SIMULATOR FIDELITY CONSIDERATIONS FOR TRAINING AND EVALUATION OF TODAY'S AIRLINE PILOTS

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ABSTRACT

Regulatory changes in response to today's airline pilot training and evaluation needs push the twin issues of effectiveness and affordability of flight simulators for use by U.S. airlines to the forefront. The Federal Aviation Administration (FAA) is sponsoring two research programs with high pay-off potential in this area, namely, platform motion and realistic radio communications. This paper describes the rationale and the initial results of this work.

TODAY'S AIRLINE ENVIRONMENT

Managers of airline pilot training programs today are increasingly being faced with some unprecedented challenges. Of these, changing demographics in the available new-hire population is clearly the most prominent. Many of the nation's largest airlines have found it necessary to dramatically decrease their entry-level requirements in terms of flight hours and prior experience. This in turn has placed even greater pressure on smaller airlines, where entry levels have been lowered to bare minimums, while turnover among pilots leaving for positions with major airlines is at an all time high. All of this is occurring in a backdrop of increased congestion within the National Aerospace System (NAS), associated short-term strategies (such as Land and Hold Short) to manage capacity, the acquisition of newer aircraft with increasingly automated cockpit systems, the merging of airlines which may differ in their operating procedures and their corporate cultures, and near term plans for new ways of operating within the NAS, such as free flight, and Air Traffic Control (ATC) data link.

CHANGE IN TRAINING AND EVALUATION NEEDS

These developments clearly have implications for the design and content of pilot training. Pilot training curricula which were based on certain entry level assumptions that no longer are valid must be revised to incorporate training in areas either not previously required for airline new-hires, or not previously addressed in depth. In some cases this will require a substantial increase in the footprints allocated to training and assessment of basic knowledge and hands-on flying skills. In all cases it will require that flight operations training include specific emphasis on building proficiency in the integration of cognitive and motor flying skills. While these needs are particularly pertinent to initial qualification curricula, they may also necessitate certain changes in recurrent training curricula, in order to assure that requisite proficiency is maintained, especially for rarely practiced skills, or those with very low prior experience histories.

Similarly, it becomes increasingly important for each airline to assure that pilot training for both new-hire and existing pilot populations appropriately reflects its dynamically changing environment, whether that be in terms of aircraft systems, flight procedures, or corporate culture.

With regard to the regulatory environment pertinent to these developments, there is both good and bad news. On the positive side, the Federal Aviation Administration (FAA) has established a voluntary regulatory program for airlines that is well suited to meet the training challenges of today and tomorrow. The Advanced Qualification Program (AQP), which was established as Special Federal Aviation Regulation (SFAR) 58 (FAA, 1990), is specifically designed to assure that pilot training programs remain responsive to changing needs, and that the graduates of such programs not only possess the requisite knowledge and hands-on skills, but that in particular, they can demonstrate proficiency in the integration of cognitive and motor skills in operationally realistic scenarios that test both.

On the negative side, the traditional pilot training regulations, Subparts N & O of Part 121 of the Code of Federal Regulations, which constitute the only alternative to AQP, are sorely out of date relative to today's needs. The FAA is presently in the process of rewriting Subparts N & O. A Notice of Proposed Rulemaking (NPRM) detailing proposed changes to traditional pilot training, testing, and checking requirements is anticipated at a future date.

AQP requires airlines to employ a systematic instructional design process in determining the content of pilot training, testing, and checking, as well as in the allocation for those purposes of training equipment to curricula. It specifically requires the use of entry level analysis to assure that training content is appropriately matched to an airline's pilot population, and it mandates the implementation of a continuing quality control process for monitoring the effectiveness of curricula. While it allows flexibility in equipment selection, AQP is not ordinarily intended for use in curricula that employ the aircraft for training. Rather, AQPs typically employ a suite of training equipment, which includes flight training devices and full flight simulators.

The revised Subpart N & O rules are expected to incorporate a similar philosophy, in contrast to the existing rules, which permit training, testing, and checking to be conducted entirely in the aircraft. It can reasonably be expected, therefore, that within a few more years, all airline pilot training in the U.S. will require the use of full flight simulators for certain training, testing, and checking tasks, while allowing for the use of flight training devices for many but not all such tasks. It can also be expected that pilot training addressing both cognitive and motor skills in simulated scenarios that require both sets of skills will be a requirement for all curricula, both in AQP and otherwise.

