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Air Traffic Control in Airline Pilot Simulator Training and Evaluation

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Much airline pilot training and checking occurs entirely in the simulator, and the first time a pilot flies a particular airplane, it may carry passengers. Simulator qualification standards, however, focus on the simulation of the airplane without reference to the air traffic environment. This paper describes research examining the question of whether simulator pilot training and evaluation would benefit from improved simulation of radio communications. First, existing radio communication simulation practices were investigated. Second, opinions from instructors/evaluators were solicited. Third, the pertinent literature was reviewed. Fourth, the effectiveness of current practices was evaluated by surveying the Aviation Safety Reporting System. Finally, recent efforts to improve radio communication simulation were examined. The paper concludes that there is much evidence that increasing the realism of radio communications would improve simulator training and evaluation of airline pilots, but that finding effective ways to do so will depend on collaboration of government, industry, military and academia.

INTRODUCTION

Simulator use in airline pilot training

Air carriers have been using airplane simulators for pilot training since the mid 1950s. Procedures training, systems knowledge, and navigation could be demonstrated and checked in a simulator, but stick and rudder skills as well as judgment had to be demonstrated in the airplane.

This changed with the introduction of the United States (U.S.) Federal Aviation Administration's (FAA) Advanced Simulation Plan (ASP) [FAA, 1980], which specified technical requirements for simulators. Total training and checking of airline pilots were now permitted in a simulator that was qualified for this purpose by the FAA. This means that certain types of training and certification of airline pilots can be completed entirely in the simulator. This is followed by supervised Initial Operating Experience (IOE) in revenue service, i.e., in the airplane carrying paying passengers, for consolidation of knowledge and skills acquired in the simulator. The FAA requires no further official training and no additional check in the airplane [FAA, 1996].

The introduction of the ASP has eliminated training-related accidents at major airlines that have access to the high-fidelity simulators required for total training and checking in the simulator--"it's a long time since I lost a buddy in a training accident" [Rolfe, 1996]. Training-related accidents, however, continue to occur at smaller airlines that still conduct some of their training in the airplane. Also, the lack of access to high-fidelity simulators deprives the smaller airlines of some of the training opportunities provided by simulators, such as carefully constructed scenarios containing emergencies.

In the interest of one level of safety for all airlines, a requirement that came into effect in 1997 [FAA, 1997], the FAA is considering a new rule mandating that all airline training and checking occur in the simulator. At the same time, the FAA is also considering an extension of the credit allowed in the highest-level simulators, which may lead to a reduction in the duration of supervised IOE.

In light of these initiatives, it becomes all the more critical that the skills acquired in the simulator fully transfer to the airplane when using the simulator for training. Just as important, pilots' in-air skills must be accurately reflected in the simulator when using the simulator for pilot certification. In other words, a valid simulator will stimulate the same pilot response as the airplane, so that both performance and behavior (control strategy and inputs) of pilots in the simulator and in the airplane are similar.

To achieve full transfer between simulator and airplane, simulators need to be validated. Today, such validation still mainly focuses on the fidelity of parameters such as flight performance, handling qualities, model confirmation, and adequacy of training and checking maneuvers. While this ensures the validity of simulators to train and check stick and rudder skills, it does not ensure their validity for training and checking the whole range of piloting skills, which more and more include cognitive skills (see below).

Shift in airline pilot training needs towards cognitive skills

Major changes, however, have occurred in the work environment of airline pilots in the past twenty years. First, although the workload reduction achieved by automation on the so-called glass cockpit has allowed the elimination of the third crew member position of the flight engineer, it has also added a fourth task, "manage systems," to the pilot's task hierarchy to first aviate, then navigate, then communicate [Schutte and Trujillo, 1996]. Second, with the increase in congestion in the global air space, coordination with entities outside the cockpit such as air traffic control (ATC) and company dispatchers has become more and more critical. Third, with the increase in demand for airline pilots, the prior jet-airplane experience of new hires at airlines has been significantly reduced [Carey, 1998]. Moreover, newly hired pilots tend to be a much more heterogeneous group then prior recruits from the military, and it is harder to develop a curriculum that suits everybody's needs [Kirijan, 2001].

Both the industry and the FAA have recognized these changes in airline pilots' work environment and the concomitant shift of training needs towards sharpening of cognitive skills in addition to stick and rudder skills. By establishing the Advanced Qualification Program (AQP) [FAA, 1990], the FAA explicitly attempted to increase aviation safety by responding to changes in aircraft technology, operations, and training methodologies [Longridge, 1997]. AQP represents an alternative means for training and checking of airline pilots. In contrast to traditional training that applies equally to crew positions across airlines and fleets (Code of Federal Regulations, Subparts N & O), AQP takes into account both the training needs and proficiency level of a particular airline and fleet. The training need is established via a front-end analysis of a particular airline and fleet. After training to a set proficiency standard within an approved curriculum, proficiency evaluation may consist of a sampling of proficiency objectives presented in a full mission simulation in a full cockpit crew environment. AQP particularly demands the integration of Crew Resource Management (CRM) skills in both training and evaluation. CRM refers to the effective use of all available resources, including human resources, hardware, and information. The Advisory Circular (AC) on CRM explicitly mentions the participation of "other groups routinely working with the cockpit crew," such as company dispatchers, flight attendants, maintenance personnel, and air traffic controllers, in the CRM process [FAA, 1998, AC 120-51C].

Implications for simulator fidelity requirements

Both the need for full mission scenarios including emergencies in AQP and the impending requirement to use simulators for all airline pilot training and evaluation underscore the necessity for all airlines to have access to effective flight simulator training and evaluation. As mentioned above, current simulator validity checks mainly focus on a faithful physical simulation of the airplane. Given the shift in training needs, however, it may well be that a faithful representation of the cognitive aspects of the flying task imposed by the air traffic environment is just as important as the faithful representation of the airplane. While high-level simulators generally provide some weather information via motion and the out-the-window view, and perhaps even some visual traffic, any representation of entities outside the cockpit such as radio communications from ATC, other airplanes talking to ATC on the same radio frequency, and communications from company representatives (dispatch, maintenance, and flight attendants) is presumably left to the creativity of each individual instructor/evaluator in the simulator. In the framework of an overall review of simulator fidelity requirements, the FAA has tasked the Volpe Center with an examination of the need for providing realistic radio communications during airline pilot simulator training and evaluation.

The following pages will summarize the results of an investigation of current radio communication practices during simulator training and evaluation, report the opinions solicited from airline pilot Instructors/Evaluators (I/Es) regarding the effectiveness of these practices, and present the findings from a literature review. The results of an examination of Aviation Safety Reporting System (ASRS) reports on IOE for evidence on the effectiveness of current radio communication simulation practices will also be presented. Finally, several airline and industry efforts to improve radio communication simulation will be described.

