvers.

MR. HARRIS: That does become aircraft dependent as opposed to motion systems dependent. If you want to quantify a particular attitude, a particular amount of cross-coupling, then these are the numbers. That's the objective. If that's what you want to do.

MR. CARDULLO: I have to take a cue from Ed [Martin]. There is an objective way of doing it which is rather expensive because it's very time-consuming. You could simply do leg balance tests, but I don't think that tells you really everything you want to know.

So given that compromise I think the subjective approach is acceptable, especially in an interim spec. Since we don't really know what numbers to put on it.

MR. BOOTHE: That's the cross-talk issue. What about—

MR. CARDULLO: I would put smoothness in the same category.

MR. BOOTHE: Okay, that was my—

MR. CARDULLO: Would you—

MR. REID: Yes.

MR. BOOTHE: We can use similar words for smoothness.

MR. BLUTEAU: Smoothness can be easily tested.

MR. CARDULLO: What's the number?

MR. BLUTEAU: Not a number but in terms of process, in terms of test procedure it's a lot easier.

MR. CARDULLO: I agree, but the number is tough to determine.

MR. REID: The other point is that smoothness is more than turn-around bump. There could be systems, maybe not our nice hydraulic systems we have now, but there could be systems, some of the electrical ones where just the actual movement, not turn-around, but actual travel has ripple, and you measure that. You have to do a big series of tests just like you do for the cross-talk tests if you want to cover every condition.

MR. BLUTEAU: I just wonder if subjective assessments will be able to pinpoint problems.

MR. CARDULLO: But that's up to the manufacturer to do, not the FAA or the user. The manufacturer can use his own tests to pinpoint problems.

MR. BLUTEAU: I mean whether the FAA will be able to say with a certain level of confidence that this simulator is actually acceptable if all that is used is a number of subjective assessments.

MR. CARDULLO: I think so. From my perspective what we are concerned about with smoothness and cross-talk is that it gives a false cue. Really the only thing we care about, is whether these are false cues. These are two things that can give rise to false cues. If it's imperceptible, that's all we care about. If it turns out it is perceptible and someone is going to try to fix it, maybe you have to run additional tests to find the problem, but I don't think the FAA should care about that. That's up to the manufacturer to go fix it.

MR. BLUTEAU: I'm trying to imagine the words to be put in the circular to tell an FAA inspector, which may or may not understand motion systems very much, what maneuvers he has to do, what to look for and how to judge whether a level is acceptable or not. I'm sure we can all do it because we know what to expect, how to trigger those problems. I just wonder—

MR. BOOTHE: I think these kinds of subjective evaluations are more within the day-to-day practice of people in the FAA who are evaluating simulators. With some exceptions, they are not engineers, they don't maybe understand the stuff we have been talking about here. But they certainly can tell whether or not there is something strange going on with the motion system when they perform a certain maneuver. So I think in that case some subjective guidance is probably better for the continuing evaluation part. So I personally don't have a problem, and particularly as Frank [Cardullo] has said, for an interim solution. If in the final solution that's found to be insufficient, then we can discuss it.

One thing I would like to do, we are coming up on lunchtime, some of us have to check out during lunch and take care of some other things, some people have to leave shortly after lunch. I know Frank [Cardullo] does. But we have sat here and I think made great progress this morning, but I don't want to put Bob Foster on the spot, but I'm kind of forced to. I wonder if I can hear a little now, if I may, the operator's perspective or your perspective as an operator, Bob [Foster], about what we have done or what we are in the midst of doing. If you don't want to do that—

MR. FOSTER: I don't mind saying that. I'm concerned we have built in excess of what Stu [Willmott] implied. I think we have built a Level E motion system. Especially if we were to put these testing requirements in any sort of recurring evaluations, I don't know what we have done to

fulfill these requirements. But it—I don't think we have done much of anything towards making a Level B simulator more affordable.

MR. BOOTHE: I thought you might say that.

MR. HEFFLEY: But I think—

MR. BOOTHE: Go ahead.

MR. HEFFLEY: I think there is another side. I think it's wrong to—I don't disagree with what you say, Bob [Foster]. But I think it's also fair to recognize that we are looking at this whole business today, we are not looking at it ten years ago or 20 years ago. We are looking at it in the context of a lot of things that have been learned over a long period of time. And it's legitimate to recognize that there are a lot of factors that really do need to be brought to the table when you are talking about the design of a simulator, even though you are trying to make it a cheap, inexpensive simulator. You know?

MR. FOSTER: I don't like the term cheap. I think what we want is an effective simulator for Level B recurrent training and checking. And to some extent it will of course be used for initial checking, initial training as well. I just—and from a pragmatic standpoint, where we are at now is these guys are not trained in simulators. They are tooling around in the middle of the night simulating engine out conditions at whatever condition an instructor feels is safe handling. They are not getting the opportunity to practice things like, you know, feather pump failures and things where they actually go in and push the buttons and cancel the bells and do all those sorts of things.

And it's just my personal feeling that we would be much further ahead to have a truly affordable Level B simulator that can be very effective for training and checking, and I don't personally see the need for anything in excess of the existing motion system to do that. The existing three axis motion systems. You might want to make it, I was talking to Paul [Ray] a little at the break, you might want to eliminate heave axis and go with pitch, roll and sway or something like that.

But to me the initial step is we have to get these guys into simulators, they should be in simulators and getting the advantage of all that repetitive training and really looking at a guy, doing demonstrations of V_{MCA} , showing what happens when that engine doesn't feather, and you better be quick and jump on that thing, and have gone through that drill. Which you can't do very effectively in the airplane.

So to me that's the first step. You look at saying I have to get these guys out of the airplane and into a simulator, and if I can keep them in a reasonable facility with a maintainable piece of equipment that doesn't drive the airplane operator out of business, then you want to go to the highest level you can.

Especially for an interim type of situation, I think we are building kind of a—like I said, a Level E with this, and I also question because of not having a wider angle visual and the other thing you are looking at is trying to convince these, especially the independent operators, to take this step. It's going to be difficult.

MR. CARDULLO: Well, we were given a ground rule at the outset that no motion was unacceptable.

MR. FOSTER: Right.

MR. CARDULLO: So we are faced then with either current level of motion or what you call the current level of motion, which I assume is three degree of freedom systems and six degree of freedom, and we argued that quite a bit yesterday and I thought we came to a consensus that you might as well not have any if you are going to have three.

MR. WILLMOTT: No.

MR. HEFFLEY: Bob [Foster] suggests another set of three, okay? It's a different set of three.

MR. CARDULLO: I understand. I understand. It's a different set of three but it's three. And, you know, we never discussed the homework assignment, but I know when I went through the maneuvers, I really couldn't find three degrees of freedom that would satisfy all these requirements. And if you are going to get false cues out of the motion system you might as well not have it. I hold that bad motion is worse than no motion. And I would rather see us throw away the motion system than put a motion system on there that's going to be bad. Unless it was just a vibration system. That, in my view, would be a preferable option to a three degree of freedom system.

MR. BOOTHE: Maybe we could before you have to leave, do some of that homework assignment quickly. You have to leave at?

MR. CARDULLO: I've got to get the 1:30 bus to the airport. I have a 2:20 airplane.

MR. BOOTHE: So immediately after lunch we could at least look at part of that.

MR. CARDULLO: We can eat and talk.

MR. BOOTHE: Would you mind a shorter lunch period?

Instead of an hour we could take, like I said, for example, I have to check out and stuff like that. So maybe 45 minutes would give us at least 15 more minutes, or say be back at quarter to 1:00 from now. Is that all right?

MR. RAY: I just want to capture one thought. Did we capture Bob's [Foster] comments from the IATA group as far as testing? The intention was to embed it in there. Did we get a consensus that the language is reasonable to embed or did we not?

MR. BOOTHE: I don't think there was any discussion to the contrary. I wrote down as much as I could, understanding that she is [The Reporter] writing down all of it. But I didn't hear that anybody objected to that kind of language. Did you, Bob [Foster]?

MR. FOSTER: I didn't, it goes along the lines of what was Chuck [Stocking] was talking about in testing these things. If we have to go in once a year and do velocity and acceleration testing and stuff it's going to take about a week to get the simulator ready for it and do the testing and then unbolt everything afterwards. It really tears it up. It really does.

MR. RAY: The reason I raise the issue, it seems like something reasonable to use regardless of what motion system you are talking about, whether a three DOF or four DOF or six DOF or a Level A or a Level D.

MR. BOOTHE: Well, I don't—I didn't hear any objection. And it is very similar to what was written in the helicopter Advisory Circular, which has not been used to any great extent, but it's there. So I think it's not precedent setting at this point.

MR. RAY: I just wanted to close that issue.

MR. BOOTHE: Okay. Lunch and return at quarter of.

(Lunch break taken.)

MR. BOOTHE: While we continue dessert, those of us who are, I want to take maximum advantage of some people's time here and probably it's a good time to begin looking at the table. I would suggest we begin by looking at takeoff. Not at the exclusion of others, but simply to get what we might think is more critical and see if we can better describe the task or motion objective for those tasks.

And so if we can read through those and if there are questions on the table, please bring them up. You notice under takeoff those objectives are really for each of the components of the task, like for acceleration along the runway, steering and crosswind, each have a motion objective written. And I'm open to correction.

MR. HEFFLEY: I have a question. Takeoff is a good example of where you can see that there—it's clear that there is motion involved on takeoff. But to what extent is motion at all essential from the standpoint of training during normal takeoff? Forget all other tasks, but if you were to design a simulator to just train for a normal takeoff, what is it that you—that would drive you to say I need to provide a motion cue in that particular task?

MR. ADVANI: Because sometimes you will have an abnormal takeoff. There is a lot of lateral, longitudinal forces.

MR. HEFFLEY: Okay. I guess I was trying to put aside the abnormal takeoff point. Clearly there are some things that come in there.

MR. ADVANI: Since it's part of training you cannot say "okay, we are going to normal takeoffs with no motion," so to speak.

MR. STOCKING: Rejected takeoff, when to make a rejected takeoff.

MR. HEFFLEY: Let's say rejected takeoff, is there cuing in that?

MR. RAY: Yes.

MR. HEFFLEY: Motion cuing.

MR. RAY: And for crosswind takeoffs.

MR. CARDULLO: This is also a workload consideration.

MR. RAY: That's correct.

MR. CARDULLO: In some respects during a takeoff, motion reduces the workload because it gives you an indication of when you've lifted off, for example. The other case, it increases a workload because if you have some vibration on the runway and that sort of stuff, so it's giving you a little bit of increase in workload. Therefore, we have to remember, as I understand our charge, this is not to be used just for training but for evaluation. And so in a way to be fair to the pilot whom you are evaluating, you have got to give him as much of the information that he would have in the airplane as possible. Although we can't give him everything.

MR. RAY: That's the genesis of it. To limit the issue to training can be a false road. There are many very effective training mediums that contribute to the ultimate proficiency in the aircraft. However, the device we are talking about is an assessment vehicle. It's that vehicle at which we are either going to recertificate or requalify a pilot for operation without another evaluation in the aircraft.

MR. HEFFLEY: Right.

MR. RAY: Many of the studies I have reviewed tend to point towards training value, which tends to become very subjective. Particularly when you start selectively including or excluding the myriad of cuing that occurs in flight. If we maintain our focus on pilot assessment, it makes the need for the respective cuing much clearer. And the reason for its need.

Imagine that you are taking a driving test in simulation. You're going to be recertified or requalified every year to drive your car on the highways. What do you need in order to assess a person's ability to safely do that? You have to include all the cues that you possibly can, that you know they will be exposed to in the real world.

MR. BOOTHE: Does that answer your question, Bob [Heffley]?

MR. HEFFLEY: Yes. I mean, there are some things in there I was looking at differently.

MR. BOOTHE: Well, I wasn't totally listening, obviously, but I think there are some secondary intrinsic things here that provide cues that we maybe unconsciously use but miss them when they aren't there. I think it's just speed cues that occur because of roughness of the runway being modeled. If you do a takeoff with no motion or even with a motion system in which there is no

runway roughness modeled and there are no “bumpetty-bumps” that get faster as you accelerate, you notice that it’s missing. And you have to shift your emphasis from things that you normally do and substitute other things. Like more concentration on the air speed indicator rather than if you make a couple takeoffs in an airplane, you know when it’s time to look at the air speed indicator at 60 knots, whatever the speed check is. If you don’t have the bumpetty-bumps collected, you have to stare at it and take your attention away from where it ought to be. I think there are a lot of subtle cues that motion provides that we really don’t give a lot of thought to.

MR. BAKER: I think there is some surprises. I know I have been surprised at least twice on motion cues in air vehicles. It turns out pilots were using them as a primary cue and I thought it was kind of a “who cares.” One of them is the transitional vibration in a helicopter when it transitions to forward flight. The guy sometimes will fly a descent down the 25 knot air speed using that as a primary cue to air speed, not looking at air speed. I would have never guessed they did that.

MR. BOOTHE: Having an extremely limited helicopter experience, but having gotten a license, my instructor taught me to use that to recognize transition. So I’m not surprised.

MR. BAKER: It’s like every heli sim that I have looked at, the high quality sim has a seat shaker in it for that reason. It’s a seat shaker instead of shaking the whole motion platform, to keep Charles’s [Stocking] visual systems from going belly up.

MR. BOOTHE: So for normal acceleration—I’m sorry, wrong terminology. For acceleration along a runway in a normal takeoff, which is what that really means, are there any objections to what’s written there or should there be additions?

MR. RAY: Ed [Boothe], have we selectively excluded sounds in there? I can’t help but believe high frequency, low amplitude sound in a turbo prop is so important. It’s a separate issue but you can almost put it into, because of the vibration created, put it in the motion category. I don’t know how that plays or how to integrate that into this table or a separate table.

MR. BOOTHE: I don’t know, Paul [Ray]. I think it’s important. But I wasn’t thinking about it when I did this.

MR. RAY: I’m raising the issue because having flown a couple of turbo props, the seat of the pants, if you want to call it, vibrations created by the turbo prop itself are significant. The vibration through the aircraft is extremely important to me, or was.

MR. CARDULLO: I remember at Sunjoo’s [Advani] conference in the Netherlands this fall one of the KLM pilots was talking about how he flew a landing profile listening to the sounds of the engines on a 737. Just by the sound of the engines he could hold the glide slope to within some small deviation. Then he said one day he was making a landing and he just couldn’t hold the air speed and the glide slope angle correctly and he suddenly realized that the problem was he had windshield wipers on and the windshield wipers were masking the sound of the engine to some extent adding another sound.

MR. BAKER: Wow.

MR. CARDULLO: And it became a problem for him.

MR. ADVANI: Did he mention by any chance what fidelity the sound was in the simulator?

MR. CARDULLO: This was in the airplane.

MR. BOOTHE: In the airplane. It was 100 percent.

MR. CARDULLO: That gave me a totally different perspective about sounds.

MR. RAY: That’s similar to the story I believe I have relayed to you before of my own personal experience. I promise this is the last time I tell the story. Bob [Foster] has heard it at least twice, where just the headset change—

MR. CARDULLO: Oh, yes.

MR. RAY: —made a major difference in my ability to control air speed and pitch attitude on the approach, particularly in the landing flare. It had a major impact on my ability to make a smooth landing. It was sound change.

MR. BOOTHE: This whole business of sound is not new. The aviation pioneers used the whistling of the wind around the structure wires, the fly wires and the ground wires to judge their speed. And half the time they didn't have an air speed indicator that was of really decent accuracy, some little flipper thing out in the wind. But they, according to my readings of aviation history, anyway, they used the sound of the wires. So we still use sounds, it's not flying wires anymore, but certainly other sounds that airplanes—

MR. BAKER: Is that what you call fly by wire?

MR. CARDULLO: Very good.

MR. BOOTHE: With that I will move on to the next.

MR. FOSTER: Ed [Boothe]? I think for the terms of Level B recurrent training and checking particularly, I don't think you really need surge and yaw for takeoff. For any of the modes of takeoff. You can do a decent job—

MR. BOOTHE: You don't?

MR. FOSTER: It's nice to have. It would be nice, but in terms of providing the essential cues, the accelerations I think can be done pretty effectively with pitch and deceleration, the runway roughness comes out of heave, the roll and sway I think—sway would be nice because you need to coordinate the roll and sway in order to provide good steering cues. But the yaw is so small.

MR. CARDULLO: I agree with Bob [Foster] on yaw, but I disagree on the surge because if you don't have that onset of acceleration on the takeoff roll, then you don't have anything with which to transition to the gravity align. So that means you have got to rotate and the guy is going to sense that rotation.

MR. ADVANI: Right away.

MR. CARDULLO: That's going to be a false cue because he feels like he is rotating when he has just begun to accelerate.

MR. FOSTER: I honestly believe if you wash that in pretty slowly, and remember for recurrent training and checking we are talking about a guy that knows the airplane, initial training I think it's a different deal. The guy, how he pumps the power to it, what to expect out of it is a different thing. But when we are talking about recurrent training and checking, I just don't think there is a requirement for that type of a cue. The guy knows what the airplane does. I don't know of any sort of abnormal emergency thing that we do where we are trying to cue him starting from no air speed, basically.

MR. CARDULLO: I agree. The only thing for longitudinal is the acceleration.

MR. FOSTER: Sure it's nice to have. But I think we are trying to say here, "what do you need to have?" at least that's what I'm trying to say.

MR. BOOTHE: I think that's what we should be saying.

MR. CARDULLO: Yes.

MR. BOOTHE: I put it in for the reason Frank [Cardullo] described. In fact keep in mind that doesn't just address normal takeoffs, it addresses rejected takeoff, engine failure and so on.

MR. CARDULLO: On rejected takeoff you might need it.

MR. BOOTHE: So it addresses this whole column of events.

MR. FOSTER: Yes.

MR. BOOTHE: One of the things I've noticed that people sometimes do, especially in turbo prop airplanes, you do it in most all airplanes, you extend the throttle up somewhere, you don't release the brake until the engines accelerate to that power setting. And then when you do release the brakes you get that surge, and if that isn't there, I had the same thought, how do you initiate the feeling of the takeoff and then how do you transition from that to a continuous—

MR. FOSTER: I think the cues come out, primarily come out of sound, especially on turbo prop as you come in and the prop governors are sorting themselves out. Then I just think you have to, you can't jerk the pitch to simulator but you wash it in. It may not be 100 percent fidelity cuing, but this guy is now rolling down the runway and everything perceives to him to be pretty normal. Maybe I didn't—I see the opposite of that, too, where a guy will do this and this (*indicating*) and then it will pitch.

MR. MARTIN: It would take about 30 seconds or so to get up to any sensible surge if the platform is rotated below perceptible rates.

MR. CARDULLO: He is off the ground.

MR. BOOTHE: Then you are airborne.

MR. CARDULLO: Yes.

MR. BOOTHE: Wait a minute, say that again.

MR. MARTIN: I said it would take 30 seconds or more to tilt the platform.

MR. BOOTHE: To get to tilt.

MR. CARDULLO: If you rotate it at a subliminal angular acceleration, is basically what he is saying. By the time you got to the right angle.

MR. MARTIN: Or sensible angle.

MR. CARDULLO: Even sensible angle.

MR. MARTIN: Threshold.

MR. BAKER: When I sit in a commercial airliner on takeoff, what I think I'm feeling is pitch and not longitudinal acceleration.

MR. CARDULLO: You know why? There is a visual illusion that's going on, it's called the oculographic illusion, but pilots are not susceptible to that illusion because they are looking out the window.

MR. ADVANI: Looking forward.

MR. CARDULLO: The illusion is the oculographic illusion. If you are sitting in the passenger cabin and the aircraft is accelerating down the runway, and you look forward, it looks like the forward bulkhead is elevated, right? So that's what you are experiencing.

MR. BAKER: Even if I look out the window that sensation doesn't go away.

MR. CARDULLO: There may be some latency in it going away. I don't know anything about that. But if you are looking out the front window driving the airplane, you won't get that sensation. You get a different sensation. Because you can't get the oculographic illusion when looking at the horizon remaining at the same level.

MR. BAKER: I don't get nearly as much in a car. You are the pilot in that case. It's an interesting—

MR. CARDULLO: It is interesting.

MR. BOOTHE: Actually sometimes frightening to me, because if I'm on a relatively light airplane like a DC-9-80 series and we rotate for takeoff, of course I've got the perspective inside the cabin, the airplane is both pitching up and accelerating. And I feel like it's doing this (*indicating*) and it scares the daylights out of me.

MR. BAKER: Because it's going to stall, right?

MR. BOOTHE: Yes. So it is a very perceptible feeling.

MR. BAKER: Taking Bob's [Foster] inputs, which I think are extremely important, I don't know exactly how to factor those into the rest of the discussion, but I keep kind of getting led back and thinking about the problem of motion base geometry and thinking maybe we can do this with a three or four axis base based on roll, pitch and yaw base, that's got the cab sitting well ahead of the pivot point. Now when you put, for example, yaw into the base, it gives you a lot of lateral motion, which is what you want to do to achieve some of these effects.

Runway you can do with pitch, because pitch at low amplitude is a vertical motion, the pitch angle is insignificantly small. Roll looks like what roll would normally.

The thing I'm trying to decide is, could we in this discussion come to any conclusion that says "well, if you did three or four degrees of freedom and did them right, that would be so close to a six axis base that it would be totally satisfactory?" I'm kind of inclined to think it would be if it was done right. But I don't know if we can make that conclusion here. I don't know if we have enough data.

MR. BOOTHE: One reason yaw was included in these, my thoughts included airplanes as small as ten passengers and as large as turbo prop airplanes to 50 passengers. And I think somewhere there must be a crossover between sway and yaw and maybe a ten passenger airplane is still above that, so it's mostly sway. I don't know, Bob [Foster], I didn't have any basis for making that decision. But if we consider basically large airplanes, with the exception of possibly wind shear, I would agree with you on yaw.

MR. FOSTER: Again I'm just coming from this position of trying to establish these interim guidelines. And trying to keep the device affordable. And give people options. I was talking a little bit to Tom [Longridge] during lunch, you can make some logical progression out of the fact if we have a Level A device as far as motion requirements and training and checking, you can't do any landings and takeoffs in it, basically. There is no aerodynamic ground effect package in it.

If you move to a Level B package, we are trying to encourage people to build Level B which is a little different than we were trying to do when we did the advanced simulation at the beginning. If we are trying to encourage people to do Level Bs because they can do all of their recurrent training and checking in it, a side effect of that is that since they now buy this device and have it, they are also going to use it for engine out takeoffs, since the rules permit that. Because of that, I think it makes a lot of sense to say, "since we are encouraging you to now buy these devices and you are going to use it for engine out work, we feel as an expert group it's very important that you give that pilot engine out cues in excess of what's available in the old style three axis machines. Then the logical progression is you get—and in addition to that we are giving you an aerodynamic package that will more correctly model the flight of this airplane."

Then you move to the next level, you get a Level C, and it gives you the ability with the addition of six axes now to do transition and upgrade training as well as the recurrent training. And then the price you pay for that is the additional realism with a wide visual system and a six degrees of freedom motion. You can now move from one model airplane to the other. We have to show you the differences in these in training.

The final level, when you go to Level D we now have to provide all the more sophisticated aerodynamic effects and also have to toss in buffets and that sort of stuff. I think if we came to some sort of interim thing I think you can make some sense out of saying if we, from the motion

standpoint say “okay, following my logic you now need for a purpose built Level B machine you need roll, pitch, heave and sway.” I think you could make a pretty good case for that.

Then we recommend some additional work to see if we are missing anything with that. Is that missing—is it asking too much or not enough to be corrected in the future if required? But hopefully giving people the economic incentive to design these machines, specific purpose built for this, and also buy the machines, hopefully, and get them out of the airplanes and into a real training environment.

MR. CARDULLO: Bob [Foster], do you think there is any reason in any of these other maneuvers for surge?

MR. FOSTER: In every case in my mind I put it as a “nice to have but not essential.”

MR. CARDULLO: How about on-ground handling and braking?

MR. FOSTER: I just don’t see it. Because the guy is flying the airplane already. He knows what this particular airplane type brakes like and steers like and everything else. We are not going to take him—

MR. CARDULLO: But remember we are testing him, not necessarily just training him.

MR. FOSTER: But in what we are testing him in I don’t see it as a problem. Because we don’t see that as a problem now.

MR. STOCKING: It’s a reinforcing cue, it’s not a primary alerting or control device. That’s where Bob [Heffley] is coming from.

MR. BOOTHE: Bob [Heffley] has been holding his hand up.

MR. HEFFLEY: Two points. One is this matter of surge versus pitch, if you really do need surge, it’s because of the necessity for very high rate of onset, and that may very well be specific airplane dependent and maybe that’s what you want to be, let the real driver do that. Otherwise I think that pitch really ought to satisfy the surge. Particularly where you have the visual that’s also furnishing strong cues to distinguish between surge and pitch.

Number two, yaw and sway. One thing that the NASA Ames people really pinned down pretty well here, is that it’s pretty hard to distinguish yaw and sway motion and they are pretty redundant. But if you want to keep one, the one to keep is sway. Again the visual fills in the yaw motion cue. So I think, you know, I think there is a real case here to be made for trying to minimize the need for yaw and surge and those I think are the things to be looking for as you continue through the list here. Where is the real driver that says “yes, I really do have to have yaw” or “I really do have to have surge.” Those are hopefully maybe the two that you will let go.

MR. FOSTER: I’m not saying you can build it any less expensively without them, but I would like to give somebody the opportunity to try.

MR. BAKER: Everything that I hear keeps me going back to the direction of building a roll, pitch, yaw motion base, perhaps with surge on it. You could add surge to it without a lot of hassle. It would be a nonstandard motion base, it wouldn’t look anything like a standard six axis motion base. And just thinking about—

MR. CARDULLO: No heave?

MR. WILLMOTT: From the pitch.

MR. BAKER: You are sitting ten feet from the pivot point. You can do heave with pitch.

MR. ADVANI: No.

MR. BAKER: You are shaking your head.

MR. CARDULLO: The reason I'm shaking my head is I don't agree. Because you know you get different size airplanes where the pilot is sitting substantially at different distances from the center of rotation. So you need that heave to be able to deal with that.

MR. BAKER: Beyond some point you can't tell the difference between heave and pitch. I don't know how far ahead of the CG you have to be, that's the whole argument that Bob [Heffley] just made about yaw and sway, was if you are going to give one up you might as well give yaw up because you really almost can't tell the difference. Admittedly if it's a helicopter and you are only six feet ahead of the CG, that's one problem. In all these airplanes you are probably at least 15 feet ahead of the CG, it's very hard to distinguish motion-wise when you get a lateral motion that it's sway or yaw or in the case of—

MR. CARDULLO: I can buy the sway—yaw part. I have trouble with the pitch surge part.

MR. BAKER: Not surge, pitch and heave.

MR. CARDULLO: I'm sorry, pitch and heave or pitch and surge. Either one of them.

MR. ADVANI: I have to agree with Frank [Cardullo].

MR. BAKER: For a runway situation where you have got high frequency, small amplitude inputs, I guarantee you if you put them in as pitch or heave you can't tell the deference. The real question I think comes in with things like transitioning when the nose comes up for takeoff and that sort of thing. Is that going to be a satisfactory cue for that part of the scenario?