A related regulatory development is the pending issuance of a NPRM on simulator qualification. Whereas presently U.S simulator qualification procedures and standards are detailed only in a FAA Advisory Circular (AC120-40B, FAA, 1991, as amended), the proposed new rule is intended to establish a regulatory basis for those procedures and standards. If issued as a final rule, airlines and training centers that do not maintain their flight simulators in accordance with the procedures and standards on which basis the FAA originally qualified the equipment could be subject to FAA enforcement action.

IMPLICATIONS FOR SIMULATORS

The net result of these developments is that ultimately all pilot training in the U.S. will be conducted in FAA qualified training equipment (full flight simulators, and, where permitted, flight training devices) rather than in aircraft. Airlines will be required by regulation to maintain the fidelity of such equipment in accordance with FAA qualification criteria. Furthermore, it can be expected that regardless of whether an airline is conducting pilot training under an AQP or under revised traditional rules, all curricula will require training in operationally realistic scenarios.

While these developments will be largely transparent to major airlines under AQP, they will be especially challenging to smaller airlines that do not presently employ simulators, or that have limited access to such equipment. Depending on the particular aircraft make, the availability of flight simulators may be problematic, and for some operators, cost could be prohibitive.

It should be clear from the various considerations discussed above that two related issues of particular importance for meeting the challenges of the future will be training effectiveness of flight simulators and their affordability. While the effectiveness of flight simulators for initial and recurrent training of airline pilots is well recognized, there are two areas that warrant further examination in light of the preceding discussion. These are platform motion and the simulation of realistic radio communications.

While all FAA qualified full flight simulators are required to have platform motion, there remain a number of questions yet to be empirically addressed through appropriate research. Specifically, the question to be answered is whether the training conducted in a fixed-base simulator with a wide Field Of View (FOV) visual system produces a result equivalent to that which would be obtained in a like system having platform motion cueing. An additional question from a regulatory perspective is whether proficiency checks conducted in a visually equipped fixed-base simulator provide an equivalent opportunity to verify the line-operational readiness of air-carrier pilots.

If the answers to these questions can reliably and validly be obtained, the FAA may be better able to determine what level of equipment should be required for initial or recurrent training programs in the future, and whether changes to future qualification criteria for such equipment are warranted. These decisions could significantly affect the cost and availability of flight training equipment in light of future regulatory plans, particularly for small operators.

One of the widely recognized deficiencies in the current state of the art in full flight simulation is realistic radio communications. The simulation of such communications is typically accomplished by the pilot instructor/evaluator (I/E), who is also tasked with operating the simulator while observing trainee performance. This mode of simulation is a highly simplified representation of radio communications, and does not even begin to approach the challenges to hearing, acknowledging, and appropriately responding to radio communications within a real world environment. It follows that scenario based training, testing, and checking that is based on such an unrepresentative means of simulation is not likely to be fully effective in developing the cognitive and workload management skills associated with radio communications. While this is obviously a deficiency of long standing, it may assume greater significance in light of the changing demographics of the pilot new-hire population. It follows that research is needed to measure the impact of realistic radio communications on training effectiveness, and to make an assessment of whether there may be an affordable means of better simulating this function in light of developing technology.

SIMULATOR MOTION FIDELITY REQUIREMENTS

Subject Matter Expert (SME) Opinion

The focus on simulator motion originated from a series of joint FAA-industry symposia on the most costly aspects of airplane simulation organized by the Department of Transportation's Volpe Center (Longridge, Ray, Boothe, Bürki-Cohen, 1996). This was part of a FAA-sponsored review of simulator requirements as outlined in AC120-40B (FAA, 1991). The SMEs from industry, academia, and FAA participating in the discussions on simulator motion generally perceived that the absence of platform motion cueing in fixed-base devices is likely to have a detrimental effect on pilot control performance, particularly in maneuvers entailing sudden motion-onset cueing with limited visual references. It was also noted, however, that there was no scientific evidence that training in a fixed-base device would lead to degraded control performance in the actual aircraft (Transcript, 1996). This issue is especially pertinent in a device equipped with a wide FOV visual system, which can generate an illusion of motion (vection).