CURRENT RADIO COMMUNICATION SIMULATION PRACTICES

The findings summarized below are based on responses from 29 I/Es of seven major, one cargo, four regional airlines participating in the Advanced Qualification Program and two non-U.S. airlines (see [Bürki-Cohen, et al., 2000] for more details on the study). Respondents averaged some 10 years of pilot instruction and evaluation. All but one of them indicated that they conducted full mission training, i.e., Line Oriented Flight Training (LOFT). Twenty reported conducting full mission evaluations, i.e., Line Operational Evaluations (LOEs). I/Es were queried on their company's current practices of simulating ATC communications and company communications to own aircraft and, for ATC, to and from other aircraft (the so-called party line), during these events. They were also queried regarding their company's visual and Traffic Alert and Collision Avoidance System (TCAS) simulation of the traffic environment.

Radio Communications to and from own airplane

Communications with Air Traffic Control. During both training and evaluation events, all I/Es reported simulating ATC communications from all tower and Terminal Radar Control (TRACON) positions. This was true also for en route communications from the Air Route Traffic Control Centers (ARTCC), with the exception of two I/Es who do not simulate ATC instructions en route during training events. Slightly fewer I/Es reported simulation of Automatic Terminal Information Service (ATIS) and pre-departure clearance delivery (PDC) (89 and 93 percent during training and 95 and 89 percent during evaluation).

Communications with Company. For company communications, the percentage of I/Es attempting communication simulation is lower. Company dispatch is most consistently simulated, by 93 percent of I/Es during training and 95 percent of I/Es during evaluation. Radio communications with maintenance personnel are simulated by 67 percent during training and 84 percent during evaluation. Sixty-three and 70 percent of I/Es, respectively, simulate Ramp/Gate and cabin personnel communications during both events.

ATC Communications to and from other aircraft

Simulation of other aircraft. Before querying I/Es about their simulation of communications between ATC and other aircraft on the same frequency, they were asked how other traffic is represented in their company's out-the-window view and TCAS simulation. Only 59 percent indicated that their simulators provided some out-the-window view of traffic, mostly on the airport surface (48 percent). Some indicated that they also simulated emergency vehicles on the surface. Ten I/Es (34 percent) each reported simulating visual traffic in the terminal and/or en-route environment. Ten I/Es also reported representation of traffic via TCAS.

Communications to and from other aircraft. Only eleven (38 percent) of all I/Es reported simulating some communications to or from other aircraft or vehicles, at least on the surface. Even fewer provide communications both ways, i.e., to *and* from other traffic (28 percent). Only two I/Es (less than 7 percent) provide communications to or from airborne aircraft.

Methods of simulating radio communications

Most radio communications have to be role-played by the individual I/Es. About a fifth of the I/Es indicated the availability of Aircraft Communications Addressing and Reporting System for communications from the company dispatcher and PDC. Fifty-six percent reported the use of audio recordings or printouts for the distribution of ATIS information.

Three of seven respondents from one airline indicated that occasionally, two I/Es may participate in a simulator session, at least when instructing a three-person crew. One of these specified that in this case, the I/E for the Captain and First Officer would role-play the ATC communications, whereas the I/E for the flight engineer would provide the company communications.

Finally, two I/Es indicated the availability of recorded or synthetic controller voice for communications to other vehicles in the terminal environment. Follow-up discussions with one of these revealed that he was referring to the availability of GATES (Ground and Air Traffic Environment Simulation) on some simulators, a new technology that will be discussed in the section discussing industry efforts of providing realistic radio communications below.

Instructor/Evaluator workload in the simulator

Given that the burden of providing realistic radio communications lies mainly with the individual I/Es, I/Es were also asked to indicate their perception of the percentage of time and effort spent running the simulation, simulating radio communications, instructing and observing. As can be seen in Figure 1, I/Es spend about half of their time and effort observing. Even during LOFT training, the time and effort spent instructing is surprisingly small, 8 percent vs. 4 percent during LOE evaluation (for Special Purpose Operational Training, SPOT, however, the time and effort spent instructing shoots up to 25 percent). The rest of I/Es' time and effort is more or less equally divided between managing the simulator systems and providing radio communications. One I/E indicated that his time and effort spent filling out forms and taking notes is similar to his involvement in radio communications and simulator management. Although this activity had not been explicitly mentioned in the question, it is probably safe to assume that all

I/Es spend some time and effort with paper work, which may further detract from their ability to provide a realistic radio communication environment.

------------ Insert Figure 1 here ------------

Figure 1. I/E reports of percentage of time and effort spent during Line Operational Evaluation (LOE), Line Oriented Flight Training (LOFT) and Special Purpose Operational Training (SPOT).

Summary of current practices

In summary, I/Es spend about a fifth of their time and effort during pilot training and evaluation providing radio communications, which they almost exclusively simulate by role play. This effort is mainly spent in the terminal environment and with ATC communications to own aircraft that are necessary for a particular scenario. "Company communications," one I/E added, "are not normally used [in simulation]; too time-consuming." With regard to communications to other aircraft, another mentioned, "some instructors simulate [them], but none of our formal training documentation requires it."

OPINIONS OF INSTRUCTOR/EVALUATORS

The same I/Es asked about airlines' current radio communication simulation practices were queried on their perceptions of the effect of role-playing radio communications on their own workload and on the workload of the pilots during simulator training and evaluation. They also offered their opinions on the importance of simulating radio communications realistically for training and evaluation effectiveness.

Effect of radio communication role play on I/E and pilot workload

I/Es rated their workload consistently higher in the simulator than for training and evaluations in the actual aircraft. This applied to all ATC environments and to all communications with company. Moreover, role-playing radio communications "divides [I/E's] attention," one I/E added. This is especially difficult for new I/Es, another mentioned. A third added that the "I/E can become task-saturated when crew works two VHF radios and/or communications with cabin simultaneously." The highest discrepancy in I/E workload was indicated for simulation of communications with other aircraft.

Pilot workload in the simulator, however, was rated consistently lower than in the actual aircraft for all ATC environments and company communications, and also for listening to the party line. "I/E [communication simulation] is less than actual, therefore it reduces pilot workload," one I/E explained. Another I/E alluded to the fact that even the manual workload of pilots is reduced by I/E role play of radio communications, because "[p]ilots are not normally given a chart frequency, nor do they need to redial a new frequency to communicate."

Importance of radio communications for training and evaluation effectiveness

I/Es were asked about the importance of radio communications for training and evaluation effectiveness in two contexts, first in the context of their company's communication practices, then in the context of specific training/evaluation goals.

