Reference
FAA-85-1

DOT/FAA/VS-84/1
DOT-TSC-FAA-85-1

Office of Flight Operations
Washington, DC 20591

A Systematic Determination of Skill and Simulator Requirements for Airline Transport Pilot Certification

David C. Gilliom
William D. Spears
H. Jan Demuth
Paul P. Eddy
David E. Hanley
Glenn E. Holmbeck
Robert P. Fishburne, Jr.

Planning Systems International, Inc.
200 Little Falls Street, Suite 104
Falls Church, VA 22406

March 1985
Final Report

U.S. Department of Transportation
Federal Aviation Administration

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT/FAA/VS-84/1		

4. Title and Subtitle
A Systematic Determination of Skill and Simulator Requirements for Airplane Pilot Certification

5. Report Date
March 1985

6. Performing Organization Code
DTS-53

7. Author(s)
D.C. Gilliom, W.D. Spears, H.J. Demuth, P.P. Eddy, D.E. Hanley, G.E. Holmbeck, R.P. Fishburne, Jr.

8. Performing Organization Report No.
DOT-TSC-FAA-85-1

9. Performing Organization Name and Address
Planning Systems International, Inc.*
200 Little Falls Street, Suite 104
Falls Church, VA 22406

10. Work Unit No. (TRAIS)
FA490/R4137

11. Contract or Grant No.
DTRS-57-84-C-00074

12. Sponsoring Agency Name and Address
U.S. Department of Transportation
Federal Aviation Administration
Office of Flight Operations
Washington, D.C. 20591

13. Type of Report and Period Covered
Final Report
April 1984 - Nov 1984

14. Sponsoring Agency Code
AFO-260

15. Supplementary Notes
*Under contract to: U.S. Department of Transportation
Research and Special Programs Administration
Transportation Systems Center
Cambridge, MA 02142

16. Abstract

This research report describes: (1) the FAA's ATP airman certification system; (2) needs of the system regarding simulator use; (3) a systematic methodology for meeting these needs; (4) application of the methodology; (5) results of the study; and (6) conclusions. The methodology developed is Airman Certification Systems Development, or ACSD. Application of ACSD entailed a systematic study of the airman certification process. The study produced behaviorally defined evaluation and training objectives; sensory cue and behavioral analyses to support these objectives; and a statement of media requirements based on the objectives and behavioral and cueing data. This report provides comprehensive documentation of the results of the ACSD methodology as a tool to analyze simulator use in FAA airline transport pilot certification.

17. Key Words	18. Distribution Statement
Simulation Requirements, Pilot Performance, Cue Analysis, Skill Analysis, Visual Simulation, Motion Simulation, Aircraft Systems Simulation, Pilot Certification, FAA Airman Certification System	DOCUMENT IS AVAILABLE TO THE PUBLIC THROUGH THE NATIONAL TECHNICAL INFORMATION SERVICE, SPRINGFIELD, VIRGINIA 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
UNCLASSIFIED	UNCLASSIFIED	254	

Form DOT F 1700.7 (8-72)

PREFACE

This report documents a study of the design of flight simulators and their effective use for airline transport pilot certification under Federal Aviation Administration (FAA) regulations. The study was sponsored by the FAA and was initiated by Mr. Walter S. Luffsey, Associate Administrator for Aviation Standards. The work was conducted under Department of Transportation Contract No. DTRS 57-84-C-00074. The prime contractor was Planning Systems International, Inc., which provided administrative support. The research work was performed by a team consisting of the FAA, Seville Training Systems, and Simtec, Inc. Mr. David C. Gilliom of the FAA planned the study and served as the Program Manager; Dr. William D. Spears headed the Seville Training Systems effort; and Mr. H. Jan Demuth represented Simtec. Mr. Demuth also was involved with the initial concept development while previously employed with the FAA.

A portion of this study, the cue and behavioral analyses, builds upon previous work accomplished by Dr. Spears and previously published as Technical Report NAVTRAEQUIPCEN 78-C-0113-4. The approach and model for the study were adapted from previous work accomplished by Mr. Gilliom and Mr. Demuth and published as SAE Technical Paper Series 831504.

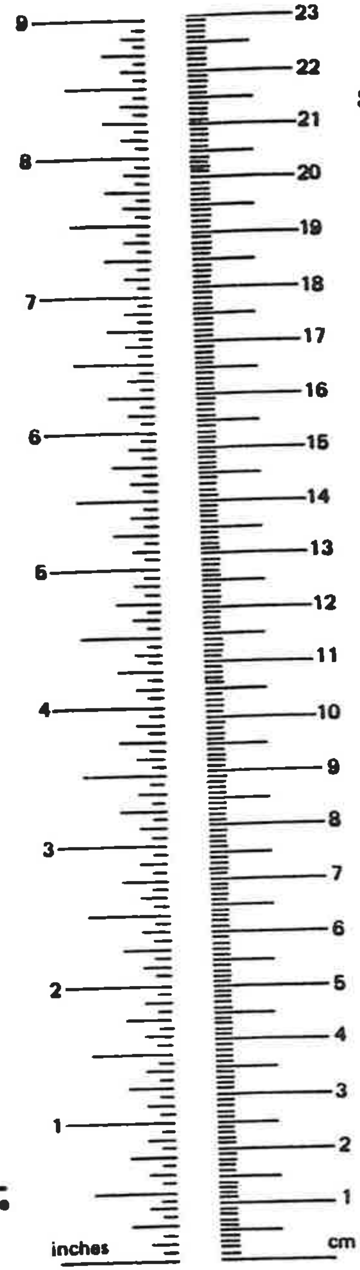
Contributions to the project by five consultants are gratefully acknowledged. Mr. Edward M. Booth, Manager of the FAA National Simulator Evaluation Program, and Mr. James L. Copeland, also a member of the National Simulator Evaluation Program, were especially helpful during the derivation of simulator requirements. Dr. Paul W. Caro and Dr. Wallace W. Prophet of Seville Training Systems were consultants for all aspects of the project. Dr. Conrad L. Kraft helped clarify minimum visual scene requirements and provided numerous data to that end.

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in. = 2.54 cm (exactly). For other exact conversions and more detail tables see NBS Misc. Publ. 286. Units of Weight and Measures. Price $2.25 SD Catalog No. C13 10 286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	36	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

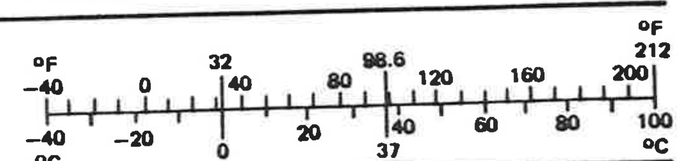


TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

LIST OF EXHIBITS

LIST OF FIGURES

LIST OF TABLES

LIST OF TABLES (Continued)

SUMMARY

Over the past three decades the Federal Aviation Administration (FAA) has made extensive provisions in its regulations to encourage the use of flight simulators for pilot training and certification. Nevertheless, the aviation community seeks still broader roles for simulators. In addressing these needs, the FAA's Associate Administrator for Aviation Standards intitiated a comprehensive, systematic analysis of the system used for certificating pilots and the ways simulators might be employed in the process. This report documents the resulting effort to date in two respects. First, it describes a methodology, termed "Airman Certification System Development" or ACSD, that was developed to complete the required comprehensive, systematic analysis. Second, the report demonstrates how the ACSD was applied to a prototypical case: certification of airline transport pilots (ATPs) to fly the Boeing 727 airplane.

Following an explanation of the rationale for and steps of ACSD, there are detailed descriptions of the methodology as applied to the prototypical case. The result was a clear "audit trail" leading from specification of ATP performance requirements, through analyses of essential dimensions of pilot behavior and cueing necessary to support it, to derivation of required simulator capabilities. The analyses drew heavily from the psychology of skill performance and perception, which also was drawn upon to formulate results of task analyses and statements of crew performance objectives in a way that minimum simulator requirements could be clearly entailed. To aid the reader in following the often tedious reasoning involved, there are several ad hoc discussions of rationales for the approach, and Section VI lists numerous special considerations that guided decisions and illustrates how they were incorporated into the reasoning.

For the prototypical case, the results included precise statements of ATP skills to be checked and trained, and requirements for simulators of varying engineering sophistication that might be used for checking and training.

As for future applications of ACSD methodology, the approach is completely general in that it can be applied readily to the utilization of simulators (and less sophisticated devices) in any aspect of aircrew certification or training. Furthermore, future use of the methodology would normally involve much less effort than was necessary in its initial application.

I. INTRODUCTION

The purpose of this report is to reexamine both the role and the fidelity requirements of flight simulators as they are used for civil aviation pilot certification. Over the past three decades, the Federal Aviation Administration (FAA) has made extensive provisions in its regulations to encourage the use of flight simulators for pilot training and checking. Despite these efforts, the aviation community seeks still broader uses for simulators, and the FAA is attempting to address these needs. The efforts are hindered, however, by the lack heretofore of a comprehensive, systematic analysis of simulator uses in pilot certification. Fidelity issues are of particular concern because simulation costs generally rise, markedly in some cases, with increases in fidelity.

In recognition of these problems, the FAA's Associate Administrator for Aviation Standards initiated a research project to analyze the system used for certificating airmen and the way simulators are used in that system. A joint team of FAA and private industry researchers subsequently developed an eclectic methodology to accomplish this work. The products of this research effort, which are published in this report, should (a) assist the FAA in developing future rules for the effective use of simulators for pilot certification; (b) provide a detailed example of an applied, systematic methodology for determining fidelity requirements in aircraft flight simulators; (c) broaden the aviation community's understanding and knowledge of flight simulator fidelity issues; and (d) help focus future research efforts on specific areas of need.

BACKGROUND.

To provide a context for the specific objectives of this project it is necessary to examine the nature of FAA's system for certificating airmen and the roles simulators have in the process.

FAA'S SYSTEM FOR CERTIFICATING AIRMEN. An analysis of the FAA's system for certificating airmen and, ultimately, of how simulators are used in that system requires a brief synopsis of the evolution of current regulations. It is also important to understand the airman certification system in its broadest context, which includes general aviation and air carrier operations. Sections 601 and 602 of the Federal Aviation Act of 1958, as amended, charge the FAA with the responsibility to promote safety of flight in civil aviation, prescribe standards for air carriers to maintain the highest level of safety in conducting air transportation services, and prescribe standards for the certification of airmen. The FAA meets these responsibilities by publishing Federal Aviation Regulations (FARs), and these are contained in Title 14, United States Code of Federal Regulations. There are three parts of the FAR that are of interest to this report. They are Parts 61, 121, and 135. Part 61 prescribes requirements for issuing pilot certificates and ratings, and Parts 121 and 135 prescribe operating rules and aircrew qualifications for air carriers providing air transportation services.

Under the authority of Part 61, pilot certificates are issued on the basis of applicants' meeting minimum eligibility requirements and demonstrating required skills during practical tests. There are five types of pilot certificates: student pilot, private pilot, commercial pilot, airline transport pilot (ATP), and instructor pilot. Except for student pilot, aircraft category, class, and type ratings are placed on each certificate to indicate the special qualifications and limitations of the holder. Eligibility, training, and practical test requirements are specified in Part 61 for the initial issuance of each type of certificate. Requirements for recurring training, recency of experience for landings and instrument flight, and recurring skill evaluation are also specified for various pilot operations.

When pilots perform duties for the holder of an air carrier operating certificate, they must comply with special qualification requirements contained in Parts 121 and 135. If the operation involves airplanes with more than 30 seats or a payload of more than 7,500 pounds, then the rules in Part 121 apply. Operations of smaller airplanes are conducted in accordance with Part 135. These sets of rules define the type of certificate that a pilot must hold, the initial and recurring training that he/she must receive, and the initial and recurring flight checks that he/she must take.

The sets of rules contained in Parts 61, 121, and 135 create a system for the certification of airmen. The system has two basic subsystems, one for initial certification and licensing and another for proficiency maintenance. The subsystem for initial certification and licensing covers three essential processes: (1) acquisition of experience required for certificate eligibility (experience requirements), (2) initial training (training requirements), and (3) initial skill evaluation (checking requirements). Regulatory experience requirements ensure a requisite level of safety in flight operations by specifying cumulative and/or recent flight experience to establish a basic repertoire of airman skills and to minimize the possibility of nonproficiency in those skills. Regulatory training requirements specify training objectives to expand, and to eliminate deficiencies in, an airman's skill repertoire. Regulatory checking requirements are to ensure evaluations, against standards, of the performance of critical skills in an airman's repertoire.

The subsystem for proficiency maintenance covers two additional essential processes: (4) recurring training and (5) recurring skill evaluation. Common elements in both subsystems are the pilot, the instructor, the evaluator, training objectives, evaluation objectives, performance standards, practical test scenarios, training media, evaluation media, and media approval criteria. Exhibit 1 shows the relationship between subsystems, the five processes, and component elements.

ROLES OF SIMULATORS. The FAA has long recognized the value of flight simulators for pilot training and checking. The fact that simulators can provide more in-depth, more efficient, safer, and less expensive training and checking than is possible in the airplane itself is readily acknowledged. Hence, over the years, the rules in Parts 61, 121, and 135 have changed to accommodate the use of flight simulators.

SUBSYSTEM FOR INITIAL CERTIFICATION AND LICENSING			SUBSYSTEM FOR PROFICIENCY MAINTENANCE	
Process #1 Experience Acquisition	Process #2 Initial Training	Process #3 Initial Skill Evaluation	Process #4 Recurring Training	Process #5 Recurring Skill Evaluation
Inputs: • Pilot • Previous certification • Flight experience • FAR experience requirements Outputs: • Pilot meeting FAR certificate eligibility	Inputs: • Process #1 output • Process #3 output (unqualified pilot) • Training objectives • Instructor • Instructional techniques • Performance standards • Training media Outputs: • Trained pilot	Inputs: • Process #2 output • Evaluation objectives • Evaluator • Practical test scenarios • Performance standards • Evaluation media Outputs: • Qualified pilot • Unqualified pilot	Inputs: • Process #3 output (qualified pilot) • Process #5 output • Training objectives • Instructor • Instructional techniques • Performance standards • Training media Outputs: • Trained pilot	Inputs: • Process #4 output • Evaluation objectives • Evaluator • Practical test scenarios • Performance standards • Evaluation media Outputs: • Qualified pilot • Unqualified pilot

EXHIBIT 1. THE AIRMAN CERTIFICATION SYSTEM.

As early as 1954, Part 121 pilots were allowed to use simulators for all but four of the tasks required for recurring proficiency checks. In 1973, Amendment 61-69 to Part 61 permitted extensive use of simulators for initial ATP checks. By 1978, improvements in visual systems and aerodynamic programming permitted selective approval of certain simulators for landing tasks; and Part 121 was amended in 1980 to allow the use of these simulators for recency of experience (landings) qualification. At that time, the FAA's rules were very close to accommodating the concept of total simulation, which would permit experienced pilots to complete all of their initial training and checking in high fidelity simulators. The air carrier industry strongly advocated developing rules to permit total simulation. This was due in part to the training benefits available through high fidelity simulation and in part to the cost benefits of total simulation, which were magnified by rapidly escalating fuel prices. Consequently, in the late 1970s, the FAA developed hardware specifications for advanced simulators that could be used for total training and checking. The specifications were developed without the benefit of a front-end analysis of training and other behavioral support requirements. Upon the urging of the air carrier industry, such an analysis was deferred in favor of hardware specifications so that the industry could reap the benefits of total simulation as soon as possible.

In 1980, the FAA published an Advanced Simulation Plan, which made the concept of total simulation an operational reality. The plan, described in Part 121, Appendix H, consists of three major sets of criteria for simulators that may be used for different levels of training. The criteria represent phases in a total plan for upgrading simulators to meet the most sophisticated of the three sets of requirements. The criteria are designated Phases I, II, and III. Each phase describes a level of simulator fidelity that is progressively more demanding. Total training and checking is permited only under Phases II and III, the difference between these two phases being that Phase III simulators may be used by pilots with less experience than those who use Phase II simulators.

Thus, over the past 30 years, the FAA has promoted the use of flight simulators by providing regulatory guarantees that if a simulator meets certain fidelity standards, then that simulator may be used to satisfy certain regulatory requirements for pilot training and checking. To simplify the administration of these rules, the FAA has defined five types of simulators, specifically nonvisual, visual, Phase I, Phase II, and Phase III. The fidelity standards and approval criteria for simulators are contained in FAA Advisory Circular 120-40, Airplane Simulator and Visual System Evaluation. According to this document, a given simulator of any of the five types must represent a specific airplane type and have a motion system. Devices without motion systems are classified as training devices, and their approval criteria are contained in FAA Order 8430.1C, Inspection and Surveillance Procedures--Air Taxi Operators/Commuter Air Carriers and Commercial Operators. Training devices and nonvisual simulators provide the least fidelity and are given the least training and checking credit. Phase III simulators provide the most fidelity and are given the most training and checking credit. Exhibit 2 presents a synopsis of major fidelity features for simulators and training

	Visual System	Motion System	Aerodynamic Programming	Aural
Training Device	• No specific fidelity requirements; each device is approved on a case-by-case basis.			
Nonvisual	N/A	• 3 DOF[a]	• Representative data[b]	• None
Visual	• 45° FOV[c] • Night • 300 ms dynamic response	• 3 DOF	• Representative data	• None
Phase I	• Same as visual simulator	• 3 DOF	• Specific flight test data to include ground effect, ground handling, ground reaction	• None
Phase II	• 75° FOV • Dusk/night • Ground and air hazards	• 6 DOF • Buffets and bumps on the ground and in the air	• Same as Phase I • Brake and tire failure dynamics, crosswind/shear, effects of runway contaminants	• Precipitation and airplane noises • Crash
Phase III	• Same as Phase II • Day/dusk/night • Wet/snow covered runways • Color	• Same as Phase II	• Same as Phase II • Flight test data for buffet motions • Modeling for icing, reverse thrust, aeroelastics, nonlinear sideslip	• Same as above • Communication static • Engines • Airframe

[a]DOF = Degrees of freedom.

[b]"Representative" data are those derived from engineering predictions for the airplane's performance.

[c]FOV = Horizontal field of view.

NOTE: The following features are required for nonvisual, visual, Phase I, Phase II, and Phase III simulators: (a) full-scale cockpit mockup; (b) functionally accurate circuit breakers; (c) aerodynamic programming for thrust and drag effects; (d) automatic instrument response to control inputs; (e) functionally accurate communications and navigation equipment; (f) operational major aircraft systems; (g) accurate rates of change for instrument readings and control forces; and (h) accurate control forces and degree of control travel.

EXHIBIT 2. FAA SIMULATOR FIDELITY REQUIREMENTS.

devices. Exhibit 3 presents a synopsis of how they can be used for training and checking credits.

Questions have been raised regarding the rules summarized in Exhibits 2 and 3, and the public has the right to petition the FAA to issue, amend, or repeal rules. The procedures for such petitions are contained in Part 11 of the FAR. Recent petitions and proposals concerning regulatory provisions for simulators raise the following questions:

- For pilots with no more than 1,500 hours of flight experience, what are the minimum simulator requirements to support total ATP training and checking? Specific areas of interest include provisions for platform motion, visual scene content and field of view, dynamic response time, cue correlation, aerodynamic programming, cockpit instrumentation, aural effects, and simulator special effects.

- What training and checking tasks can be accomplished in airplane-specific simulators that do not have visual or motion systems?

- What training and checking tasks can be accomplished in generic simulators that do not have visual or motion systems?

At this point in the evolution of simulator rules, the FAA feels that public interest will be best served if these questions are answered following a thorough, systematic study.

STATEMENT OF THE PROBLEM.

The FAA plays a critical role in maintaining safety of flight in civil aviation, and the airman certification system is an important part of that role. When the FAA issues a pilot certificate, the issuing inspector is, in effect, stating that he/she has witnessed the applicant's performance across a broad spectrum of piloting skills and that the applicant is competent to perform the duties authorized by the certificate. When the pilot's performance is witnessed in media such as simulators, which are surrogates for airplanes in flight, the FAA inspector must still be able to make this intrinsic statement before a certificate is issued. Consequently, when a simulator is used for pilot performance evaluations, the piloting skills witnessed must either be identical to the skills the applicant would evince with the actual equipment, or they must be approximations that will transfer to the actual equipment without further practice or training. The integrity of the airman certification system can be maintained only if this principle is upheld.

Thus, when the FAA makes a determination about the adequacy of a simulator for various checking functions, FAA must ensure that the simulator can provide for essentially 100 percent transfer of skills observed in the simulator to an appropriate airplane. This task requires a systematic approach incorporating behavioral theory, research data, and anecdotal documentation. The FAA, in the past, has not used a systematic approach due to time and resource

Training Device	• Checking credits: Oral equipment examination, preflight visual inspection, one of two required nonprecision approaches, systems malfunctions (hydraulic, electrical, landing gear, and flaps). • Training credits: Same as checking credits with the addition of normal and abnormal systems operation (pneumatic, pressurization, air conditioning, fuel and oil, flight controls, power plant, smoke control), missed approaches other than from an ILS or with a power plant failure.
Nonvisual	• Checking credits: Training device credits plus all normal and abnormal systems operation, power plant checks, rejected takeoff, instrument departure and arrival, holding, steep turns, approaches to stalls, specific flight characteristics, normal and abnormal procedures, emergency procedures, maneuvering with a power plant failure (Appendix F, Part 121, only). • Training credits: Same as checking credits with the addition of turns with and without spoilers, tuck and Mach buffet, maximum endurance/maximum range procedures, missed approaches except from an ILS.
Visual	• Checking credits: Nonvisual simulator credits plus instrument takeoff, takeoff with a power plant failure, one of two ILS approaches with or without an engine out, nonprecision approaches, circling approaches, maneuvering to a point from which a landing could be made from a circling approach, one of two missed approaches, approaches with 50 percent power loss, zero flap approach, rejected landing. • Training credits: Same as checking credits; however, one missed approach must be accomplished with a power plant failure. Additionally, manual reversion.
Phase I	• Checking credits: Visual simulator credits plus landing from an ILS approach, required landings for recurring proficiency checks (FAR 61.58; FAR 135.293, 135.297; Part 121, Appendix F). • Training credits: Same as checking credits. Additionally, night landings (Part 121, Appendix E), landing currency (FAR 121.439).
Phase II	• Checking credits: Phase I credits plus taxiing, normal takeoff, crosswind takeoff, all required missed approaches, maneuvering with a power plant failure, normal landings, crosswind landing, engine out landing (ATP applicants must meet the experience requirements listed in Part 121, Appendix H, to use a Phase II simulator for a check). • Training credits: Same as checking credits.
Phase III	• Checking credits: Same as Phase II (All ATP applicants meeting the minimum eligibility requirements of FAR 61.155 may use a Phase III simulator). • Training credits: Same as checking credits.

Note: Checking credits apply to ATP checks (Part 61, Appendix A), recurring proficiency checks (FAR 61.58), Part 121 proficiency checks (Part 121, Appendix F), Part 135 instrument proficiency checks/competency checks (FAR 135.297, 135.293). Training credits apply to Part 121, Appendix E, initial training and to Part 135 initial training.

EXHIBIT 3. TRAINING AND CHECKING PERMITTED IN APPROVED SIMULATORS.

constraints. The result was ad hoc studies of advanced simulator hardware specifications as requested by the airline industry, and a corresponding delay in an analysis of behavioral support requirements.

The problem, then, was to develop a systematic approach to defining requirements for simulators that are used to check and train pilots, and to implement the methodology in a prototypical case. Without a systematic approach, effective regulation of simulators by the FAA is difficult, and there is a risk that critical elements in the airman certification system may be overlooked when simulator use and fidelity determinations are made. Elements that affect simulator design and use include experience and motivation of the pilot, type of mission, training and checking objectives, type of aircraft, and instructional techniques. All of these elements and their various combinations have implications for the specification of simulator hardware and software (Caro, 1977, AGARD, 1980). A systematic approach is needed to ensure integration of these system elements.

Additionally, a systematic approach is needed to translate FAA training and checking requirements into behavioral objectives that define tasks, task activities, task conditions, and performance standards. These are important ingredients in the methods used to determine media requirements; and these ingredients must be defined systematically. Furthermore, a systematic approach will provide a detailed data base and audit trail to support regulatory decisions. Lacking an adequate audit trail in the past, many simulator rules were misunderstood by the public; and new regulatory initiatives required extensive duplications of effort. Also, existing simulator fidelity requirements may well be overly rigorous in some instances while not rigorous enough in others, because a fine-grained analysis was not available to support relaxing or strengthening requirements.

SCOPE OF THE PROJECT. The airman certification system is designed to uphold the FAA's statutory responsibilities as previously summarized. In this regard, the effectiveness of the system depends on the adequacy of regulations specifying experience, training, and checking requirements. This research project focuses on the subsystem for initial certification and licensing as identified earlier in Exhibit 1. More specifically, this project deals primarily with the initial skill evaluation of airline transport pilots. Nevertheless, ATP experience and training requirements are also dealt with, but to a lesser level of detail.

The focus on ATP certification was because of its ubiquity in the airman certification system. An ATP certificate is required of all Part 121 pilots in command; it is also required of Part 135 pilots in command who operate turbojet airplanes, airplanes with 10 or more passenger seats, or commuter multiengine airplanes. In addition, the requirements for ATP certificates form the basis for proficiency checks required by FAR 61.58, 121.441, and 135.297 for general aviation and air carrier pilots. And finally, under current regulations, the use of simulators is limited predominantly to ATP checking and to air carrier training and checking. Thus, an analysis of simulator and fidelity features for ATP checks has wide-ranging value, because such an analysis has a direct impact on other parts of the regulations that are related to ATP checks.

OBJECTIVES. The specific objectives of this project were to develop and apply systematic methods to:

- Define airline transport pilot knowledge and skill requirements;

- Develop an evaluation process that ensures adequate demonstration of skills by candidates for airline transport pilot certificates;

- Identify training requirements that will ensure mastery of skills that are not included in ATP checks;

- Develop training and checking processes that permit the maximum use of flight simulators; and

- Define simulator requirements for ATP checking and training.

To develop a methodology for accomplishing these objectives, FAA training specialists conducted a search of simulator literature and examined several models of instructional system design. From this effort they developed an approach based on behavior theory and system design technology. The methodology that was thus synthesized is termed Airman Certification System Development (ACSD).

ACSD uses an eight-step model that is uniquely tailored to the needs of the FAA airman certification system: (1) Identify, analyze, and describe ATP flight tasks and task conditions; (2) classify tasks and task conditions as experience, training, or checking requirements; (3) define crew performance objectives for checking requirements; (4) define crew performance objectives for training requirements; (5) analyze real-world perceptual cue requirements for task performance; (6) define media requirements for checking functions; (7) define media requirements for training functions; and (8) validate training and checking functions. Steps 1, 2, 3, 4, and 5 involve primarily analytic methods; Steps 6 and 7 use primarily synthetic methods; and Step 8 uses experimental and other empirical methods. Only the first seven steps of the model are used in this research project. The eighth step, a validation step, is beyond the scope of the present work.

The stated scope of this project limits the present application of the ACSD model to ATP certification. In this context, a short elaboration of each step is provided here. The remainder of this report provides detailed explanations and documentation of the ACSD approach and of each step as it is applied to accomplish the required research work.

Step 1 requires an analysis of the duties authorized to be performed by the holder of an FAA airline transport pilot certificate. The purpose of this step is to generate data to be used in subsequent steps of the ACSD process to analyze perceptual cues, derive crew performance objectives, and determine media fidelity features. This step involves a task analysis to identify and define major flight segments, component tasks, task behaviors (procedural and motor skills), and task conditions (environmental conditions, equipment malfunctions, and special airplane maneuvering requirements).

Step 2 involves classification of flight segments, tasks, and task conditions into experience, training, and checking requirements. Important considerations in this classification process are levels of criticality, difficulty, frequency, complexity, and safety for each task and task condition. National Transportation Safety Board Safety Recommendations, accident and incident data, and FAA regulatory precedents are used in these determinations.

Steps 3 and 4 define crew performance objectives (CPOs) for training and checking requirements identified in Step 2. Each CPO contains a description of the flight segment, a statement of training and evaluation objectives, practical test scenarios, and performance standards.

Step 5 requires an analysis of the real-world perceptual cues used in task performance. The cue analysis describes visual, force motion, and aural information requirements and cue topology. The effects of task conditions on cueing requirements are included in the analysis.

Steps 6 and 7 define media requirements necessary to support the CPOs. In this step, a team consisting of airman certification system designers, airplane subject matter experts, perceptual and behavioral psychologists, simulator design engineers, and simulator test engineers, synthesize the data collected in previous ACSD steps to define media requirements.

Step 8 is a validation step and closes the loop of the ACSD model. Feedback on the effectiveness of training and checking functions is obtained in this step and used to make necessary modifications. Step 8 is beyond the time constraints of the present effort, and is not developed in this report.

ORGANIZATION OF REPORT.

Section II, which follows, explains the overall strategy for adapting ACSD to present purposes, and subsequent sections provide details of the applications and their results--task analysis (III), development of crew performance objectives (IV), cue analyses (V), and derivation of simulator requirements for ATP checks and training (VI). Section VII discusses major implications of the study for the the use of simulators in ATP checks and training.

There are also seven appendices which provide detailed supporting data for the main products of the research: crew performance objectives given in Section IV and simulator requirements identified in Section VI. It was not practical to include all supporting data, however, even in the appendices, for the data were voluminous. Nevertheless, full records are maintained in project files.

The last appendix, G, presents performance test data relevant to inspection of simulators for ATP checks and training. These data are not discussed in the body of the report, because being beyond the scope of the project, simulator performance criteria were not addressed specifically. The data grew out of other analyses, and are presented in Appendix G as part of the record.

II. APPROACH

As applied during this project, Airman Certification System Development (ACSD) focuses on three major topics: the definition of knowledge and skills required for certification of airline transport pilots (ATPs); assurance that through experience, training, and certification checks, ATPs will be proficient in the required knowledge and skills; and maximizing opportunities to use simulators in demonstrating proficiency in required ATP knowledge and skills. Although these topics are related, they involve different methodologies, thus requiring a multifaceted approach to their study. Overall, the approach had to lay clear foundations for any conclusions and recommendations that emerged from the effort. An "audit trail" was required whereby conclusions and recommendations can be seen as entailed by the analyses of issues that are addressed.

The emphasis for the present study was on pilots who will be certified to fly the Boeing 727 (B-727) airplane. However, the methodologies developed are to be readily generalizable to other aircraft, rotary wing as well as fixed wing. The same is true, insofar as feasible, of the results of the study. Thus, it was necessary to address each issue in a manner that fulfilled the purposes for the B-727, while keeping in mind the generalizability of the methodologies and results to other aircraft.

This section provides an overview of the approach to the present study. It will be apparent that the general approach is applicable to any similar effort. Later sections which concern various facets of the problem describe the specific methodologies used during those phases of the project. It will also be apparent that the separate methodologies can be readily adapted to similar efforts addressing other aircraft.

GENERAL CONSIDERATIONS.

A brief discussion of some general considerations will provide a context for the approach. They are grouped under three heads as they relate to (a) ATP skill knowledge and performance; (b) media that might be used for ATP checks and training; and (c) requirements for simulators that are to be used for ATP checks and training.

ATP KNOWLEDGE AND PERFORMANCE. ATP certification must be based on demonstrations of proficiency in all aspects of flight in the airplane of concern, the environment for flight, and the management of the crew and airplane systems. This is not to say that an ATP candidate will be formally checked on all aspects, however. Rather, experience and training requirements are to provide evidence of proficiency in some types of knowledge and skill; and formal ATP checks are for demonstrations of proficiency in selected samples of the required skill repertoire. The skills comprising the sample are to be such that, in toto and with the perspective of experience and training requirements, demonstrated proficiency in them is indicative of proficiency in all aspects of an ATP's responsibility.

Hence, the first task was to delineate the knowledge and skills required for efficient, safe operation of the airplane under the conditions that can arise during flight and ground operations. This objective was achieved through analyses of tasks to be performed and conditions (weather, malfunctions, etc.) that could accompany the tasks during flight. These analyses included definitions of standards for proficient performance.

As stated, ATP certification checks would involve only a sample of a candidate's repertoire. The reason is that the several tasks and separate kinds of conditions that could accompany each can yield a very large number of possible combinations of tasks and sets of conditions, by far too large a number to check separately. It was also stated that the sample of tasks and conditions to be checked would be indicative of overall proficiency. That is, proficiency during the check would <u>signify</u> proficiency on task-condition combinations that are not checked. To ensure this, it is necessary that the tasks and conditions being checked have integral relations with those not checked such that proficiency on the former implies proficiency on the latter.

A necessary condition for this implication to hold true is that the applicant have a broad experiential base of piloting an airplane. The experience should be of a nature and duration that ensure integration of all skills into a coordinated system. A novice might, for example, practice only tasks to be checked under stipulated conditions until he could easily perform them within standards. However, the skills and proficiency would likely be task- and condition-specific. The novice would not have skill "robustness," that quality of proficient performance that transcends particular tasks and conditions, even type of airplane (see Prophet, Shelnutt, & Spears, 1981; Spears, 1983; Thorpe, 1978). Skill robustness means skill adaptability to peculiarities of immediate requirements, and it comes about through varied experiences.

The issue becomes one, then, of ensuring experience sufficient for thorough integration of a comprehensive skill repertoire. Thereby, a properly selected sample to be checked by FAA inspectors <u>can</u> signify overall proficiency or lack thereof. Hence, another task during the project was to specify experience requirements for ATP candidates. Two classes of requirements emerged. One related to background flight experience, including total previous hours as pilot in command, types of airplanes flown, minimal hours and qualifications for special kinds of flight (e.g., instrument flight), etc. The second class of required experiences concerned training, especially that for the type of airplane for which ATP certification is being sought. As for general background experience, the requirements represent an extensive repertoire of basic airmanship skills in which proficiency is to have been previously demonstrated during practical testing for lower grade pilot certificates (or their equivalent in the case of foreign airmen or United States Armed Forces pilots). Specifically, FAR 61.155 requires that ATP applicants have at least

1,500 hours of flight time as a pilot, including 500 hours of cross-country flight time (during which pilot-in-command duties are performed for at least 100 hours); 100 hours of night flight time (during which pilot-in-command duties are performed for at least 25 hours); 75 hours of actual or simulated instrument flight time (of which a minimum of 50 hours was accomplished in flight); and a minimum of 250 hours of flight time during which pilot-in-command duties are performed. Special provisions are made in FAR 61.155 for the substitution of equivalent experience in specific cases, for example, flight engineer flight experience may be substituted for up to 500 hours of the 1,500 hour requirement if the applicant is participating in an approved air carrier pilot training program.

It is emphasized that adequacy of the minimum flight experience for ATP eligibility, required by FAR 61.155, was not challenged in this study. This experience requirement is based on internationally negotiated accords adopted by the International Convention of Aviation Organizations of which the United States is a member. However, this requirement was carefully reviewed in the analytic process used in ACSD Step 2. It was also necessary to examine checking and training requirements as specified in FAR 61.157. These requirements, based as they are on more than 40 years of successful ATP checking and training, have considerable overall validity, and their practical utility was weighted accordingly. Nevertheless, the systematic development of requirements during ACSD Steps 2, 3 and 4 led to a few specific deviations from FAR 61.157.

The next step was to identify flight tasks and conditions for ATP checks, and to relegate other tasks and conditions to training. In this case, it was assumed that by meeting stipulated experience and training criteria, proficiency on the skills involved would be assured, so most task-condition combinations assigned to experience and training need not be included during certification checks.

MEDIA FOR ATP CHECKS AND TRAINING. The principal concern regarding media was their appropriateness for ensuring ATP proficiency in various phases of actual flight. However, the concern was not how an air carrier might plan and implement a training program, nor what instructional media might be employed in general. Rather, the concern was with simulators that would either be used during ATP certification checks, or used to fulfill training requirements that are in addition to ATP checks.

Ostensibly, the airplane itself would be an acceptable medium either for checks or for fulfilling specified training requirements. However, use of the airplane for these purposes can result in unnecessary expense for the carriers, which is a major reason for developing an airman certification program that exploits what flight simulators can offer. Simulators are less expensive than airplanes to acquire, operate, and maintain. They can be expensive nevertheless. So a major concern was avoiding specification of expensive capabilities for simulators that were not actually needed for adequate checking and training. (This topic will be treated further below.)

There is another consideration that, aside from economy, makes simulators more desirable than the airplane for many aspects of ATP checks and training. When the airplane is used, there are rarely if ever opportunities to check or train under many flight conditions with which ATP candidates should learn to cope. This is especially true of certain malfunctions. Also, special weather and other environmental conditions with which pilots must deal may not exist at times convenient for checking or training. As a result, checks and training in the airplane may not involve the range of conditions desired. Hence, it is not feasible in an airplane to standardize the range of flight tasks and conditions for either ATP checks or training.

In this regard, it was necessary to qualify certain checking requirements by a phrase such as "if practicable under existing conditions" (e.g., crosswind takeoffs in the airplane that depend on meteorological, airport, and traffic conditions). The qualifications arose because it is permissible for an entire ATP check to be conducted in the airplane where there may be no way to impose some of the conditions desired. As a result, one ATP candidate would almost surely be examined under conditions that differ in some respects from those faced by other candidates.

In contrast, conditions for checks could be standardized in simulators. Perhaps such standardization should be a goal. If it is important that ATP candidates demonstrate during a check their proficiency in dealing with various flight conditions, they should be checked in media where the conditions can be present. Hence, there are good grounds for requiring that at least some parts of ATP checks and training occur in simulators with suitable capabilities. To some extent, the crew performance objectives (CPOs), developed during the project to define performance requirements, imply a need for simulators when checking some skills.

SIMULATION REQUIREMENTS. The foregoing discussion referred generally to simulator capabilities that would be required if ATP checks are to be conducted in simulators. Also, an implicit point was that minimal simulator capabilities are necessary if successful completion of some aspects of training in a device is to be accepted as demonstrating required proficiency. It is important to have valid bases for determining required simulator capabilities in either case, and to define the requirements clearly. The CPOs developed during the project, together with extensive analyses of cues used during task performance, constitute valid bases for defining simulation requirements.

Simulation requirements are perhaps most often thought of in terms of "fidelity," or the correspondence of a device and its dynamics to the airplane simulated. This term "fidelity" was avoided during the present project as a criterion per se, and for two reasons. First, it is too vague to be a guide. It has become a "catch-all" to cover a variety of types of correspondence of device capabilities to an airplane. In some cases the correspondence may be physical in nature as in the structural components of a cockpit, the functioning of instruments, or the aerodynamic characteristics of the airplane. In other cases, physical correspondence is not possible (unrestricted motion through the external environment) or not feasible (complete visual scene simulation). For these latter cases, one often hears reference to "psychological fidelity" or a similar concept. In effect, "fidelity" comes to include any simulator characteristic that is adequate to support performance. Yet, what may be adequate for one pilot or situation may not be for another pilot or situation. Hence, the vagueness of the term.

The second reason for avoiding "fidelity" as a criterion per se is that an approach is available to defining simulation requirements that addresses not fidelity, but the cues actually used during task performance and the necessary functioning of the equipment involved. In some cases, physical fidelity may be involved, especially as concerns control and instrument dynamics. But again, the issue is not fidelity per se, but equipment characteristics necessary for task performance. Even so, there were constraints that sometimes entailed close correspondence between a simulator and the airplane simulated, especially insofar as control, aerodynamic, and instrument simulation are concerned. It is possible that an ATP candidate can be certified in a simulator even though he or she has never flown the airplane for which certification is granted. Or, a pilot may have obtained all transition training in the airplane, and performs in the simulator for the first time only during an ATP check. In either case, essentially 100 percent transfer of skills must be assured. For the pilot who has never flown the plane, the FAA Inspector who conducts the simulator check must be confident that proficiency as demonstrated in the device transfers 100 percent to the airplane. For the pilot who has never "flown" the simulator prior to the check, the simulator's dynamics must correspond to those of the airplane enough for the pilot to demonstrate the proficiency achieved in the airplane at the outset, and without having to adapt his or her skills to peculiarities of the simulator.

Thus, there were nine types of requirements to consider in defining simulator capabilities:

1. Structural characteristics of the cockpit environment
2. Degree of need for control correspondence
3. Degree of need for aerodynamic correspondence
4. Degree of need for instrument correspondence
5. Cueing and feedback capabilities of out-the-window visual scenes
6. Cueing and feedback capabilities of platform or other types of motion simulation
7. Cueing and feedback capabilities of the aural environment

8. Environmental conditions and their effects on cueing and response requirements

9. Malfunctions and other emergency conditions and their effects on cueing and response requirements

At some stage during the project, each of these types of requirements was related to the outcomes of the task analyses. For the first four, requirements were defined more or less in one step according to objectives stated in CPOs for flight segments and component tasks. For the remaining five requirements, extensive cue-response analyses preceded the matching of required simulator capabilities to CPO purposes and objectives.

As mentioned, there was a need not to overstate simulation requirements because of the unnecessary expense that can be involved in providing capabilities that are not actually needed to train or evaluate pilots' proficiency. In following this plan, examination of the task descriptions and crew performance objectives revealed that, for purposes of ATP checks and training in simulators, there were two classes or types of objectives. The types in this instance differ in the nature and extent of simulator capabilities required for ATP candidates to demonstrate proficiency in the skills to which the CPOs apply. These classes were termed "Type A objectives" and "Type B objectives." From a performance standpoint, the difference is primarily in a focus on complex cognitive-motor coordination for Type A objectives, and on cognitive-procedural coordination for Type B objectives.

More specifically, the purpose of Type A objectives is to require ATP candidates to demonstrate proficiency in fine motor control of the airplane and its systems under conditions of heavy workloads. The workloads, which are to be imposed through simulated malfunctions, environmental conditions, and special maneuver requirements, put stress on both cognitive and psychomotor functioning. Hence, not only must the simulator used to check Type A objectives be capable of imposing these conditions, the device must simulate ranges of cues and control-aerodynamic correspondence to the airplane that may not be needed for Type B objectives.

In contrast, Type B objectives target mostly cognitive-procedural aspects of performance under conditions where only basic control skills are required. These basic skills, which a pilot of 1,500 or more hours of stipulated experiences should have acquired, still must be performed to standard. But the primary intent is to examine the consistency with which the candidate can make correct, timely judgments and properly implement procedures associated with more or less normal flight. For Type B objectives, then, there can often be some relaxation of simulation requirements as regards ranges of cues and control-aerodynamic correspondence to the airplane.

OVERVIEW OF THE METHOD.

Following the ACSD model, there were seven major steps to achieving the objectives of the project. The products of these steps form a clear audit trail for justifying the conclusions reached. Each step was a considerable undertaking. For this reason, the specific procedures and methods used for each step are described in later sections. The present discussion only provides a general overview which explains why the steps were taken and shows their interrelations. The seven steps are identified in the flow diagram in Figure II-1.

ACSD STEP 1: TASK ANALYSIS. The first step, the analysis and description of ATP flight tasks, was a basis for all remaining steps. During this step, a group of subject matter experts (SMEs--see below) developed a comprehensive task list and identified possible conditions under which the tasks may have to be performed. Assuming at first that the tasks were performed without complications arising from flight conditions (adverse weather, malfunctions, etc.), the SMEs determined for each task the occasions for its performance, the nature and sequence of actions, and criteria for successful completion of the task components and the task as a whole. These products, which will be referred to in what follows as task descriptions, were the immediate bases for Steps 2 through 5.

ACSD STEP 2: CONDITIONS FOR PERFORMANCE. The second step was the selection of conditions for task performance to consider in developing CPOs. In other words, the lengthy lists of environmental conditions, malfunctions, emergencies, and special maneuver requirements developed during Step 1, were examined for appropriateness to the purpose and for redundancy. In this case, redundancy refers to similarities among conditions such that proficient performance under one condition (e.g., ice covered runway; 50 percent power loss) is indicative of proficiency under another condition (e.g., snow covered runway; one engine failed). From this examination of conditions, the original lists were shortened considerably. Nevertheless, the resulting curtailed lists were only candidates for later inclusion in CPOs (Steps 3 and 4 in Figure II-1). That is, acceptance of a condition at this point did not necessarily mean that it would be incorporated into a CPO.

ACSD STEPS 3 AND 4: DEVELOPMENT OF CPOS. The results of Step 2, together with the task descriptions of Step 1, were the bases for pursuing Steps 3 and 4 (refer to Figure II-1). During these latter steps, CPOs were developed which defined performance requirements to be demonstrated during ATP checks and ATP training separately from the checks. It was necessary at this point to consider the nature and scope of background experience requirements, whose contributions are evident in CPOs for checks and training in that mastery of a number of basic piloting skills is assumed. The CPOs themselves focus on high levels of proficiency, often under demanding conditions.

The results of Steps 3 and 4 fulfill one objective of the project, a systematic development of skills to be demonstrated by ATP candidates.

ACSD STEP 5: CUE ANALYSES. Following Step 2, and concurrently with Steps 3 and 4, analyses of cues used during real-world performance of each task were completed. At the first stage the analyses treated each task only as if it

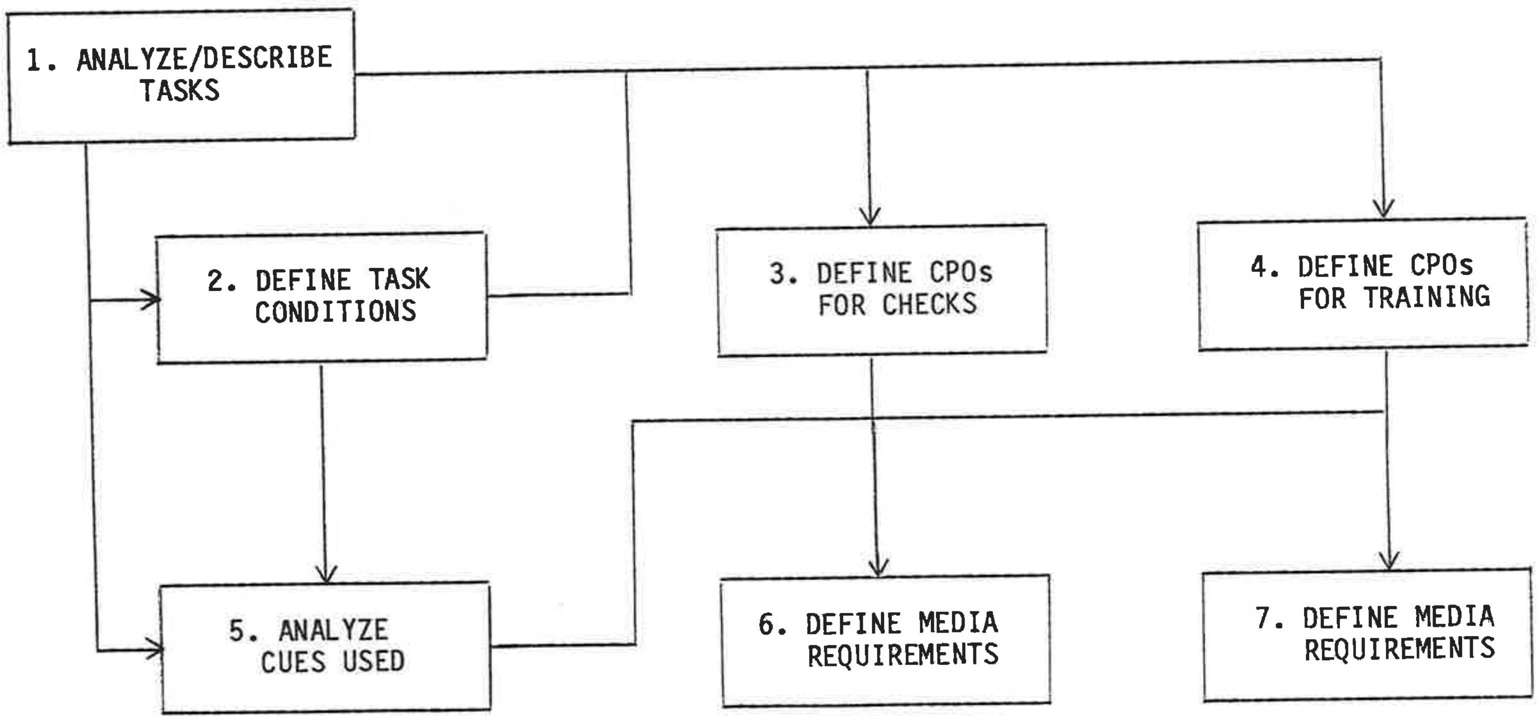


FIGURE II-1. FLOW DIAGRAM FOR STEPS OF THE APPROACH.

would be performed under "normal" conditions--in other words, without complicating conditions arising from adverse weather, malfunctions, etc. The results were elaborate matrices of the kinds of information used by pilots and sources of the information.