MR. CARDULLO: I think if you use pitch for surge and the takeoff roll, there is going to be an ambiguity that you cannot resolve. You are going to perceive that as pitch. It's going to take some time before the person integrates the visual information to come to the fact that it's not pitch that he is accelerating down the runway. What effect that ambiguity has on performing the tasks, I can't say. But there is that theoretical ambiguity.

MR. BOOTHE: Three comments on that.

MR. HEFFLEY: I really disagree, Frank [Cardullo]. I mean, the visual is right there right now. The visual cuing is immediate. That's what fills in these ambiguities.

MR. CARDULLO: The visual cuing is not immediate, Bob [Heffley]. It's slow.

MR. HEFFLEY: If you start your takeoff roll, and with pitching motion furnishing the surge cue, but visual is still saying I'm level, I'm nose level, there is a strong sense that you are nose level, and you are just being accelerated—

MR. CARDULLO: But it takes a little bit of time for that ambiguity to be resolved. I agree, you do resolve the ambiguity with the visual, but there is latency in the process.

MR. HEFFLEY: I think we are arguing a minor degree of foundation—

MR. CARDULLO: Could be.

MR. HEFFLEY: —as opposed to the cost of another axis.

MR. RAY: If I could throw in another comment as far as visual. A large percentage, if not a majority of training and checking we are talking about, is done under low visibility conditions. Not ten miles visibility, but with as little as 300 foot forward visibility. How visual and motion fit together there, I don't have the answer to it.

MR. BOOTHE: Norm [Bluteau]?

MR. BLUTEAU: Yes. Three comments. In my experience tuning motion systems with a number of customers, number of pilots, there were times when some of the axes weren't tuned properly. So effectively some axes were missing. As a result of that we examined what problems the lack of specific axes caused in pilot performance.

In terms of pitch and yaw and x, in some cases especially around landing and takeoff, when the surge was not sufficient, and when the pitch was used to generate longitudinal accelerations, many pilots, as Frank [Cardullo] indicated, perceived an acceleration as a pitch of the aircraft. Because we tilted the simulator. In many cases the pilot corrected or the pilot reaction to this acceleration was to provide a column input. Believing that the aircraft was actually tilting. And many pilots crashed the simulator because of the lack of discerning.

I remember one case, it was actually (*American Airlines*), the pilot crashed on the go-around because he applied power, he felt a pitch up so he just automatically reacted with a column input. Even before the visual cue was recognized. He just had the reflex of reacting to it. So he just crashed into the ground.

Another case for having surge is on rejected takeoff. When a pilot suddenly decides to stop the aircraft, applies the brake, but doesn't get the surge to indicate that he has gotten a deceleration, so those pilots tend to panic, they don't get the reaction they expect because the pitch takes a little while to build in.

The last point is with respect to the mechanism using long drag lengths trying to combine heave and pitch. One of the difficulties there might be to attain enough pitch angle and takeoff gravity alignment, long runway length makes it difficult to tie in 10 or 20 degrees of pitch.

MR. BAKER: I was only suggesting as a compromise, I really wanted some discussion, some negative.

MR. CARDULLO: Ed [Boothe], excuse me. I have to leave.

MR. BOOTHE: I wish you could stay. I understand. Thank you very much for joining us.

MR. CARDULLO: You are welcome. Good-bye everybody. I'm happy for the interchange. I stir up a pot and leave.

MR. BAKER: Okay. Now we get to work, right?

MR. STOCKING: I was going to reiterate much the same thing. For instance the pitch. The synchronization of the angle of the platform with the longitudinal surge is very critical. That's the difference between providing a true cue from the aircraft and supplying something else. If you are going to go to say eliminate surge, I would not tune the pitch to give the same cue. What you are doing then from that point on is you are trying to provide a cue that enhances his controllability of the device. You are not providing an aircraft cue without that synchronization of the pitch and surge, or in the case of roll and sway of the gravity align. As far as what's the most important or the least important degree of motion, the yaw angle is the least used in the simulator. But that's the only one that I could eliminate right off the bat and say, you know, for the type of training we do in airline simulators we could eliminate one degree of axis. That's only sometimes. I would still find a case or two where I would like to have it.

MR. BAKER: Eliminating one axis doesn't buy you anything.

MR. BOOTHE: Maybe not. It may not buy anything, it may not change the final design, but still if it adds nothing then we shouldn't say it should be there. So.

MR. STOCKING: It's the least desirable.

MR. BOOTHE: We may still end up with six degrees of freedom because that's the most sensible and economic way to do it. But still, if it's not necessary to have that degree of freedom, then it shouldn't be part of the performance specification. And if somebody decides they are going to have it anyway, that's fine. I could live without yaw here. I have trouble considering living without surge.

MR. FOSTER: I just go back to remember what this device is for. It's for recurrent training and checking. And before this guy, he is going to go out and have to fly the airplane with an instructor before—has to get his three landings and takeoffs, right?

MR. BOOTHE: In a Level B it's a landing qualified simulator—

MR. FOSTER: Right.

MR. BOOTHE: The total, correct me if I'm wrong, rules are changing faster than I can read, a Level B is a total recurrent check.

MR. FOSTER: Recurrent.

MR. BOOTHE: Recurrent. And I think Norm [Bluteau] brought something up, Bob [Foster], that I think is real important. And that is a rejected takeoff. There is a—surge and pitch I think are pretty important there, because one of the problems, I don't know if it's been a problem so much with regionals because a lot of them have propellers and a lot of them in a rejected takeoff would use reverse propeller thrust, which will throw you out of the seat if you use it correctly. But we have a very poor record of successful rejected takeoffs, especially in larger airplanes. And I think largely it's because people, pilots, were not familiar with what it means to use maximum braking, so they didn't use maximum braking unless it happened to be autobrakes, and then they would get on the brakes and dump that. I think for that kind of maneuver, if we are going to do that in a recurrent check, it may not occur in every recurrent check, I think those degrees of freedom are important to demonstrating how a rejected takeoff should feel with maximum braking and reverse thrust. I don't think surge is important there.

MR. FOSTER: I don't think you can come close to it with surge, it's hardly anything on a rejected takeoff.

MR. BOOTHE: When you first put the brakes on.

MR. FOSTER: Maybe when you first touch them. You can't maintain that surge. Really what you get, the banging of the airplane is what you get on rejected takeoff. There is tremendous deceleration there. The thing that pulls the pilots off is the fact that the airplane shudders and shakes so bad it scares them. I think you can reproduce that without surge. It's a pretty violent maneuver.

MR. WILLMOTT: I thought we heard Frank [Cardullo] say earlier in the day that the acceleration cue duration should be the order of 0.2 to 0.3 of a second. Aren't we talking, as far as this surge is concerned, like a quarter of a second, I'll call it jerk? And it is later followed by pitch gravity align that gives you the sustained braking feel, and this is one area where the FAA is quite concerned to make sure that you do get the hang-on-the-straps feeling when you are decelerating hard. It really comes from the gravity align, it doesn't come from surge.

MR. HEFFLEY: That's right.

MR. STOCKING: In a six DOF system that's the one place where we run out of longitudinal surge. I end up with a cue that's less than ideal because I have run out of longitudinal. I don't have enough room to supply that longitudinal trade-off to where he gets to the pitch attitude, which is making me a little apprehensive about a smaller system because I can see that same thing begin to happen in other areas.

MR. BOOTHE: So would no surge at all be better in your opinion?

MR. STOCKING: Well, right now on a 60-inch system I need everything that I can get to give them a proper cue that he is getting on the brakes properly.

MR. BOOTHE: Well, if we are talking about the system we described this morning, maybe Bob [Foster] has a point, maybe you couldn't get enough surge to make a difference anyway, so why require it?

MR. STOCKING: We are going to end up with less surge and it's going to be a more washed-out cue but it will be stronger than not having it at all. I can't make any judgment about which is correct, whether it's better to have some or not at all.

MR. HEFFLEY: Again, the real answer to this question is that it depends. It depends on the aircraft. It depends on the specific aircraft and task that you are trying to simulate here. If there is not a rapid onset of, I guess with braking of course that's—that's inherently a quick onset. But you know that as Chuck [Stocking] actually points out, with any reasonable amount of surge motion, you still can't sustain it. You have to very quickly fill that in with the pitch.

MR. BAKER: Not only can't you sustain it but in pitch you can't get anywhere as much acceleration, you are limited to two-tenths of a g probably.

MR. HEFFLEY: Granted. That's always going to be scaled down by a fair amount.

MR. BAKER: You can give the guy a pretty good jolt initially, but sustain, why even 20 degrees, that's like a four-tenths of a g at the most. Then you have used up all the motion base just to give that one cue.

MR. STOCKING: That is one area though where a pilot will accept feeling the pitch rotation because he knows it can't be happening. He is on the ground, he knows he is not rotating. And even though he feels a pitch rotation to get immediately to that location, he will accept something above his threshold. I routinely put it there.

MR. FOSTER: This issue of rejected takeoffs, though, if you look at the takeoff safety training aid, there is a lot of issues involved besides just the deceleration cues. I mean, the other things that are important is the brake pedal forces have to be correct in the simulator, there have been some cases on that where people were misled.

The other thing is the demonstration in the simulator should show, it should someplace show them what happens on a balanced runway takeoff when you reject at V_1 , you do indeed stop right at the end if you use full braking, et cetera. You show the facts of reverse thrust and why you can't depend on it, all those sorts of things.

I contend from the simulations, from having done these in the airplane, I was amazed at how—I don't want to call it violent or how exciting the maneuver, a real RTO is. My experience was out at Boeing on test flights for airplane acceptance. What amazed me, when you are going to buy the airplane, before you buy it they have carpet runners down the aisle so you can't get it dirty. They were demonstrating to one of our captains what the RTO function did. And we did it. The carpet slid up the aisle, that's how hard you are stopping. To me admittedly the deceleration is very strong, but just as strong is the banging and shaking that goes on. Because you have that strut compressed so hard every little crack in the runway is felt. And admittedly, it's a nice little cue when you start it, surge, but it's that sustained.

MR. BOOTHE: What about an anti-skid cycle, is surge—

MR. FOSTER: That's going to vary. The whole airplane is shaking.

MR. BOOTHE: So you can't distinguish from an anti-skid?

MR. FOSTER: I couldn't tell but I don't have a lot of experience on it.

MR. STOCKING: On the older systems that go to full release you can tell. But on the newer ones they are nice and smooth. If you have commuter class, what kind of anti-skid systems do they have?

MR. BOOTHE: I have no idea.

MR. STOCKING: You are talking about system differences.

MR. FOSTER: Where I have seen surge being a nice effect is where you have a condition where you've got patchy ice and stuff and you have feedback from the visual and that can go into the—that can—but you don't need that for recurrent range and checking, it's a nice effect, but again, given the mission don't hang any drop tanks on this we don't need.

MR. BOOTHE: Especially those that can fall off and burn.

MR. FOSTER: Or have to be maintained or cost me a couple bucks extra.

MR. BOOTHE: Tom [Longridge], Paul [Ray], what do you think you have heard in the last half hour?

MR. LONGRIDGE: I think we have gone around in a circle.

MR. RAY: I think Bob's [Foster] comment is exactly on. The violence of rejected takeoff, particularly as you point out up at V_1 where you are making the maximum effort stop, it almost makes the case for heave needs to be back in there, because how do you do—

MR. BOOTHE: We have heave.

MR. RAY: I thought somebody struck heave. Surge is certainly a player with anti-skid, as you can feel it cycling. If you want to call it the seat of your pants, you do in fact feel the anti-skid system—all aircraft I'm familiar with.

MR. BOOTHE: If it's as great a conglomeration of shaking as Bob [Foster] is describing, can you distinguish that from the other shaking? If you shake the thing and heave rather than surge, are you going to know the difference?

MR. RAY: I'm only pointing out you can distinguish from all that shake, rattle and roll that's going on, that change in deceleration through surge. You can detect it. That's why we put the question on the table.

MR. STOCKING: For—

MR. RAY: I know my own personal preference but I'm holding it back.

MR. BOOTHE: I don't want you to hold it back.

MR. STOCKING: For this type of maneuver to leave out surge you can use smoke and mirrors to cover it up with the accelerations, the violence of the maneuver and whatnot, the pilot will be able to tell the difference but he may not react to the difference.

MR. RAY: Right.

MR. STOCKING: Again, you are talking about what he can get away with or what you can get away with to meet your training objectives. That's a decision that maybe has to be made somewhere else.

MR. BOOTHE: Lloyd [Reid]?

MR. REID: What about what Norm [Bluteau] was saying? The crashes they experienced, it wasn't a full brake maneuver that was causing it, it was putting the power on.

MR. BLUTEAU: It was a go-around situation.

MR. REID: There is no shaking going on there.

MR. WILLMOTT: What if you had reduced the rate of inputs of the gravity align? You normally input the gravity align at a rate that the pilot will not feel.

MR. MARTIN: Then it's going to take you 30 seconds to make any sensible input.

MR. ADVANI: It will take a long time.

MR. STOCKING: You are talking about very specific programming to get it in one place where you want it, and another place where you don't want it. To me, going to the lesser degrees of freedom is much more rigorous a task in programming to try to get your cues back or some semblance of cue for any specific maneuver. It really becomes a problem.

MR. BLUTEAU: There is another aspect of this, which may be motion sickness. If you see something and you don't get the corresponding motion cue, you may cause sickness problems and

the longitudinal versus pitch is sometimes a factor in sickness where people feel the pitching but don't actually see it. After a while they are dizzy.

MR. BOOTHE: That is a good point, because I think cue, lack of cue correlation certainly does promote some sort of sickness or so-called simulator sickness, I guess. But I still, I have sympathy for your issue because I do think if we just run out to the regionals and say okay, guys, just get a six degree of freedom system with these specs, we may have less than a totally successful experience here. On the other hand, we do need to provide the cues that are necessary and sufficient, I guess, for the task.

And the third thing there is if this is to be an interim Level B standard, can it be written in such a way that we can recover later? Normally if we do something it's awfully hard to increase it, it's always easy to back off, but it's pretty hard to increase the stringency of a performance standard unless we are very careful the way we write it in the first place. So I can't answer those questions.

I don't have a problem with yaw, I think nobody in the room has a problem with eliminating yaw. So it's just a surge thing, and if we were to eliminate it, can we do our work in such a way that we can recover it later if we found it doesn't work? Is that a possibility?

MR. HEFFLEY: Well, Ed [Boothe], again this is—it's one of these "it depends" things. It depends on the abruptness of the specific case. In discussing math models for these we talked about the need to go out and obtain flight records. You are going to have documentation of what actual motion there is in some tasks and conditions and something like surge could be in there only if it's needed based on flight records.

And again you have to come up with some sort of recovery factor, some number that we don't know. And we aren't going to get it here.

MR. BOOTHE: So we can say if the airplane is severely underpowered you don't need surge?

MR. REID: And the brakes are real mushy.

MR. HEFFLEY: But it does seem like the right thing to do to try to give some benefit to reduce the number of axes or reduce level of complexity, and we are—it seems to me we are debating this surge thing pretty well on both sides. I mean, it's not an easily decided thing, I think.

MR. HARRIS: It seems the main thing about surge, the braking, it's onset, the thing about surge, it's an onset cue. You have to time stamp from there, you expect certain things to happen to decelerate at a certain cue. But the onset surely is important. Because you expect things to happen in certain times after it.

MR. HEFFLEY: Actually I suspect it's important from the standpoint of actually closing the loop on the brake pedal force.

MR. HARRIS: Normand [Bluteau] mentioned if you don't get the breaking cue, the onset cue for braking, you think there is no brakes.

MR. HEFFLEY: That actually seems pretty compelling right there, I suppose.

MR. BOOTHE: Paul [Ray]?

MR. RAY: If I could weigh that with the feedback I'm getting in the brake pedals themselves I may know what's needed. If I have a manually controlled brake system the responses are different than with anti-skid. A 757 or 767, for example, where you clearly experience anti-skid system cycling, that's where I feel the surge, personally. But I should also feel the correct feedback in the brake pedals.

My tendency to believe that we might be able to do away with surge on a Level B, rationally, is dependent upon the performance characteristics of the aircraft. There may be some aircraft that need additional motion cuing based upon the specific characteristics of that aircraft.

Particularly, in what is essentially a failure mode. Rejected takeoff means something failed. Now you are into abnormals. Baseline is that there is reasonable logic to exclude the need for surge, but potential performance characteristics of a given aircraft may necessitate surge.

MR. BOOTHE: So how are you going to know?

MR. RAY: It's up to the operator to figure out.

MR. BOOTHE: No, it's up to you to figure out later. He is going to throw the monkey in your lap.

MR. RAY: That's true.

MR. SMITH: Any abrupt throttle movements on a prop jet it seems consistent with what you are saying, even on a turbo you would need surge to get the right cue.

MR. BOOTHE: Stu [Willmott]?

MR. WILLMOTT: I guess it's a comment. Twenty percent of the simulators that are out there now are Level B, which means there are a hundred simulators out there now that are Level B that are being used for this type of training without surge and without sway (*Mr. Willmott later determined that there are 35 Level B FAA approved simulators*). We are suggesting that we add sway and that is the one thing that actually is a motion that triggers the pilot to respond. And that to me is the key in this takeoff and engine failure situation, you must have the cue that triggers a response that he must give. That's a part of the training that he needs to have. But, you know, I really don't see that we are making it easier for the regionals by asking them to put in surge as well.

MR. RAY: Those numbers, 20 percent, that's more or less [Levels] A and B combined, is it not, Stu [Willmott]?

MR. WILLMOTT: I think I counted [Level] B.

MR. RAY: I can't recall the specific numbers. But in fact the vast majority of the commuter simulators that have been brought on line in the last ten years are the [Levels] C and D, where in fact they do have all the motion cuing we're talking about. Over the last ten years, only five or so commuter Level B simulators have been brought into the marketplace.

MR. WILLMOTT: I mean, you know, the surge is something nice to add but it's not triggering the pilot to do something. It is, as you say, it's what he expects to feel when he does that. But he knows what he feels in the airplane when he does that.

MR. BOOTHE: It's not stimulating him to respond but feeding back information. Is that fair?

MR. WILLMOTT: But the key thing is adding the sway that is actually triggering him to do something.

MR. HARRIS: Just a quick one. Onset cues don't necessarily need to be large amplitude. So for employing the brakes you get a small kick forward, small amplitude.

MR. BOOTHE: Well, let me ask a question about that. If your pilot brakes you are going to get a little pitch, too.

MR. HARRIS: Sure.

MR. ADVANI: Very small.

MR. BOOTHE: Why can't we substitute that small pitch change, can I tell the difference between that and a surge anyway?

MR. HARRIS: Yes.

MR. ADVANI: You can tell.

MR. FOSTER: On an RTO the big difference you get with that nose strut compressed you get a lot more runway rumble. That comes back through even pitch.

MR. BOOTHE: Okay. I'm leaning towards—it's not my decision. I'm leaning towards scratching surge with the condition that Paul [Ray] might want to keep it if it's needed for the airplane. I have no clue right now how you might make that determination.

MR. RAY: I don't know, either.

MR. BAKER: So we are getting down to leaving two degrees of freedom out and the other four in?

MR. BOOTHE: I don't know what the consensus here is.

MR. LONGRIDGE: Let's go back to the original cost discussion. I thought we decided this morning that it might be as expensive to try to build a four degree of freedom system that still minimizes false cues as it would be to go ahead and build a six degree of freedom system. Are we throwing that argument out now and deciding "yes, there is a significant cost saving with going with a four DOF?"

MR. BAKER: Here is the situation with respect to motion based designs. As far as I know, there aren't any designs in the inventory right now that match what we are deciding right now, that's something, four axis lacking surge and yaw. There isn't a device out there like that. Certainly you could design one. A clever mechanic will design it, and will make something that does that. It's the position of the guys that build simulators that that's not going to be a cheap thing to do. And I tend to agree with that.

It also isn't clear how many simulators you have to build with this abbreviated motion base to cover your nonrecurring costs. So it's not real clear anybody is going to want to belly up to the bar and say we are going to build a cheaper motion base on the basis we are going to sell a hundred simulators a year. I don't think the market is a hundred simulators a year. If you could build a hundred or a thousand of them, it would be a moot point. You would go ahead and do that. But there are a lot of designs around for six axis bases, even if you don't have a 36-inch stroke, six axis base design in inventory, you can take the 60-inch design and scale it down, it scales down easily, you know the numbers are going to come out right. You don't have to do a lot of nonrecurring engineering to arrive at a 36-inch stroke base.

So I think if you deviate from an existing three axis design of which, you know, there is some on the Level B sims right now, you say I want a new three axis design, the practicality of it is that until I think the motion, the simulator manufacturers are convinced there is enough market there, they are not going to spend the nonrecurring engineering costs to do it. There isn't any cost savings in the ten you build. It costs even more to build the first few than it is to use an existing design.

Right now I would suggest that there isn't a marketing plan or a business plan for this particular device that says with any kind of accuracy how many we are going to sell, as an industry. How many we are going to sell to the regional airlines. I'm sure that people expect to sell some, clearly the FAA expects there will be some built or we wouldn't be going through this exercise. I think there isn't any question that there is a requirement that exists that has to be satisfied in some way or other.

But I still think that, especially based on historical data, the regionals are not going to step up and order these things by the hundreds. It would be a real surprise if that happened. So that's the practicality of building a new special motion base just for this application. And I'm not going to say it wouldn't happen, I'm not going to say we ought not to allow for that in the Advisory Circular, but we could go through an awful lot of exercise in trying to discover how to design a motion base that had only four axes and it would all come to nothing because the practicalities of designing it didn't ever yield a design.

We could exercise the psychologists and they could go off and run studies and they could say “yes, you could sort of do it if you leave these axes out and it doesn’t make a difference.” Two years from now we may have an answer, two years from now doesn’t get a solution to the problem. And, you know, somebody wants a four axis base, sure we can put one on paper, that’s not a problem. It’s just a question of whether or not there is enough market there to make it a reasonable thing to do.

MR. BOOTHE: I have a slightly different philosophical answer from that. I don’t think we are violating anything we said about six degrees of freedom standard system might be the cheapest way to go. That could very well be. But I do think we owe the industry a minimum requirement. If they choose to exceed that, it’s wonderful. But if we in this room were to say only four degrees of freedom are necessary for the takeoff task with the various kind of events listed here, then I think that’s what we should say. If they choose to meet that by the most economical means, which may be a six degree of freedom system that already exists, then that’s their decision, I think, and that may be the cheapest way for them to go.

But if we include things in a requirement that are not necessary, then I think we have exceeded the—I think we have exceeded the performance, minimum performance requirement concept.

So I don’t think it violates anything, Tom [Longridge], I’m just saying we ought to say what is least required to get the job done. And leave the design to the folks that want to build it, and then if it meets those least requirements to get the job done, it passes. That’s just my philosophy. And that’s what I was trying to get at when I was saying “well, what is the consensus on surge?” Paul [Ray]?

MR. RAY: I agree with that philosophy. Particularly in light of where we are currently looking. In our discussion of a Level B simulator, we must recognize that in initial training pilots are still going to the aircraft for certain maneuvers. However, they are not going to do V_1 cuts in the aircraft. They are going to do them in simulation, in Level B. But we can’t extrapolate or take our comments regarding surge and yaw to the Level C and D environment. In that case, with [Level] C or D, we are talking about all initial training, all takeoffs and landings, with zero airplane time. I’m confining my comments just to Level B, knowing what that environment means.

MR. BOOTHE: I confine my thoughts to a Level B for recurrent training. Now if a Level B is going to be used for initial training, which we have to consider, there would be a follow-up either in a higher level simulator or in an airplane. But if we try to maintain that application of recurrent training, then I think we ought to specify the minimum to do that.

MR. RAY: Right.

MR. BOOTHE: And if surge is not important in that concept, then we shouldn’t specify it. Even though I think the chances are ninety-nine and a half percent we are going to get it anyway, because I think to build a four degree of freedom system, as we have heard for two days, is probably not very practical unless something unexpected happens to the market. That doesn’t look likely.

MR. FOSTER: I think you have to throw out there that it’s not a four degree of freedom motion system, it’s saying a Level B purpose built simulator. It’s just one piece of the package.

MR. BOOTHE: That’s true.

MR. FOSTER: Which that is going—from the people I talked to, that’s going to get some attention of some manufacturers to try to do some innovative things.

MR. LONGRIDGE: Are we all saying some of the specifications that we recommended this morning would now apply to this four degree of freedom system even though the discussion was in the context of a six DOF system?

MR. BOOTHE: Well, it was, but I don't think that we would change what we said this morning. It would apply to the degrees of freedom that are left, if you will. Some of you that are more familiar with building motion systems might help me out.

MR. BAKER: I don't see any reason to change the numbers.

MR. BOOTHE: I don't think what we are saying now in any way violates or diminishes what we said this morning.

MR. SMITH: Ed [Boothe], it was kind of interesting, something Paul [Ray] said, you said and maybe Tom [Longridge] has a lot of insight on this, but I was talking with someone in the training industry who is pretty knowledgeable, and they seem to think the real training requirement is initial as much as recurrent because of the turn-over.

MR. BOOTHE: Yes, I think that's true.

MR. LONGRIDGE: I think that's true, but the feedback we get is they are not complaining about having to use Level C and D for initial. They are willing to eat that cost, wherever they need to go to get it. The issue is recurrent training.

MR. BOOTHE: I think if we could get a couple more tasks done in a simulator, their attitude will change about using the airplane. A few years ago it was absolutely "no, if I've got to use the airplane, if I've got to use the airplane for anything, I will use it for everything." I have seen a shift in attitude of people I have talked with. If we could do 80 percent or 85 percent of an initial certification in a simulator, including such things as engine failures, if we have to go out and do some normal procedures in the airplane, which is what would be required is acceptable, I see a shift there. I think this may serve initial enough in that respect.

MR. FOSTER: I agree with that, yes.

MR. BOOTHE: So the requirement is there, no doubt about it. I think this will do as I said, 80 or 85 percent, something like that.

So to go back to my question, trying to get from you a consensus or at least a majority opinion, do we strike surge here?

MR. HARRIS: Well, don't you think aircraft results—we can't strike surge?

MR. BOOTHE: Aircraft results?

Bob [Foster] can say for one commuter airplane—

MR. FOSTER: I'm not basing it so much on airplane results as to a lot of what Stu [Willmott] was saying about the fact that you are looking at cuing in the case of, I don't know what you call it, causal cuing versus feedback cuing or something like that. I'm not sure what the right terms are. Where we are saying or what I'm saying is that the surge effect is a nice effect and reinforces the pilot's behavior, but it's not what made him start to do the rejected takeoff or it's not what—I don't think it's what tells him necessarily that the anti-skid cycling, I agree with Paul [Ray], especially with the older systems you feel the pedals cycling is what you feel more than the airplane. But sway, its two primary purposes that I see is for runway alignment steering, it's a causal cue, it causes him to use the rudders to keep straight on the runway; and the other thing is to recognize the onset of that engine failure.

MR. HARRIS: You mentioned different types of cue that are known among psychologists as maneuver cue, which is pilot induced. And disturbance cue, which is somebody else shifting the aircraft, the pilot has to react. The disturbance cues are the ones that require attention.

Judith [Burki-Cohen] is going to agree or disagree, did I make sense, maneuver cues and disturbance cues?

MS. BÜRKI-COHEN: Can you repeat?