Some I/Es may have downgraded the importance of radio communications in the context of their own company's practices, because they feel that their company's communication simulation is "not very effective during simulation, because the instructor must cover all bases himself," as one I/E explicitly stated. Nevertheless, as many as 73 percent of respondents rated the overall importance of ATC communication simulation in the context of their company's practices as high or very high (for communications with TRACON). (The corresponding percentages for the other ATC communications were, in descending order, 68 for tower ground, 65 for tower local, and 61 percent for ARTCC.) No more than 8 percent of the respondents rated any of the ATC communications as of low importance. None of the ATC communications were rated as of very low importance.

Fewer I/Es rated the importance of company communications in the context of their company's practices high or very high. Communications with cabin personnel achieved the highest rating with 57 percent considering it highly or very highly important. (The corresponding percentages for dispatch and ramp/gate were 43 and 27, respectively.) Up to 15 percent of I/Es rated any of the indicated company communications as of low or very low importance.

Despite the limitations of their own company's practices, as many as 84 percent of the I/Es considered ATC communications to other aircraft medium to highly important. Sixteen percent gave it low importance in the context of their own practices. However, several I/Es commented on the importance of radio communications to other aircraft for the realism of the simulation. "I believe the 'simulator mind-set syndrome' must be fought with realism. How can we expect crews to 'treat the sim[ulator] like the aircraft' when the audio environment belies the condition so often?" one I/E asked. "Party line enables CRM elements such as workload and distraction to be assessed more effectively," added another. One last I/E mentioned that the simulation of ATC communications to other aircraft is his "biggest concern, so pilots are listening."

These opinions that radio communications are important were confirmed in the context of specific training (or evaluation) goals. I/Es indicated how often they relied on radio communications and how important they found radio communications for effective training (and evaluation).

I/Es indicated relying most often on radio communications for training CRM and non-routine ATC, such as pilot-ATC coordination, where 93 percent of the respondents indicated that they use it at least sometimes. The importance of radio communications for effectively training CRM and non-routine ATC was rated as high or very high by 89 and 86 percent of the I/Es, respectively. "If CA[ptain] does not delegate duties, my technique is to load the crew with B.S. [*sic*] radio transmissions," one I/E added.

Radio communications are also very important for training and evaluating distraction management skills. Eighty-two percent of I/Es rely on radio communications for this purpose at least sometimes, with 78 percent rating their importance as high or very high. They are used to train and evaluate situation awareness skills, where 88 percent of I/Es reported using them at least sometimes, with 68 percent rating their importance as high or very high. For training and evaluation of new ATC procedures, such as simultaneous approaches to closely spaced parallel runways, 92 percent of I/Es responding to this question indicated relying on radio communications at least sometimes, and 62 percent rated the importance of radio communications as high or very high.

I/Es overall 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, which was not learned during training. This new (additional) component can really complicate line flying."

LITERATURE REVIEW

This section presents the results of a review of the Advanced Qualification Program/Crew Resource Management and the task management training literature. It was found that many of the subject matter expert opinions found in the previous section are confirmed in the literature (for more detail, see [Bürki-Cohen et al., 2000]).

Advanced Qualification Program and Crew Resource Management

CRM training and evaluation is an integral part of AQP, which emphasizes both technical *and* cognitive skills [Longridge, 1997]. CRM skills include leadership, communication skills, time management, situational awareness, and attitudes in flight operations [FAA, 1990, AC 120-35B]. As mentioned in the introduction, its importance has been growing over the last decades due to the increase in flight deck automation and the concurrent reduction in crew size, as well as the increase in congestion of the airspace.

The founding principle of AQP is that training and evaluation of pilots should be based on the activities encountered on the job. Both the AQP and CRM literatures underscore the importance of realistic scenarios. AQP requires a thorough analysis of all tasks a pilot needs to perform during actual operations, which then guides curriculum and scenario development. The AQP task-listing example found on the FAA AQP Management Website [FAA, 2000] clearly shows that coordination with company and

ATC over the radio frequencies is an integral part of line operations and that frequency monitoring is important for maintaining traffic and weather situation awareness.

The Advisory Circular on CRM training explicitly not only lists onboard flight deck and cabin personnel, but also ground-based maintenance personnel, aircraft dispatchers, and air traffic controllers as part of the CRM process [FAA, 1998, AC 120-51C, Crew Resource Management Training, CRM]. In a section on extending training beyond the flight deck, the AC highlights the benefits of using real air traffic controllers, dispatchers, and maintenance personnel during full mission simulation training.

A 1996 Air Line Pilot article concluded that pilot confusion can “best be prevented through continuing emphasis on crew performance, with the understanding that ATC is a key member of the flight team” [Rosenthal et al., 1996]. The authors had surveyed 100 ASRS reports explicitly mentioning pilot confusion, many of them involving amended ATC clearances, and recommend that CRM place greater emphasis on crew-ATC interactions.

Many ASRS surveys, research investigations, and aviation magazine articles discuss the role of communications in incidents and accidents. The Flight Safety Foundation Approach and Landing Accident (ALA) Reduction Task Force report found that “incorrect or inadequate ATC instruction/advice/service” was a causal factor in 33 percent of the 76 ALAs and serious incidents analyzed (Khatwa and Helmreich, 1999). It ranked eleventh among the most common causal factors, long before “interaction with automation” in seventeenth place. “[D]emanding ATC clearances” are also explicitly mentioned in context with even higher placed causal factors such as the eighth placed "press-on-itis." In many cases of "press-on-itis," "a breakdown in CRM between the flight crew and ATC" was observed.

Other ATC-communications-related causal factors in the ALA reduction task force report that are not included in the 33 percent mentioned above are misunderstood or missed communications such as missed read backs, call sign confusions, and simultaneous transmissions (12 percent). Instances of controllers and crews using non-standard phraseology are also mentioned. This can become especially problematic when non-native English speakers/listeners and an emergency situation are involved, as shown by the 1990 Avianca Airlines crash on Long Island and the 1995 American Airlines crash near Cali, Columbia [National Transportation Safety Board, 1991; Simmon, 1998].

In summary, the 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."

Cockpit task management training

The need for cockpit task management (CTM) training has been documented not only using incident and accident reports, but also experimentally. Chou, Madhavan, and Funk [1996] elicited the CTM errors found in an accident and incident review in a controlled simulator experiment and confirmed that task prioritization is greatly degraded by the number of concurrent tasks. Another study found that ATC interruptions significantly increased procedure performance errors as well as flight-path management workload of commercial airline pilots [Latorella, 1996].

The question then is whether CTM training in the simulator is effective. Gopher, Weil, and Bareket [1994] showed that task management trained even in a very low physical-fidelity computer game did transfer to flight. Gopher et al. report that the computer game was perceived as such a successful auxiliary training tool that the Israeli Air Force incorporated it into their curriculum.