Literature Review

An extensive literature review confirmed that platform motion in the simulator might improve the acceptability of the simulator, at least when the pilots were aware of the motion manipulation (Reid and Nahon, 1988; but see Bussolari, Young, and Lee, 1987). Motion also improved pilot performance and control behavior in the simulator, especially for disturbance tasks and tracking tasks of aircraft with low dynamic stability (Hosman and van der Vaart, 1981; Hall, 1978; Hall, 1989). Some of the benefits of platform motion have also been shown to transfer to a higher fidelity simulator (Levison, 1981). However, the literature review also showed that the benefits of platform motion have not been proven in the case of transfer of training to the airplane (see, e.g., Waag, 1981).

Volpe has therefore been tasked to obtain objective data on simulator motion requirements. Questions to be answered include, but are not limited to, the following: Are there any flight tasks for which a measurable difference in simulator training effectiveness can be found with and without platform motion? What is the relationship in motion cueing effectiveness for a wide FOV visual display versus platform motion? Are existing platform motion qualification criteria optimal? Is there a relationship between pilot experience level and the effectiveness of platform motion for training?

Current Findings

A first experiment intended to answer some of these questions used a FAA qualified Level C simulator with a six degree-of-freedom (DOF) synergistic motion system and a wide angle high-quality visual system, simulating a 30 passenger turboprop airplane with twin wing-mounted engines (Bürki-Cohen, Boothe, Soja, DiSario, Go, and Longridge, 2000; Go, Bürki-Cohen, and Soja, 2000). Deficiencies identified in a review of prior research designs were avoided by measuring both pilot stimulation and response, testing both maneuvers and pilots that are diagnostic of a need for motion, preventing pilot and instructor bias, and ensuring sufficient statistical power to capture operationally relevant effects. Experienced airline pilots were evaluated and trained in the simulator, half of them with and the other half without motion. Then the transfer of skills acquired by both groups during this training was tested in the simulator with the motion system turned on as a stand-in for the airplane (quasi-transfer). The test maneuvers selected were engine failures on take-off with either rejected take-off (RTO) or continued take-off ($V_{1/R}$ cut), which satisfied the criteria described in the literature as diagnostic for the detection of a motion requirement. These criteria included 1) closed loop, to allow for motion to be part of the control feedback loop to the pilot; 2) disturbance maneuver, to highlight an early alerting function of motion (Gundry, 1976; Hall, 1989); 3) high gain, to magnify any motion effects and to reduce the stability of the pilot/airplane control loop (Hall, 1989); 4) high workload with crosswind and low visibility, to increase the need for redundant cues such as provided by motion, out-the-window view, instruments and sound; and 5) short duration, to prevent pilots from adjusting to a lack of cues. Both subjective (I/E grades, questionnaires) and objective data recorded from the simulator were collected from the experiment.

The results of the study indicate that the motion provided by the test simulator did not, in an operationally significant way for the tasks tested, affect either evaluation, training progress, or transfer of training, acquired in the simulator with or without motion, to the simulator with motion. It also didn't consistently affect the Pilots' Flying (PF), Pilots' Not Flying (PNF), and I/Es' subjective perception of the PFs' performance, workload, and training, or of their own comfort in the simulator. Neither did it affect the acceptability of the simulator to the PF and the PNF.

Note, however, that because the current simulator qualification procedures do not provide a means to objectively assess the quality of the produced motion (Lahiri, 2000), the motion provided by the test simulator may not be typical of other FAA qualified Level C simulators. Specifically, the observed lack of lateral acceleration produced by the simulator shortly following the engine failure compared to the lateral acceleration from the aircraft mathematical model suggests that the simulator used in the study may not have provided sufficient motion stimulation to the pilot. Clearly, additional steps must be taken to determine the extent to which it may or may not be appropriate to draw generalization based on these results.

Further Studies

To validate and generalize the previous results, two follow-up studies are underway. One examines the typicality of the test simulator used in the previous experiment, by gathering data from other Level C and D simulators and then comparing these data to the test simulator. This effort will provide information on whether the earlier results may apply to other FAA qualified simulators, at least for the maneuvers and pilot population tested.

The second study will be similar to the previous one, while eliminating any possible causes of not having found an effect of motion. For example, the motion system of the test simulator will be tuned to provide the best possible performance within its operational envelope. Also, test subjects will fly different maneuvers considered to be diagnostic for detecting an effect of motion. Finally, the type of airplane simulated and the pilot population will be different from the previous experiment. Results of this study will help determine whether the benefits of tighter motion standards, as currently considered, would justify the potential reduction in simulator availability due to an inevitable increase in acquisition, maintenance, as well as enforcement efforts.