MR. HARRIS: I talked about maneuver cuing being pilot, and disturbance cues as external cues, as outside induced.

MR. BOOTHE: That's either God did it or you did it.

MR. RAY: That raises a good point, Ed [Boothe], that you may not have addressed. At least I don't think you did. The issue being random disturbance motion cuing during the simulated flights. Flights don't always occur in smooth air. Typically in simulation, instructors have a button that turns turbulence on or off. If it's off, you know it's off, it never occurs. Smooth air is present all the time. It's maybe a rhetorical question, should there be some random turbulence of varying levels occurring during the entire flight?

MR. HARRIS: Well, a lot of instructors that we have put the turbulence on like the lowest level, if it goes from one to nine they often put it on one and do flying like that. But there are other people who don't. Those tools are there for them to use.

MR. RAY: My question, Stu [Willmott], I appreciate your comment, is that continuous or is it random?

MR. WILLMOTT: I'm sure it's random with the instructors.

MR. RAY: It's random continuous versus random—

MR. WILLMOTT: Oh, the turbulence itself is random. Of course. Yes. We use the Dryden spectrum with "patchiness" on top.

MR. BOOTHE: Poor choice of words, maybe you are picking on my "continuous." What I could say in general and on all the time atmospheric disturbance, but I didn't mean to imply that the turbulence model would be changed. The patchy model with random disturbance, the continuous simply meant on all the time.

MR. RAY: I was referring to systems I have observed, the selection of turbulence is constant, it's not random in nature. I have seen more than one sim that have that type of turbulence embedded. That's the only turbulence they have. You can selectively pick one, two, three, four, perhaps even through ten levels. But if it's on, it's on all the time. It's not in fact a random disturbance.

MR. BOOTHE: Well, I don't want to spend time on that right now.

MR. RAY: I agree.

MR. BOOTHE: Stu [Willmott]?

MR. WILLMOTT: I was just going to comment if you intend to leave all of those things in the specification for the simulator that we were talking about, the phase margins, the 110 degrees per second squared, things like that, that's great as far as specifying the hardware that you need to be used for the motion. But we have still not specified what it is that we want it to do. It's rather like defining the control loading system in great detail but not ever doing any checks on the forces that are on the controls, as I see it.

MR. BOOTHE: No, I don't see it that way. Because you have an objective reference against which to check your control loading in. And here we have no objective reference against which to say we need this much sway or that much heave. And we have—you are right. We haven't addressed that. I brought that subject up on several occasions. But we haven't really addressed it, and the alternative was, which we have now drifted away from, the alternative was to just look at the motion objectives and see if we can work on them and we sort of stalled out about to spin in on surge.

So I am for just voting for four degrees of freedom here unless there are violent objections in the room, and write the specification in such a way that if we determine that's a mistake, then we can recover from it. I think since it's interim we ought to have that privilege. What do you think?

MR. BAKER: Isn't that going to create a problem for you if you decide it really doesn't work and you have got a bunch of four axis motion bases built? Is that an acceptable end game? I'm not suggesting what you said is a bad idea, I just want to say that's definitely a thing that could happen.

MR. BOOTHE: It is a thing that could happen, Bruce [Baker]. And I would hope, since we are talking of an interim requirement, that people would cautiously approach that with an existing design and limit it to provide these degrees of freedom somehow. Maybe that's not properly with the synergistic system—

MR. REID: No problem.

MR. BOOTHE: No problem?

MR. REID: Carrying on of extra expense in hardware, some extra.

MR. BAKER: You wouldn't limit a six axis base to four axis.

MR. REID: You could.

MR. BAKER: You wouldn't do it.

MR. BOOTHE: I wouldn't want to see somebody tool up for a four DOF system that's capable of only four degrees of freedom and then change the spec on them later. However, the caveat would be there.

MR. BAKER: Yes.

MR. BOOTHE: I don't know how to answer your question.

MR. BAKER: Is it also acceptable that we could start down this road with a four axis base and there could be two or three simulators under construction when we discover that that wasn't a good idea and change the spec and then you tell those simulator constructors you all are going to have to change your motion platform because you didn't get grandfathered in quite fast enough.

MR. ADVANI: Or the other way around, where someone starts building a six DOF and later on you say "well, you only needed four."

MR. BAKER: Well, yes, but in that case the system can still get certified.

MR. ADVANI: But the investment was made.

MR. BAKER: The investment was made and it's unfortunate. It's a lot more unfortunate to come and tell the guy "by the way, your motion platform is now a hunk of scrap. Go get another one." So I'm not saying what we are suggesting to do here is wrong, I'm just saying that the transition can get to be painful if it's not—if it ever does occur. If we have several machines under construction and some in the inventory—

MR. LONGRIDGE: We have to be careful to assure the industry that this is not going to be a risk. We have to be willing to bite the bullet, otherwise no one will ever build one of these things.

MR. SMITH: Typically when we have a draft interim we allow them to go ahead. However the reality of it has been pointed out, if you cut it off at very few machines, then they will never recover the design cost. And somebody is going to be—

MR. BAKER: Will be upset.

MR. SMITH: But then at the same time they would be almost unwise to even launch upon it considering it's an interim, and be advised this may be changed.

MR. BOOTHE: You had one more thing.

MR. FOSTER: That's the manufacturer and the buyer's decision. I think our purpose here is to say what are the requirements. And you guys put the programs together.

MR. BOOTHE: The same thing for a manufacturer would be if this is an interim thing to go with six degrees of freedom, I guess, the safe thing.

MR. FOSTER: I would approach it by either having some sort of prearranged thing like we have had with interim advisory circulars in the past, our Dash 8 was built on an interim Advisory [Circular 120-]40B. We had a letter to you we were starting that project, it would be okay.

The alternate approach would be if I'm going to take this bite of building this simulator as a user, I would put in the contract to have some sort of what does it mean if I now have to buy a six degree of freedom motion in terms of the manufacturer? What will you, to make that change to the contract and put a six DOF under it, what's it going to cost me if I have to do that? So there wouldn't be anything undefined. There is no risk.

MR. SMITH: Yes, there is. That's covered. That goes without saying you would be grandfathered if it were a draft and you start construction. The problem, the cost that the manufacturer would have, he spent all the up front money to design this which would take empty-ump—

MR. FOSTER: That's his decision.

MR. SMITH: Are we misleading him?

MR. BAKER: I don't think he is being misled. I don't think you are going to get very many four axis motion base for the first simulators.

MR. BOOTHE: I can't shake we have to specify the minimum and let the industry do its design.

MR. BAKER: The industry guys are here, they should be sensitive to this.

MR. HARRIS: It's up to you to specify the requirements. It's up to us to decide how we fulfill the requirements. I would say rather than build a four degree of freedom motion and design from cold, I would take a scaled down six degree of freedom.

MR. BOOTHE: So if that in the interim, if the final requirement were for more degrees of freedom you would be able to, rather than rehardware you could resoftware to get the additional degrees of freedom?

MR. BAKER: I think he did.

MR. HEFFLEY: You do it for a different reason, you do it just because it is cheaper to start with six.

MR. HARRIS: We have the software, we have the hardware, we have the nuts and bolts to go with it.

MR. BAKER: You wouldn't rewrite software to take out two degrees of freedom.

MR. HARRIS: Sure.

MR. BAKER: It's more work to take them out then leave them alone.

MR. BOOTHE: We are at a point where Allison's [The Reporter] fingers are turning blue. Perhaps since we started 15 minutes early we can take a break for 15 minutes and come back and settle this argument.

(Break taken.)

MR. RAY: I wanted to comment if I could, Ed [Boothe], apologies to everyone. Hilton [Smith] and I have to catch the 4:00 flight. We will be leaving in the next ten or 15 minutes.

On behalf of everyone here, thanks to you for the way you conducted the meeting and also the participation of everyone in the room. While some may not think we have gotten too far in two days, I think we have gotten farther than some may have expected to begin with. Thanks everyone for your outstanding input and freedom of the input. I haven't seen too much parochialism in the

comments. It's been an honest discussion of a very serious issue. We are seriously committed to increasing simulation use across the industry. Particularly focusing on the commuter industry. While we are trying to do it as cheaply as we possibly can we can't lose focus of the fact we are certifying pilots in these devices. While everyone may have the dream of getting a Level D sim or a Level E, as some have commented about, for under ten thousand dollars, there is that balance of recognizing what we are doing with these devices and the public trust that's been thrust upon our shoulders to make sure we maintain that safety that's needed, and it's in these devices we are putting together.

Thanks again, for the outstanding job you have done with putting this together, you [Boothe] and Don [Eldredge], Judith [Burki-Cohen] and our lovely group of transcribers [Allison and Dave Hoyman].

MR. BOOTHE: That applies to one.

MR. SMITH: I have enjoyed this, too, renewing old acquaintances, making new ones, I have really learned a lot. Thank you.

MR. BOOTHE: Are you going to leave right now?

MR. RAY: We have ten minutes.

MR. BOOTHE: There is just a couple things. We didn't close the issue on surge. I assume we are going to try without it. Is that concluded?

MR. RAY: I will try to wrap up my thoughts about it, at least. Where I think we are with this. I'm going to go from Level A up. It appears to me we are at a point where we have the obligation to identify those degrees of freedom required from Level A through D. I believe everyone understands what six degrees of freedom consists of. We, the FAA, have never, and erroneously so, identified what three degrees of freedom are satisfactory for a Level A simulator. We have assumed that those three degrees are what was present in the old Link system.

I believe we have the obligation today to clearly identify which three degrees. Based upon this meeting, those three would be pitch, roll and sway, for a Level A simulator.

Level B, from what I'm hearing here, would be the addition of heave, because we are involving a landing maneuver and the resultant necessity of having heave.

MR. BOOTHE: That's the question I've had. We have only talked about takeoff, if we say that for takeoff do we follow through the rest of the book for landing and post landing, four degrees of freedom?

MR. RAY: If that works. If the consensus is that a fifth degree is needed on landing, then it may change what I just said. It doesn't change the fact that I think we need to clearly identify what degrees of freedom we are talking about, not just any three, but a clearly defined three, four, five, whatever it should be.

MR. BOOTHE: We are not going to get all that done, obviously, so I don't know how we will handle completing that task, whether we might revise this and send it to you or perhaps if we could ask some of you to follow through on the thoughts and send them to me. I would appreciate any thoughts I get from you in that respect.

MR. RAY: If I could add another comment, I'm not trying to set aside all of the discussion that went on on the six degree system. That would similarly be a part of the same option available to anyone, if they selected a six degree system in lieu of a three degree defined as pitch, roll and sway for a Level A, or a four degree assuming the definition is pitch, roll, heave and sway. Such a six degree system alternative would be the six degree system as defined this morning.

MR. BOOTHE: I think you can always go to six.

MR. RAY: Sure. A six defined, you don't have to go to a six, a 60-inch six degree system, a six degree system defined as this, to put it very quickly, a 36-inch system that was defined this morning. That also drives the necessity to clearly define in the standards what [Levels] C and D six degree would be. It has to come out at the same time. And the inclination is to go with what the international group, even though it didn't get embedded, is to take a good look at that along with the requirement in [AC]120-63 and see if there are any disconnects. And then come out with [Levels] C and D six degree requirements at the same time. That's the general feeling or thought pattern I'm going through right now.

MR. BOOTHE: Thank you, Paul [Ray]. I had a suggestion, too, it would be nice to hear a little bit more about longer term plans, and not in detail, but just in some summary of what sort of research ideas to have in mind longer term. I don't know quite how to say what kinds of things or what things are to be studied, maybe Bruce [Baker], you have a better description of that.

MR. BAKER: Well, you and I talked about it during the break. And essentially I brought up, do we want to try to make suggestions of particular studies that we would like to see done and/or even make some gross suggestions on the approach that might be used to determine answers to questions that have come up in this meeting that we just don't have answers to.

MR. LONGRIDGE: I think we do. As a matter of fact I think that's on the agenda for the last hour, to get input of the group with regard to what are the most important research ideas that we ought to pursue because there is almost an infinite variety of them, we need to prioritize those.

MR. BAKER: We have 20 or 30 years of research of one type or another that's been looking at this type of problem and yet we don't seem to have any really good answers to the questions that keep coming up in these meetings. This isn't the first time I have sat in a meeting like this and we have said "well, how much motion do we need? How big should it be? What should its characteristics be? How many degrees of freedom?" And some, while I will admit this is a very hard problem, this is not something a couple guys will do in a couple weeks' time.

It would seem as a result of this meeting we have got some significant direction and I will bet you we can get two or three good ideas at least out of this group that says here is how we ought to attack this problem, and at least kind of head off in that direction and provide some feedback to the group and let us as individuals evaluate it and say "yes, I think that's a good result," or how about also looking at this and take another day or something during the test and look at another aspect of it, because the day will come when we are going to get asked how did you arrive at these conclusions, and the day is probably already here. If they didn't want to embarrass us, they would go ahead and ask the questions anyway.

MR. RAY: If I could offer at least one input to that process.

Going back to the comments that I made yesterday morning. We must define the training environment. Training environment being classically plus or minus 45 degrees of bank, plus or minus 30 degrees of pitch. If those aren't the right numbers, then we can modify those somewhat. We are not addressing acrobatic flight. We are talking basically IFR training that we provide typically to the commercial pilot. Any study, in my opinion, needs to focus on an environment. That impacts the visual requirements and how visual rolls into motion. To acquire results as we alluded to earlier with ten miles or 20 miles visibility as the focus, could provide some improper results, where in fact the training and the need for pilot assessment is reduced visibility such as with 150 feet or 300 feet visibility as opposed to 20 miles.

MR. BAKER: I'm reminded of another thing that happened some years ago when I didn't have as much gray hair. We ran a study up at Fort Monmouth in the avionics lab, we only ran one pilot in each aircraft, which of course is an anathema to a good psychologist. The fact is before we ran that pilot we had no data points. We knew we were closer to the answer than before we had any data points at all. I'm not suggesting we have to be totally thorough and run every aircraft type and every flight condition, because we have identified in this meeting flight conditions that we know are more critical than others. Like ground taxi isn't as important as aborted takeoff.

If I was going to spend my money I would spend it on aborted takeoffs as opposed to taxiing around the ramp.

MR. RAY: Proper cues resulting from any control input, whether it be nose wheel steering or braking action, I think are extremely important to pilot acceptance and realism. The need to visually navigate in and about an airfield would depend on the checking requirement.

MR. BAKER: I bet you could get consensus that the hardest problem to solve and the most critical one in terms of training the pilot has to do with emergency procedures in takeoff and landing. If we are going to solve one first, let me suggest we do one of those and not worry about taxiing on the apron over to the jetway. Maybe I'm naive about that.

MR. RAY: I go back to the initial instruction I received in a larger airplane, our instructor would not let us take off until we could taxi the aircraft satisfactorily on the ground with his eyes closed, without him being able to detect the aircraft stopping. It's a lot more important than some may want to give to it.

I have to run.

MR. BOOTHE: Yes, you do. That bus leaves early.

MR. RAY: Thanks again.

MR. BOOTHE: Chuck [Stocking]?

MR. STOCKING: I was going to say as long as we are talking about R&D projects, from the point of view, my point of view, which has been mostly cuing and supplying cues for the Level C and D simulators, plus or minus 30, 60-inch system would be to answer the question "can you take a six DOF, cut the stroke in half, and see what that does to the quality of the cues?" That would be my number one concern if we are going to go to a limited excursion six DOF system.

MR. ADVANI: Or even reduce the degrees of freedom on the six DOF system.

MR. STOCKING: I wouldn't reduce—first I would not reduce the degrees of freedom. First of all I would go to a six DOF system with restricted throw and see what that does to the quality of the simulation on a device that has been certified to Level C or D so you have a point of reference. You have got to—here are the crews that were flying this before, here is the crew flying it again, what is their attitude towards it? Does it have aircrew acceptance? What did it do to their flying? Did it degrade it? No impact at all? Those are the kind of questions you want answered.

From that point on you begin taking away your degrees of freedom. And assess what the impact is on that. You may get down to the point where all you need is heave.

MR. BAKER: I think that's a very reasonable thing to do and I think it's important to do that in a full flight sim.

MR. STOCKING: Yes. Using past experience as your steering course.

MR. BAKER: Essentially what you would like to do is change one parameter at a time and see if you can discover what the effects of the parameter is. Take a guy that flies the airplane, two or three guys to satisfy Judith [Burki-Cohen], and put them in there and take one thing away from them and see what his reaction is, see if he even notices. And look at both stroke and degrees of freedom on the motion platform and probably there is going to be other things people would want to look at unrelated to motion cue.

MR. BOOTHE: I would want to do more than see if he notices it. That doesn't really count to me. I would want to measure any change in his performance and workload, because without those I don't care whether he notices or not. Pilots don't notice things and compensate for them and don't know they compensated until some point at which they can no longer compensate. So asking them whether they noticed it, unless they reached that compensation saturation point, they won't tell you, they won't know.

MR. ADVANI: You do, however, have to be careful in how you measure workload.

MR. BOOTHE: I realize that. I made it sound simple and it's not, but still you have to come up with some sort of measurement, otherwise performance doesn't mean anything, in my opinion. Anyway, I just wanted to kick that in.

MR. BAKER: I agree with your comments, I agree exactly.

MR. ADVANI: Also going back to yesterday's discussion regarding phase lag, that's another very important design related parameter that needs further investigation. Although you need a system that has the response in order to study that and degrade the system qualities and assess then the pilot performance as a result.

MR. BAKER: Of all the parameters that we have discussed in the last two days that one is the one in which I think we can probably analytically get a better grip on than most of the other ones. Furthermore, in terms of getting it to what we agree is a good number we can get there.

MR. ADVANI: Analytically and empirically.

MR. BAKER: And with the hardware. I would like to answer the question how good does it need to be, because the question keeps coming up, particularly with respect to older equipment. We can potentially advise the industry you can get improvement in the handling qualities of the simulator if you go back and fix this one little parameter.

In terms of answering questions for this kind of study or this kind of project, since the industry feels it's not that hard to achieve a good result as far as phase is concerned, that's not as important as deciding how well can you do it if you start leaving out degrees of freedom.

MR. HARRIS: When you are talking about phase are you talking about the motion phase or are you talking motion phase with relation to available—

MR. ADVANI: Both.

MR. BAKER: Today we were talking about the phase on the motion platform.

MR. HARRIS: Motion is very straightforward. But motion with relation to visual is not quite so easy.

MR. BAKER: I agree with that.

MR. WILLMOTT: I think one of the things that would be in question in doing these studies is the drive equations, the model that you are using would suggest that those ought to be clearly understood by all before the study is done to ensure everyone is in agreement with those. If you do a study and there is one set of models and Frank [Cardullo] comes up and says "yes, you should have had nonlinear something or other," that throws all the results away.

MR. BAKER: We don't want the dimension of the parameter space to get too confining.

MR. BOOTHE: Lloyd [Reid] has done work in drive equations.

MR. REID: Many moons ago. You are right. I was going to bring up eventually that we haven't talked about one of the biggest distortions in our motion systems, and that's the washout.

MR. ADVANI: That's perhaps the most detectable variable.

MR. REID: I know we spend a lot of time making the hardware part as perfect as we can, then we throw these tremendous phase distortions and amplitude distortions in with our algorithms and try to minimize the false cues, the various imperfect cues that result, and maximize the good cues that result, and one of the things I was going to mention, it's maybe a little too researchy for this group to consider, but someone, and we might be interested in participating, should provide some subjective correlation between what pilots think and what the false cues are [that] they are facing under a range of conditions.

We have defined ways of specifying hardware properties like the AGARD[-AR-]144 did, the different things you can measure and systematically specify for your hardware. But the follow-on project was supposed to be the subjective ratings of different degrees of imperfection in the simulator by human pilots, so you would be able to have both parts of the picture. And that work was never done, never sponsored and carried out. We have poked away at it over the years but we haven't addressed the problem in any systematic way.

MR. ADVANI: We are gearing up to do that work.

MR. REID: Again, you are a few years away from doing that.

MR. ADVANI: I don't know about that.

MR. BOOTHE: You are talking about the subjective correlation between what pilots think—

MR. REID: When you put a pilot in and he flies a maneuver you ask him how was the motion, he will say “too jerky” or “I felt a bump in the wrong direction as I entered the turn” or whatever. You go back, look at time domain effects, usually, and try to determine what he was sensing and correct that. And quite often you are faced, if you are the tuning man, as I guess Chuck [Stocking] knows, you have trade-offs between different degrees of freedom. Quite often in the same maneuver you can make one thing better by making something else worse. Say tilt coordination during braking.

MR. STOCKING: Magnify the thing—

MR. REID: Get rid of the angular problem by making a linear problem worse, vice versa. That's the art, right? We don't have any documented pilot rating values for different levels of typical imperfect cues. There is a whole range of things, you can call them false cues, missing cues, scale cues, there is a whole range of things. It's a lot of work, someone is going to have to spend a lot of time to complete. And so that was one, it's not the kind of thing you want to put in a regulation, I'm sure.

MR. BOOTHE: There is something else we don't know. We never could get to today because we don't know how, if I wanted to do almost any kind of research in a simulator it seems to me the first thing I ought to know how to do is establish that simulator's known set cuing parameters as a reference base and work from there. For example, if I were to go out to an airline and say I'm going to measure motion effectiveness one way or another, and use their simulator, I'm measuring from a reference basis that they have established, and it may be useless. In fact it often is, because it's for various reasons that were mentioned in the room today, like shake and visual systems and that sort of thing, is attenuated and we don't know what the starting point is. We don't know what the starting point is for setting a simulator up in terms of what are the effective cues that ought to be there for a motion system to be effective. I'm not making myself clear, I guess I really don't know.

MR. REID: You are talking about the good cues, I was talking about the bad.

MR. ADVANI: I think what you are suggesting, Ed [Boothe], is that the simulator on which you do such evaluation should not be polluted by its own natural properties.

MR. BOOTHE: That, too, but I don't know what should the baseline be? What should the thing do to measure?

MR. BAKER: I was going to suggest a solution to that because Sunjoo [Advani] and I talked about that at the break. It's not unreasonable to take a reasonably good [Level] C or D simulator and start with that and make some measurements on that to get a baseline. Then have some of us engineering folks that have got motion experience, and I don't know if I want to put myself in that category compared to what some of these guys seem to know, but improve the system to where there is at least some reasonable consensus that's as good as you can do. And I think that you can do that mostly with software changes, okay? And then try different algorithms and try different

things that we have talked about. And at least from that we are going to get some data points, right?

We don't have any data points right now. We don't have an idea except for engineering judgment on a lot of these things. Admittedly probably that device, even after it's been modified, will not be as perfect as you could do if you started from scratch and did the best you know how. At least if we document what's there, and you know we can extrapolate a little bit off of what we measure if we know what it was we were dealing with as far as the device is concerned. If we don't document the device, as we have criticized other people for doing, and if we don't have some engineers look at it and say "yes, I think what's in there is about as good as we can do or as good as we can do with this device," then once again we have taken a lot of data and analyzed the data but we don't know for sure—

MR. BOOTHE: Even more so, if you do research on a simulator and you conclude certain things about the effectiveness of motion, and Lloyd [Reid] does an experiment and concludes certain things about the effectiveness of motion, I can't compare them because you started at different places. And we need a common starting place. What should the thing—

MR. BAKER: That's the reason I said use a training simulator. Something that is certified, Level C or Level D, because it's at least very, very representative of what the training manufacturers are building.

MR. BOOTHE: It's representative of what that airline got set up and approved, I'm sorry, it's not what these guys built.

MR. REID: I think maybe part of the answer to your problem could be that it depends on how basic the research is you are doing. If you are down to the nitty-gritty of saying I want to just study the acceleration cue for a one g step acceleration input, then you can, no matter what simulator you are using, you can document what's coming out in terms of the response using the instrumentation package that's there, and so it may not be what you think is the best or whatever but at least it will tell you what came out exactly. And then you can compare what different simulators did because each of them had a specific force and angular velocity trace for the same input and now you are comparing apples and apples in a sense.

It got to be the way it is of course because of the other things we were worried about but at least you know where it is. That's a real simple test, it's not the complete flying task you were thinking of.

MR. BOOTHE: I was thinking of a flying task, and if you were to set up your simulator and you were to eliminate surge and do tests with and without surge and see the difference, and Bruce [Baker] did the same thing with his simulator, unless you both started with the same set of cue capabilities that's very close, I couldn't use those results comparatively.

MR. LONGRIDGE: I'm not sure that's true.

MR. REID: I'm not sure you couldn't.

MR. LONGRIDGE: I think as long as you know what they are, you have to know what they are in engineering terms. You are certainly going to want to have more than one value of a simulator configuration, so you have some variability to which you can draw relationships.

I think the one thing that's missing in this discussion and that we all recognize, is ultimately we want to know whether this has any impact on how the pilot performs in the aircraft, and also what we need to do in addition to the ideas that we are going to propose is apply some of these engineering measures, like control technique, to how the individual performs in the aircraft, having been exposed to a given measured configuration in the simulator.

And that would be one of the priorities I think that we would like to pursue in this regard. I mean, it's been established that, and we all know, you can affect the performance of the pilot in the simulator by manipulating these various design characteristics of motion, but the claim of the

nonbelievers is “so what, you have never established that this has anything to do with how the individual performs in the airplane.”

So I would suggest that ought to be perhaps our number one priority in whatever research initiative we end up undertaking.

MR. BAKER: I wanted to make a comment on something Frank [Cardullo] said, I wish he was here to rebut what I say. He made a comment about proving anything about training transfer.

MS. BÜRKI-COHEN: Backward transfer.

MR. BAKER: I realize that may be, there isn't any proof of training transfer specifically for motion but there sure is for simulators in general. I mean, you guys certify people in simulators, now if there wasn't any training transfer I don't think you would do that.

MR. LONGRIDGE: Clearly there isn't extensive literature which documents there is transfer from a simulator to an airplane. What's different I think in this application, we are looking for 100 percent transfer and I don't think it's ever been documented that is in fact what happens when we certify somebody in a simulator.

MR. BAKER: I think you can probably rationally argue you don't need 100 percent transfer. If you get a high percentage of transfer that's sufficient.

What you are trying to do also is not have negative training in a simulator, not where he has to unlearn something to fly the airplane he just has to learn something additional in the airplane, because you can't learn something in the simulator.

There are simulators that I'm aware of that teach negative training real bad to the point where the instructor pilots are apprehensive about taking the student pilots up in the air after they have been in the simulator for two days. It's a military aircraft, so it's not anything he is going to have to face on CNN one of these nights, but that's a really scary thing to me that the simulator would be that bad. I mean, I have talked to several of the instructor pilots, I know some of them personally, it's a real thing.

Clearly that's off on one end of the spectrum in an area where we hope the FAA certified trainers never get. And the, you know, I think that there can be things done that will show positive training transfer and prove that there is training transfer in various areas of the simulator. Frank [Cardullo] said about motion he wasn't sure you could prove it, I'm not quite that negative, I think maybe it just hasn't been attacked from the right direction. And basically I make that statement very simply because we know if you turn the motion off, the guy flies the simulator a lot different than he does the airplane. So if the motion makes the simulator fly more like the airplane, then there is positive training transfer. Then you could almost make a proof just from that.