Given that CTM training can be effectively trained in a synthetic environment, the next question is what are the best methods for such training. One of the I/Es queried in the study presented earlier indicated that communications are "most important at the end of training," implying that pilots may not be able to handle radio communications in addition to aviating during early training. He seems to favor part-task training, where trainees are only gradually introduced to the full complexity of aviating, navigating, communicating, and managing systems.

There is much theoretical and experimental evidence, however, 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. The Gopher et al. study mentioned above also compared different training regimes, one a hierarchical part-task technique where trainees worked their way up through part-task games of increasing complexity to exposure to the full game, the other a whole-task technique. For the whole-task training, emphasis was shifted between different aspects of the game in subsequent training trials. Although the part-task group outperformed the whole-task group when tested on the game, there was no difference between the groups in actual flight performance. Fabiani, Buckley, Gratton, Coles, Donchin, and Logie [1989], extended these results by finding that the whole-task group outperformed the part-task group even in the game when additional tasks were added, but only when trained with the shifting-emphasis technique.

These results bolster the theoretical argument that a complete mental model of the task needs to be acquired during training [Bransford and Franks, 1976; Mangold and Eldredge, 1993]. Learning is an active process, and practice can lead to either activation or inhibition of cognitive pathways. If pilots are consistently exposed to an impoverished environment during training compared to the real world, they may end up unprepared for the complexity of flying in the air, where "he must add a new (additional) component" that "can really complicate line flying," as one of the I/Es in the study presented earlier admonished.

EFFECT ON INITIAL OPERATING EXPERIENCE IN THE AIR

A review of the Aviation Safety Reporting System (ASRS) was conducted to see whether the concerns expressed both by I/Es and in the literature would be confirmed by reports of line check airmen (LCA) and pilots on events during their initial operating experience in the air.

Method

A search of the 205,070 reports in the ASRS database, which was established in 1988, up to October 1999 [ASRS, 2001] using the terms Initial Operating Experience, IOE, and

Operating Experience yielded 423 reports after exclusion of duplicates. After exclusion of reports referring to incidents that had occurred prior to 1993 or not during IOE, or reports covering non-flying issues, 93 reports remained for analysis. The authors determined types of errors and primary and contributing factors based on the ASRS reporters' narrative. Most of the errors involved several factors.

Types of errors reported

More than a third (32) of the 93 reports involved altitude deviations or crossing restriction violations, including two near controlled flights into terrain. Course deviations were mentioned in 12 of the reports. Legal separation between airplanes was lost in six of the reports, including three near-midair collisions.

Landings without clearance were the subjects of 11 reports. Seven reporters approached the wrong runway, including one who actually landed. Four crews, of which one landed, approached the wrong airport. Two crews took off without clearance. Runway incursions were reported six times.

Communications were lost three times. The remaining 10 errors were reported each only once.

Factors contributing to errors

General factors. Several reports appeared to indicate that training is not completed when pilots transition from the simulator to the airplane. In almost a quarter of the reports, the fact that the LCA was administering remedial training at least contributed to the incident. One LCA explained a course deviation by his becoming “preoccupied with instructing the first officer to give passenger briefing.”

Insufficient stick and rudder skills played a role in 15 percent of the reports. “[The pilot’s] unfamiliarity with the actual aircraft performance and the quickness of the events” was given as the reason for an altitude deviation.

Violation of standard operating procedures played a role in almost 8 percent of the reports. A pilot who had failed to establish contact with ATC as requested by the standard taxi clearance explained that the “controller’s workload was very high with a lot of frequency congestion.”

Other factors cited included equipment failures, which contributed to 8 percent of the reports. Problems with the automation contributed to 11 percent. Weather contributed to 20 percent of the reports, and fatigue to 9 percent.

Radio Communication Factors. Radio communications contributed to as many as 87 percent (81) of the reports, and was the primary factor in 72 percent (67). This clearly demonstrates the importance of radio communication training. Figure 2 shows the number and types of errors where radio communication problems played a primary role.

------------ Insert Figure 2 here ------------

Figure 2. Number and types of errors with radio communications as primary factor.

The radio communication factors contributing to errors are shown in Figure 3. Demanding, inadequate, or even erroneous ATC instructions were implicated most often as a primary or (23) or contributing (15) factor. Reporters often cited amended clearances requiring reprogramming of the automation or erroneous expectations raised by the controllers. After an instruction to “expect no delays,” e.g., the crew “perceived that there would be no delay at the end” and taxied on an active runway.

------------ Insert Figure 3 here ------------

Figure 3. Radio communication factors contributing to reports.

Inadequate CRM or CTM involving radio communications played a role in 40 reports (21 primary, 19 contributing). “The cause […] was my inexperience with the quick pace of an airline environment and its associated distractions,” explained a pilot after deviating from the assigned altitude. Another explained a near-midair collision during an approach to the wrong runway by the crew being “so busy that we were not paying attention to what the controller was saying.” An LCA after landing without clearance blamed the fact that IOE is comparable to “flying ‘single pilot with a distraction',” explaining the error by being distracted by the trainee who didn't contribute much else to flying.

ATC interruptions including traffic calls were mentioned in 14 reports, and in eight of these they appeared to be the primary reason. After a crew missed an instruction to clear the runway, the pilot complained “tower controllers […] give instructions […] while the aircraft is still in a critical phase.”

Frequency congestion, stuck microphones blocking an entire frequency, or pilots stepping on an ongoing conversation played a role in 14 reports as well, but were the primary reason in only five reports. After a course deviation due to a misunderstanding, the pilot reported, “several aircraft were stepping on each other's radio calls.”

Problems with tuning the radio played a role in four reports and was the suspected primary reason for each of the errors, such as in a runway incursion after loss of communications where the “F[irst] O[fficer] possibly moved [the] radio select switch from tower to [the] other side in [an] attempt to contact ground control prior to selecting [the] frequency.”

Phraseology and/or accent contributed to seven reports. They appeared to be the primary reason in three of these, such as in an approach to the wrong airport in Mexico where “the transmissions and comm[unication]s from the tower were exceedingly hard to understand and [we] had to ask several times for clarification.”

Interruptions from the cabin, be it from flight attendants or passengers, played a role in seven reports, being the primary reason in three. One pilot reported a near-midair collision and mentioned that "as [the] clearance was coming off the printer, [the] F[light] A[ttendant] entered [the] cockpit for meal orders."

No comparison has been made to determine whether radio communication related problems occur more frequently in IOE than during non-IOE flights (see literature review). Also, the overall incidence of such occurrences cannot be determined from ASRS reports, which are naturally biased towards cases where something did happen. Nevertheless, improved realism of radio communication simulation during simulator training may have better prepared pilots for many of these IOE occurrences.