REALISTIC RADIO COMMUNICATIONS SIMULATION FIDELITY REQUIREMENTS

Given the engineering efforts expended on the simulation of the airplane, the lack of sophistication in representing the operational environment, of which radio communications represent the largest aspect, may be due both to a historical emphasis on motor flying skills as well as the technical difficulties of simulating radio communications realistically without additional personnel. As has been explained earlier, however, today's training and evaluation needs increasingly require the inclusion of the cognitive aspects of the flying task. Volpe, in collaboration with NASA Ames, has therefore examined 1) airlines' current methods of simulating radio communications, 2) the effect of these practices on training and evaluation according to subject matter experts, literature, and reports on initial operating experience (IOE), and 3) industry efforts to improve the current situation. A summary of this work follows (see Bürki-Cohen, Kendra, Kanki, and Lee, 2000, for details). Future efforts may experimentally examine the impact of providing realistic radio communications.

Current practices

The findings summarized below are based on information collected from 29 I/Es from 14 AQP airlines, including seven major, one cargo, four regional, and two foreign airlines. I/Es were queried about their simulation of different events, including ATC (tower, approach/departure, en route) and company communications (dispatch, ramp, maintenance, flight attendants) to own aircraft, ATC communications to and from other aircraft or ground vehicles (the so-called party line), as well as visual representation of other traffic.

A first finding was that the method of simulating radio communications is indeed almost exclusively I/E role-play, where the I/E issues instructions and responds from his station directly behind the crew. This was found both for company and ATC radio communications.

With regard to communications to own airplane, all I/Es reported simulating ATC clearances in the terminal environment, and all but two provide communications en route. Fewer I/Es make time to role-play company communications, between 63 (ramp/gate) and 94 percent (dispatch).

I/Es were also queried about representation of other traffic. Only 59 percent indicated that their simulators provide some out-the-window view of traffic, mainly on the airport surface. Ten reported simulation of traffic via the Traffic Alert and Collision Avoidance System (TCAS). With regard to the party line, only 38 percent of all I/Es reported simulating any communications to and/or from other aircraft or vehicles, mainly on the airport surface.

Instructor/Evaluator Opinions

I/Es were asked to indicate their allocation of time and effort between running the simulation, simulating radio communications, instructing and observing. I/Es spend about 50 percent their time and effort observing, twenty percent each role-playing radio communications and operating the simulator, and less than ten percent instructing.

Not surprisingly, I/Es rated their workload consistently higher for training and checking in the simulator than in the actual aircraft with real communications and no simulator to run. On the other hand, they feel that the communications workload of the pilots is significantly reduced. One I/E mentioned that even the manual workload of pilots is reduced, because "[p]ilots are not normally given a chart frequency, nor do they need to redial a new frequency to communicate."

I/Es stressed the importance of radio communications simulation for teaching such skills as (new) ATC procedures, Crew Resource Management (CRM) and situation awareness effectively. The overall importance of radio communications is perceived highest in the terminal environment. I/Es concern with simulating radio communications may have best been summarized by the I/E who stated: "Without communication simulation, when the pilot trainee finally arrives in the 'real world,' he must add another component…This new (additional) component can really complicate line flying."

Literature review

Many of the I/E opinions found in the previous section are confirmed in the literature (for more detail, see Bürki-Cohen et al., 2000). Both AQP and CRM recognize that coordination with ATC, company, and flight attendants is an integral part of line operations and that frequency monitoring is important for maintaining traffic and weather situation awareness (FAA, 2000; FAA, 1998).

Incident and accident investigations highlight the importance of radio communications. The Flight Safety Foundation Approach and Landing Accident (ALA) Reduction Task Force recommends that operators "[i]nclude training scenarios that allow crews to experience overload, task saturation, loss of situational awareness, out-of-control and too-far-behind-the aircraft-situations, and communications in stressful circumstances." Joint training should be held between pilots and air traffic controllers including scenarios that "promote mutual understanding of issues on both the flight deck and in the ATC environment, and foster improved communications during emergency situations" (Khatwa and Helmreich, 1999).

There is much theoretical and experimental evidence that whole-task training in a fully loaded environment is superior to part-task training in an incomplete environment that may induce a false sense of operational simplicity akin to tunnel vision (see, e.g., Fabiani, Buckley, Gratton, Coles, Donchin, and Logie, 1989). Learning is an active process, and practice can lead to either activation or inhibition of cognitive pathways (Bransford and Franks, 1976). If pilots are consistently exposed to an impoverished environment during training, they may end up unprepared for the "quick pace of an airline environment and [its] associated distractions,"[1] where their inexperience may prove fatal.