MR. LONGRIDGE: I think part of the problem is failure to use measures which are sufficiently sensitive to differences. That's why I say when we go to the aircraft we ought to be measuring things like control technique, control input, in addition to some of the other more grosser maneuver-oriented standard considerations.

MR. BAKER: Control input is a very important measure because you can take a PSD of it and you can make an estimate of how hard the guy is working. The PSD has a lot of energy, at two hertz you know the guy is working real hard. If the energy is all down at a half hertz or less you say he is not working very hard. You can make comparative measurements by looking at the power density.

MR. ADVANI: You definitely get a transfer between the aircraft and the simulator in that case. And that will lead you to some—in some direction at least.

MR. BAKER: That's right.

MR. BOOTHE: I think Bob [Heffley] has been looking at formulating some comment.

MR. HEFFLEY: I've been squirming around here. I mean, what all of you have just been saying, there is nothing to disagree with. I think what we see is that there are a lot of things to be answered and defined. We are having an awful time pinning down the requirements for this particular level of simulator that we are talking about with respect to motion. But it's all because we don't have the right engineering data to start with.

And, you know, it's another case here where the technology, simulator technology, in terms of sophistication of the systems being built has just totally outstripped all of the basic rationale and data that you need to get in and rationally design the systems. What people have been talking about in terms of gathering what we need is right on the mark. But the number one thing is to go about it in a way where you do gather data in a very systematic way. It really can't be done by one little group or another. It really needs to be done by whomever can bring something to bear on this. And the idea of a common baseline case that everybody shares in order to relate to one set of data to another, is really important. Except there probably needs to be several of these baseline cases.

MR. LONGRIDGE: Oh, yes.

MR. HEFFLEY: They need to be defined in terms of a very specific training segment or task. You really have to focus on these things in order to really study them properly. I think you really want to take advantage of not only these larger six degree of freedom training simulators that you all are familiar with, but you also want to go to very, very large amplitude simulators like an Ames VMS so you can really back way off in terms of motion limits and you can have rather long washouts. And then move back in. And let me just note that some of that stuff is going on right now. And I showed some of the material to Ed [Boothe] yesterday.

Some of the questions that we have been debating are under way, but they are not in the context of training. They are in the context of perceptual fidelity for research simulators which maybe lead to different answers on what are the system requirements.

And finally, real important, this idea of keeping track of what the pilot is doing when a pilot is in there either flying the simulator or flying the real aircraft. People have invented dozens of ways of looking at how pilots are flying the aircraft in terms of performance or control strategy or power spectral density or other metrics. But that's where I think you have to leave things up to individual research groups, maybe doing whatever they are doing—working the problem however they want to work it. But that is the key way that you start to get a handle on control strategy and whether what the pilot is learning in the simulator is getting carried over to flight. I've got some study results from several years back where we did actually measure control strategy in very direct engineering terms and where we had good control groups between simulator training and in aircraft training for transition training. And you could sure see transfer of training okay, but you could also see the fact that when the pilots were learning how to—in this case—land an airplane, that what they were learning on the simulator was not a very good control strategy. And it got carried over in their check rides to the real aircraft. There were clear instances of hard landings and also the identified control strategies were inappropriate to flight.

Yes, they readapted after they made two or three landings in the real aircraft, but there were serious training deficiencies. I think these are the things that somehow you really want to bring all to bear in a systematic way so that the next time this whole issue of how to specify simulator requirements comes up, there is hopefully a more rational approach in answer to all of the things that we have been concerned with.

MR. MARTIN: Just to add some thoughts on that, and maybe to extend it a tad. One thing I was thinking is that you could take a look at some training transfer effects from some of your current simulators and try some transfer studies into a variable stability aircraft—that may not cost you much more than renting time in a VMS or something. You might do some interesting studies there if you can figure out what sort of control strategy measures and workload measures you want to look at.

MR. LONGRIDGE: How come the Air Force has never done this?

MR. MARTIN: Well, there were plans at one time. They got thwarted by cutbacks in funding for this sort of research.

MR. LONGRIDGE: Probably so. They already proved that motion is not necessary, so.

MR. MARTIN: You can make a variable stability aircraft behave pretty much as the aircraft for whatever simulator might be available to do the ground-based portion of the study on.

MR. LONGRIDGE: But you would have to have matching ground—the aircraft that you are simulating in both situations would have to be the same one. Is that not true?

MR. MARTIN: Well, you probably want to take your aero data from the simulator, and put it into your variable stability aircraft and operate in some region where the variable stability aircraft would represent that data. You would be able to control things like turbulence or whatever parameters you wish to look at. You could make that variable stability aircraft behave like the other aircraft for landing and whatever.

MR. STOCKING: We will see you all. Thank you very much. Nice to meet you all. Maybe we will get together again.

MR. LONGRIDGE: I'm sure we will.

MR. HEFFLEY: Following on to what Ed [Martin] is saying here, you don't necessarily even have to be thinking in terms of a variable stability aircraft. Look, if somebody is going to go out and build a simulator, they may be having to instrument an aircraft in order to gather validation data. Perfect opportunity, if you happen to have a little bit of extra engineering resources, to also gather data on how the pilot is flying the particular maneuvers and gather in-flight data that are appropriate, and finally, to bring him back to the simulator.

MR. REID: You could make that part of the process that the companies like Dave Kohlman's company would perform as part of your sim package. Part of the sim package would be pilot flying characteristics or technique. As part of the package.

MR. HEFFLEY: Because it's important to be looking at, in the end to be looking at your simulator in the very same context that you have been looking at that real aircraft. And you have got to have the time history data, or the—you have to have some documentation of where exactly you were flying and how you were flying it. And you just cannot ever go too terribly far, it seems, with just simply subjective or commentary, you have to have the records.

MR. BOOTHE: But it would be really interesting to have an instrumented airplane so we could measure at least pilot control inputs. And do handling quality rating in the airplane using recognized standards, and that's subjective but it's a very structured subjective scale.

MR. HEFFLEY: Absolutely.

MR. BOOTHE: So there is a small standard deviation of answers. If pilots use it correctly. So then you could do that same thing in a simulator using the same pilot rating scale. And I think you would just be surprised at the outcome. I think that would be a most interesting thing to do. It won't tell you what's wrong, it will just tell you there is a difference.

MR. HEFFLEY: And Ed [Boothe], you know, in the last couple of years I guess we have been doing exactly that same thing, and this is in the military helicopter area, but there has been a lot of hours of flying a Chinook around through specific flight tasks and getting careful pilot ratings and careful flight data records and bringing that back to a manned simulator in order to try and validate that, and even though in this case it's a simulator with very, very large motion excursions, same—all the same issues have come up that we have been talking about here. And you have to have the objective engineering data in order to really understand what's going on and understand whether your simulator really is valid, whether it's inducing the same way of flying.

But, you know, I think a lot of the methods are really there. And it's a matter of really bringing it to bear on this sort of a problem in a systematic way, which is something that the FAA could really foster.

MR. LONGRIDGE: I agree.

MR. HEFFLEY: Really help everybody focus in a coordinated way.

MR. ADVANI: I think what you are also suggesting is that you need the availability of an aircraft and high enough bandwidth simulators so it's the quality of the simulation facility that you are also—I should emphasize the availability of high bandwidth six DOF system as well as an aircraft and the model of that aircraft in the simulator.

MR. BOOTHE: Tom [Longridge], how much money have you got?

MR. LONGRIDGE: Not enough. I'm sure.

MR. BAKER: He didn't ask you if you had enough, he asked you how much.

MR. BOOTHE: Smart man over there.

MR. BAKER: Then he will decide if it's enough or not.

MR. ADVANI: It doesn't necessarily have to be something unaffordable if it could be tied into existing research plans, such as what we are already undertaking. So it could be very cost effective in the long term.

MR. LONGRIDGE: I think we are never going to do all that needs to be done, but clearly I think we can make a significant inroad in terms of some of the issues that were raised today. I don't see why we can't do that. I'm just amazed it's never been done.

MR. BAKER: What kind of time schedule would you see you are under to get some—

MR. LONGRIDGE: We are under immediate, I don't know, before the end of this calendar year with regard to whatever interim advisory circular revisions are going to be made for Level B, those will have been accomplished. I can absolutely guarantee that.

With regard to the research, we are not under any particular gun, it's really a matter of our own desires to get the answers to these questions as soon as we can. I would anticipate that is something we would like to initiate within the next year. The R&D. But we are not going to wait for the R&D in order to make these changes, we can't do that.

MR. ADVANI: You mean the final changes or preliminary changes?

MR. LONGRIDGE: You know, I was talking to Paul [Ray] about this. It's kind of a matter of semantics, isn't it? Everything is always subject to revision.

MR. ADVANI: Yes.

MR. LONGRIDGE: Whether we want to call these interim or whatever we want to call them, there is going to be a certain element of risk involved for someone that wants to build a four DOF system.

MR. BOOTHE: Yes. Everything is subject to revision, I think how you aim it in the first place gives sort of signals to the industry as to what your intent might be. If you don't say it's interim then they might think this is it.

MR. LONGRIDGE: That might be a reason not to call it interim. So that we don't raise fears unnecessarily. It's probably not going to be interim. You know, at least until the R&D is done.

MR. BOOTHE: If that's the case then I would agree we shouldn't say interim, and people that can go do their thing with the assurance whatever they do has some remaining rights and use after the next revision, which is the way we have always done it, that's, as you know, that's good and bad because Bob [Foster] can sit there and honestly say all those old [Level] B, three degree of

freedom B systems, those that are still working we don't really know what they are doing, but they are working and pilots are flying airplanes.

MR. LONGRIDGE: That's true. We are talking about Level B for the commuter community and there aren't a whole lot of ones out there that we need to worry about.

MR. BOOTHE: That is a question that maybe some people have, and I have myself, is the intention to revise the Advisory Circular to add a category that's called Level B regional or something like that? Or will we simply revise the existing Level B?

MR. LONGRIDGE: That's up to Paul [Ray]. My recommendation would be that we are just going to revise Level B. Clearly whatever we do for the regionals ought to be available to the entire industry.

MR. BAKER: The other side of it is people are not building new Level B sims in any quantity at all, it's not cost effective—

MR. LONGRIDGE: That's right.

MR. BAKER: —the way the regs are written right now. I don't think you are going to penalize anybody by revising Level B aiming it towards the commuter aircraft operators. And ignoring the fact that somebody sometime might want to design a new Level B to the old standard. You could still allow them to do that if you wanted to, you could put a caveat or not in there you could go back and use [AC]120-40B the way it is for a Level B sim. I don't think you are going to have a lot of takers on that.

MR. LONGRIDGE: I wouldn't think so. And no one is going to build to the new standard, either, unless it's cost effective and unless those regional airlines that are presently contemplating trying to convince the FAA to allow them to use FTDs can buy these Level Bs for about the same amount of money as they would have spent on those FTDs.

MR. BOOTHE: I think the only way we can do that is twist the FTD manufacturers' arms to raise their prices.

MR. REID: That's one approach. You can always add a surtax.

MR. BOOTHE: I just don't think a Level B can be produced for that amount of money. I know there are people who say they can do it, and I hope they can. But I just can't put it together in my own mind that that can be done. So I hope they are innovative enough to follow through and to be able to produce a Level B for the numbers I've heard quoted.

MR. LONGRIDGE: All we can do is create the conditions.

MR. BOOTHE: Absolutely. So—

MR. BAKER: Have you all looked at the problem of the economics of this new Level B definition? I assume that you have looked at the training scenario that would be allowed under this category Level B.

MR. LONGRIDGE: Sure.

MR. BAKER: Have you run that by a few of the airlines to get their comment on it to say "yes, we would buy a Level B as opposed to Level C because it provides"—well, you can't ask them that question, you have to say what price would a Level B be desirable versus Level C because it gives you enough training value that you don't get in an FTD but it's enough cheaper than a Level C to make it worthwhile to buy it instead of going on and buying a Level C.

MR. LONGRIDGE: We have had these two discussions, we have had two meetings with the Regional Airline Association specifically on this subject. We have indicated, I mean we have indicated that we are looking for something in the neighborhood of a three million to four million dollar price range, which we think is significantly cheaper than a Level C or D.

MR. BAKER: Yes.

MR. BOOTHE: But hasn't the regional airline industry also established a target price that they say beyond this we can't play the game?

MR. LONGRIDGE: It depends on who you talk to. There is quite a diversity of opinion even among those airlines. Some of the regionals are very safety conscious, they are willing to spend the money, and there are others that aren't. It's hard to get a consensus. They are not as organized a group as the Air Transport Association is, for example.

MR. BOOTHE: Do you have any feel for where the more safety consciousness lies, does it lie amongst those who may fly smaller jet airplanes or do you have any feel for how people that fly regional jets, say, compare to those who fly Beech 1900s in terms of—

MR. LONGRIDGE: We have people that fly regional jets and Beech 1900s, so Comair is a good example. I don't know if I want to respond to that.

MR. BOOTHE: All right. What level of safety—as soon as you start naming airplanes you almost start naming airlines. Sorry I asked that.

MR. LONGRIDGE: I think something brought up earlier about having research designs reviewed maybe by this group or somebody like this group is a good idea. Because so much of the research that has been done has been flawed in one way or the other and that may be because the people that are doing it have expertise in a certain area and maybe not in another, and what we need is an interdisciplinary group. Clearly we need to bring the engineering expertise to bear. On the other hand, we need to have the behavioral science expertise there as well because ultimately we are interested in behavior in that aircraft.

What I would propose is the FAA and Volpe, you know, develop their prototype research designs and maybe run it by this group for those people willing to take the time and read what we are proposing to do and make criticisms, so we are probably only going to get one shot at this. We need to try to do as good a job as we can do.

MR. BAKER: You will get more shots if the person is a good one. But if the person doesn't yield anything useful, you will probably have trouble getting money for the second shot.

MR. LONGRIDGE: That's probably true.

MR. BAKER: If something really good, I expect that it's likely that something really good would come out of this research. If something really good comes out of this you can stand on the soap box and say "hey, look right here what we did, we got good answers to tough questions." You go in the next time and you want to pursue that a little further and look at different aircraft or parameters, people would be more inclined to give you the money.

But if you come up with another one of these studies that's inconclusive for the application, then the boss is probably going to say why bother.

MR. LONGRIDGE: I agree.

MS. BÜRKI-COHEN: One thing to keep in mind, the more you want a conclusive answer, the simpler the question has to be. You cannot ask too many questions in one experiment if you want to have a conclusive answer.

MR. LONGRIDGE: The usual conclusion is more research is needed.

MR. BAKER: I don't want that answer.

MR. IRVING: More money.

MR. BOOTHE: Is the JAA pursuing anything such as we have been discussing for the last half hour or so, Don [Irving], that you know about? Are there any ideas of any research in this full flight training or flight simulation?

MR. IRVING: Most definitely not. The JAA has no money to do any such thing. It's a very small umbrella body in Europe, it draws its resources from the various national authorities. There is absolutely nothing.

MR. BOOTHE: What about national authorities such as the CAA?

MR. IRVING: We have a research project, it's mainly air traffic directed, human factors, technical things, whatever. Nothing I'm aware of. But I'm sure that's an area we have to explore. Sunjoo [Advani] is—

MR. ADVANI: There is an interest from the RLD, the Dutch Department of Civil Aviation, in looking at simulator fidelity. They are interested in tying up with other activities such as this, and conducting a multi-disciplinary effort in that sense, so yes, there is an interest from our side and we shall have backing as well as interest. We now have to work together to make this real.

MR. LONGRIDGE: Yes.

MR. BOOTHE: You have a money source, huh?

MR. ADVANI: We are working on that. We are trying to establish a synergistic cooperation and funding source, where airlines, aviation authorities, [and] simulator manufacturers are all involved with research institutes. That's the only way which we feel that something like this can be done. Not only to address the financial issues, but so that the interest of all these groups are addressed simultaneously.

MR. BOOTHE: Are you forming some sort of advisory group amongst those people to monitor and fund research for simulation?

MR. ADVANI: SIMONA has an Advisory Board for Research and Development. The members of this group, including those whom I just mentioned, provide at least an input, and yes, financial support. We have to make the rest of this take shape, because, as you know, it's a fairly new program. It's just becoming operational. And so we would like to see a joint effort with all of you people to carry this through. But yes, the infrastructure is taking shape, to address your concerns effectively.

MR. BOOTHE: Okay, I see Lloyd [Reid] is getting his coat on.

MR. REID: It's cold in here.

MR. BOOTHE: While I still have an opportunity, those of us remaining I would certainly like to thank you for being here. I know it's a big hunk out of your time to come and spend two days with us and give us your advice. And I certainly appreciate it and we have people from Canada and the UK and Netherlands and the UK again, and Canada again, as well as scattered around the USA, and I know you came a long way and if you are like me you notice those trips these days. So I say I appreciate your participation very much, all of you.

MR. LONGRIDGE: I would certainly like to second those remarks, you know, and those that Paul Ray made. This has been a very, very enjoyable experience for me and I believe that the input that we've heard today will indeed have an impact on where we go in the future in flight simulation, especially for the commuters. Thank you all.

MR. IRVING: Thank you very much for the invitation, we look forward to simulated travel in the future. A really useful discussion.

**Transcript of the
Joint FAA/Industry Symposium
on
Level B Airplane Simulator
Motion Requirements**

Part 7 of 9

Appendix 1:

Longridge, T., Ray, P., Boothe, E., & Bürki-Cohen, J. (1996). Initiative towards more affordable flight simulators for U.S. commuter airline training. *Royal Aeronautical Society Conference on Training - Lowering the Cost, Maintaining the Fidelity* (pp. 2.1-2.17), London, UK

**Washington Dulles Airport Hilton
June 19 - 20, 1996**

**INITIATIVE TOWARDS MORE AFFORDABLE FLIGHT SIMULATORS
FOR U.S. COMMUTER AIRLINE TRAINING**

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Abstract

Recent regulatory action, coupled to a policy of encouraging commuter airlines to conduct all pilot training and checking activities in ground based equipment, has created an impetus to consider how best to ameliorate the conditions which have discouraged the use of such equipment for pilot recurrent training by commuter airlines in the United States. This paper compares the relative merits of permitting additional recurrent training credit for enhanced flight training devices versus revising the qualification standards for Level B full flight simulators to achieve enhanced affordability. The current status of an ongoing Level B flight simulator qualification standards review, results to date, and future plans, including plans for the development of a comprehensive applied research program, are discussed.

Background

The use of flight simulators for initial and recurrent pilot training by U.S. major airlines is universal, and its effectiveness is well recognized. However, the use of such equipment by smaller U.S. commuter airlines is mixed. While many commuter airlines use approved simulator resources available from aircraft manufacturers and training centers for initial pilot certification, smaller airlines frequently do not make use of such equipment for recurrent pilot training, due to various considerations, such as cost, convenience, and flight simulator availability. For airlines employing small aircraft, the per hour cost of operating an aircraft for training may compare favorably with the cost of contracting for simulator time. For some commuter aircraft, simulator resources may be very limited in availability, and they may be inconveniently located geographically for U.S. operators.

On 20 December 1995, the Federal Aviation Administration (FAA) issued a new regulation (Ref 1) applicable to all airlines that operate scheduled air carrier service in airplanes having ten or more passenger seats. This new regulation, Part 119 of Title 14, Code of

Federal Regulations (14 CFR), encompasses all scheduled commuter airlines that operate airplanes of 10 or more seats under 14 CFR, Part 135. Among its provisions, it requires all such airlines to conduct pilot training and evaluation in accordance with the same provisions of the Federal Aviation Regulations (FAR) that apply to major airlines, namely 14 CFR, Part 121. These changes are intended to encourage one standard of safety for all air carriers, regardless of the size of their aircraft or the range of their flight operations. In concert with these new rules, the FAA has adopted a policy of encouraging commuter airlines to transition their pilot training programs out of the aircraft and into ground-based training equipment. However, it is likely the effective realization of this policy will not occur until the major obstacles which have historically restricted access of commuter airlines to such equipment, namely cost, convenience, and availability, are removed. If this is to occur on a timely basis, the FAA must act proactively in meeting the needs of the commuter airlines for affordable training equipment. The FAA has also concluded that for any such effort to be successful without compromising safety, it must be accomplished without degradation in the qualification standards for such equipment.

The FAA qualification requirements for a flight training device (FTD) are defined by Advisory Circular (AC) 120-45A (Ref 2), which defines seven levels of such equipment. The credit permitted for a corresponding FTD level is proscribed as an appendix to the FAA Practical Test Standards, as revised (Ref 3). Within the U.S., the Regional Airline Association has proposed that the FAA consider expanded options for the use of FTDs, a proposal which has also been enthusiastically endorsed by those equipment manufacturers for whom FTDs constitute a principle product line. The proposed strategy would entail an upgraded Level 5 or Level 6 FTD, consisting of an enhanced aeromodeling package and the addition of some type of visual image generation and display system. In some proposals, the addition of a low cost, small throw, three or four degree-of-freedom motion

platform has also been discussed, although design specifications and associated capabilities have yet to be clearly defined. This enhanced FTD alternative is considered appealing by its proponents, because, provided the FAA were to agree to allow full credit for the use of such equipment in recurrent training and checking, it appears that this proposal would have the potential of addressing all of the major obstacles discussed above.

From a regulatory perspective, however, there are certain drawbacks to this proposed approach. The first such drawback concerns the need for standardization in equipment qualification, in order to maintain acceptable standards of safety for pilot training and checking. As the purposes for which the FAA established the category of equipment called FTD did not incorporate an intent to address the full spectrum of pilot training needs, the existing FTD qualifications standards are not applicable to the use of these devices for such broad purposes. FTDs were established for use within an overall air carrier pilot training curriculum, which must either employ a full flight simulator (FFS), or the aircraft itself, as an essential component. The FFS provides an FAA-qualified vehicle for training and testing the skill integration required for the full range of flight operations. The FTD provides an FAA-qualified vehicle for mastering the skills associated with individual flight tasks, particularly procedural skills. Use of an FTD better enables matching training objectives to training equipment, by virtue of permitting training on lower level enabling objectives to occur on lower level equipment.

This practice clearly permits more efficient use of FFS time, by concentrating use of the latter on those skills for which the FTD is not a suitable vehicle - namely, flight operations training and evaluation, in which the training equipment must be capable of presenting a full representative range of operational tasks, conditions, and contingencies. While the FAA has authorized training and checking credit for certain individual flight maneuvers to be accomplished in an FTD, the FAR also require

that the demonstration of pilot proficiency for certain other tasks be completed in an appropriately qualified FFS, or in an aircraft, as part of the air carrier's approved overall training program. For recurrent pilot training proficiency checks, unless the landing maneuvers are accomplished in a Level B or higher FFS, evaluation of proficiency on these maneuvers must be conducted in the aircraft, typically accomplished by the satisfactory completion of at least two landings during the required operational (line) evaluation. In addition, 14 CFR Part 121 requires that recurrent windshear training be accomplished annually in a FFS.

In 1990 the FAA issued Special Federal Aviation Regulation (SFAR) 58, Advanced Qualification Program (AQP), which created a voluntary alternative to the traditional 14 CFR Part 121 requirements for pilot training and checking (Ref 4). SFAR 58 provides a regulatory mechanism on which basis the FAA may approve significant departures from traditional requirements, including the authorized use of equipment for training. It has been argued by some in the training development community that "..... qualification of ground-based devices for training needs to be based on their effectiveness for that purpose, not solely on their verisimilitude to an airplane" (Ref 5), and that ".....what an effective simulation requires is as many of the psychophysical, cockpit management and communications demands as possible, rather than technical, physical, or aerodynamic fidelity to a particular aircraft type. Suitable simulation devices thus need "functional" fidelity and the simulation scenario must ensure appropriate "operational" and "embodied" fidelity." (Ref 6). Under AQP it is possible to conduct pilot training which is fully consistent with this philosophy, and to obtain FAA approval for the use in an AQP curriculum of equipment based upon such functional considerations, rather than on engineering criteria. It is not possible, however, to conduct the evaluation of end-level pilot proficiency in such equipment.

In the U.S., as in many other countries today, regulations permit pilot training, qualification, and certification to be conducted entirely in ground-based equipment. Pilots qualified on such a basis are permitted to perform immediately as cockpit crewmembers in aircraft which fly passengers in revenue operations, albeit under the supervision of a check airman during the initial operating experience which follows upgrade or transition training. Recurrent training for continuing qualification of pilots can be accomplished entirely in ground-based equipment. Consequently, it is critical to safety that the ground-based equipment employed to evaluate end level proficiency for such purposes be qualified as replicating the aircraft over the full range of operational tasks, conditions, and contingencies.

Even in AQP, therefore, there are clear restraints on the use of equipment for assessing terminal proficiency. Such equipment must be qualified by the FAA, and it must be approved for its intended use as AQP proficiency evaluation media. AQP does offer considerably flexibility with respect to the use of FTDs for the progressive sign-off of proficiency on individual objectives, including training to proficiency on technical and/or cognitively oriented objectives. However, the final criterion for successful completion of an AQP curriculum is the formal evaluation of proficiency in realistic operational scenarios that test a diagnostic sample of technical and cognitive skills in a systematically developed Line Operational Evaluation (LOE), which is designed to test both sets of skills together. The FAA has determined that only a qualified FFS is an acceptable media for LOE.

Authorization of an “enhanced” FTD to accomplish recurrent training and checking, whether for credit on specific maneuvers under a traditional 14 CFR Part 121 program or under SFAR 58 with respect to evaluation on specific proficiency objectives, would require the development of appropriate equipment qualification standards for the modified configuration of devices to be employed for those purposes. Alternatively, it would

necessitate the application of existing FFS qualification standards to the enhanced components of that equipment. It would also require modification to, or exemption from, the existing FAR pertaining to the requirements for FAA approval of an air carrier’s pilot training program under Part 121. Since the enhancements to an FTD necessary to justify these actions would in effect be identical to those required to upgrade the device to a FFS, it is highly questionable whether this proposed course of action is warranted.

From an FAA perspective, a more rationale course of action would be to take the existing qualification standards for a Level B simulator as a starting point, and determine (a) whether more affordable means of meeting those equipment standards can be achieved, and (b) if certain revisions to those qualification standards can be accomplished which would enhance affordability without degrading the quality of equipment performance. AC 120-40B (Ref 7) defines four FFS levels - A, B, C, and D. Of these, Level B appears to be the most logical target for this endeavor, because it can be used for 100% of recurrent training, equipment for recurrent training use is among the most significant cost considerations for U.S. commuter airlines, and the engineering requirements for a Level B simulator are such that the likelihood of a successful outcome for this review is higher than would be the case for a Level C or D simulator. Most U.S. regional airlines are already using a Level C or D FFS for initial and transition pilot training. Their use for that purpose is recognized as cost effective, but the cost of purchasing or leasing access to that level of equipment for pilot recurrent training is not considered to be acceptable by many commuter airlines, which continue to find it financially advantageous to conduct recurrent training and checking in the aircraft. Few, if any, Level B (or Level A) simulators are presently available for use with commuter class aircraft in the U.S..