Effect of pilot experience on radio communication problems during IOE

One of the I/Es queried in the study presented earlier in this paper expressed his opinion that experienced airline pilots have "proven their abilities" to handle radio communications, implying that airline pilots may require radio communication training and evaluation only early in their career. The ASRS reports do not consistently provide a direct means to test this hypothesis, such as flight time of the pilot flying, but may indirectly indicate the experience level of crews by providing the weight class of the airplane involved. The assumption is that in general, pilot experience increases with airplane weight.

If radio communication problems decrease with experience disproportionately to other problems, then the weight class distribution in the IOE reports with communications problems should be different from the weight class distribution of reports involving airline pilots in the overall database, resulting in a low correlation between the two distributions.

In fact, the opposite was found. At a ratio of .97, the airplane weight class distribution in the sample of IOE ASRS incidents where communications were the primary factor correlated very highly with the airplane weight class distribution in the overall airline reports. Similarly high were the weight class distribution correlations of all airline reports with all IOE reports as well as all IOE reports where communications played at least a contributory role (.95 each).

This analysis shows that there is no difference between the distributions of airplane types represented in the overall ASRS database and in the samples reporting communication problems. Therefore, prior experience with communications in different airplanes does not seem to protect airline pilots from experiencing problems with radio communications during IOE.

INDUSTRY INITIATIVES

The previous sections have shown that subject matter expert opinions, accident and incident reports, and the AQP, CRM and academic literatures concur that realistic radio communications are important. It is thus not surprising that airlines and simulator manufacturers have made several efforts to improve the realism of radio communications in simulator events. Although the following pages will describe only examples of airline efforts to include radio communications into training and evaluation of pilots, it is interesting to note that even the manufacturers of personal-computer (PC) flight-simulator systems see a market value in offering realistic radio communication add-ons to their products. Typical features of these systems include recorded natural speech ATC instructions to own airplane (with limited response capability) and communications to and from invisible other aircraft consisting of random chatter with no relevance for traffic or weather awareness (see Bürki-Cohen et al., [2000], for more detail on PC and other supporting technologies).

United Airlines' Interactive Real Time Audio System (IRAS)

The most comprehensive effort to provide automated realistic radio communications in the simulator is United Airlines' (UAL) Interactive Real Time Audio System (IRAS), also known as "Chatter Program." It is an in-house development with very high operational realism. It is based on field recordings of actual ATC communications on UAL routes. By dubbing ATC with the respective I/E voice, the I/E can intervene without the pilot trainees realizing it. The engineers at United attempted to include many subtle nuances of audio communications into the environment, including demanding timing imposed by ATC, frequency congestion, foreign and regional accents, stuck microphones blocking an entire frequency, and meaningful communications to and from other aircraft to train pilots to listen.

The system, however, encountered many technical difficulties. Algorithms coded to trigger radio communication recordings at appropriate times did not always function adequately, forcing an embarrassed instructor to intervene, thus increasing instructor stress and workload. Operations in dense terminal areas also taxed the scenario algorithms, with normal variations in crew response causing additional timing problems and workload for the instructor.

The IRAS interface was often not well integrated into the instructor station and was hard to use. Different instructor interfaces across simulator models often made it even harder for instructors to operate the system. The cost and difficulty of system-wide implementation was further hampered by different simulator designs with different visual, audio, and navigation models.

All of the above in combination with expensive scenario development including field recording, transcribing, dubbing, database maintenance, as well as costly route, sector map, and simulator-interface code development contributed to the program gradually losing support. As of the end of the 1990s, the program had been scaled back to use only one generic ATC voice, and it was only used for new-hire screenings in a B-727 flight-training device. The applicants were presented with relevant communications to and from other aircraft to evaluate their planning abilities during an approach, as well as automated frequency changes. New-hire evaluators reportedly complained when the system was down because of the increased workload of providing frequency changes.

The lessons learned from IRAS are that for a system to be successful, it must be flexible, transparent, easy to use, easy to implement and maintain, and easy to integrate with different scenarios, simulators, and simulator systems (e.g., visual, audio, etc.). There may be a cost/benefit trade-off for the different aspects of realism required for different training and evaluation events that must be examined in this research. For instance, it may not be necessary to conceal instructor intervention from the pilots, a capability achieved by IRAS, but at a high price.

Ground and Air Traffic Environment System (GATES)

Airlines have advanced the state of the art by specifying requirements to the simulator manufacturers. The Canadian simulator manufacturer's CAE product GATES was developed after a request from an airline to provide a visual representation of traffic in the airport terminal environment. It soon became obvious to the developers and the airline that correlated and meaningful radio communications would have to be an essential component of such traffic representation.

Several U.S. airlines and training facilities as well as non-U.S. airlines and military are currently installing GATES-equipped simulators. The product as it is today provides simulated aircraft traffic and associated relevant communications to and from aircraft on the airport and in the terminal environment. The product also provides visual simulations of ground traffic such as emergency vehicles.

GATES-simulated vehicles do not follow scripted scenarios. A continuous flow of arriving and departing traffic is generated. The traffic elements are aware of and will react to each other and the simulated own airplane. The I/E has limited ability to control specific situations like runway incursions and emergency vehicles. The I/E still provides all ATC communication to own airplane, however.

The main reason a U.S. airline cited for choosing GATES was to add realism and increase distraction factors for LOFT sessions. Specifically, they wanted to enhance TCAS scenarios, ground hazard avoidance, and runway incursions. A senior check airman responsible for GATES implementation stated that the improved overall sense of realism alone justified its purchase and support costs. Workload increase for the I/E is reportedly minimal. He added that interactive/reactive communications capability would enhance usability and realism.

Lufthansa's Joint Operational Incidents Training (JOINT)

A last effort to expose pilots to realistic radio communications in the simulator to be described here is the German airline Lufthansa's Joint Operational Incidents Training (JOINT) with the German ATC organization, Deutsche Flugsicherung (DFS) [Hensel, 2000; Jung, 1999; Lexen, 1999; Strassburger and Novack, 1997]. JOINT started in 1996 with the connection of one DFS ATC simulator representing one control sector with pseudo traffic to one B-737 simulator at Lufthansa Flight Training's facilities in Frankfurt. The purpose was to expose crews to abnormal procedures in a realistic ATC environment.

The program was expanded in 1998 to encompass two DFS ATC simulators representing two control sectors with pseudo traffic that can be connected to up to eight full flight simulators representing the entire Lufthansa fleet (B-737, B-747, A310/300, A320, A340). 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. The flight crews and the pseudo pilots communicate with the sector controllers via two VHF frequencies.