As mentioned earlier, cues from instruments and those related to control and aerodynamic simulation requirements did not require extensive analyses so they were not considered at this point. The assumption was that some minimal correspondence to the airplane of simulation of these factors would be available, and the degree of correspondence would be defined later during Steps 6 and 7. Hence, the primary concerns of Step 5 were cues arising from out-the-window visual scenes, force motion,[1] and the aural environment.

Accordingly, visual, motion, and aural information, and sources for it, were identified as they are used during actual flight. A number of cue matrices resulted that related types of information needed and their sources to the separate tasks. Next, the results of Step 2, the conditions for performing each task, were used as a system of "overlays" on cue matrices for the separate tasks. The purpose was to determine what changes in informational requirements (usually shifts in priorities, if any) each condition would require, and the effects on informational sources.

It should be emphasized that these analyses concerned real-world cues, not those available in simulators where motion and visual systems cannot duplicate circumstances of actual flight. Simulation requirements would be determined at a later time. However, two related criteria which guided the nature of the cue analyses ensured an audit trail from simulation requirements back to the cue analyses. (Both criteria are discussed at length by Spears, 1983.) One criterion concerned the topological properties of cues, or those characteristics that provide the essential dimensions of perceptual experiences required for task performance. The topological properties, or dimensions of experience, would be common to a variety of different circumstances. For example, to perceive motion nonvisually, pilots must experience acceleration on certain parts of their bodies. To perceive distance, pilots depend on apparent sizes of familiar objects, on linear perspective (apparent convergence of parallel lines with distance), on occulting of objects, etc. The matrices used for visual and motion cue analyses incorporated such topological properties of cueing sources.

The second goal that guided the cue analyses was to maintain functional equivalence of cues in a simulator and those essential to actual flight. That is, whatever perceptual experiences a simulator provides, they must have the same cue informational content that their analogs have in the real world. For example, acceleration experienced during takeoff cannot be duplicated by a

---

[1] "Force motion" refers to all direct perceptions of motion arising from applications of physical force on body tissues.

platform motion system. But the perceptual experience of acceleration can be closely approximated by providing an initial linear acceleration, "washing out" this motion subliminally, but coordinating a tilt of the platform with the washout so as to maintain pressure on the pilot's back where this type of accelerative sensation predominates.

In his treatment of functional equivalence of cues, Spears (1983) allowed for a wider range of cue substitution than was practical within the constraints of this project. In one example, he pointed out that the appearance of a light and the sound of a buzzer, which involve different sensory modes, can be functionally identical if they evoke the same response. For a training simulator, the equating of a light to a buzzer, or either to a more expensive cueing capability, can often be accomplished cognitively by the student. (For some purposes cross-modal cue substitution is even desirable early in training to avoid interference within a sensory mode.) However, if 100 percent immediate transfer from aircraft to simulator, or vice versa, is to be achieved, opportunities to substitue widely differing sources for cues are limited. The focus must generally be on the same sensory modes, and functional equivalence of substitutes to real-world cues must be immediately effective and not disrupting.

In most instances emphasis was on providing equivalent perceptual experiences of topological cue characteristics; or downplaying one type of cue because another naturally occurring cue is sufficient (e.g., motion as perceived visually is often adequate for task performance, so platform motion may not be required). These kinds of considerations will be evident in the later detailed discussions of Steps 6 and 7 in Section VI.

ACSD STEPS 6 AND 7: SIMULATOR REQUIREMENTS. These steps were to define required capabilities for simulators to be used for demonstrations of proficiency during checks or training. Hence, Steps 6 and 7 built on results of Steps 3 and 4, respectively, and on the cue analyses completed during Step 5. The focus was on minimal capabilities required for adequate checking and training. A number of trade-offs were involved, which were facilitated by separating objectives into Type A versus Type B as explained earlier.

The cue analyses, based as they were on actual flight experiences, required further specification in terms of minimal topological properties to be represented for cues. For motion, this involved an axis-by-axis analysis of accelerative and G-status components, plus possible substitutions for a platform motion system (e.g., seat shakers). For out-the-window visual scenes, night conditions were generally assumed as a baseline because the richness of scene content, and hence the multiplicity of cues, is naturally reduced even during actual flight. The same parsimony characterized determinations of needs for instrument, control, and aerodynamic simulation. Withal, present FAA standards (FAA Advisory Circular AC 120-40) for defining simulator requirements were guides in determining needed simulation capabilities. However, the project team did not feel compelled to conform to existing definitions of classes of simulators. The standards were viewed as guides, not prescriptions. They were valuable in the deliberations nevertheless, especially in helping maintain a perspective regarding simulators now owned by air carriers and adapting combinations of tasks and conditions to them.

PROJECT PERSONNEL.

The project team consisted of seven persons. The project manager, who had 5,500 hours of flight time, is an FAA air carrier inspector and training specialist. He is an active Air Force Reserve pilot (C-130) and a licensed airline transport pilot (B-727, B-737; commercial pilot privileges, L-382 and single-engine land). He is also a licensed turbojet flight engineer. Another member of the team, an aircrew training systems consultant, is a licensed commercial pilot with 5,300 hours of flight time. He had formerly been an FAA technical advisor on simulation and manager of an FAA B-727 simulator procurement program. He had also been an Air Force pilot (FB-111, B-52, T-39).

Three other FAA personnel served specifically as subject matter experts (SMEs). One had 15,000 hours of flight time and is currently an FAA B-727 flight instructor. He is a licensed airline transport pilot (CV-340/440, BAC-111, DC-8, B-727, B-747) and a licensed flight engineer (turbojet, turbopropeller, reciprocating engine). He is also a licensed aircraft dispatcher and a former air traffic controller. He has served as pilot in command in Part 121 air carrier operations on each of the airplanes in which he is type-rated. A second SME is an FAA air carrier inspector and training specialist with 5,200 hours of flight time. He is an active Air Force Reserve pilot (C-130), a licensed airline transport pilot (B-727, DC-9, L-382; commercial pilot privileges, single-engine land), and a licensed turbojet flight engineer. The third SME is an FAA air carrier inspector and operations specialist with 6,000 hours of flight time. He is a licensed airline transport pilot (DC-9, C-500), a certificated flight instructor, and a certificated ground instructor (advanced/instruments).

The other two members of the project team were an experimental psychologist and a specialist in training systems design and performance evaluation. The experimental psychologist had 30 years' professional experience and specialized in behavioral, cognitive, and perceptual processes, including their measurement. For the last 7 years he had specialized in simulator training and training requirements, particularly as concerns flight simulators. His role on the project team was as a human factors specialist. The specialist in training systems design and performance evaluation had 12 years' experience in training development, especially for aircrews, including problem analysis, needs assessment, task analysis, development of performance objectives, and development of evaluation procedures and materials. His principal responsibilities during the project concerned the task analysis (ACSD Step 1) and the development of crew performance objectives and standards (Steps 3 and 4).

In addition, there were four consultants to the project team. One, the manager of the FAA National Simulator Evaluation Program, is an aerospace engineer with considerable research experience, an engineering pilot, and a flight test pilot. He is also a licensed airline transport pilot and a certificated flight instructor. A second consultant, also a member of the FAA National Simulator Evaluation Program, was a former NASA research engineer (theoretical simulation techniques) and former manager of the NASA simulator development division. These two consultants participated during much of ACSD Steps 6 and 7 when simulation requirements were defined.

The other two consultants were psychologists. One, an engineering psychologist, has 25 years' experience in aviation training research and in deriving flight simulator design requirements. The other psychologist, a specialist in visual perception, has done extensive research on visual cues during flight.

III. TASK ANALYSIS

The task analysis completed ACSD Steps 1 and 2. The purpose of the analysis was to provide behavioral descriptions of ATP flight tasks, which then could be used as a basis for analyzing perceptual cues, developing crew performance objectives (CPOs), and, ultimately, deriving simulator requirements. Thus, task analysis data serve as departure points for the remaining activities in the ACSD process. During the task analysis, a comprehensive task list was developed. Then, each task involving control of the airplane while it is in motion was analyzed to determine the confines of the task, the nature and sequence of behavioral activities required for task completion, and performance criteria for task accomplishment. In addition, potential conditions that might accompany performance (weather, malfunctions, and special maneuvering requirements) were also identified for each task. These conditions were examined for redundancy and to determine their appropriateness for ATP certification. The list of conditions was reduced based on this examination, and the remaining conditions were used for the cue analysis and CPO development.

RATIONALE FOR THE TASK ANALYSIS.

This research effort is concerned with developing an effective overall system that maximizes the use of simulators for the initial certification of airline transport pilots. There are three processes involved in the system. They are experience acquisition, training, and checking. Although the primary goal was to determine requirements for simulators used within this system, it was necessary to approach the analysis comprehensively enough to assure, through these three system processes, that ATP applicants are proficient in all aspects of required knowledge and skills. Thus, while the methods used for the task analysis support subsequent ACSD activities leading to the derivation of crew performance objectives and simulator requirements, they also provide for the systematic development of ATP experience and training requirements.

A comprehensive analysis also requires provisions for the various circumstances of task performance with which pilots must deal, for ultimately, ATP certification processes are designed to ensure safety in all flight operations. Thus, task analytic methods had to identify all of the knowledge and skills necessary to meet all realistic task demands, usual and unusual, so that the experience, training, and checking can account for all of the tasks and task conditions that the pilot is likely to encounter during flight operations authorized by an ATP certificate.

Accordingly, the task analysis encompassed the entire knowledge and skill repertoire of an airline transport pilot. However, the level of analytic detail was determined by the information needed for subsequent ACSD activities. In this respect, the thrust was to describe tasks at a component level rather than in terms of task elements comprising components. For example, an instrument approach to landing requires coordination of flight control according to a preconceived plan for implementation and continuous information from instruments. Flight control is maintained through adjustments of throttles and control surfaces of the airplane. For present purposes, it was not necessary to specify the ongoing cueing values of various instruments, the controls used, nor specific adjustments to control inputs. Instead, it was sufficient to describe the effects of control inputs on the airplane (airspeed, altitude, heading, rate of descent, etc.) in terms that defined standards for the performance. This is not to say that all specific instrument cues and pilot responses were ignored, for in later analyses of visual, motion, and aural cues it was necessary to visualize each element of the task that had implications for these cue analyses. Rather, the approach was to avoid details in the task analysis that would be of no value in defining performance standards or in identifying visual, motion, and aural cue requirements.

It should be emphasized that identification of task elements related to airplane systems operation and basic instrument flying was not necessary. Beyond a certain point, such analytic detail is useful primarily for designing training to teach novices the basic cue-response skills required for these purposes. The development of instructional systems or techniques for teaching required flight skills was not an objective of this research effort; and insofar as simulation requirements are concerned, it was assumed that adequate simulation of aircraft systems and flight instrumentation would be required for any simulator used in the ATP certification process. (Some minor relaxations of these requirements are discussed in Section VI.)

The approach adopted also simplified the overall analysis of tasks and possible conditions for their performance. First, each task was considered only in terms of basic requirements for performance, that is, with no complications arising from weather, malfunctions, or special maneuver requirements. Second, these conditions as they might accompany each basic task were identified so the conditions could be used later as "overlays" in determining their effects on the tasks as such and on experience, training, and checking requirements. This approach eliminated the need for separate overall descriptions of a task, one for each of the possible task-condition combinations.

To accomplish the task analysis efficiently, it was necessary to choose a particular airplane type as a baseline. This is due to the wide diversity of airplanes and operations that are possible under the authority of an ATP certificate and the wide variations in tasks often associated with airplanes of different types (e.g., single reciprocating engine airplanes versus multiengine turbojets). The Boeing 727 (B-727) was selected for the analysis because of its broad use in air transportation service and because of the FAA's access to flight test data used for simulator aerodynamic programming. (These data were useful in the cue analysis and in the derivation of simulator requirements.) However, although the baseline analysis was for a B-727, most ACSD products are generic; and when they are not, appropriate annotations are made.

METHOD.

The task analysis was accomplished primarily by the three subject matter experts (SMEs) described in Section II. Each had extensive piloting experience in transport category airplanes. The SMEs were assisted by the project manager, who is also a large-airplane pilot, and a specialist in training design and performance evaluation.

The task analysis began with a review of actual airplane operations. This review generated a detailed, generic task list composed of 10 flight segments and 38 component tasks. The SMEs also developed a comprehensive list of task conditions consisting of 18 weather-related environmental parameters, 19 equipment malfunctions, and 11 special maneuvering requirements. From this list of conditions, those applicable to specific tasks were listed separately and later combined to cover entire flight segments. The task list was as follows:

1. Preflight

    1.1 Prepare/review flight plan

    1.2 Analyze weather and NOTAMS

    1.3 Prepare/review dispatch/flight release

    1.4 Prepare/review load manifest

    1.5 Inspect airplane documents

    1.6 Perform exterior inspection

    1.7 Perform interior inspection

    1.8 Perform preflight checks

    1.9 Perform prestart checks

    1.10 Start engines

    1.11 Perform pretaxi checks

2. Taxi

    2.1 Taxi airplane to takeoff position

    2.2 Taxi airplane to gate

3. Takeoff

   3.1 Perform takeoff ground roll

   3.2 Rotate airplane

   3.3 Control flight path during climb to airfoil cleanup point

   3.4 Control flight path during airfoil cleanup

   3.5 Reject takeoff

4. Area Departure

   4.1 Control flight path during climb to cruise altitude

   4.2 Level off at cruise altitude

   4.3 Perform holding

5. Cruise

   5.1 Control flight path from begin cruise point to descent point

6. Area Arrival

   6.1 Control flight path from the arrival descent point to the level-off point

   6.2 Perform level-off

7. Approach

   7.1 Control visual approach flight path from end of level-off point to visual glidepath intercept point

   7.2 Control instrument approach flight path from end of level-off point to visual glidepath intercept point or to circling approach visual transition point

   7.3 Control circling approach flight path from circling approach visual transition point to visual glidepath intercept point

   7.4 Control flight path from visual glidepath intercept point to landing maneuver transition point

   7.5 Perform missed approach

   7.6 Reject landing

8. Landing

   8.1 Control flight path from landing maneuver transition point to flare point

   8.2 Control flight path from flare point to initial touchdown

   8.3 Control flight path from initial touchdown to start ground roll

   8.4 Perform landing ground roll

9. Emergency Descent

   9.1 Control flight path from emergency descent point to level-off point

   9.2 Perform level-off following emergency descent

10. In-flight Maneuvers

   10.1 Perform recovery from imminent stalls

   10.2 Perform steep turns

Of the 38 tasks, 27 involve control of the airplane while it is in motion, so task descriptions were written for each of these to the level of detail indicated above. The remaining 11 tasks concern preflight functions that do not require a detailed analysis because they primarily involve the operation of airplane systems; and given the assumption that these systems will always be adequately represented in simulators, no detailed analysis was needed to determine cueing and response requirements.

For the 27 tasks that were analyzed, each task description contains: (a) a descriptive title; (b) definitions of beginning and ending points for the task; (c) descriptions of specific procedural and psychomotor activities that are required for task completion; and (d) additional descriptions of behavioral activities in terms general enough to apply to a variety of airplanes. Complete task descriptions appear in Appendix A, and the list of candidate conditions to accompany each is in Appendix B.

Criterion performance standards were also written for each task, based on the behavioral activities in the task descriptions. These standards were later consolidated to cover entire flight segments and expanded to accommodate specific task conditions. Performance standards are not included in the task descriptions, but, rather, are published in Appendix C as performance criteria for evaluation CPOs.

For the work accomplished in Step 1, the SMEs relied on the following information sources:

FAA-approved airplane operating manuals and airplane flight manuals

Airman Information Manual

Title 14, Code of Federal Regulations, Parts 1, 61, 91, 97, 121, and 135

Airline Transport Pilot Airplane Practical Test Guide (FAA Advisory Circular AC 61-77)

Flight Test Guide, Instrument Pilot Airplane (FAA Advisory Circular AC 61-56A)

Instrument Flying Handbook (FAA Advisory Circular AC 61-27C)

Holding Pattern Criteria (FAA Order 7130.3)

Civil Use of U.S. Government Produced Instrument Approach Charts (FAA Advisory Circular 90-1A)

United States Standard for Terminal Instrument Procedures (TERPS) (FAA Order 8260.3B)

Task activities and performance standards were referenced to these sources, and the information is available in the files of this project.

ACSD Step 2 involved selecting conditions for task performance to be included in the CPOs, to be developed later in Steps 3 and 4. To develop a background for the selections, the project team reviewed air carrier accident and incident statistics; National Transportation Safety Board (NTSB) Safety Recommendations; FAA Order 8430.17, Air Carrier Operations Bulletins (ACOBs); and FAR precedents (see following paragraphs). Additionally, flight segments were assigned a qualitative rating for criticality, psychomotor difficulty, and procedural difficulty; and each condition for performance was subsequently analyzed to determine its impact on the criticality and difficulty ratings. Criticality is defined as the likelihood that loss of airplane control or a catastrophe will result by not meeting the criterion performance standards specified for a given flight segment. Difficulty is defined as the degree of procedural or psychomotor skill required to accomplish the tasks comprising a flight segment within the criterion performance standards established for the segment. Criticality and difficulty were rated as high, moderate, or low for each flight segment. Conditions that increased a segment's criticality were so annotated, and the effect of each condition on difficulty was indicated by assigning a 1 (significant effect), 2 (moderate effect), or 3 (little or no effect). Finally, qualitative ratings (high, moderate, or low) for frequency of occurrence were made for each condition. The results of this analysis are presented in Tables B-1 through B-10 in Appendix B.

FAA air carrier accident and incident data involving airplanes exceeding an operating weight of 12,500 pounds and having two or more engines were reviewed for the years 1979 through 1984. These data revealed that a preponderance of accidents and incidents involved the following conditions: turbulence; mismanaged systems operations; inadequate flight planning; icing conditions; collision with obstacles; improper alignment with the runway; bird strikes; unsafe airport conditions; takeoff weather; failure to follow approved procedures; improper operation of brakes; pilot incapacitation; and equipment malfunctions involving flaps, gear, wheels/brakes, hydraulics, power plants, pressurization, fire detection, lift augmentation, fuel control, engine oil, thrust reversers, and bleed air.

The review of NTSB Safety Recommendations covered the years 1968 through the present. These recommendations resulted from accident analyses and the observed trends of causes. Of particular interest is the fact that many of these recommendations, prior to 1974, deal with air carrier, in-flight training accidents that could have been avoided had simulators been used for the training. Additionally, the NTSB notes that weather is the most frequently cited causal factor in fatal general aviation accidents. In summary, over this period of time, the NTSB recommended training in the following areas (asterisks indicate NTSB recommendations for checking as well): stalls*; effects of spoilers on performance and stall warning; wind shear; hydroplaning; thunderstorm avoidance and weather radar operation; rejected takeoffs* on wet runways at maximum gross weight with an engine or tires failed; cockpit resource management; high altitude flight characteristics of the airplane; the pilot's physiology; unique flight characteristics; microburst encounters during takeoff/approach/landing; icing conditions (ground and air); rudder blanking; pilot response to the ground proximity warning system* (GPWS); and partial panel instrument flight.

The review of FAA ACOBs covered the entire contents of FAA Order 8430.17, Air Carrier Operations Bulletins. Although many of these bulletins deal with subjects in ways that suggest training requirements, only those containing explicit training (and checking*) requirements are identified here: propeller systems; engine-out takeoff and climb; pretakeoff power plant checks; in-flight maneuvering with an engine out; braking on slippery surface; icing conditions; thunderstorms and weather radar operation; compass system malfunctions; use of the autopilot; nonprecision approaches; airplane performance; decompression procedures; ILS procedures; pilot induced upsets; transition from instrument to visual conditions during approach; hydroplaning; wind shear; fuel system management; stalls; specific flight characteristics; cockpit resource management; maximum weight rejected takeoffs*; and pilot response to GPWS warnings*. Many ACOBs overlap NTSB recommendations because they were written to implement these recommendations. However, some ACOBs deal solely with other sources of information such as FAA field experience and Service Difficulty Reports.

The reviews of accident and incident statistics, safety recommendations, and ACOBs were combined with a review of existing training and checking requirements specified in FAR Part 61, Appendix A; Part 121, Appendices E, F, and H; FAR 61.157; FAR 135.293; and FAR 135.297. Regulatory Preamble material for these rules was also examined as part of the review. These reviews provided a broad background for the SMEs to use in making their judgments, and the results are incorporated in Tables B-1 through B-10 in Appendix B.

The SMEs next determined which conditions could be eliminated on the basis of the previous flight experience that is required of all ATP applicants. ATP flight experience requirements are contained in FAR 61.155 and are outlined in Section II. They represent a comprehensive repertoire of basic airmanship skills. Conditions for which experience credit was given are listed in the tables of Appendix B. For the most part, these conditions do not have a significant effect on task criticality or difficulty; and pilots who meet the experience requirements of FAR 61.155 could reasonably be expected to deal with these conditions on the basis of skills previously acquired and tested by the FAA during the practical test required for lower grade pilot certificates, which are a prerequisite for the ATP license.

The remaining conditions were candidates to be included in CPOs. These conditions were examined for redundancy as explained in Section II. Redundant conditions were eliminated, and a final review was accomplished to determine which conditions were appropriate checking requirements and which were appropriate training requirements. The classificaton of conditions was strongly influenced by the review of accident/incident data, NTSB Safety Recommendations, FAA ACOBs, and FAR precedents. Checking requirements were based on the need to sample enough task-condition combinations to ensure skill robustness in all areas of flight operations with which an airline transport pilot should reasonably be expected to cope. Training requirements were based on two needs. First, it is important to ensure that the limited sampling accomplished during practical testing is truly representative of the entire gamut of airplane-specific skills that a pilot must possess for safe flight operations after certification. As explained in Section II, appropriate training is necessary to ensure this. Second, it is important to train the pilot to deal with extreme task demands that occur with low frequency in the operational environment but increase task difficulty to the extent that accidents and incidents are probable outcomes if such training is not provided. The latter need is concerned with task-condition combinations such as wind shear encounters during takeoffs, or landings accomplished during manual reversion of the flight controls.

Allocations of task-condition combinations as training requirements and as checking requirements are presented in the tables of Appendix B. During Steps 3 and 4 conditions were quantified, where possible, to permit standardization during checking and training when simulation allows control of these parameters, and this is reflected in the crew performance objectives. The evaluation and training CPOs are largely mutually exclusive in that conditions listed as checking requirements only rarely overlap with conditions listed as training requirements. This does not mean that a pilot should not be trained in the skills that constitute practical tests. Obviously, a pilot should receive the training necessary to prepare for the practical test. However, because proficiency in these skills is ultimately witnessed by the FAA, it is not necessary to specify them as training requirements. On the other hand, proficiency in task-condition combinations listed as training requirements may not be witnessed during practical tests. In fact, of these conditions, only those involving equipment malfunctions that do not have major aerodynamic impact are intended to be sampled during practical tests. Therefore, the completeness of the ATP certification process rests on the combination of checking and training requirements. Training requirements supplement and complement checking requirements, and mastery of the skills represented by both sets of requirements must be assured. This is an important consideration in the derivation of simulator requirements, which is the topic of Section VI.

IV. CREW PERFORMANCE OBJECTIVES

This section, covering ACSD Steps 3 and 4, deals with the development of crew performance objectives (CPOs), which in themselves fulfill one objective of the project, a systematic identification of skills to be acquired and demonstrated by ATP candidates during checking and training processes. As incorporated into scenarios, CPOs describe ATP skill requirements in terms of explicit evaluation or training objectives, performance conditions, and criterion performance standards. Objectives, conditions, and standards serve important roles in determining simulator requirements and in ensuring that simulators are used properly.

RATIONALE FOR DERIVING CPOS.

Two goals of this project are, first, to define the skills required for ATP certification systematically and, then, to derive supporting simulator requirements, also systematically. These two goals are not independent. Necessary simulator features depend on how the simulator is used, for what it is used, and by whom it is used (AGARD, 1980; Caro, Shelnutt, & Spears, 1981). Consequently, it is important that ATP checking and training functions be developed in a manner that clarifies simulator design criteria. Simulator capabilities should not dictate checking or training objectives, but checking and training objectives _should_ dictate simulator requirements. At the same time, the objectives can be formulated to permit the maximum use of simulators while avoiding specification of unnecessary features. The thrust here was to identify _essential_ simulator requirements by carefully defining the precise purpose for checking or training specific skills.

During development of the CPOs, two classes of objectives emerged that have subtle differences in purpose. These were termed "Type A" objectives and "Type B" objectives. As explained in Section II, Type A objectives focus on complex cognitive-motor skills and on task loading that complicates psychomotor behavior due to adverse operating conditions. Type B objectives are concerned with the cognitive-procedural aspects of performance when task loading has little impact on the psychomotor activities required for basic task performance. (Even so, Type B objectives frequently involve tasks and psychomotor behaviors that overlap considerably those of tasks classified as Type A.) The purpose in differentiating between Type A and Type B objectives is that Type B objectives permit relaxation of some simulator features regarding the ranges of cues required and control and aerodynamic correspondence to the airplane.

In developing CPOs, it was important to assure that pilots who perform within standards are, in fact, proficient in all of the skills necessary to deal with the task-condition combinations allocated as training and checking requirements in Step 2. Thus, these task-condition combinations are basic ingredients in the CPOs. However, the CPOs are written to minimize redundancy and to capitalize on the fact that proficiency in some skills signifies proficiency in certain others (see discussion of skill robustness in Section II). Thirteen CPOs were thus developed, 11 for checking (evaluation CPOs) and 2 for training (training CPOs). An evaluation CPO was written for each flight segment that contains checking requirements (only the cruise segment does not contain checking requirements), for airplane systems operation, and for cockpit resource management. The two training CPOs cover special training tasks and line-oriented flight training (LOFT) requirements.

Like the task-condition combinations which spawned them, the CPOs, in and of themselves, represent fragmented flight segments. Yet, it is important that ATP applicants demonstrate in a realistic flight environment not only proficiency in, but also integration of, all required skills, including management of the crew and airplane systems. Therefore, the separate practical test scenarios are designed to be linked together in a real-world, real-time format. This type of linkage is essential for both Type A and Type B practical test scenarios, and it is particularly important if a simulator is used for the practical test.

An attempt was made, initially, to develop CPOs so that all required training and checking could be accomplished using an airplane in flight. However, it became readily apparent that this constraint severely limited the certification process due to the safety implications of some task-condition combinations and due to the impossibility of manipulating certain desired environmental and equipment malfunction parameters in the airplane. Because simulators are widely available and used in the certification system, it is no longer justifiable to constrain checking and training objectives within the limitations imposed by an airplane in flight and to ignore the potential of simulators for enhancing the certification process. Therefore, CPOs incorporate all of the task-condition combinations identified as important ATP flight skills regardless of the practicality of performing these skills in flight. Conditions should be precisely controlled when a simulator is used. When an airplane is used, conditions should be controlled to the extent possible; but even then, some training and checking objectives cannot be accomplished.

METHOD.

CPOs were developed by the three SMEs identified in Section II, two of whom have extensive experience in administering FAA ATP checks. The SMEs were assisted by the project manager, who is also an experienced FAA inspector with a broad background in regulatory policy, and by a specialist in the design of instruction and evaluation systems. After the initial draft of the CPOs was written, a human factors specialist joined the team to assist in defining behavioral objectives and in classifying them as Type A or Type B for inclusion in the final CPO document. Evaluation CPOs for ATP checks were developed jointly by all three SMEs. Training CPOs were developed by a single SME and the project manager after the evaluation CPOs were completed.

DEVELOPMENT OF EVALUATION CPOS. The project team's first activity involved the synthesis of data generated by Steps 1 and 2. Task descriptions, including criterion performance standards, were integrated to describe entire flight segments. Conditions identified for each flight segment were then analyzed to determine their impact on performance standards; and addendums were written for some of the standards to accommodate the more adverse conditions. The SMEs wrote statements of purpose for evaluating each flight segment. This activity produced the rudiments of generic CPOs. However, at this point, there was little information on which to base practical test scenarios because the task list and task descriptions did not address pragmatic piloting operations such as ILS approaches, standard instrument departures, etc.

Thus, the next assignment for the SMEs was to write practical test scenarios that would permit each evaluation purpose to be fulfilled. The practical test scenarios stated checking requirements in terms of specific procedures and maneuvers such as ILS and nonprecision approaches that fall within each flight segment. Conditions for performance such as restricted visibility, power plant failure, etc., were incorporated into the practical test scenarios. Some alterations were made to the task-condition list at this point due to the discovery of redundancies and other information affecting the appropriateness of some conditions for the stated evaluation purpose. Considerable emphasis was placed on previous reviews of accident and incident statistics, NTSB Safety Recommendations, FAA ACOBs, and FAR precedents. However, the SMEs were not constrained by any of these in making final determinations.

Finally, evaluation purposes were redefined as Type A or Type B evaluation objectives. This was accomplished by examining practical test scenarios and task descriptions in order to identify checking requirements involving cognitive-motor skills and those involving cognitive-procedural skills and only basic motor requirements, as described in Section II and earlier in this section. Three flight segments, taxi, landing, and in-flight maneuvers, contain only Type A objectives. Four segments, preflight, area departure, area arrival, and emergency descent, contain only Type B objectives. The remaining two segments, takeoff and approach, and the CPOs for airplane systems operation and cockpit resource management, contain both Type A and B objectives. The Type B evaluation objective for takeoff involves performance of rejected takeoffs. (Note that while the rejected takeoff is a Type B checking objective, it is a Type A training objective due to the addition of a visual tracking task--staying centered on the runway--for rejected takeoffs performed on contaminated surfaces in conjunction with brake and tire failures.) Type B objectives for the approach segment involve additional sampling of instrument flying skills to assure consistency in skill performance. This additional sampling does not involve imposing conditions that affect aerodynamic control of the airplane, nor does it involve cognitive skills relying on visual information to make decisions regarding continuation or termination of an approach at the missed approach point.

Evaluation CPOs are given at the end of this section. Each CPO contains: (a) a description of the segment of flight activity; (b) statements of Type A and Type B evaluation objectives, as appropriate; and (c) Type A and Type B practical test scenarios, as appropriate. Criterion standards for task performance appear in Appendix C. Practical test scenarios specify precise conditions under which performance should be checked. These conditions should be precisely imposed when a simulator is used for the practical test, and they should be imposed to the greatest extent practical when an airplane is used.

DEVELOPMENT OF TRAINING CPOS. Training CPOs were developed from the list of task-condition combinations identified as training requirements during Step 2. As with evaluation CPOs, this list was modified somewhat during Steps 3 and 4 to eliminate redundancies and inappropriate conditions for performance. The remaining task-condition combinations were classified as Type A training objectives, Type B training objectives, or ground training requirements. Type A and B objectives involve training in an airplane or suitable simulator, and the classification of task-condition combinations into these categories was based on the previously explained rationale.

Two training CPOs evolved. One specifies special training tasks and lists each task-condition combination in which ATP applicants should be trained to ensure proficiency in skills that are required for safe job performance. The other training CPO specifies a general LOFT requirement that is designed to permit a newly certificated airline transport pilot to acquire supervised operating experience prior to exercising the privileges of the certificate. This type of operating experience is important to ensure that the newly certificated pilot has integrated task-specific skills with the skills required for crew and cockpit management under normal and abnormal operating conditions. Although LOFT experience may be as important for pilots trained using only the airplane as for pilots trained using only high fidelity simulators (total simulation), regulatory precedents require LOFT training only for pilots in the latter group. There are two reasons for this. First, pilots trained under a total simulation concept may have had less opportunity to perform task-specific skills in a fully integrated, real-time flight environment. This is true because the simulator may be manipulated (repositioned, frozen, etc.) to maximize the training time spent in the simulator. While such manipulation enhances training, it reduces the pilot's opportunities to integrate newly acquired skills. Second, a previous regulatory effort to require operating experience for newly certificated general aviation ATPs was effectively resisted. Public comments responding to the Notice of Proposed Rule Making (NPRM) cited a lack of demonstrated need, and the NPRM was withdrawn. Although NTSB Safety Recommendations advocate operating experience for pilots with low flight time in the airplanes they are flying, there has not been another regulatory initiative to require operating experience for general aviation pilots; and the LOFT requirement discussed here is intended to apply only to pilots trained and checked entirely in a simulator.

Acquisition of this experience should occur after certification and before unsupervised operations, or, in the case of airline employees, before revenue operations. LOFT training should be conducted in accordance with guidelines like those developed during joint FAA, National Aeronautics and Space Administration (NASA), and airline industry workshops that occurred in 1981

(Lauber & Foushee, 1981). These guidelines specify real-world, real-time flight scenarios that involve passive instructor techniques (as opposed to the active instructor techniques required for training in the special training tasks). In this context, postcertification LOFT creates a safe environment in which normal and abnormal task loading can be controlled to permit newly licensed pilots to integrate their skills without direct interaction with instructors. This type of training can enhance transfer of skills to the operational environment and greatly improve safety in flight operations conducted by pilots with minimal flight time in the airplane they are flying.

Training CPOs appear at the end of this section. The CPO for special training tasks contains a brief description of the types of training tasks which are specified in the CPO. It also contains detailed lists of task-condition combinations in which training should be completed. For clarity, rejected takeoff is listed separately from the takeoff segment. The in-flight maneuvers segment includes training in stall recoveries under adverse conditions and training in specific flight characteristics for a given type of airplane. Specific flight characteristic training is determined by the appropriate FAA Flight Standardization Board (FSB) in accordance with Chapter 14 of FAA Order 8430.6B, Air Carrier Operations Inspector Handbook. The CPO for LOFT describes the intent of the recommended training, lists specific training objectives, and describes general requirements for LOFT scenarios. Neither CPO contains performance standards. However, when appropriate, the criterion standards contained in the evaluation CPOs (Appendix C) should apply.

MAJOR CONSIDERATIONS REGARDING CPOS.

The foregoing discussion dealt with the development of crew performance objectives for ATP checking and training. The CPOs incorporate task and condition combinations developed and defined in previous ACSD steps. CPOs were developed to permit the maximum use of simulators and to take full advantage of their capabilities. The following points emphasize certain details regarding the contents of the CPOs and their development.

- The differentiation between Type A and Type B objectives is based on subtle distinctions in the behaviors implicit in the objectives and is designed to minimize requirements and features in simulators used to satisfy the objectives.

- Type A objectives involve complex cognitive-motor behaviors that are frequently complicated by imposing task loading such as power plant failure and adverse weather that increases cognitive, procedural, and psychomotor workload.

- Type B objectives focus on the cognitive-procedural aspects of psychomotor skills that are not complicated by additional task loading and that are redundant with psychomotor behaviors involved in Type A objectives. Type B objectives are primarily designed to ensure consistency of skill performance.

• For checking, the rejected takeoff task is a Type B objective which is procedurally oriented and does not include a visual tracking task to maintain runway centerline. For training, the rejected takeoff is a Type A objective, which is psychomotor oriented and entails acquisition of skills required for effective braking and runway tracking under conditions involving contaminated surfaces and brake and tire failures.

• For checking, and except for rejected takeoff, the takeoff segment consists of Type A objectives involving adverse conditions including power plant failure and crosswind. For training, the takeoff segment includes both Type A and Type B objectives. The Type B objectives include acquisition of procedurally oriented skills required to deal with equipment malfunctions that either do not affect aerodynamic control or do not require external visual cues or force motion cues.

• The cruise segment does not involve skills that were considered essential to check for a pilot meeting the minimum flight experience prerequisites of FAR 61.155. Therefore, there are no evaluation objectives for this segment.

• The area departure, area arrival, and emergency descent segments involve psychomotor skills that are redundant with skills involved in the approach segment. However, the procedural application of these skills varies in each segment, thus dictating Type B requirements.

• The in-flight maneuvers segment involves Type A objectives that include steep turns, stall recoveries, and recovery from conditions arising from the specific flight characteristics of the airplane type. In the latter category are maneuvers such as recovery from Dutch roll or high speed buffet. The FAA FSB determines the need for this type of training and/or checking for each airplane type. Evaluation objectives regarding recovery from specific flight characteristics are intended to evaluate a pilot's performance only in regard to approved operating procedures. These objectives are not designed to evaluate performance which is not desired or required in actual flight operations.

• Type A evaluation objectives for the approach segment include cognitive skills required for processing visual information to make correct decisions concerning the continuation or termination of an instrument approach at decision height or the missed approach point. These objectives also include visual tracking tasks involved in correcting final approach course alignment when misalignment is caused by normal tolerances in navigation equipment or by operations at the limits of the tolerances specified in the performance standards. There is no requirement during the approach segment for a visual approach, per se. However, a visual final approach is required to evaluate a pilot's ability to cope with certain operating conditions such as no flaps and no visual approach slope indicator (VASI) or electronic glidepath guidance.

• Type B objectives for the approach segment deal with the cognitive-procedural aspects of behaviors that are redundant with those specified in Type A objectives. Type B objectives are necessary to assure consistency of skill performance or the transfer of skill to similar, but slightly different conditions, on different occasions.

• The practical test scenario contained in the Approach CPO does not address the requirements of FAR 61.67 (Category II pilot authorization requirements), which constitutes an additional certification function that is separate from ATP certification functions. Pilots who are qualifying for Category II operations in conjunction with ATP practical testing must satisfy the additional requirements specified in FAR 61.67 for Category II authorization. This is equally true for pilots qualifying for lower weather minimums under air carrier operations specifications.

• The CPO specifying special training tasks is designed to supplement and complement skills designated as checking requirements. This training rounds out an airman's skill repertoire by ensuring proficiency in a broader spectrum of skills than those that can reasonably be observed during practical testing, and by exposing an airman to task and condition combinations such as takeoff wind shear that require training but are not appropriate for formal evaluation. Special training tasks require active, direct instruction, however.

• The Special Training Tasks CPO requires training for wind shear encounters during takeoff, approach, and landing. This training requires practice at escape maneuvering during encounters with microburst phenomena on takeoff and approach and during encounters with horizontal shear on landing. The required training is intended to teach the pilot necessary maneuvering techniques to escape "survivable" phenomena. The training is not intended to expose the pilot to wind shears that exceed the performance capabilities of the airplane.

• With the exception of night landings, time of day was not a condition that significantly affected task difficulty. Therefore, time of day is not specified in the CPOs except for night landing training. For the most part, night conditions, which minimize external visual cues and make cockpit instruments more difficult to read, were determined to increase task difficulty, but not to a point that would exceed the adaptability of skills demonstrated under daylight conditions by a pilot meeting minimum ATP experience requirements. Daylight conditions increase task difficulty only during the approach and landing segments, and then only in conjunction with low visibility caused by heavy rain or snow. This combination of conditions, however, was not implicated in accidents, incidents, safety recommendations, or ACOBs. Therefore, there was little justification to require this special combination of conditions in the CPOs, particularly in view of the fact that low visibility approaches are required.

• The CPO specifying LOFT requirements is concerned with the full integration of task-specific skills, including cockpit resource management, under normal and abnormal operating conditions. LOFT is designed to assure that the newly licensed pilot is capable of exercising his or her skills as a pilot in command under the authority of an ATP certificate. LOFT requires imposing conditions that significantly increase task loading and difficulty during real-world, real-time scenarios, although active instructor assistance is not necessary.

CREW PERFORMANCE OBJECTIVES: EVALUATION.

GENERAL GUIDELINES FOR PRACTICAL TESTS. Practical test scenarios list the minimum testing events necessary to accomplish Type A and Type B objectives for each CPO. However, repetitions of testing events beyond the minimum specified in the scenarios may be necessary to determine an applicant's competency in regard to a given evaluation objective. Prior to beginning a practical test, the applicant should be briefed on required checking events and criterion performance standards. When a simulator is used, the applicant should also be briefed on the capabilities and limitations of the simulator and should acknowledge his/her contract to demonstrate required knowledge and skills under the conditions imposed by the simulator. CPO scenarios specify explicit environmental conditions, equipment malfunctions, emergencies, and special maneuvering requirements as appropriate for each testing event. When an airplane is used for the practical test, each condition should be simulated to the maximum extent practical. When a simulator is used, scenario requirements should be integrated into real-world, real-time formats, and each of the specified conditions should be strictly applied to the testing event. Simulator slewing and repositioning functions should not be used except to shorten en route (cruise) segments during which performance evaluation is not required.

All practical tests conducted in simulators, including abbreviated checks following a previous failure, should begin with preflight activities and engine starting and should end with engine shutdown. The applicant should be provided with normally available flight planning information such as departure, destination, and alternate airports; weather forecasts; NOTAMs; fuel load; weight and balance information; route of flight; and MEL/CDL requirements. To enhance realism during practical tests in simulators, a takeoff and landing should be accomplished even if the simulator is not approved for these maneuvers. However, the pilot's performance should not be evaluated during tasks for which the simulator is not approved. Realistic ATC clearances should be issued by the examiner or an external communications operator. Normal communications equipment (headsets or speakers) should be used when available; and controls for the aural environment should be set to provide realistic noise levels. The activities of other crewmembers should be limited to accomplishing standard operating procedures unless the applicant explicitly delegates additional duties or seeks additional information. The examiner should refrain from interacting with the flight crew except to issue ATC clearances. Practical tests should be conducted so that the objectives listed for cockpit resource management and airplane systems operations are satisfied in conjunction with the testing required for each flight segment.

As applicable for each CPO, the tasks included in the CPO are listed first. Statements of Type A and Type B objectives follow, and then practical test scenarios for the two types of objectives. The standards that are to be met during practical tests appear in Appendix C.

Abbreviations used in CPOs are:

ATP	Airline transport pilot
ATC	Air traffic control
DME	Distance measuring equipment
FAA	Federal Aviation Administration
FL	Flight level
IFR	Instrument flight rules
ILS	Instrument landing system
MDA	Minimum descent altitude
NOTAM	Notice to airmen
RVR	Runway visual range
SID	Standard instrument departure
STAR	Standard arrival procedure
V_1	Takeoff decision speed
V_2	Takeoff safety speed
V_r	Rotation speed
WX	Weather

DESCRIPTIONS OF EVALUATION CPOS. There are 11 Evaluation CPOs as follow:

1. Preflight
2. Taxi
3. Takeoff
4. Area departure
5. Area arrival
6. Approach
7. Landing
8. Emergency descent
9. In-flight maneuvers
10. Airplane systems operations
11. Cockpit resource management

1. PREFLIGHT

Description: Preflight is the phase of operation during which flight planning and preflight inspections occur. This segment begins with flight planning and ends when the airplane first moves under its own power.

Preflight Component Tasks:

- 1.1 Prepare/review flight plan
- 1.2 Analyze weather and NOTAMs
- 1.3 Prepare/review dispatch/flight release
- 1.4 Prepare/review load manifest
- 1.5 Inspect airplane documents
- 1.6 Perform exterior inspection
- 1.7 Perform interior inspection
- 1.8 Perform preflight checks
- 1.9 Perform prestart checks
- 1.10 Start engines
- 1.11 Perform pretaxi checks

Preflight Evaluation Purpose:

A. Type A Objectives: None.

B. Type B Objectives:

1. To determine that the applicant can make safe, correct decisions to conduct the flight by accurately analyzing weather, NOTAMs, route, and fuel requirements, and that the applicant can prepare or supervise the preparation of all required preflight documents.

2. To determine that the applicant can perform an actual preflight inspection of the airplane or can supervise certain inspection functions.

3. To determine that the applicant can perform or supervise the performance of prestart, engine start, poststart, and pretaxi checks.

Preflight Practical Test Scenario:

A. Type A Maneuvers/Procedures: None.

B. Type B Maneuvers/Procedures: The applicant will perform the planning and preparation necessary for the certification flight test or for a hypothetical flight appropriate to the specific airplane.

1. Preflight activities will include a demonstration of the applicant's ability to determine the airworthiness of the airplane by actual inspection and by performing preflight checks. (If the approved airplane operations manual prescribes that portions of the visual inspection are normally performed by another flight crewmember, the examiner may determine by other means that the applicant understands the location, function, and purpose of inspection items.)

2. Preflight activities will include the use of checklists; engine starting procedures; and checks of control, navigation, and communication systems.

2. TAXI

Description: The taxi segment includes all operations during which the airplane is in motion on the ground except for takeoff and landing. This segment begins when the airplane first moves under its own power at the origination of flight and ends when power is applied for takeoff, or the segment begins when taxi speed is attained after landing and ends when the airplane is parked following termination of flight.

Taxi Component Tasks:

2.1 Taxi airplane to takeoff position
2.2 Taxi airplane to gate

Taxi Evaluation Purpose:

A. Type A Objectives:

1. To determine that the applicant can safely and accurately taxi the airplane by outside visual reference. (Evaluation of this event is not required for applicants who are type rated in airplanes of similar fuselage length and cockpit height or who have taxied the actual airplane during training.)

2. To determine that the applicant can make timely and correct judgments regarding this phase of operation, including obstruction avoidance judgments and determination of safe taxi speed in consideration of surface conditions and airplane ground handling characteristics.

B. Type B Objectives: None.

Taxi Practical Test Scenario:

A. Type A Maneuvers/Procedures: The applicant will taxi the airplane in accordance with a clearance issued by ATC or the examiner to the extent required to determine that the evaluation objectives are satisfied.

   1. Taxi maneuvers will include at least one 90° turn.

B. Type B Maneuvers/Procedures: None.

3. TAKEOFF

Description: Takeoff is the phase of flight during which the airplane initially becomes airborne. This segment begins when power is applied for takeoff and ends when climb airspeed is established with high lift devices retracted or when an altitude at least 400 feet above the airport elevation is reached, whichever occurs last. If the takeoff is rejected, this segment ends when the airplane is slowed to taxi speed or stopped on the runway.

Takeoff Component Tasks:

3.1 Perform takeoff ground roll
3.2 Rotate airplane
3.3 Control flight path during climb to airfoil cleanup point
3.4 Control flight path during airfoil cleanup
3.5 Reject takeoff

Takeoff Evaluation Purpose:

A. Type A Objectives:

   1. To determine that the applicant can safely and accurately perform takeoffs by reference to the external visual environment and to airplane-specific flight instruments under the meteorological conditions and in conjunction with the equipment malfunctions specified in the practical test scenario.

   2. To determine that the applicant can safely and accurately make the transition from visual to instrument cues during takeoff.

   3. To determine that the applicant can make timely, correct, and safe judgments regarding this phase of flight including the decision to continue or to reject the takeoff.

B. Type B Objectives:

   1. To determine that the applicant can safely and accurately perform maximum deceleration rejected takeoffs and make timely, correct decisions to reject the takeoff.

Takeoff Practical Test Scenario:

A. Type A Manuevers/Procedures: The applicant will perform a minimum of two takeoffs under the following conditions, which may be combined at the discretion of the examiner.

1. At least one takeoff will begin when the airplane is taxied into position on the runway to be used.

2. At least one takeoff will be performed with a crosswind (20 knots of right crosswind if accomplished in a simulator; existing wind conditions if accomplished in the airplane).

3. At least one takeoff will be accomplished under simulated or actual instrument meteorological conditions (RVR set to the lowest authorized takeoff minimums if accomplished in a simulator; ceiling simulated at 100 feet above airport elevation if accomplished in the airplane).

4. At least one takeoff will be accomplished with a simulated failure of the most critical power plant at a point after V_1 and before V_2 that is appropriate to the airplane type under the prevailing conditions, or at a point as close as possible after V_1 when $V_1 = V_2$ or $V_1 = V_r$, or at an appropriate airspeed for nontransport category airplanes.

B. Type B Maneuvers/Procedures: The applicant will perform at least one rejected takeoff.

1. The rejected takeoff will be performed at the maximum allowable gross weight for the runway in use, and the rejection will be initiated as close to V_1 (or rotation speed for nontransport category airplanes) as is practicable if accomplished in a simulator.

2. If performed in the airplane, the rejected takeoff will be initiated from a reasonable speed determined by the examiner in consideration of airplane characteristics, runway length, surface conditions, wind, brake energy, and other factors that may adversely affect safety.

4. AREA DEPARTURE

Description: Area departure is the phase of flight during which an IFR departure is accomplished in accordance with an ATC clearance. This segment begins at a point where the first turn is required after lift off or the takeoff segment is complete, whichever occurs first. The segment ends when transition to the en route environment is complete. Portions of the area departure segment may overlap the takeoff segment.

Area Departure Component Tasks:

4.1 Control flight path during climb to cruise altitude
4.2 Perform level off at cruise altitude
4.3 Perform holding

Area Departure Evaluation Purpose:

A. Type A Objectives: None.

B. Type B Objectives:

1. To determine that the applicant can safely and accurately comply with IFR departure clearances by reference to airplane-specific flight instruments under the meteorological conditions and in conjunction with the equipment malfunctions specified in the practical test scenario.

2. To determine that the applicant can make timely and correct judgments regarding this phase of flight, including the decision to continue the area departure or to return to the departure airport due to abnormalities occurring during or after takeoff.