The choice of a Level B simulator as a target system is driven by the stated policy of the FAA to encourage commuter airlines to conduct all of

their training in ground-based equipment, rather than in the aircraft. While a Level A simulator can be employed under 14 CFR Part 121 to accomplish most of the requirements for aircraft specific recurrent pilot training and checking, the regulations require that if limited to that level of equipment, then two landings under the observation of a check airman must also be accomplished in the aircraft within the due period of the proficiency check for a given pilot. As previously noted, the two landings are typically observed during the required operational (line) evaluation, thereby necessitating at least two flight segments. If a Level B simulator is utilized for the proficiency check, the line checking requirement may be satisfied with a single flight segment, thereby potentially reducing the workload on check airmen by 50%. Another consideration for choice of Level B as the starting point concerns the feasibility of generalizing between equipment levels. Downward extension from Level B to Level A would appear to be more practical than attempting to extrapolate in the opposite direction..

Accordingly, the FAA is undertaking a comprehensive review of the equipment qualification standards for Level B FFS. This effort constitutes the initial phase of a systematic, multi-year program of FAA-sponsored flight simulator applied research, intended to provide empirical data on the relationships between training equipment engineering characteristics, pilot cueing requirements, equipment cueing effectiveness, and equipment pilot training and evaluation effectiveness. As results become available, they will be presented by the FAA for discussion and potential application internationally.

FAA efforts regarding this issue are supportive of ongoing international initiatives to improve the quality of simulation and its use. The FAA actively supports the recently adopted international standards for Level I and II simulators, as exemplified by their incorporation into FAA Level C and D simulator qualification standards. This paper will describe the current status of the Level B

flight simulator qualification standards review, progress to date, and future plans, including plans for the development of a comprehensive applied research program. The paper constitutes a description of work in progress.

Review of Level B Simulator Qualification Standards

The baseline for this review is AC120-40B and the simulator validation tables therein. The review is being conducted on a progressive basis, beginning with the data requirements for validation of the aeromodel for a Level B flight simulator, since this consideration is fundamental to the fidelity of the simulator's handling characteristics, and is crucial for pilot acceptance of such equipment as a substitute for the aircraft. The second priority for this review is Level B flight simulator motion cueing. The third priority is Level B flight simulator visual display technology. Although there are other considerations to simulator validation, the FAA has determined that these three priorities have the biggest potential for success relative to achieving increased flight simulator affordability. To date, however, only the aeromodel review has been initiated.

Aeromodel Validation

In initiating a review of those portions of AC120-40B pertaining to the validation of the aeromodeling for a Level B simulator, each test was examined with regard to the following questions: Given a commuter class aircraft with wing mounted turboprop engines, (a) what is the objective of this test? (b) is the test important to simulator fidelity from the perspective of what the pilot actually sees and feels in the cockpit? (c) are there modifications to the test that would reduce costs without seriously impacting simulator handling characteristics? and (d) are there modifications to the flight data instrumentation requirements that would reduce costs without seriously impacting the reliability and validity of the aeromodel verification process? A meeting of selected subject matter experts from industry, academia, and government in the disciplines of

aerodynamic modeling, aircraft flight test instrumentation, simulator qualification, aircraft certification, and air carrier pilot training was convened to examine the tests in light of the above questions. The results of this review are summarized in Table I, and the verbatim transcript of the proceedings from this meeting has been documented (Ref 8).

As Table I indicates, changes were proposed to more than half of the existing tests. Of 48 total tests, 27 were changed, including two which were deleted entirely - (2.d.(2): Roll Response Rate, and 2.e.(4): Rudder Effectiveness with Reverse Thrust. The most significant change was the elimination of angle-of-attack and control-surface-position measurements from all flights tests. While these recommendations do not depart dramatically from the existing requirements of AC120-40B, it is estimated that the net effect of adopting these proposed changes would be a savings of at least 25% in the cost of flight simulator validation, by virtue of reduced requirements for certain flight test instrumentation. For example, for Crosswind Landing - 2.e.(2), and Engine Inoperative- 2.e.(3), the replacement of angle-of-attack and sideslip measures with normal and lateral acceleration measures would result in a significant instrumentation savings. While all these proposed changes would simplify flight testing and thereby reduce costs, it was the consensus of the review team that the quality of Level B simulator performance would not be adversely affected for pilot recurrent training purposes.

In addition to a review of FAA simulator qualification requirements as embodied in the AC120-40B validation tables, consideration was given to the feasibility of using predictive modeling as a substitute for the flight test data typically required by the simulator manufacturer in order to tune an aeromodel to better match aircraft handling characteristics throughout the maneuver envelope. The use of flight data for this purpose is not a requirement of the objective tests specified in the FAA validation tables, which tend to reflect the acquisition of data taken from the middle of the flight

envelope during steady state conditions. Nevertheless, simulator manufacturers have historically required flight data beyond that required for FAA objective tests, in order to refine the equations of motion so that simulation of aircraft dynamics is acceptable for the purposes of FAA-required subjective tests, and ultimately, for pilot acceptance. This requirement can add to the overall cost of the data package for a given flight simulator.

Considerable progress has been made in recent years in the use of predictive modeling techniques to generate estimated flight data. In conjunction with increased accessibility to very high-powered computer technology, these techniques have become quite sophisticated. Moreover, it has been possible to refine the precision of such models by comparisons of their output with actual flight data on an iterative basis over a period of years. Indeed, the use of such techniques has become standard practice for simulator manufacturers, as a means of establishing new simulator configurations pending the availability of actual flight test data. These techniques are also gaining acceptance as a means for transport category aircraft manufacturers to reduce the amount of actual flight testing required for certification of variants from a previously flight-tested aircraft make and model.

If predictive modeling can be successfully used to significantly reduce the requirement for flight data needed for aerodynamic model programming, it is estimated that an additional reduction of 25% in the cost of a simulator data package could be achieved. It was the consensus of the review team that this proposal has merit, and warrants further exploration, though it remains to be satisfactorily demonstrated that this approach would produce sufficiently accurate results for commuter class turboprop aircraft. The net cost savings for the flight test data package, which would result from the proposed validation table changes, and the use of predictive modeling as the primary source for supplemental flight data, is estimated to be 50%.

Motion Cueing

There is probably no topic in the domain of flight simulation in more dire need of a unified approach to the quantitative analysis of flight simulator cueing requirements than that of motion cueing. In the absence of tools for that purpose, the continuing controversy over motion extends to diametrically opposing arguments (Ref 9, 10, 11, and 12), resolution of which is unlikely to ever occur unless a systematic program of properly designed research is undertaken to develop the requisite methodologies and to conduct the necessary critical studies. Surprisingly little satisfactory progress has occurred toward that end in recent years.

The presently described FAA program is committed to the application of resources to address this need, but this effort is only in an early planning stage, and it remains to be determined whether such a program will be more successful than previous endeavors in this arena. In the meantime, the FAA must move forward to address the motion cueing considerations that would be applicable to updating the qualification requirements for a Level B flight simulator. Pending the availability of new scientific data, decisions in this regard must be based on the existing literature, and on best expert judgment.

In light of the current state of knowledge (Refs 13, 14, 15, 16, and 17), the FAA has determined that both Level A and B full flight flight simulators must continue to be equipped with full-body-motion capability. Remaining at issue is whether the existing standards for motion platform performance for a Level B simulator should be left unchanged, or whether, in the interest of equal or better fidelity at reduced cost, modifications may be warranted. The objective tests in AC120-40B only directly address motion platform hardware performance, not motion drive software, which is only indirectly assessed by virtue of subjective acceptance testing. Consequently, there is presently no defined standard which validates that the motion system *per se* provides

appropriate cueing. Nor is there a requirement for objective tests which specifically address acceptable phase lag relationships between flight simulator visual and motion systems, though there is ample data that the lack of simulator fidelity for onset cueing therein can not only impact motion perception (Refs 14, 15, and 17), but it can be a contributor to simulator sickness (Ref 18). While consideration of additional standards or guidelines along these lines might on the surface appear to risk increasing rather than reducing the costs for a Level B simulator, it is entirely possible that the establishment of such standards could enable increased regulatory flexibility with respect to approval criteria for alternative full-body-motion simulator system configurations. For this reason, these issues will be addressed as part of the FAA's comprehensive Level B simulator qualifications standards review.

Visual Image Generation & Display Technology

The existing requirements in AC120-40B for simulator visual image generation systems could be considered to be minimal, given the progress that has occurred in the capabilities of commercial off-the-shelf technology (COT), and the associated significant drop in the cost of such systems during the past decade. Not only are relatively inexpensive full-color, photo-texture-capable image generation systems suitable for Level B simulator use available in the marketplace, but user friendly, relatively inexpensive data base modeling systems are also available, as a result of which there does not appear to be any requirement to address image generation from either the perspective of the FAA Level B qualification standards review, or planned research. On the other hand, progress in the development of affordable visual system display technology, though evident, has been less dramatic. Until recently, there have been few alternatives to calligraphic displays, or to hybrid rastergraphic/calligraphic displays, suitable for meeting FAA Level B qualification standards for approach and runway lights. Similarly, although Level B standards do not

explicitly call out a requirement for collimated optics, it is unlikely that a display system without such optics could qualify with respect to simultaneous field-of-view, sink rate cueing, and depth perception. Although Level B qualification standards only specify a requirement for a 45 H by 30 V degree field-of-view for each pilot, the provision of such displays systems can be relatively expensive. No change in the existing standards for Level B simulator display systems is contemplated. However, it is planned to seek the recommendations of subject matter experts concerning alternatives for more affordable display technology capable of meeting existing Level B standards.

Future Plans

Practical Applications

Plans for the immediate future include convening groups of recognized subject matter experts in the areas of simulator motion cueing, as well as simulator visual display technology, respectively, for the purposes of reviewing the existing AC120-40B qualification standards for Level B flight simulators in light of the considerations discussed above, and formulating recommendations to the FAA that could enhance simulator affordability without degrading quality of performance.

Following FAA review, collation, and integration of expert input on aeromodeling, motion systems, and visual display systems, the FAA will publish an addendum to AC120-40, as revised, which will incorporate any appropriate revisions to qualification standards for Level A and B full flight simulators.

Planned Research Program

Planning for an FAA-sponsored comprehensive simulator research program is still in development. The research plan will not be finalized until the recommendations from the remaining subject matter expert groups discussed above are available, and a presently

ongoing review of the pertinent scientific literature in these areas has been completed. However, certain research priorities have already emerged for the immediate future. First, with regard to the use of predictive modeling as a substitute for the supplementary flight data used to tune the math model, the FAA will sponsor research to compare the results of predictive modeling with actual flight data for commuter class turboprop aircraft. Provided the results of that endeavor are positive, the characteristics of effective strategies for the use of predictive models to generate valid data estimates, and the properties of effective models for that purpose, will be documented. This information will be disseminated to industry. Concomitantly, the FAA will seek recommendations on whether guidelines for the application of such models to flight data estimation should be incorporated into agency advisory materials.

Secondly, a research program to address the key unanswered issues in flight simulator motion cueing for transport category aircraft will be designed and initiated. Such a program must advance our state of knowledge regarding the critical interactions between the human visual/somatosensory/vestibular senses relating to motion, simulator hardware characteristics, simulator software-drive algorithms, and the transfer of pilot performance to the aircraft. As a minimum, this research must resolve the question of whether whole-body cueing information is needed for performance of particular flight tasks in the simulator, and if so, whether its presence or absence impacts transfer of pilot performance on those tasks from the simulator to the aircraft. If simulator motion is needed for particular maneuvers, then research must establish the nature of the translational, linear acceleration, and angular acceleration motion cueing required for those maneuvers. Since it is known that there exists a powerful interaction between visual perception and motion perception (Ref 9), if motion cueing is needed, then research must address the requirements for the synchronization between visual and motion cueing systems. Given that a Level B simulator only requires a 45 H by 30 V

degree field-of-view per pilot eye point, the research must include consideration of field-of-view size effects on visually induced motion perception, and the associated interaction of visual field size with whole-body motion cueing. And in particular, since a flight simulator is restricted in its physical capacity to provide translational and acceleration motion cues, if motion cueing is warranted, research is needed on to how to optimize motion system design, so as to most effectively provide the essential cues, while minimizing false cues.

Though none of these questions are new, all of them remain controversial, despite the existing body of research literature. It is therefore appropriate that they should be reexamined in light of the most recent improvements in simulator visual and motion system technology, with a focus on better quantifying the relationships between the pertinent engineering and behavioral variables.

Conclusions

The FAA is undertaking a proactive effort to increase the accessibility of flight simulators to commuter airlines for use in recurrent pilot training in the United States. This strategy entails examining the qualification standards for a Level B simulator, to determine whether revisions which enhance affordability without degrading fidelity may be feasible. The most immediate product of this ongoing effort will be an update to AC120-40, as revised, addressing modified qualification standards for Level A and B flight simulators. It is hoped that this will serve as an enabling initiative for industry, by virtue of providing advance notice of FAA acceptance of more streamlined qualification criteria for such equipment. Whether such equipment will in fact ever be built must be determined by the marketplace. While the FAA encourages the use of FTDs as a means of increasing training efficiency, the FAA does not anticipate any change in the requirement to utilize an approved FFS for accomplishing certain pilot evaluation requirements. The FAA has no plans to authorize the use of an enhanced

FTD to substitute for use of a FFS to accomplish those requirements.

In conjunction with its review of Level B qualification standards, the FAA is in the process of initiating a comprehensive program of flight simulator research. The short term goals for this program entail the acquisition of data needed to support the Level B initiative, such as the feasibility of using predictive modeling to generate estimated flight data suitable for use in tuning the simulator aeromodel. On a more long term basis, the research will address certain fundamental issues in flight simulation, such as the contribution of whole-body motion cueing to effective flight simulation training in transport category aircraft. Although still in an early planning stage, the FAA has elected to announce its intentions for such a program in the interest of soliciting suggestions on how it should best be formulated, and for the purpose of seeking partnerships in its execution. The FAA welcomes the recommendations and participation of interested parties to this endeavor.

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Table 1

PROPOSED
 VALIDATION TEST DATA SOURCES
 AND TEST TECHNIQUES
 FOR LEVEL B FLIGHT SIMULATOR
 (Multi-engine Turboprop Aircraft)

120-40B test No	Test Name	Existing Data Source	Test Objective (Obj) Proposed Test Technique and Instrumentation	Comment
PERFORMANCE				
TAXI				
1.a.(1)	Min Rad turn	AFM/Ops Manual	Obj: Verify ground handling and required ground maneuvering surface area. None Required	NC
1.a.(2)	Rate of Turn vs Nosewheel Steering angle		Obj: Verify that steering is commensurate with airplane steering . Tiller protractor and video of heading indicator during steady state turn or <u>full rudder pedal steady state turn</u> and video. If less than full rudder pedal is used, pedal position must be recorded. (A single test procedure may not be applicable to all airplane's steering systems, therefore appropriate measurement procedures should be devised and proposed for FAA concurrence.) If heading change rate and speed are constant, ground speed can be calculated, otherwise groundspeed must be measured by accepted methods.	Rev
TAKEOFF				
1.b.(1)	Ground Acceleration	Cert Data TIR AFM	Obj: Confirm the simulator model ground performance during acceleration. As currently permitted by 40B. Also, could use stop watch, calibrated A/S and rwy markers to acquire data during a takeoff with power set before brake release. Power settings hand recorded. If an inertial measurement system is installed, speed and distance may be derived from acceleration measurements.	Rev
1.b.(2)	Min Cont Spd, Grd	Cert Data TIR AFM	Obj: Confirm the simulator on ground aerodynamic controls, thrust and control models. Available in AFM, Required Certification Test	NC
1.b.(2)	Alternative to Min Cont Spd, Gnd	None	Obj: Confirm the simulator on ground aerodynamic controls, thrust and control models. Rapid throttle reductions at speeds near Vmcg recording yaw rate, control inputs etc. The nose wheel must be free to caster, or equivalently freed of sideforce generation. The applicant for simulator qualification must demonstrate that the simulator yawing moment due to asymmetric thrust and the rudder yawing moment to compensate are the same as those of the airplane. Inertial measurement system and cockpit control force and position measurement device.	** Rev

120-40B test No	Test Name	Existing Data Source	Test Objective (Obj) Proposed Test Technique and Instrumentation	Comment
1.b.(3)	Min Unstick Speed	Cert Data TIR	Obj: Confirm low speed elevator effectiveness in ground effect and confirm lift model at high angle of attack in ground effect. Required speed definition for Part 25, not defined for Part 23 Commuter Category. Rotate, using full elevator input, at a speed less than V_R , hold a constant attitude until lift off etc. The test and procedure are described in AC 25-7 para 10. B.(5) which should be consulted for the test procedure. An equivalent test may be used for Part 23 Commuter Category airplanes for which V_{MU} is not an airplane certification requirement. The elevator effectiveness and lift computation for the simulator must be verified by comparison to the airplane. Inertial measurement system and control input measurement devices.	** NC
1.b.(4)	Normal Takeoff	Cert - Performance Only	Obj: Confirm the overall performance and handling of the simulator model during ground, lift off and transition through ground effect, and initial climb operations. Calculate AOA from pitch attitude and flight path. Inertial measurement system, radio altimeter, video of calibrated aircraft instruments, Force and position measurement on cockpit controls.	** NC
1.b.(5)	Critical Engine Failure on Takeoff	Performance data available from certification	Obj: Confirm simulator model response to a critical engine failure during the take off run, corrective control inputs, effect on takeoff distance, and initial climb with one engine inoperative. Need is aircraft dynamic response to engine failure and control inputs required to correct flight path. Inertial measurement system and video system. Omit AOA measurement. Measure heading and lateral acceleration.	** Rev
1.b.(6)	Crosswind Takeoff	None, except limiting crosswind	Obj: Confirm proper response of simulator model, including flight controls, to a crosswind during take off and post lift off. Inertial measurement system, video of calibrated aircraft instruments, Control forces measurement device, Omit AOA. Measure heading and lateral acceleration. The wind profile should be specified. The 1/7 law to 10 meters is suggested as an acceptable wind profile model that is now in use.	** Rev
1.b.(7)	Rejected	None	Obj: Confirm simulator model overall on ground performance and modeled wheel brake effectiveness during maximum wheel braking. Use ground acceleration per 1.b.(1) and stopping per 1.d.(1) except that take off flap settings must be used which may effect the stopping distance.	Rev
CLIMB				
1.c.(1)	Normal Climb, all engines	Certification data, TIR, AFM,	Obj: Confirm simulator model climb performance. As now permitted by 40B, could also do with stop watch and calibrated ships airspeed system.	Rev
1.c.(2)	Second Segment Climb, One Engine Inoperative	Certification data, TIR, AFM	Obj: Confirm simulator model climb performance in airplane take off configuration with one engine inoperative. As now permitted by 40B, could also do with stop watch and ships calibrated airspeed system.	Rev

120-40B test No	Test Name	Existing Data Source	Test Objective (Obj) Proposed Test Technique and Instrumentation	Comment
1.c.(3)	Approach Climb, one engine inoperative	Certification data, TIR, AFM	Obj: Confirm simulator model climb performance in airplane approach configuration with one engine inoperative. As now permitted by 40B, could also do with stop watch and ships calibrated airspeed system.	Rev
STOPPING				
1.d.(1)	Deceleration Time and Distance, Wheel Brakes	Certification data, landing distance tests, TIR, AFM	Obj: Confirm simulator overall lift, drag and wheel braking model on the ground. None Required if time to stop is available in certification data.	Rev
1.d.(2)	Deceleration Time and Distance, Reverse Thrust	None	Obj: Confirm simulator on ground overall lift, drag and thrust modeling with reverse thrust. Landing Tests, stop watch, runway markers, video, calibrated aircraft instruments. Thrust control lever positions and engine output (pertinent parameters) must be recorded.	Rev
ENGINES				
1.e.(1)	Acceleration	None	Obj: Demonstrate that the simulator engine model responds correctly during the specified condition. Calibrated aircraft instruments, video with time read out.	Rev
1.e.(2)	Deceleration	None	As above	Rev
HANDLING QUALITIES				
STATIC CONTROL CHECKS				
2.a.(1)	Column Position vs Force	Maintenance Manual for surface to column calibration	Obj: Confirm model of flight control system force, position and friction relationships. Control force and position measurement device and x - y recorder needed. Surface position could be measured from FDR sensor or, if no FDR sensor, at selected column positions using a control surface protractor.	* Rev
2.a.(2)	Wheel Position vs Force	Maint Man as above	Same as above	* Rev
2.a.(3)	Pedal Position vs Force	Maint Man as above	Same as above	* Rev
2.a.(4)	Nosewheel Steering Force and Position	None	Obj: Confirm important nosewheel steering metrics of the simulator model which are important to ground handling. Use 45A. Measure breakout with hand held force gauge. Use hand held gauge to measure force after breakout for small arc. Predict remainder.	Rev
2.a.(5)	Rudder Pedal Steering Calibration	Acft Design Data	Obj: Confirm important nosewheel steering metrics of the simulator model which are important to ground handling. Force pads on pedals, pedal position measurement device, design data for nose wheel position. (Turn radius will be compared to AFM at full pedal, and possibly other, deflections also) [See 1.a.(2) above]	* Rev
2.a.(6)	Pitch Trim Calib. Indicate vs Compute	None	Obj: Validate the simulator model pitch trim calculation. Calculated	NC

120-40B test No	Test Name	Existing Data Source	Test Objective (Obj) Proposed Test Technique and Instrumentation	Comment
2.a.(7)	Power Lever and other engine control levers Angle vs Engine Indication	None	Obj: Confirm that given engine control lever positions result in the proper engine performance indications. Fabricate scale to use on throttle quadrant. Video camera to record steady state instrument readings or hand record steady state engine performance readings.	Rev
2.a.(8)	Brake Pedal Position vs Force	Acft Design Data	Obj: Assure that the brake pedal produces the appropriate force feedback for a given brake pedal position. Use design/predicted data. As for Level 6, measure only at 0 and maximum and use acft design data curve for deflections between extremes.	* Rev
LONGITUDINAL				
2.c.(1)	Power Change Dynamics	None	Obj: Confirm the correct simulator model dynamic response to an in flight airplane power or configuration change. Do as per AC120-40B. Inertial measurement system would then be required. Transient data is needed therefore the dynamic case must be done.	** NC
2.c.(2)	Flap/Slat Change Dyn	None	Same as above	** NC
2.c.(3)	Spoiler/Speedbrake Change Dyn	None	Same as above	** NC
2.c.(4)	Gear Change Dynamics	None	Same as above	** NC
2.c.(5)	Gear Flap Slat Operating Time	Design Data, Certification Tests	Obj: Assure that the simulator model configuration change time increment corresponds to that of the airplane. Measure in conjunction with acquisition of data for 2.c.(1), (2), (3), (4) above. Statement of compliance referencing an appropriate data source. [Such as design data, production flight test schedule, maintenance test specification etc.]	Rev
2.c.(6)	Longitudinal Trim	Certification Tests (limited)	Obj: Confirm that simulator model parameters are correct in level flight steady state conditions. Inertial measurement system for pitch attitude, cockpit controls position measurement equipment with a calibration of cockpit controls positions and surface positions, ships engine instruments, do a number of level runs in accordance with the guidance of AC120-40B.	** Rev
2.c.(7)	Longitudinal Maneuver Stability	Certification Tests, TIR	Obj: Confirm the simulator model longitudinal control force as a function of normal acceleration. Ships calibrated airspeed indicator. Apply a temporary high resolution bank angle scale to attitude indicator, inertial measurement system and wheel/column force measurement device.	** NC
2.c.(8)	Longitudinal Static stability	Certification Tests TIR	Obj: Confirm the simulator model longitudinal control force as a function of airspeed increments from trim airspeed. Ships instruments, hand held force gauge.	NC
2.c.(9)	Stick Shaker, Airframe Buffet, Stall Speeds	TIR, AFM	Obj: Confirm that the simulator model produces stall at the correct airspeed and incorporates the appropriate warning modeling at airspeeds approaching the stall. Acquire using stop watch, ships calibrated airspeed, and video, hand record flight condition and configuration. The speeds are available in the TIR and AFM. Consideration should also be given to stall characteristics	NC

120-40B test No	Test Name	Existing Data Source	Test Objective (Obj) Proposed Test Technique and Instrumentation	Comment
2.c.(10)	Phugoid	None	Obj: Confirm that the phugoid is correct as this mode is indicative of certain features of the longitudinal aerodynamic model and is very important to longitudinal trim ability. Inertial measurement system is necessary to accurately measure this important response. Cockpit controller positions are also important, especially in cases where the dynamics of flight control system components alter the character of the response.	** NC
2.c.(11)	Short Period	None	Obj: To assure that this primary longitudinal maneuvering mode is correctly produced by the simulator model. Inertial measurement system, measuring primarily accelerations (normal), video.	** NC
LATERAL DIRECTIONAL				
2.d.(1)	Minimum Control Speed, Air	Certification Tests, TIR,	Obj: Confirm the minimum airspeed at which control can be maintained with one engine inoperative. Control force and deflection, asymmetric thrust and overall handling approaching and at the minimum control speed are important and should be recorded. Inertia measurement system, cockpit control force and position measurement device. An alternative procedure to measuring just the minimum speed at which control can be maintained is to measure the needed control deflections and other parameters at several speeds as the speed approaches the minimum control speed and as close as possible to the minimum speed in order to develop several simulator validation points at progressively lower speeds.	** NC
2.d.(2)	Roll Response (Rate)	None	Stop watch, ships calibrated instruments, high resolution scale on attitude indicator, FDR sensor for lateral control (wheel) deflection. Do roll in both directions using a number of wheel deflections and measure only the steady state rates. Video of instruments	* Delete
2.d.(3)	Roll Response to Step Input	None	Obj: Confirm that the simulator model properly produces this primary lateral-directional dynamic response mode and produces the correct steady state roll rate. Inertial measurement system to obtain rates. Lateral control input measurement device, video . Cruise case in addition to flight conditions specified in AC120-40B.	** Rev
2.d.(4)	Spiral Stability	None	Obj: Confirm that the simulator model properly produces this primary lateral-directional dynamic response mode. Stop watch, ships calibrated instruments, high resolution scale on attitude indicator or video.	NC
2.d.(5)	Engine Inoperative Trim	None	Obj: Validate simulator trim or control deflections required to counterbalance engine inoperative asymmetric forces and moments. Apply high resolution scales to trim controls and perform a ground calibration using protractors on the control/trim surfaces (ignores airloads). Use control scales for in-flight measurements. Very system dependent, but similar methods for other controls. Alternatively measure cockpit control force and position, especially during second segment climb where trimming is not a certification requirement and not a task to be accomplished in flight until the proper altitude and conditions are satisfied.	Rev

120-40B test No	Test Name	Existing Data Source	Test Objective (Obj) Proposed Test Technique and Instrumentation	Comment
2.d.(6)	Rudder Response	None	Obj: Validate simulator model short term transient response to rudder inputs. Inertial measurement system, Rudder pedal input position measurement device.	** NC
2.d.(7)	Dutch Roll	None, maybe TIR	Obj: Confirm the lateral-directional simulator modeling as manifest by this coupled primary response mode. Inertial measurement system. Record with and without yaw damper. Rudder pedal input position measurement device.	** NC
2.d.(8)	Steady State Sideslip	None, maybe TIR	Obj: Confirm the relationships that exist between sideslip and rolling moment and secondarily the rudder and roll control power. Use ground reference (a long straight path) for track and heading indicator for sideslip angle. Cockpit controller force and positions measurement device. If inertial measurement system is installed, measure lateral acceleration. Video. This test was not discussed during SME meeting. Revisions have been made based on the overall discussions.	* Rev
LANDINGS				
2.e.(1)	Normal Landing	None	Obj: Confirm the overall performance and handling of the simulator model during descending flight near the ground, transition through ground effect, landing flair and touch down. Inertial measurement system, cockpit control force and position measurement device.	** NC
2.e.(2)	Crosswind Landings	None	Obj: Confirm proper response of simulator model, including flight controls, to a crosswind during descending flight near the ground, transition through ground effect, decrab and touchdown/rollout. Inertial measurement system, cockpit controller positions and forces, record normal and lateral acceleration in lieu of AOA and sideslip.	** NC
2.e.(3)	One Engine Inoperative Landing	None	Obj: Confirm proper response of simulator model, including flight controls, with one engine inoperative during descending flight near the ground, transition through ground effect, touchdown and rollout. Same as above	** NC
2.e.(4)	Rudder Effectiveness with Rev Thrust	None	Obj: Demonstrate that the rudder effectiveness during reverse thrust on landing in the simulator is representative of the airplane. No test recommended since the test was specific to airplanes with aft fuselage mounted engines.	Delete
GROUND EFFECT				
2.f.(1)	Ground Effect Demonstrate G.E.	None	Obj: Confirm the simulator modeling and proper aerodynamic modeling changes as a function of height and rate of change of height in ground effect. Level fly-by trim runs. Use high resolution scale on elevator trim control. Ground calibrate Trim control with trim surface. Use ships calibrated flight instruments and engine instruments, video of trim controls and aircraft instruments. Or fly low angle constant pitch attitude approach and landing at constant power and record trim, control displacement and airspeed changes as ground is approached (not applicable to all airplanes). Inertial measurements system, cockpit controller force and positions, radio altitude and altitude rate are needed.	** Rev

Comments Legend

- ** tests for which an inertial data acquisition system is recommended - 20 tests
- * tests for which some instrumentation less than inertial is recommended - 6 tests
- Total number of tests requiring installation of instrumentation - 26
- Total number of tests listed - 48

NC no change from the current AC120-40B guidance

Rev revision of the current AC120-40B guidance, usually by the use and acceptance of existing data sources or the use of more basic (less sophisticated and complex) flight test methods.