JOINT training takes place during recurrent training. Two controllers providing approach/departure and/or area ATC communications and two pseudo pilots providing pseudo traffic that can be seen on the radarscope and heard on the respective frequencies represent DFS. Lufthansa is represented by an average of four crews and their instructors. While the DFS controllers and pseudo pilots provide approach/departure and/or area communications to and from other aircraft, Lufthansa instructors still have to provide tower communications. Lufthansa also maintains the simulators.

For the past two years, JOINT sessions took place weekly during a four-hour simulator session (due to a controller shortage at DFS, this has been reduced to once a month in January 2001) [Hensel, 2001]. Lufthansa and DFS jointly define the scenarios, which include abnormal procedures and emergencies such as fuel leaks, jammed flaps, engine failures on take-off, degraded navigation capabilities, hydraulic failures, etc. Each simulator is presented with one or more of these problems at a predefined point in time unknown to the participating flight and controller crews. While one simulator crew may be in the take-off phase, two may be controlled by departure and one or two more by arrival, all while pseudo traffic is sharing the same frequencies and airspace. Each scenario lasts about two hours and is followed by a thorough joint debriefing of air traffic controllers and flight crews.

JOINT was conceived as part of Lufthansa's shift in training from pilot flying oriented maneuver training towards CRM oriented LOFT, where CRM involves not only the flight crew, but also coordination between pilots and controllers and controllers and controllers. Both controllers and pilots are enthusiastic and feel that JOINT realistically prepares them for the coordination and concentration demands of real-life emergencies with all their uncertainties and distractions. Moreover, both find the insight into the realities of each other's jobs invaluable.

Given a Lufthansa/DFS shared development cost of about $110,000 [Lexen, 1999], Lufthansa anticipates important economic benefits from its pilots' increased understanding of ATC management and thus optimized operational decision making capabilities [Hensel, 2001]. Lufthansa/DFS are discussing further enhancements of the system, such as synchronization of the auditory traffic environment with the out-the-window view and the TCAS displays. This would permit increased training credit in the simulator.

SUMMARY AND CONCLUSIONS

The principal issue examined in this paper was whether realistic radio communication simulation is necessary to ensure full transfer of performance and behavior from the simulator to the airplane (for training) and from the airplane to the simulator (for evaluation). This issue is especially pertinent in view of the impending regulatory changes making the simulator the sole tool for airline pilot training and evaluation. Other factors contributing to its relevance are the growing complexity of the global airspace, the shrinking pool and increasing heterogeneity of new-hires, and the increase in automation and concomitant reduction in crewmembers. All this dramatically increases especially the cognitive demands on the remaining crew. It is therefore critical that the simulator environment poses the same task demands pilots encounter in the air to ensure the safety of their future passengers.

A review of current airline practices, however, showed that radio communications transmitted over the ATC and company frequencies are not consistently simulated, thus reducing the workload of pilots during training and evaluation. This is especially true for company communications and for communications to other aircraft (party line). This is mainly because the simulation of radio communications is left to the individual I/Es, who have at most one fifth of their time left to role-play radio communications after observing, operating the simulator, instructing, etc. The consequences of this minimal consideration of radio communications during training and evaluation are that close to 90 percent of incidents during IOE reported to the ASRS system involve radio communications at least as a contributing factor.

The I/Es themselves and the literature emphasize the importance of realistic radio communications to achieve full transfer of performance and behavior between the simulator and the airplane and thus ensure safety. Even if expanded data link capabilities should succeed in replacing some voice communications, the basic issue of the importance of simulating realistic communications-related cognitive demand remains unchanged. In some ways, data link may actually increase the challenges to the pilot in that arena (see, e.g., [Latorella, 1998]).

The initiatives by UAL, CAE, and Lufthansa/DFS demonstrate that both the airline and the simulator industry have recognized the potential increase in safety and thus economic value of providing realistic radio communications to some degree, especially for training and evaluating line-oriented full-flight and operational incident scenarios.

Despite of all this evidence that increasing the realism of radio communications may improve transfer of performance and behavior between simulator and airplane and thus overall training and evaluation effectiveness of simulators, the authors know of no official regulations that would render the simulation of realistic radio communications mandatory. Much collaboration of government, industry, military and academia will be required, both in the area of improving technologies supporting realistic radio communication simulation and in demonstrating an objective safety and economic value before either market forces or regulatory requirements will lead to a general improvement of radio communication realism in airline pilot simulator training.

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ACRONYMS AND ABBREVIATIONS

AC	Advisory Circular
AQP	Advanced Qualification Program
ASP	Advanced Simulation Plan

ALA	Approach and Landing Accident
ARTCC	Air Route Traffic Control Center
ASRS	Aviation Safety Reporting System
ATC	Air Traffic Control
ATIS	Automatic Terminal Information Service
CRM	Crew Resource Management
CTM	Cockpit Task Management
DFS	Deutsche Flugsicherung
FAA	Federal Aviation Administration
GATES	Ground and Air Traffic Environment System
I/E	Instructor/Evaluator
IOE	Initial Operating Experience
IRAS	Interactive Real Time Audio System
JOINT	Joint Operational Incidents Training
LCA	Line Check Airman
LOE	Line Operational Evaluation
LOFT	Line Oriented Flight Training
LOS	Line Oriented Simulation
PC	Personal Computer
PDC	Pre-departure Clearance
SPOT	Special Purpose Operational Training
TCAS	Traffic Alert and Collision Avoidance System
TRACON	Terminal Radar Control

UAL	United Airlines
U.S.	United States
VHF	Very High Frequency

REFERENCES

Aviation Safety Reporting System (2001), *National Aeronautics and Space Administration,* Moffett Field, CA [On-line]. Available: http://nasdac.faa.gov/asp/asy_asrs.asp.

Bransford, J. and Franks, J. (1976), "Towards a Framework for Understanding Learning," *The Psychology of Learning and Motivation,* 10: 93-127.

Bürki-Cohen, J., Kendra, A., Kanki, B., and Lee A. (2000*), Realistic Radio Communication in Pilot Simulator Training.* Final Report No. DOT/FAA/AR-00/62, Washington, DC.

Carey, S. (1998), "Demand for Pilots is Soaring as Old-Timers Take Off," *The Wall Street Journal,* June 4.

Chou, C., Madhavan, D., and Funk, K. (1996), "Studies of Cockpit Task Management Errors," *The International Journal of Aviation Psychology,* 6: 307-320.

Fabiani, M., Buckley, J., Gratton, G., Coles, M., Donchin, E., and Logie, R. (1989), "The Training of Complex Task Performance," *Acta Psychologica,* 71: 259-299.

Federal Aviation Administration (1980), *Advanced Simulation Plan,* 14 C.F.R. Part 121, Appendix H, Department of Transportation, Washington DC.