Area Departure Practical Test Scenario:

A. Type A Maneuvers/Procedures: None.

B. Type B Maneuvers/Procedures: The applicant will perform at least one area departure in accordance with an ATC clearance to join an airway or route (other than a radar vector route) under the following conditions:

1. The clearance will include a published IFR departure procedure, SID, holding pattern, or any other appropriate procedure.

2. The area departure will be conducted in simulated or actual instrument meteorological conditions.

3. The area departure will be flown with a 30 knot wind aloft and in mild atmospheric disturbance if accomplished in a simulator or under existing conditions if performed in an airplane.

4. The area departure must be conducted to a point where, in the examiner's judgment, the transition to the en route environment is complete.

5. AREA ARRIVAL

Description: Area arrival is the phase of flight during which an IFR arrival is accomplished. This segment begins when descent from the en route environment is initiated and ends when an approach procedure is commenced.

Area Arrival Component Tasks:

6.1 Control flight path from descent point to level-off point
6.2 Perform level-off
6.3 Perform holding

Area Arrival Evaluation Purpose:

A. Type A Objectives: None.

B. Type B Objectives:

1. To determine that the applicant can safely and accurately comply with IFR arrival clearances by reference to airplane-specific flight instruments under the meteorological conditions and in conjunction with the equipment malfunctions specified in the practical test scenario.

2. To determine that the applicant can make timely and correct judgments regarding this phase of flight, including determination of start-descent points in consideration of crossing altitude, level-off, and airspeed restrictions and including the selection/acceptance of appropriate approach procedures.

Area Arrival Practical Test Scenario:

A. Type A Maneuvers/Procedures: None.

B. Type B Maneuvers/Procedures: The applicant will perform at least one area arrival in accordance with an ATC clearance to join an assigned route (other than a radar vector route) under the following conditions.

1. The clearance will include a STAR, published profile descent procedure, holding pattern, or any other appropriate procedure.

2. The area arrival will be conducted under actual or simulated instrument meterological conditions.

3. The area arrival will be flown with a 30 knot wind aloft and in mild atmospheric disturbance if accomplished in a simulator or under existing conditions if performed in an airplane.

6. APPROACH

Description: The approach segment is the phase of flight during which an instrument or visual approach is accomplished. This segment includes nonprecision and precision instrument approaches, rejected landings, and missed approaches. The segment begins when the airplane reaches an initial approach fix, commences a radar vector initial approach segment, or commences a visual approach. The segment ends at the landing maneuver transition point or when a rejected landing/missed approach procedure is complete, whichever occurs last. (The landing maneuver transition point is defined as a point on the final approach path that is 200 feet above touchdown zone elevation or precision approach decision height, whichever is applicable.)

Approach Component Tasks:

7.1 Control visual approach flight path from end of level-off point to visual glidepath intercept point
7.2 Control instrument approach flight path from end of level-off point to visual glidepath intercept point or to circling approach visual transition point
7.3 Control circling approach flight path from circling approach visual transition point to visual glidepath intercept point
7.4 Control flight path from visual glidepath intercept point to landing maneuver transition point
7.5 Perform missed approach
7.6 Reject landing

Approach Evaluation Purpose:

A. Type A Objectives:

1. To determine that the applicant can consistently, safely, and accurately perform instrument approaches, visual approaches, and missed approaches/rejected landings by the reference to airplane-specific flight instruments under the meteorological conditions and in conjunction with the equipment malfunctions specified in the practical test scenario.

2. To determine that the applicant can make the transition from instrument to visual cues and maneuver the airplane to a point from which a landing can be made.

3. To determine that the applicant can make timely and correct judgments regarding this phase of flight, including the selection of runways, approach procedures, airplane configuration, continuation of the approach to a landing based on visual cues at the missed approach point, and execution of a missed approach/rejected landing.

B. Type B Objectives:

1. To determine, through additional sampling of performance, that the applicant can consistently exhibit proficiency in the procedural and basic motor skills required to safely and accurately execute instrument approaches and missed approaches; and that the applicant can make timely and correct judgments regarding this phase of flight, including the selection of runways, instrument approach procedures, and airplane configuration.

Approach Practical Test Scenario:

A. Type A Maneuvers/Procedures: The applicant will perform at least one instrument approach, one visual final approach, and one missed approach/rejected landing under the following conditions, which may be combined at the discretion of the examiner.

1. At least one instrument approach will be conducted with a 20 knot wind aloft and in mild atmospheric disturbance if accomplished in a simulator or under existing conditions if accomplished in an airplane.

2. At least one instrument approach will include a circle-to-land maneuver at the published circling MDA to a runway that is aligned at least 90° from the final approach course.

3. At least one instrument approach will be flown to the landing maneuver transition point.

4. Instrument approaches will be flown in actual or simulated instrument meteorological conditions (RVR and ceiling set at published approach minimums if accomplished in a simulator; ceiling simulated at published minimums if accomplished in an airplane).

5. At least one instrument approach and missed approach will be accomplished with the simulated failure of the most critical power plant (simulated power plant failure will be initiated prior to the final approach course).

6. At least one visual or instrument approach will be accomplished with the simulated failure of 50% of the available power plants with the power loss occurring on one side of the airplane (center engine and one outboard engine on three-engine airplanes).

7. At least one visual approach to the landing maneuver transition point will be accomplished with zero flaps unless sytem design makes flap failure extremely remote.

8. At least one visual final approach will be accomplished without the use of a visual approach slope indicator (VASI) or electronic glide slope if accomplished in a simulator.

9. At least one instrument approach, missed approach, and circle-to-land maneuver will be flown without using the autopilot.

B. Type B Manuevers/Procedures: The applicant will perform at least two instrument approaches and one missed approach/rejected landing under the following conditions, which may be combined at the discretion of the examiner.

1. At least one instrument approach must be an ILS during which the autopilot is not used unless a manually flown ILS is accomplished under Type A practical testing.

2. At least one instrument approach must be a nonprecision approach that includes a procedure turn, holding-in-lieu-of procedure turn, procedural track, DME arc, or other course reversal procedure and must be flown without the use of the flight director or autopilot.

3. At least one instrument approach must be accomplished with a 20 knot wind aloft if accomplished in a simulator or under existing conditions if accomplished in an airplane.

4. At least one missed approach must include a complete published missed approach procedure.

5. Instrument approaches and missed approaches will be flown in simulated or actual instrument meteorological conditions (RVR and ceiling set at or below published minimums and in mild atmospheric disturbance if accomplished in a simulator; ceiling simulated at or below published minimums if accomplished in an airplane).

7. LANDING

Description: Landing is the phase of flight during which airborne operations are terminated. This segment begins at the landing maneuver transition point when the pilot has sufficient external visual references to control the flight path to touchdown. This segment ends when taxi speed is reached on the runway or when power is applied to execute a missed approach/rejected landing or a takeoff from a touch-and-go landing.

Landing Component Tasks:

8.1 Control flight path from landing maneuver transition point to flare point
8.2 Control flight path from flare point to initial touchdown
8.3 Control flight path from initial touchdown to start ground roll
8.4 Perform landing ground roll

Landing Evaluation Purpose:

A. Type A Objectives:

1. To determine that the applicant can consistently, safely, and accurately land the airplane under the meteorological conditions and in conjunction with the equipment malfunctions specified in the practical test scenario.

2. To determine that the applicant can make timely and correct judgments regarding this phase of flight, including the decision to continue or reject the landing.

B. Type B Objectives: None.

Landing Practical Test Scenario:

A. Type A Maneuvers/Procedures: The applicant will perform at least three landings under the following conditions, which may be combined at the discretion of the examiner.

1. At least one landing will be accomplished with a crosswind (20 knots of right crosswind, unless otherwise limited by the approved airplane flight manual, and with mild atmospheric disturbance if accomplished in a simulator; existing conditions if accomplished in an airplane).

2. At least one landing will be accomplished to a full stop with the simulated failure of 50% of the available power plants with the power loss occurring on one side of the airplane (center engine and one outboard engine on three-engine airplanes).

B. Type B Maneuvers/Procedures: None.

8. EMERGENCY DESCENT

Description: Emergency descent is a contingency phase of flight during which a rapid descent is required by an in-flight emergency. This segment begins with the first indication of an abnormality requiring a rapid descent and ends when level-off at an appropriate altitude is complete.

Emergency Descent Component Tasks:

9.1 Control flight path from emergency descent point to level-off point
9.2 Perform level-off following emergency descent

Emergency Descent Evaluation Purpose:

A. Type A Objectives: None.

B. Type B Objectives:

1. To determine that the applicant can safely and accurately perform emergency descents by reference to airplane-specific flight instruments under the meteorological conditions and in conjunction with the equipment malfunctions specified in the practical test scenario.

2. To determine that the applicant can make timely and correct judgments regarding this phase of flight, including the decision to initiate an emergency descent, selection of descent profile, and selection of an appropriate level-off altitude.

Emergency Descent Practical Test Scenario:

A. Type A Maneuvers/Procedures: None.

B. Type B Maneuvers/Procedures: For airplanes certificated to operate at altitudes above FL 250, the applicant will perform an emergency descent. For other airplanes, the applicant will perform an emergency descent if the approved airplane flight manual contains procedures for an emergency descent.

1. Emergency descents will be conducted in simulated or actual instrument meteorological conditions.

2. The emergency descent will be accomplished in mild atmospheric disturbance if a simulator is used.

3. The emergency descent will be accomplished in conjunction with a simulated rapid decompression.

9. IN-FLIGHT MANEUVERS

Description: The in-flight maneuvers segment is comprised of demonstrations of general airmanship and of airplane-specific, critical maneuvering. This segment includes recovery from approaches to stalls and from specific flight characteristics peculiar to the airplane type. This segment also includes manuevering the airplane at steep bank angles.

In-flight Maneuvers Component Tasks:

10.1 Perform recovery from imminent stalls
10.2 Perform steep turns

In-flight Maneuvers Evaluation Purpose:

A. Type A Objectives:

1. To determine that the applicant can, by instrument reference, safely and accurately recover from various in-flight situations

that may result from flight path/energy mismanagement, environmental conditions, and specific flight characteristics peculiar to the airplane type.

2. To determine that the applicant possesses the degree of skill required to operate the airplane by instrument reference in attitudes not encountered in normal maneuvering.

B. Type B Objectives: None.

In-flight Maneuvers Practical Test Scenario:

A. Type A Maneuvers/Procedures: The applicant will perform steep turns, recoveries from imminent stalls in two different airplane configurations, and recovery from specific flight characteristics.

1. Stall recoveries will include entry procedures and will be accomplished in any airplane configuration and attitude and at any altitude that the examiner selects.

2. Steep turns will be for any specified duration using a 45° bank angle.

3. Recovery from specific flight characteristics peculiar to the airplane type will consist of maneuvers identified as checking requirements by the FAA Flight Standarization Board.

4. All in-flight maneuvers will be accomplished in actual or simulated instrument meterological conditions.

B. Type B Maneuvers/Procedures: None.

10. AIRPLANE SYSTEMS OPERATIONS

Description: Airplane systems operations are integral parts of each phase of flight and are required for safety and efficiency. Systems operations involve normal, abnormal, and emergency procedures and include the following: fire and smoke control, pressurization and rapid decompression, propulsion systems, hydraulic and flight control systems, pneumatic systems, electrical systems, landing gear and flaps, fuel systems, anti-ice and deice systems, autoflight systems, stability augmentation systems, stall warning/avoidance systems, and navigation/communication systems.

Systems Operations Component Tasks: Not specified.

Systems Operations Evaluation Purpose:

A. Type A Objectives:

1. To determine that the applicant can apply knowledge of airplane systems and procedures under the normal, abnormal, and emergency conditions specified in the practical test scenario.

B. Type B Objectives: Same as for Type A.

Systems Operations Practical Test Scenario:

A. Type A Maneuvers/Procedures: During each practical test event, the applicant will perform the systems operations required for the particular phase of flight and for the explicit meteorological conditions and equipment malfunctions specified in the applicable scenario. Equipment malfunctions such as engine failure and no flaps, which are specified in the practical test scenarios, should be logical consequences of realistically simulated systems anomalies. Compounding of abnormal and emergency procedures should not occur unless specifically required by the practical test scenario or unless compounding is a logical consequence of flight crew actions or of the system anomaly being simulated. The examiner will impose additional conditions and anomlies such as icing and flight instrument/navigation failures to the extent necessary to ensure that the applicant possesses a practical knowledge of airplane systems and procedures. These additional conditions and anomalies should not significantly affect aerodynamic performance. Practical tests should be planned so that inoperative or abnormal systems are not restored while the airplane is airborne unless restoration normally results from the procedures accomplished.

B. Type B Maneuvers/Procedures: Same as for Type A.

11. COCKPIT RESOURCE MANAGEMENT

Description: Cockpit resource management tasks are integral activites in each phase of flight and are required for safe and efficient operations. During each phase of flight, the pilot's primary responsibility is to maintain safe and accurate flight path control. Cockpit resource management involves the pilot's ability to execute this responsibility, safely and efficiently, by acquiring needed information, making decisions, implementing decisions, and using feedback. Cockpit resource management tasks include accomplishment of standard operating procedures, distribution of workload, elicitation of information, decision making, decision implementation, and flight crew supervision.

Cockpit Resource Management Component Tasks: Not specified.

Cockpit Resource Management Evaluation Purpose:

A. Type A Objectives:

1. To determine that the applicant maintains constant vigilance and awareness of the airplane's flight path.

2. To determine that the applicant can recognize conditions affecting the flight environment and can acquire needed information to deal with those conditions using all available resources.

3. To determine that the applicant uses acquired information to make timely and correct decisions regarding flight management and flight path control.

4. To determine that the applicant implements decisions effectively and uses feedback to ensure effectiveness.

5. To determine that the applicant accomplishes standard operating procedures in a timely, complete, and accurate manner.

B. Type B Objectives: Same as for Type A.

Cockpit Resource Management Practical Test Scenario:

A. Type A Maneuvers/Procedures:

1. During each practical test event, the applicant will manage the workload imposed by normal, abnormal, and emergency conditions that are specified in the practical test scenarios. At the discretion of the examiner, workload will be increased to the extent necessary to ensure that the evaluation objectives are satisfied.

B. Type B Maneuvers/Procedures: Same as for Type A.

CREW PERFORMANCE OBJECTIVES: TRAINING.

Training CPOs are designed to maximize the benefit of using simulators for airman certification. Certain flight conditions with which an airline transport pilot must cope can only be accomplished safely and efficiently in a simulator. Therefore, when an ATP applicant chooses to use a simulator, rather than the airplane, for a portion or all of the required practical test, that applicant should incur a commitment to undertake training in special skills for which simulators are the optimal training media.

1. SPECIAL TRAINING TASKS

Description: Special training tasks consist of maneuvers and procedures that are not specified in the practical test scenarios. They supplement and complement practical test requirements. Supplemental training tasks consist of airplane operations under task conditions such as maximum gross weight, maximum allowable crosswind, and wind shear that demand maximum performance. Complementary training tasks consist of abnormal and emergency operations, such as recovery from Mach tuck or total hydraulic failure, that either are not mandatory or not appropriate for the limited sampling of skills accomplished during practical tests. These special training tasks round out the airman's knowledge and skill repertoire.

Special Training Tasks Objective: To assure proficiency in the skills and knowledge required to deal with the task-condition combinations listed as Type A, Type B, and ground training requirements.

Special Training Tasks Requirements: Task-condition combinations in which training is required are listed below.

Type A

Preflight (None)

Taxi
- Nosewheel steering failures[a]
- Reverse taxi

Takeoff
- Wind shear[b]
- Wind gusts/turbulence

Rejected Takeoff
- Surface contaminants (wet)
- Surface contaminants (icy)
- Brake and tire failures
- Rudder blanking (if applicable)
- Asymmetrical reverse thrust

Area Departure (None)

Cruise (None)

Area Arrival (None)

Approach/Missed Approach/Rejected Landing
- Wind gusts/turbulence
- Wind shear[b]

Landing
- Surface contaminants (wet)
- Surface contaminants (icy)
- Surface wind (tail wind)
- Surface wind (maximum crosswind)
- Wind gusts
- Wind shear[c]
- Turbulence
- Night
- Restricted visibility
- Zero flaps
- Brake and tire failures
- Hydraulic system failure (total)
- Flight control failures (manual reversion, jammed stabilizer)
- Asymmetrical reverse thrust
- Maximum gross weight
- Extreme center of gravity
- Landing illusions[d]
- Rudder blanking (if applicable)

Emergency Descent (None)

In-Flight Maneuvers[e]
- Power plant failure (single)[f]
- Maximum gross weight[f]
- Extreme center of gravity[f]

---

[a]Training is required in taxiing the airplane using differential power and brakes.

[b]Takeoff and approach wind shear training requires the simulation of three dimensional microburst effects positioned on the departure and approach courses to permit positive escape maneuvering within airplane performance capabilities.

[c]Landing wind shear training requires the simulation of horizontal wind shears that do not exceed airplane performance capabilities.

[d]Training is required in landing illusions that tend to cause significant glide path deviations.

[e]Training is required in recovery from imminent stalls and specific flight characteristics such as Dutch roll and Mach tuck, as determined by the FAA Flight Standarization Board for a given airplane type.

[f]These conditions are applicable to stall recovery only.

Type B

Preflight (None)

Taxi (None)

Takeoff
- Engine icing
- Airframe icing
- Flight instrument failures
- Engine instrument failures
- High lift device failures (retraction)
- Landing gear failures (retraction)
- Flight control failures (runaway trim)
- Maximum gross weight
- Extreme center of gravity
- Reduced power operations

Rejected Takeoff (None)

Area Departure
- Engine icing
- Airframe icing
- Flight instrument failures
- Engine instrument failures
- Tailskid retraction failure
- Nonaerodynamic system failures[a]

Cruise
- Flight instrument failures
- Engine instrument failures
- Hydraulic failures (total)
- Hydraulic failures (partial)
- Flight control failures
- Nonaerodynamic system failures[a]
- Maximum gross weight

Area Arrival
- Engine icing
- Airframe icing
- Flight instrument failures
- Engine instrument failures
- Hydraulic failure (total)
- Hydraulic failure (partial)
- Nonaerodynamic system failures[a]

Approach/Missed Approach/Rejected Landing
- Engine icing
- Airframe icing
- Flight instrument failures
- Engine instrument failures
- Landing gear failures (extension)
- Hydraulic failure (total)
- Hydraulic failure (partial)
- Flight control failures
- Nonaerodynamic system failures[a]
- Maximum gross weight
- Extreme center of gravity

Landing (None)

Emergency Descent
- Engine icing
- Airframe icing

In-Flight Maneuvers (None)

---

[a]Training is required in nonaerodynamic system failures that are applicable for the phase of operation. These system failures include: pressurization, pneumatic, air conditioning, fuel and oil, electrical, and any other systems requiring knowledge of abnormal or emergency procedures.

Ground Training

Preflight[a]
- Surface contaminants (wet)
- Surface contaminants (icy)
- Surface wind (tail wind)
- Low density altitude
- Engine icing
- Airframe icing
- CDL/missing components
- Maximum gross weight
- Extreme center of gravity
- Reduced power operations
- Short/narrow runways
- Sloping runways

Taxi
- Engine icing
- Airframe icing
- Brake and tire failures
- Hydraulic failure (total)
- Hydraulic failure (partial)
- Nonaerodynamic system failures

Takeoff
- Thunderstorms (wx radar)
- CDL/missing components

Rejected Takeoff (None)

Area Departure
- Thunderstorms (wx radar)
- Autopilot malfunctions
- CDL/missing components

Cruise
- Thunderstorms (wx radar)
- Autopilot malfunctions
- CDL/missing components

Area Arrival
- Thunderstorms (wx radar)
- Autopilot malfunctions
- CDL/missing components

Landing
- Engine icing
- Airframe icing
- CDL/missing components

Emergency Descent (None)

In-Flight Maneuvers
- Specific flight characteristics[b]

---

[a]Training is required to ensure that the applicant understands the effects of the listed conditions on specific airplane performance.

[b]Ground training is required regarding specific high altitude flight characteristics, if applicable to the airplane type.

2. LINE-ORIENTED FLIGHT TRAINING

Description: Line-oriented flight training (LOFT) is required for newly certificated airline transport pilots who have received all required training and checking in a total simulation training program that does not involve operation of the actual airplane in flight. LOFT permits the pilot to integrate newly acquired, task-specific skills with those skills required for crew and cockpit management in a realistic flight environment without relying on instructor assistance. LOFT is designed to expose the pilot to normal and abnormal task loading while resources for task accomplishment are limited to those typically available outside of the training environment. Active instruction does not occur during LOFT, but a thorough performance critique from a qualified instructor is provided following the training. Thus, LOFT is designed to facilitate transistion from a total simulation training program to actual airplane operation. It provides a final opportunity for performance of fully integrated skills and adds a significant margin of safety to initial flight operations conducted by pilots with essentially no flight time in the airplane they are flying.

LOFT Objective: To assure complete integration of task-specific skills with those skills required for crew and cockpit management and to provide an opportunity for exercising command authority during normal and abnormal flight operations.

LOFT Requirements: LOFT is a Type A requirement and follows satisfactory completion of other required training and practical tests. The newly certificated pilot should complete two LOFT scenarios in an appropriate simulator. The first scenario consists of normal flight procedures; and the second, of normal, abnormal, and emergency procedures. Each scenario requires a complete flight segment between different airports. Scenarios must be realistically designed, and the LOFT session should begin with preflight planning and end with engine shutdown. Simulator features for repositioning and slewing should not be used except to reduce unproductive cruise portions of the scenario. During LOFT, appropriately qualified airmen should occupy each required flight crewmember position and should limit their voluntary activities to accomplishing standard operating procedures unless directed to do otherwise by the pilot in command. Active instruction should not occur while scenarios are in progress. The pilot in command should have complete authority and responsibility for safe conduct of the flight, and scenario design should require the pilot to exercise command authority and contingency planning. Appropriate guidelines for designing scenarios and conducting LOFT are contained in NASA Conference Publication 2184, Guidelines for Line-Oriented Flight Training.

V. ANALYSES OF CUES USED DURING TASK PERFORMANCE

The purpose of the cue analyses, ACSD Step 5, was to provide a basis for determining cueing capabilities to be required in simulators used for ATP checks and training. These analyses did not in themselves define simulator cueing requirements. They were concerned with types and sources of information used by pilots during actual flight in an airplane, with special reference to the Boeing 727. However, the findings are readily applicable to similar airplanes, and with only minor changes, to a wide variety of aircraft.

As explained in Section II, the cue analyses discussed in this section focused on out-the-window visual scenes, force motion, and the aural environment. Cues arising from instruments and control manipulations do not require the sort of analyses these other sources do, so cues arising from airplane systems will be addressed in Section VI which describes the derivation of simulation requirements.

It is emphasized again that the analyses discussed here focused on real-world cueing. The intent was to understand all types of cues pilots normally use and that could be identified. Because of inherent shortcomings in simulation, especially regarding true motion and realistic visual scenes, it is important to have comprehensive checklists of what pilots normally depend on during task performance. Then, through topolgical analyses of cue properties as discussed in Section II, one can determine the extent to which simulation can provide cues that are functionally equivalent to those in the real world. It will be apparent in Section VI that, because of considerable cueing redundancy in the real world, the variety of cues requiring simulation is less comprehensive than the analyses reported in this section may suggest.

The persons having primary responsibility for these analyses were three subject matter experts (SMEs) and a human factors specialist (HFS). The SMEs were all currently FAA Inspectors. The HFS organized matrices to be completed by the SMEs and himself. In most cases, the matrices were first completed independently by the participants, who then met as a group to resolve any differences. (Procedures used for specific matrices are identified below.) Two additional members of the project team, both pilots of considerable experience, usually participated in the conferences to resolve differences. It can be pointed out at this time that the analyses were done with considerable care and deliberation. The quality of the results was especially apparent in the internal consistency evidenced by the analyses, both from substantial agreement among the SMEs during the analyses and from the consistency and facility with which their analyses could be used later in determining simulation requirements.

The remainder of this section is organized under three major heads, one dealing with each of the areas of visual, motion, and aural cueing. In each case, the first step was to identify and prioritize the kinds of information used by pilots separately for each task. At this stage, only "normal" conditions for task performance were considered, that is, a day time scene and no adverse weather conditions, malfunctions, etc. Second, conditions that had been identified to accompany performance of the separate tasks were used as overlays on the task-information matrices to determine changes, if any, they would entail in the previously assigned priorities.

VISUAL CUE ANALYSIS.

The analysis of visual cues used by pilots followed an approach developed by Seville Training Systems (Caro, Spears, Isley, & Miller, 1980; Spears, Marcantonio, & Smith, 1983). The first of the cited reports became one basis for a later comprehensive analysis of synthetic flight training systems (Science Applications, Inc., 1983), with the analysis of visual requirements taken more or less verbatim from Seville's report.

The visual cue analysis involved five steps: (a) prioritization of types of visual information used in performing 25 basic tasks (Tasks 2.1 through 9.2 in Section III) under good visibility, daylight conditions; (b) prioritization of visual scene characteristics for providing the necessary visual information; (c) revisions of the foregoing priorities as required for additional maneuvers and malfunctions that could be combined with the basic tasks; (d) identification of types of visual information affected by given environmental conditions; and (e) determination of minimum field of view (FOV) for the visual scene.

TYPES OF VISUAL INFORMATION. The types of visual information of concern are those that pilots use to determine the status and movement of an airplane relative to the external environment. The information is used to cue and monitor control actions; as feedback to confirm results of control inputs and make adjustments to them; and as general information on which to base decisions, judgments, and plans regarding flight. Twenty types of visual information were considered for each of the 25 basic flight tasks. These types are listed below in the form they appear in matrices, together with a brief statement regarding the primary concern with each.

Vertical movement (LA): detection or awareness at low altitude (LA) of movement of the aircraft either up or down relative to the ground or ground-based objects.

Pitch angle (LA): detection or awareness of a tilting of the visual scene relative to the horizontal plane, reflecting nose-up or nose-down flight.

Horizontal movement (LA): detection or awareness at low altitude of movement of the airplane in any direction in a plane parallel to the ground.

Pitch angle (HA): same as for LA but for high altitude (HA).

Horizontal movement (HA): same as for LA but for high altitude; also, visual reference could be clouds or other airborne objects.

Linear accel/decel (LA): detection or awareness at low altitude of a change in horizontal velocity (acceleration or deceleration).

Vert[ical] rate of closure: awareness of rate of continuous change in "nearness" to the ground or to ground-based objects, or in rate of approach to the plane of an airborne object higher or lower than the horizontal vector of the plane in which one's own airplane is moving.

Horizon[tal] rate of closure: awareness of rate of continuous change along a horizontal vector in "nearness" of an object or terrain feature relative to one's airplane, or in the horizontal rate of approach to airborne objects.

Rate of turn: awareness of rate of continuous change in heading of the airplane.

Bank angle: awareness of the status of the lateral plane of the airplane relative to the ground, horizon, or objects in the plane of airplane movement.

Altitude (low): knowledge of distance of the airplane above the terrain in feet or in terms of task requirements (e.g., altitude proper for flight or adequate to clear an obstacle).

Altitude (high): realistic perspective of height above the ground relative to simulated altitude and terrain characteristics.

Relative distances (obj): awareness of relative distances to objects and specific terrain characteristics (rivers, ridges, etc.).

Relative hght (obj/ter): knowledge of heights of objects and terrain in feet or in terms of task requirements (e.g., maneuvering to avoid objects and terrain); for taxiing, takeoff, low flight, and landing, relative heights required for realism in ground and object patterns.

Directional orientation: use of terrain features, clouds, etc., for awareness of, and to monitor path of, movement.

Ter feature ident: identification of characteristics of the terrain such as its nature, general contours, ground cover, and relative heights of various portions of the terrain.

Lateral context: a visual scene in the pilot's left 90° region as needed during taxi and circling approaches (not considered for other tasks).

Near-object detail: information required to recognize separate parts of an object as needed to judge position and distance from the object when close.

Object features: characteristics of an object that enable recognition of the kind of object (tree, tower, building, etc.) and its shape.

Absolute distance: knowledge of distance to a point of interest in feet, miles, or in terms of task requirements.

Priorities were assigned for each type of information separately for each task. The assignments were first made independently by each of three SMEs and a human factors specialist. Then all four participants met to resolve any discrepancies. Bases for priorities were as follow:

Priority 1: information type is needed for cueing or feedback, and with a high level of perceptual accuracy.

Priority 2: information type is needed for feedback (especially to avoid confusion), but at a lesser level of perceptual accuracy than for priority 1.

Priority 3: information type is not needed for cueing or feedback; it is only slightly perceivable and/or its omission would not result in scene confusion.

Following a joint meeting of raters to resolve discrepancies, the original list of 25 basic flight tasks was examined to determine if a visual scene could be eliminated entirely for some individual tasks. Accordingly, ten tasks were judged not to require an external visual scene for cueing, at least for certification checks, because they depended primarily on use of flight instruments for both cueing and feedback. These tasks, numbers 4.1 through 6.2 in Section III, would normally follow airfoil cleanup and precede approach to landing, except for missed approach (7.5) which would occur after an approach was initiated. The remaining 15 tasks, those that require an external visual scene for adequate certification checks, are listed below in abbreviated form (see Section III for complete statements of each).

2.1 Taxi to takeoff position

2.2 Taxi to gate

3.1 Takeoff ground roll

3.2 Rotation

3.3 Climb to cleanup (early portion only)

3.5 Reject takeoff

7.1 Visual approach to visual glidepath

7.2 Instrument approach to visual glidepath or circling visual transition point (late portion only)

7.3 Circling approach to visual transition to visual glidepath

7.4 Visual glidepath to LMTP (landing maneuver transition point)

7.6 Reject landing (early portion only)

8.1 LMTP to flare

8.2 Flare to initial touchdown

8.3 Initial touchdown to start ground roll

8.4 Landing ground roll

SOURCES OF VISUAL INFORMATION. Each type of visual information was then related to characteristics of scene contents that could provide the information. Thereby, a second set of priorities was assigned separately for each task. The latter priorities were for the importance of separate scene characteristics for providing the previously prioritized types of information. These two sets of priorities are independent of each other. For example, a given type of information may have a low priority of 3; but if it is to be provided at all, certain scene characteristics can be very important in the provision, thus having high priorities of 1. Conversely, some scene characteristics can have low priorities when they are not important for providing information of high priority.

The scene characteristics considered for the present purpose overlap to some extent because they include determiners of perception (especially depth perception) as identified during more than a century of psychological research (parallax, linear perspective, relative motion and size, etc.), together with kinds of scene contents that are especially useful to pilots (terrain patterns, horizon, etc.). In all cases, candidate sources were restricted to scene characteristics that could be presented with state-of-the-art visual systems. (For example, true motion parallax is not possible with state-of-the-art visual systems, nor is stereoscopic vision, so these sources of information were not considered.)

The 23 sources of visual information, i.e., scene characteristics, were as follow:

Aerial perspective
Parallax: forward perspective
Parallax: oblique perspective
Parallax: lateral perspective
Occulting: forward perspective
Occulting: oblique perspective
Occulting: lateral perspective
Relative motion: separate objects
Relative motion: terrain features

Relative size: objects and terrain
Apparent terrain elevation/relief
Terrain patterns: distal
Object/terrain patterns: proximal
Textural perspective
Linear perspective: forward
Linear perspective: oblique
Linear perspective: lateral
Horizon/change in
Shadows
Contour/change: forward perspective
Contour/change: oblique perspective
Contour/change: lateral perspective
Clouds or cloud layer

Some of these terms have technical meanings in the psychology of perception, so a few brief definitions are in order.

Aerial perspective refers to a gradient of vividness. Far-off objects are less vivid than near objects due to ever-present water and dust particles in the air that obscure their characteristics. Substantial amounts of water and dust, as well as smoke, are referred to as fog or haze.

Parallax is the differing views of an object and its environs that vary with the position of the perceiver relative to the object. In an external visual scene, views change according to the distance of an object and the perceiver's motion that is not directly toward or away from it. (Although parallax results from motion in such cases, this is not what "motion parallax" technically refers to. Motion parallax is evident when the eye is focused at a certain distance away, and the terrain between the perceiver and the point of focus appears to move in a direction opposite that of the perceiver's motion, while terrain beyond the point of focus appears to move in the same direction as the observer. A change in distance of the point of focus thus changes the direction of apparent motion of parts of the visual field. State-of-the-art visual systems cannot provide this phenomenon, though it can be experienced in some holographic images.)

Occulting, or interposition as it is called in psychology, refers to blocking the view of part or all of an object by another object between it and the perceiver. It is thus important for judging relative distances of objects.

Relative motion is the apparent change in location of parts of the visual scene due to movement by the perceiver. The rate of change is correlated with the direction and speed of the perceiver's motion, and with the distance of separate portions of the visual field. Relative motion is thus a cue for one's own rate and direction of movement as well as for the distances of objects.

Relative size refers to the fact that the apparent size of an object (i.e., size of the image on the retina of the eye) becomes smaller with distance. It is a distance cue because perceivers interpret variations in the apparent size of a familiar object as due to nearness or distance, not as variations in actual size.

Textural perspective is the gradient of discriminable surface characteristics that is due to distance. Yard-line markers on a football field appear relatively far apart when they are near the perceiver, but closer together at a distance as one looks down the field. Depending on one's altitude and the distance of the surface viewed, texture can refer to natural irregularities in a runway (when near) or to vegetation, shadows, or other grosser terrain patterns (when at a distance).

Linear perspective refers to the apparent convergence of parallel lines with distance. The phenomenon occurs in all perspectives, horizontal through vertical (e.g., when at low altitude, a runway appears narrower at the far end, and the far end also appears to rise; one normally translates these phenomena into distance judgments, assuming in the process that the runway is constant in width and level). Linear perspective is such a dominant distance cue that its accommodation can often lead to optical illusions (the runway may really rise at the far end).

It will be noted that for certain informational sources, "forward," "oblique," and "lateral" perspectives are specified separately. This is not to imply that orientation for perspectives is not important for the other sources. Rather, anticipating simulation requirements, the implication is that scene contents should provide the needed information simultaneously in each perspective as prioritized. For the others, the requirement is that overall scene content should be adequate for providing the information realistically somewhere within the pilot's normal scan pattern. Furthermore, scene continuity should be such that scene contents appear to move to different parts of the visual field according to the motion of the airplane.

Priorities for the scene characteristics were first assigned by a human factors specialist on the ACSD team, using guides for priorities developed by Seville. The guides were adapted to the requirements peculiar to the 15 tasks requiring a visual scene and to piloting the Boeing 727 airplane. Then, two SMEs reviewed the priorities independently, and final revisions were made following a joint meeting where disagreements were discussed. Bases for the priorities were as follow:

Priority 1: can serve as a primary information source; high level of accuracy required.

Priority 2: while not a primary source, important for scene coherence and as a supplementary check on interpretations of other sources; accuracy not an issue unless discrepancies lead to conflicts in scene interpretation.

Priority 3: not needed for cueing or feedback (but may be required to provide continuity from task to task).

The results of the analyses thus far are presented as matrices in Appendix D. There is a matrix for each of the 15 tasks that normally require a visual scene. The task title is given in the upper left corner of the page on which that task's matrix appears. Types of information are listed in a column on the left, followed by priorities for the types for that task. The remaining entries are priorities for scene characteristics corresponding to each prioritized type of information.

MALFUNCTIONS AND ADDITIONAL MANEUVERS. During the performance of any of the 15 basic tasks that require a visual scene, certain malfunctions might be introduced or certain additional maneuvers may be required to be performed jointly (see Section III and Appendix B). A general provision that apparent movement of the scene will be closely correlated with the simulated movement of the airplane provides for essentially all necessary changes in the visual scene. However, in certain cases, priorities for types of visual information are higher than for the basic tasks performed under "normal" conditions. Hence, if the malfunctions or additional maneuvers that affect informational priorities are to be introduced, informational priorities should be increased as shown in Table D-2 in Appendix D. Only one malfunction (one-engine failure) and four special maneuvers (climbing turn, stall, unusual bank, unusual pitch) affected priorities previously assigned, and then only for certain tasks. (The minor adjustments in task-condition lists, referred to in Section IV, were made after the cue analyses reported in Appendix D had been completed. However, the adjustments were assimilated during ACSD Steps 6 and 7.)

EFFECTS OF ENVIRONMENT. A number of environmental conditions, if accompanying a task performance, would affect the visual scene. A total of 18 such conditions were considered. However, for purposes of certification checks, the list of candidates was reduced to 13 conditions, mostly those either inclusive of the others, in some instances as a "worst case" (e.g., ice on runway instead of snow), or those putting greatest demands on task performance. Of these 13 conditions, 8 affected the types of information to be obtained from the visual scene. In most cases, the effects reduced informational content (ice on runway reduces textural cues; lowered visibility reduces all cues; etc.). In a few instances, however, environmental conditions (e.g., thunderclouds) can provide additional visual cueing sources.

The environmental conditions to be included overall were identified jointly by the three SMEs together with the Project Director. The SMEs then identified types of information that would normally be affected by each of the conditions that remained to be considered. The results appear in Table D-3 in Appendix D. The environmental conditions were low ceiling; reduced visibility; thunderstorms; ground effects; ice on runway; wind gusts; wind shears; and turbulence.

FIELD OF VIEW. For each task requiring a visual scene, two SMEs were asked to identify independently the horizontal dimension of the FOV that would be necessary to perform the 15 tasks requiring a visual scene. Except where cross-cockpit references might be involved, the right limit of the FOV would be the center of the forward windscreen, or 22° to the right of the pilot's eye point.

There was less agreement between the SMEs on this task than on the others undertaken during the cue analyses. One kind of disagreement is easily resolved, however. In considering "worst-case" conditions, one SME assumed a moderately strong crosswind during tasks in which line-up with the runway center line is necessary. With a wind from the left, cross-cockpit views may be desirable.

For most tasks, the smaller FOV as suggested by the two SMEs was taken (tentatively) as the minimal requirement. These data appear in the upper right of the visual matrices in Appendix D. Possible needs for cross-cockpit views are given as notes. For the two taxiing tasks and a circling approach, "plus lateral" is added to FOV size to indicate the need for scenes in the left 90° region. While a 90° FOV might be more desirable, it may be possible to use a smaller forward and oblique FOV, have a break in the scene, and then present a small FOV in the 90° region.

At any rate, the data regarding FOV as given with visual matrices are tentative. This issue was later clarified and resolved as explained in Section VI.

NONVISUAL MOTION CUE ANALYSIS.

The approach to the analysis of nonvisual motion cues was analogous to that for the visual cue analysis but involved only three steps: (a) prioritization of types of motion information used in performing the 25 basic tasks under normal conditions of flight; (b) revisions of these priorities as required for additional maneuvers and malfunctions that could accompany the basic tasks; and (c) identification of environmental conditions that could affect the types of information.

TYPES OF MOTION INFORMATION. Ten types of motion information were considered for each of the 25 basic tasks. These were:

- Change in speed (acceleration/deceleration)
- Uncoordinated flight (yaw out of trim)
- Change in pitch
- Change in roll
- Change in yaw
- Buffet pitch
- Buffet roll
- Buffet yaw
- Constant G loading
- Constant deck angle

During normal flight, these types of information are represented in varied combinations more or less constantly. However, the analysis focused on cueing values of the information which were peculiar to the 25 basic tasks (Tasks 10.1 and 10.2 in Section III are treated here under additional maneuvers). There are three roles the cues could serve. These roles (and symbols representing them) are:

Onset cue (C): a signal required to initiate flight control inputs.

Feedback cue (F): a signal required to regulate or refine flight control inputs.

Monitoring cue (M): a signal required to confirm airplane status or the effects of control inputs when they do not require further refinements.

The three SMEs were first asked to identify independently the primary cueing role (if any) for each of the 10 types of motion information for each of the 25 tasks when performed under normal conditions (no malfunctions or adverse weather). They then assigned a priority to each role. A priority of 1 indicated that the type of motion was the main source for the information involved. That is, a C1 (or an F1 or M1) indicated that the perceived physical movement was more important for cueing than any other source of information such as instruments, sounds, or the external visual scene. A priority of 2 indicated that, while the movement was an important cue, other sources of information were more important. A priority of 3 indicated that the cueing value of the movement was of no particular value to task performance.

After determining primary roles for the 10 types of information in the performance of each task and assigning priorities to the roles, the three SMEs jointly resolved any discrepancies in their original evaluations. The results appear in Table E-1 in Appendix E.

MALFUNCTIONS AND ADDITIONAL MANEUVERS. Following the procedures used with the 25 basic tasks, the three SMEs identified types of motion information used during malfunctions and performance of the additional maneuvers. The results appear in Tables E-2 and E-3, respectively, in Appendix E. It will be noted that malfunctions especially resulted in changes in priorities for, and primary roles served by, some types of motion information. For this reason, results for malfunctions are presented in two parts. The first part of Table E-2 represents malfunctions that could be introduced during ATP checks. The second part of the table identifies malfunctions with which ATP candidates are to learn to cope during training. This distinction facilitated the identification of simulator capabilities required for ATP checks as opposed to training as discussed in Section VI.

EFFECTS OF ENVIRONMENT. The 13 environmental conditions that could be introduced during ATP checks were examined for their effects on the 10 types of motion information. Of these, 11 would affect one or more types. The conditions are:

Thunderstorms
Ground effects
Ice on runway
Head wind
Tail wind
Crosswind
Wind gusts
Wind shears
Turbulence
Engine icing
Airframe icing

The types of information affected by each are shown in Table E-4 in Appendix E. These data, developed jointly by the three SMEs, do not include priorities. The extent to which they must be represented in a motion system (and the nature of the system) was decided when simulator requirements were derived (Section VI).

AURAL CUE ANALYSIS.

For present purposes, "aural environment" refers to all sounds normally heard by a pilot that arise from the functioning of the aircraft and its systems. Two general kinds are of interest for cueing and feedback value. First, there are sounds such as engine noises and the flow of air across aircraft surfaces that continue through all or most tasks. These sounds serve especially as feedback cues. Second, various tasks involve the production of specific sounds, as do some malfunctions. These sounds may serve either as feedback to pilot actions, as onset cues to initiate actions, or as both.

A simulation of aircraft systems to a satisfactory level of fidelity will include two types of specific sounds: all aural warnings and alerts; and all sounds arising within the cockpit from manipulations of controls, switches, etc. These sounds are not identified here. Rather, focus is on sounds arising from outside the cockpit. As for sounds resulting from engines and airflow, there are times when their intensities will be too low to be audible. Their presence was identified anyway in the analysis. The guiding rule if they are to be simulated is to duplicate these sounds to the extent they are audible in the cockpit, or deliberately reduce them to facilitate communication during checks and training.

The analysis of aural cues involved fewer steps than that for vision and motion. Specifically, there was no need to identify types of sounds beyond the two general classes just discussed; and no analysis was required to relate sounds to sources. Rather, the focus was on what happened during task performance and its audible effects. For the analysis, then, one SME drew up a list of potentially audible sounds that would accompany each task and each applicable malfunction. Two other SMEs went over the list, and then all three participated jointly in developing the final list.

The two kinds of sounds mentioned earlier are grouped separately in Table F-1 in Appendix F. For continuing sounds (engines and airflow), there are provisions for each basic task for sounds of constant intensity (and quality) as well as changes in intensity during the progress of the task. Thus, during cruise, for example, airflow and engine sounds are constant most of the time, but occasional throttle adjustments can result in increases as well as decreases in intensities of either sound. Hence, the presence of constant sound is indicated by an X under "Con." Increases and decreases in these sounds could provide feedback. If so, an F appears under "Inc" and/or "Dec," respectively. If the sound serves to cue an action, a C appears under "Inc" or "Dec" as appropriate. Engine and airflow sounds were not assigned priorities.

The roles of specific sounds are also indicated as F or C, or as both if feedback and cueing are both provided. In addition, the F and C roles are prioritized according to their usual value. A priority of 1 indicates that realistic sound is important for task performance; a 2 indicates that it is important to identify the sound as to source, but that quality per se is not important; a 3 indicates that the sound is not actually needed for cueing or feedback because the value of the sound for these purposes is negligible.

In addition to listing sounds for the 25 basic tasks, Table F-1 also identifies specific sounds accompanying selected malfunctions. Other sounds accompanying the malfunctions would be those associated with the task(s) underway at the time the malfunctions occur.

VI. SIMULATOR REQUIREMENTS FOR ATP CHECKS AND TRAINING

This section presents performance and functional requirements for simulators used to conduct ATP checking and training and explains how they were derived. The specification of simulator requirements, a result of Steps 6 and 7 in the ACSD process, was one primary goal of this research project. The second primary goal, development of crew performance objectives (CPOs), was achieved as explained in Section IV.

This section has seven major subsections. They are organized to reflect the nature of the reasoning processes that led to the specification of simulator requirements. The sequencing of the subsections is from general, pervasive considerations, through explanations of categories of issues, to specific statements of simulator requirements. It is hoped that this organization permits the reader to follow with little difficulty what was, actually, involved, often tedious, reasoning processes.

The first subsection to follow explains the general rationale of the approach. It summarizes considerations that affected, in one way or another, all decisions that were made. The second subsection presents general methodological concerns that guided utilization of CPOs and data from the cue analyses.

The third and fourth subsections address, respectively, how the analyses of real-world visual and motion cues were used in identifying minimal corresponding cueing capabilities for simulators. As pointed out earlier, cues related to the aural environment, control loading, aerodynamics, instruments, etc., did not involve topological analysis, so there are no subsections for cueing requirements for these sources that are comparable to those for vision and motion. Instead, major points that governed their simulation requirements are covered in a fifth subsection that lists considerations affecting identification of all simulation requirements.

The sixth subsection then summarizes in narrative form the cueing requirements for each flight segment identified in Section IV. Finally, the seventh subsection is comprised of detailed tables and annotations thereto that identify specific simulation requirements by flight segment, or by task as appropriate to differentiate among requirements within a segment.

RATIONALE FOR DERIVING REQUIREMENTS.

As mentioned or implied on several occasions, the focus in all analyses reported here was on a human performer who obtains information from the environment, interprets the information, and takes actions according the relation of the interpreted information to the person's goals. This is a very complex process, more complex than most past derivations of simulation requirements might suggest. In the past, emphasis has been mainly on the objective cueing information that should be available and provisions for the actions. The second stage, the interpreting or processing of the information, has been largely ignored. But it is in the second stage that the complexity of the human performance resides. It is also in this stage that essential simulation requirements are ultimately determined.

This point is becoming recognized today, even if it has not yet been well assimilated in decisions regarding simulator design. However, the processing of information by pilots was a central consideration during the research reported here, ranging from allowing for idiosyncratic reaction times that help govern equally idiosyncratic harmonic patterns of control inputs, to the structure of generalizations of cues and responses that will determine the extent of transfer to an airplane of skill performance as evaluated in a simulator.

It is not possible in this report to explain the numerous ad hoc analyses that were involved in this respect. (The nature of the analyses can be inferred from the detailed treatment by Spears, 1983, of cognitive and motor processes underlying skilled performance.) Instead, there was an attempt to highlight central concerns by brief discussions of topics such as functional equivalence (Section II) and topological properties of cues (Sections II and V). The distinction between Type A and Type B objectives emerged from underlying cognitive and motor processes (Section II <u>et seq.</u>), as did the conditions that must obtain if proficiency on an observed <u>sample</u> of behavior (i.e., during an ATP check) is to signify proficiency in skills not observed (Section II).

The major considerations that governed all decisions regarding simulation requirements were ramifications of the concepts just mentioned: functional equivalence of cues and responses and its dependence on topological properties of cues; characteristics of Type A versus Type B objectives; and the need to ensure that performance observed during an ATP check <u>signifies</u>, not just samples, how well a pilot will perform skills that are <u>not checked</u>. (This last point was a prime consideration in developing CPOs.)

To recall, briefly, the implications of these considerations, criteria for simulators should specify (a) the minimal requirements to provide needed information, and (b) the minimal mechanisms for response that are necessary to support the pilot performance. The object is to minimize simulator costs by concentrating on functional equivalence, rather than objective realism, between the simulator's cueing mechanisms and the operational environment and, similarly, between the simulator's mechanisms for response and the operational environment. Functional equivalence, as defined in the context of information processing, means that cues and responses in the simulator are interchangeable with those in the airplane from the standpoint of their role in pilot performance. In order to specify functionally equivalent cue and response mechanisms for a simulator, it is first necessary to determine the topological properties of cues and responses in the operational environment. Once this is done, then topological properties may be translated into simulator features; and the need to provide objective realism may be decreased. For example, if cues derived from the in-flight visual environment are analyzed in terms of informational content such as vertical movement, pitch angle, horizontal movement, etc., and in terms of informational sources such as parallax, occulting, relative motion, etc., then it is possible to specify visual system features that provide the same informational content as the real world, often without demanding objective realism.