Notes:

1. Measurement of angle of attack and sideslip have been omitted for all tests. Also measurement of control surface positions is not required, however, cockpit controller positions must be measured where indicated and tolerances comparable to those for the control surfaces determined. These measurements alone result in revision to most Level B validation tests.
2. With the exception of the alternative, and in some cases relieving, techniques and instrumentation recommendations given above, all tests should be done to comply with the guidance of AC120-40B.
3. Measurements of control surface deflections/positions have been omitted in the above table, however, cockpit controller positions must be substituted and equivalent tolerances will have to be used when complying with AC120-40B Level B simulator qualification guidance.
4. To accommodate the recommended test methods and techniques, some measurements would be replaced with pilot's notes.
5. Certification/TIR data points are usually at the extremes of weight and CG, but still lie on the locus of a given parameter and are useful for model validation.
6. TIR data may be proprietary and should not be relied upon until known to be available

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**Transcript of the
Joint FAA/Industry Symposium
on
Level B Airplane Simulator
Motion Requirements**

Part 8 of 9

Appendix 2:

Proposed Revision to Level B Standards Contained in
AC120-40C (Draft)

**Washington Dulles Airport Hilton
June 19 - 20, 1996**

**PROPOSED REVISION TO LEVEL B STANDARDS
CONTAINED IN AC120-40C (DRAFT)**

AIRPLANE SIMULATOR QUALIFICATION

PURPOSE. In March and June of 1996 the FAA Advanced Qualification Program(AQP) Manager and the National Simulator Program (NSP) Manager convened workshops of Subject Matter Experts on flight simulator aerodynamic programming and on motion systems to specifically address Level B flight simulator standards. The objective was to identify Level B flight simulator characteristics specific to the needs of regional air carriers for recurrent training. For the AQP, the Level B simulator will totally support a Line Oriented Evaluation. Of course, once the standards for Level B simulators are agreed and promulgated, they will be applicable to any user of Level B simulators in an FAA approved flight training program.

The proposed revision contained herein reflects the results of the Level B Flight Simulator SME Workshops. Changes to Appendix 1, Simulator Standards, and Appendix 2, Simulator Validation Tests, of Advisory Circular (AC)120-40C (Draft) are proposed as indicated in the following tables. These tables would replace, or revise as indicated, the pertinent sections of the AC tables. The aerodynamic programming workshop addressed data sources and flight testing techniques. Those results are in Appendix 7.

APPENDIX 1. SIMULATOR STANDARDS Changes

SIMULATOR STANDARDS	SIMULATOR LEVEL				COMMENTS
	A	B	C	D	
2. GENERAL					
v. Relative responses of the motion system, visual system , and cockpit instruments shall be coupled closely to provide integrated sensory cues. These systems shall respond to abrupt pitch, roll, and yaw inputs <i>for levels A, C, and D, and to abrupt pitch, roll and sway inputs for Level B</i> at the pilot’s position within 150/300 milliseconds of time, but not before the time, when the airplane would respond under the same conditions. Visual scenes ...	X				For Level A response must be within 300 milliseconds
		X	X	X	For Levels B, C and D response must be within 150 milliseconds
3. MOTION SYSTEM.	X	X	X	X	
a. Motion (force) cues...					
b. A motion system having a minimum of three degrees of freedom.	X				
c. <i>A motion system having a minimum of four degrees of freedom which must be at least pitch, roll, sway and heave</i>		X			
d. re-designate “c.”, “d.”			X	X	
e. re-designate “d.”, “e.”	X	X	X	X	

APPENDIX 2. TABLE OF VALIDATION TESTS Changes:

There is a disagreement between Appendices 1 and 2. Appendix 1, Item 3.e. requires motion special effects for Level B, Appendix 2, Item 3.e. does not. Therefore, at least App. 2 Item 3.e. (2) through (6) and (8) and (9) should be marked as applicable to Level B.

Appendix 2, Item 3.a., b., and c. Should be unmarked for Level B and a comment added that Level B is listed separately.

Following is a proposed revision to the Table of Validation tests for Motion.

TABLE OF VALIDATION TESTS

I = Initial Evaluation

R = Recurrent Evaluation

TESTS	TOLERANCE	FLIGHT CONDITION	QUALIFICATION REQUIREMENT				COMMENTS
			A	B	C	D	
3. MOTION SYSTEM							
a. Frequency Response	As specified by operator for simulator acceptance	N/A	IR		IR	IR	Appropriate test to demonstrate frequency response required
b. Leg Balance	As specified by operator for simulator acceptance		IR		IR	IR	Appropriate test to demonstrate leg balance required
Leg Balance	Design dependent			I			See Appendix 7
c. Turn Around Check	As specified by operator for simulator acceptance		IR		IR	IR	Appropriate test to demonstrate smooth turn around required
Turn Around Check				I			See Appendix 7
e. Motion Excursion		N/A					See appendix 7 for a full description of Level B motion requirements and recommendations. Total minimum usable non-simultaneous excursions about a single reference point. See Appendix 7
(1) sway 45 in	-0 + as desired			I			
(2) heave 40 in	-0 + as desired			I			
(3) pitch 40°	-0 + as desired			I			
(4) roll 40°	-0 + as desired			I			
f. Accelerations							
(1) sway ± 0.6g	-0 + as desired			I			See Appendix 7 for systems having more than four degrees of freedom
(2) heave ± 0.6g	-0 + as desired			I			
g. Velocity							
(1) sway 20 in/s	-0 + as desired			I			See Appendix 7 for systems having more than four degrees of freedom
(2) heave 20 in/s	-0 + as desired			I			
h. Bandwidth: phase lag at 0 - 4 hertz	not to exceed 45°						See Appendix 7
i. Crosstalk				I			See Appendix 7
j. Smoothness				I			See Appendix 7

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3. Motion System continued

k. Motion Cue Repeatability	Use AC120-63 procedure			R		Use procedure from AC120-63 or the IATA Procedure
l. Special Effects	<i>Re-designate "e" to "l"</i>					
6. Simulator Systems a. Visual, Motion and Cockpit Instrument Display	<i>Change Level B from 300 to 150 milliseconds</i>					

APPENDIX 7. Level B Motion and Aerodynamics Tests Requirements

The Level B motion criteria and the aerodynamic data sources and test techniques contained in this Appendix are intended to replace those given in Appendix 2 and elsewhere in this AC.

1. DISCUSSION. In March of 1996 the FAA Advanced Qualification Program (AQP) Manager and the National Simulator Program (NSP) Manager convened a workshop of Subject Matter Experts to address and attempt to simplify the aerodynamic data and flight testing requirements for Level B flight simulators. The results of that effort are tabulated in this Appendix.

In June of 1996 the FAA AQP and NSP convened an additional workshop of Subject Matter Experts on flight simulator motion systems to specifically address the Level B flight simulator. The objective was to identify the characteristics of a motion system applicable to Level B simulators to specifically address the needs of regional air carriers for recurrent training. More specifically, for the AQP, the Level B simulator will totally support a Line Oriented Evaluation. Of course, once the standards for Level B simulators are agreed and promulgated, they will be applicable to any user of Level B simulators in an FAA approved flight training program

For the first time, a table of motion objectives was provided prior to the meeting. Although the motion objectives were not discussed in detail during the SME workshop, they were deemed to be descriptive of the contribution of motion to pilot certification and training activities. An edited version of the table of motion objectives is, therefore, included in this appendix.

2. LEVEL B MOTION CHARACTERISTICS

a. Transport Delay/Cue Synchronization

Transport Delay: 150 milliseconds is the maximum permitted. The time delay may also be measured as a “latency” or lag of the response of the motion, visual or instruments following the input when compared to the airplane response time.

Motion/Visual Phase Relationship: motion response must lead visual response. There is no specified amount of lead. When measured to assure that motion does not lag visual, motion acceleration is measured and visual displacement is measured.

b. Degrees of Freedom

At least four degrees of freedom are necessary to satisfy the motion objectives of critical pilot certification and training tasks. The following degrees of freedom are necessary:

Pitch, Roll, Heave and Sway.

c. Motion Platform Excursions

Acceptable usable, non-simultaneous excursions are the minimum limits of movement about a single specified reference point. Usable excursions are those actually used by the simulator in normal training mode without exceeding any safety limits. Total minimum excursions, which may be split to best advantage (for example pitch could be + 10 and - 30 or other split values), must be measurable about a common reference point as follows:

Lateral (sway)	45 inches
Vertical (heave)	40 inches

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Pitch 40 degrees

Roll 40 degrees

If the motion system provides six degrees of freedom the following additional minimum excursions will apply:

Longitudinal (surge) 50 inches

Yaw 45 degrees

These six excursions are the undistorted displacements that can be achieved by driving one degree of freedom at a time.

d. Accelerations

Accelerations of the motion platform shall be measured about the same platform reference point about which excursions are measured. Minimum accelerations are:

Lateral (sway) ± 0.6 g

Vertical (heave) ± 0.6 g

Pitch not specified

Roll not specified

If the motion system provides six degrees of freedom the following additional minimum acceleration will apply:

Longitudinal (surge) ± 0.6 g

Yaw not specified

e. Velocities

Velocities of the motion platform shall be measured about the same platform reference point about which excursions and accelerations are measured. Minimum velocities are:

Lateral (sway) 20 inches per second

Vertical (heave) 20 inches per second

Pitch not specified

Roll not specified

If the motion system provides six degrees of freedom the following additional minimum velocity will apply:

Longitudinal (surge) 20 inches per second

Yaw not specified

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f. Bandwidth

The motion base platform shall exhibit a maximum phase lag of 45 degrees at a frequency of 4 hertz. At lower frequencies the phase lag shall be 45 degrees or less. This characteristic shall be determined by injecting an acceleration command into the kinematic transformation equations and measuring the acceleration output of the motion platform. The response bandwidth shall be determined in each translational degree of freedom.

g. Crosstalk

Motion response in a given degree of freedom should not be perceptibly distorted by response in other degrees of freedom. For example, if the desired response is sway, there should be no perceptible roll or other responses. Crosstalk perceptibility is a subjective measure. Crosstalk shall be imperceptible to a trained observer during operational use of the flight simulator. The observer must be at the proper location, seated at the pilot station with the seat adjusted to the appropriate operational position, during crosstalk evaluations.

h. Smoothness

There shall be no perceptible “turnaround bump” as the direction of motion of any actuator of the system reverses with the simulator being “flown” normally.

i. Leg Balance

If a synergistic hexipod (6 degrees of freedom) or similar system is used to satisfy the Level B flight simulator requirements, no leg of the system shall lead or lag a selected reference leg by more than 1.5 degrees. This requirement shall apply to other system designs if more than one actuator is required to drive the system in any single degree of freedom.

j. Recurrent Evaluation Procedure

The “Motion Cue Repeatability Testing” procedure described in AC120-63 Helicopter Simulator Qualification or similar tests developed by the International Air transportation Association, when released and published, may be used for this procedure.

3. LEVEL B FLIGHT SIMULATOR MOTION OBJECTIVES

a. Training/Pilot Certification Events

Events are listed in the order of Appendix 3 of draft Advisory Circular 120-40C. The associated maneuver or disturbance is listed in the “Event” column under each pertinent event. The pertinent degrees of freedom (DOF) shown in column 2 apply to the group of training events or special effects shown in column 1. The training events (maneuver or disturbance) are grouped in column 1 when the same DOF apply to all maneuvers or disturbances in the group.

b. Level B Motion Objectives

Event maneuver or disturbance	Pertinent Degree(s) of Freedom	Motion Objective
1.b. Surface Operations (Pre-takeoff)		
(2) pushback/ powerback	sway heave	Provide the pilot with the sensation of aircraft movements, thrust effects and side motion. Avoid the effects of a “sterile” motion environment that occurs with only visual stimulus
(3) Taxi		
(iii) ground handling	sway	Provide sensation of the effects of rapid steering inputs, roughness of taxiway/runway surface.
(iv) nosewheel scuffing	heave	Feedback to the pilot the effect of turns at excessive groundspeed causing the nose wheel tire(s) to lose sideforce friction and “scuff”
(v) brake operation	pitch	Familiarize pilot with braking technique appropriate for the sensitivity of the brakes and provide deceleration sensation.
(vi) brake fade		Less than expected deceleration with brakes
1.c. Takeoff(s)		
(1) normal (ii) acceleration	pitch	Provide the sensation of acceleration on a surface with some roughness, the pitch or heave sensation during takeoff rotation.
(iii) steering	sway	Effects of nosewheel and rudder inputs during the takeoff roll. These effects are usually side to side accelerations at the pilot station.
(iv) crosswind	heave	Effects of sidewise skipping on the ground if adequate wind compensation is not used.
(2) Abnorm/ Emergency	roll	Subject the pilot to the accelerations, and pitch over associated with maximum braking and with side accelerations associated with directional control.
(i) rejected (ii) engine failure		Induce the rapid sway accelerations, “the lead cue”, that may occur at the pilot station when there is an engine failure.
(iv) windshear		Acquaint the pilot with the large accelerations that may be associated with windshear and impose the task difficulty that accompanies escape from an windshear encounter where there may be heavy turbulence.
1.d. In-Flight Operation		
(2) Cruise		
(v) High M handling/over- speed warning	sway heave	Provide the buffets and vibrations associated with speeds near. the critical Mach number
(viii) approach to stalls	sway heave	Provide the buffets and vibrations associated with speeds. approaching the stall speed
(x) engine inoperative	sway roll	Provide the accelerations resulting from a sudden change in thrust and the thrust asymmetry. Provide the lead cues of a shutdown in the event of an unexpected engine failure
(3) Descent		
(ii) maximum rate	pitch	Familiarize the pilot with the pitch attitude and the accelerations associated with the large pitch change to effect an emergency descent.
1.e. Approaches		
(1)(ii)(B) missed approach engine inop	pitch sway roll	Familiarize the pilot with the pitch attitude, the large yawing moments and the accelerations associated with the large pitch change and large asymmetric thrust change to effect a missed approach with a critical engine inoperative

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Level B Motion Objectives continued

Event maneuver or disturbance	Pertinent Degree(s) of Freedom	Motion Objective
1.f. Visual Segment and Landing		
(1) Normal (i) crosswind	sway	Feedback to the pilot the proprioceptive cues associated with landing, especially touchdown sink rate and side forces which help inform the pilot of the “quality” of the landing. The side forces and associated rolling moments resulting from dragging a wheel sideways are essential to estimating the quality of a crosswind landing
	heave	
	pitch	
	roll	
(2) Abnormal (i) engine inoperative (ii) rejected (iii) with windshear (viii) with flight control system failures	sway	Same as for normal/crosswind
	heave	Provide the sensation of quickly changing from large positive acceleration to the acceleration associated with maximum braking and high speed steering.
	pitch	Acquaint the pilot with the large accelerations that may be associated with windshear and impose the task difficulty that accompanies escape from an windshear encounter where there may be heavy turbulence.
	roll	Same for normal/crosswind
1.g. Surface Operations (Post Landing)		
(ii) reverse thrust (v) brake and anti-skid	sway	Provide lead information of asymmetric reverse thrust and the deceleration cues associated with reverse thrust
	heave	
	pitch	
3. SPECIAL EFFECTS		
a. runway rumble	heave	Speed information and rough runway feedback
b. buffets, on ground	sway	Familiarize the pilot with the effects of spoilers, thrust reverse
	heave	
c. Bumps after lift off of nose and main gear	heave	Provide systems operations information
d. buffet, landing gear in transit	sway	Same as above
	heave	
e. flap, spoiler, speedbrake, stall buffet	sway	Familiarize the pilot with the characteristic buffets of in-flight deployment of spoilers and approach to stall buffet warning
	heave	

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Level B Motion Objectives continued

f. touchdown cues, main and nose wheels	sway	Same as landings
	heave	
	pitch	
	roll	
g. nosewheel scuffing	sway	Familiarize pilot with nose tire scuffing speed and characteristics
	heave	
h. thrust effect w/ brakes set	sway	Provide information on thrust level and the associated vibrations.
	heave	
Unusual Attitudes	sway	Provide lead information on the development of a rapidly developing unusual attitude and the response of recovery control inputs
	heave	
	pitch	
	roll	
General and Continuous Atmospheric Disturbance	sway	Remove the sterility of the smooth no motion environment. The real atmosphere contains frequent disturbances which continually induce minor upsets from the straight and level flight and flight during maneuvers
	heave	
	pitch	
	roll	

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4. VALIDATION TEST DATA SOURCES AND TEST TECHNIQUES FOR LEVEL B FLIGHT SIMULATOR COMPLIANCE WITH (DRAFT) AC120-40C

a. DISCUSSION. In March of 1996 the FAA AQP Manager and the NSP Manager convened a workshop of Subject Matter Experts to simplify the aerodynamic data and flight testing requirements for Level B flight simulators. The workshop resulted in the following table. These data sources and test techniques may be used in lieu of those otherwise contained in this AC.

b. TABLE OF LEVEL B DATA SOURCES AND TEST TECHNIQUES

120-40C test No	Test Name	Existing Data Source	Test Objective (Obj) Proposed Test Technique and Instrumentation	Comment
1. PERFORMANCE				
a. TAXI				
1.a.(1)	Min Rad turn	AFM/Ops Manual	Obj: Verify ground handling and required ground maneuvering surface area. None Required	NC
1.a.(2)	Rate of Turn vs Nosewheel Steering Angle		Obj: Verify that steering is commensurate with airplane steering . Tiller protractor and video of heading indicator during steady state turn or <u>full rudder pedal steady state turn</u> and video. If less than full rudder pedal is used, pedal position must be recorded. (A single test procedure may not be applicable to all airplane's steering systems, therefore appropriate measurement procedures should be devised and proposed for FAA concurrence.) If heading change rate and speed are constant, ground speed can be calculated, otherwise groundspeed must be measured by accepted methods.	Rev
b. TAKEOFF				
1.b.(1)	Ground Acceleration	Cert Data TIR AFM	Obj: Confirm the simulator model ground performance during acceleration. As currently permitted by 40B. Also, could use stop watch, calibrated A/S and rwy markers to acquire data during a takeoff with power set before brake release. Power settings hand recorded. If an inertial measurement system is installed, speed and distance may be derived from acceleration measurements.	Rev
1.b.(2)	Min Cont Spd, Grd	Cert Data TIR AFM	Obj: Confirm the simulator on ground aerodynamic controls, thrust and control models. Available in AFM, Required Certification Test	NC

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1.b.(2)	Alternative to Min Cont Spd, Gnd	None	Obj: Confirm the simulator on ground aerodynamic controls, thrust and control models. Rapid throttle reductions at speeds near V _{mcg} recording yaw rate, control inputs etc. The nose wheel must be free to caster, or equivalently freed of sideforce generation. The applicant for simulator qualification must demonstrate that the simulator yawing moment due to asymmetric thrust and the rudder yawing moment to compensate are the same as those of the airplane. Inertial measurement system and cockpit control force and position measurement device.	** Rev
1.b.(3)	Min Unstick Speed	Cert Data TIR	Obj: Confirm low speed elevator effectiveness in ground effect and confirm lift model at high angle of attack in ground effect. Required speed definition for Part 25, not defined for Part. 23 Commuter Category. Rotate, using full elevator input, at a speed less than V _R , hold a constant attitude until lift off etc. The test and procedure are described in AC 25-7 para 10. B.(5) which should be consulted for the test procedure. An equivalent test may be used for Part 23 Commuter Category airplanes for which V _{MU} is not an airplane certification requirement. The elevator effectiveness and lift computation for the simulator must be verified by comparison to the airplane. Inertial measurement system and control input measurement devices.	** NC
1.b.(4)	Normal Takeoff	Cert - Performance Only	Obj: Confirm the overall performance and handling of the simulator model during ground, lift off and transition through ground effect, and initial climb operations. Calculate AOA from pitch attitude and flight path. Inertial measurement system, radio altimeter, video of calibrated aircraft instruments, Force and position measurement on cockpit controls.	** NC
1.b.(5)	Critical Engine Failure on Takeoff	Performance data available from certification	Obj: Confirm simulator model response to a critical engine failure during the take off run, corrective control inputs, effect on takeoff distance, and initial climb with one engine inoperative. Need is aircraft dynamic response to engine failure and control inputs required to correct flight path. Inertial measurement system and video system. Omit AOA measurement. Measure heading and lateral acceleration.	** Rev
1.b.(6)	Crosswind Takeoff	None, except limiting crosswind	Obj: Confirm proper response of simulator model, including flight controls, to a crosswind during take off and post lift off. Inertial measurement system, video of calibrated aircraft instruments, Control forces measurement device, Omit AOA. Measure heading and lateral acceleration. The wind profile should be specified. The 1/7 law to 10 meters is suggested as an acceptable wind profile model that is now in use.	** Rev
1.b.(7)	Rejected	None		Rev

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c. CLIMB				
1.c.(1)	Normal Climb, all engines	Certification data, TIR, AFM,	Obj: Confirm simulator model climb performance. As now permitted by 40B, could also do with stop watch and calibrated ships airspeed system	Rev
1.c.(2)	Second Segment Climb, One Engine Inoperative	Certification data, TIR, AFM	Obj: Confirm simulator model climb performance in airplane take off configuration with one engine inoperative. As now permitted by 40B, could also do with stop watch and ships calibrated airspeed system	Rev
1.c.(4)	Approach Climb, one engine inoperative	Certification data, TIR, AFM	Obj: Confirm simulator model climb performance in airplane approach configuration with one engine inoperative. As now permitted by 40B, could also do with stop watch and ships calibrated airspeed system	Rev
e. STOPPING				
1.d.(1)	Deceleration Time and Distance, Wheel Brakes	Certification data, landing distance tests, TIR, AFM	Obj: Confirm simulator overall lift, drag and wheel braking model on the ground. None Required if time to stop is available in certification data	Rev
1.d.(2)	Deceleration Time and Distance, Reverse Thrust	None	Obj: Confirm simulator on ground overall lift, drag and thrust modeling with reverse thrust. Landing Tests, stop watch, runway markers, video, calibrated aircraft instruments. Thrust control lever positions and engine output (pertinent parameters) must be recorded.	Rev
f. ENGINES				
1.e.(1)	Acceleration	None	Obj: Demonstrate that the simulator engine model responds correctly during the specified condition. Calibrated aircraft instruments, video with time read out.	Rev
1.e.(2)	Deceleration	None	As above	Rev
2. HANDLING QUALITIES				
a. STATIC CONTROL CHECKS				
2.a.(1)	Column Position vs Force	Maintenance Manual for surface to column calibration	Obj: Confirm model of flight control system force, position and friction relationships. Control force and position measurement device and x - y recorder needed. Surface position could be measured from FDR sensor or, if no FDR sensor, at selected column positions using a control surface protractor.	* Rev
2.a.(2)	Wheel Position vs Force	Maint Man as above	Same as above	* Rev
2.a.(3)	Pedal Position vs Force	Maint Man as above	Same as above	* Rev
2.a.(4)	Nosewheel Steering Force and Position	None	Obj: Confirm important nosewheel steering metrics of the simulator model which are important to ground handling. Use 45A. Measure breakout with hand held force gauge. Use hand held gauge to measure force after breakout for small arc. Predict remainder.	Rev

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2.a.(5)	Rudder Pedal Steering Calibration	Acft Design Data	Obj: Confirm important nosewheel steering metrics of the simulator model which are important to ground handling. Force pads on pedals, pedal position measurement device, design data for nose wheel position. (Turn radius will be compared to AFM at full pedal, and possibly other, deflections also) [See 1.a.(2) above]	* Rev
2.a.(6)	Pitch Trim Calib. Indicate vs Compute	None	Obj: Validate the simulator model pitch trim calculation. Calculated	NC
2.a.(7)	Power Lever and other engine control levers Angle vs Engine Indication	None	Obj: Confirm that given engine control lever positions result in the proper engine performance indications. Fabricate scale to use on throttle quadrant. Video camera to record steady state instrument readings or hand record steady state engine performance readings	Rev
2.a.(8)	Brake Pedal Position vs Force	Acft Design Data	Obj: Assure that the brake pedal produces the appropriate force feedback for a given brake pedal position. Use design/predicted data. As for Level 6, measure only at 0 and maximum and use acft design data curve for deflections between extremes	* Rev
c. LONGITUDINAL				
2.c.(1)	Power Change Dynamics	None	Obj: Confirm the correct simulator model dynamic response to an in flight airplane power or configuration change. Do as per AC120-40B. Inertial measurement system would then be required. Transient data is needed therefore the dynamic case must be done.	** NC
2.c.(2)	Flap/Slat Change Dyn	None	Same as above	** NC
2.c.(3)	Spoiler/Speedbrake Change Dyn	None	Same as above	** NC
2.c.(4)	Gear Change Dynamics	None	Same as above	** NC
2.c.(5)	Gear Flap Slat Operating Time	Design Data, Certification Tests	Obj: Assure that the simulator model configuration change time increment corresponds to that of the airplane. Measure in conjunction with acquisition of data for 2.c.(1), (2), (3), (4) above. Statement of compliance referencing an appropriate data source. [Such as design data, production flight test schedule, maintenance test specification etc.]	Rev
2.c.(6)	Longitudinal Trim	Certification Tests (limited)	Obj: Confirm that simulator model parameters are correct in level flight steady state conditions. Inertial measurement system for pitch attitude, cockpit controls position measurement equipment with a calibration of cockpit controls positions and surface positions, ships engine instruments, do a number of level runs in accordance with the guidance of AC120-40B.	** Rev