Federal Aviation Administration (1990), *Advanced Qualification Program,* 14 C.F.R. Part 121, SFAR 58, Department of Transportation, Washington DC.

Federal Aviation Administration (1990), *Crew Line Operational Simulations: Line Oriented Flight Training, Special Purpose Operational Training, Line Operational Evaluation,* Advisory Circular No. 120-35B, U.S. Department of Transportation, Washington DC.

Federal Aviation Administration (1996), *Crewmember Qualifications,* 14 C.F.R. Part 121, Subpart O, Department of Transportation, Washington DC.

Federal Aviation Administration (1997), "FAA One Level of Safety Commuter Rule Deadline Marks Safety Improvements, Decline in Accident Rate," *FAA News,* APA 44-97, March 21 [On-line]. Available: http://www.dot.gov/affairs/1997/apa4497.htm.

Federal Aviation Administration (1998), *Crew Resource Management Training*. Advisory Circular No. 120-51C, U.S. Department of Transportation, Washington, DC.

Federal Aviation Administration (2000), *Advanced Qualification Program,* AFS-230 Web site: http://www.faa.gov/avr/afs/aqphome.htm.

Gopher, D., Weil, M., and Bareket, T. (1994), "Transfer of Skill from a Computer Game Trainer to Flight," *Human Factors,* 36: 387-405.

Hensel, D. (2000), "The A340 Recurrent Training: A New Philosophy," *Proceedings of the International Conference Flight Simulation--The Next Decade, Royal Aeronautical Society,* London, UK.

Hensel, D. (2001), e-mail, February 2001.

Jung, S. (1999), "Gemeinsam den Notfall trainieren," *transmission,* DFS, März.

Kirijan, F. (2001), Personal Communication, January 24, Tempe, Arizona.

Khatwa, R. and Helmreich, R. (1999), “Analysis of Critical Factors During Approach and Landing in Accidents and Normal Flight,” *Flight Safety Digest*, Flight Safety Foundation, Alexandria, VA.

Latorella, K. (1998), “Effects of Modality on Interrupted Flight Deck Performance: Implications for Data Link,” *Proceedings of the Human Factors and Ergonomics Society 42nd Annual Meeting,* Santa Monica, CA.

Latorella, K. (1996), “Investigating Interruptions: An Example from the Flightdeck,” *Proceedings of the Human Factors and Ergonomics Society 40th Annual Meeting,* Santa Monica, CA.

Lexen, G. (1999), “Flight Simulator and ATC Simulator Coupling,” *5th Annual International Flight Simulator Engineering and Maintenance Conference,* Denver, Colorado [On-line]. Available: http://www.arinc.com/fsemc/99_fsemc_presentations.html.

Longridge T. (1997), “Overview of the Advanced Qualification Program,” *Proceedings of the Human Factors and Ergonomics Society 41st Annual Meeting,* Santa Monica, CA.

Mangold, S. and Eldredge, D. (1993), “An Approach to Modeling Pilot Memory and Developing a Taxonomy of Memory Errors,” *Proceedings of the Ohio State University Seventh International Symposium on Aviation Psychology,* Columbus, OH.

National Transportation Safety Board (1991), *Aircraft Accident Report-Avianca, The Airline of Colombia, Boeing 707-321B, HK 2016, Fuel Exhaustion, Cove Neck, New York.* Report PB91-910404, Washington DC.

Rolfe, John (1996). Twenty-five Years of Flight Simulation - or - It's a Long Time Since I Lost a Buddy in a Training Accident. The Royal Aeronautical Society [On-line]. Available: http://www.raes.org.uk/fl-sim/fsg25yer.htm.

Rosenthal, L., Chamberlin, R., and Matchette, R. (1996), "Flight Deck Confusion: A Survey of ASRS Reports Indicates That Better Communication Between Cockpit Crews and ATC Could Help Prevent Confusion-Related Incidents," *Air Line Pilot.* Vol. 65.

Schutte, P. and Trujillo, A. (1996), Flight Crew Task Management in Non-Normal Situations, *40th Annual Meeting of the Human Factors and Ergonomics Society*, Philadelphia, PA.

Simmon, D. (1998), "Boeing 757 CFIT Accident at Cali, Colombia Becomes Focus of Lessons Learned," *Flight Safety Digest*, Flight Safety Foundation, Alexandria, VA.

Strassburger, A., and Nowack, S. (1997), "Training Connection," *transmission,* DFS, März.

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Figure 1.

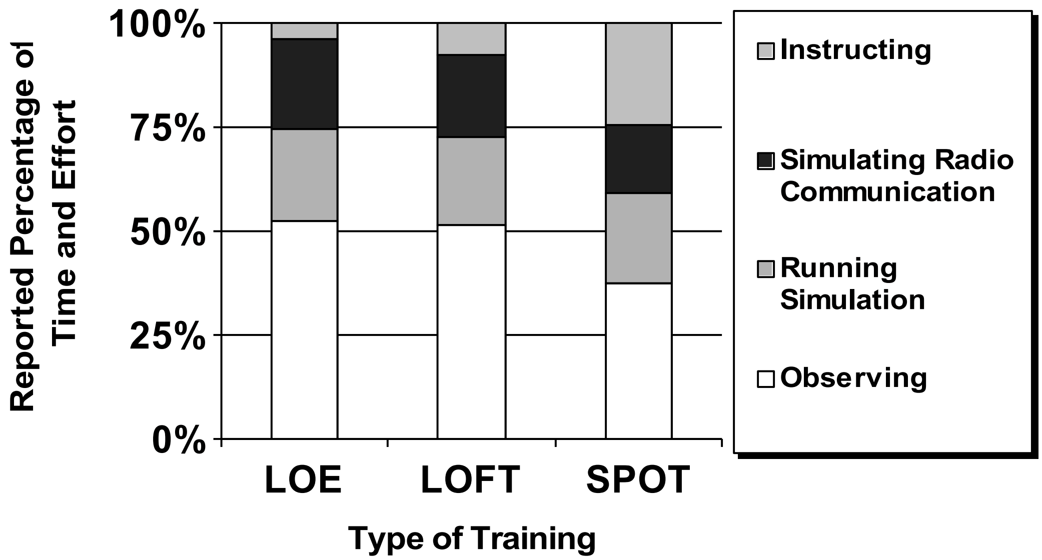
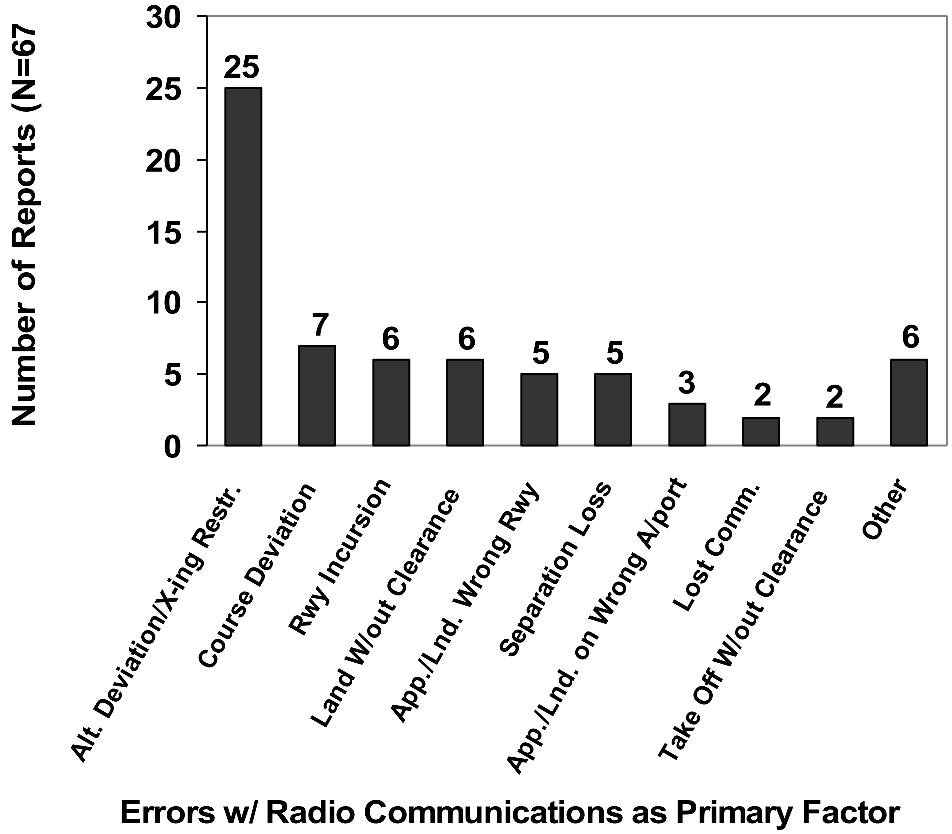