The distinction between Type A and Type B objectives further clarifies minimal simulator requirements because performance of skills involving Type B objectives requires less in the way of simulator fidelity. In addition, there is another distinction among objectives--or more accurately in this case, among the skills involved--that also helps in identifying differences in simulation requirements for different kinds of skills. Some skills are essentially "closed loops" as the term is used in cybernetics. The essential components of a closed loop are inputs, outputs, and servomechanisms. When speaking of closed-loop skills, inputs are onset cues, outputs are responses to them, and servomechanisms are feedback cues that tell the performer when and what refinements and adjustments in responses are needed. The loop is closed in that, once a skill is initiated, its execution depends on information (feedback) arising within the loop as a result of responses, and while the performance is in progress. The feedback helps determine what is done, and how, on a continuing basis.

Execution of an "open-loop" skill is not affected by what happens while the performance is in progress. Feedback as to the adequacy of actions cannot interrupt the performance at the time. The actions are set, as though programmed, at the outset. Feedback may affect the "program" for the next try at the skill, but not the performance at the time the feedback occurs.

An important implication of this distinction for simulation is that less feedback cueing is required to the extent skill components involve open loops. For example, when a pilot decides to reject a takeoff, a "programmed" set of all-or-none responses should ensue. The pilot should use maximum brake pressure, specified reverse thrust, etc. These responses do not require refinements, so feedback can play no effective role. Only actions concerned with keeping the airplane on the runway during the task utilize feedback, and the cueing involved can be rather gross in nature. On the other hand, an instrument approach to a visual glidepath requires numerous refinements and adjustments of control inputs. Turbulence, engine failure, etc., increase the need for adjustments. Here, accurate instrument and aerodynamic simulation can be critical. This distinction between closed- and open-loop skills will be referred to several times in what follows.

METHODOLOGICAL GUIDES.

The methods used to derive simulator requirements were eclectic and comprehensive. They involved the efforts of a multidisciplinary team of specialists who analyzed the task descriptions, perceptual cue data, evaluation and training objectives, performance standards, and practical test scenarios to derive simulator requirements. Six disciplines were represented on the team. They were pilot/evaluator, pilot/subject matter expert, behavioral psychologist, training psychologist, simulator design engineer, and simulator test engineer.

Two steps were involved in deriving simulator requirements. First, worksheets were developed for six classes of requirements: general simulator requirements; aerodynamic programming requirements; control loading requirements; visual system requirements; motion system requirements; and aural requirements. In order for the final product to relate to existing simulators, the worksheets incorporated requirements presently specified in FAA Advisory Circular 120-40. Second, the worksheets were completed separately for Type A and Type B evaluation objectives and practical test scenarios. A second iteration then added requirements derived from the training CPOs. Data from the task descriptions and cue analyses were examined from the perspective of each team member's discipline in order to determine the necessity for including identified cue information in the simulation required to support an objective. Anecdotal and research data were used when available, and flight test data were used to clarify and validate certain aspects of the cue analyses.

<u>USE OF CUE ANALYSES</u>. Data from the task and cue analyses were used extensively during ACSD Steps 6 and 7. The task analysis (Section III) had identified cognitive, procedural, and motor behaviors involved in task performance and specified task conditions required for checking and training. The cue analyses (Section V) had concentrated on describing the topology and priorities for use of perceptual cues available during actual flight. The analyses dealt with visual, motion, and aural sensory modes. As is evident from the criteria, priorities had been assigned primarily on the basis of whether cue information was used in closed-loop or in open-loop tasks. Cue information used in closed-loop tasks was generally given a higher priority. Further differentiation of priorities had been made on the basis of whether perceptual cues were primary, secondary, or tertiary sources of information.

These data were critical ingredients in the process used to derive simulator requirements. However, these data dealt only with the information available to the pilot in actual flight and the priorities for using that information. In and of themselves, they do not dictate what information is essential for simulation in relation to specific evaluation and training objectives and practical test scenarios. Thus, the multidisciplinary team that accomplished the work of ACSD Steps 6 and 7 had one central question before them: "What cue information and response mechanisms are essential in a simulator in order to support the pilot's mediational processes and consequent procedural and motor behaviors?" Using data from the task and cue analyses, this question was answered for each evaluation objective and practical test scenario and documented on the worksheets. The following general guides were employed for data analysis:

- Onset or alerting cue information that enables either closed- or open-loop behaviors should be provided in the simulation.

- Feedback cues that are primary sources of information in closed-loop behaviors should be provided in the simulation. An example is external visual scene information that is used in the feedback loop for tracking tasks or for deceleration tasks (landing and taxi) using airplane brakes.

- Cueing information identified in the cue analyses should not be ignored on the basis of research data, anecdotes, or intuitive analyses that are equivocal. This was necessary to minimize the risk of compromising first-time transfer of skills, which is essential in ensuring the integrity of the FAA's airman certification system when simulators are used for checking.

USE OF CREW PERFORMANCE OBJECTIVES. As described in Section IV, CPOs were developed for certification checking and training requirements. Evaluation CPOs contain descriptions of flight segments, evaluation objectives, practical test scenarios, and performance standards. Training CPOs contain lists of task-condition combinations in which training is required, and LOFT requirements. Like the task and cue analyses, CPOs were critical elements in the process used to derive simulator requirements. To permit the maximum use of simulators and to avoid overspecification of requirements, evaluation and training objectives were classified as Type A and Type B in accordance with the rationale provided in Sections II and IV.

Tasks having Type A and/or Type B evaluation objectives are listed below by flight segment and scenario conditions.

Type A Evaluation Maneuvers/Procedures

1. Taxi

   a. Departure taxi
   b. Arrival taxi

2. Takeoff

   a. Normal takeoff with crosswinds
   b. Takeoff with a power plant failure

3. In-flight maneuvering

   a. Steep turns
   b. Recovery from approaches to stalls
   c. Recovery from specific flight characteristics

4. Approach

   a. Instrument approach with a power plant failure
   b. Missed approach/rejected landing with a power plant failure
   c. Visual/instrument approach with 50 percent power plant failure
   d. Zero-flap visual approach
   e. Circle-to-land maneuver

5. Landing

   a. Normal landings with crosswinds
   b. Landing with 50 percent power plant failure

Type B Evaluation Maneuvers/Procedures

1. Preflight

   a. Planning and preparation for flight
   b. Preflight visual inspections
   c. Cockpit checks
   d. Engine start

2. Takeoff

   a. Rejected takeoff on a dry runway

3. Area departure

   a. SID/radar departure
   b. Holding

4. Emergency descent

5. Area arrival

   a. STAR/profile descent/radar arrival
   b. Holding

6. Approach

   a. Normal instrument approaches

7. Systems operations (nonaerodynamic)

Additionally, CPOs for cockpit resource management and airplane systems operations were developed. The evaluation objectives in these CPOs must be satisfied in conjunction with practical test scenarios for the other flight segments. Therefore, Type A and B evaluation objectives for these CPOs are the same. However, these objectives do have some media implications regarding systems operations and communications capabilities.

The following general guides were employed in the analysis of CPO data:

- Evaluation objectives and test scenarios may dictate the need, or obviate the need, for major cueing systems. An example is elimination of the need for a visual system for Type B Approach objectives because these objectives entail complete instrument meteorological conditions and do not involve decision-making components during transition to visual conditions. Type A Approach objectives include visual tracking tasks and decision-making components. Thus, Type A objectives dictate the need for external visual information.

- Certain performance standards may require simulator features needed to support the evaluator in making performance evaluations. For example, it was agreed among the three SMEs that platform motion cues may often be required to evaluate smoothness of control manipulation even though such cues may not be primary information sources in the pilot's feedback control loop.

- Special environmental conditions, equipment malfunctions, and maneuvering requirements specified in practical test scenarios must be provided in the simulation.

- Simulation used for Type A objectives must fully support motor behaviors that are complicated by the special environmental conditions, equipment malfunctions, and maneuvering requirements specified in practical test scenarios.

- Simulation supporting Type B objectives need only support basic motor behaviors not complicated by adverse conditions.

VISUAL SCENE REQUIREMENTS.

In Section V, sources for visual information were identified only generically. The reason was that, unlike force motion and aural cues, innumerable circumstances can provide essentially the same types of visual information. Linear perspective can be gained from highways, power lines, vegetation patterns, or a number of other aspects of a visual scene; relative size indications of distance can be provided by any one or more of a host of familiar objects and terrain characteristics.

Hence, the choice is to translate the visual cue analysis into specific scene contents and to require those scenes per se; or to keep specifications for visual scenes generic in nature. The former option is undesirable. Not only would it fail to allow for variations in actual scenes at different airports, specification of scene details per se would stifle creativity in an important area of engineering development. Further, it would render obsolete numerous existing visual simulations that are actually adequate for the purpose.

The choice had to be the second alternative: generic specifications for scene contents. However, it was still necessary to translate the analysis of real-world visual cues into particular kinds of simulation requirements, and to provide guides as to how they can be satisfied. The discussion that follows addresses these points. The effort involved four steps: (a) summarization of types of real-world visual information pilots use, by CPO flight segment; (b) translation of these requirements into characteristics of simulated scenes; (c) identification of minimal requirements for each segment; and (d) specification of kinds of scene contents that can satisfy minimal requirements.

SUMMARY OF REAL-WORLD INFORMATION. For ATP checks, the 38 basic tasks were divided into 11 groups or segments as explained in Section IV. Of these segments, four require a visual scene. These segments and tasks comprising them are as follow:

Segment	Tasks
Taxiing	Taxi to takeoff position Taxi to gate
Takeoff	Takeoff ground roll Rotation Climb to cleanup *Airfoil cleanup Reject takeoff
Approach	*Holding Instrument approach to visual glidepath Circling approach to visual glidepath *Missed approach Visual glidepath to LMTP Reject landing
Landing	LMTP to flare point Flare point to touchdown Touchdown to initial ground roll Landing ground roll

Asterisks identify tasks which do not require a visual scene. Also, as stated in Section IV, the task, visual approach to visual glidepath, is not a mandatory requirement, but visual requirements for this task were included in the analyses that follow.

Visual information requirements varied by segment and often across tasks within segments. Beginning with priorities for types of information, two considerations governed the assignments of summary priorities to segments as a whole. First, for segments in which the quality of available information in the real world varies with the succession of tasks, priorities for the information are identified as ranges with the first number indicating the priority for the first task of the segment and the second number that for the last task of the segment. If the information had no priority for the first or last task, an X is used in place of a number. For example, during takeoff, visual perception of acceleration had a priority of 1, but by climb to cleanup, acceleration per se is not perceptible visually so no priority was assigned. Hence, for the takeoff segment, the summary of the priority for acceleration is given as "1-X."

The second consideration in assigning summary priorities to types of visual information concerned types whose qualities do not change during a segment but whose importance for performing separate tasks within the segment does. In these cases, the highest separate task priority for the type of information was assigned for the entire segment. The point is that continuity of the visual scene entails consistent scene qualities, at least to a considerable degree, even though the usefulness of certain types of visual information changes during the segment. Hence, whereas the first consideration might relax the stringency of simulation requirements for portions of some segments, the second consideration, taken alone, appears to increase the requirements for some tasks within segments. However, further summarizations of the sources for the information as presented later relax the requirements in the latter case in most instances.

For most segments and types of information, priorities did not change across tasks. In these cases, the summary priorities are those holding for all tasks within the segment. The summary priorities appear by segment in Table VI-1.

SIMULATION OF CUES. The next task was to translate priorities for types of visual information, and those for sources of the information, into characteristics for visual scenes. This step recognized that high priorities for sources that provide information do not necessarily entail high fidelity of corresponding objective representations of the source. For example, in clear weather, the horizon and its apparent motion are of priority 1 for knowledge of rate of turn and bank angle. However, the essential requirements for the horizon to serve this purpose is its discriminable, accurate, apparent movement relative to the simulated motion of the aircraft. It is not necessary to have a great amount of detail at the horizon (there is little detail in the real world), but only enough discriminable features to observe apparent motion. Similarly, when the horizon or distant terrain patterns provide contexts for judging distances to various components of the scene, it is sufficient that their vividness reflect the gradient of vividness characteristic of actual experiences when viewing these sources.

On the other hand, sources such as relative size, linear perspective, and texture often depend on gradients that begin relatively close to the observer and continue vividly for considerable distances away. (The composition of perceived texture changes, however, from variations in local surfaces when near, to variations in terrain patterns and ground cover at a distance.) If

TABLE VI-1. SUMMARY OF SMES' PRIORITIES FOR VISUAL INFORMATION, BY FLIGHT SEGMENT

	Segment			
Type of Information	Taxiing	Takeoff	Approach	Landing
Vertical movement (LA)		X-1	1	1-X
Pitch angle (LA)	3	1	1	1
Horizontal movement (LA)	1	1-2	1	1
Pitch angle (HA)			1-X	
Horizontal movement (HA)				
Linear accel/decel (LA)	1	1-X	*	2-1
Vert rate of closure		X-2[a]	1	1-X
Horiz rate of closure	1	1-3[a]	1	1
Rate of turn	1	1-2	1	1
Bank angle	3	1-2	1	1
Altitude (low)	1	1-2	1	1
Relative distances (obj/ter)	1	1-3	1	1
Relative height (obj/ter)	1	1-3	1	1
Directional orientation	1	1-2	1	1
Terrain feature ident	1	1-3	1	1
Lateral context	1		**	
Near-object detail	1	1-3	3-1	1
Object features	1	1-3	2-1	1
Absolute distance	1	1-3[a]	1	1

[a]Priority always 1 for airborne aircraft and thunderstorms in the vicinity.

*Priority = 1 for reject landing only; no priority for other tasks in this segment.

**Priority = 1 for circling approach only; no priority for other tasks in this segment.

such sources have high priorities, as these examples usually do, it is necessary to provide sufficient realistic detail for the gradients to be interpreted accurately and continuously.

Accordingly, the priorities for visual information and sources for the information, which indicated their importance, led to identifying three classes of requirements for visual scene contents (i.e., sources) to provide the information. The three classes will be referred to as Class A, Class B, and Class C. The distinctions among classes concern (1) the need for detail; (2) precision of scene dynamics relative to the simulated motion of the airplane; and (3) the need for continuity of scene characteristics during the simulated motion. Specifically,

Class A sources require:

1. maximum feasible detail consistent with that perceivable in the real world, and with a gradient of observability with distance;

2. highly accurate dynamics of the scene relative to simulated motion; and

3. continuity of detail and dynamics during apparent motion of the scene through the field of view.

Class B sources require:

1. representation of features of scene contents sufficient to maintain unambiguous identification of scene components;

2. no noticeable deviation of scene dynamics relative to simulated motion; and

3. continuity of features and dynamics during apparent motion of the scene through the field of view.

Class C sources require:

1. representation only to the extent of providing a context for the scene while avoiding unrealistic (see below) confusion in perception;

2. accurate dynamics only to the extent of avoiding confusion in perception; and

3. continuity of representation and of apparent motion through the field of view only to the extent of avoiding confusion in perception.

It is clear that all sources of visual information that were assigned a priority of 1 must be either Class A or B, as appropriate, especially for completeness of object and terrain details and features and their corresponding distance gradients. Class C scene contents provide primarily contexts for the scene, but nevertheless contexts that aid in interpreting other cues (e.g., linear perspective becoming partially obscured due to aerial perspective). Generally, sources with priority 2 received at least a B classification, with an A classification in those instances where one or more tasks of those comprising a segment required a Class A source although other tasks in the segment did not. This kind of "upgrading" was common for priorities of 3 for which a C-level representation would have been otherwise adequate for some tasks in a segment. However, upgradings most often were a function of simulated distances to the scene components of interest. For example, texture of local surfaces is not very apparent at the beginning of an approach to landing, even in the real world. But texture normally is apparent by the end of this segment (visual glidepath to landing maneuver transition point). Hence, a Class A requirement for texture implies that the emergence of texture should be realistic, and that texture should be clearly represented by the end of the segment.

There are a few instances in which informational sources change classifications on bases other than realistic gradients. Such is the case, for example, for aerial perspective during an approach. When judging a distance of two or more miles from a runway, aerial perspective can be important, so it has a B classification early in a landing approach. As the distance to the runway becomes less during the approach, aerial perspective becomes less important, and hence it is downgraded to C. Similarly, forward linear perspective can be critical (Class A) during a takeoff ground roll, but not during climb to airfoil cleanup (Class C). Such changes are indicated in Table VI-2 as ranges, B-C for aerial perspective during the approach segment, and A-C for forward linear perspective during the takeoff segment. In these and other cases, the first letter indicates the class at the beginning of the segment and the second letter the class at the end.

There is a danger in constructing a visual scene solely on the basis of unambiguous sources of visual information. Specifically, the real world presents conflicting information that must be accommodated or which can often result in illusions. In fact, numerous illusions to which we become adapted actually aid in depth perception. For example, stereoscopic vision not only presents differing but integrated views to the two eyes of the point of focus; it gives double images at points nearer and farther away than the point of focus. It is not clear to what extent we use the double images unconsciously to help judge the distance to the point of focus; but just the need to accommodate them implies their perceptual processing.

Photographs of a tanker during aerial refueling provide an example of a nonstereoscopic illusion that is pertinent to simulated visual scenes. Photographs taken from an airplane being refueled, that is, from below and slightly aft of the tanker's engine pylons, show the pylons appearing to lean inward toward the body of the tanker. On the other hand, photographs taken from slightly above and forward of the tanker show the pylons appearing to lean outward. In all likelihood, if one removed this illusion the pilot of

TABLE VI-2. SUMMARY REQUIREMENTS FOR SOURCES OF VISUAL INFORMATION IN DAY SCENES, BY FLIGHT SEGMENT

Source	Segment			
	Taxiing	Takeoff	Approach	Landing
Aerial perspective	C	C	B-C	C
Parallax: forward		B	B-C	C
Parallax: oblique	B	C-B	B	C
Parallax: lateral	A		*	
Occulting: forward	A	B	B	B
Occulting: oblique	A	B	A-B	B
Occulting: lateral	A		*	
Relative motion: obj	A	A	A	A
Relative motion: terr	A	A	A	A
Relative size: obj/terr	A	A	A	A
Terrain elevat/relief	A	B	B	B
Terrain patterns: distal	B	B	B	B
Obj/terr patterns: proximal	A	A	A	A
Textural perspective	A	A-B	A	A
Linear perspective: forward	A	A-C	B-A	A
Linear perspective: oblique	A	A	B	A
Linear perspective: lateral	B		**	
Horizon	B	B	B	B
Shadow	B	B	B	B
Contours: forward	A	B-C	B	A
Contours: oblique	A	B	B	B
Contours: lateral	A		**	
Clouds/cloud layer		***	***	

*Class B for circling approach only; not included for other tasks in this segment.

**Class A for circling approach only; not included for other tasks in this segment.

***Optional class B source of information at higher altitudes.

the airplane being refueled could well experience perceptual confusion because an accommodated illusion was not present. Similar illusions may well characterize some scenes observed by Boeing 727 pilots.

Pilots experience other naturally occurring illusions, especially during night landings, that are not easily accommodated (landing in a "black hole"; autokinesis or apparent movement of isolated stationary light points). And it is here that a specially constructed, unambiguous visual scene can over simplify a task. Hence, when using the results of the visual cue analyses to guide the simulation of visual scenes, it is important to provide for these naturally occurring disruptive illusions. Some will probably emerge as inherent properties of complexes of separately unambiguous information sources, just as they do in the real world. Others may require special provisions for them.

MINIMAL SCENE REQUIREMENTS. Minimal scene requirements recognize that it will be permissible for simulator checks requiring a visual system to use only night scenes. This increases the difficulty for some tasks, but at the same time it eases simulation requirements considerably. That is, night scenes in the real world provide many fewer sources of information than do day scenes. It is necessary, then, to adapt the SMEs' visual cue analysis to night scenes. Certain changes in Table VI-2 are immediately apparent. First, with the exception of the Taxiing segment, ten of the sources of visual information are no longer necessary because they are not effective at night in actual flight. Second, most Class A sources become Class B sources, corresponding to the loss of scene details (as opposed to features) at night. The adaption of information source requirements to night scenes is shown in Table VI-3.

Comparison of Tables VI-2 and VI-3 reveals the reduction in otherwise desirable scene richness when night scenes are used. As for sources not appearing in night scenes, forward parallax is not usually effective at all at night because there are no visible irregular surfaces above or below the pilot that appear different when the pilot changes position; distal terrain patterns are not visible, and clouds can be seen as such only dimly and then only when near the line of sight to the moon.

Regarding other changes from Table VI-2 to Table VI-3, sources for day scenes were identified 39 times as Class A, 40 times as Class B, and 10 times as Class C, a total of 89. Similar counts for night scenes were 14 Class A sources, 26 Class B, and 13 Class C, for a total of 53. Some general comments regarding the sources in Table VI-3 will help clarify the changes.

Aerial perspective (all segments): to be consistent with visibility conditions; however, only Class C provisions needed, although there should be a gradient of vividness within the visibility range.

Parallax: oblique and lateral (Taxiing only): restricted to obstructions to be avoided (if any) in areas where the obstructions are illuminated; and to departure from and arrival at a gate.

TABLE VI-3. ADAPTION OF REQUIREMENTS FOR SOURCES OF VISUAL INFORMATION TO NIGHT SCENES, BY FLIGHT SEGMENT

Source	Segment			
	Taxiing	Takeoff	Approach	Landing
Aerial perspective	C	C	C	C
Parallax: oblique	B			
Parallax: lateral	B			
Occulting: forward	B			
Occulting: oblique	B			
Occulting: lateral	B		*	
Relative motion: obj	A	B	B	B
Relative motion: terr	B	B	B	B
Relative size: obj/terr	B	B	B	B
Terrain elevat/relief	B	B	B	B
Obj/terr patterns: proximal	A	A	B	A
Textural perspective:	A			
Linear perspective: forward	A	A-C	B-A	A
Linear perspective: oblique	A	A	B	A
Linear perspective: lateral	B		*	
Horizon	C	C	C	C
Shadow	C	C	C	C
Contours: forward	A			
Contours: oblique	A			
Contours: lateral	A		*	

*Class B for circling approach only; not included for other tasks in this segment.

Parallax: oblique and lateral (Taxiing only): restricted to obstructions to be avoided (if any) in areas where the obstructions are illuminated; and to departure from and arrival at a gate.

Occulting: all orientations (Taxiing only[1]): restricted to realistic interposition of objects that may be represented in a visual scene--obstructions and buildings.

Relative motion: objects (all segments): restricted to light points except as structures might be illuminated just prior to landing. Even then, only Class B provisions required except for Taxiing, at which time supports for lights along taxi strip, and building surfaces and contours when very close, would be Class A.

Relative motion: terrain (all segments): for illuminated surfaces only. May be restricted to runway and a gradient of illumination in its immediate vicinity, in which case only the later portion of an approach would need relative motion of terrain (however, see Relative motion: objects).

Relative size: objects and terrain (all segments): restricted to visible features such as runway and adjacent lights, and obstructions and buildings for Taxiing.

Terrain elevation and relief (all segments): as indicated mainly by light points.

Object/terrain patterns: proximal (all segments): applies mostly to objects (runway and other lights, etc.) except as for Terrain elevation and relief (above).

Linear perspective: all orientations (all segments): As indicated by light points, primarily runway and taxi strip lights, and by runway surface to the extent it is illuminated.

Horizon (all segments): Class C provisions only, and then only if visibility permits; horizon would be ill-defined in any case.

Shadow (all segments): restricted to gross differences between illuminated surfaces (e.g., runway) and those not illuminated ("black holes"), except for illumination gradients as under Relative motion: terrain.

Contours: all orientations (Taxiing only): restricted to obstructions and buildings when leaving or arriving at a gate.

---

[1]If varying elevations of terrain are included in the scene during Approach, realistic occulting per one's altitude is necessary.

A question arises concerning how the reductions of cueing sources affect the informational content of the visual scenes. Granted that actual night scenes are generally drastically reduced in richness, is there still enough information available in the reductions as indicated in Table VI-3 for tasks in each segment to be performed realistically in a simulator? This question was answered by determining the effects of the reductions on cueing sources of priorities 1 and 2, separately by task and type of information. The detailed results appear in Table D-4 in Appendix D. In summary, the percents of original priority 1 sources (and priority 2 sources) remaining for each segment are: Taxiing--83 (77); Takeoff--77 (53); Approach--71 (59); Landing--72 (65).

Assuming adequately realistic night scenes, these reductions are of no consequence. First, the sources lost are those normally missing in night scenes, such as surface texture, distal terrain patterns, and contours of objects and terrains. These three alone accounted for 71 percent of the reduction in priority 1 sources and 56 percent of that in priority 2 sources. Second, examination of reductions by segment and type of information (Appendix D) shows that there are ample sources for the necessary information. Only those types such as object details, terrain feature identification, etc., that are largely unavailable at night anyway were appreciably affected. Considering the redundancy present in the visual world, the provisions in Table VI-3, as explained by comments following the table, conform to the SMEs' analysis. Third, the most important depth cues for pilots at night arise from geometric patterns (Zacharias & Levison, 1981) which also provide cues from linear perspective, relative motion, and relative size. These sources are well provided for in all scenes; and because these sources are so dominant in distance judgments, not having full redundancy of less important sources presents no problems.

PLATFORM MOTION REQUIREMENTS.

Section V discussed the analysis of force motion cues that was completed by the SMEs with help from other members of the project team. The analysis addressed types of motion information normally used during actual flight. The types of information were defined according to the ways pilots normally identify or describe the characteristics of an airplane's movements. For each task, the primary role of each type of information was identified as onset cueing (C), feedback (F), or monitoring (M) information. Further, a priority rating accompanied each C, F, and M to indicate whether it was the first or primary source of the information (priority 1); an important, but not the primary source (priority 2); or an unimportant source which did not affect task performance (priority 3).

The purpose of this subsection is to explain how the SMEs' analysis was used to identify motion, specifically platform motion, cueing equivalences for simulation. As with vision, the focus was on topological properties of motion cueing. Three main topics are discussed: (a) summarization of types of real-world motion information pilots use, by CPO flight segment; (b) translation of the motion information into means of representing it through simulation; and (c) minimal motion requirements.

SUMMARY OF REAL-WORLD INFORMATION. According to the SMEs' analysis, all CPO flight segments identified in Section IV except preflight, and all their component tasks, involved motion cueing of some kind. The same is true for a number of malfunctions, additional maneuvers, and environmental conditions. The procedure for summarizing the analysis was similar to that for summarizing the visual cue analysis explained in the preceding subsection, except that it was necessary to address malfunctions, additional maneuvers, and environmental conditions specifically.

The first step was to summarize the analysis for each CPO segment, considering only the basic tasks comprising it. This resulted in a single designation for role (C, F, M) of each type of information and a single priority for the role. As to the role, onset cueing C was considered more important than feedback F, and the latter more important than monitoring M.[1] Thus, for a given segment and type of motion information, a single letter was assigned, C if C occurred for any component task; F if no C occurred but an F did; and M if neither a C nor an F occurred and an M did. The effect of this procedure was to recognize the most important role of the informational type; and for practical purposes of simulation, to require that the potential for representation of the information continue throughout the segment. (As will be apparent later, this procedure resulted in close correspondence of derived simulation requirements to the SMEs' analysis for Type A objectives, and without conflict with their analysis when motion is not required for Type B objectives.)

The next step was to assign a priority to each "summary" role, actually, most important role. This could be done in a straightforward manner because of the close correlation between priorities and roles in the SMEs' data. As apparent in Appendix E, all Cs for basic tasks have priorities of 1, so if a summary C was assigned as just described, a priority of 1 was also assigned. Similarly, all Fs for basic tasks had priorities of 2, so 2 was assigned if feedback was the most important role of the information. Ms had priorities of either 2 or 3; and since M is the least important role, if M was assigned to a type of information for the entire segment, a priority of 2 was assigned if any component task had an M2, and a priority of 3 otherwise.

The resulting roles and priorities were then adjusted for overlays of malfunctions and additional maneuvers that were included in the CPO scenario for the segment. The same procedure was followed, often resulting in upgradings of roles (M to F, F to C, M to C) of the information and corresponding changes in priorities. The correlation between C, F, or M and priorities was affected only for speed-brake extension/retraction where buffet pitch, buffet roll, and buffet yaw had been assigned F1 by the SMEs. The results of these three procedures are shown in Table VI-4. Note that the overlay of environmental conditions is not included at this point; the effects of this overlay are included in later discussions, however.

---

[1]Note that as defined here, if a monitored motion condition leads to a new response or an adjustment to ongoing responses, it would be classified as C or F, respectively, not as M.

TABLE VI-4. SUMMARY OF SMES' ANALYSES OF ROLES AND PRIORITIES FOR TYPES OF MOTION INFORMATION, BY SEGMENT

	Segment								
Type of Information	Taxi	Takeoff	Area Departure	Cruise	Area Arrival	Approach	Landing	Emergency Descent	In-flight Maneuvers
Change in speed (accel/decel)	F2	C1				C1	C1	M2	M3
Uncoordinated flight (yaw out of trim)	F2	C1	C1	C1	C1	C1	C1	C1	C1
Change in pitch	M3	F2	F2	F2	F2	C1	F2	F2	F2
Change in roll	M3	F2	F2	F2	F2	F2	F2	F2	F2
Change in yaw	F2	C1	C1	C1	C1	C1	C1	C1	C1
Buffet pitch		M2				M2	M2	M2	
Buffet roll		M2				M2	M2	M2	
Buffet yaw		M2				M2	M2	M2	
Constant G loading		M3	M3	M3	M3	M3	M2	M2	F2
Constant deck angle		M2	M2		M3	M2	M2	M2	M3

NOTE: C = onset cue; F = feedback cue; M = monitoring cue.

SIMULATION OF CUES. A state of constant linear motion, once initiated, cannot be perceived except by reference to a visual environment. Through other senses, one can only perceive positive or negative accelerations.

An airplane has six axes, or six degrees of freedom, for movement. Three axes define translational motion, fore-aft, left-right, up-down. Ignoring vision, movement in the first two directions can be perceived only when rate of movement changes. Up-down movements, even if constant in rate, can provide perceivable acceleration through gravitational or G forces. The other three degrees of freedom of airplane movement, pitch, roll, and yaw, provide rotational motion. Angular acceleration is inherent in any movements of these sorts.

Since only accelerations, including those arising from G forces, can be perceived, identification of sources to simulate the 10 types of motion information amounted to specifying the axes with which accelerations can be identified. The contemporary six-axis motion platorm was used as the reference system. This is not to be construed, however, as a recommendation for a specific engineering approach. The motion platform is an acceptable system for providing motion effects, and it can be a standard with which alternative approaches can be compared.

Using this reference system, an analysis was made by a pilot who was thoroughly experienced both as a pilot and in the design of flight simulators, and by a simulator design engineer with extensive experience with platform motion systems. They first determined, for each of the 10 types of motion information, the principal axes needed to simulate the accelerative onset of the motion, and the principal axes needed to sustain the experience of continuing acceleration. The results appear in Table VI-5. A lower case o in the table means the axis is primary for the onset of simulated acceleration; a lower case s means the axis is important for sustaining the experience of acceleration. For example, at the beginning of a takeoff roll, a sudden thrust along the longitudinal axis of the simulator provides onset (o) acceleration. The thrust then is "washed out" subliminally as the nose of the simulator is pitched upward to sustain (s) the pressure on the pilot's back (and friction on the seat) that would normally accompany sustained acceleration. With help from the project director and a simulator test engineer, the pilot and simulator design engineer next applied this analytic scheme to the basic flight tasks and to malfunctions, additional maneuvers, and environmental conditions that are to be combined with the basic tasks. The results were incorporated in the next step as described below.

MINIMAL MOTION REQUIREMENTS. The axis-by-axis analysis just discussed defined "minimal" motion requirements in the sense that, as explained later, only Type A objectives are involved. However, there are three other considerations. The first concerns priorities shown in Table VI-4. It is immediately apparent that monitoring roles, indicated by Ms in Table VI-4, are at best only secondarily served by platform motion. Primary information for monitoring is provided by external visual scenes, instruments, and kinesthesis related to

TABLE VI-5. ONSET (o) AND SUSTAINING (s) ROLES OF AXES IN PROVIDING MOTION INFORMATION

Type of Information	Longitudinal Translation	Lateral Translation	Vertical Translation	Pitch	Roll	Yaw
Change in speed (accel/decel)	o			s		
Uncoordinated flight (yaw out of trim)		o			s	
Change in pitch			o	s		
Change in roll					o/s	
Change in yaw		o			s	
Buffet pitch			o/s			
Buffet roll					o/s	
Buffet yaw		o/s				
Constant G loading			o	s		
Constant deck angle			o	s		

control manipulations. Hence, platform motion is not necessary for monitoring as this term was defined here (see footnote above).

Second, platform motion cues can be effective as feedback during performance only to the extent closed-loop skills are involved. Hence, regardless of priorities shown in Table VI-4 and especially in Appendix E for feedback, such motion cues are not needed for tasks for which the checking (or training) objectives require only open-loop performance. When closed-loop skills are involved, then the extent of their involvement, and the priority assigned the feedback role, become the determiners of need.

Third, onset cueing roles, Cs in Table VI-4, should be evaluated in terms of specifications of checking and training objectives. The closed- versus open-loop distinction is of no consequence here; the key issue is getting an appropriate response under way, and in a timely manner. The best guides in this respect were explained by Caro (1979) and Gundry (1976). Briefly, platform motion cues are not important when they arise within the control loop and only confirm the pilot's expectations through feedback from or monitoring of effects of control inputs. On the other hand, motion cues are of value when they alert the pilot to forces outside the control loop (disturbance cues), and when they provide certain kinds of feedback technically within the control loop.

It is readily apparent that disturbance motion cues, especially when primary for perceiving the disturbance, should be provided for first-trial transfer of simulator performance to the airplane or vice versa. The feedback role needs more specification, however. Caro (1979) approached the problem in terms of basic aircraft stability. With stable, "forgiving" aircraft, instruments and the external visual scene provide the needed feedback for control. The implication is that platform motion cues are not primary in this regard. On the other hand, for some airplanes and most helicopters, inherent instabilities often require rapid control adjustments; and reaction times are more rapid to tactile stimuli (which includes accelerative forces on body tissues arising from motion) than to visual stimuli. We can add that at the limits of stability, small deviations beyond the envelope are more likely to be felt than seen in an airplane.

The implications of these points are that platform motion is needed to achieve the simulator-airplane transfer required for ATP checks and training when (a) disturbance or alerting cues are involved; or (b) when the airplane is flown near the limits of stability.[1] The first point applies especially to certain malfunctions and weather conditions; the second to maneuvers likely to

---

[1]This conclusion may well need qualification as the control of flight becomes more and more automated. Computerized monitoring and feedback systems will often remove the pilot from the control loop, especially as envelopes of flight stability in high performance airplanes become narrower and exceeding them more hazardous.

lead to unstable airplane performance, or to malfunctions and weather conditions that of themselves can readily lead to unstable airplane performance.

Using these two implications as guides, the SMEs' analysis of motion cues, and the consequent axis-by-axis requirements for providing motion as just discussed, were adapted to reflect need for disturbance and feedback cueing.

The results appear in Table VI-6 separately for tasks and selected flight conditions. Entries in the table are both upper and lower case letters. The former, C or F, indicate as before onset (i.e., disturbance) cueing and feedback roles, respectively. The lower case letters, o and s, accompanying C or F indicate whether the axis of motion so identified provides the onset of acceleration or sustains the simulated force for the C or F role.

It will be noted in Table VI-6 that, for simulation, the longitudinal axis is restricted to ground operations and to certain task conditions. Furthermore, the yaw axis is not involved at all. As for the longitudinal axis, the roles served are certainly not critical because the duration of longitudinal acceleration is highly restricted in a simulator. A word of caution is in order concerning the yaw axis, however. The airplane used as a baseline, the B-727, has a center of gravity almost 60 feet behind the pilot's seat. Hence, experience of yaw would be transmitted more as a lateral than a rotational movement. (In some airplanes, pitch could be experienced more as a vertical than rotational movement as well.) This would not necessarily be true for other given airplanes, especially small ones, nor for helicopters.

CONSIDERATIONS FOR DERIVING SIMULATION REQUIREMENTS.

This subsection presents a detailed summary of criteria and other considerations that guided decisions regarding requirements for simulators that are used for ATP checking and training. Discussions are organized under eight heads. The first two discussions concern requirements for Type A and Type B simulators, that is, those to be used for checking and training skills as identified by Type A and Type B performance objectives. Next there are separate discussions of general considerations, and then of particular considerations as they relate to requirements for visual systems, motion systems, aerodynamic programming, control loading, and the aural environment. There is some repetition in these discussions, but it should help clarify the issues involved.

TYPE A SIMULATORS. Type A simulators should represent a full-scale mockup of the cockpit of the airplane being simulated. The simulation of airplane systems (controls, circuit breakers, displays, and their operations) should be functionally accurate. The simulation of instrument rates of change should correspond accurately with the airplane's response to control inputs, power inputs, and changes in configuration under actual flight conditions. The accuracies of simulated navigational systems should represent realistic tolerances prescribed for airborne and ground equipment. Instructor/evaluator

TABLE VI-6. DISTURBANCE CUEING (C) AND FEEDBACK (F), BY AXIS AND ONSET (o) AND SUSTAINING (s) ROLE

	Axis					
Flight Task	Longitudinal Translation	Lateral Translation	Vertical Translation	Pitch	Roll	Yaw
Taxi to takeoff position	Fo	Fo		Fs	Fs	
Takeoff ground roll	Fo	Fo	Co*	Fs		
Rotation		Fo	Fo	Fs		
Climb to cleanup		Co			Cs Fo/s	
Airfoil cleanup		Co Fo	Fo	Fs	Cs Fo/s	
Rejected takeoff	Fo	Fo		Fs	Fs	
Climb to cruise altitude		Co	Fo	Fs	Cs Fo/s	
Level off at cruise altitude		Co	Fo	Fs	Cs Fo/s	
Cruise		Co	Fo	Fs	Cs Fo/s	
Arrival descent		Co	Fo	Fs	Cs Fo/s	
Level off from arrival descent		Co	Fo	Fs	Cs Fo/s	
Emergency descent		Co	Fo	Fs	Cs Fo/s	
Level off from emergency descent		Co	Fo	Fs	Cs Fo/s	
Holding		Co	Fo	Fs	Cs Fo/s	

(Continued)

TABLE VI-6. (Continued)

	Axis					
Flight Task	Longitudinal Translation	Lateral Translation	Vertical Translation	Pitch	Roll	Yaw
Visual approach to visual glidepath		Co	Fo	Fs	Cs Fo/s	
Inst. approach to visual glidepath or circling visual transition		Co	Co	Cs	Cs Fo/s	
Circling approach visual transition to visual glide path		Co	Fo	Fs	Cs Fo/s	
Missed approach			Fo	Fs	Cs Fo/s	
Visual glidepath to LMTP		Co	Fo	Fs	Cs Fo/s	
LMTP to flare		Fo	Fo	Fs	Fo/s	
Flare to initial touchdown		Fo	Fo	Fs	Fo/s	
Initial touchdown to start ground roll		Fo	Fo	Fs	Fo/s	
Landing ground roll	Fo	Fo		Fs	Fs	
Steep turns		Co	Fo	Fs	Cs Fo/s	
Stall recovery		Co	Fo	Fs	Cs Fo/s	
Dutch roll		Co			Cs Fo/s	

(Continued)

TABLE VI-6. (Continued)

Flight Condition	Axis: Longitudinal Translation	Lateral Translation	Vertical Translation	Pitch	Roll	Yaw
1 Engine fail	Co	Co		Cs	Cs Fo/s	
2 Engine fail	Co	Co	Fo	Fs	Cs Fo/s	
Asymmetrical flaps			Co	Cs		
Asymmetrical leading edge		Co	Fo	Fs	Co/s	
Flaps fail extend			Fo**	Fs**		
Thunderstorm	Co	Co	Co	Cs	Cs	
Crosswind		Co			Co	
Turbulence	Co	Co	Co	Cs	Co/s	
Wind shear	Co	Co	Co	Cs	Co/s	
Wind gust	Co	Co	Co	Cs	Co/s	
Ice on runway	Co	Co			Cs	
Brake failure	Co	Fo		Cs	Fs	
Manual reversion	Fo	Co		Fs	Cs Fo/s	
Tire failure	Fo	Fo	Fo	Fs	Fo/s	

* Provided only for speed bump.

** Cue is absence of motion in this axis.

control of systems malfunctions and environmental conditions should be provided.

Type A simulator control forces and degrees of travel should correspond to those of the airplane under static and dynamic flight conditions. Aerodynamic programming should represent combinations of thrust and drag normally encountered in flight and should also represent the specific ground effects, ground reaction, and ground handling characteristics of the airplane simulated. The dynamic effects of normal and reverse thrust on airplane control surfaces should be represented, and the aerodynamic programming should also include specific airframe buffet effects for airplanes in which those effects provide low speed stall indications or entail training in recovery from high speed buffet. Simulated braking characteristics should account for dry, wet, and icy runway surfaces for checking and training in rejected takeoffs and landings. Three-dimensional wind shear effects, crosswind effects, and airframe icing should also be modeled.

Visual systems for Type A simulators should provide a horizontal field of view in excess of 90° to the pilot's left to accommodate taxiing and circle-to-land maneuvers. A night scene is required for training in night landings, and the effect of landing lights should be portrayed. The visual environment must relate accurately to simulator attitudes. The conditions of restricted visibility, low ceilings, fog effects on lighting, and gradual breakout from instrument meteorological conditions should be simulated. Dynamic response (transport) delay of the visual system should be compatible with aerodynamic programming for the specific airplane and should not exceed 100 milliseconds following normal airplane response time. Visual scene content should include runway/taxiway surface markings and lights (red and green); surface features or lights that provide depth perception and permit the pilot to assess sink rate for landing; wet and icy runway representations for training in landings and rejected takeoffs on contaminated surfaces; adequate occulting to support required scene content; and sufficient surface texture to permit accurate assessment of taxi speeds.

Type A motion systems should provide motion effects at the pilot's position for lateral translation, vertical translation, pitch, and roll. Motion effects should precede corresponding effects in the visual scene but should not precede actual airplane response times for identical flight conditions. The motion system should represent special effect requirements such as mild atmospheric disturbance, turbulence, wind shear, contaminated surfaces, etc., and should be correlated with cues provided for other sensory modes regarding these effects.

Realistic communications systems (internal and external) should be provided in the simulator for purposes of evaluating cockpit resource management tasks. These capabilities should include ATC frequency congestion which might cause miscommunication. When Type A simulators are used in programs in which all initial training and checking is accomplished in the simulator, they should represent the sounds caused by power plants (normal and reverse thrust) and by gear/flap/speed-brake extension and retraction.

TYPE B SIMULATORS. Type B simulators do not require visual systems or force motion systems. Like Type A simulators, they should represent a full-scale mockup of the cockpit of the airplane being simulated and airplane systems (controls, circuit breakers, displays, and their operations) should be functionally accurate. Instrument rates of change should correspond accurately to airplane responses to control and power inputs and to changes in configuration under actual flight conditions. Instructor/evaluator control of systems malfunctions should be provided.

Type B simulator control forces and degree of travel should correspond to those of the airplane under static flight conditions. The aerodynamic programming should accurately represent combinations of thrust and drag normally encountered in flight. The effects of wind aloft on navigational systems should be programmed, and the effects of mild atmospheric disturbance on instruments and controls should be represented. Type B simulators should provide realistic alternate communications systems (internal and external) as required by procedures involved in rapid decompression leading to an emergency descent. Automated performance measurement capabilities to determine maximum effort brake applications is required for checking rejected takeoff procedures.

GENERAL CONSIDERATIONS. Guides affecting a variety of decisions were as follow:

- Type A simulators, whose requirements meet or exceed those of Type B simulators, are always appropriate for checking or training skills related to Type B objectives.

- Training requirements do not overlap checking requirements with the exception of certain airplane systems anomalies. Training requirements, which include events such as wind shear training, rejected takeoffs and landings on contaminated surfaces, and landing with manual reversion of the flight controls, are important components of the certification system. Simulators used to accomplish these requirements must support total acquisition of the skills involved.

- Once proficiency in particular motor skills has been established in conjunction with Type A objectives, there may be a decreased need for full simulator support of these and functionally similar skills when they are involved in Type B objectives. This is true because Type B objectives focus on the cognitive-procedural aspects of these skills. This premise affects force motion, aerodynamic programming, and control loading requirements.

- Simulator operator controls should permit manipulation of airplane systems malfunctions and environmental parameters to the extent necessary to accomplish training and checking requirements.

- To accomplish evaluation objectives for the approach segment, tolerances for navigational system accuracies should be realistic so that task difficulty regarding final approach course alignment during the transition from instrument to visual conditions is not artificially decreased.

• The evaluation objective for rejected takeoffs is oriented toward checking procedures for maximum effort braking on a dry surface. Therefore, this is a Type B objective. However, to measure a pilot's proficiency at this task, some type of automated performance measurement equipment is required when a visual scene is not provided.

• When all initial training and checking is accomplished in a simulator under a total simulation concept, instructors must explain to ATP candidates the differences between the simulator and airplane to facilitate first-time skill transfer to the airplane. Additionally, total simulation training program curricula must be systematically developed to ensure that skills which are largely self-taught during actual airplane operations, such as braking and turning techniques during taxi, are not neglected during simulator training.

• Airplane systems, which the pilot or other crewmembers operate from the cockpit or which affect crew procedures or tasks, are to be accurately and functionally represented. This requirement includes normal, abnormal, and emergency operations. It also includes instruments, instrument indications, controls and switches, and circuit breakers.

• All airplane flight instruments and systems, including electronic flight instrument systems (EFIS) if applicable, will be accurately and functionally represented. Instrument accuracies and rates of change will correspond to those of the airplane under actual flight conditions.

• Airplane navigational systems and instruments which are required by the practical test scenarios will be accurately and functionally represented. Tolerances for navigational system accuracies will be the same as those specified for the actual ground and airborne equipment.

• Piloting skills involve several kinds of tracking tasks with innumerable variations of each kind. As usually conceived, tracking performance is by definition a closed-loop skill, and as such requires immediate feedback for quality performance. Hence, any delay in simulated feedback relative to that in the real world might be expected to result in simulator-induced oscillations in tracking that exceed what they would be in the airplane. For this reason, all delays in simulated responses of instruments, aerodynamics, etc., ideally should conform to those of the airplane simulated. This is readily feasible within acceptable limits in state-of-the-art simulators. Even so, most existing simulators fall short in some respects, especially in response or transport delays of visual and platform motion systems. For this reason, Part 121, Appendix H stipulates, for example, a generous maximum delay of 300 msec for a Phase I visual system. Yet, studies of lateral and vertical tracking tasks often reveal degradation of performance with delays as small as 100 msec (Ricard & Puig, 1977). Also, straight-forward engineering analyses (cf. Carey, Densmore, Kerchner, Lee, & Hughes, 1983) show that even an 80 msec delay should result in observable deviations in tracking accuracy simply because the airplane has had 80 msec to continue to deviate before the pilot even receives the feedback indicating a control adjustment is needed. On the other hand, there is ample evidence that some kinds of performance do not suffer appreciably with 150 msec delay or even longer. In sifting the evidence on effects of unrealistic delays, the project team was able to resolve issues by focusing on the peculiarities of Type A versus Type B objectives, and on the nature of closed- versus open-loop skills. Type A objectives involve highly controlled tracking, so simulations of instruments, aerodynamics, etc., should conform to actual flight test data; and visual and motion response delays should not exceed 100 msec except when the response of the airplane itself exceeds this delay (a 600 msec delay for yaw response to rudder inputs is not uncommon for some transport airplanes). For Type B objectives, representative data (i.e., engineering projections) are adequate; and visual and motion systems are not even involved. Thus, delays are to be minimal when they are critical, and compromised or rendered irrelevant when they are not. In making these judgments, it was recognized that a thoroughly experienced performer actually approaches even a tracking task largely in terms of open-loop behavior. Unlike a novice, the expert has organized the required actions into open-loop segments which require only periodic feedback, depending in the meantime on a "programmed" feedforward schema (see Spears, 1983, for a detailed treatment of this point). This is not only a basis for accepting small unrealistic delays in visual and motion system responses, it also explains why studies of effects of transport delays can be equivocal.

- Except for acceptable differences in system response delays as defined later, responses of all aircraft systems affected by simulated conditions and control inputs must be closely correlated.

VISUAL REQUIREMENTS. Considerations affecting visual requirements were as follow:

- Experimental and anecdotal evidence indicates that a horizontal field of view in excess of 45° may assist some pilots in vertical tracking tasks during final approach maneuvering prior to crossing the runway threshold (C. L. Kraft, personal communication, June 20, 1984). This evidence is supported by the cue analysis. Additionally, anecdotal evidence suggests that after crossing the runway threshold, pilots who are very experienced in the airplane being simulated are more likely to process and use peripheral visual information than less experienced pilots. Nevertheless, as task loading increases, the processing and use of peripheral information decreases even for experienced pilots. Furthermore, pilots meeting ATP experience requirements should be capable of adapting control strategies to accomplish these tasks without peripheral visual information (cf. Brown, 1976).