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2.c.(7)	Longitudinal Maneuver Stability	Certification Tests, TIR	Obj: Confirm the simulator model longitudinal control force as a function of normal acceleration. Ships calibrated airspeed indicator. Apply a temporary high resolution bank angle scale to attitude indicator, inertial measurement system and wheel/column force measurement device.	** NC
2.c.(8)	Longitudinal Static stability	Certification Tests TIR	Obj: Confirm the simulator model longitudinal control force as a function of airspeed increments from trim airspeed. Ships instruments, hand held force gauge	NC
2.c.(9)	Stick Shaker, Airframe Buffet, Stall Speeds	TIR, AFM	Obj: Confirm that the simulator model produces stall at the correct airspeed and incorporates the appropriate warning modeling at airspeeds approaching the stall. Acquire using stop watch, ships calibrated airspeed, and video, hand record flight condition and configuration. The speeds are available in the TIR and AFM. Consideration should also be given to stall characteristics	NC
2.c.(10)	Phugoid	None	Obj: Confirm that the phugoid is correct as this mode is indicative of certain features of the longitudinal aerodynamic model and is very important to longitudinal trim ability. Inertial measurement system is necessary to accurately measure this important response. Cockpit controller positions are also important, especially in cases where the dynamics of flight control system components alter the character of the response.	** NC
2.c.(11)	Short Period	None	Obj: To assure that this primary longitudinal maneuvering mode is correctly produced by the simulator model. Inertial measurement system, measuring primarily accelerations (normal), video	** NC
d. LATERAL DIRECTIONAL				
2.d.(1)	Minimum Control Speed, Air	Certification Tests, TIR,	Obj: Confirm the minimum airspeed at which control can be maintained with one engine inoperative. Control force and deflection, asymmetric thrust and overall handling approaching and at the minimum control speed are important and should be recorded. Inertia measurement system, cockpit control force and position measurement device. An alternative procedure to measuring just the minimum speed at which control can be maintained is to measure the needed control deflections and other parameters at several speeds as the speed approaches the minimum control speed and as close as possible to the minimum speed in order to develop several simulator validation points at progressively lower speeds	** NC
2.d.(2)	Roll Response (Rate)	None	Stop watch, ships calibrated instruments, high resolution scale on attitude indicator, FDR sensor for lateral control (wheel) deflection. Do roll in both directions using a number of wheel deflections and measure only the steady state rates. Video of instruments	* Delete

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2.d.(3)	Roll Response to Step Input	None	Obj: Confirm that the simulator model properly produces this primary lateral-directional dynamic response mode and produces the correct steady state roll rate. Inertial measurement system to obtain rates. Lateral control input measurement device, video . Cruise case in addition to flight conditions specified in AC120-40B	** Rev
2.d.(4)	Spiral Stability	None	Obj: Confirm that the simulator model properly produces this primary lateral-directional dynamic response mode. Stop watch, ships calibrated instruments, high resolution scale on attitude indicator or video	NC
2.d.(5)	Engine Inoperative Trim	None	Obj: Validate simulator trim or control deflections required to counterbalance engine inoperative asymmetric forces and moments. Apply high resolution scales to trim controls and perform a ground calibration using protractors on the control/trim surfaces (ignores airloads). Use control scales for in-flight measurements. Very system dependent, but similar methods for other controls. Alternatively measure cockpit control force and position, especially during second segment climb where trimming is not a certification requirement and not a task to be accomplished in flight until the proper altitude and conditions are satisfied.	Rev
2.d.(6)	Rudder Response	None	Obj: Validate simulator model short term transient response to rudder inputs. Inertial measurement system, Rudder pedal input position measurement device.	** NC
2.d.(7)	Dutch Roll	None, maybe TIR	Obj: Confirm the lateral-directional simulator modeling as manifest by this coupled primary response mode. Inertial measurement system. Record with and without yaw damper. Rudder pedal input position measurement device.	** NC
2.d.(8)	Steady State Sideslip	None, maybe TIR	Obj: Confirm the relationship that exist between sideslip and rolling moment and secondarily the rudder and roll control power. Use ground reference (a long straight path) for track and heading indicator for sideslip angle. Cockpit controller force and positions measurement device. If inertial measurement system is installed, measure lateral acceleration. Video. This test was not discussed during SME meeting. Revisions have been made based on the overall discussions.	* Rev
e. LANDINGS				
2.e.(1)	Normal Landing	None	Obj: Confirm the overall performance and handling of the simulator model during descending flight near the ground, transition through ground effect, landing flair and touch down. Inertial measurement system, cockpit control force and position measurement device	** NC

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2.e.(3)	Crosswind Landings	None	Obj: Confirm proper response of simulator model, including flight controls, to a crosswind during descending flight near the ground, transition through ground effect, decrab and touchdown/rollout. Inertial measurement system, cockpit controller positions and forces, record normal and lateral acceleration in lieu of AOA and sideslip.	** NC
2.e.(4)	One Engine Inoperative Landing	None	Obj: Confirm proper response of simulator model, including flight controls, with one engine inoperative during descending flight near the ground, transition through ground effect, touchdown and rollout. Same as above	** NC
2.e.(7)	Rudder Effectiveness with Rev Thrust	None	Obj: Demonstrate that the rudder effectiveness during reverse thrust on landing in the simulator is representative of the airplane. No test recommended since the test was specific to airplanes with aft fuselage mounted engines	Delete
f. GROUND EFFECT				
2.f.(1)	Ground Effect Demonstrate G.E.	None	Obj: Confirm the simulator modeling and proper aerodynamic modeling changes as a function of height and rate of change of height in ground effect. Level fly-by trim runs. Use high resolution scale on elevator trim control. Ground calibrate Trim control with trim surface. Use ships calibrated flight instruments and engine instruments, video of trim controls and aircraft instruments. Or fly low angle constant pitch attitude approach and landing at constant power and record trim, control displacement and airspeed changes as ground is approached (not applicable to all airplanes). Inertial measurements system, cockpit controller force and positions, radio altitude and altitude rate are needed.	** Rev

Comments Legend

- ** tests for which an inertial data acquisition system is recommended - 20 tests
- * tests for which some instrumentation less than inertial is recommended - 6 tests
- Total number of tests requiring installation of instrumentation - 26
- Total number of tests listed - 48

NC no change from the current AC120-40B guidance

Rev revision of the current AC120-40B guidance, usually by the use and acceptance of existing data sources or the use of more basic (less sophisticated and complex) flight test methods.

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Notes:

1. Measurement of angle of attack and sideslip have been omitted for all tests. Also measurement of control surface positions is not required, however, cockpit controller positions must be measured where indicated and tolerances comparable to those for the control surface determined. These measurements alone result in revision to most Level B validation tests.
2. With the exception of the alternative, and in some cases relieving, techniques and instrumentation recommendations given above, all tests should be done to comply with the guidance of AC120-40C.
3. Measurements of control surface deflections/positions have been omitted in the above table, however, cockpit controller positions must be substituted and equivalent tolerances will have to be used when complying with AC120-40C Level B simulator qualification guidance.
4. To accommodate the recommended test methods and techniques, some measurements would be replaced with pilot's notes.
5. Certification/TIR data points are usually at the extremes of weight and CG, but still lie on the locus of a given parameter and are useful for model validation.
6. TIR data may be proprietary and should not be relied upon until known to be available.

**Transcript of the
Joint FAA/Industry Symposium
on
Level B Airplane Simulator
Motion Requirements**

Part 9 of 9

Appendix 3:

Bürki-Cohen, J., Soja, N., & Longridge, T.: Simulator Platform Motion—The
Need Revisited.

Draft submitted to the *International Journal of Aviation Psychology*

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Simulator Platform Motion—The Need Revisited

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Abstract

The need to provide increased access to flight simulator training for U.S. regional airlines, which historically have been limited by cost considerations in the use of such equipment for pilot recurrent training, is discussed. In light of that need, the issue of whether more affordable fixed-base simulators, identical to full flight simulators in all respects except for absence of platform motion, might provide an equivalent level of safety when employed for recurrent training, is examined. Pertinent literature from the past two decades is reviewed. The paper observes that no definitive conclusion can be drawn that would warrant modification of current qualification requirements for platform motion in full flight simulators. The article concludes that this situation will remain unchanged unless new research is undertaken, which takes into account the lessons learned from past research, and the opportunities engendered by new technology. Broad guidelines for an appropriate research design are discussed.

Platform Motion—A Need To Re-Examine The Requirement

The use of full flight simulators for pilot training and evaluation is universal among major air carriers in the United States, all of whom have, within their own corporate resources, access to full flight simulators equal to both the maneuver and scenario oriented requirements of Federal Aviation Administration (FAA) approved training programs. Flight simulators not only enable savings in training costs, they also allow the training of emergency maneuvers which are inherently unsafe in the aircraft; and they permit crews to gain experience in operationally realistic scenarios that focus on both technical and crew resource management skills. One might well conclude that this type of training is essential to safety, and should therefore be required of all air carriers under CFR 14, Part 121 and Part 135 operations (National Transportation Safety Board, 1993). The use of flight simulators remains optional, however, in the United States. U.S. airlines electing to conduct training and checking in the aircraft are free to do so, subject to FAA approval of their respective programs, including acceptable provisions for windshear training. Indeed, under current regulations U.S. airlines not conducting initial or transition training under CFR 14, Part 121, Appendix H (Advanced Simulation Plan, 1980), or under SFAR 58 (Advanced Qualification Program, 1990), **must** complete certain checking requirements in the aircraft. Many U.S. regional airlines conduct their pilot training programs on that basis.

Compared to U.S. major airlines, regional airlines, most of which do not own their own training equipment, have historically not had equal access to full flight simulators. Regional airlines electing to use flight simulators for training must establish contractual arrangements with training centers, or with other air carriers, who have the appropriate simulation equipment. As it turns out, the cost of such contractual arrangements, when coupled with the travel expenses for cockpit crew, can exceed the per hour cost of conducting training in some regional aircraft. Moreover, for some regional aircraft operated in the U.S., the worldwide availability of qualified flight simulators may be extremely limited. As a result, though most U.S. regional airlines would clearly prefer to conduct all their training in flight simulators, many such carriers have found it necessary to either conduct all training in the aircraft, or to limit the use of simulators to initial and transition training. The cost and limited availability of flight simulator access for recurrent pilot training has simply been prohibitive for small airlines. For many of these U.S. regional carriers, recurrent proficiency checks, and recurrent flight operations training, if any, are conducted in the aircraft. However, the need for flight simulation training for regional airline pilots is at least equal to that for pilots in major airlines, when considered in light of the fact that (a) the experience levels of regional pilots tend to be lower, (b) pilot turnover tends to be higher, (c) certain regional airport environments are less well

equipped with navigation aids, (d) U.S. regional aircraft certification standards entail certain reduced system redundancy requirements, and (e) the procedures for powerplant malfunction or engine failure in turboprop aircraft can be more demanding than for jet aircraft. Clearly it is in the interest of safety to consider what measures can be taken to increase the accessibility of simulation equipment for regional air carriers.

In recent years the cost of full flight simulators has fallen significantly, and the availability of even less costly flight training devices (FTDs) has grown. At the upper end of the FAA defined continuum of approved FTDs (AC-120-45A, FAA 1992), the equipment fully duplicates a flight simulator, except for visual and platform-motion cueing requirements, which are optional. Since the cost of high fidelity simulator visual image generation and display equipment has also become more affordable, U.S. regional airlines are increasingly interested in the question of whether an FTD equipped with such a visual system (i.e., a fixed-base simulator) could be employed to fully accomplish the FAA requirements for recurrent training and checking, which constitutes a major cost consideration for such airlines. Allowing complete credit for the use of such devices in recurrent training could reduce the cost of access, or permit the direct acquisition of such equipment by regional airlines to accomplish their own training. It would permit airlines now conducting such training in the aircraft to take full advantage of the more comprehensive maneuver-oriented and scenario-based training opportunities available in a simulator. The overall safety of regional airlines could thereby be enhanced.

The FAA is therefore undertaking to revisit the issue of platform motion in the context of regional airline recurrent pilot training and checking. Given a pilot who is already qualified as a crew member in the aircraft and who has been serving in line operations in that aircraft for at least six months, the FAA is interested in obtaining data pertinent to the following questions. Broadly, does the training conducted in a fixed-base simulator with a wide field-of-view (FOV) visual system produce a result equivalent to that which would be obtained in a like system having platform-motion cueing? Specifically, with regard to the sudden onset of asymmetrical thrust, does recurrent training accomplished in the absence of motion-platform cueing have any measurable effect on the pilot's capacity to respond in a timely and appropriate manner in the aircraft during maneuvers entailing powerplant failure? And finally, from a regulatory perspective, do recurrent proficiency checks conducted in a visually equipped fixed-base simulator provide an equivalent opportunity to verify the line-operational readiness of air-carrier pilots?

In the interest of obtaining information pertinent to the issue of simulator-motion fidelity requirements for recurrent training, the FAA has convened two workshops comprised of recognized experts in aeromodeling, and in platform-motion cueing, respectively (Transcripts, 1996; Longridge, Ray, Boothe, & Bürki-Cohen, 1996). It was generally

concluded from these meetings that while certain economies in existing simulator qualification standards could be achieved without significantly degrading the cueing effectiveness of such equipment, an absence of platform-motion cueing is likely to have a detrimental effect on pilot control performance in fixed-base devices, particularly in maneuvers entailing sudden motion-onset cueing, such as loss of engine during initial segment climb, where visual references are limited. It was also noted, however, that there is no evidence that training conducted in such an equipment configuration would lead to degraded control performance in the aircraft. It was observed that pilots readily adapt their control strategies to the equipment at hand, whether in the direction of simulator to aircraft, or vice versa.

The FAA has also sponsored a comprehensive review of the past two decades of research literature pertinent to the contribution of simulator platform motion to training effectiveness, selections from which are summarized below.

The FAA Perspective

A flight simulator is intended to imitate or simulate, from the point of view of the pilot, both the physical characteristics and the behavior of an airplane and its environment, on the ground and in the air. A simulator that “successfully imitates” the airplane will, on the one hand, effectively train a pilot for flying the airplane and, on the other hand, accurately reflect a pilot’s proficiency in the airplane. Substituting the simulator for the airplane in training and qualification of airline pilots avoids training accidents, enables controlled flight scenarios including emergencies, helps identify and satisfy individual training needs, and, dependent on the nature of the air carrier’s operations, can reduce costs.

It is important to note that the use of flight simulators in air-carrier training and checking activities goes beyond the standard transfer-of-training paradigm. When used as a substitute for the aircraft, the evaluation of pilot performance in the device constitutes a determination of the readiness of the pilot to perform immediately in line operations involving the flying public. That is, unlike many classical transfer-of-training situations, the simulator-trained air-carrier pilot is expected to perform within satisfactory standards of proficiency in the aircraft from day one. Consequently, the simulator must be capable of supporting 100 percent transfer of performance to the aircraft. **Anything less would compromise safety.** The existing standards for full flight simulator qualification, all of which entail a requirement for platform-motion cueing, have a twenty year record of meeting the requisite criterion for transfer of performance. In the absence of compelling evidence to the contrary, it is therefore prudent to maintain these standards in the interest of public safety. Regulatory authorities will therefore continue to require platform motion for flight-operations training and checking conducted in higher-end devices, even under the more flexible requirements of SFAR 58, as long as there is any reasonable indication that simulator

platform motion is beneficial, and, concomitantly, the FAA will continue to limit the credit permitted for use of non-motion equipped Flight Training Devices (FAA-S-8081-5B).

An Alternative Viewpoint

While it is certainly the case that there is no compelling evidence that platform-motion cueing can safely be eliminated from present flight simulator qualification requirements, it can also be observed that the evidence in favor of the requirement is itself less than compelling, and therefore warrants reexamination. As Bussolari, Young, & Lee comment in 1989, “[t]he requirement for platform motion is ostensibly based on the assumption that physical fidelity is highly correlated with training effectiveness. Since airplanes are capable of motion in all six axes (three translational, three angular), it is believed that the absence of motion in the simulator would significantly reduce its training effectiveness.” Since there are hardly any objective criteria available, however, on what type of motion is required (given the fact that a simulator can never duplicate the range of motion cueing experienced in an aircraft), the existing regulations in FAR Part 121 Appendix H and the guidance given in the Advisory Circular on Airplane Simulator Qualification AC-120-40B (FAA, 1991; and its draft revision AC-120-40C) are largely based on subject matter expert opinion. While the Advisory Circular recommends extensive subjective evaluation by trained FAA flight inspectors, the reliability and validity of this subjective evaluation strategy has never been subject to systematic quantification. The principle argument in favor of present qualification standards for simulator motion—that they have stood the test of time—is weak. To the extent that continued adherence to these standards may actually preclude a significant segment of the air-carrier industry from the safety benefits of flight simulator training, it is reasonable to suggest that, unless objective criteria for motion requirements can be obtained, the requirement has no justifiable basis in fact.

Objective Vs Perceptual Fidelity

Since Edwin Link conceived his “Blue Box” in the late twenties, simulator engineers and engineering psychologists have been grappling with the question of what makes a simulation successful. The North Atlantic Treaty Organization’s Advisory Group for Aerospace Research & Development distinguishes between objective (i.e., physical) and perceptual fidelity of a flight simulator (Advisory Group for Aerospace Research and Development, 1980). **Objective fidelity** of a flight simulator is relatively easy to determine. Using precise instruments that are free from the limitations and distortions of the human perceptual system, simultaneous recordings of all pertinent variables of both the airplane simulator

and the simulated environment are compared with the corresponding measurements from the pilot's seat in the actual airplane (Ashkenas, 1985). The closer the match, the more objectively faithful the simulator is to the airplane. A more valid measure, however, may be the more elusive **perceptual fidelity**. It is defined as a match between not only pilots' subjective perception of the simulator and the airplane, but also between pilots' performance and control strategy or behavior in the simulator and the airplane. Its determination requires carefully controlled experiments.

The discussion of objective versus perceptual fidelity is especially pertinent in the context of simulator motion, which is inherently limited in its objective fidelity despite substantial technological advances. Even as late as 1989, Brown, Cardullo, & Sinacori (p. 78) state that “[b]arring an unforeseen revolution in the technology of force and motion cueing, it is evident that it is hopeless to attempt to provide realistic force and motion stimuli in the sense that the acceleration forces produced by the aircraft can be replicated in the simulator.” In particular, it is impossible to simulate sustained acceleration without sustained displacement, and any direct application of whole body acceleration forces will require inappropriate counter forces. The only way out of this dilemma is to focus not on the reality of the force and motion stimuli, but on the perceptions associated with force and motion, i.e., perceptual fidelity. The question that needs to be answered is how can pilots best be stimulated to perceive airplane motion in the simulator.

Motion occurs in space and over time. The most important sensor of motion occurring in the world around us is our visual system, perceiving motion from changes in position; and velocity and acceleration by additionally taking time into account (Sedgwick, 1986). Vision is also important for the perception of our own motion and posture, especially in the case of sustained, constant motion as often occurs when riding within a vehicle. Psychophysical evidence points to the ambient or peripheral visual system as especially important for processing dynamic and orientation information (see, e.g., McCauley, 1984; Dichgans & Brandt, 1978). However, we also rely on our tactile and somatic (perceiving pressure changes on skin and organs), our kinesthetic (perceiving joint position and muscle forces), and, more importantly, on our vestibular system (registering angular velocity and linear acceleration) for the perception of self-motion (Hall, 1989). All four of these perceptual systems have been called upon, either together or in isolation, to stimulate pilots to perceive motion in airplane simulators, and the degree of their success has been the subject of extensive research and controversy. Although there have been some promising results from tactile and somatic stimulation via dynamic seat pans (see, e.g., Martin, 1985), such devices have not gained much popularity beyond the armed forces. We will therefore restrict this discussion to a comparison of airplane simulations using either whole-body motion or visual displays or both to stimulate pilots to perceive motion.

Acceptability Of Simulator

As we will see, there are few points of general agreement in the discussion of whether whole-body motion is a required stimulus for successful training and qualification in the simulator. One area of consensus, however, is that pilots prefer vestibular motion cues to be present in the simulator. This has been confirmed both in informal discussions with pilots and in controlled experiments (but see Lee & Bussolari, 1989, discussed below).

Acceptability Of Several Motion Algorithms With Limited Visual Stimulation

In 1988, e.g., Reid & Nahon compared nine motion conditions (three different motion algorithms, each with three different parameter sets) with no motion using a B-747 simulator with a state-of-the-art six degrees-of-freedom (DOF) synergistic motion base incorporating hydrostatic bearings. Although the presence or absence of motion did not appear to affect pilots' performance and control behavior, it definitely affected their opinion regarding the simulation environment, both in their comments and ratings. Pilots were asked to "judge the quality of the motion cues and not any other aspects of the simulation," on two different rating scales. The University of Toronto Institute for Aerospace Studies (UTIAS) scale was used to assess the quality of motion associated with control inputs on the column, wheel, rudder pedals and throttle, as well as with turbulence and ground contact. The Massachusetts Institute of Technology (MIT) scale rated smoothness, sense, amplitude, phase lag, discomfort, disorientation and overall impression. The summary of average UTIAS rankings by the seven pilots shows that the no-motion condition was consistently in the last place for all items but for turbulence, where it was in the second to last place. In the MIT ratings, the no-motion condition fared somewhat better, although it still was in the last position for overall impression. Disorientation was experienced second to worst without motion; and sense, discomfort, and phase lag occupied middle rankings. With regard to discomfort, for all three algorithms the parameter set resulting in the largest travel was rated worse than the no-motion condition. Smoothness of the simulator, of course, was rated best without motion, as amplitude was worst. Taking into account both ratings and comments from pilots, the authors conclude that "[t]he pilots preferred physical motion to be present in the simulator. They felt that it added to the realism of the simulation and was helpful in the piloting task."

Acceptability Of Motion Vs No Motion With A Wide Field Of View

One explanation for the preference for motion in the Reid & Nahon study might be that the visual stimulus was very sparse, thus requiring platform motion to provide the necessary cues to achieve the best percept of motion. They used a collimated out-the-window CRT with a narrow FOV (40 degrees horizontally and 30 degrees vertically) on which they

displayed a yellow line drawing indicating depth and path on a black background. Hall (1978), however, extended the FOV to 200 degrees horizontally using a skyscape shadowgraph projector and found that even with this wide FOV (and less-than-perfect motion cues), the pilots still preferred the motion to the no-motion conditions for controlling a vehicle with an unstable Dutch roll. Specifically, he used a simulated Harrier GR Mk 3 with a three DOF motion system (roll, pitch, and heave) that was “suffering from backlash, low gain and hence reduced perception thresholds.” The pilots rated lateral control in transition from hovering to jet-borne forward flight on a Cooper-Harper scale, where 10 is the worst score and means that the vehicle is uncontrollable. Unfortunately, Hall reports no queries regarding pilot comfort. There were eight different conditions resulting from all possible combinations of the presence or absence of motion, TV monitor, and skyscape (which provided the additional peripheral view). All conditions also included an instruments display (both head-down and head-up). Pilot C’s results were provided as an example of the overall results. Each of the motion conditions was preferred to the corresponding no-motion condition, including the case in which the best vision was available. That is, the condition with motion, TV monitor, and skyscape (6, unsatisfactory) was preferred to the condition with no-motion, TV monitor, and skyscape (7, unacceptable). Interestingly, however, motion appeared to be most important when there was no visual information available besides instruments. Here, removing motion worsened the rating from 7 (unacceptable) to 9 (unacceptable and just controllable). Thus, Hall’s study confirms Reid & Nahon’s finding that pilot acceptance of a simulator depends on the presence of motion, extending it to simulators including a wide FOV visual system.

Acceptability Of Full Motion Vs Special-Effects Vibration With A Wide Field Of View And “Naïve” Pilots

Lee & Bussolari (1989, also reported in Bussolari, Young, & Lee, 1987) also looked at the effect of motion on pilot acceptance. They used a Boeing 727 Phase II (now Level C) simulator with a wide FOV (75 degrees horizontal and 30 degrees vertical per pilot seat) (FAR Part 121, Appendix H). There were two significant differences, however, between their study and Hall’s (1978). First, the pilots in the Lee & Bussolari study did not know when the motion was on and off. Second, Lee & Bussolari used a “special-effects” condition instead of an actual no-motion condition. In this condition, the motion platform heaved at an extremely small amplitude (0.25 inches). This slight movement was intended to provide cues for the touchdown bump; runway roughness; buffets associated with flap, gear, and spoiler extension; and Mach and stall buffets. This condition was compared to full six DOF motion and to two DOF motion (heave and sway). In contrast to the other studies, Lee & Bussolari found that there were no differences in pilots’ ratings of workload, control responsiveness, utility for training and checking, and overall realism, between any of the three conditions (or in performance and control

behavior either). No information on simulator sickness is given. Young, however, in response to a question after his presentation at the Aerospace Medical Panel Symposium on Motion Cues in Flight Simulation and Simulator Induced Sickness in Brussels (Bussolari et al., 1987), reported that informal queries revealed no simulator sickness. These results indicate that the preference for motion found in the other experiments might be due to pilots' **expectation** that motion would be better, not to actual preference (see, e.g., Ebbinghaus, 1964). Another possible explanation is that some vibration as feedback for certain events is important for pilot acceptance, but that large displacements are not required.

Clearly, motion improves pilot acceptance of the simulator in some cases. Whether that improvement is due to a real preference or just a positive bias towards motion, and whether a full motion platform is required, are less clear.

Performance/Control Behavior Assessment In Simulator

The studies discussed in this section examined whether the preference pilots expressed for simulators including a motion platform over fixed-base simulators manifests itself also in improved performance and control behavior in the presence of vestibular motion cues compared to visual cues alone.

Motion Vs Visual Cues For Control Of An Unstable Vehicle

The Hall (1978) study previously described examined the impact of motion on pilots' control of Dutch roll oscillations in addition to pilot acceptance. Recall that Hall compared the effect of a less-than-perfect three DOF motion system with the effect of a central visual display (TV monitor) and the effect of a peripheral visual display (skyscape) on lateral control of a Harrier GR Mk 3 without autostabilizers. He measured aileron deflection or stick activity, roll rate, bank angle, and sideslip while transitioning from hovering to jet-borne forward flight. As with the Cooper-Harper ratings, the motion condition fared better than the corresponding no-motion condition regardless of whether there were both, only one, or no visual displays added to the instruments. This is seen in consistently higher-amplitude residual oscillations without motion in all measurements for pilot C (sideslip was not given for any of the conditions with skyscape). As with the pilot ratings, the difference appeared most pronounced for the instruments-only condition.

Hall concludes that even a "practical" motion system is "as good or better (in terms of performance) than nominally perfect peripheral vision for controlling a vehicle with an unstable Dutch roll." He continues to explain that this was due to the inability to generate sufficient lead to reduce the amplitude of the oscillations to an acceptable level in the absence of motion cues. It appears, though, that this explanation results from a comparison of the instruments-only conditions with and without motion, rather than from a comparison of the conditions including visual cues.