Effect on initial operating experience (IOE)

A search of the ASRS database from January 1993 to October 1999, resulting in 93 reports related to flight events during IOE, confirmed some of the concerns expressed by I/Es and the literature (see Bürki-Cohen and Kendra, manuscript, for details). Most of the errors reported involved altitude deviations or course deviations. Other multiple errors were landing or take-off without clearance, approach to or landing on the wrong runway or airport, runway incursions, and loss of communications.

Radio communications played a major role in 72 percent of the reports. Demanding, inadequate, or even erroneous ATC instructions spearheaded the factors leading to events deemed worthy of a report. Amended clearances requiring reprogramming of the automation or erroneous "expect" instructions were often cited. This was followed by inadequate CRM or task management related to radio communications, ATC interruptions including traffic calls and frequency congestion, stuck microphones blocking an entire frequency, or pilots stepping on an ongoing conversation. Next were radio-tuning problems and unfamiliar phraseology and accent, the latter usually in non-English speaking territory.

Industry initiatives

Given all the evidence presented in the previous section, it is not surprising that both airlines and simulator industry are striving to improve radio communications realism. Only efforts known to have been used in airline training will be discussed (see Bürki-Cohen et al, 2000, and Bürki-Cohen and Kendra, manuscript, for details).

[1] From an ASRS report

Among the most operationally realistic efforts is United Airlines' Interactive Real Time Audio System (IRAS). It is based on field recordings of actual ATC communications, including both communications to own and to and from other aircraft with controller voices dubbed with the individual instructors' voices. The system, however, is no longer operational due to high scenario-development, integration and instructor-training costs.

The Canadian simulator manufacturer CAE has developed the Ground Air Traffic Environment System (GATES) after a request from a foreign airline to provide a visual representation of traffic in the airport terminal environment. It soon became obvious that correlated and meaningful radio communications would have to be an essential component of such traffic representation. The I/E still provides all ATC communications to own airplane, however. Several domestic airlines and training facilities as well as foreign airlines and military are currently equipping their simulators with GATES.

Lufthansa and the German ATC organization Deutsche Flugsicherung (DFS) are collaborating on Joint Operational Incidents Training (JOINT). Up to eight Lufthansa simulators can be linked to two DFS ATC control sector simulators, resulting in highly effective recurrent training of both pilots and controllers. Each ATC simulator consists of a controller work station with a radar display showing the simulated airplanes flown by the flight simulator crews as well as other airplanes sharing the same airspace operated by a pseudo pilot sitting at a connected computer station.

CONCLUSIONS

The twin issues of training effectiveness and affordability of flight simulators for use by U.S. airlines will become increasingly critical in light of anticipated regulatory changes, dramatically reduced pilot new-hire experience levels and growing operational complexity. In that regard, two research areas with high pay-off potential are platform motion and realistic radio communications. Initial FAA sponsored research on the training effectiveness of a fixed-base simulator with a wide field-of-view visual system compared to a like system having platform motion failed to find an operationally significant effect of motion using FAA qualified equipment. Acquisition of objective data to determine the extent to which the platform motion characteristics of the equipment employed are typical of other FAA qualified simulators is presently ongoing. A second training effectiveness study is planned using a test simulator tuned to provide the best possible platform motion performance and maneuvers selected to be especially diagnostic. However, considering the controversial nature of this issue, the safety implications, and the fact that no changes in regulatory requirements can be expected without absolute confidence in the reliability and validity of the results, it is likely that considerable additional research in this area will still be needed. Initial research on the simulation of radio communications for U.S. airline pilot training strongly suggests that in order to be fully effective in developing the cognitive and workload management skills associated with radio communications, significant improvements are needed in the resources available to the pilot instructor for that purpose. The present practice of relying on IOE to compensate for the deficiencies in simulator resources for training radio communications skills may become increasingly inadequate in view of the changing demographics of the pilot new-hire population, as well as the anticipated future regulatory requirement for all airlines to conduct training in operationally realistic flight simulator scenarios. Although there have been a number of promising developments in this arena, considerable additional research is needed to reduce the cost and labor requirements associated with simulating radio communications in an operationally realistic fashion.

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