- Circling approaches and taxi tasks, as defined in the practical test scenarios, require a horizontal field of view in excess of 90° to the pilot's left for ground orientation and to evaluate the pilot's ability to make a 90° taxi turn so that the main landing gear track the taxiway centerline.

- Visual system dynamic response must be less than that which causes pilot-induced oscillations. Research data indicate that for high gain tracking tasks, response times should not exceed 100 milliseconds (Carey et al., 1983; see also Ricard, Norman, & Collyer, 1976; Westra, 1983; Westra, Simon, Collyer, & Chambers, 1981). Exceptions are for the tracking tasks involved during taxi and normal takeoff. These tasks may be adequately supported by a 300 millisecond response time due to the slow speeds involved during taxi and due to the limited use of external visual information during takeoff after rotation. However, when the takeoff is complicated by wind gusts/shear or critical engine failure, then the importance of visual tracking increases and dynamic response times for these conditions should not exceed 100 milliseconds.

- Visual scene content requirements are based on a night scene for two reasons. First, during ACSD Steps 3 and 4, it was determined that day, dawn/dusk, and night conditions are equally acceptable for required training and practical tasks except that specific training is required for night landings. Thus, the only requirement for an explicit time of day is a <u>night landing</u> requirement. Second, other things being equal, a night visual scene permits specifying minimal visual scene requirements. This is especially true in that only an airport and its environs has to be represented, and at night all airports have similar objective characteristics.

- For vertical tracking during the approach segment, it is critical to represent identifiable runway surfaces at approximately one mile from the runway threshold (C. L. Kraft, personal communication, June 20, 1984).

- Practical test scenarios for the taxi segment require scene content, including taxiway markings and lights, that permits the performance of 90° taxi turns.

- Consistent with Zacharias and Levison's (1981) findings, scene content for night landings and takeoffs should include geometric patterns such as provided by runway lights, runway markings, and additional lights to provide peripheral context.

- Fog effect on lighting is required for low visibility takeoffs because it increases task difficulty.

- The scene content for the approach segment should provide sufficient surface lights peripheral to the airport environment to permit the pilot to assess the proper vertical and horizontal flight path (unless the intent is to make illusions possible).

<u>MOTION SYSTEM REQUIREMENTS</u>. Considerations affecting force motion requirements were as follow:

- Although not all pilots perform better in simulators with motion cues, certain motion cues should be provided if they help some pilots during flight control tasks.

- For experienced pilots, motion cues improve performance of certain dynamic closed-loop skills such as those involved in Type A objectives for landing (Parrish & Bowles, 1983), outboard engine failure (Cefoldo, Brady, & Knapp, 1981), and gusty flight conditions (Perry & Naish, 1964).

- Research with modern motion and visual systems indicates that force motion cues should always precede visual cues.

- The motion requirements analysis revealed that all essential motion cues could be provided through vertical translation, lateral translation, pitch, and roll.

- In identifying motion requirements in terms of axes involved, it is assumed that resultant response vectors of the prescribed axes correspond to those of the airplane under similar conditions.

- Although Type A objectives are involved, the taxi segment does not require motion cueing if an adequate visual scene is provided. Taxi involves closed-loop control tasks (braking and steering) that rely on visual feedback and kinesthetic feedback from the brake pedals and steering controls. (Because of the airplane's slow speed, surface texture is required to provide the necessary visual information.)

- Evaluation of a pilot's performance during rejected takeoffs does not require force motion cues because the evaluation objective deals primarily with open-loop control tasks (maximum effort braking). Although motion cues could provide a realistic context for these tasks, they do not comprise useful feedback during the tasks. Therefore, they are not essential to provide. On the other hand, rejected takeoff training under conditions of contaminated surfaces and brake/tire failures involves closed-loop control tasks (controlled braking and centerline tracking). Under the conditions required for training, force motion cues are used for feedback and are essential to provide.

- Experimental and anecdotal evidence suggests that force motion cues are most important when they alert the pilot (disturbance motion) to aerodynamic effects that are not consequences of control inputs (e.g., engine failure, turbulence, etc.). The importance of force motion cues that result from control inputs (maneuver motion) increases in less stable aircraft or flight regimes (stalls, steep turns, etc.) that approach the limits of stable flight (Caro, 1979; Gundry, 1976).

- Type A objectives frequently involve closed-loop tasks that require force motion cues to alert the pilot to abnormal conditions or to support closed-loop control tasks in unstable flight regimes.

- Control tasks involved in recovery from impending stalls rely on force motion information provided by vertical translation, lateral translation, pitch, and roll. An essential part of the training required for stalls involves teaching the pilot to recognize unusual airplane attitudes associated with imminent stall. Pitch cues are necessary to accomplish this objective. Additionally, elevator, aileron, and rudder control tasks must be executed with precision during stall recovery; and these tasks rely on information provided by vertical translation, lateral translation and roll in stall flight regimes.

- Pitch and roll control during steep turns requires information provided by vertical translation and pitch.

- Force motion cues normally classified as maneuver motion take on a disturbance motion (alerting) role when they result from uncoordinated or other unintentional/undesirable control inputs.

AERODYNAMIC PROGRAMMING REQUIREMENTS. Considerations affecting aerodynamic programming requirements were as follow:

- Mild atmospheric disturbance effects on flight instruments and control surfaces are required for all Type A and B objectives except for stalls. Mild atmospheric disturbance is defined as the minimal degree of disturbance that requires the pilot's constant vigilance and attention to flight instruments.

- Airframe icing effects, when required for the landing segment, are only to provide continuity when icing conditions existed in the approach segment.

- Representative crosswind effects are to be provided throughout the normal operating range of the airplane.

- Buffet associated with approach to stall is to be represented for all airplanes that do not have a stall warning system.

- Three-dimensional wind shear effects are required for Type A special training tasks that specify wind shear encounters during takeoff, approach, and landing. During takeoff and approach, the effects of a microburst phenomenon are required based on real-world, three-dimensional data. Microburst effects should be positioned on the departure and approach courses to permit positive escape maneuvering within airplane performance capabilities. Dynamic modeling, that is, continuing real-time microburst movement in three dimensions, is not required. During landing, the effects of a horizontal wind shear is required. The shear should not exceed airplane performance capabilities in regard to escape maneuvering.

- Simulation of actual flight performance specific to the airplane type is necessary for tasks where large changes in trim occur during short periods of time, or where environmental conditions or systems malfunctions increase control difficulty.

CONTROL LOADING REQUIREMENTS. Considerations affecting control loading requirements were as follow:

• Control feel dynamic performance tests are required for the approach segment because some approach tasks (e.g., the transition to missed approach) involve large changes of airplane attitudes around trim conditions.

• Control feel dynamic tests are not required for Type B simulators because of the procedural orientation of Type B objectives.

• Control feel dynamics are not required for in-flight maneuvers (stall recoveries, steep turns, and recovery from specific flight characteristics). This determination is based primarily on anecdotal evidence gleaned from FAA experience using simulators lacking this quality to perform in-flight maneuvers.

AURAL REQUIREMENTS. Considerations affecting aural requirements were as follow:

• A realistic aural environment enhances the experience of actual flight, but except as stipulated below, aural cues are not necessary for task performance.

• Navigational aid audio identification functions are to operate accurately and all aural cockpit warnings are to be accurately and functionally represented.

• Cockpit noises associated with systems operations (control and switch manipulations, etc.) are to be adequately represented.

• The sound of touchdown during landing (touchdown squeak) could be substituted for a touchdown force motion cue (touchdown bump).

• Evaluation of pilot performance during emergency descent requires adequate replication of alternate communications systems because part of the evaluation objective involves the pilot's ability to establish alternate means of internal and external communications.

• To accomplish cockpit resource management objectives, it is necessary to provide realistic background noise in the cockpit to the extent that it disrupts internal communications in the normal flight environment. For some airplane types, background noise increases task difficulty.

• Information normally received through communications with other crewmembers or with external controlling agencies must be provided if it is necessary for proper performance.

• Cockpit resource management objectives include evaluating the pilot's skill at dealing with sources of potential miscommunications such as extraneous ATC communications to aircraft with similar call signs.

• Total simulation training programs require simulation provisions for special aural (and motion) effects such as those involved with gear/flap/speed-brake extension and retraction. This requirement is not based on the pilot's use of information provided by these effects during task performance. Rather, the requirement is to ensure that the pilot will not be confused by these effects when they occur for the first time in flight during critical flight regimes.

CUEING REQUIREMENTS BY FLIGHT SEGMENT.

This subsection summarizes cueing requirements for simulators used for ATP checks and training. There are eight separate discussions directed toward taxiing; takeoff; rejected takeoff; steep turns; stall recovery; area departure/arrival and emergency descents; approach; and landing.

TAXI SEGMENT. The taxi segment involves Type A objectives. The objectives are concerned primarily with visual tracking tasks and speed control. Adverse conditions are not involved in this segment. Speed control using power and brakes is required for straight ahead taxiing and for turns. Judgment and adjustment of speed requires external visual information that is provided by detailed scene content. Controlling the main landing gear track of a large turbojet through a 90° turn requires accurate speed control and knowledge of turn performance and geometry. A 1,500 hour pilot can be expected to have sufficient experience with taxi speed control and turning geometry to adapt required skills to a new airplane type on the first exposure if the new airplane type is similar to other airplanes the pilot has taxied in regard to fuselage length and cockpit height. A 90° field of view is required to allow a pilot to determine when to start a turn unless the scene is carefully constructed to provide sufficient cues in the forward field of view to permit making a 90° turn at a "T" intersection. Scene content must allow judgment of speed to within approximately 5 knots and brake applications must yield appropriate deceleration for the brake pedal force applied. The addition of force motion cues in the form of bumps for expansion joints, accelerations/decelerations, and vibration of brake pucks on discs can add much to the perception of changing speed. However, an adequate visual scene can support the evaluation objectives without motion. Aerodynamic programming must include ground reaction and ground handling and must provide instrument indications in response to control inputs as they occur in the actual aircraft. Nosewheel steering and/or rudder forces for steering and/or braking must yield rates of changes that correspond to actual aircraft performance. Break-out thrust and taxi speed should be appropriate for throttle position and gross weight to include reverse thrust effects. If motion is provided, it must be correlated with other cues. Aural cues are not required except for simulators used in total simulation training programs.

TAKEOFF SEGMENT. Takeoff involves Type A objectives for checking and Type B for training. Rotation is the most critical task in this segment. The complexity of the rotation task is increased during Type A practical tests due to the addition of crosswind and critical engine failure. It is important to provide for specific aircraft performance in ground handling, ground reaction, and ground effects. Aircraft directional momentum effects are critical when marginal performance is caused by critical engine failure or when the forward flight vector is changing rapidly during ground-to-air transition with a crosswind. Force motion and visual cueing are important for rotation tasks that are complicated by crosswind or critical engine failure. Vertical and lateral translation and pitch and roll provide onset cues for crosswind factors and engine failure. They also provide primary feedback cues needed to refine control inputs during rotation. Dynamic control feel/forces should be based on specific flight test data. A visual scene horizontal field of view of 45° is adequate for centerline tracking tasks during takeoff.

REJECTED TAKEOFF. Rejected takeoff involves Type B objectives for checking and Type A for training. Rejected takeoff evaluation objectives are concerned with the procedural aspects of the maneuver and are not concerned with centerline tracking tasks. The practical test scenario calls for maximum effort braking, which is essentially an open-loop skill and can be accomplished without force motion or visual cue information. On the other hand, rejected takeoff training includes wet and icy runway surfaces and brake and tire failures. These requirements involve closed-loop skills for braking and centerline tracking, and these skills require both force motion and visual cueing.

STEEP TURNS. Steep turns involve Type A objectives that concern aircraft control in less stable flight regimes. Aerodynamic programming should provide simulator responses that are representative of the airplane, and control forces and travel should correspond to the airplane under normal flight conditions. Aerodynamic effects for thrust and drag should accommodate the bank angles normally used in this maneuver (nominally 45°). Flight instrument indications and rates of change should correspond to control inputs as they would under actual flight conditions. Task difficulty is increased by a reduction in roll stability at high bank angles and by increased G loading. Force motion cueing is important for pitch control under these conditions, and vertical translation is used to provide information regarding pitch changes while rotation around the lateral axis (pitch) is used to simulate sustained G loading. Roll motion cueing is provided adequately through the flight instruments. A visual scene, aural cues, and flight control feel dynamics are not required. Mild atmospheric disturbance effects should be represented in the flight instruments, flight controls, and motion system.

STALL RECOVERY. Stall recoveries involve Type A objectives concerning controlling the airplane in less stable flight regimes. These objectives include recognition of impending stalls and proper recovery. Low airspeed and high angle of attack usually precedes low speed buffet onset. This flight condition is accompanied by reduced G load per stick force and a sustained gravity vector perceived in the pilot's back rather than the buttocks. Cues to alert the pilot to these conditions are provided through appropriate aerodynamic programming and pitch. For airplanes with artificial warning systems, the buffet accompanying stall onset is not required. Roll that may accompany stalls should be provided by force motion cues in order to direct the pilot's attention to the attitude indicator to determine appropriate corrective action. Force motion roll cues also provide adequate yaw information to prevent uncoordinated or improper rudder pedal inputs. Stall recovery requires fine adjustments in pitch to allow the airplane to accelerate while minimizing loss of altitude. Vertical translation assists in these closed-loop control skills. Aerodynamic programming should be representative of the airplane. Except as specified for Type A objectives in general, there are no special considerations regarding thrust and drag combinations, instrument rates of change, or control forces. A visual system and aural cues are not required.

AREA DEPARTURE, AREA ARRIVAL, AND EMERGENCY DESCENT SEGMENTS. These segments involve Type B objectives that are primarily concerned with the cognitive and procedural aspects of the required skills. Mild atmospheric disturbance effects should be represented in the flight instruments and controls. A full-scale cockpit mockup is required due to the airplane-specific nature of the procedural skills being evaluated. Flight instrument indications and rates of change should correspond to those of the airplane in normal flight conditions. Aerodynamic programming, thrust and drag combinations, and control forces and travel should be representative of the airplane. A visual system is not required, and aural cueing is not required unless the simulation is used in a total simulation training program. However, accurate replication of an alternate communication system is required for evaluation of emergency descents in which part of the evaluation objective is to determine the pilot's ability to establish alternate means of internal and external communication.

APPROACH SEGMENT. The approach segment includes visual approaches, instrument approaches, and missed approaches/rejected landings. All visual approaches involve Type A objectives. Instrument approaches and missed approaches involve both Type A and B objectives. Type B instrument approaches and missed approaches involve tasks that do not require external visual information nor involve abnormal conditions with significant aerodynamic effects. Consequently, no external visual or force motion cueing is necessary for Type B approach tasks. Mild atmospheric disturbance effects should be represented in the flight instruments and controls. Aerodynamic programming, flight instrument indications and rates of change, control forces and travel, and thrust and drag combinations should represent the airplane in normal flight conditions. A full-scale cockpit mockup is required due to the airplane-specific nature of the procedural skills being evaluated. The effects of a 20 knot wind aloft are required in the simulator.

Type A evaluation and training objectives for instrument approaches involve engine failures and turbulence, as well as large changes in trim conditions over short periods of time during initiation of missed approaches and during corrections for misalignment with the runway. Also, decisions by the pilot to continue an approach or execute a missed approach are to be based on visual information.

Like Type B instrument approaches, Type A approaches require a specific full-scale cockpit. Aerodynamics must replicate the specific type of aircraft with controls and instruments responding as they would in flight, including control feel dynamics. Programming should include stall buffet if buffet is the first indication of an imminent stall. Tolerances for accuracies of navigational equipment should be realistic so that task difficulty regarding final approach course alignment during the transition from instrument to visual conditions is not artifically reduced. A 45° horizontal field of view is adequate for all tracking tasks with the exception of circle-to-land maneuvers which require a 90° field of view left from the pilot's forward focal point. A night scene portraying airport, approach, and runway lights, including appropriate red and green lights and directionality, is required. The brightness of lights should be calibrated for required weather conditions and should be controllable over realistic steps as requested by the pilot. The visual system's dynamic response should be within 100 milliseconds of actual airplane performance, and force motion effects should precede corresponding visual effects. The force motion system should provide vertical translation, lateral translation, pitch, and roll. Turbulence effects should be represented in all four of these axes of motion. The effects of engine failure should be provided by lateral translation and roll. Relatively high bandwidth control tracking tasks, such as initiation of a missed approach or rejected landing and corrections for misalignment with the runway, are enhanced by accurate motion cueing in all four axes.

The required conditions for visual approaches are analogous in difficulty to Type A instrument approaches, and simulator requirements are identical to those required by the circle-to-land maneuver. Basic VMC navigation, glide-path intercept and vertical tracking, and runway centerline tracking must be demonstrated for both the circling and visual approach. Airport area scene content should support these activities.

LANDING SEGMENT. The landing segment involves Type A objectives that concern vertical and horizontal tracking tasks with high cognitive-motor skill demands. Pilot control strategies are not generalizable from airplane type to airplane type due to differences in stability, control augmentation, pilot eye height, airplane response in ground effects, ground reaction, and ground handling. Research data indicate that control reversals can occur as frequently as four times per second in pitch and roll during flare for normal landings. Therefore, aerodynamic modeling affecting these factors must be accurate and specific for each airplane type. Visual system dynamic response should not exceed 100 milliseconds, and force motion cues should precede the corresponding visual cues. Control forces and feel dynamics should represent the specific aircraft in flight. Representative modeling for maximum allowable crosswind is required by the training objectives. Airframe icing effects are required for continuity with the approach segment. Normal and reverse dynamic thrust effects on control surfaces should be provided. The effects of dry, wet, and icy surfaces on directional control and stopping should also be represented. Visual scene content should provide depth perception, assessment of sink rate, and capabilities for tracking the runway centerline. Realistic green, red, and white lighting; the effects of landing lights on surfaces; and the effects of fog on runway lights should be provided.

Programming must include turbulence and low speed buffet if buffet is the first indication of impending stall. Lateral translation, vertical translation, pitch, and roll are required to support basic control tasks and to provide alerting cues associated with engine failure, wind gusts and shears, and turbulence.

SIMULATOR REQUIREMENTS: DETAILED SPECIFICATIONS.

Detailed simulator requirements are presented in ten tables, six for Type A simulators and four for Type B simulators (visual and motion tables do not appear for Type B simulators because these systems are not required). The table numbers and titles are as follow:

- VI-7. General Requirements for Type A Objectives
- VI-8. Aerodynamic Programming Requirements for Type A Objectives
- VI-9. Control Loading Requirements for Type A Objectives
- VI-10. Visual Requirements for Type A Objectives
- VI-11. Motion Requirements for Type A Objectives
- VI-12. Aural Requirements for Type A Objectives
- VI-13. General Requirements for Type B Objectives
- VI-14. Aerodynamic Programming Requirements for Type B Objectives
- VI-15. Control Loading Requirements for Type B Objectives
- VI-16. Aural Requirements for Type B Objectives

Column heads in the tables indicate the flight segments or component tasks for which given required simulator capabilities are identified by Xs. Four general points should be borne in mind when interpreting the requirements. First, effects of mild atmospheric disturbance are to be represented during all in-flight tasks. As defined earlier, this level of disturbance is the minimum that requires the pilot's constant attention to control. Second, Rejected Takeoff has only Type B evaluation objectives, but it has Type A training objectives. Third, Takeoff and Cruise segments, when identified for Type B simulators, apply to training only. Fourth, when a capability listed on the left is a present requirement for a simulator as stipulated in FAA Advisory Circular AC 120-40, Airplane Simulator and Visual System Evaluation, it is identified in parentheses following the capability. For example, (II; A2, 2M) following item 6 in Table VI-7 means that a Phase II simulator is the lowest level of simulators for which this capability is presently required. (Once identified as a requirement for a given level, the capability is also required for all higher level simulators.) The first symbol may be, then, NV (Nonvisual) or V (Visual), or I, II, or III, representing the three phases of simulator levels above V. The second set of symbols, A2 in the above example, refers to the appendix number (Appendix 2) of FAA Advisory Circular AC 120-40 where this requirement is identified, and the last pair of symbols, 2M in this case, is the paragraph number of the appendix stating the requirements.

There are numerous footnotes to the tables. Numbered footnotes may accompany a table title or a simulator capability listed in the columns on the left. Footnotes identified by asterisks and lower-case letters (a, b, etc.) accompany only entries in the tables. The meanings of footnotes, which vary from table to table, are explained at the ends of the tables.

TABLE VI-7. GENERAL REQUIREMENTS FOR TYPE A OBJECTIVES

Requirement	Taxi	Takeoff	Rejected TO	In-Flt Maneuv	Visual Apch	Inst Apch	Landing
1. Specific full-scale cockpit mockup (NV; A1, 1a)	X	X	X*	X	X	X	X
2. Functionally accurate circuit breakers (NV; A1, 1b)	X	X			X	X	X
3. Accurate instrument indications in response to control movement (NV; A1, 1d)	X	X	X*	X	X	X	X
4. Navigation equipment corresponding to actual airplane/tolerances (NV; A1, 1e)	X				X	X	
5. Accurate systems replication:							
a. Normal (NV; A1, 1g)	X	X	X*	X[a]	X	X	X
b. Abnormal (NV; A1, 1g)	X	X	X*	X[b]	X	X	X
c. Emergency (NV; A1, 1g)	X	X	X*	X*,[c]	X	X	X
6. Omega, INS, EFIS, etc. (II; A2, 2M)	X[d]	X[d]	X[d]	X[d]	X[d]	X[d]	X[d]
7. Mild atmospheric disturbance		X		X	X	X	X
8. [1]Two instructor seats (NV; A1, 1f)	X	X	X*	X	X	X	X

(Continued)

TABLE VI-7. (Continued)

Requirement	Taxi	Takeoff	Rejected TO	In-Flt Maneuv	Visual Apch	Inst Apch	Landing
9. Instructor controls							
a. Visual system (NV; A1, 1h)	X	X			X	X	
b. Abnormal/emergency conditions (NV; A1, 1h)	X	X	X*	X[c]	X	X	X
c. Initial conditions		X			X	X	X
10. Cue correlation: Inst/Visual/Motion/Aural	X	X	X*	X	X	X	X

[1]A seat for evaluator with full view of cockpit instruments is mandatory; a second seat is required if a simulator operator is on board.

*Specification derived from training requirements.

[a]Not required for steep turns.

[b]Required when applicable to specific flight characteristics (e.g., inoperative yaw dampers for Dutch roll training).

[c]Required for stall recovery training with an inoperative engine.

[d]EFIS is required if it is the flight instrument system used in the airplane.

TABLE VI-8. AERODYNAMIC PROGRAMMING REQUIREMENTS FOR TYPE A OBJECTIVES

Requirement	Taxi	Takeoff	Rejected TO	In-Flt Maneuv	Visual Apch	Inst Apch	Landing
1. Aerodynamic changes for normal combinations of thrust and drag (NV; A1, 1c)		X	X[*]	X	X	X	X
2. Instrument/control force rate of change corresponds to actual rate of change caused by control inputs/power inputs/airplane configuration (NV; A1, 1i)	X	X	X[*]	X	X	X	X
3. Specific ground effect [I; A1, 1k (1)]							X
4. Specific ground reaction [I; A1, 1k (2)]	X	X	X[*]				X
5. Specific ground handling [I; A1, 1k (3)]	X	X	X[*]				X
6. Representative brake and tire failure dynamics (II; A2, 2K)			X[*]				X[*]
7. Representative crosswind modeling (II, A3, 3a)		X			X[a]	X[a]	X
8. Representative 3-dimensional windshear (II, A3, 3a)		X[*,b]				X[*,b]	X[*,c]
9. Low-altitude, level-flight ground effect (III; A3, 3m)							
10. High-altitude mach effect (III; A3, 3m)				X[d]			

(Continued)

TABLE VI-8. (Continued)

Requirement	Taxi	Takeoff	Rejected TO	In-Flt Maneuv	Visual Apch	Inst Apch	Landing
11. Specific airframe icing (III; A3, 3m)		X[e]				X[e]	X[e]
12. Normal and reverse dynamic thrust effect on control surfaces (III; A3, 3M)	X*	X	X*,f		X	X	X[f]
13. [1]Aero-elastic representations (III; A3, 3m)							
14. [1]Side-slip non-linearities (III; A3, 3m)							
15. Aerodynamic programming							
a. Representative				X[g]			
b. Specific		X	X*	X[g]	X	X	X
16. [2]Low speed buffet		X		X	X	X	X

[1]Aero-elastic effects and side-slip nonlinearities are inherent in the proper modeling of other aerodynamic programming requirements. While ACSD analytic methods cannot identify a stand-alone need for these effects, simulator handling qualities will be different from the airplane if they are not inherent in the data used to program other required effects.

[2]Required if buffet is the initial onset warning cue for stall.

*Specification derived from training requirements.

[a]Effect of 30 knot wind aloft.

[b]Effect of a microburst using real-world, three-dimensional data positioned on departure or approach course to permit positive escape. Real-time growth and movement of the model is not required.

[c]Horizontal shear effects.

[d]As required for specific flight characteristics identified as training and/or checking by the FSB.

[e]Specific effects, in this case, do not require flight test data.

[f]Thrust reverse effects to include asymmetry and rudder blanking, if applicable.

[g]Steep turns require only representative programming; other in-flight maneuvers require specific programming.

TABLE VI-9. CONTROL LOADING REQUIREMENTS FOR TYPE A OBJECTIVES

Requirement	Taxi	Takeoff	Rejected TO	In-Flt Maneuv	Visual Apch	Inst Apch	Landing
1. Control forces/travel (static) corresponding to the airplane in actual flight conditions (NV; a1, 1i)	X	X	X*	X	X	X	X
2. Representative stopping and directional control forces:							
a. Dry (II; A3, 3b)	X						X
b. Wet (II; A3, 3b)			X*				X*
c. Icy (II; A3, 3b)			X*				X*
d. Patchy wet (II; A3, 3b)							
e. Patchy ice (II; A3, 3b)							
f. Wet on rubber (II; A3, 3b)							
3. Control feel dynamics (specific) (II; A3, 3g)		X			X	X	X

*Specification derived from training requirements.

TABLE VI-10. VISUAL REQUIREMENTS FOR TYPE A OBJECTIVES

Requirement	Taxi	Takeoff	Rejected TO	In-Flt Maneuv	Visual Apch	Inst Apch	Landing
1. 45° Field view (Vis; A1, 3b)		X	X*			X	X
2. 75° Field of view (II; A1, 3b)	X[a]				X[b]		
3. Accurate portrayal of environment relating to simulator attitudes [Vis; A2, 2n(1)]	X	X	X*		X	X	X
4. Scene content:							
a. Taxiways [Vis; A2, 2n(3a)]	X						
b. Ramps/terminal bldgs. [I; A2, 2n(3b)]							
c. Surface on runways/ markings [Vis; A2, 2n(3c)]		X	X				X
d. Surface on taxiway/ ramps/marking [I; A2, 2n(3d)]	X[c]						
e. Representative runway lighting [Vis; A2, 2n(3d1)]		X	X*		X	X	X
f. Wet/snow covered runway [III; A2, 2n(3d13)]			X*				X*
g. Directionality of airport lighting [III; A2, 2n(3d14)]					X	X	

(Continued)

TABLE VI-10. (Continued)

Requirement	Taxi	Takeoff	Rejected TO	In-Flt Maneuv	Visual Apch	Inst Apch	Landing
4. Scene content (continued):							
h. Realistic daylight color [III; A2, 2n(3d14)]							
i. Visual cues to assess sink rate/depth perception during landing [I; A2, 2n(3d4)]							X
j. Minimum of 3 airport scenes [II; A2, 2n(3d7)]							
k. General terrain characteristics/ landmarks [II; A2, 2n(3d8)]							
l. Ground/air hazards [II; A2, 2n(3d10]							
m. Landing illusions [III; A2, 2n(3d11)]					X*		X*
n. Realistic runway light colors (Red/Green)		X			X	X	X
o. EFIS weather radar correlation to visual scene [III; A2, 2n(3d15)]							
p. Occulting							
(1) Adequate	X	X			X	X	X
(2) 10 levels min. (II; A3, 3k)							

(Continued)

TABLE VI-10. (Continued)

Requirement	Taxi	Takeoff	Rejected TO	In-Flt Maneuv	Visual Apch	Inst Apch	Landing
4. Scene content (continued):							
q. Surface lights to provide peripheral scene context		X			X	X	
5. Features:							
a. Landing lights [Vis; A2, 2n(3d2)]	X[d]	X[d]	X[*,d]				X[*]
b. Dusk/night [II; A2, 2n(3d6)]							X[*,e]
c. Daylight [III; A3, 3q)]							
d. Variable cloud density [II; A2, 2n(3d9a)]							
e. Partial obscuration of ground scene due to scattered/broken clouds [II; A2, 2n(3d9b)]							
f. Gradual breakout [II; A2, 2n(3d9c)]						X	
g. Patchy fog [II; A2, 2n(3d9d)]							
h. Fog effect on lights [II; A2, 2n(3d9e)]		X				X	X
i. Precipitation near a thunderstorm on takeoff, approach, landing [III; A2, 2n(3d12)]							
6. Final picture resolution in compliance with A2, 2n(2)					X		X

(Continued)

TABLE VI-10. (Continued)

Requirement	Taxi	Takeoff	Rejected TO	In-Flt Maneuv	Visual Apch	Inst Apch	Landing
7. Visual system compatibility with aerodynamic programming (Vis; A1, 3a)	X	X			X	X	X
8. Maximum transport delay:							
a. 300 ms. [Vis; A3, 2b(9a)	X						
b. 150 ms. [II; A3, 2b(9b)]		X	X[*,f]		X	X	X
9. Instructor control					X	X	

[*]Specification derived from training requirements.

[a]Required field of view for taxi is 90°.

[b]Required for circle-to-land maneuvers.

[c]Surface texture required for taxi to control speed in low speed ranges.

[d]A night scene is not required, but if it is used, the effects of landing lights must be represented.

[e]Night scene only.

[f]Required for runway tracking tasks when a takeoff is rejected after reaching high speeds.

TABLE VI-11. MOTION REQUIREMENTS FOR TYPE A OBJECTIVES

Requirement	Taxi	Takeoff	Rejected TO	In-Flt Maneuv	Visual Apch	Inst Apch	Landing
1. Translation axes							
a. Longitudinal							
b. Lateral		X	X[a]	X	X	X	X
c. Vertical		X	X[a]	X	X	X	X
2. Rotation axes							
a. Pitch		X		X	X	X	X
b. Roll		X		X	X	X	X
c. Yaw							
3. Special effects:							
a. Runway rumble/oleo deflection/groundspeed/uneven surface [I; A2, 2j(1a)]							
b. Ground buffeting due to spoiler extension/reverse thrust [I; A2, 2j(1b)]							
c. Nose/main gear bumps after liftoff [I; A2, 2j(1c)]							
d. Gear extension/retraction buffet:							
(1) Representative [I; A2, 2j(1d)]		X[*,b]			X[*,b]	X[*,b]	
(2) Specific (III; A3, 31)							

(Continued)

TABLE VI-11. (Continued)

Requirement	Taxi	Takeoff	Rejected TO	In-Flt Maneuv	Visual Apch	Inst Apch	Landing
3. Special effects (continued):							
e. Flap/spoiler extension buffet:							
(1) Representative [I; A2, 2j(1e)]		$X^{*,b}$			$X^{*,b}$	$X^{*,b}$	
(2) Specific [III; A3, 31)							
f. Approach-to-stall buffet:							
(1) Representative [I; A2, 2j(1f)]		X^{c}		X^{c}	X^{c}	X^{c}	X^{c}
(2) Specific [III; A3, 31]							
g. Main/nose gear touchdown bump [I; A2, 2j(1g)]							X
h. Nosewheel scuffing:							
(1) Representative [I; A2, 2j(1h)]							
(2) Specific (III; A3, 31)							
i. Thrust effect with brakes set [I; A2, 2j(1i)]							
j. Brake and tire failure dynamics (II; A2, 2k)			X^{*}				X^{*}
k. Specific high speed buffet (III; A3, 31)				$X^{*,d}$			

(Continued)

TABLE VI-11. (Continued)

Requirement	Taxi	Takeoff	Rejected TO	In-Flt Maneuv	Visual Apch	Inst Apch	Landing
3. Special effects (continued):							
l. Rough air/cobblestone turbulence (III; A3, 31)							
m. Turbulence		$X^{*,e}$			$X^{*,e}$	$X^{*,e}$	X^{*}
4. Respond to control in compliance with A3, 3i (150 ms)		X		X	X	X	X

[*]Specification derived from training requirements.

[a]These requirements resulted from an independent determination by the team members who drived simulator requirements. They did not result from the cue analysis accomplished by the SMEs during ACSD Step 5.

[b]Required when all training and checking is accomplished in a simulator.

[c]Required if buffet is the initial onset warning cue for stall.

[d]Representative buffet effects should be provided; specific effects are not required.

[e]Turbulence effects must interface with aerodynamic programming.

TABLE VI-12. AURAL REQUIREMENTS FOR TYPE A OBJECTIVES[1]

Requirement	Taxi	Takeoff	Rejected TO	In-Flt Maneuv	Visual Apch	Inst Apch	Landing
1. Communications equipment corresponding to actual airplane (NV; A1, 1e)	X	X			X	X	X
2. Sound of precipitation (II; A2, 21)							
3. Representative airplane noises:							
a. Engines (II; A2, 21)	X	X	X		X	X	X
b. Flap extension (II; A2, 21)	X	X			X	X	
c. Gear extension (II; A2, 21)	X	X			X	X	
d. Spoiler extension (II; A2, 21)					X	X	X
e. Thrust reversal (II; A2, 21)	X		X		X	X	X
4. Sound of a crash (II; A2, 21)							
5. Specific airplane noises:							
a. Precipitation (III; A3, 3n)							
b. Static discharge (III; A3, 3n)							
c. Engines (III; A3, 3n)							
d. Airframe (III; A3, 3n)							

[1]All aural requirements are derived from unique considerations when all training and checking is accomplished in a simulator.

TABLE VI-13. GENERAL REQUIREMENTS FOR TYPE B OBJECTIVES

Requirement	Takeoff	Rejected TO	Area Departure	Cruise	Emergency Descent	Area Arrival	Inst Apch
1. Specific full-scale cockpit mockup (NV; A1, 1a)	X*	X	X	X*	X	X	X
2. Functionally accurate circuit breakers (NV; A1, 1b)	X*		X	X*	X	X	X
3. Accurate instrument indications in response to control movement (NV; A1, 1d)	X*	X	X	X*	X	X	X
4. Navigation equipment corresponding to actual airplane/tolerances (NV; A1, 1e)			X			X	X
5. Accurate systems replication:							
a. Normal (NV; A1, 1g)	X*	X	X	X*	X	X	X
b. Abnormal (NV; A1, 1g)	X*	X	X	X*	X	X	X
c. Emergency (NV; A1, 1g)	X*	X	X	X*	X	X	X
6. Omega INS, EFIS, etc. (II; A2, 2m)	X[a]	X[a]	X[a]	X[a]	X[a]	X[a]	X[a]

(Continued)

TABLE VI-13. (Continued)

Requirement	Takeoff	Rejected TO	Area Departure	Cruise	Emergency Descent	Area Arrival	Inst Apch
7. Mild atmospheric disturbance	X*		X	X*	X	X	X
8. [1]Two instructor seats (NV; A1, 1f)	X*	X	X	X*	X	X	X
9. Instructor controls:							
a. Visual system (NV; A1, 1h)							
b. Abnormal/emergency conditions (NV; A1, 1h)	X*	X	X	X*	X	X	X
c. Performance measurement		X[b]					
d. Initial conditions	X*		X			X	X
10. Cue correlation: Inst/Visual/Motion/Aural	X[c]	X[c]	X[c]	X[c]	X[c]	X[c]	X[c]

*Specification derived from training requirements.

[1]A seat for the evaluator with full view of cockpit instruments is necessary; a second seat is required if a simulator operator is on board.

[a]EFIS is required if it is the flight instrument system used in the airplane.

[b]Automated performance measurement capability is required to evaluate maximal effort brake application.

[c]Flight instrument cue correlation only.

TABLE VI-14. AERODYNAMIC PROGRAMMING REQUIREMENTS FOR TYPE B OBJECTIVES

Requirement	Takeoff	Rejected TO	Area Departure	Cruise	Emergency Descent	Area Arrival	Inst Apch
1. Aerodynamic changes for normal combinations of thrust and drag (NV; A1, 1c)	X*	X	X	X*	X	X	X
2. Instrument/control force rate of change corresponds to actual rate of change caused by control inputs/ power inputs/airplane configuration (NV; A1, 1i)	X*	X	X	X*	X	X	X
3. Specific ground effect [I; A1, 1k(1)							
4. Specific ground reaction [I; A1, 1k(2)]							
5. Specific ground handling [I; A1, 1k(3)]							
6. Representative brake and tire failure dynamics (II, A2, 2k)							
7. Representative crosswind modeling (II, A3, 3a)			X[a]			X[a]	X[b]
8. Representative 3-dimensional windshear (II, A3, 3a)							

(Continued)

TABLE VI-14. (Continued)

Requirement	Takeoff	Rejected TO	Area Departure	Cruise	Emergency Descent	Area Arrival	Inst Apch
9. Low-altitude, level-flight ground effect (III; A3, 3m)							
10. High-altitude mach effect (III; A3, 3m)							
11. Specific airframe icing (III; A3, 3m)	$X^{*,c}$		X^{c}	$X^{*,c}$	$X^{*,c}$	X^{c}	X^{c}
12. Normal and reverse dynamic thrust effect on control surfaces (III; A3, 3m)							
13. Aero-elastic representations (III; A3, 3m)							
14. Side-slip nonlinearities (III; A3, 3m)							
15. Aerodynamic programming							
a. Representative	X^{*}	X	X	X^{*}	X	X	X
b. Specific							
16. Low speed buffet							

[*]Specification derived from training requirements.

[a]Wind aloft (30 knots).

[b]Wind aloft (20 knots).

[c]Effects of airframe icing can be representative; they need not be specific.

TABLE VI-15. CONTROL LOADING REQUIREMENTS FOR TYPE B OBJECTIVES

Requirement	Takeoff	Rejected TO	Area Departure	Cruise	Emergency Descent	Area Arrival	Inst Apch
1. Control forces/travel (static) corresponding to the airplane in actual flight conditions (NV; A1, 1i)	X*	X	X	X*	X	X	X
2. Representative stopping and directional control forces:							
a. Dry (II; A3, 3b)							
b. Wet (II; A3, 3b)							
c. Icy (II; A3, 3b)							
d. Patchy wet (II; A3, 3b)							
e. Patchy ice (II; A3, 3b)							
f. Wet on rubber (II; A3, 3b)							
3. Control feel dynamics (specific) (II; A3, 3g)							

*Specification derived from training requirements.

TABLE VI-16. AURAL REQUIREMENTS FOR TYPE B OBJECTIVES[1]

Requirement	Takeoff	Rejected TO	Area Departure	Cruise	Emergency Descent	Area Arrival	Inst Apch
1. Communications equipment corresponding to actual airplane (NV; A1, 1e)					X[a]		
2. Sound of precipitation (II; A2, 21)							
3. Representative airplane noises:							
a. Engines (II; A2, 21)	X	X	X	X	X	X	X
b. Flap extension/ retraction (II; A2, 21)	X					X	X
c. Gear extension/ retraction (II; A2, 21)	X					X	X
d. Spoiler extension (II, A2, 21)					X	X	
e. Thrust reversal (II; A2, 21)		X					
4. Sound of a crash (II; A2, 21)							

(Continued)

TABLE VI-16. (Continued)

Requirement	Takeoff	Rejected TO	Area Departure	Cruise	Emergency Descent	Area Arrival	Inst Apch
5. Specific airplane noises:							
a. Precipitation (III; A3, 3n)							
b. Static discharge (III; A3, 3n)							
c. Engines (III; A3, 3n)							
d. Airframe (III; A3, 3n)							

[1]Aural requirements apply only to simulators used in total simulation training programs.

[a]Replication of alternate communications systems involved in emergency descent procedures.

VII. IMPLICATIONS

Much has been written within the last decade about systematic approaches to simulator design. The approaches have ranged from those with an engineering orientation to those with a user-need orientation. Engineering approaches tend to focus on providing maximal representation of the real world in simulators, while approaches based on user needs focus on minimal simulator requirements as dictated by how, and for what, the device is to be used. Judging from simulators actually in use today, it appears that the engineering approach has dominated the design field. This, no doubt, has produced many high quality simulators, particularly when viewed from an historical perspective that takes into account the engineering capabilities available at the time simulators have been produced. However, the engineering approach can lead to very high simulator procurement and maintenance costs. Consequently, user-need approaches to simulator design have received a great deal of conceptual and theoretical interest. Many publications, a few dating from the 1950s, explain behavioral theories that provide rationales for deriving simulator requirements, and there is a wealth of highly specific, need oriented research data and anecdotal documentation that bear on simulator design issues.

One major accomplishment of the research reported here was the development and implementation of a methodology or model for Airman Certification System Development (ACSD). This model addresses user needs; but throughout its implementation there is emphasis on adequate engineering of simulators. And it is in this respect that the ACSD approach is an improvement over approaches that have stressed either engineering issues or user needs. In the past, user needs have led to "front-end" analyses, ending in definitions of "training requirements" which were to drive simulator capabilities. However, the derivations of simulator specifications from training requirements, or those entailed from user needs other than training, have been largely intuitive and often gross in nature. There have been no clear audit trails showing how, specifically, each simulator specification is driven by the intended use of the device.

Existing visual and platform motion systems are cases in point. What, specifically, is the need for a particular scene content or a given axis of platform motion? Assuming the scene content is needed, what specific perceptual characteristics must it possess? Or, assume a given axis for platform motion may be needed. What specific movement information should it simulate? Once the movement information is identified, might an alternative system for providing it be at least equally effective?

Answers to these questions require detailed audit trails if simulator capabilities are to be derived on other than a gross basis. It is not sufficient to specify only an airport scene, or three or four or six axes of platform motion. As illustrated over and over in Section VI, detailed specifications can be derived quite readily provided grounds have been clearly delineated from analyses of perceptual, cognitive, and response processes.

Herein is the basis for one major implication of the present research, one concerning existing FAA specifications for simulators that are used for pilot training and evaluations. The ACSD approach led, first, to precise specifications of what an airline transport pilot (ATP) must be able to do, and under what conditions. Then, equally precise analyses of perceptual, cognitive, and response bases for required ATP skills identified the essential dimensions of pilots' interactions with airplanes and various flight environments. Finally, necessary simulator capabilities to support the interactions became matters of matching simulator specifications to results of the dimensional analyses of perceptions, cognitions, and responses involved in ATP performance.

As a result, it was found that, when carefully and precisely stated, both checking and training purposes and objectives could be divided into two groups, based on the essential characteristics of the skills involved. In like manner, simulator requirements for ATP checks and training are separable into two groups, corresponding to the dichotomy of objectives. The designations for the classifications were Type A objectives and simulators, and Type B objectives and simulators.

These parallel dichotomies have significant implications for definitions of simulator requirements in general and for ATP checks and training in particular. A Type A simulator is an advanced technology simulator that incorporates requirements, presently listed in FAR Part 121, Appendix H, that are necessary for the certification of an airline transport pilot. At the same time, Type A criteria would eliminate those present requirements that were not found to be necessary by this study. Furthermore, by eliminating redundant tasks and conditions from crew performance objectives (CPOs), a further reduction in certain simulator special effects was possible. In this context, Type A simulator criteria avoid the underspecification or overspecification of requirements when compared with current Phase I, II, and III criteria which were developed using less comprehensive and systematic methods. (A word of caution is in order, however. This project focused only on the tasks and conditions involved in flight operations authorized by an ATP certificate. The analysis did not involve special operations such as Category II and III approaches; some of the special effects currently specified in Appendix H may be required for the training and checking necessary to support these special operations.)

As for Type B simulators, they are not addressed at all in existing FAA rules for simulators. The careful and precise analyses of ATP skill requirements, CPOs, and necessary simulator support capabilities found that considerable reductions could be made in simulated cue and response environments compared to those presently assumed necessary. So, in effect, the present research created a new, feasible and efficient category of simulation.

It can be added that the dichotomy between Type A and Type B objectives has implications in its own right. The considerations that led to the dichotomy are completely general, and they transcend not only simulation but essentially all aspects of training and its evaluation. Further, any number of different kinds of cognitive-motor skills, not just piloting, lend themselves to this useful categorization.

Similarly, the ACSD model has implications of its own. The methodology is readily adaptable to any definition of skill requirements for pilots, and to derivations of capabilities for equipment to be used for their training and evaluation. In this respect, the ACSD approach could be of much value to the FAA in other projects that seek to clarify and justify regulatory requirements, or to define new requirements in areas where they are needed but do not now exist. In fact, the results of this study, where the focus was on ATPs and the Boeing 727 as prototypical examples, are often immediately generalizable to other pilot classifications and types of airplanes. As explained in Section I, the choice of ATP certification as the specific problem for the present research was because of the potential generality of the findings. But beyond immediate general validity of the findings, results are stated in generic ways, the focus on ATPs and the B-727 notwithstanding. The results are also well organized and detailed so that in future efforts, commonalities and differences between present interim data and final products, and those entailed by a different pilot population or aircraft, can be identified with only a fraction of the effort needed to develop the prototypical findings presented here.

In this regard, future training and checking needs will be generated by changes in the national airspace system and advancements in cockpit technology. Also, as in the past, airplane accident and incident analyses will surface causal factors that have training implications. Aircrew training is the key to accident prevention. As new training and checking requirements are identified from these sources, they should be systematically processed through the ACSD model for incorporation into CPOs and to determine simulation requirements. Thus, future iterations of the ACSD process could ensure that FAA certification rules are current and that simulators are adequately and efficiently designed and used.

Still another implication of this study relates to the confirmation of the value of simulators as viewed by FAA. In fact, when the triad of ATP certification requirements--experience, training, evaluation checks--is considered overall, it is even more apparent that simulators should always fill certain vital roles. For example, the emphasis during this effort was on identifying <u>all</u> tasks and conditions for which checking and training are important. An implicit assumption was that simulation obviates the need to consider safety implications during checking and training. Yet, much of training especially involves critical phases of flight, such as takeoff, approach, and landing, occurring under highly adverse conditions, such as wind shear, flap failures, and flight control malfunctions. This type of training is neither safe nor practical to conduct in the airplane itself. Thus, simulators must be used if pilots are to learn to cope with the full spectrum of situations that they may encounter after they are licensed. The same considerations apply to some of the task-condition combinations identified as checking requirements, although to a lesser degree.

It must be acknowledged, however, that for the purpose of pilot licensing, existing FAA regulations provide the public with an option to demonstrate proficiency in the airplane itself. The use of simulators is entirely voluntary under the rules; and, indeed, simulators do not exist for some airplane types. Thus, if the use of simulators for pilot certification is to remain voluntary, and there is good reason that this should be, the FAA must deal with the dilemma that some pilots will be licensed under more stringent criteria than other pilots. Further, only those pilots choosing to use appropriate simulators can be completely trained and checked under the multifarious conditions and to the rigorous standards developed during this research project and specified in ACSD products. Pilots using only the airplane for checking and training should at least receive compensatory ground training to make the certification process as comprehensive as possible under the given constraints.

In line with the value of simulators in the certification of pilots, results of this study indicate that cost reductions are possible over and above the use of simulators in place of airplanes for checks and training. Specifically, the differentiation of Type A and Type B simulators, and precise statements of crew performance objectives, can often permit reductions in the time pilots spend in full-mission simulators, which are expensive to operate. Less sophisticated, Type B devices will be adequate for a number of purposes; and when used as envisioned here, neither evaluations nor training will be compromised.

REFERENCES

AGARD. (1980, December). Fidelity of simulation for pilot training (AGARD-AR-159). Neuilly sur Seine, France: Advisory Group for Aerospace Research and Development, NATO.

Brown, J. L. (1976). Visual elements in flight simulation. Aviation Space and Environmental Medicine, 47, 913-924.

Carey, M. S., Densmore, J. E., Jr., Kerchner, R. M., Lee, A. T., & Hughes, R. (1983, September). Effects of transport delay on simulator air-to-air engagements (AFHRL-TR-83-8). Brooks Air Force Base, TX: Air Force Systems Command.

Caro, P. W. (1977, March). Some factors influencing Air Force simulator training effectiveness (Tech. Rep. 77-2). Alexandria, VA: Human Resources Research Organization.