100%
75%
50%
25%
0%
Reported Percentage of Time and Effort
LOE
LOFT
SPOT
Type of Training
Instructing
Simulating Radio Communication
Running Simulation
Observing

Figure 2.



Number of Reports (N=67
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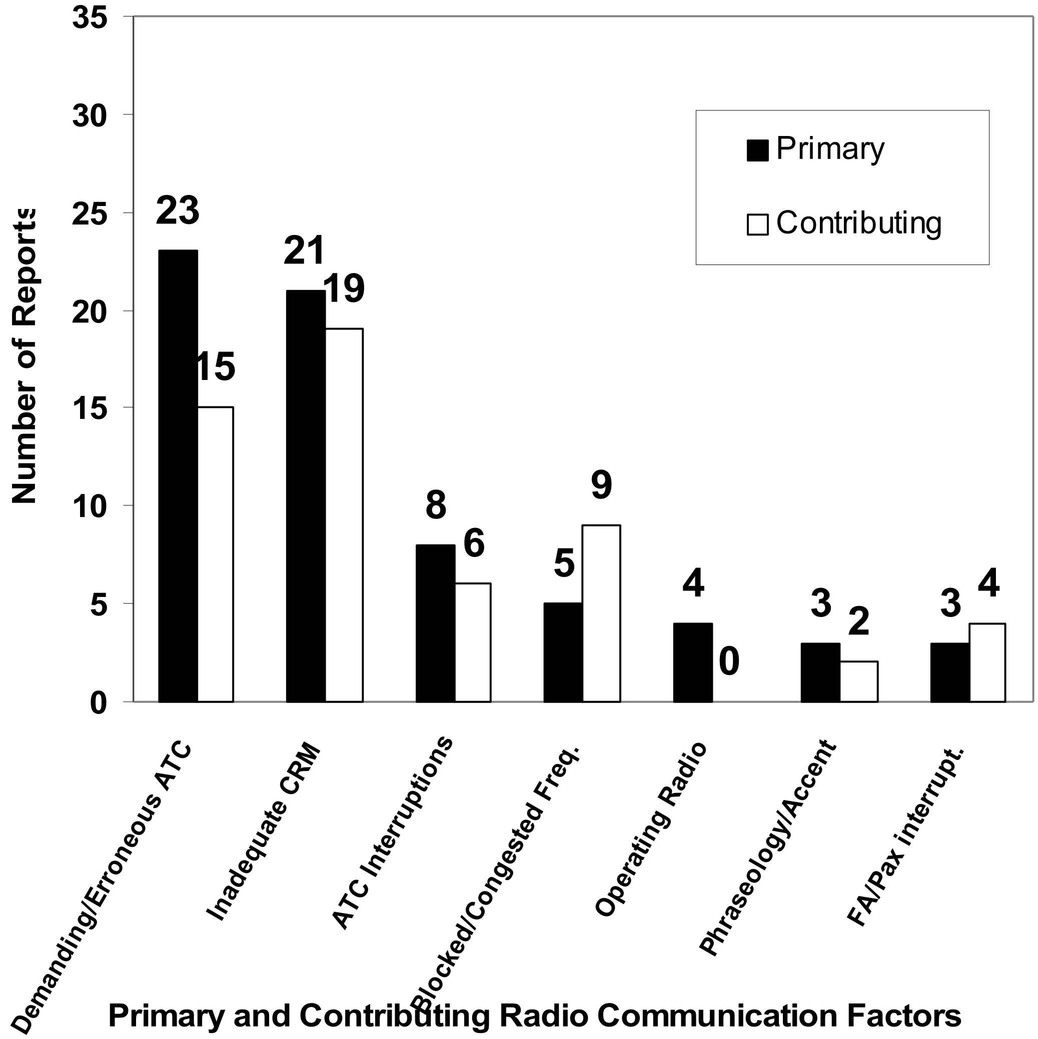
20
15
10
5
0
25
7
6
6
5
5
3
2
2
6
Alt. Deviation/X-ing Restr.
Course Deviation
Rwy Incursion
Land W/out Clearance
App./Lnd. Wrong Rwy
Separation Loss
App./Lnd. on Wrong A/port
Lost Comm.
Take Off W/out Clearance
Other
Errors w/ Radio Communications as Primary Factor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30
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20
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10
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0
Number of Reports
Primary
Contributing
23
15
21
19
8
6
5
9
4
0
3
2
3
4
Demanding/Erroneous ATC
Inadequate CRM
ATC Interruptions
Blocked/Congested Freq.
Operating Radio
Phraseology/Accent
FA/Pax interrupt.
Primary and Contributing Radio Communication Factors

Figure 3.