Motion Vs Visual Cues For Disturbance and Target Following (Tracking) Tasks

Hosman & van der Vaart (1981) also compared the effect of central and peripheral visual cues with motion cues on pilot performance and control behavior. In addition, they compared two different types of control tasks, a disturbance task and a target following task. In a **disturbance** task a random signal perturbs the controlled system and requires correction. This can be compared to a pilot stabilizing an airplane in turbulence. The signal affects all information displays the same, including the motion system. In a target-following or **compensatory tracking** task, a displayed random signal needs to be tracked. This task corresponds to a pilot following another airplane in formation flight. The lateral control task in the Hall (1978) study would also qualify as a compensatory tracking task, where pilots “track” a straight and level flight path. In fact, all flying tasks that do not involve any weather or mechanical failures can be looked upon as compensatory tracking of a flight path. Here, the signal goes only to the central display (or instruments), and **not** to the peripheral display or the motion system. The **maneuver** motion experienced during a compensatory tracking task contributes to the pilots’ perception of the handling qualities of the simulator (or airplane) and of the effect of their control actions.

Hosman & van der Vaart (1981) included both kinds of tasks because motion is assumed to serve different functions in each case. Gundry (1976, for example) asserts that disturbance motion, but not maneuver motion, is generally assumed to serve an alerting function. Maneuver motion, on the other hand, provides feedback on pilot control behavior, but even so may be necessary only when controlling unstable vehicles, especially under high gain (cf. Hall, 1978; 1989).

Peripheral visual cues were provided by two CRTs displaying a moveable checkerboard pattern against the side windows of the simulator. Vestibular motion cues were provided using a three DOF (pitch, roll, and heave) system with hydrostatic bearings and “low noise motion characteristics.” Three qualified jet transport pilots were tested. For both kinds of maneuvers, subjects had to correct for a quasi-random signal with a standard deviation of 1.875 degrees affecting roll attitude. In the disturbance task, the signal affected all available cueing systems, i.e., motion and peripheral and central visual displays, the CRT providing the central visual cues displaying the roll angle as the difference between airplane attitude and artificial horizon. In the tracking task, the signal affected only the central display, which showed the difference between the quasi-random signal and the roll angle of the simulator, i.e., the roll angle error. For both tasks, pilots were to minimize the difference displayed on the central CRT, using a spring-centered side stick controller.

Hosman & van der Vaart (1981) examined both the performance and control behavior of the pilots. Performance was reported as the standard deviation of roll angle for the disturbance task and the standard deviation of roll angle error for the tracking task. The results show that in both kinds of tasks, the addition of vestibular motion cues had a more

significant impact on performance than the addition of peripheral visual cues. This was especially pronounced for the disturbance task.

For the control behavior assessment, pilots' frequency responses describing the relation between roll angle or roll angle error and pilots' side stick deflections were calculated for all conditions. For the purpose of the present discussion, we will report only the results for crossover frequency and phase margin, which were "markedly" different for the two tasks. A high **crossover frequency** reflects high controller **gain** over a wide bandwidth, and will thus result in good performance for both tasks. The **phase margin** reflects the remaining margin of **stability** of the human-machine system and is therefore also important for good performance. Generally, a trade-off relationship exists between phase margin and crossover frequency. Hosman (1996) reports that for the **disturbance task**, "the crossover frequency increased only slightly as a result of the peripheral displays, but strongly as a result of cockpit motion" in comparison with central visual cues alone. Phase margin was affected by neither the addition of peripheral visual or vestibular motion cues. That is, in the disturbance task, vestibular motion provided the primary cueing enabling pilots to increase gain without losing stability. In contrast, for the **tracking task**, crossover frequency decreased when motion cues alone, or motion and peripheral cues together, were combined with central visual cues. This was offset, however, by a large increase in phase margin when motion cues were present (or only a slight increase when peripheral vision was combined with central vision). That is, in the tracking task, vestibular motion also provided the primary cueing, but in this case it resulted in an increase in stability with a concomitant loss of gain. This, combined with Gundry's (1976) report that maneuver motion is only useful in controlling unstable vehicles, suggests that the primary role of motion during tracking tasks is increasing stability.

Thus, the Hall (1978) and the Hosman & van der Vaart (1981) papers concur in finding that the presence of motion improves pilot performance and behavior in the simulator, and that this improvement cannot be duplicated by the presence of peripheral vision in the absence of motion. In addition, Hosman & van der Vaart demonstrated that the effect of motion is mediated by the kind of maneuver, both in terms of the strength of the effect and the type of the effect. That is, the performance results indicate that the need for motion is greater with disturbance maneuvers than with tracking maneuvers; and the control behavior assessment indicates that the effect on disturbance maneuvers is an increase in pilot gain, whereas the effect on tracking maneuvers is an increase in stability (and a **loss** of gain).

Training Assessment in Simulator (Quasi-Transfer)

None of the studies considered thus far have examined the impact of motion on the **training** of pilots. That is, at best they have shown that motion is important for the flying **of simulators**. But, pilots are not trained to fly simulators—they are trained to fly airplanes. To discern whether simulator motion is valuable in the training of pilots, it is necessary to examine whether the presence of motion **in a simulator** improves pilot performance and behavior **in the airplane** above a baseline effect of simulator training without motion.

However, for the same reasons that it is difficult to use airplanes for the full training of pilots, it is also difficult to use airplanes in experiments. That is, it is impossible to control the weather, it is extremely difficult to do multiple repetitions of individual maneuvers, the degree of danger is too high for certain maneuvers such as responding to system failures, and airplane time is very costly. Consequently, some scientists have chosen to test the validity of simulator training by training pilots in a simulator and then testing the acquired skills in a different simulator or in the same simulator running under a different configuration. The assumption is that the new simulator (or simulator configuration) is more like an airplane than the trained-on simulator. This paradigm is called “Quasi-Transfer” because it tests for transfer of training, but not to an actual airplane.

Quasi-Transfer Of Training Of A Simple Tracking Task Under Different Motion Conditions

Levison (1981) used a quasi-transfer paradigm to study the effects on training of simulator motion and of the time lags between simulator vestibular motion and visual cues. He used the Multi-Axis Tracking Simulator at the Air Force’s Aerospace Medical Research Laboratory, which was simulating a single seat cockpit. Presumably, only the roll-axis motion capability was used in this experiment, and visual information was presented on a television monitor (Levison & Junker, 1977). Subjects were to keep the simulator in straight and level flight during gust-like disturbances and were described as “naïve to the task” (no other information on subjects is given). Each subject was trained under one of five conditions, vision-only, synchronous vision and motion, and three lag conditions. In the lag conditions, motion lagged vision by 80, 200, or 300 ms. During training, large reductions of mean-squared tracking error (roll angle) were observed in all conditions, but especially in the 80 ms lag and synchronous motion conditions.

The subjects in all lag and in the vision-only conditions were then tested in the synchronous motion condition as a stand-in for the real airplane (the group trained with synchronous motion had reached asymptotic performance very early in the training and was thus not tested again). All groups showed immediate improvement with synchronous motion, but only

the group trained with the very short motion lag (i.e., 80 ms) appeared to transfer their training to the new condition, achieving the equivalent of the asymptotic performance of the synchronous motion group on the first post-transition trial. The vision-only group achieved the same performance after three more trials. With large lags, however, the positive impact of motion on training was gone or reversed. Specifically, after transition to the synchronous condition, the subjects trained with a 200 ms motion lag performed barely better than the vision-only group; and the subjects trained with a 300 ms motion lag actually performed worse, still trailing behind all other groups after seven post-transition trials. This shows that badly synchronized motion is in fact worse than no motion at all. One interesting note is that the advantage of near-synchronized motion was much smaller after transfer to the synchronized condition than it had been prior to transfer. Most likely, this is due to a floor-effect. That is, because the 80 ms delay group could not have improved any further (having immediately reached the best possible performance as defined by the synchronous group), differences between the 80 ms delay group and the other groups may appear smaller than they really are. Alternatively, it is possible that the attenuation of group differences is not an artifact, but indeed indicates that if there is a motion advantage in the simulator, only a small portion will be transferred to a higher-level device (and, presumably, the airplane). In either case, it is clear that the presence of motion, if closely aligned with vision, had a positive impact on the training of subjects, not just on their performance within the original simulator configuration.

Pilot behavior was assessed by obtaining frequency response measures from selected subjects. For our purposes, we will only report the comparison between the control behavior of the vision-only and the 80 ms motion lag groups during the early post-transition trials. The parameter of interest is observation noise, which is an Optimal Control Model parameter reflecting subjects' information-processing limitations. The observation noise/signal ratios were lower for subjects trained with motion than for subjects trained with only visual cues. This indicates that the presence of delayed motion during training, if the delay is short (i.e., 80 ms), improves the subjects' efficiency in processing synchronized visual and motion cues when transferred to a higher level device, compared to having had no motion at all during training. Presumably, "subjects trained initially with the 80-msec delayed motion cues were exposed to a perceptual situation more like the transfer task than were subjects trained fixed base, and were therefore able to more quickly learn to process faithful motion cues and adopt the appropriate control strategy in the transfer condition."

Quasi-Transfer Of Engine-Failure (Disturbance) Training Under Different Motion Conditions

A few years earlier, DeBerg, McFarland, & Showalter (1976) had used a quasi-transfer design to study the effect of motion and visual cueing on take-off engine-failure training. Recovery from a take-off engine failure is exactly the high-gain, asymmetric, closed-loop disturbance task where vestibular motion cues may serve as an early alert. Thirty-six KC-135A aircraft commanders who were matched for initial proficiency were trained in one of four simulator configurations, resulting in nine pilots per condition. The National Aeronautics and Space Administration's Flight Simulator for Advanced Aircraft (FSAA) at Ames Research Center was used because of its "unique ability to generate the types of aircraft motion cues which an outboard engine failure would generate," namely "yaw, roll, and lateral motion." The four training phase configurations ranged from maximum cueing with visual and motion cues to minimal cueing with neither motion nor visual cues, via motion-only and vision-only configurations. For the training configurations, the FSAA motion was restricted to "an envelope roughly analogous to that of a six-post synergistic motion system." The visual system was described as a "six-degree of freedom system in which a color television camera is mounted on a gantry and moves relative to a fixed-model board. The scene is presented to the pilot, through collimation optics, on a cathode-ray tube situated in the forward cockpit window." After training, transfer was assessed in the unrestricted motion configuration with the full visual system.

The authors maintain that their experiment shows an increase in training effectiveness both with the addition of a visual or a motion system, and a synergistic improvement in training when both are used together. Neither subjective pilot opinion nor the analysis of the performance variables measured during the evaluation phase fully warrant this claim. Pilots rated both the "sufficiency of cues to negotiate engine failures" and the "cueing system as a training device" twice, once after the training and once after the assessment phase. When rating, on a scale from one to five, the **sufficiency of cues** to negotiate engine failure after the training phase, pilots indeed rated the configuration with both motion and vision most positively (4.89). After they had experienced also the assessment phase with the full simulator capabilities, however, they gave the configuration with neither motion nor visual cues the highest rating! The motion-only condition was rated lowest after either phase (3.89 and 4.33, respectively). As a **training device**, the no-motion/no-vision configuration was rated least favorable after both phases (3.22 and 3.33, respectively), in each case followed by the motion-only configuration. After training, pilots rated vision-only highest (5); and after assessment, they rated vision with motion highest (5). It appears, then, that the only claim consistent with all results would be that, in most cases, pilots favor simulator configurations including a visual system.

To assess performance, the authors claim to have measured 34 variables during the evaluation phase. But most of their conclusions are based on mean total roll and total yaw, which “best discriminated between the four cueing systems employed,” as determined by “multivariate statistical analyses” (a somewhat obscure analysis of variance is also presented). For ground engine failures (at 140 knots), De Berg et al. correctly state that performance deteriorated with vision or motion alone compared to the configuration with neither vision or motion. Vision and motion combined, however, was no better than the no-vision/no-motion condition, at least for roll (for yaw there was indeed a slight improvement). For flight engine failures (at 47 feet altitude), visual and motion together were indeed best, followed by motion alone, neither motion nor vision, with vision in the last position. Thus, with regard to performance, motion may be beneficial, but only for flight engine and not at all for ground engine failures. With the *caveat* that pertinent data may have been lost in the analysis procedures, all we can conclude from the uneven results of this study is that nine pilots in each condition may not be quite enough to allow true differences between groups to emerge from the variability of pilots within groups.

In sum, the Levison (1981) study confirms the previous results (Hall, 1978; Hosman & van der Vaart, 1981; Reid & Nahon, 1988) that demonstrate a benefit of motion in simulator training, yet extends those findings in a significant way. Levison (1981) showed that the advantage of motion in the simulator transfers to a higher level device, suggesting that it may transfer to the airplane as well. DeBerg, McFarland, & Showalter’s (1976) results, however, which were obtained using more realistic equipment, real transport aircraft pilots, and a highly diagnostic task with the quasi-transfer paradigm, do not fully confirm Levison’s conclusions.

Training Assessment in Airplane (Transfer)

Despite the inherent constraints on transfer-to-airplane studies, several people have attempted them. In contrast to the Levison (1981) quasi-transfer study, in all cases the motion benefit found in the simulator was completely lost in the airplane. However, each of the studies has some form of methodological shortcoming; some out of the control of the scientists such as the state of technology at the time of the experiment and the inherent problems of airplane experimentation. Below is a brief description of several such studies.

Transfer Of Training—Tracking Maneuvers

Jacobs (1976) trained 27 subjects in a non-visual Singer-Link GAT-2 trainer with three DOF (presumably roll, pitch, and heave). He then tested them, as well as a group of control subjects who received no training, in a Piper Cherokee

Arrow airplane. The subjects who received training were evenly divided into three groups. One group was trained in the simulator without motion, another with normal washout motion in bank with sustained pitch angles, and the third with directionally-random motion (i.e., “washout banking motion in which the direction of motion relative to that of the simulated airplane was randomly reversed 50% of the time as the cab passed through a wings-level attitude”). Subjects in each of the three experimental groups were trained on 11 tasks, all tracking maneuvers (straight and level flight, straight and level power changes and airspeed transitions, climbs and descents, constant bank angle and standard rate turns, airspeed transitions during turns, climbing and descending turns, instrument navigation patterns). Training performance was evaluated through experimenter observation of number of “errors,” i.e., violation of FAA private-pilot flight check standards. Transfer was evaluated through time and trials to FAA performance criteria and number of errors. Jacobs found that during simulator training the group with washout motion had fewer errors than the other groups, demonstrating again that in the simulator good motion is advantageous—even with tracking maneuvers. However, after the subjects transferred to the airplane, although all three groups performed better than the control group with no simulator training on all of the three dependent variables, there were no significant differences between the three experimental groups. That is, simulator training improved performance in the airplane, but motion in the simulator (whether no motion, “bad” motion, or “good” motion) had no additional effect on performance in the airplane.

Although the results from this study appear to be straightforward, their credibility is undermined by at least two factors. First, the motion platform on a Singer-Link GAT-2 trainer is much less advanced than the motion platforms available now. Even if that type of simulator motion did not affect airplane performance, current motion might be able to. That is, it may be that skills learned under the more realistic motion cues available today would transfer better to real flight than skills learned under any of Jacobs’ motion conditions. Second, Jacobs used tracking maneuvers. Although this choice is understandable considering the safety and logistical problems of performing disturbance maneuvers in real flight, it undermined his goal of evaluating the usefulness of motion. An additional factor that may have obscured a potential training advantage of motion is that student subjects used in the study received fixed amounts of training in the simulator instead of being trained to asymptotic performance.

Transfer Of Training—Disturbance Maneuvers

Ryan, Scott, & Browning (1978), on the other hand, used a more diagnostic set of maneuvers to investigate the effect of simulator motion on performance in the airplane, consisting of instrument maneuvers and take-offs and landings

with and without engine failures. The asymmetric engine failures create a sudden disturbance that the pilots must recognize and correct in the shortest possible time (Hall, 1989). The subjects were first-tour naval aviators that had recently completed multi-engine undergraduate training and possessed “Standard Instrument Cards.” They were trained in a P-3 “Operational Flight Trainer” with a narrow-angle television for (modelboard) visual cues and a six DOF motion system that was disabled for the no-motion group. All 39 no-motion students and four of the motion students transferred to a S-2, a small twin reciprocating-engine airplane. Six motion students transferred to the T-44 twin turboprop airplane. Questionnaires revealed that student and instructors “strongly favor[ed] having motion cues available,” but did not indicate any motion sickness associated with either condition. Performance was rated by instructors. These results show that even with these maneuvers, the results were again the same as in the Jacobs study. That is, the presence of simulator motion improved performance in the simulator, but had no bearing on performance in the airplane. A footnote is that the presence of a sudden disturbance did, indeed, increase the diagnosticity of maneuvers—the engine abort on take-off¹ was the **only** maneuver that demonstrated the motion advantage **in the simulator**.

Prediction Of Performance In The Airplane From Performance In The Simulator

Koonce (1974) had used the same non-visual simulator as Jacobs (1976) (i.e., GAT-2, but with just pitch and roll) for a study examining transfer of training to a Piper Aztec-D. In this study, he trained three groups of thirty pilots with multi-engine and instrument ratings on five maneuvers representative of those usually performed under instrument flight rules (IFR) (cruise on a VOR airway, holding at a VOR station, ADF approach, ILS approach, missed approach) and five maneuvers usually performed under visual flight rules (VFR) (take-off and climbout; 360 degrees steep turn; chandelle; lazy eight; landing). In addition to the no-motion and washout-motion conditions, he used a sustained motion condition where the simulator moved in the appropriate direction and then stayed there until pilot control activity indicated a change. Koonce found the exact same results as Jacobs (1976). That is, “simulator motion tends to increase the subject’s acceptance of the device, lower performance error scores, and reduce workload on the subjects and the observers through the aiding effects of the motion onset cues. But the differential effects of motion on the simulator performance does not transfer to the performance in the aircraft.” Additionally, however, Koonce examined under which condition performance in the airplane best predicted performance in the simulator. He found that the sustained motion condition had the most predictive power. In sum, although all three conditions trained the pilots equally well for flying the airplane, the pilots’ performance in the

¹It is unclear whether the take-off was rejected or continued.

airplane could be best predicted from their performance in a simulator with sustained motion. He argued that this is due to greater stability of performance in this simulator condition. Unfortunately, this study suffers from the same flaws as the Jacobs study, outdated motion platform and non-diagnostic maneuvers.

Air Force Human Resources Laboratory Transfer Studies

The only other widely-known studies using transfer-of-training to real airplanes were conducted by the Operations Training Division of the Air Force Human Resources Laboratory. Martin (1981; Waag, 1981) reviewed six of these studies. Each used a simulator with six DOF, five studies used the Advanced Simulator for Pilot Training (ASPT) located at Williams Air Force Base (AFB) and one used the Simulator for Air-to-Air Combat (SAAC) located at Luke AFB. Most of the studies varied only the presence or absence of motion during training, one varied also the FOV (without finding an effect). A variety of different maneuvers were used, such as basic contact maneuvers (including stalls), aerobatics, basic fighter maneuvering, and air-to-surface weapon delivery. As with all other transfer-to-airplane studies, there was no benefit of simulator motion in the airplane despite a benefit of motion in the simulator for some of the studies. Bussolari, Young, & Lee (1989) conclude that “while it is arguable that the motion systems in these studies were of the highest quality, the absence of motion effects across such diverse training environments and simulator equipment considerably weakens the case for requiring elaborate motion platform systems in flight simulators used for training pilots in fixed wing aircraft operations.”

Summary of Transfer-Of-Training Studies

In sum, several investigators have examined transfer of training from the simulator to the airplane. In nearly all cases the advantage of simulator motion during training within the simulator seen in most simulator-only and quasi-transfer studies, is confirmed. However, the indication from the Levison (1981) study that this advantage would transfer to real airplanes was not borne out in any of these studies. The only benefit of simulator found was an increase in the predictability of airplane performance from simulator performance (Koonce, 1974). This result, however, will need to be confirmed with state-of-the-art motion and visual systems.

The failure of these studies to find an impact of simulator motion on airplane flying might be due to aspects of the experiments, as opposed to a real lack of benefit of simulator motion. This is of particular concern due to the fact that all of these studies suffer from the same set of problems. First, all used outdated equipment, in particular with respect to the motion and visual systems. Also, most of the equipment suffered from large transport delays, bad synchronization of the

visual and motion systems, and lack of calibration of the motion system. Second, in most cases they used non-diagnostic maneuvers. Disturbances are difficult or impossible to initiate and to terminate in the real world and dangerous to maneuver. However, disturbance maneuvers are required for testing the value of simulator motion. Third, many of the experiments used non-representative subject samples, both with respect to number of subjects sampled and their flying experience. None of the studies cited so far analyzed the interpilot variability within groups to determine the number of pilots required to determine a specific effect size. Moreover, most of the studies used student pilots. There is evidence, however, that well-trained pilots may be more sensitive to the presence or absence of motion than beginner pilots or non-pilots (Young, 1967). Fourth, pilots and instructors were not naïve regarding the motion condition, which may have allowed bias to affect performance or performance evaluation, respectively (Ebbinghaus, 1964). Fifth, all of the studies measured only performance. Control behavior and subjective responses, however, may be more sensitive to the effects of motion. In fact, these problems are not limited to the transfer-to-airplane studies; many of them affect the simulator-only studies and quasi-transfer of training studies, as well.

Why Revisit Motion Fidelity Requirements Now?

The question of whether to require vestibular motion cueing in simulators used for flight training has been researched for at least four decades. A marked decline in research activity in the nineties may be attributed to the failure of this extensive research to resolve the issue. Our endeavor to readdress this question is spurred both by the failure of previous work to adequately address the motion fidelity requirements issue for current air-carrier pilots and equipment as well as changes in the research environment and opportunities.

Major technological advances have occurred in the wake of the recent “virtual reality”—or rather simulated reality—frenzy in the entertainment industry. Due to its marketing value, efforts mainly focused on the visual system. The most advanced image generators and display systems are at a point where they can almost perfectly reproduce the visual stimulation resulting from real airplane motion. In particular, the widening of the FOV resulted in increased stimulation of the peripheral visual system, resulting in “a more compelling visual display of motion” (McCauley, 1984). As we have seen even in the research showing an advantage of motion, at least in the simulator, this advantage was often reduced with improved visual stimulation. In contrast, the last major advances with regard to motion cueing date back to at least the early eighties. They include the practice of providing critical onset cues followed by subliminal washout, and to use “gravity align” platform attitudes (Brown et al., 1989). These techniques do indeed help to achieve some perception of sustained

acceleration, but still do not overcome the inherent limitations in simulating vestibular motion cues. It is possible, then, that today's visual systems provide such high quality motion cues as to render the inherently imperfect vestibular motion cues superfluous, at least for recurrent pilot training.

One *caveat* that needs to be raised here, however, is simulator sickness. A widely accepted explanation of simulator sickness is the sensory conflict resulting from discrepancies between visual and vestibular cues (see, e.g., McCauley, 1984; Oman, 1991). As the quality and, in particular, the FOV of the visual system increase disproportionately compared to the motion system, so will the sensory conflict between visual and vestibular motion cues. Guedry (1987) suggests that this, coupled with an overall increase in simulator use, is one of the main reasons for the increase in reports of simulator sickness over the past decade. McCauley, Hettinger, Sharkey, & Sinacori (1990) cite evidence found by McGuiness, Bouwman, & Forbes (1981), indicating that more experienced pilots may be more susceptible to simulator sickness than novice pilots, just as they may be more likely to rely on vestibular motion cues (Young, 1967). Experienced pilots' increased reliance on vestibular cues may make them more sensitive to sensory conflicts and thus simulator sickness. Potentially, then, even if a sophisticated visual system alone were to provide sufficient motion cues for recurrent pilot training in the simulator, forgoing motion may still be unacceptable due to the effects of the ensuing sensory conflict on pilots.

The final reason for returning to the question of how best to simulate airplane motion is the ever increasing use of flight simulators in air-carrier training. Not only does this increase the urgency of this reexamination, but it also has greatly improved research opportunities. One result of the increased experience with and improved quality of flight simulators in air-carrier training is the practice of total training and checking in a Level D, and, with appropriate pilot experience prerequisites, a Level C simulator, sometimes referred to as "zero-flight-time training." Total recurrent training can be accomplished in either of these levels of simulators. This practice was established in the Advanced Simulation Plan put forth by the FAA in 1980 (FAR Part 121, Appendix H). While the difficulty of doing transfer-of-training experiments remains, the experience with zero-flight-time training represents a *de facto* validation of high-level full-platform-motion simulators as a stand-in for the airplane in quasi-transfer studies.

The Need for Further Research

It is clear from a review of the pertinent literature that no definitive conclusion can be drawn that would warrant modification of current qualification requirements for platform motion in full flight simulators. The FAA believes that this

situation will remain unchanged unless new research is undertaken, which takes into account the lessons learned from past research, and the opportunities engendered by new technology.

The research literature suggests certain potentially fruitful strategies to be considered in developing a practical research design. To assess training effectiveness, the research might employ a quasi-transfer paradigm, testing transfer of training to an FAA-certified stand-in for the airplane for recurrent “zero-flight-time” training. To assess evaluation, the study design could employ a modified backward or reverse-transfer paradigm, that is, it could measure how well pilots’ control performance and behavior in the simulator reflect their proficiency in the airplane (Cross, 1991). Such a research design would allow a determination of the extent to which there are control strategy differences now between qualified full flight simulators and their target aircraft, since this represents an existing baseline which constitutes an accepted standard of safety. Combining these two approaches, quasi-transfer and reverse transfer, could strengthen the validity of results, provided that they are in agreement.

In setting up the experiments, the study design should build on the lessons from previous work: It should use a state-of-the-art, FAA qualified Level C simulator with a wide-angle collimated cross-cockpit visual system and a modern six DOF freedom synergistic motion system that is carefully calibrated before each experimental session. It should use a homogeneous pilot sample from the population of interest, that is, regional airline pilots qualified on the simulated airplane. It should seek to prevent pilot or instructor bias by concealing both the purpose of the experiment, and the specific simulator motion/no-motion condition to be applied (through automated programming of motion conditions, with an identical motion platform initialization sequence). Pilots should be asked to fly highly diagnostic disturbance (closed-loop) maneuvers that are characterized by high-gain, high-workload and unpredictability. As a worst case, the flight tasks should entail the lowest level of outside-world visual cues (e.g., loss of engine during initial segment climb) encountered in recurrent training and checking (cf. Hall, 1978;1989). The study should examine both control performance and control behavior by collecting objective data at a high sampling rate, as well as pilot and instructor subjective data on the most pertinent variables, including pilot queries regarding simulator sickness. The study should compare the extremes of the continuum from full six DOF platform motion to no motion at all. If no effect of simulator motion on transfer is found, a follow-on study should be conducted to validate the results. Should it be determined that motion does affect transfer, the question should be further pursued by examining whether anything less than a full six DOF motion platform system could also impart the required cues.

In conclusion, the findings to date do not solve the FAA's questions regarding the role of platform-motion cueing in regional airline recurrent pilot training and checking. Previous investigations have been extremely useful, however, in defining the type of experimental design that would best address these questions. Moreover, technological advances and improved research conditions provide the ideal opportunity for pursuing this research. It is hoped that by readdressing these questions, simulator availability and affordability will be improved, resulting in better training with a concomitant increase in overall safety.

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