Caro, P. W. (1979). The relationship between flight simulator motion and training requirements. Human Factors, 21, 493-501.

Caro, P. W., Shelnutt, J. B., & Spears, W. D. (1981, January). Aircrew training devices: Utilization (Tech. Rep. AFHRL TR-80-35). Brooks AFB, TX: Air Force Human Resources Laboratory.

Caro, P. W., Spears, W. D., Isley, R. N., & Miller, E. J. (1980, December). Analysis of the design of an AH-64 combat mission simulator (Tech. Rep. TR 80-17). Pensacola, FL: Seville Research Corporation.

Cefoldo, G. L., Brady, C. J., & Knapp, R. K. (1981, June 10-12). Effects of visual and motion cues on pilot effectiveness during engine-out training. The 1981 Image Generation/Display Conference II. Scottsdale, AZ.

Gundry, J. (1976, April 8). Man and motion cues. Royal Aeronautical Society Third Flight Simulation Symposium: Theory and Practice in Flight Simulation.

Lauber, J. K., & Foushee, H. C. (1981). Guidelines for line-oriented flight training--Volumes I and II (NASA Conference Publication 2184). Washington, DC: National Aeronautics and Space Administration.

Parrish, R. V., & Bowles, R. L. (1983). Motion/visual cueing requirements for vortex encounters during simulated transport visual approach and landing (Technical Paper 2136). Hampton, VA: National Aeronautics and Space Administration, Langley Research Center.

Perry, D. H., & Naish, J. M. (1964). Flight simulation for research. Journal of the Royal Aeronautical Society, 68, 645-662.

Prophet, W. W., Shelnutt, J. B., & Spears, W. D. (1981, January). Simulator training requirements and effectiveness study (STRES): Future research plans (AFHRL TR-80-37). Brooks AFB, TX: Air Force Human Resources Laboratory.

Ricard, G. L., & Puig, J. A. (1977, March). Delay of visual feedback in aircraft simulators (NAVTRAEQUIPCEN TN-56). Orlando, FL: Naval Training Equipment Center.

Ricard, G. L., Norman, D. A., & Collyer, S. C. (1976, November). Compensating for flight simulator CGI system delays. Ninth NTEC/Industry Conference Proceedings. Orlando, FL: Naval Training Equipment Center.

Science Applications, Inc. (1983, December). Synthetic flight training system study (Final draft). Orlando, FL: Author.

Spears, W. D. (1983, November). Processes of skill performance: A foundation for the design and use of training equipment (NAVTRAEQUIPCEN 78-C-0113-4). Orlando, FL: Naval Training Equipment Center.

Spears, W. D., Marcantonio, A. W., & Smith, B. A. (1983, November). Training requirements for the B-1B simulator system, Part II (Technical Document TD 83-24). Pensacola, FL: Seville Training Systems.

Thorpe, J. A. (1978, November). Meeting report: Quantifying visual scene parameters. Washington, DC: Life Sciences Directorate, Air Force Office of Scientific Research.

Westra, D. P. (1983, September). Simulator design features for air-to-ground bombing I: Performance experiment I (NAVTRAEQUIPCEN 81-C-0105-4). Orlando, FL: Naval Training Equipment Center.

Westra, D. P., Simon, C. W., Collyer, S. C., & Chambers, W. S. (1981, December). Simulator design features for carrier landings: I. Performance experiments (NAVTRAEQUIPCEN 78-C-0060-7). Orlando, FL: Naval Training Equipment Center.

Zacharias, G. L., & Levison, W. H. (1981, June 10-12). A model-based procedure for determining visual cue requirements. The 1981 Image Generation/Display Conference II. Scottsdale, AZ.

APPENDIX A

RESULTS OF TASK ANALYSIS

This appendix contains task descriptions developed in Step 1 of the Airman Certification System Development (ACSD) process and explained in Section III. In Step 1, the duties of an airline transport pilot were grouped into ten operational flight segments. These segments were then divided into 38 component tasks. Of these, 27 tasks involving the airplane in motion were further analyzed to define beginning and ending points, behavioral activities, and performance standards.

The ten flight segments and their components tasks are:

1. Preflight

    1.1 Prepare/review flight plan
    1.2 Analyze weather and NOTAMS
    1.3 Prepare/review dispatch/flight release
    1.4 Prepare/review load manifest
    1.5 Inspect airplane documents
    1.6 Perform exterior inspection
    1.7 Perform interior inspection
    1.8 Perform preflight checks
    1.9 Perform prestart checks
    1.10 Start engines
    1.11 Perform pretaxi checks

2. Taxi

    2.1 Taxi airplane to takeoff position
    2.2 Taxi airplane to gate

3. Takeoff

    3.1 Perform takeoff ground roll
    3.2 Rotate airplane
    3.3 Control flight path during climb to airfoil cleanup point
    3.4 Control flight path during airfoil cleanup
    3.5 Reject takeoff

4. Area Departure

    4.1 Control flight path during climb to cruise altitude
    4.2 Level off at cruise altitude
    4.3 Perform holding

5. Cruise

5.1 Control flight path from begin cruise point to descent point

6. Area Arrival

6.1 Control flight path from the arrival descent point to the level-off point
6.2 Perform level off

7. Approach

7.1 Control visual approach flight path from end of level-off point to visual glidepath intercept point
7.2 Control instrument approach flight path from end of level-off point to visual glidepath intercept point or to circling approach visual transition point
7.3 Control circling approach flight path from circling approach visual transition point to visual glidepath intercept point
7.4 Control flight path from visual glidepath intercept point to landing maneuver transition point
7.5 Perform missed approach
7.6 Reject landing

8. Landing

8.1 Control flight path from landing maneuver transition point to flare point
8.2 Control flight path from flare point to initial touchdown
8.3 Control flight path from initial touchdown to start ground roll
8.4 Perform landing ground roll

9. Emergency Descent

9.1 Control flight path from emergency descent point to level-off point
9.2 Perform level-off following emergency descent

10. In-flight Maneuvers

10.1 Perform recovery from imminent stalls
10.2 Perform steep turns

The 27 task descriptions which follow are for tasks that involve the airplane in motion. Tasks 1.1 through 1.11 concern preflight activities and are not included in this appendix. The Specific Behavioral Activities listed for each task relate to B-727 airplane operations; the lists of General Behavioral Activities apply to all airplanes. These two lists describe cognitive-procedural and cognitive-motor skills for basic task performance, uncomplicated by specific task conditions. Task conditions that alter behavioral descriptions and that were selected as training or checking requirements are listed in Appendix B, and their impact on perceptual cueing and media requirements was determined in ACSD Steps 5, 6, and 7. Performance standards, which also reflect changes dictated by specific task conditions, were initially defined for each task but were later consolidated into standards for an entire flight segment. The standards appear as Appendix C.

Abbreviations used in this appendix are listed below:

AAOM	Approved airplane operating manual
AGL	Above ground level
ATC	Air traffic control
DH	Decision height
DME	Distance measuring equipment
EPR	Engine pressure ratio
FL	Flight level
fpm	Feet per minute
ILS	Instrument landing system
MDA	Minimum descent altitude
MSL	Mean sea level
NoPT	No procedure turn
NOTAM	Notice to airmen
V_r	Rotation speed
V_{ref}	Approach speed
V_{zf}	Zero flap maneuvering speed
V_2	Takeoff safety speed

TASK DESCRIPTIONS

2.1 TAXI AIRPLANE TO TAKEOFF POSITION

Begins: Initial power increase for taxi to the departure runway.

Ends: Initial power increase for takeoff.

Specific Behavioral Activities: (1) Advance the power, not to exceed maximum allowable RPM for breakaway thrust, to begin moving the airplane. Consider jet blast hazards at all times. (2) Smoothly steer the airplane into and out of turns with nosewheel steering. Ensure that the taxi area is clear of other aircraft, persons, and objects. (3) Allow the airplane to accelerate to moderate speed before using brakes to slow the speed smoothly. Do not ride the brakes. (4) Monitor and comply with all ATC instructions. (5) Do not allow performance of checklists and other duties to detract from required vigilance and control.

General Behavioral Activities: (1) Acceleration and deceleration using power and brakes. (2) Turns using nosewheel steering. (3) Taxiway centerline tracking. (4) Airport surface navigation. (5) Obstruction/ground hazards avoidance. (6) Smooth and positive manipulation of power, brakes, and nosewheel steering.

2.2 TAXI AIRPLANE TO GATE

Begins: Safe taxi turnoff speed established after landing.

Ends: Airplane stopped at gate.

Specific Behavioral Activities: (1) Taxi from the runway, without delay, at the nearest suitable taxiway. (2) If the airplane stops during taxi, advance the power to resume taxiing, considering jet blast hazards at all times. (3) Smoothly steer the airplane into and out of turns with nosewheel steering and ensure that the taxi area is clear of other aircraft, persons, and objects. (4) Allow the airplane to accelerate to moderate speed before using the brakes to slow the speed smoothly. Do not ride the brakes. (5) Monitor and comply with all ATC instructions. (6) Do not allow performance of checklists and other duties to detract from required vigilance and control.

General Behavioral Activities: (1) Acceleration and deceleration using power and brakes. (2) Turns using nosewheel steering. (3) Taxiway centerline tracking. (4) Airport surface navigation. (5) Obstruction/ground hazards avoidance. (6) Precise maneuvering and parking at gate. (7) Smooth and positive manipulation of power, brakes, and nosewheel steering.

3.1 PERFORM TAKEOFF GROUND ROLL

Begins: Initial advancement of power for takeoff.

Ends: Airplane accelerating through V_r; nosewheel on runway centerline; wings level; initial control input for rotation.

Specific Behavioral Activities: (1) Advance the power to standup position (1.4 EPR). (2) If not aligned with the runway centerline, turn the airplane using nosewheel steering until lineup is accomplished. Minimize side loads. (3) Apply forward elevator pressure to ensure positive nosewheel contact with the runway. (4) Position the ailerons as required for known crosswind. (5) Release the brakes (if applied) while simultaneously advancing the power toward the computed takeoff setting. Set final takeoff thrust by approximately 60 knots. (6) As the airplane accelerates, keep the nosewheel on the runway centerline using nosewheel steering and rudder pedal inputs. Keep the wings level with the ailerons (no spoilers).

General Behavioral Activities: (1) Power application and brake release to begin acceleration. (2) Rudder and nosewheel steering inputs for directional control to track the runway centerline. (3) Aileron inputs to keep the wings level. (4) Elevator inputs to keep the nosewheel firmly on the runway.

3.2 ROTATE AIRPLANE

Begins: Initial control input to rotate airplane.

Ends: Target pitch attitude established; wings level; landing gear retraction initiated; airspeed at V_2+10 knots minimum.

Specific Behavioral Activities: (1) At V_r, begin a smooth continuous rotation (approximately 2° per second) using the elevator to establish target pitch attitude. (2) Upon ensuring that a positive rate of climb exists, retract the landing gear. (3) Make aileron inputs to keep the wings level. (4) Modify elevator inputs to stop rotation and maintain target pitch attitude.

General Behavioral Activities: (1) Pitch changes at a constant rate. (2) Rudder pedal inputs to track runway centerline. (3) Aileron inputs to keep the wings level.

3.3 CONTROL FLIGHT PATH DURING CLIMB TO AIRFOIL CLEANUP

Begins: Target pitch attitude (rotation) established.

Ends: Initial control input for airfoil cleanup; airplane climbing through minimum altitude for airfoil cleanup (normally 1,000 feet AGL); airspeed at V_2+10 knots minimum.

Specific Behavioral Activities: (1) Adjust the pitch attitude to maintain V_2+10 knots, not to exceed maximum recommended pitch attitude. (2) Climb straight ahead to 400 feet AGL before turning to assigned heading or to intercept departure course. (3) Continue climb to 1,000 feet AGL.

General Behavioral Activities: (1) Pitch changes to maintain a constant airspeed climb. (2) Turns above 400 feet AGL to comply with ATC requirements. (3) Smooth and coordinated control manipulations.

3.4 CONTROL FLIGHT PATH DURING AIRFOIL CLEANUP

Begins: Initial control input for airfoil cleanup.

Ends: Target climb airspeed established with a clean airfoil; climb power set with a positive rate of climb.

Specific Behavioral Activities: (1) Reduce existing pitch attitude by approximately 1/3 (not to exceed 1/2) to increase speed from V_2+10 knots to V_{zf} while maintaining a rate of climb of at least 500 fpm. (2) As airspeed increases through 10 knots below minimum safe maneuvering airspeed for each flap setting, retract flaps incrementally until the flaps/leading edge devices are fully retracted. (3) As flaps/leading edge devices retract, modify elevator inputs to maintain a positive rate of climb and trim the stabilizer to neutralize control pressures. (4) After the flaps/leading edge devices are retracted, adjust pitch attitude to establish and maintain climb airspeed. (5) Make turns as required to comply with ATC clearances during and after cleanup. Use a 15° bank angle or less until reaching minimum safe maneuvering airspeed for the selected flap setting and do not exceed 30° of bank thereafter. Adjust the pitch attitude as necessary in turns to compensate for changes in the lift vector. (6) Reduce power to climb setting.

General Behavioral Activities: (1) Pitch adjustments to accelerate while maintaining a positive rate of climb and to compensate for changing lift during flap/leading edge device retraction and turns. (2) Turns to comply with ATC clearance. (3) Power changes to meet computed climb schedules. (4) Smooth and coordinated control input.

3.5 REJECT TAKEOFF

Begins: Initial control input to reject the takeoff.

Ends: Airplane stopped on the runway or taxied off the runway.

Specific Behavioral Activities: (1) Announce abort intentions to other flight crewmembers. (2) Move the throttles to idle while holding forward pressure on the yoke to keep the nosewheel firmly on the ground. (3) Apply maximum brakes as dictated by surface conditions and antiskid availability. If the runway is dry and antiskid is available, apply maximum brake pedal deflection. (4) Extend the speed brakes (spoilers), if applicable. (5) Raise the reverse thrust levers and move them aft to the spring detent, or further aft if more reverse power is required. (6) As airspeed decreases through 70 knots, move the reverse thrust levers toward the idle detent (1.2 EPR) to prevent a compressor stall. (7) At a safe taxi speed, move the reverse thrust levers to the full down position (forward idle) and note that the reverser lights are out. Reduce brake application. (8) Stop straight ahead on the runway or, conditions permitting, turn off onto an available taxiway.

General Behavioral Activities: (1) Thrust reductions to idle power. (2) Maximum braking based on surface conditions (directional control considerations) and antiskid availability. (3) Speed brake (spoiler) extension. (4) Reverse thrust application to varying degrees based on procedures, deceleration rate, airspeed, and runway remaining. (5) Rudder pedal inputs to track runway centerline until the airplane is stopped or slowed to a safe taxi speed. (6) Elevator inputs to ensure positive nosewheel contact. (7) Aileron inputs to keep wings level.

4.1 CONTROL FLIGHT PATH DURING CLIMB TO CRUISE ALTITUDE

Begins: Target climb airspeed established with a clean airfoil.

Ends: Airplane at the level-off lead point with target airspeed being maintained; initial control input to level off.

Specific Behavioral Activities: (1) Maintain target climb airspeed by adjusting the pitch attitude. Accelerate to new target climb airspeeds as altitude stratum dictates, e.g., from 200 knots (or no-flap minimum safe maneuvering speed) to 250 knots upon leaving an airport traffic area at 3,000 feet AGL, and from 250 knots to proper climb profile airspeed. (2) Accelerate the airplane by reducing the existing pitch attitude by approximately 1/2 until the new target airspeed is approached, then increase the pitch attitude to maintain the new airspeed. (3) Adjust throttle position to computed climb power settings, as necessary, during the climb. (4) Upon reaching the airspeed/Mach crossover point for the proper climb profile (approximately FL 230), adjust the pitch attitude to maintain the proper Mach number until reaching the level-off lead point for cruise altitude. (5) Perform turns as required to comply with ATC clearances using bank angles that do not exceed 30°.

General Behavioral Activities: (1) Pitch attitude adjustments to maintain constant airspeed/Mach climbs and to establish new target airspeeds. (2) Turns during climbs to comply with ATC requirements and navigational tasks. (3) Intermediate level-offs to comply with ATC clearances. (4) Smooth and coordinated control manipulation.

4.2 PERFORM LEVEL-OFF AT CRUISE ALTITUDE

Begins: Initial control input to level off.

Ends: Airplane in level flight at assigned altitude; cruise airspeed/Mach established.

Specific Behavioral Activities: (1) At the level-off lead point make elevator inputs to reduce the pitch attitude and decrease the rate of climb while allowing the airplane to accelerate. (2) Approaching the assigned altitude, further reduce the pitch attitude to decrease the rate of climb gradually to zero as the assigned altitude is reached. (3) Trim the stabilizer to neutralize elevator control forces. (4) Reduce the power to maintain cruise airspeed/Mach. (5) Perform turns as required by ATC clearances with bank angles that do not exceed 30°. Adjust elevator inputs as necessary to maintain altitude in turns.

General Behavioral Activities: (1) Pitch adjustments for the transition from climb to level flight. (2) Turns to comply with ATC clearances. (3) Power reduction to cruise setting. (4) Smooth and coordinated control manipulation.

4.3 PERFORM HOLDING

Begins: First control input to slow the airplane prior to holding fix.

Ends: Holding maneuver complete; airplane departed from the holding fix/pattern.

Specific Behavioral Activities: (1) Establish holding airspeed by reducing power and increasing the pitch attitude while maintaining altitude (use of speed brakes is optional). (2) If speed brakes are used, adjust elevator inputs to counteract pitching tendency during speed brake extension. (3) Retract speed brakes, if used, as airspeed decreases to within 10 knots of holding airspeed and adjust elevator inputs to counteract pitching tendency. (4) Upon arrival at the holding fix, turn the airplane to the required heading for a teardrop, parallel, or direct entry, as appropriate. Maintain altitude and airspeed in this and all subsequent level flight turns by adjusting pitch and power. Decrease power and pitch during rollout. (5) Maintain the entry heading for the prescribed time interval or until the proper DME indication in the case of DME holding patterns. Timing begins over or abeam the fix, whichever occurs later. (6) Turn the airplane to intercept the inbound course. (7) Begin inbound timing unless the holding pattern is defined by DME. (8) Make heading changes as necessary to track the inbound course. (9) Over the holding fix, turn the airplane to the outbound heading. (10) Maintain the outbound heading for the time required to yield the prescribed inbound time interval or until the proper DME indication in the case of DME holding patterns. Timing begins abeam the fix (or when the turn to the outbound leg is complete if a position abeam the holding fix cannot be determined). (11) Repeat activities 6 through 10 until holding is terminated. (12) Upon termination of holding, turn the airplane to a heading to comply with ATC clearance.

General Behavioral Activities: (1) Deceleration without speed brakes. (2) Deceleration with speed brakes. (3) Standard rate and/or 30° bank turns, left and right, constant airspeed. (4) Constant airspeed climbs. (5) Constant airspeed climbs while turning. (6) Constant airspeed descents without speed brakes. (7) Constant airspeed descents with speed brakes. (8) Constant airspeed descents while turning. (9) Navigational course interceptions and tracking. (10) Smooth and coordinated control manipulation.

5.1 CONTROL FLIGHT PATH FROM BEGIN CRUISE POINT TO DESCENT POINT

Begins: Cruise Mach/airspeed established in level flight.

Ends: Airplane in level flight at the descent point and target cruise airspeed maintained.

Specific Behavioral Activities: (1) Maintain assigned altitude using the elevator to change the pitch attitude resulting in a continuous series of small attitude corrections. (2) Maintain cruise airspeed by adjusting the throttles as necessary. (3) Make turns as necessary to comply with ATC clearances, using bank angles that do not exceed 30°.

General Behavioral Activities: (1) En route navigation tasks. (2) Altitude changes as directed or required. (3) Airspeed/Mach changes as directed by ATC or required to comply with flight plan. (4) Smooth and coordinated control manipulation.

6.1 CONTROL FLIGHT PATH FROM DESCENT POINT TO LEVEL-OFF POINT

Begins: Initial control input to descend.

Ends: Airplane at level-off lead point; target descent airspeed being maintained; initial control input to level off.

Specific Behavioral Activities: (1) At the appropriate descent point, reduce power to idle (or to the minimum setting consistent with pressurization considerations) while maintaining cruise Mach by making pitch adjustments. (2) If speed brakes are used (optional), make additional pitch adjustments to maintain cruise Mach with the additional drag. Use the elevator to compensate for the pitching tendency caused by speed brake deployment. After speed brake retraction, increase the pitch attitude to maintain desired Mach with reduced drag. Use the elevator to compensate for the pitching tendency caused by speed brake retraction. (3) Maintain cruise Mach while descending with idle power by adjusting the pitch attitude. (4) At the Mach/airspeed crossover point, adjust the pitch attitude to maintain the proper airspeed at a fixed power setting. (5) Approaching 10,000 feet MSL, increase the pitch attitude to establish 250 knots. (6) Descend to the appropriate level-off lead point using pitch adjustments to maintain 250 knots with idle power. (7) Make turns during the descent to intercept and track required courses or to maintain assigned headings. If speed brakes are partially deployed, less aileron input may be required for desired roll rates.

General Behavioral Activities: (1) Constant Mach descents. (2) Constant airspeed descents. (3) Constant rate (vertical speed) descents. (4) Turns to headings during descent. (5) Navigational course interception and tracking. (6) Smooth and coordinated control manipulation.

6.2 PERFORM LEVEL-OFF

Begins: Initial control input to level off.

Ends: Target maneuvering airspeed established in level flight; thrust stabilized.

Specific Behavioral Activities: (1) At 1,000 feet above the assigned altitude (level-off lead point), decrease vertical speed by increasing pitch and simultaneously increase the power to maintain airspeed. At the appropriate lead point, make a final pitch increase (approximately 1 1/4°) to decrease vertical speed to zero at the moment the assigned altitude is reached. (2) Trim the stabilizer to neutralize elevator forces and adjust the power to maintain airspeed. (3) If the level-off occurs in a turn, increase the pitch attitude sufficiently to cause vertical speed to decrease to zero at the moment the assigned altitude is reached.

General Behavioral Activities: (1) Pitch changes required to establish level flight. (2) Power changes to maintain airspeed/Mach. (3) Turns to a heading during level-off with bank angles not to exceed 30°. (4) Constant airspeed/Mach level-offs. (5) Airspeed/Mach changes during level-off. (6) Pitch changes to transition from constant airspeed descent to constant rate descent at a constant airspeed. (7) Navigational course interception and tracking.

7.1 CONTROL VISUAL APPROACH FLIGHT PATH FROM END OF LEVEL-OFF POINT TO VISUAL GLIDEPATH INTERCEPT POINT.

Begins: Target maneuvering airspeed established in level flight.

Ends: Airplane on glidepath with sufficient visual cues to control the glidepath; target airspeed established; landing configuration established.

Specific Behavioral Activities: (1) Retard the power to reduce speed for flap extension. (2) Extend speed brakes to aid in deceleration, if required. Compensate for pitching tendencies during speed brake extension and retraction by adjusting the pitch attitude. Retract the speed brakes prior to flap extension. (3) Begin flap extension; compensate for pitching moment with elevator inputs. (4) Based on desired altitude versus the distance from the runway, control the rate of descent to establish a normal glidepath. (5) Make turns as required (using bank angles up to 30°) to fly a ground track that will allow the aircraft to be positioned on the extended runway centerline at an altitude that will allow a normal descent profile (approximately a 3° glidepath) to the intended touchdown point. (6) Make throttle adjustments to maintain target maneuvering airspeeds and to reduce the airspeed for flap and landing gear extension. (7) Extend flaps on schedule as airspeed permits. (8) Extend landing gear on schedule as airspeed permits.

General Behavioral Activities: (1) Airspeed reductions with and without drag inducing devices (speed brakes, flaps/leading edge devices, and landing gear). (2) Level flight and descending turns, in both directions, using up to 30° of bank to comply with ATC clearances and to establish headings that result in a ground track that will position the aircraft on the extended runway centerline at a distance that permits a normal descent profile to the intended touchdown point. (3) Constant rate/airspeed and variable rate/airspeed descents and level-offs. (4) Combinations of all of the above. (5) Smooth and coordinated flight control manipulation.

7.2 CONTROL INSTRUMENT APPROACH FLIGHT PATH FROM END OF LEVEL-OFF POINT TO VISUAL GLIDEPATH INTERCEPT POINT OR TO CIRCLING APPROACH VISUAL TRANSITION POINT

Begins: Target maneuvering airspeed established in level flight.

Ends: Airplane on glidepath with sufficient visual cues to control the glidepath (or sufficient visual cues to control circling approach flight path) or at the missed approach point without sufficient visual cues; target approach/maneuvering airspeed established; landing/circling configuration established.

Specific Behavioral Activities: (1) Accomplish level and descending turns and level-offs required to establish and maintain assigned headings, courses, and altitudes before and during the initial and intermediate approach segment. Procedural requirements may include radar vectors, DME arcs, procedure turns, holding pattern in lieu of procedure turn, feeder routes to NoPT transitions, and other published procedures, each with possible assigned, mandatory, maximum, minimum, or recommended altitudes. (2) After passing the initial approach fix/point and at or before establishing a final intercept heading to the inbound approach course, slow the airplane for scheduled flap extension. (3) After established inbound on the final approach course and prior to reaching the final approach fix or intercepting the glide slope, extend the landing gear. Extend final flaps at the final approach fix or glide slope intercept point. (4) Upon intercepting the glide slope (precision approaches), reduce the pitch attitude to establish a rate of descent that will maintain the glidepath. At the final approach fix (nonprecision approaches), reduce the pitch attitude to establish a rate of descent that will ensure arrival at the MDA at, or prior to, a point where the MDA intercepts a normal glidepath (or for circling approaches at, or prior to, a point from which a normal circle-to-land maneuver can be accomplished). Adjust the power to establish and maintain final approach airspeed (or target maneuvering airspeed for circling approaches). (5) Approaching MDA, increase the pitch attitude to level off at MDA and continue to fly at that altitude on the final approach course until the visual glidepath intercept point, circling visual transition point, or missed approach point is reached. Increase power as necessary during the level-off to maintain target airspeed. If performing a straight-in ILS, continue descent on the glide slope to DH.

General Behavioral Activities: (1) Level and descending turns and level-offs, including side-step maneuvers to align the aircraft with a parallel runway. (2) Airspeed reductions with and without configuration changes. (3) Constant airspeed/rate and variable airspeed/rate descents. (4) Altitude changes and step-downs prior to and during the initial, intermediate, and final approach segments. (5) Combinations of all of the above.

7.3 CONTROL CIRCLING APPROACH FLIGHT PATH FROM CIRCLING APPROACH VISUAL TRANSITION POINT TO VISUAL GLIDEPATH INTERCEPT POINT

Begins: Airplane on approach course with sufficient visual cues to control the flight path.

Ends: Airplane on glidepath with sufficient visual cues to control the glidepath; target airspeed maintained; landing configuration established.

Specific Behavioral Activities: (1) Make turns as required, not exceeding a 30° bank angle, to intercept the final approach course for the landing runway. Maneuver the airplane at the MDA to remain within the circling approach area while keeping an identifiable part of the airport in sight except during normal banking maneuvers. (2) Adjust the pitch attitude to maintain the MDA and adjust power to maintain target maneuvering airspeed. (3) Prior to the visual glidepath intercept point, extend flaps to the final landing setting.

General Behavioral Activities: (1) Level-flight turns at a constant airspeed with and without flap configuration changes. (2) Maneuvering to remain within a specified radius of the airfield by continual visual reference. (3) Smooth and coordinated control manipulation.

7.4 CONTROL APPROACH PATH FROM VISUAL GLIDEPATH INTERCEPT POINT TO LANDING MANEUVER TRANSITION POINT

Begins: Airplane on glidepath with sufficient visual cues to control glidepath.

Ends: Airplane at landing maneuver transition point (LMTP) in final landing configuration, at approach speed, aligned with the runway centerline, and on a normal (approximately 3°) glidepath. (LMTP is defined as a point on final approach that is 200 feet above touchdown zone elevation or precision approach decision height, whichever is appliable.)

Specific Behavioral Activities: (1) If not established on the extended runway centerline, fly a heading that will allow a turn onto final approach course at least 1 1/2 NM from the runway threshold. (2) Extend approach flaps/leading edge devices (if not already accomplished) while adjusting power to maintain target maneuvering airspeed and adjusting pitch to establish and maintain a normal glidepath (approximately 3° from the planned touchdown point). (3) Extend the landing gear (if not already accomplished) while making power and pitch adjustments as described in the previous step. (4) Extend final landing flaps and, when the bank angle decreases through 15° (if turning), slow the airplane to final approach speed (V_{ref} plus addition for wind/abnormals/gusts). Adjust power to maintain final approach speed and adjust pitch to maintain normal glidepath. Aircraft configuration, speed, and glidepath should be stabilized as early as possible within approximately 5 NM from the threshold, but no later than 1 1/2 NM from the threshold.

General Behavioral Activities: (1) Elevator and throttle inputs to establish and maintain the glidepath and target airspeed. (2) Aileron and rudder inputs to capture and track the extended runway centerline. (3) Flight path control during changing lift and drag conditions caused by extension of flaps, slats, and landing gear, while accomplishing changes in airspeed, heading, and rate of descent. (4) Visual tracking of extended runway centerline. (5) Visual tracking of the glidepath. (6) Smooth, coordinated control manipulation.

7.5 PERFORM MISSED APPROACH

Begins: Initial control input to abandon the approach.

Ends: Airplane properly configured· target airspeed established; missed approach maneuver complete.

Specific Behavioral Activities: (1) Increase the pitch attitude as specified by the AAOM while simultaneously applying maximum power. Increase pitch promptly but not at a rate that causes the airspeed to decrease below V_{ref}. (2) When descent is stopped, retract flaps on the schedule specified by the AAOM. (3) When a positive rate of climb exists, retract the landing gear. (4) Adjust the pitch as necessary, not to exceed maximum recommended pitch attitude, to maintain V_{ref}+10 knots to airfoil cleanup altitude. (5) Accomplish required turns using bank angles that do not exceed 15° until minimum safe maneuvering airspeed for the selected configuration is reached and do not exceed 30° thereafter.

General Behavioral Activities: (1) Pitch changes to accomplish the transition from level flight or descent to a climb. (2) Constant airspeed and variable airspeed climbs straight ahead and during turns. (3) Navigational course intercepts and tracking. (4) Turns to specified headings. (5) Coordinated, positive control manipulation.

7.6 REJECT LANDING

Begins: Initial control input to abandon the landing.

Ends: Airplane at the airfoil cleanup altitude with flaps at 15° and landing gear retracted; airspeed at V_{ref}+10 knots and/or airplane at the maximum recommended pitch attitude with maximum power set.

Specific Behavioral Activities: (1) Increase the pitch attitude as specified by the AAOM while simultaneously adding maximum power. Increase pitch promptly but not at a rate that causes the airspeed to drop below V_{ref}. (2) When descent is stopped, retract the flaps on the schedule specified by the AAOM. (3) When a positive rate of climb is established, retract the landing gear. (4) Adjust the pitch attitude as necessary, but not to exceed maximum recommended pitch attitude, to maintain V_{ref}+10 knots to airfoil cleanup altitude. (5) Accomplish required turns using bank angles that do not exceed 15° until at least the minimum safe maneuvering airspeed for the selected configuration is reached and do not exceed 30° thereafter.

General Behavioral Activities: (1) Pitch changes to accomplish the transition from a descent to a climb. (2) Constant and variable airspeed climbs straight ahead and during turns. (3) Smooth, coordinated control manipulation. (4) Visual tracking of the runway centerline.

8.1 CONTROL FLIGHT PATH FROM LANDING MANEUVER TRANSITION POINT TO FLARE POINT

Begins: Airplane at the landing maneuver transition point.

Ends: Target airspeed established; landing configuration established; initial control input for flare.

Specific Behavioral Activities: (1) Adjust the pitch attitude as necessary to control the rate of descent to maintain the desired glidepath to the intended touchdown point. (2) Adjust the power to maintain target final approach airspeed. (3) Make coordinated aileron and rudder inputs to maintain, or correct toward, the extended runway centerline. Avoid spoiler-induced lateral oscillations.

General Behavioral Activities: (1) Coordinated aileron and rudder inputs to maintain the runway centerline ground track. (2) Small pitch changes for glidepath control. (3) Small throttle adjustments for airspeed control. (4) Smooth and positive control manipulations. (5) Visual tracking of extended runway centerline. (6) Visual tracking of the glidepath.

8.2 CONTROL FLIGHT PATH FROM FLARE POINT TO INITIAL TOUCHDOWN

Begins: Initial control input for flare.

Ends: First gear contact with runway; longitudinal axis aligned with runway centerline.

Specific Behavioral Activities: (1) Gradually increase the pitch attitude while moving the throttles toward idle. The resulting pitch attitude should permit initial touchdown on the main landing gear at a rate of descent that does not result in a hard landing or bounce and does not result in excessive floating. Smoothly retard the throttles to idle no later than immediately after initial touchdown. (2) Make aileron and rudder inputs to neutralize crab angle and prevent lateral drift prior to initial touchdown. Keep the wings level to the extent possible considering the need for zero drift at initial touchdown.

General Behavioral Activities: (1) Pitch changes to decrease rate of descent and to establish proper landing attitude. (2) Power reductions to minimize float. (3) Aileron and rudder inputs to align the longitudinal axis with the runway centerline and to prevent drift. (4) Smooth, positive, and timely control manipulation. (5) Visual tracking of the runway centerline.

8.3 CONTROL FLIGHT PATH FROM INTITIAL TOUCHDOWN TO START GROUND ROLL

Begins: First gear contact with runway.

Ends: Last gear contact with runway.

Specific Behavioral Activities: (1) Level wings (if crosswind correction is applied) allowing opposite (downwind) main gear tires to touchdown. (2) Ensure thrust levers are retarded to idle. (3) Apply forward elevator control to lower nose. (4) Move speed brake/spoiler handle to full aft or confirm auto spoiler action, if applicable. (5) While lowering the nose gears to the runway, move reverser levers up and aft firmly against reverser interlock stops. Hold firm pressure until reverser operating indicators illuminate or until a crewmember verifies thrust reversal. (6) When all reversers are operational, apply reverse thrust by continuous aft lever movement to the spring detent. (7) Begin brake application when the nosewheels are in positive contact with the runway. (8) Continue tracking runway centerline with rudder.

General Behavioral Activities: (1) Centerline tracking with rudder. (2) Reduction of forward engine thrust; actuation of speed brakes/spoilers. (3) Reverse thrust and braking initiation. (4) Smooth, positive, and timely control manipulation.

8.4 PERFORM LANDING GROUND ROLL

Begins: Last gear contact with runway.

Ends: Safe turn-off taxi speed attained (approximately 40 knots).

Specific Behavioral Activities: (1) Extend speed brakes (spoilers) if not already extended. (2) As the nosewheel contacts the runway and nosewheel steering becomes available, make rudder pedal inputs as required to track runway centerline while simultaneously applying nose-down elevator input to ensure positive nosewheel contact for steering effectiveness. (3) Pull reverse levers aft to apply reverse thrust and adjust lever position to prevent exceeding maximum EPR limit. (4) Apply brakes as required based on runway length remaining, desired turnoff point, surface conditions, and deceleration rate. (5) Make aileron inputs as necessary to keep the wings level. (6) Decelerating through 70 knots, advance the reverse levers to 1.2 EPR by 60 knots, and to idle reverse (or below) by the time a safe taxi speed is attained. Continue moving the reverse levers forward to the stowed position.

General Behavioral Activities: (1) Rudder pedal inputs to track the runway centerline. (2) Elevator inputs to ensure positive pressure on the nosewheel. (3) Aileron inputs to keep the wings level. (4) Brake and reverse thrust application to decelerate the airplane to a safe taxi speed. (5) Visual tracking tasks. (6) Positive and timely control manipulation.

9.1 CONTROL FLIGHT PATH FROM EMERGENCY DESCENT POINT TO LEVEL-OFF POINT

Begins: Initial control input for emergency descent.

Ends: Airplane at level-off lead point; thrust at idle; speed brakes deployed, if appropriate; initial control input to level off from emergency descent.

Specific Behavioral Activities: (1) Don oxygen mask and establish alternate means of internal and external communication. (2) Reduce all engine thrust levers to idle. (3) Deploy speed brakes to decrease lift and increase drag. Consider extending gear if conditions require or permit (i.e., turbulence or structural damage requiring a slower Mach/airspeed). (4) Disengage autopilot. (5) Decrease pitch attitude, simultaneously rolling into a bank to minimize negative G forces and to depart the airway (other air traffic considerations). (6) Descend at the recommended Mach to the indicated airspeed crossover point. (7) Descend at the recommended indicated airspeed to 2,000 feet above the intended level-off altitude.

General Behavioral Activities: (1) Banking activities to assist in rapid pitch decrease. (2) Turns to accommodate traffic and navigational considerations. (3) Constant Mach descent. (4) Constant airspeed descent. (5) Pitch changes to capture and hold specific Mach and indicated airspeed. (6) Coordinated, positive control manipulation.

9.2 PERFORM LEVEL-OFF FOLLOWING EMERGENCY DESCENT

Begins: Initial control input to level off from emergency descent.

Ends: Target maneuvering airspeed established in level flight; speed brakes retracted; thrust stabilized.

Specific Behavioral Activities: (1) At 2,000 feet above the assigned altitude (level-off lead point), gradually decrease existing nose down pitch attitude by 1/2. (2) At approximately 1,000 feet above the intended level-off altitude, retract the speed brakes. (3) At 1,000 feet above the intended level-off altitude, adjust pitch to decrease vertical speed and increase power to maintain desired airspeed. At the appropriate lead point, increase pitch (approximately 1 1/4°) to decrease vertical speed to zero at the moment the assigned altitude is reached. (4) Trim the stabilizer to neutralize elevator forces and adjust power to maintain airspeed.

General Behavioral Activities: (1) Pitch changes required to establish level flight. (2) Power changes to establish and maintain airspeeds. (3) Turns to a heading during level-off with bank angles not to exceed 30°. (4) Constant airspeed level-off. (5) Airspeed changes during level off. (6) Pitch changes to accomplish the transition from a constant airspeed descent to constant rate descent. (7) Smooth and coordinated control manipulation.

10.1 PERFORM RECOVERY FROM IMMINENT STALLS

Begins: First positive indication of imminent stall.

Ends: First power reduction following recovery; airplane at maneuvering airspeed at the assigned altitude and wings level.

Specific Behavioral Activities: (1) Enter the maneuver stabilized on altitude and heading in coordinated flight and in the proper configuration. (2) Reduce power and make pitch changes to maintain altitude while establishing the appropriate configuration. (3) Maintain heading, or the target bank angle, as dictated by the maneuver. (4) On the first positive indication of imminent stall, advance the throttles to the computed takeoff power setting. (5) Adjust pitch to maintain the target pitch attitude for recovery while establishing the appropriate recovery configuration. (6) Smoothly level the wings if an entry bank angle was used, or maintain heading if an entry bank angle was not used. (7) As target airspeed is attained, adjust the pitch to climb to the entry altitude. (8) Reduce power to maintain maneuvering airspeed upon completion of stall recovery.

General Behavioral Activities: (1) Airspeed reductions with and without drag inducing devices (speedbrakes, flaps/leading edge devices, and landing gear). (2) Level flight, with and without turns using up to 15° of bank, during airspeed reductions. (3) Airspeed increases with and without airplane configuration changes. (4) Constant airspeed climbs. (5) Smooth and coordinated flight control manipulation.

10.2 PERFORM STEEP TURNS

Begins: Initial aileron input to establish turn.

Ends: Airplane in wings-level, stabilized flight at the target airspeed and on assigned altitude.

Specific Behavioral Activities: (1) Establish a constant roll rate with the ailerons to increase bank angle to 45°; adjust pitch to maintain altitude. (2) Adjust pitch and power to maintain altitude and airspeed during the turn. (3) At the appropriate lead point, establish a constant roll rate with the ailerons to decrease bank angle and to attain wings-level flight when the target heading is attained. (4) Adjust pitch and power to maintain altitude and airspeed during rollout.

General Behavioral Activities: (1) Constant roll rates into and out of 45° bank angles. (2) Constant airspeed turns. (3) Constant altitude turns. (4) Smooth and coordinated flight control manipulation.

APPENDIX B

CONDITIONS FOR TASK PERFORMANCE

This appendix contains matrices showing environmental conditions, equipment malfunctions, and special maneuvering requirements that may be imposed on task performance as determined during ACSD Steps 1 and 2, Section III of the text. There is a separate table for each of 10 segments as follows:

Table	Segment
B-1	Preflight
B-2	Taxi
B-3	Takeoff
B-4	Area departure
B-5	Cruise
B-6	Area arrival
B-7	Approach
B-8	Landing
B-9	Emergency descent
B-10	In-flight maneuvers

A comprehensive list of conditions that were considered appears first, followed by the matrices. The following notes explain how to interpret the matrices.

<u>Acc/Inc Data</u> - an X is placed in this column if the condition is a causal factor in an air carrier accident or incident reviewed during Step 2.

<u>NTSB/ACOB</u> - a T (recommended training) or C (recommended checking) is placed in this column if the condition is recommended for training or checking by an NTSB Safety Recommendation or required by an FAA Air Carrier Operations Bulletin (ACOB).

<u>Criticality</u> - an X is placed in this column if the condition significantly affects the criticality of a segment. The basic criticality rating for the segment is given at the top of the matrix.

<u>Frequency</u> - the frequency of occurrence of each condition is indicated by L (low), M (moderate), or H (high).

<u>Difficulty</u> - the effect of each condition on segment difficulty is indicated by 1 (significant impact on difficulty), 2 (moderate impact on difficulty), or 3 (slight or no impact on difficulty). Basic psychomotor and procedural difficulty ratings are given at the top of each matrix.

FAR Precedent - a T appears in this column if the condition is currently required for training but not checking; a C in this column indicates the condition is required for both checking and training.

Checking/Training/Experience - an X is placed in these columns to indicate the classification of the condition as a result of the analysis performed in ACSD Step 2.

TASK CONDITIONS

Environmental Conditions

Surface contaminants (wet)
Surface contaminants (icy)
Wind aloft (direction/velocity)
Surface wind (head wind)
Surface wind (crosswind)
Surface wind (tail wind)
Wind gusts
Wind shear
Turbulence
Density altitude
Mild atmospheric disturbance
Thunderstorms
Ceiling
Restricted visibility
Engine icing
Airframe icing
Night
Nonstandard airport lighting

Equipment Malfunctions

Communication failures
Navigational inaccuracies
Flight instrument failures
Engine instrument failures
High-lift device failures
Landing gear failures
Brake and tire failures
Nosewheel steering failure
Tailskid retraction failure
Hydraulic failure (total)
Hydraulic failure (partial)
Flight control failure
Autopilot malfunctions
Fuel imbalance
CDL/missing components
Thrust reverser malfunctions
Power plant failure (single)
Power plant failure (multiple)
Nonaerodynamic system failures

Special Maneuvering Requirements

Reverse taxi
Partial power taxi
Maximum gross weight
Extreme center of gravity
Reduced power operations
Short/narrow runways
Complex navigation
Obstructions (obstacles, terrain)
Conflicting air traffic
Landing illusions
Sloping runways

TABLE B-1. CONDITIONS FOR PREFLIGHT

Criticality: Not rated Psychomotor Difficulty: Not applicable Procedural Difficulty: Not rated	ACC/INC Data	NTSB/ACOB	Criticality	Frequency	Difficulty	FAR Precedent	Checking	Training	Experience
Surface contaminants (wet)								X	
Surface contaminants (icy)								X	
Wind aloft (direction/velocity)									X
Surface wind (head wind)									X
Surface wind (crosswind)									X
Surface wind (tail wind)								X	
Wind gusts									X
Wind shear									X
Turbulence									X
Density altitude								X	
Thunderstorms									X
Ceiling									X
Restricted visibility									X
Engine icing								X	
Airframe icing								X	
CDL/missing components								X	
Maximum gross weight								X	
Extreme center of gravity								X	
Reduced power operations								X	
Short/narrow runways								X	
Complex navigation									X
Obstructions									X
Sloping runways								X	

Note: Criticality, frequency, and difficulty were not rated for conditions affecting preflight tasks. Conditions required for training are intended to ensure competence in computing specific airplane performance.

TABLE B-2. CONDITIONS FOR TAXI

Criticality: Moderate Psychomotor Difficulty: Low Procedural Difficulty: Low	ACC/INC Data	NTSB/ACOB	Criticality	Frequency	Difficulty	FAR Precedent	Checking	Training	Experience
Surface contaminants (wet)				H	3				X
Surface contaminants (icy)			X	L	2				X
Surface wind (head wind)				H	3				X
Surface wind (crosswind)				H	3				X
Surface wind (tail wind)				H	3				X
Wind gusts				H	3				X
Density altitude				M	3				X
Restricted visibility			X	M	2				X
Engine icing				M	2	T	*	X	
Airframe icing				M	3	T	*	X	
Night				H	2				X
Nonstandard airport lighting				L	2				X
Communication failures			X	L	2				X
Brake and tire failures			X	L	2			X	
Nosewheel steering failure			X	L	2			X	
Hydraulic failure (total)			X	L	2	T		X	
Hydraulic failure (partial)				L	3	T		X	
Nonaerodynamic system failures			X	L	2	T	*	X	
Reverse taxi				H	2			X	
Partial power taxi				H	3				X
Maximum gross weight				H	3				X
Extreme center of gravity				M	3				X
Obstructions	X		X	H	2				X

*As required to evaluate airplane systems operation.

TABLE B-3. CONDITIONS FOR TAKEOFF (INCLUDES: REJECTED TAKEOFF)

Criticality: High Psychomotor Difficulty: Moderate Procedural Difficulty: Low (Rejected takeoff: Moderate)	ACC/INC Data	NTSB/ACOB	Criticality	Frequency	Difficulty	FAR Precedent	Checking	Training	Experience
Surface contaminants (wet)		T	X	M	2			X	
Surface contaminants (icy)		T	X	L	1			X	
Wind aloft (direction/velocity)				H	3				X
Surface wind (head wind)				H	3				X
Surface wind (crosswind)			X	H	2	C	X		
Surface wind (tail wind)			X	L	2				X
Wind gusts			X	H	2			X	
Wind shear	X	T	X	L	1			X	
Turbulence			X	M	2			X	
Mild atmospheric disturbance				H	2		X		
Density altitude			X	H	2				X
Thunderstorms			X	M	2			X	
Ceiling	X		X	H	2	C	X		
Restricted visibility	X		X	M	2		X		
Engine icing	X	T	X	L	2	T	*	X	
Airframe icing	X	T	X	L	2	T	*	X	
Night				H	2	T			X
Nonstandard airport lighting			X	L	2				X
Communication failures			X	L	2				X
Flight instrument failures			X	L	2	T	*	X	
Engine instrument failures				L	2	T	*	X	
High-lift device failures			X	L	2	T		X	
Landing gear failures			X	L	2	T		X	
Brake and tire failures**		T	X	L	1			X	
Nosewheel steering failure			X	L	2			X	
Tailskid retraction failure				L	3			X	
Hydraulic failure (total)			X	L	1	T		X	
Hydraulic failure (partial)			X	L	2	T		X	
Flight control failures			X	L	2	T		X	
Fuel imbalance			X	L	2				X
CDL/missing components			X	L	2			X	
Thrust reverser malfunctions**		T	X	L	2	T		X	
Power plant failure (single)		C	X	L	1	C	X		
Nonaerodynamic system failures			X	L	2		*	X	
Maximum gross weight		T	X	H	2			X	
Extreme center of gravity		T	X	M	2			X	
Reduced power operations			X	H	2			X	
Short/narrow runways			X	M	2				X
Complex navigation				M	2				X
Obstructions			X	M	2				X
Conflicting air traffic			X	M	2				X
Sloping runways			X	H	2				X

*As required to evaluate airplane systems operations.
**Rejected takeoff only.

TABLE B-4. CONDITIONS FOR AREA DEPARTURE

Criticality: Low Psychomotor Difficulty: Low Procedural Difficulty: Low	ACC/INC Data	NTSB/ACOB	Criticality	Frequency	Difficulty	FAR Precedent	Checking	Training	Experience
Wind aloft (direction/velocity)				H	3		X		
Wind shear			X	L	2			X	
Turbulence	X		X	M	2			X	
Mild atmospheric disturbance				H	2		X		
Thunderstorms		T	X	M	1			X	
Restricted visibility				H	2	C	X		
Engine icing	X	T	X	M	2	T	*	X	
Airframe icing	X	T	X	M	2	T	*	X	
Night				H	3				X
Communication failures				L	2	T			X
Flight instrument failures		C		L	2	T	*	X	
Engine instrument failures				L	3	T	*	X	
Tailskid retraction failure				L	2	T		X	
Hydraulic failure (total)			X	L	2	T		X	
Hydraulic failure (partial)				L	2	T		X	
Flight control failures			X	L	2	T		X	
Autopilot malfunctions			X	L	2	T		X	
Fuel imbalance				L	2	T			X
CDL/missing components				L	2			X	
Power plant failure (single)			X	L	2	T		X	
Nonaerodynamic system failures			X	L	2	C	*	X	
Maximum gross weight				H	3			X	
Extreme center of gravity			X	L	3			X	
Complex navigation				M	3		X		
Conflicting air traffic			X	M	2				X

*As required to evaluate airplane systems operations.

TABLE B-5. CONDITIONS FOR CRUISE

Criticality: Low Psychomotor Difficulty: Low Procedural Difficulty: Moderate	ACC/INC Data	NTSB/ACOB	Criticality	Frequency	Difficulty	FAR Precedent	Checking	Training	Experience
Wind aloft (direction/velocity)				H	3				X
Turbulence				L	2				X
Thunderstorms		T	X	M	2			X	
Restricted visibility				M	3				X
Engine icing			X	M	2	T		X	
Airframe icing			X	M	2	T		X	
Night				H	3				X
Communication failures			X	L	3	T			X
Flight instrument failures				L	2	T		X	
Engine instrument failures				L	2	T		X	
Hydraulic failure (total)			X	L	1	T		X	
Hydraulic failure (partial)			X	L	2	T		X	
Flight control failures			X	L	2	T		X	
Autopilot malfunctions			X	L	2	T		X	
Fuel imbalance				L	3	T			X
CDL/missing components				L	2			X	
Power plant failure (single)			X	L	2	T		X	
Power plant failure (multiple)			X	L	2	T		X	
Nonaerodynamic system failures			X	L	2	T		X	
Maximum gross weight				H	3			X	
Extreme center of gravity				M	3				X
Complex navigation				M	3			X	
Conflicting air traffic			X	M	3				X

TABLE B-6. CONDITIONS FOR AREA ARRIVAL

Criticality: Moderate Psychomotor Difficulty: Low Procedural Difficulty: Moderate	ACC/INC Data	NTSB/ACOB	Criticality	Frequency	Difficulty	FAR Precedent	Checking	Training	Experience
Wind aloft (direction/velocity)				H	3		X		
Turbulence				M	2			X	
Mild atmospheric disturbance				H	2		X		
Thunderstorms		T	X	M	2			X	
Restricted visibility				M	2	C	X		
Engine icing		T	X	M	2	T	*	X	
Airframe icing		T	X	M	2	T	*	X	
Night				H	2				X
Communication failures				L	2	T			X
Flight instrument failures		C		L	2	T	*	X	
Engine instrument failures				L	3	T	*	X	
Hydraulic failure (total)			X	L	1	T		X	
Hydraulic failure (partial)				L	2	T		X	
Flight control failures			X	L	2	T		X	
Autopilot malfunctions			X	L	2	T		X	
Fuel imbalance				L	2	T			X
CDL/missing components				L	2			X	
Power plant failure (single)			X	L	2	T		X	
Power plant failure (multiple)			X	L	1	T		X	
Nonaerodynamic system failures			X	L	2	C	*	X	
Extreme center of gravity				L	3				X
Complex navigation			X	M	2		X		
Obstructions			X	M	2				X
Conflicting air traffic			X	M	2				X

*As required to evaluate airplane systems operation.

TABLE B-7. CONDITIONS FOR APPROACH
(INCLUDES MISSED APPROACH/REJECTED LANDING)

Criticality: Moderate
Psychomotor Difficulty: Moderate
Procedural Difficulty: High

	ACC/INC Data	NTSB/ACOB	Criticality	Frequency	Difficulty	FAR Precedent	Checking	Training	Experience
Wind aloft (direction/velocity)			X	H	2		X		
Wind gusts			X	M	2			X	
Wind shear		T	X	L	1			X	
Turbulence	X		X	M	2			X	
Mild atmospheric disturbance				H	2		X		
Density altitude			X	M	2				X
Thunderstorms		T	X	M	2			X	
Ceiling			X	M	2	C	X		
Restricted visibility			X	M	2		X		
Engine icing	X	T	X	M	2	T	*	X	
Airframe icing	X	T	X	M	2	T	*	X	
Night			X	H	2				X
Communication failures			X	L	2	T			X
Navigation inaccuracies			X	L	2		X		
Flight instrument failures		C	X	L	1	T	*	X	
Engine instrument failures				L	3	T	*	X	
High-lift device failures	X		X	L	1	C	X		
Landing gear failures	X		X	L	1			X	
Hydraulic failure (total)	X		X	L	1	T		X	
Hydraulic failure (partial)			X	L	2	T		X	
Flight control failures		T	X	L	1	T		X	
Autopilot malfunctions			X	L	1	T		X	
Fuel imbalance			X	L	2	T			X
CDL/missing components			X	L	2			X	
Power plant failure (single)	X		X	L	2	C	X		
Power plant failure (multiple)			X	L	1	C	X		
Nonaerodynamic system failures			X	L	2	C	*	X	
Maximum gross weight			X	L	2			X	
Extreme center of gravity			X	L	2			X	
Complex navigation			X	H	2	C	X		
Obstructions			X	M	2				X
Conflicting air traffic	X		X	M	2				X

*As required to evaluate airplane systems operations.

TABLE B-8. CONDITIONS FOR LANDING

Criticality: High
Psychomotor Difficulty: High
Procedural Difficulty: High

	ACC/INC Data	NTSB/ACOB	Criticality	Frequency	Difficulty	FAR Precedent	Checking	Training	Experience
Surface contaminants (wet)		T	X	M	2			X	
Surface contaminants (icy)			X	L	1			X	
Surface wind (head wind)				H	3				X
Surface wind (crosswind)			X	H	2	C	X		
Surface wind (tail wind)			X	M	2			X	
Wind gusts			X	M	2			X	
Wind shear	X	T	X	L	1			X	
Turbulence	X		X	M	2			X	
Mild atmospheric disturbance				H	2		X		
Density altitude			X	M	2				X
Restricted visibility			X	M	1			X	
Engine icing	X	T	X	M	2	T	*	X	
Airframe icing	X	T	X	M	2	T	*	X	
Night			X	H	2	T		X	
Nonstandard airport lighting			X	L	2				X
Communication failures			X	L	2	T			X
High-lift device failures	X		X	L	1			X	
Brake and tire failures	X		X	L	1			X	
Nosewheel steering failure			X	L	2			X	
Hydraulic failure (total)	X		X	L	1	T		X	
Hydraulic failure (partial)	X		X	L	2	T		X	
Flight control failures			X	L	2	T		X	
Autopilot malfunctions			X	L	2	T		X	
Fuel imbalance			X	L	2	T			X
CDL/missing components			X	L	2			X	
Thrust reverser malfunctions	X		X	L	2			X	
Power plant failure (single)	X	T	X	L	2			X	
Power plant failure (multiple)	X		X	L	1	C	X		
Nonaerodynamic system failures			X	L	2	T	*	X	
Maximum gross weight			X	L	2			X	
Extreme center of gravity			X	L	2			X	
Short/narrow runways			X	L	1				X
Obstructions			X	L	1				X
Landing illusions			X	L	1			X	
Sloping runways			X	L	2				X

*As required to evaluate airplane systems operations.

TABLE B-9. CONDITIONS FOR EMERGENCY DESCENT

Criticality: High Psychomotor Difficulty: Moderate Procedural Difficulty: Moderate	ACC/INC Data	NTSB/ACOB	Criticality	Frequency	Difficulty	FAR Precedent	Checking	Training	Experience
Wind aloft (direction/velocity)				H	3				X
Turbulence			X	M	2			X	
Mild atmospheric disturbance				H	2		X		
Thunderstorms			X	L	1			X	
Restricted visibility			X	L	2	C	X		
Engine icing			X	L	2			X	
Airframe icing			X	L	2			X	
Night			X	H	2				X
Communication failures				L	2				X
CDL/missing components			X	L	2			X	
Power plant failure (single)			X	M	2			X	
Power plant failure (multiple)			X	M	1			X	
Nonaerodynamic system failures	X		X	L	2	C	X		
Obstructions			X	M	2				X
Conflicting air traffic			X	L	2				X

TABLE B-10. CONDITIONS FOR IN-FLIGHT MANEUVERS
(STALLS, STEEP TURNS, SPECIFIC FLIGHT CHARACTERISTICS)

Criticality: High Psychomotor Difficulty: Moderate Procedural Difficulty: Low	ACC/INC Data	NTSB/ACOB	Criticality	Frequency	Difficulty	FAR Precedent	Checking	Training	Experience
Wind aloft (direction/velocity)				H	3				X
Density altitude			X	M	2				X
Restricted visibility			X	M	2	C	X		
Night			X	M	2				X
Power plant failure (single)		T	X	L	2			X	
Maximum gross weight			X	M	2			X	
Extreme center of gravity			X	M	2			X	
Obstructions			X	M	2				X

APPENDIX C

CRITERION PERFORMANCE STANDARDS

This appendix contains criterion standards for measuring pilot performance during ATP practical tests as described in Section IV of the text. The standards may also be used to determine proficient performance of tasks specified in the training CPOs; however, some relaxation of tolerances may be necessary due to the demanding nature of certain task-condition combinations. Performance standards are given for each evaluation CPO listed below.

1. Preflight
2. Taxi
3. Takeoff
4. Rejected takeoff
5. Area departure
6. Area arrival
7. Approach
8. Landing
9. Emergency descent
10. In-flight maneuvers
11. Systems operations
12. Cockpit resource management

Note that rejected takeoff standards are listed separately for clarity. Also, the last two sets of standards are not discussed in Section IV nor are they supported by task descriptions in Appendix A. Airplane systems operations and cockpit resource management are functions involved in all flight operations. Thus, these two sets of standards are general in nature and are designed as overlays to the other standards listed in this appendix.

Standards address parameters for measuring procedural and psychomotor skills and list tolerances for the performance of these skills, when appropriate. Tolerances for psychomotor parameters, e.g., heading control, altitude control, airspeed control, etc., are based on smooth air and good flying conditions. Adjustments to these tolerances are listed for various environmental conditions, equipment malfunctions, and emergency situations. Deviation from the specified tolerances during testing is not indicative of unsatisfactory performance if the pilot makes immediate and positive corrections. During the practical test, the applicant is expected to comply with the Federal Aviation Regulations, procedures in the Airman's Information Manual, and limitations in the Airplane Flight Manual or its equivalent.

Abbreviations used in this appendix are defined below:

AAOM	Approved airplane operating manual
AFM	Airplane flight manual
AGL	Above ground level
AIM	Airman Information Manual
ASR	Area surveillance radar
ATC	Air traffic control

CDI	Course deviation indicator
CVFP	Charted visual flight procedure
DH	Decision height
DME	Distance measuring equipment
FAR	Federal Aviation Regulations
FL	Flight level
fpm	Feet per minute
IAP	Instrument approach procedure
IFR	Instrument flight rules
ILS	Instrument landing system
LMTP	Landing maneuver transition point
MDA	Minimum descent altitude
MSL	Mean sea level
NoPT	No procedure turn
NM	Nautical mile
PAR	Precision approach radar
SID	Standard instrument departure procedure
SM	Statute mile
STAR	Standard arrival procedure
RVR	Runway visual range
VASI	Visual approach slope indicator
VDP	Visual descent point
V_r	Rotation speed
V_{ref}	Approach speed
V_1	Takeoff decision speed
V_2	Takeoff safety speed

1. PREFLIGHT

Altitude: Not applicable.

Airspeed: Not applicable.

Heading: Not applicable.

Bank angle: Not applicable.

Rate of climb/rate of descent: Not applicable.

Control manipulation: Not applicable.

FAR/ATC compliance:

1. Applicant uses all available flight planning information in preparation for the flight.

2. Flight plan includes all information required by the FAR.

3. Applicant makes proper determination of the airworthiness of the airplane.

4. Applicant ensures the availability and currency of all flying equipment, aeronautical charts, and data.

5. Applicant ensures that the fuel supply meets at least the minimum quantity specified by the FAR.

AIM compliance:

1. Preflight actions, preparation, and planning accomplished in accordance with recommended practices and procedures in the AIM.

2. ATC notified prior to engine start, when required.

AAOM compliance:

1. Flight preparation, inspections, checks, and engine start conducted in accordance with procedures specified in the AAOM.

Course deviation: Not applicable.

IAP compliance: Not applicable.

Other procedural compliance:

1. Applicant ensures coordination with ground crew or ensures proper clearance prior to moving doors, hatches, or control surfaces that could cause injury.

2. Applicant ensures proper clearance and coordination with ground crew prior to engine start.

Cognitive:

1. Preflight planning includes options for contingencies such as weather or traffic delays.

2. Applicant ensures accurate coordination of personnel and activities to prevent ground operation hazards.

2. TAXI

Altitude: Not applicable.

Airspeed:

1. Not to exceed a safe taxi speed considering surface conditions; proximity to other aircraft, persons, or objects; taxiway width; and turn radius.

Heading:

1. Taxi path provides safe margin of clearance from other aircraft, persons, and objects. Taxiway centerline track maintained.

Bank angle: Not applicable.

Rate of climb/rate of descent: Not applicable.

Control manipulation:

1. Performed in a smooth, timely manner.

2. Brakes applied smoothly and only as needed. Pilot does not "ride" the brakes.

FAR/ATC compliance:

1. Taxi conducted in compliance with the FAR and ATC clearances. Consideration is given to taxiway hold lines and ILS localizer and glide slope critical areas.

AIM compliance:

1. Taxi conducted in accordance with the recommended procedures in the AIM.

2. After landing at an airport with an operating control tower, taxi conducted so as to exit the runway without delay at the nearest suitable taxiway unless ATC instructs otherwise.

AAOM compliance:

1. Taxi conducted in accordance with the AAOM, including taxi speeds, power settings, use of brakes, nosewheel steering, and other procedures and recommendations.

2. Taxi conducted in compliance with the operating limitations of the AFM or its equivalent.

3. Breakaway power and power during taxi/turns does not exceed that recommended in the AAOM in consideration of jet blast hazards.

Course deviation: Not applicable.

IAP compliance: Not applicable.

Other procedural compliance: None

Cognitive:

1. Applicant demonstrates proper judgment concerning safe margins from other aircraft, persons, and objects.

2. Applicant demonstrates proper judgment concerning turning radius, start-turn points, and main landing gear position during turns.

3. Applicant demonstrates proper judgment regarding control of taxi speed.

4. Applicant demonstrates proper judgment in maintaining vigilance and control while checklists and other duties are performed.

3. TAKEOFF

Altitude: Not applicable.

Airspeed:

1. Rotation commenced promptly at, but not before, V_r; and rotation rate allows airspeed to increase to at least V_2+10 knots at 35 feet AGL. (Engine failure at V_1: Rotation commenced promptly at, but not before, V_r; and rotation rate allows airspeed to increase to V_2 at 35 feet AGL.)

2. Unless maximum recommended pitch attitude results in a higher airspeed, $\pm$ 10 knots of target climb airspeed but not below V_2+10 knots. (Engine failure: $\pm$ 5 knots of target climb airspeed unless maximum recommended pitch attitude results in a higher airspeed. Turbulence: minimal airspeed deviations consistent with procedures for flight in turbulence contained in the AAOM.)

3. Airspeed constantly increasing during flap and leading edge device retraction to at least minimum safe maneuvering airspeed for the clean configuration.

Heading:

1. Appropriate centerline track maintained during ground roll and rotation.

2. After liftoff, heading controlled within $\pm$ 10° of the heading required to track the runway centerline (extended) until the first turn is initiated.

3. $\pm$ 10° of assigned or published headings. (Turbulence: minimal heading deviations to the extent possible without overcontrolling.)

Bank angle:

1. Wings remain level during ground roll, and bank angle does not exceed 5° until the aircraft reaches 50 feet AGL. (Crosswind/wind gusts/turbulence: minimal deviations from wings level during rotation and climb to 50 feet AGL.)

2. Bank angle not to exceed 15° until minimum safe maneuvering airspeed is reached and not to exceed 30° thereafter. (Turbulence: minimal deviations from the desired bank angle to the extent possible without overcontrolling.)

Rate of climb/rate of descent:

1. Positive rate of climb maintained after liftoff. (Engine failure: Airplane does not descend at any time.)

2. Positive rate of climb maintained during flap and slat retraction. (Engine failure: This standard does not apply during operations with a failed engine.)

Control manipulation:

1. Performed in a smooth, timely, and coordinated manner. (Engine failure: Some degree of uncoordinated flight, i.e., side slip, may be required for performance and directional control in accordance with the AAOM.)

2. Elevator inputs must ensure positive nosewheel contact with the runway for directional control during ground roll.

FAR/ATC compliance:

1. Takeoffs conducted in compliance with the FAR and ATC clearances. (Engine failure/icing conditions/turbulence/flight instrument failures: Deviation is permitted to the extent necessary to meet emergencies.)

2. Climb in compliance with IFR departure procedures and SID's, as applicable.

AIM compliance:

1. Takeoff conducted in accordance with the recommended procedures in the AIM.

AAOM compliance:

1. Takeoff conducted in accordance with the AAOM, including target airspeeds, power settings, airplane configuration, pitch attitudes, rotation rates, and other procedures and recommendations.

2. Takeoffs conducted in compliance with the operating limitations of the AFM or its equivalent.

Course deviation:

1. Proper intercept and tracking procedures used so as to establish and maintain assigned courses within 1/2 scale deviation of the CDI or within ± 5° if a CDI is not used.

IAP compliance: Not applicable.

Other procedural compliance:

1. Takeoff power applied in a smooth, symmetrical manner.
2. Maximum available runway used when required by takeoff performance limitations.
3. No unnecessary brake applications during the ground roll.
4. Recommended target pitch attitudes achieved within ± 2° without exceeding maximum recommended pitch attitude.

Cognitive:

1. Correct decision made to continue takeoff.

4. REJECTED TAKEOFF

Altitude: Not applicable.

Airspeed:

1. Airplane slowed to a safe taxi speed prior to the initial control input to turn off the runway.

Heading:

1. Approximate runway centerline track maintained.

Bank angle:

1. Wings remain level.

Rate of climb/rate of descent: Not applicable.

Control manipulation:

1. Performed in a smooth, prompt, and coordinated manner.

FAR/ATC compliance:

1. Deviation from the FAR and ATC clearances is permitted to the extent necessary to meet emergencies.

AIM compliance: None.

AAOM compliance:

1. Rejected takeoff conducted in accordance with the AAOM, including power reduction, use of brakes, spoilers, reverse power, and other procedures and recommendations.

Course deviation: Not applicable.

IAP compliance: Not applicable.

Other procedural compliance:

1. Maximum brake pedal deflection applied if the runway is dry and antiskid is operative. Brake application in accordance with recommended procedures in the AAOM if the runway is slippery or antiskid is inoperative. No significant asymmetric brake application affecting directional control should occur.

2. With all engines and reversers operating, no significant asymmetric power condition affecting directional control should occur.

3. Control inputs ensure that all landing gear remain firmly on the runway surface with sufficient weight on the nosewheel for positive directional control.

Cognitive:

1. Applicant demonstrates prompt recognition of the requirement to reject the takeoff.

5. AREA DEPARTURE

Altitude:

1. ± 100 feet of assigned altitude. (Turbulence: minimal altitude deviations consistent with procedures for flight in turbulence contained the AAOM.)

Airspeed:

1. ± 10 knots of target climb airspeed but not below minimum safe maneuvering airspeed. (Turbulence: minimal airspeed deviations consistent with procedures for flight in turbulence contained in the AAOM.)

Heading:

1. ± 10° of assigned or published headings. (Turbulence: minimal heading deviations to the extent possible without overcontrolling.)

Bank angle:

1. Not to exceed 30°. (Turbulence: minimal deviations from the desired bank angle to the extent possible without overcontrolling.)

Rate of climb/rate of descent.

1. Climb conducted at optimum rate consistent with the operating characteristics of the airplane to 1,000 feet below the assigned altitude and then at a rate of at least 500 fpm until level off is initiated unless ATC is informed otherwise. (Engine failure: climb at the optimum rate consistent with performance capabilities.)

2. Level-off conducted with a smooth, nearly continuous decrease in the rate of climb until the assigned altitude is reached.

Control manipulation:

1. Performed in a smooth, timely, and coordinated manner. (Engine failure: Some degree of uncoordinated flight, i.e., side slip, may be required for performance and directional control in accordance with the AAOM.)

FAR/ATC compliance:

1. Area departure conducted in accordance with the FAR and ATC clearances. (Engine failure/icing conditions/turbulence/flight instrument failures: Deviation is permitted to the extent necessary to meet emergencies.)

2. Airspeed shall not exceed airport traffic area speed restrictions, if applicable, unless minimum safe maneuvering airspeed is greater.

3. Airspeed shall not exceed 250 knots below 10,000 feet MSL.

4. Area departure conducted in compliance with IFR departure procedures and SID's, if applicable.

5. Intermediate level-offs that are not specified in the ATC clearance shall not be made.

AIM compliance:

1. Area departure conducted in accordance with the recommended procedures in the AIM.

2. Holding conducted in accordance with the procedures in the AIM, including timing to establish the proper inbound leg length and holding fix departure time, if so cleared.

3. Correct choice of entry procedure, including entry heading to compensate for wind drift if approximate wind direction and speed is, or should be, known by the pilot.

AAOM compliance:

1. Area departure and holding conducted in accordance with the AAOM, including target airspeeds, power settings, airplane configuration, pitch attitudes, and other procedures and recommendations.

2. Area departure and holding conducted in compliance with the operating limitations of the AFM or its equivalent.

Course deviation:

1. Proper intercept and tracking procedures used so as to establish and maintain assigned courses within 1/2 scale deviation of the CDI or within ± 5° if a CDI is not used.

IAP compliance: Not applicable.

Other procedural compliance: None.

Cognitive:

1. Correct decision made regarding when to initiate level-off.

6. AREA ARRIVAL

Altitude:

1. ± 100 feet of assigned altitudes. (Turbulence: minimal altitude deviations consistent with procedures for flight in turbulence contained in the AAOM.)

Airspeed:

1. ± 10 knots of target descent airspeed but not below minimum safe maneuvering airspeed. (Turbulence: minimal airspeed deviations consistent with procedures for flight in turbulence contained in the AAOM.)

2. ± 10 knots of target holding airspeed but not below minimum safe maneuvering airspeed. (Turbulence: minimal airspeed deviations consistent with procedures for flight in turbulence contained in the AAOM.)

Heading:

1. ± 10° of assigned headings. (Turbulence: minimal heading deviations to the extent possible without overcontrolling.)

Bank angle:

1. Not to exceed 30°. (Turbulence: minimal deviations from the desired bank angle to the extent possible without overcontrolling.)

2. When holding, bank angle not to exceed that required for a standard rate turn, or 30° of bank, or the bank angle commanded by a flight director, whichever produces the least bank angle.

Rate of climb/rate of descent:

1. Descent conducted at optimum rate (exept descents at the pilot's discretion) consistent with the operating characteristics of the airplane to 1,000 feet above the assigned altitude and then at a rate of at least 500 fpm until level-off is initiated unless ATC is informed otherwise.

Control manipulation:

1. Performed in a smooth, timely, and coordinated manner.

FAR/ATC compliance:

1. Area arrival and holding conducted in accordance with the FAR and ATC clearances and instructions. (Engine failure/icing conditions/turbulence/flight instrument failures: Deviation is permitted to the extent necessary to meet emergencies.)

2. Airspeed shall not exceed 250 knots below 10,000 feet MSL.

3. Airspeed shall not exceed speed restrictions for an airport traffic area, if applicable, unless minimum safe maneuvering airspeed is greater.

4. Intermediate level-offs not specified in the ATC clearance shall not be made unless:

    a. Descent is at the pilot's discretion, or

    b. Level-off is made at 10,000 feet MSL to comply with FAR airspeed restriction prior to descending below that altitude, or

    c. Level-off is made at 3,000 feet above airport elevation to comply with FAR airspeed restriction prior to entering an airport traffic area.

5. Speed reduction, if necessary, started within 3 minutes prior to arrival at the holding fix so as to cross the holding fix at or below maximum holding airspeed.

6. Area arrival in compliance with STARs and published profile descent procedures, if applicable.

AIM compliance:

1. Area arrival conducted in accordance with the recommended procedures in the AIM.

2. Holding conducted in accordance with the procedures in the AIM, including timing to establish the proper inbound leg length and holding fix departure time, if so cleared.

3. Correct choice of holding entry procedure, including establishing an entry heading to compensate for wind drift if approximate wind direction and speed is, or should be, known by the pilot.

AAOM compliance:

1. Area arrival and holding conducted in accordance with the AAOM, including target airspeeds, power settings, airplane configuration, pitch attitudes, and other procedures and recommendations.

2. Area arrival and holding conducted in compliance with the operating limitations of the AFM or its equivalent.

Course deviation:

1. Proper intercept and tracking procedures used so as to establish and maintain assigned area arrival and holding courses within 1/2 scale deviation of the CDI or within $\pm$ 5° if a CDI is not used.

IAP compliance: Not applicable.

Other procedural compliance: None.

Cognitive:

1. Correct decisions made concerning when to start descent and rate of descent to comply with ATC crossing and level-off restrictions and ATC/FAR airspeed restrictions.

2. Correct decision made concerning when to initiate level-off.

7. APPROACH

Altitude:

1. $\pm$ 100 feet of assigned, prescribed, or traffic pattern altitudes, as appropriate. (Two engine failure: $\pm$ 200 feet of assigned,

prescribed, or traffic pattern altitude, as appropriate. Turbulence: minimal altitude deviations consistent with procedures for flight in turbulence contained in the AAOM.)

2. + 50/ - 0 feet of the MDA, DH, or other prescribed altitudes of the final approach segment. (Two engine failure: + 100/ - 0 feet of MDA.)

3. + 100/ - 0 feet of the MDA during a circle-to-land maneuver.

4. Minimal altitude loss during the transition to the initial climb of a rejected landing or missed approach.

Airspeed:

1. Prior to reduction to target final approach airspeed, ± 10 knots of assigned or target maneuvering airspeeds but not less than minimum safe maneuvering airspeed. (Turbulence: minimal airspeed deviations consistent with procedures for flight in turbulence contained in the AAOM.)

2. Following reduction to final approach airspeed, ± 5 knots of target final approach airspeed but not less than V_{ref}. (Turbulence: minimal airspeed deviations consistent with procedures for flight in turbulence contained in the AAOM. No flap: following reduction to final approach airspeed, + 10/ - 5 knots of target final approach speed but not less than V_{ref}.)

3. ± 5 knots of the target circling airspeed during a circle-to-land maneuver. (Turbulence: minimal airspeed deviations consistent with procedures for flight in turbulence contained in the AAOM. Two engine failure: during the circle-to-land maneuver, ± 10 knots of target circling airspeed but not below minimum safe maneuvering airspeed until on final approach to the landing runway.)

4. During the transition to a climb for a rejected landing/missed approach, ± 10 knots of target climb speed but not below V_{ref}.

Heading:

1. ± 10° of assigned or published headings. (Turbulence: minimal heading deviations to the extent possible without overcontrolling. Two engine failure: ± 15° of assigned or published headings.)

2. ± 5° of assigned headings on PAR and ASR approaches.

3. ± 10° of the heading required to track the runway centerline during a rejected landing until the first turn is initiated.

Bank angle:

1. Not to exceed 30° when at or above minimum safe maneuvering airspeed and not to exceed 15° when below that airspeed.

(Turbulence: minimal deviations from the desired bank angle to the extent possible without overcontrolling.)

2. Not to exceed the bank angle required for standard rate turns or 30° during a no-gyro approach until advised by ATC to make turns at half of standard rate on final approach.

Rate of climb/rate of descent:

1. Optimal rate of climb during a missed approach or rejected landing. Minimal rate of descent during transition to the climb and no rate of descent after establishing initial climb. (Two engine failure: minimal rate of descent during transition to climb consistent with the procedures in the AAOM.)

2. Rate of descent does not exceed 1,000 fpm at altitudes below 1,000 feet AGL.

3. For nonprecision approaches, rate of descent must ensure arrival at the MDA at, or prior to, a depicted VDP or at, or prior to, a point where the MDA intersects a normal (approximately 3°) glide path to the intended touchdown point if a VDP is not depicted.

4. For circling approaches, rate of descent must ensure arrival at the MDA at, or prior to, a point from which a normal circle-to-land maneuver can be accomplished.

5. For ILS approaches, rate of descent must ensure that the glide slope is maintained at 1/2 scale (one dot) deviation, or less, on the glide slope indicator.

Control manipulation:

1. Performed in a smooth, timely, and coordinated manner. (Engine failure: Some degree of uncoordinated flight, i.e., side slip, may be required for performance and directional control in accordance with the AAOM.)

FAR/ATC compliance.

1. Approaches conducted in compliance with the FAR and ATC clearances. (Engine failure/icing conditions/ turbulence/flight instrument failures: Deviation is permitted to the extent necessary to meet emergencies.)

2. Proper DH or MDA used for the landing runway, airplane approach Category, circling maneuver airspeed, available approach aids, and inoperative components.

3. Upon receiving approach clearance, last assigned altitude maintained until a different altitude is assigned by ATC or until the airplane is established on a segment of a published route or IAP at which time the published minimum altitude associated with that segment applies.

4. Descent below DH or MDA does not occur unless:

   a. The airplane is continuously in a position from which a descent to a landing on the intended runway can be made at a normal rate of descent using normal maneuvers, and the descent rate will allow touchdown to occur within the touchdown zone; and

   b. The flight visibility is not less than the prescribed minimum visibility; and

   c. At least one of the visual references specified in FAR 91.116 (c) (3) (or in air carrier operations specifications for Category II ILSs) is visible; and

   d. The airplane has reached the depicted VDP on a nonprecision approach, except when the airplane is not equipped to determine the VDP, or a descent to the runway cannot be made using normal procedures or rates of descent if descent is delayed until reaching the VDP.

5. Circle-to-land maneuver conducted so that an identifiable part of the airport remains distinctly visible unless the inability to see an identifiable part of the airport results from a normal bank.

6. Descent below the MDA of a circling approach is not initiated until the airplane intercepts a normal (approximately 3°) glide path to the intended touchdown point.

7. Airplane is not operated below the VASI glide slope, if available, until a lower altitude is necessary for a safe landing.

8. Airplane is not operated below the ILS glide slope, if available, between the outer and middle marker (or 200 feet above the touchdown zone elevation if a middle marker is not present).

AIM compliance:

1. Approaches conducted in accordance with the recommended procedures in the AIM.

2. Visual approach clearance accepted only after visual contact is made with the airport, preceding aircraft, or depicted landmark of a CVFP, as appropriate.

3. Airplane is not operated below minimum altitudes specified in a CVFP or in FAR 91.87(d)(1) for operations in an airport traffic area.

4. Adequate separation from preceding aircraft is maintained when responsible for following that aircraft during an approach.

5. Procedure turn is conducted on the proper (depicted) side of the inbound course and within the prescribed procedure turn distance.

6. Unless specifically authorized by ATC, a procedure turn is not performed when:

   a. Receiving radar vectors during the initial approach segment to the final approach fix or position; or

   b. A timed approach from a holding fix is conducted; or

   c. The procedure specifies "NoPT".

7. Side-step maneuver, if so cleared, is initiated as soon as possible after the runway or runway environment is in sight.

8. Initial turn specified in the published missed approach procedure is not performed until the published missed approach point is reached.

9. If missed approach is initiated during a circle-to-land maneuver, initial climbing turn is performed toward the landing runway and continued until established on the published missed approach course.

10. Holding conducted in accordance with the procedures in the AIM, including timing to establish the proper inbound leg length and holding fix departure time, if so cleared.

11. Correct choice of holding entry procedure, including an entry heading to compensate for wind drift if approximate wind direction and speed is, or should be, known by the pilot.

AAOM compliance:

1. Approaches conducted in accordance with the procedures and recommendations in the AAOM, including target airspeeds, power settings, airplane configuration, pitch attitudes, and other procedures and recommendations.

2. Approaches conducted in compliance with the operating limitations of the AFM or its equivalent.

Course deviation:

1. During instrument approach procedures, proper intercepts and tracking procedues used on the outbound course so as to establish and maintain the course at less than full-scale deviation of the CDI or within ± 10° if a CDI is not used. Proper intercept and tracking procedures used on the inbound course so as to establish and maintain the course within 1/2 scale deviation of the CDI or within ± 5° if a CDI is not used. Localizer deviation upon reaching DH of a Category II ILS approach shall not exceed 1/6 scale CDI deviation, and the cockpit shall be within, and tracking to remain within, the lateral confines of the extended runway.

2. DME arcs shall be maintained within $\pm$ 2 NM.

3. When radial, bearings, or localizer courses are assigned in conjunction with visual approaches, proper intercept and tracking procedures used so as to establish and maintain courses at less than full-scale deviation of the CDI or within $\pm$ 10° if a CDI is not used.

4. During missed approach procedures, proper intercept and tracking procedures used so as to establish and maintain courses at less than full-scale deviation of the CDI or within $\pm$ 10° if a CDI is not used.

IAP compliance:

1. Approach conducted in accordance with the published IAP, including the published missed approach procedure, if applicable.

Other procedural compliance:

1. If minimum visibility exists during a circling approach, the radius of turn dictated by the published visibility minimum should not be exceeded.

2. Circling approach flight path shall be controlled so that the airplane remains within the circling approach area. The circling approach area is the maneuvering area that provides a prescribed minimum obstacle clearance at circling MDA. The limits of the area are defined by the following radii from the threshold of each usable runway: Category A, 1.3 NM (1.5 SM); Category B, 1.5 NM (1.7 SM); Category C, 1.7 NM (2 SM); Category D, 2.3 NM (2.6 SM); Category E, 4.5 NM (5.2 SM).

Cognitive:

1. Flight path shall be controlled in such a manner that the airplane is positioned on final approach at an altitude that will allow a normal descent profile (approximately a 3° glide path) to the intended touchdown point.

2. Instrument approach flight path shall be controlled so that the airplane is at DH or MDA in a position from which a straight-in landing or circle-to-land maneuver, as applicable, can be accomplished using normal rates of descent and normal maneuvers.

3. Applicant shall demonstrate prompt recognition of the requirement to perform a missed approach or a rejected landing.

8. LANDING

Altitude: Not applicable.

Airspeed:

1. $\pm$ 5 knots of target final approach airspeed but not below V_{ref}.

2. Normal touchdown airspeed established at touchdown.

3. Airplane slowed to safe taxi speed prior to initial control input to turn off the runway.

Heading:

1. Airplane aligned with the runway centerline at touchdown, and an appropriate centerline track is maintained until safe turnoff taxi speed is reached.

2. Airplane within the lateral confines of the runway upon reaching the landing threshold.

3. No drift occurs at touchdown.

Bank angle:

1. Not to exceed 30° when at or above minimum safe maneuvering airspeed and not to exceed 15° when below that airspeed.

2. No excessive banks during flare and touchdown considering the potential for wing structures (wingtips, flaps, engines, etc.) contacting the surface.

3. Wings level during landing rollout.

Rate of climb/rate of descent:

1. Rate of descent does not exceed 1,000 fpm at altitudes below 1,000 feet AGL.

2. Rate of descent must ensure that a normal (approximately 3°) glide path to the intended touchdown point is established and maintained.

3. Rate of descent must allow for a smooth transition to flare without excessive floating prior to touchdown.

4. Rate of descent at touchdown must not cause a hard landing or bounce.

5. Nosewheel must be smoothly lowered to the runway surface at a rate that does not result in a hard touchdown and does not waste excessive runway.

Control manipulation:

1. Performed in smooth, timely, and coordinated manner. (Engine failure: Some degree of uncoordinated flight, i.e., side slip, may be required for performance and directional control in accordance

with the AAOM. Crosswind/wind gusts: Some combination of uncoordinated flight and bank may be required for alignment with the runway and to establish zero drift.)

2. Elevator inputs must ensure positive nosewheel contact with the runway during rollout for directional control.

FAR/ATC compliance:

1. Landings conducted in compliance with the FAR and ATC clearances.

2. Airplane is not operated below the VASI glide slope, if available, until a lower altitude is necessary for a safe landing.

AIM compliance:

1. Landings are conducted in accordance with the recommended procedures in the AIM.

AAOM compliance:

1. Landings conducted in accordance with the procedures and recommendations in the AAOM, including target airspeeds, power settings, airplane configuration, pitch attitudes, use of brakes/reverse power, and other procedures and recommendations.

2. Landings conducted in compliance with the operating limitations of the AFM or its equivalent.

Course deviation: Not applicable.

IAP compliance: Not applicable.

Other procedural compliance:

1. No "duck under" or unstabilized increase in descent angle preceding the flare.

2. Flare point allows for a smooth, continuous transition to an appropriate touchdown attitude.

3. Initial touchdown is on the main landing gear.

4. All main landing gear firmly on the runway prior to nosewheel touchdown.

5. No significant asymmetric power condition affecting directional control should occur during use of reverse power.

6. No significant asymmetric braking condition affecting directional control should occur.

7. Unnecessarily high reverse power settings and unnecessary heavy braking should not occur.

Cognitive:

1. Flight path controlled so that initial touchdown occurs 1,000 feet ± 500 feet down the runway from the landing threshold.

2. Applicant makes correct decisions concerning continuation of the landing.

9. EMERGENCY DESCENT

Altitude:

1. ± 100 feet of assigned or selected altitude after level-off. (Turbulence: minimal altitude deviations consistent with procedures for flight in turbulence contained in the AAOM.)

Airspeed:

1. ± .02 Mach of target emergency descent Mach not to exceed maximum Mach limitation.

2. ± 15 knots of target emergency descent airspeed not to exceed maximum airspeed limitations. (Turbulence: minimal airspeed deviations consistent with procedures for flight in turbulence contained in the AAOM.)

Heading:

1. ± 10° of assigned headings after level off. (Turbulence: minimal heading deviations to the extent possible without overcontrolling.)

Bank angle:

1. Not to exceed 45°. (Turbulence: minimal deviations from the desired bank angle to the extent possible without overcontrolling.)

Rate of climb/rate of descent: None.

Control manipulation:

1. Performed in a smooth, prompt, and coordinated manner without excessive G forces.

FAR/ATC compliance:

1. Deviation from the FAR and ATC clearance is permitted to the extent necessary to meet the emergency.

AIM compliance:

1. Emergency descent conducted in accordance with the recommended procedures in the AIM, including ATC notification and use of proper transponder codes.

AAOM compliance:

1. Emergency descent conducted in accordance with the AAOM, including target Mach numbers, target airspeeds, power settings, airplane configuration, pitch attitudes, and other procedures and recommendations.

2. Emergency descent conducted in compliance with the operating limitations of the AFM or its equivalent.

Course deviation: None.

IAP compliance: Not applicable.

Other procedural compliance: None.

Cognitive:

1. Applicant demonstrates prompt recognition of the requirement for an emergency descent.

2. Applicant makes correct decision regarding descent profile and configuration, considering structural damage and turbulent air conditions.

10. INFLIGHT MANEUVERS

Altitude:

1. ± 100 feet of assigned altitude during steep turns, level flight entry to imminent stalls, and level flight following return to original altitude after stall recovery.

Airspeed:

1. ± 10 knots during steep turns.

2. Stall recovery initiated promptly when a perceptible buffet, stall warning, or computed stall airspeed is reached, whichever occurs first.

Heading:

1. ± 10° of assigned entry and rollout headings during steep turns.

2. ± 15° during straight ahead stall entry and recovery.

Bank angle:

1. 45° $\pm$ 5° during steep turns.

2. $\pm$ 5° of assigned bank angles during entry to turning stalls.

Rate of climb/rate of descent:

1. $\pm$ 200 fpm during entry to stalls.

2. Minimal altitude loss during stall recovery consistent with recovery of full control effectiveness.

3. Expeditious climb to original altitude following stall recovery.

Control manipulation:

1. Performed in a smooth, timely, and coordinated manner.

2. Secondary buffets or stall warning indications shall not occur.

FAR/ATC compliance: None.

AIM compliance: None.

AAOM compliance:

1. Steep turns and stalls conducted in accordance with the AAOM, including target airspeeds during steep turns, minimum airspeeds and recovery airspeeds during stalls, power settings, airplane configuration, stall entry and recovery procedures, minimum altitudes, and other procedures and recommendations.

Course deviation: Not applicable.

IAP compliance: Not applicable.

Other procedural compliance: None.

Cognitive:

1. Demonstrates prompt recognition of imminent stall.

2. Makes correct decision on when to initiate rollout during steep turns.

11. SYSTEMS OPERATIONS

Altitude: Not applicable.

Airspeed: Not applicable.

Heading: Not applicable.

Bank angle: Not applicable.

Rate of climb/rate of descent: Not applicable.

Control manipulation: Not applicable.

FAR/ATC compliance:

1. Deviation from the FAR and ATC clearances is permitted to the extent necessary to meet emergencies.

AIM compliance: Not applicable.

AAOM compliance:

1. Normal, abnormal, and emergency systems operations conducted in accordance with the AAOM.

2. System operations in compliance with the operating limitations in the AFM.

Course deviation: Not applicable.

Other procedural compliance:

1. Normal, abnormal, and emergency checklists accomplished in a timely, accurate, sequentially correct, and complete manner.

Cognitive:

1. Applicant correctly identifies the necessity for procedural action and/or correctly identifies systems anomalies.

2. Applicant correctly identifies required or recommended procedures.

12. COCKPIT RESOURCE MANAGEMENT

Altitude:

1. Applicant is constantly aware of altitude control.

Airspeed:

1. Applicant is constantly aware of airspeed control.

Heading:

1. Applicant is constantly aware of heading control.

Bank angle:

1. Applicant is constantly aware of bank control.

Rate of climb/rate of descent:

1. Applicant is constantly aware of climb and descent rate.

Control manipulation: None.

FAR/ATC compliance:

1. All phases of operation conducted in compliance with the FAR and ATC clearances. Deviation is permitted to the extent necessary to meet emergencies.

AAOM compliance:

1. Applicant is knowledgeable of, and supervises, the duties of other crewmembers, as specified in the AAOM, to ensure timeliness, accuracy, and completeness of their actions.

Course deviations:

1. Applicant is constantly aware of course maintenance.

Other procedural compliance:

1. Applicant ensures that checklists and standard operating procedures are accomplished in a timely, accurate, sequentially correct, and complete manner.

2. Applicant properly uses cockpit resources, e.g., other crewmembers, flight director, autopilot, ATC, publications, etc., to manage the in-flight workload.

Cognitive:

1. Applicant effectively delegates cockpit workload to, and supervises the activities of, other crewmembers to ensure task accomplishment.

2. Applicant assigns priorities to tasks to ensure that each crewmember's workload remains at a manageable level.

3. Applicant ensures safe flight path management while checklists and other tasks are performed.

APPENDIX D

RESULTS OF THE VISUAL CUE ANALYSIS

This appendix presents detailed results of the visual cue analysis explained in Section V, as well as supporting information for the identification of visual simulation requirements as presented in Section VI. There are a total of four tables. Each table is described immediately below. The tables then appear in sequence following the descriptions.

TABLE D-1.

The main body of Table D-1 presents priorities assigned as described in Section V. The table has 15 parts, one for each task that was considered to rely on out-of-window scenes. In each part, types of visual information normally used by pilots when performing the task are listed in a column at the left (the types are explained individually in Section V). In a column next to the types, priorities appear that reflect the importance of each.

The remaining columns of the table, identified by letters A through W, represent possible sources for the various types of information. The numbers appearing in these columns are priorities representing the importance of each source per information type. The priorities for sources are independent of those for types of information. That is, a given type of information may have a high priority, but some sources may be of low priority for providing it. Similarly, a type of information may have a low priority, but if it is to be provided at all, certain sources can have a high priority for doing so.

The sources of information, which are explained in Section V, and their corresponding letters are as follow:

A Aerial perspective (vividness)
B Parallax: forward perspective
C Parallax: oblique perspective
D Parallax: lateral perspective
E Occulting: forward perspective
F Occulting: oblique perspective
G Occulting: lateral perspective
H Relative motion: separate objects
I Relative motion: terrain features
J Relative size: objects and terrain
K Apparent terrain elevation/relief
L Terrain patterns: distal
M Object/terrain patterns: proximal
N Textural perspective
O Linear perspective: forward
P Linear perspective: oblique
Q Linear perspective: lateral
R Horizon/change in
S Shadows

- T Contour/change: forward perspective
- U Contour/change: oblique perspective
- V Contour/change: lateral perspective
- W Clouds or cloud layer

At the upper right of each task's part of the table, the minimum field of view (FOV) is given in degrees for the horizontal dimension, extending left from the center of the front windscreen. (As explained in Sections V and VI, these minima are tentative.) Also, "plus lateral" is added for some tasks, indicating a need for a view in the left 90° region. Finally, notes as indicated by asterisks identify a possible need for a cross-cockpit view for some tasks.

TABLE D-2.

This table represents the effects of "overlays" of malfunctions and additional special maneuvers on the priorities for types of visual information for the basic tasks. In each instance where priorities were affected, the result was an increase in priority. (Priorities for sources of information were not affected in any instance.) Only one malfunction and four special maneuvers resulted in changes, so only these are shown.

TABLE D-3.

Environmental conditions were identified to accompany the tasks as explained in Section III (see also Appendix B). Eight of the environmental conditions accompanied the tasks that required visual scenes. These conditions and the types of information they affect are indicated by Xs in Table D-3. Priorities are not involved in this analysis. Rather, if an environmental condition is to occur, its affects on the visual scene are to be realistic for the intensity or degree of the condition.

TABLE D-4.

Section VI explains the substitution of night for day scenes insofar as minimal requirements for simulators to be used for APT checks are concerned. Table D-4 summarizes the effects on information available from night scenes as compared to the day scenes represented in Table D-1. Entries in the table are counts of priorities 1 or 2 for sources of the information types appearing at the left. These counts are separate by day and night scenes, and by flight segment. Note that the types of informationn affected most are those types that normally are degraded at night (object and terrain features, object details, etc.). And, although not shown as such in the table, the primary losses of informational sources are those normally not available at night--texture, object and terrain contours, and distal terrain patterns.

TABLE D-1. PRIORITIES FOR TYPES OF VISUAL INFORMATION AND FOR INFORMATIONAL SOURCES, BY TASK

TASK: Taxi to takeoff position

*FOV: 75° + lateral
*Cross-cockpit reference also

Information	Inform Priority	Cue Priority A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
Vertical movement (LA)																								
Pitch angle (LA)	3								1	1			3						2					
Horizontal movement (LA)	1			2	2	2	2	2	1	1	1			1	2	1	2	3						
Pitch angle (HA)																								
Horizontal movement (HA)																								
Linear accel/decel (LA)	1			2	2				1	1	1			1	1	1	1	2						
Vert rate of closure																								
Horiz rate of closure	1			2	2				2	1	1			1	1	1	2	3						
Rate of turn	1								1	1			1	1					1					
Bank angle	3								1	1			3						2					
Altitude (low)	1								3	3	2*			2	1	1	1	2	3					
Altitude (high)																								
Relative distances (obj)	1	3		3		1	1	1	1	1	1	1	2	3	1	1	1	2	1					
Relative hght (obj/ter)	1					2	2	2			1	1	1	1					2		3	3	3	
Directional orientation	1								2	2	1	1	1	1					1					
Ter feature ident	1					1	1	1		3	1	1	2	1		3	3	3	3	2	2	2	2	
Lateral context	1	3			2						1	3	2	2					2	3			2	
Near-object detail	1			3	3						1				1					1	1	1	1	
Object features	1			2	2	3	3	3			1			1	1	1	2	2		2	1	1	1	
Absolute distance	1			2	2	1	2	2	1	1	1	1		1	1	1	1	1		2	1	2	2	

(Continued)

TABLE D-1. (Continued)

TASK: Takeoff ground roll FOV: 45°

Information	Inform Priority	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
											Cue Priority													
Vertical movement (LA)																								
Pitch angle (LA)	1								1	1			3						2					
Horizontal movement (LA)	1			3					1	1	1			2	1	1	1					2		
Pitch angle (HA)																								
Horizontal movement (HA)																								
Linear accel/decel (LA)	1			3					1	1	1			2	1	1	1					3		
Vert rate of closure																								
Horiz rate of closure	1			3					1	1	1	3		2	1	1	1					3		
Rate of turn	1								1	1			1	1					1					
Bank angle	1								1	1			3						1					
Altitude (low)	1								3	3	2			2	1	1	1		3					
Altitude (high)																								
Relative distances (obj)	1	3		3		1	1		1	1	1	3	2	2	2	1	2		2					
Relative hght (obj/ter)	2					2	2				1	1	2	1					3					
Directional orientation	1								2	2		1	1	1					1					
Ter feature ident	1					1	1		2	2	2	1	1	1	3	2	3		3	2		2		
Lateral context																								
Near-object detail	1										1				1					1	1	1		
Object features	1			3		3	3				1			1	2	3	3			2	1	1		
Absolute distance	1			3		2			1	1	1	2		1	1	1	2		3					

(Continued)

TABLE D-1. (Continued)

TASK: Rotation FOV: 45°

Information	Inform Priority	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
									Cue Priority															
Vertical movement (LA)	1								2	1	1				1	2	2		1		2	2		
Pitch angle (LA)	1								1	1			1	1					1					
Horizontal movement (LA)	1			3					1	1	1			2	1	1	1					2		
Pitch angle (HA)																								
Horizontal movement (HA)																								
Linear accel/decel (LA)	1			3					1	1	1			2	1	1	1					3		
Vert rate of closure	1		2	2		2	2		3	1	1				1	2	2		2		3	3		
Horiz rate of closure	1			3					1	1	1			2	1	1	1					3		
Rate of turn	1												1	1					1					
Bank angle	1											2	1	1					1					
Altitude (low)	1		3	3		2	2		2	1	1	2	3	1	1	2	2		2		2	2		
Altitude (high)																								
Relative distances (obj)	2	3		3		1	1		1	1	1		2	2	2	1	2		2					
Relative hght (obj/ter)	2					2	2				1	1	2	1					3					
Directional orientation	1								2	2		1	1	1					1					
Ter feature ident	1					1	1		2	2	2	1	1	1	3	2	3		3	2		2		
Lateral context																								
Near-object detail	1										1				1					1	1	1		
Object features	1			3		3	3				1			1	2	3	3			2	1	1		
Absolute distance	1			3					1	1	1	3	2	1	1	2	2		3	3				

(Continued)

TABLE D-1. (Continued)

TASK: Climb to cleanup (early part only) FOV: 45°

Information	Inform Priority	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
									Cue Priority															
Vertical movement (LA)	1			2			2		2	2	1	2	3	1	2		1		1	3		2		2
Pitch angle (LA)	1								1	1				1					1					2
Horizontal movement (LA)	2			2			2		1	1	3	3		2	2		1			2		2		2
Pitch angle (HA)																								
Horizontal movement (HA)																								
Linear accel/decel (LA)																								
Vert rate of closure	2*			3			3		2	2	1	2	3	2	2		1		2	3		2		2
Horiz rate of closure	3*			3			2		1	1	1	3		2	2		1			2		2		2
Rate of turn	2								1	1			1	1					1					2
Bank angle	2								1	1			1	1					1					2
Altitude (low)	2			3			2		1	1	1	2	2	2	1		1		1	3				
Altitude (high)																								
Relative distances (obj)	3			2			2		1	1	1		2	1	2		1		3			2		
Relative hght (obj/ter)	3						2				1	1	2	1					2					
Directional orientation	2											1	1	1					1			2		2
Ter feature ident	3			3			2		2	2	1	1	2	1	3		2		3	2				
Lateral context																								
Near-object detail	3										1													
Object features	3			2							1													
Absolute distance	3*			2			2		1	1	1	3	3	1	1		1		3		3			

*Priority = 1 for airborne aircraft/thunderstorms.

(Continued)

TABLE D-1. (Continued)

TASK: Reject takeoff FOV: 45°

Information	Inform Priority	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
		Cue Priority																						
Vertical movement (LA)																								
Pitch angle (LA)	1								1	1			3						2					
Horizontal movement (LA)	1			3					1	1	1			2	1	1	1					2		
Pitch angle (HA)																								
Horizontal movement (HA)																								
Linear accel/decel (LA)	1			3					1	1	1			2	1	1	1					3		
Vert rate of closure																								
Horiz rate of closure	1			3					1	1	1			2	1	1	1					3		
Rate of turn	1								1	1			1	1					1					
Bank angle	1								1	1			3											
Altitude (low)	1								3	3	2			2	1	1	1		3					
Altitude (high)																								
Relative distances (obj)	1	3		3		1	1		1	1	1		2	2	2	1	2		2					
Relative hght (obj/ter)	1					2	2				1	1	2	1					3					
Directional orientation	1								2	2		1	1	1					1					
Ter feature ident	1					1	1		2	2	2	1	1	1	3	2	3		3	2		2		
Lateral context																								
Near-object detail	1										1				1					1	1	1		
Object features	1			3		3	3				1			1	2	3	3			2	1	1		
Absolute distance	1			3		2			1	1	1	2		1	1	1	2		3					

(Continued)

TABLE D-1. (Continued)

TASK: Visual approach to visual glidepath

*FOV: 75°
*Cross-cockpit reference also

Information	Inform Priority	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
											Cue Priority													
Vertical movement (LA)	1					2	2		2	1	1	3	3	2	1	2	2		1					
Pitch angle (LA)	1											2	1	1					1					
Horizontal movement (LA)	1		2	2		3	1		1	1	1	2	3	1	1	1	1		3		2	2		
Pitch angle (HA)	1											3	1						1					2
Horizontal movement (HA)	1		3	3						1	1					1	2				3	3		2
Linear accel/decel (LA)																								
Vert rate of closure	1		3	3		3	3		2	1	1	3	3	1	1	2	2		2					
Horiz rate of closure	1		2	2		2	2		1	1	1	2		1	1	1	1		3		2	2		
Rate of turn	1								1	1		2	1	1		3	3		1					
Bank angle	1								1	1		2	1	1		3	3		1					
Altitude (low)	1	2				3	3		1	1	1	1	3	2	1	3	3		2	2	2	2		
Altitude (high)																								
Relative distances (obj)	1	2		3		1	1		1	1	1	2	2	1	2	1	1		2	3				
Relative hght (obj/ter)	1					1	1				1	1	3	1					2					
Directional orientation	1								1	1		1	2	1		1	1		1					
Ter feature ident	1		3	3		1	1				1	1	3	1	1	2	2		1	1	1	1		
Lateral context																								
Near-object detail	3										1			2	1					1	2	2		
Object features	2										2			1	1	3	3			1	1	1		
Absolute distance	1	2		3		1	1			1	1		2	1	1	1	1		3	2				

(Continued)

TABLE D-1. (Continued)

TASK: Instrument approach to visual glidepath (end of approach only) FOV: 45°

Information	Inform Priority	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
											Cue Priority													
Vertical movement (LA)	1					2	2		2	1	1	3	3	2	1	2	2		1					
Pitch angle (LA)	1											2	1	1					1					
Horizontal movement (LA)	1		2	2		3	1		1	1	1	2	3	1	1	1	1		3		2	2		
Pitch angle (HA)	1											3	1						1					2
Horizontal movement (HA)																								
Linear accel/decel (LA)																								
Vert rate of closure	1		3	3		3	3		2	1	1	3	3	1	1	2	2		2					
Horiz rate of closure	1		2	2		2	2		1	1	1	2		1	1	1	1		3		2	2		2
Rate of turn	1								1	1		2	1	1		3	3		1					2
Bank angle	1								1	1		2	1	1		3	3		1					2
Altitude (low)	1	2				3	3		1	1	1	1	3	2	1	3	3		2	2	2	2		
Altitude (high)																								
Relative distances (obj)	1	2		3		1	1		1	1	1	2	2	1	2	1	1		2	3				
Relative hght (obj/ter)	2					1	1				1	1	3	1					2					
Directional orientation	1								1	1		1	2	1		1	1		1					
Ter feature ident	1		3	3		1	1				1	1	3	1	1	2	2		1	1	1	1		
Lateral context																								
Near-object detail	3										1			2	1					1	2	2		
Object features	2										2			1	1	3	3			1	1	1		
Absolute distance	1	2		3		1	1			1	1		2	1	1	1	1		3	2				

(Continued)

TABLE D-1. (Continued)

TASK: Circling approach to visual glidepath

*FOV: 75° + lateral
*Cross-cockpit reference also

Information	Inform Priority	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
		Cue Priority																						
Vertical movement (LA)	2					2	2	2	2	1	1	3	3	2	1	2	2	2	1					
Pitch angle (LA)	1											2	1	1					1					
Horizontal movement (LA)	1		2	2	2	3	1	1	1	1	1	2	3	1	1	1	1	1	3		2	2	2	
Pitch angle (HA)	1											3	1						1					2
Horizontal movement (HA)																								
Linear accel/decel (LA)																								
Vert rate of closure	1		3	3	3	3	3	3	2	1	1	3	3	1	1	2	2	2	2					
Horiz rate of closure	1		2	2	2	2	2	2	1	1	1	2		1	1	1	1	1	3		2	2	2	3
Rate of turn	1								1	1		2	1	1		3	3	3	1					2
Bank angle	1								1	1		2	1	1		3	3	3	1					2
Altitude (low)	1	2				3	3	3	1	1	1	1	3	2	1	3	3	3	2	2	2	2	3	
Altitude (high)																								
Relative distances (obj)	1	2		3	3	1	1	2	1	1	1	2	2	1	2	1	1	1	2	3				
Relative hght (obj/ter)	1					1	1	2			1	1	3	1					2					
Directional orientation	1								1	1		1	2	1		1	1		1					
Ter feature ident	1		3	3	3	1	1	1			1	1	3	1	1	2	2	2	1	1	1	1	1	
Lateral context	1	2			1			1	1	1	1		2	1	1			1	1	2			2	
Near-object detail	2				2						1			2	1					1	2	2	2	
Object features	1				2						2			1	1	3	3	3		1	1	1	1	
Absolute distance	1	2		3	3	1	1	2		1	1		2	1	1	1	1	1	3	2				

(Continued)

TABLE D-1. (Continued)

TASK: Visual glidepath to LMTP

FOV: 75°

Information	Inform Priority	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
		Cue Priority																						
Vertical movement (LA)	1					3	3		2	1	1			3	1	2	2		1		2	2		
Pitch angle (LA)	1								1	1			1	1					1					
Horizontal movement (LA)	1			2					1	1	1			2	1	1	1					2		
Pitch angle (HA)																								
Horizontal movement (HA)																								
Linear accel/decel (LA)																								
Vert rate of closure	1		3	2		3	2		2	1	1	3		3	1	2	2		2		3	3		
Horiz rate of closure	1			2					1	1	1	3		2	1	1	1					3		
Rate of turn	1								1	1			1	1					1					
Bank angle	1								2	1		2	1	1					1					
Altitude (low)	1		3	2		2	1		2	1	1	2	3	1	1	2	2		2	3	2	2		
Altitude (high)																								
Relative distances (obj)	1	3		2		1	1		1	1	1	3	2	2	2	1	2		2					
Relative hght (obj/ter)	1					2	1				1	1	2	1	3				3					
Directional orientation	1								2	2		1	1	1		1	1		1					
Ter feature ident	1					1	1		2	2	2	1	2	1	1	2	3		3	2		2		
Lateral context																								
Near-object detail	1										1									1	1	1		
Object features	1			2		3	2				1			1		3	3			2	1	1		
Absolute distance	1	2		2		1	1			1	1		2	1	1	1			3	2				

(Continued)

TABLE D-1. (Continued)

TASK: LMTP to flare

FOV: 45°

Information	Inform Priority	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
												Cue Priority												
Vertical movement (LA)	1					3	3		2	1	1			3	1	2	2		1		2	2		
Pitch angle (LA)	1								1	1			1	1					1					
Horizontal movement (LA)	1			3					1	1	1			2	1	1	1					2		
Pitch angle (HA)																								
Horizontal movement (HA)																								
Linear accel/decel (LA)	2			3					1	1	1			2	1	1	1					3		
Vert rate of closure	1		3	2		3	3		2	1	1	3		3	1	2	2		2		3	3		
Horiz rate of closure	1			3					1	1	1	3		2	1	1	1					3		
Rate of turn	1								1	1			1	1					1					
Bank angle	1								2	1		2	1	1					1					
Altitude (low)	1		3	3		2	2		2	1	1	2	3	1	1	2	2		2	3	2	2		
Altitude (high)																								
Relative distances (obj)	1	3		3		1	1		1	1	1	3	2	2	2	1	2		2					
Relative hght (obj/ter)	1					2	2				1	1	2	1	3				3					
Directional orientation	1								2	2		1	1	1					1					
Ter feature ident	1					1	1		2	2	2	1	2	1	1	2	3		3	2		2		
Lateral context																								
Near-object detail	1										1									1	1	1		
Object features	1			3		3	3				1			1		3	3			2	1	1		
Absolute distance	1	2		3		1	1			1	1		2	1	1	1			3	2				

(Continued)

TABLE D-1. (Continued)

TASK: Flare to initial touchdown FOV: 45°

Information	Inform Priority	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
		Cue Priority																						
Vertical movement (LA)	1					3	3		2	1	1			3	1	2	2		1		2	2		
Pitch angle (LA)	1								1	1			1	1					1					
Horizontal movement (LA)	1			3					1	1	1			2	1	1	1					2		
Pitch angle (HA)																								
Horizontal movement (HA)																								
Linear accel/decel (LA)	2			3					1	1	1			2	1	1	1					3		
Vert rate of closure	1		3	2		3	3		2	1	1	3		3	1	2	2		2		3	3		
Horiz rate of closure	1			3					1	1	1	3		2	1	1	1					3		
Rate of turn	1								1	1			1	1					1					
Bank angle	1								2	1		2	1	1					1					
Altitude (low)	1		3	3		2	2		2	1	1	2	3	1	1	2	2		2	3	2	2		
Altitude (high)																								
Relative distances (obj)	1	3		3		1	1		1	1	1	3	2	2	2	1	2		2					
Relative hght (obj/ter)	1					2	2				1	1	2	1	3				3					
Directional orientation	1								2	2		1	1	1					1					
Ter feature ident	1					1	1		2	2	2	1	2	1	1	2	3		3	2		2		
Lateral context																								
Near-object detail	1										1									1	1	1		
Object features	1			3		3	3				1			1		3	3			2	1	1		
Absolute distance	1	2		3		1	1			1	1		2	1	1	1			3	2				

(Continued)

TABLE D-1. (Continued)

TASK: Initial touchdown to start ground roll FOV: 45°

Information	Inform Priority	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
		Cue Priority																						
Vertical movement (LA)	1					3	3		2	1	1			3	1	2	2		1		2	2		
Pitch angle (LA)	1								1	1			1	1					1					
Horizontal movement (LA)	1			3					1	1	1			2	1	1	1					2		
Pitch angle (HA)																								
Horizontal movement (HA)																								
Linear accel/decel (LA)	3			3					1	1	1			2	1	1	1					3		
Vert rate of closure	1		3	2		3	3		2	1	1	3		3	1	2	2		2		3	3		
Horiz rate of closure	1			3					1	1	1	3		2	1	1	1					3		
Rate of turn	1								1	1			1	1					1					
Bank angle	1								2	1		2	1	1					1					
Altitude (low)	1		3	3		2	2		2	1	1	2	3	1	1	2	2		2	3	2	2		
Altitude (high)																								
Relative distances (obj)	1	3		3		1	1		1	1	1	3	2	2	2	1	2		2					
Relative hght (obj/ter)	1					2	2				1	1	2	1	3				3					
Directional orientation	1								2	2		1	1	1					1					
Ter feature ident	1					1	1		2	2	2	1	2	1	1	2	3		3	2		2		
Lateral context																								
Near-object detail	1										1									1	1	1		
Object features	1			3		3	3				1			1		3	3			2	1	1		
Absolute distance	1	2		3		1	1			1	1		2	1	1	1			3	2				

(Continued)

TABLE D-1. (Continued)

TASK: Landing ground roll   FOV: 45°

Information	Inform Priority	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
		Cue Priority																						
Vertical movement (LA)																								
Pitch angle (LA)	1								1	1			3						2					
Horizontal movement (LA)	1			3					1	1	1			2	1	1	1					2		
Pitch angle (HA)																								
Horizontal movement (HA)																								
Linear accel/decel (LA)	1			3					1	1	1			2	1	1	1					3		
Vert rate of closure																								
Horiz rate of closure	1			3					1	1	1	3		2	1	1	1					3		
Rate of turn	1								1	1			1	1					1					
Bank angle	1								1	1			3											
Altitude (low)	1								3	3	2			2	1	1	1		3					
Altitude (high)																								
Relative distances (obj)	1	3		3		1	1		1	1	1	3	2	2	2	1	2		2					
Relative hght (obj/ter)	1					2	2				1	1	2	1					3					
Directional orientation	1								2	2		1	1	1					1					
Ter feature ident	1					1	1		2	2	2	1	2	1	1	2	3		3	2		2		
Lateral context																								
Near-object detail	1										1				1					1	1	1		
Object features	1			3		3	3				1			1	2	3	3			2	1	1		
Absolute distance	1			3		2			1	1	1	2		1	1	1	2		3			2		

(Continued)

TABLE D-1. (Continued)

TASK: Reject landing (part of maneuver only) FOV: 45°

Information	Inform Priority	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
		Cue Priority																						
Vertical movement (LA)	1					3	3		2	1	1			3	1	2	2		1		2	2		
Pitch angle (LA)	1								1	1			1	1					1					
Horizontal movement (LA)	1			3					1	1	1			2	1	1	1					2		
Pitch angle (HA)																								
Horizontal movement (HA)																								
Linear accel/decel (LA)	1			3					1	1	1			2	1	1	1					3		
Vert rate of closure	1		3	2		3	3		2	1	1	3		3	1	2	2		2		3	3		
Horiz rate of closure	1			3					1	1	1	3		2	1	1	1					3		
Rate of turn	1								1	1			1	1					1					
Bank angle	1								2	1		2	1	1					1					
Altitude (low)	1		3	3		2	2		2	1	1	2	3	1	1	2	2		2	3	2	2		
Altitude (high)																								
Relative distances (obj)	1	3		3		1	1		1	1	1	3	2	2	2	1	2		2					
Relative hght (obj/ter)	1					2	2				1	1	2	1	3				3					
Directional orientation	1								2	2		1	1	1					1					
Ter feature ident	1					1	1		2	2	2	1	2	1	1	2	3		3	2		2		
Lateral context																								
Near-object detail	1										1									1	1	1		
Object features	1			3		3	3				1			1		3	3			2	1	1		
Absolute distance	1	2		3		1	1			1	1		2	1	1	1			3	2				

(Continued)

TABLE D-1. (Continued)

TASK: Taxi to gate

*FOV: 75° + lateral
*Cross-cockpit reference also

Information	Inform Priority	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
		Cue Priority																						
Vertical movement (LA)																								
Pitch angle (LA)	3								1	1			3						2					
Horizontal movement (LA)	1			2	1	2	2	2	1	1	1			1	2	1	2	3						
Pitch angle (HA)																								
Horizontal movement (HA)																								
Linear accel/decel (LA)	1			2	1				1	1	1			1	1	1	1	2						
Vert rate of closure																								
Horiz rate of closure	1			2	1				2	1	1			1	1	1	2	3						
Rate of turn	1								1	1			1	1					1					
Bank angle	3								1	1			3						2					
Altitude (low)	1								3	3	2			2	1	1	1	2	3					
Altitude (high)																								
Relative distances (obj)	1	3		3		1	1	1	1	1	1	1	2	3	1	1	1	2	1					
Relative hght (obj/ter)	1					2	2	2			1	1	1	1					2		3	3	3	
Directional orientation	1								2	2	1	1	1	1					1					
Ter feature ident	1					1	1	1		3	1	1	2	1		3	3	3	3	2	2	2	2	
Lateral context	1	3		2	1			1	1		1	3	2	2				3	2	3			2	
Near-object detail	1			3	2						1				1					1	1	1	1	
Object features	1			2	2	3	3	3			1			1	1	1	2	2		2	1	1	1	
Absolute distance	1			2	1	1	2	1	1	1	1	1		1	1	1	1	1		2	1	2	2	

TABLE D-2. CHANGES IN PRIORITIES FOR TYPES OF VISUAL INFORMATION DUE TO MALFUNCTIONS AND SPECIAL MANEUVERS

Malfunction or maneuver	Basic task	Type of information	Basic priority	Revised priority
One-engine failure	Climb to cleanup	Rate of turn	2	1
		Bank angle	2	1
Climbing turn (to avoid an obstacle)	Climb to cleanup	Horizontal movement	2	1
		Horizontal rate of closure	3	1
		Rate of turn	2	1
		Bank angle	2	1
		Relative dist (obj/terr)	3	1
		Relative hght (obj/terr)	3	1
		Directional orientation	2	1
		Terr feature identification	3	1
		Absolute dist (obj/terr)	3	1
Stall	Climb to cleanup	Vert rate of closure	2	1
		Bank angle	2	1
		Altitude (low)	2	1
Stall	Circling appr to visual GP	Vert movement (LA)	2	1
Unusual bank	Climb to cleanup	Bank angle	2	1
Unusual pitch	Circling appr to visual GP	Vert movement (LA)	2	1

TABLE D-3. VISUAL INFORMATION AFFECTED BY GIVEN ENVIRONMENTAL CONDITIONS

	Environmental Condition							
Visual Information	Ceiling	Visibility	Thunderstorms	Ground effects	Ice on runway	Wind gusts	Wind shears	Turbulence
Vertical movement (LA)	X	X	X	X	X	X	X	X
Pitch angle (LA)		X	X	X		X	X	X
Horizontal movement (LA)		X	X			X	X	
Pitch angle (HA)	X	X	X			X	X	X
Horizontal movement (HA)	X	X	X					
Linear accel/decel (LA)	X	X	X		X	X	X	
Vert rate of closure	X	X	X	X	X	X	X	
Horiz rate of closure	X	X	X		X	X	X	
Rate of turn		X	X			X	X	X
Bank angle	X	X	X			X	X	X
Altitude (low)	X	X			X	X	X	X
Altitude (high)		X						
Relative distances (obj)	X	X	X					
Relative hght (obj/ter)	X	X	X					
Directional orientation	X	X	X					
Ter feature ident	X	X	X		X			
Lateral context	X	X	X		X			
Near-object detail	X	X	X		X			
Object features	X	X	X		X			
Absolute distance	X	X	X		X			

TABLE D-4. NUMBERS OF SOURCES OF PRIORITIES 1 AND 2 FOR DAY AND NIGHT SCENES, BY TYPE OF INFORMATION

	Taxi				Takeoff				Approach				Landing			
	P = 1		P = 2		P = 1		P = 2		P = 1		P = 2		P = 1		P = 2	
Information	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night
Vertical movement (LA)					8	7	13	6	20	15	30	20	12	9	15	9
Pitch angle (LA)	4	4	2	0	13	12	3	2	19	14	3	3	17	14	1	1
Horizontal movement (LA)	11	11	13	13	21	18	13	5	37	30	22	6	23	19	8	4
Pitch angle (HA)									6	3	3	0				
Horizontal movement (HA)									3	3	2	1				
Linear accel/decel (LA)	15	15	5	5	18	15	3	3	6	5	1	1	24	20	4	4
Vert rate of closure					5	4	14	7	18	13	24	21	9	6	15	12
Horiz rate of closure	11	11	7	7	22	19	9	5	34	29	27	7	24	20	4	4
Rate of turn	10	6	0	0	18	14	1	0	25	20	4	3	20	16	0	0
Bank angle	4	4	2	0	13	11	2	1	23	18	8	7	14	11	6	6
Altitude (low)	6	6	6	6	15	12	17	11	24	18	36	22	15	11	29	17
Altitude (high)																
Relative distances (obj)	22	20	4	2	23	17	19	8	37	27	27	16	24	16	20	12
Relative hght (obj/ter)	8	6	8	6	12	12	12	1	22	15	9	5	12	12	12	0
Directional orientation	10	6	4	4	16	12	8	6	31	29	7	4	16	12	8	8
Ter feature ident	12	12	10	6					42	20	21	17	20	8	28	20
Lateral context	5	5	10	6					9	8	4	2				
Near-object detail	12	10	1	1	16	7	0	0	17	10	11	4	16	8	0	0
Object features	14	14	10	8	13	7	7	3	24	10	8	6	16	8	5	4
Absolute distance	24	24	12	10	23	19	11	6	39	24	17	11	27	17	13	8
Total	168	154	94	74	264	195	156	83	436	311	264	156	289	207	168	109

APPENDIX E

RESULTS OF THE MOTION CUE ANALYSIS

This appendix presents detailed results of the motion cue analysis explained in Section V. There are a total of four tables. Each table is described immediately below. The tables then appear in sequence following the descriptions.

TABLE E-1.

This table presents the primary roles of and priorities for ten types of motion information that are normally available during performance of 25 basic flight tasks identified in Section III. The types of information appear in the left column, and primary roles and priorities are the column entries under the separate flight tasks. Primary roles may be C (onset cue), F (feedback), or M (monitoring). Priorities are given as numbers following letter symbols for roles. See Section V for full explanations of how roles were identified and priorities assigned.

TABLE E-2.

This table identifies the primary roles of and priorities for types of motion information when selected malfunctions are introduced (see Section III and Appendix B). The letter symbols and priorities have the same meanings as in Table E-1. The top portion of the table identifies malfunctions that may be introduced during ATP checks. Those assigned as training requirements appear in the bottom portion of the table.

TABLE E-3.

This table continues the role-priority analysis, this time for the additional maneuvers that may be required during performance of one or more of the basic flight tasks. Note that these results, and those shown in Table E-2, are to be used as overlays on the basic motion-flight task matrix. See Section V for a full explanation, and Section VI for the effects of the overlays.

TABLE E-4.

This table identifies the types of motion information that would be affected by each of 11 environmental conditions. No priorities are given. Rather, Xs indicate types of motion information affected, the assumption being that the effects would be appropriately represented in the simulator motion system if and when they occur.

TABLE E-1. CUE (C), FEEDBACK (F), AND MONITORING (M) PRIORITIES FOR PLATFORM MOTION DURING FLIGHT TASKS

Type of Information	Flight Task: Taxi to takeoff position	Takeoff ground roll	Rotation	Climb to cleanup	Airfoil cleanup	Reject takeoff	Climb to cruise altitude	Level off at cruise altitude	Cruise	Arrival descent	Level off from arrival descent	Emergency descent	Level off from emergency descent	Holding	Visual approach to visual glidepath	Inst. approach to visual glidepath circling vis. trans.	Circling approach trans. to visual glidepath	Missed approach	Visual glidepath to LMTP	LMTP to flare	Flare to initial touchdown	Initial touchdown to start ground	Landing ground roll	Reject landing	Taxi to gate
Change in speed (accel/decel)	F2	F2			M3	F2						M2	M3		M2	M2		M2	M2		M3	M2	F2	M2	F2
Uncoordinated flight (yaw out of trim)	F2	F2	F2	C1	C1	F2	C1	C1	C1	C1	C1	C1	C1	C1	C1	C1	C1	C1	C1	F2	F2	F2	F2	C1	F2
Change in pitch	M3	M3	F2	M3	F2	M3	F2	F2	F2	F2	F2	F2	F2	F2	F2	C1	F2	F2	F2	F2	F2	F2	M3	F2	M3
Change in roll	M3	M3	M3	F2	F2	M3	F2	F2	F2	F2	F2	F2	F2	F2	F2	F2	F2	F2	F2	F2	F2	F2	M3	F2	M3
Change in yaw	F2	F2	F2	C1	C1	F2	C1	C1	C1	C1	C1	C1	C1	C1	C1	C1	C1	C1	C1	F2	F2	F2	F2	C1	F2
Buffet pitch					M2	M2						M2	M2		M2	M2	M2	M2	M2	M3			M2	M2	
Buffet roll					M2	M2						M2	M2		M2	M2	M2	M2	M2	M3			M2	M2	
Buffet yaw					M2	M2						M2	M2		M2	M2	M2	M2	M2	M3			M2	M2	
Constant G loading				M3	M3		M3	M3	M3	M3	M3	M2	M2	M3	M3	M3	M3	M3	M3	M3	M2	M3		M3	
Constant deck angle			M2	M2			M2	M2		M2	M2	M2	M2	M3	M2	M2	M2	M2	M2	M2	M2	M2		M2	

TABLE E-2. CUE (C), FEEDBACK (F), AND MONITORING (M) PRIORITIES FOR PLATFORM MOTION DURING MALFUNCTIONS

Malfunction	Change in speed	Uncoordinated flt.	Change in pitch	Change in roll	Change in yaw	Buffet pitch	Buffet roll	Buffet yaw	Constant G lds.	Constant deck angle
	Type of Information									
ATP checks (to replace inspection):										
30. One engine fails	C1	C1		F2	C1					
31. Two engines fail	C1	C1	F2	F2	C1					M2
58. Flaps (TE) fail to extend										
59. Asymmetric/split flaps (TE)	M2		C1	M3	M3	M2	M2	M2		M3
60. Asymmetric leading edge devices	M3	C1	F2	C1	C1	M2	M2	M2		
Training:										
47. Gear extends partially	M2	C1	M3	F2	C1	M2	M2	M2		
52. Antiskid fails	F2	F2	M3	M3	F2	M2	M2	M2		
54. Brakes fail	C1	F2	M3	M3	F2	M2	M2	M2		
55. "A" hydrol fails	F2		M2	F2		F2	F2	F2		
56. "B" hydrol fails	F2		M2	F2		F2	F2	F2		
57. Total hydrol failure	F2	C1	M2	F2	C1	M3	M3	M3		
61. Spoiler float		F2		M3	F2	M3	M3	M3		
62. Lower rudder limiter fails		C1		F2	C1	M3	M3	M3		
63. Yaw dampers fail		C1			C1					
64. Runaway stabilizer trim			C1							
70. No reverse (one engine) on landing	C1	F2			F2	M2	M2	M2		
XX. Tire failure	F2	F2	F2	F2	F2	M2	M2	M2		

TABLE E-3. CUE (C), FEEDBACK (F), AND MONITORING (M) PRIORITIES FOR PLATFORM MOTION DURING MALFUNCTIONS

Type of Information	Level turns w/ roll in/roll out	Climbing turns w/ roll in/roll out	Descending turns w/ roll in/roll out	Climbs	Descents	Steep turns	Dutch roll	Stalls	Gear extension/ retraction	Speed brake extension/retraction	Flap extension/retraction	Recognition of excessive pitch	Recognition of excessive bank	Recovery from excessive pitch	Recovery from excessive bank
	Additional Maneuvers														
Change in speed (accel/decel)								M3	M2	M2	M2	M3		M3	
Uncoordinated flight (yaw out of trim)	C1	C1	C1	C1	C1	C1	C1	C1		C1			M2		M2
Change in pitch	F2	F2	F2	F2	F2	F2	M3	F2	M3	F2	C1	M2	M2	F2	F2
Change in roll	F2	F2	F2	F2	F2	F2	F2	F2		F2	F2		M2		F2
Change in yaw	C1	C1	C1	C1	C1	C1	C1	C1		C1			M2		M2
Buffet pitch							M3		M2	F1	M2				
Buffet roll							M3		M2	F1	M2				
Buffet yaw							M3		M2	F1	M2				
Constant G loading	M3	M3	M3	M3	M3	F2	M3	M3				M2	M2	F2	F2
Constant deck angle		M2	M2	M2	M2			M3			M2	M2		F2	

TABLE E-4. PLATFORM MOTION CHARACTERISTICS AFFECTED BY GIVEN ENVIRONMENTAL CONDITIONS

Type of Information	Environmental Condition										
	Thunderstorms	Ground effects	Ice on runway	Head wind	Tail wind	Crosswind	Wind gusts	Wind shears	Turbulence	Engine icing	Airframe icing
Change in speed (accel/decel)	X	X	X	X	X	X	X	X	X	X	
Uncoordinated flight (yaw out of trim)	X		X			X	X	X	X		
Change in pitch	X	X					X	X	X		
Change in roll	X					X	X	X	X		
Change in yaw	X		X			X	X	X	X		
Buffet pitch	X							X	X		X
Buffet roll	X							X	X		X
Buffet yaw	X							X	X		X
Constant G loading	X										
Constant deck angle	X									X	X

APPENDIX F

RESULTS OF THE AURAL CUE ANALYSIS

This appendix presents detailed results of the aural cue analysis explained in Section V. In contrast to analyses of visual and motion cues, sounds have specific sources and qualities. Hence, the results of the analysis of aural cues can be presented in a single table.

The sounds identified in Table F-1 are divided into two classes, continuing sounds (engines and airflow) and sounds specific to tasks and equipment. For continuing sounds, there are provisions with each basic task for sounds of constant intensity (and quality) as well as changes in intensity during the progress of the task. Thus, during cruise, for example, airflow and engine sounds are constant most of the time, but occasional throttle adjustments can result in increases as well as decreases in intensities of either sound. Hence, the presence of constant sound is indicated by an X under "Con." Increases and decreases in these sounds could provide feedback. If so, an F appears under "Inc" and/or "Dec," respectively. If the sound serves to cue an action, a C appears under "Inc" or "Dec" as appropriate. Engine and airflow sounds were not assigned priorities.

The roles of specific sounds are also indicated as F or C, or as both if feedback and cueing roles are both served. In addition, the F and C roles are prioritized according to their usual values during task performance (see Section V). In addition to listing sounds for 25 basic tasks, Table F-1 also identifies specific sounds accompanying selected malfunctions. Other sounds accompanying the malfunctions would be those associated with the task(s) underway at the time the malfunctions occur.

TABLE F-1. ROLES AND PRIORITIES OF SOUNDS ACCOMPANYING TASK PERFORMANCE

Task	Airflow Con	Airflow Inc	Airflow Dec	Engines Con	Engines Inc	Engines Dec	Specific Sound: Source	Role C/F	Priority
Taxi to takeoff position				X	C/F	F	Nosewheel surface noise/bumps	F	2
							Air condit air flow	F	3 *
Takeoff ground roll		F		X	F		Compressor stalls	C/F	2/2
							Nosewheel surface noise/bumps	F	2
Rotation	X			X			Nosewheel retraction	F	1
							Nosewheel doors opening	F	1
Climb to cleanup	X	F	F	X		F	Nosewheel retraction	F	1
							Nosewheel doors closing	F	1
Airfoil cleanup	X	F			F	F			
Rejected takeoff			F	X	F	F	Nosewheel surface noise/bumps	F	2
							Main gear brakes	F	3
							Nosewheel brakes	F	2
							Compressor stalls	C/F	2/2
Climb to cruise altitude	X	F	F	X					
Level off at cruise altitude	X	F		X	F	F			
Cruise	X	F	F	X	F	F			
Arrival descent	X	F	F	X		F	Speed brakes buffet	F	3

* To be included in all basic tasks.

(Continued)

TABLE F-1. (Continued)

Task	Airflow Con	Airflow Inc	Airflow Dec	Engines Con	Engines Inc	Engines Dec	Specific Sound Source	Role C/F	Priority
Level off from arrival descent	X	F	F	X	F	F	Speed brakes buffet	F	3
Emergency descent	X	F	F	X		F	Nosewheel doors opening	F	1
							Nosewheel extending	F	1
							Nosewheel doors closing	F	1
							Speed brakes buffet	F	3
Level off from emergency descent	X		F	X	F		Nosewheel doors opening	F	1
							Nosewheel retracting	F	1
							Nosewheel doors closing	F	1
							Speed brakes buffet	F	3
Holding	X	F	F	X	F	F	Speed brakes buffet	F	3
Visual approach to visual GP	X	F	F	X	F	F	Nosewheel doors opening	F	1
							Nosewheel extending	F	1
							Nosewheel doors closing	F	1
Instr approach to visual GP	X	F	F	X	F	F	Nosewheel doors opening	F	1
							Nosewheel extending	F	1
							Nosewheel doors closing	F	1
Circling approach to visual GP	X	F	F	X	F	F	Nosewheel doors opening	F	1
							Nosewheel extending	F	1
							Nosewheel doors closing	F	1
Missed approach	X	F	F	X	F	F	Nosewheel doors opening	F	1
							Nosewheel retracting	F	1
							Nosewheel doors closing	F	1

(Continued)

TABLE F-1. (Continued)

Task	Airflow Con	Airflow Inc	Airflow Dec	Engines Con	Engines Inc	Engines Dec	Specific Sound: Source	Role C/F	Priority
Visual GP to LMTP	X	F	F	X	F	F	Nosewheel doors opening	F	1
							Nosewheel extending	F	1
							Nosewheel doors closing	F	1
LMPT to flare	X	F	F	X	F	F			
Flare to initial touchdown	X		F	X	F	F	Main gear contacting runway	F	2
Initial touchdown to start GR	X		F	X	F	F	Nosewheel contacting runway	F	2
Landing ground roll			F	X	F	F	Nosewheel surface noise/bumps	F	2
							Brakes	F	3
Reject landing	X	F	F	X	F		Nosewheel doors opening	F	1
							Nosewheel retracting	F	1
							Nosewheel doors closing	F	1
Taxi to gate				X	C/F	F	Nosewheel surface noise/bumps	F	2
Malfunction: Engine(s) failure									
Takeoff ground roll through Climb to cleanup						F	Engine seizure (possible)	C/F	2/2
							Air cond air flow	F	2
Airfoil cleanup through Taxi to gate						F	Engine seizure (possible)	C/F	2/2

(Continued)

TABLE F-1. (Continued)

	Airflow			Engines			Specific Sound		
Task	Con	Inc	Dec	Con	Inc	Dec	Source	Role C/F	Priority
Malfunction: Anti-skid fails									
Reject takeoff							Tire blowout	C/F	3/3
Landing GR							Tire blowout	C/F	3/3

APPENDIX G

SIMULATOR PERFORMANCE TESTS

This appendix contains performance tests for Type A and Type B simulators as described in Section VI. Test requirements are presented in two tables, one for Type A and one for Type B simulators. The tables were constructed predominantly from tests contained in FAA Advisory Circular AC 120-40, Airplane Simulator and Visual Systems Evaluation. However, new tests were added for brake pedal position versus force, wind-shear takeoff, no-flap landing, wind-shear approach, asymmetrical reverse thrust effect, reverse-thrust rudder blanking, and motion system acceleration by axis. Column heads in the tables show which flight segments drive the test requirement. However, this is not intended to reflect the specific flight condition for conducting the test. In this regard, the flight conditions, parameters, and tolerances contained in AC 120-40 are considered adequate unless qualified by specific footnotes.

Performance test requirements were derived as an adjunct to the formal determination of simulator requirements using ACSD methods. They are included in this appendix for the sake of completeness.

ORGANIZATION OF TABLES.

The column at the left of each table identifies the nature of each simulator performance test. The column heads identify flight segments. Entries are either upper-case Xs or lower-case letters beginning with a. Xs indicate required performance tests, as do the lower-case letters. However, the latter are qualified as indicated in lists of notes following the tables. The notes also contain other important information applicable to the tables.

TABLE G-1. PERFORMANCE TEST REQUIREMENTS FOR TYPE A SIMULATORS

Performance Test	Taxi	Takeoff	Rejected TO	In-Flt Maneuv	Visual Apch	Inst Apch	Landing
1. Static Control Checks							
a. Column position vs. force and surface position calibration		a		a	a	a	a
b. Wheel position vs. force and surface position calibration		a		a	a	a	a
c. Rudder pedal position vs. force and surface position calibration		a	X	a	a	a	a
d. Nosewheel steering force	X	X	X				X
e. Rudder pedal steering calibration force	X	X	X				X
f. Pitch trim calibration indicator vs. computed		X	X	X	X	X	X
g. Alignment of power lever angle (cross-shaft angle) vs. selected engine parameter (EPR, N_1)	X	X		X	X	X	X
h. *Brake pedal pos vs. force	X		X				X
2. Taxi							
a. Minimum radius turn	X						
b. Rate of turn vs. nosewheel steering angle	X		X				X

(Continued)

TABLE G-1. (Continued)

Performance Test	Taxi	Takeoff	Rejected TO	In-Flt Maneuv	Visual Apch	Inst Apch	Landing
3. Takeoff							
a. Ground acceleration time and distance		X					
b. Minimum control speed, ground		X					
c. Minimum rotate speed		X					
d. Minimum unstick speed		X					
e. Types of takeoff required through 500 feet AGL							
(1) Normal		b					
(2) Engine-out takeoff		b					
(3) Crosswind takeoff		b					
(4) *Wind-shear takeoff		c					
4. Climb Rate							
a. Normal climb		X		X	d	d	
b. Engine-out second segment climb		X					
c. Engine-out approach climb						X	

(Continued)

TABLE G-1. (Continued)

Performance Test	Taxi	Takeoff	Rejected TO	In-Flt Maneuv	Visual Apch	Inst Apch	Landing
5. Longitudinal Control							
a. Power change forces or power change dynamics				X	X	X	X
b. Flap change forces or dynamics		X		e	X	X	
c. Gear change forces or gear change dynamics		X		e	X	X	
d. Gear and flap operating times		X		e	X	X	
e. Longitudinal trim		X		X	X	X	X
f. Longitudinal maneuvering stability (stick force/G)		X		e	X	X	X
g. Longitudinal static stability		X		f	X	X	
h. Short-period dynamics		X		X	X	X	X
i. Phugoid dynamics		X		X	X	X	X
j. Stick shaker, airframe buffet, stall speeds		X		X	X	X	X
6. Lateral Control							
a. Minimum control speed, air		X		e			X
b. Roll response (rate)		X		X	X	X	X

(Continued)

TABLE G-1. (Continued)

Performance Test	Taxi	Takeoff	Rejected TO	In-Flt Maneuv	Visual Apch	Inst Apch	Landing
6. Lateral Control (continued):							
c. Roll overshoot		X		f	X	X	X
d. Spiral stability		X		X		X	
e. Engine out trim		X		g	X	X	X
f. Rudder response		X	X	X	X	X	X
g. Cross control		X		X	X	X	X
h. Dutch roll dynamics				X		X	
7. Landing							
a. Normal landing							X
b. Hands-off landing							
c. Crosswind landing							
d. Engine-out landing							X
e. Stopping time and distance: wheel brakes			X				X
f. Stopping time and distance: reverse thrust			X				X
g. No-flap landing							X
h. Wind-shear approach						X	
i. Asymmetrical reverse thrust effects			X				X

(Continued)

TABLE G-1. (Continued)

Performance Test	Taxi	Takeoff	Rejected TO	In-Flt Maneuv	Visual Apch	Inst Apch	Landing
7. Landing (continued):							
j. Reverse-thrust rudder blanking			X				X
k. Demonstration of ground effect							X
8. Motion System Checks							
a. Frequency response checks							
b. Leg balance check							
c. Turn around check		X	X	X	X	X	X
d. Acceleration by axis		h	h	h	h	h	h

Notes for Table G-1:

General and miscellaneous:

(1) Except as noted in (2) below, parameters, tolerances, and flight conditions for performance are listed in FAA Advisory Circular AC 120-40.

(2) New tests include the following:

1-h. Brake pedal pos(ition) vs. force
3-e(4). Wind-shear takeoff
7-g. No-flap landing
7-h. Wind-shear approach
7-i. Asymmetrical reverse thrust effects
7-j. Reverse-thrust rudder blanking
7-k. Demonstration of ground effects
8-d. Acceleration by axis

(3) Re 5-h. Short-period dynamics: The short period is the principal longitudinal maneuvering mode and must be accurately protrayed to achieve representative longitudinal handling qualities.

(4) Re 5-i. Phugoid dynamics: Phugoid is a measure of the long period longitudinal dynamics and relates drag and pitching moment to speed variations. If phugoid is not accurately portrayed, pilot workload may be artificially increased or decreased.

(5) Re 6-h. Dutch roll dynamics: The Dutch roll mode couples the airplane's roll and yaw motion and is an important handling qualities parameter.

(6) For entries in the left column preceded by asterisks, these tests are based on training requirements, not checking requirements.

(7) Instrument Approach includes Missed Approach.

Special column entries:

a Tests for dynamic damping cycles of the controls are required in addition to static control tests.

b Parameters for these dynamic tests are pitch, roll, yaw, airspeed, and altitude.

c Takeoff and approach wind-shear tests should ensure that approved maneuvers permit positive escape from real-world, three-dimensional microburst effects. Escape capabilities should be based on airplane performance characteristics and escape maneuver control models.

d Required for missed approach/rejected landing.

e Required for stall recovery.

f Required for steep turns.

g Required for stall-recovery training with engine failure.

h These tests should be conducted for a representative sample of motion effects. The tests measure accelerations (magnitude and response time) in the primary axis used for onset cueing for a given effect. Onset accelerations should correspond to airplane data. The tests also measure accelerations in the primary axis used to sustain an onset cue. These accelerations should represent the gravitational vector required to sustain the cue.

TABLE G-2. PERFORMANCE TEST REQUIREMENTS FOR TYPE B SIMULATORS

Performance Test	Takeoff	Rejected TO	Area Departure	Cruise	Emergency Descent	Area Arrival	Inst Apch
1. Static Control Checks							
a. Column position vs. force and surface position calibration	X		X	X	X	X	X
b. Wheel position vs. force and surface position calibration	X		X	X	X	X	X
c. Rudder pedal position vs. force and surface position calibration	X	X	X	X	X	X	X
d. Nosewheel steering force	X	X					
e. Rudder pedal steering calibration force	X	X					
f. Pitch trim calibration indicator vs. computed	X	X	X	X	X	X	X
g. Alignment of power lever angle (cross-shaft angle) vs. selected engine parameter (EPR, N_1)	X		X	X	X	X	X
h. *Brake pedal pos vs. force		X					
2. Taxi							
a. Minimum radius turn							
b. Rate of turn vs. nosewheel steering angle		X					

(Continued)

TABLE G-2. (Continued)

Performance Test	Takeoff	Rejected TO	Area Departure	Cruise	Emergency Descent	Area Arrival	Inst Apch
3. Takeoff							
a. Ground acceleration time and distance	X						
b. Minimum control speed, ground							
c. Minimum rotate speed	X						
d. Minimum unstick speed	X						
e. Types of takeoff required through 500 feet AGL							
(1) Normal	X						
(2) Engine-out takeoff							
(3) Crosswind takeoff							
(4) *Wind-shear takeoff							
4. Climb Rate							
a. Normal climb	X		X			X	a
b. Engine-out second segment climb							
c. Engine-out approach climb							

(Continued)

TABLE G-2. (Continued)

Performance Test	Takeoff	Rejected TO	Area Departure	Cruise	Emergency Descent	Area Arrival	Inst Apch
5. Longitudinal Control							
a. Power change forces or power change dynamics			X		X	X	X
b. Flap change forces or dynamics	X						X
c. Gear change forces or gear change dynamics	X						X
d. Gear and flap operating times	X						X
e. Longitudinal trim	X						
f. Longitudinal maneuvering stability (stick force/G)	X		X	X	X	X	X
g. Longitudinal static stability	X		X	X	X	X	X
h. Short-period dynamics	X		X	X	X	X	X
i. Phugoid dynamics	X		X	X	X	X	X
j. Stick shaker, airframe buffet, stall speeds	X		X			X	X
6. Lateral Control							
a. Minimum control speed, air							
b. Roll response (rate)	X		X	X	X	X	X

(Continued)

TABLE G-2. (Continued)

Performance Test	Takeoff	Rejected TO	Area Departure	Cruise	Emergency Descent	Area Arrival	Inst Apch
6. Lateral Control (continued):							
c. Roll overshoot	X		X	X	X	X	X
d. Spiral stability				X			X
e. Engine out trim							
f. Rudder response	X	X	X	X	X	X	X
g. Cross control	X		X	X	X	X	X
h. Dutch roll dynamics				X			X
7. Landing							
a. Normal landing							
b. Hands-off landing							
c. Crosswind landing							
d. Engine-out landing							
e. Stopping time and distance: wheel brakes		X					
f. Stopping time and distance: reverse thrust		X					
g. No-flap landing							
h. Wind-shear approach							
i. Asymmetrical reverse thrust effects							

(Continued)

TABLE G-2. (Continued)

Performance Test	Takeoff	Rejected TO	Area Departure	Cruise	Emergency Descent	Area Arrival	Inst Apch
7. Landing (continued):							
j. Reverse-thrust rudder blanking							
8. Motion System Checks							
a. Frequency response checks							
b. Leg balance check							
c. Turn around check							
d. Acceleration by axis							

Notes for Table G-2:

General and miscellaneous:

(1) Parameters, tolerances, and flight conditions for performance tests are listed in FAA Advisory Circular AC 120-40.

(2) Re 5-h. Short-period dynamics: The short period is the principal longitudinal maneuvering mode and must be accurately protrayed to achieve representative longitudinal handling qualities.

(3) Re 5-i. Phugoid dynamics: Phugoid is a measure of the long period longitudinal dynamics and relates drag and pitching moment to speed variations. If phugoid is not accurately portrayed, pilot workload may be artificially increased or decreased.

(4) Re 6-h. Dutch roll dynamics: The Dutch roll mode couples the airplane's roll and yaw motion and is an important handling qualities parameter.

(5) For entries in the left column preceded by asterisks, these tests are based on training requirements, not checking requirements.

(6) Takeoff tests for training only.

(7) Instrumental Approach includes Missed Approach.

Special column entry:

a Required for missed approach.

☆ U. S. GOVERNMENT PRINTING OFFICE: 1985--501-129--678

160 copies