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Abstract

Modern aircraft employ a wide ,variety of advanced flight instrument systems that have been designed to reduce pilot workload and promote safe, efficient flight operations. Research to date on advanced flight instrumentation has primarily focused on mode confusion or pilot misinterpretation of system information. A few studies have also identified pilot concern with a reduction in manual flight skills as a result of regular operation in automated modes. This paper addresses that concern in an attempt to identify factors useful to flight curriculum development. Study participants included 110 experienced airline, corporate, and military pilots who were surveyed before and after a training session in a transport category flight training device with round dial instrumentation. An experienced instructor rated participant flight skills during the simulator activity. Study findings suggest that pilots who are more likely to use automated modes of modern "glass cockpit" aircraft have a less effective crosscheck and reduced manual flight skills. Issues related to advanced flight deck operations and training are discussed.

Impact of Glass Cockpit Experience on Manual Flight Skills

Over the past two decades, aircraft have become increasingly more automated and electro-mechanical instrumentation has been replaced with computer-generated (or "glass cockpit") displays that replicate the same information. Flight management systems (FMS), more sophisticated autopilots, flight guidance systems, and integrated cockpit instrumentation have become the standard in new aircraft. Flight mapping and weather depiction, combined on one display, provide enhanced situational awareness (Wiener, 1993). This newer technology enables the pilot to program flight modes, including autoflight takeoff, climb, cruise, descent, and landing, that do not require manual control inputs (Billings, 1997). Airline industry confidence in the efficiency and safety of autoflight systems has led many companies to mandate the fullest use of automated systems. However, many pilots are concerned with the loss of manual flying skills in a highly automated environment (Roessingh et al., 1999). Data gathered from this study sheds further light on concerns of experienced pilots who operate new generation aircraft.

Advances in glass cockpit flight instrumentation have resulted in many advantages and perhaps a few disadvantages to aircraft operations. Hawkins (1993) details three advantages to automating the flight deck, including: improved aircraft and systems performance, more efficient management and scheduling of aircraft operations, such as with an FMS, and reduction of crew workload. These advantages have proven especially beneficial to the air transportation industry. ICAO Circular 234 (1992) cites additional advantages of automated cockpits, including increased safety, the need for fewer required crewmembers, and more economical use of cockpit space. However, several studies have indicated that automated cockpits present a set of disadvantages that must be addressed. Safety concerns, such as loss of manual flying skills and reduced situational awareness, have been raised (Sharma, Pfister, & Heath, 1999). Dornheim (1995) and Hughes (1995) have discussed the potential for mode confusion, automation surprises, and inadequate automation feedback. While automation has generally helped reduce pilot workload during most phases of flight, last minute changes to arrival and approach clearances can, in many cases, dramatically increase pilot workload (Sarter et al., 2003). Automation and advanced cockpit instrumentation have certainly increased efficiency of line operations, but also present many new challenges for operators and trainers.

One area of pilot concern is loss of manual flying skills. Many aircraft operators strongly encourage or require their flight crews to use all automation available to them. Other operators leave decisions regarding the use of

automation to individual flight crews. Regardless of company policy, crews should be trained to determine when to program a higher automation level and conversely when a reduced level of automation would be appropriate. Wright, Kaber, and Endsley (2003) found that during revised approach clearances, in particular, manual flight operations might be preferential to higher levels of automation. In addition to automation-related policy restrictions, pilots with several companies may be assigned to a mixed fleet of traditional, round dial aircraft along with newer glass cockpit aircraft. Wiener, Chute, and Moses (1999) refer to pilots who move from newer to older, traditional aircraft as experiencing "backward transition." While there does not seem to be industry concern regarding backward transition, little research has been conducted on this issue. Findings from Wiener's interviews and surveys suggest pilots make a backward transition quickly after a few days of retraining in classroom, simulator, and line flying. However, pilots stated they missed the moving map displays and experienced a consequent loss of situational awareness in aircraft with older systems. Degradation of previously gained automation programming and interpretation skills while operating older system aircraft was also raised as a concern. Examining the experiences of pilots who have experienced a backward transition provides insights to be considered during training of pilots who will fly the next generation of glass cockpit aircraft. Since aircraft manufacturers now produce all new aircraft with glass cockpits and advanced automation levels, from single-engine piston aircraft to transport jet aircraft, such considerations are especially important.

Training issues involving automation continue to challenge the industry. The manufacturers and engineers of current instrumentation technology have developed valuable resources for flight crew use. However, the capabilities of aircraft computer systems go far beyond what is needed for normal line operations. Two operational extremes may occur. Crewmembers may become so involved with directing automated flight modes that they lose situational awareness of basic flight parameters. On the other hand, pilots who are uncomfortable with computers may feel intimidated by their presence, and consequently leave the use of this technology to the other member of the pilot team with a resulting reduction in crew coordination. Another issue related to increased levels of automation is crewmember over reliance on the new technology. Since computers do a much better job of monitoring system status, flight crewmembers can become complacent. The result may be a reduction or loss of situational awareness (Casner,

2001; Wiener, et al., 1999).

Crew training is a major financial burden for operators, and there has been a tendency to minimize the number of training hours spent on automation technology instruction, including use of the FMS. Sarter and Woods (1993) surveyed pilot knowledge of FMS operations, and found gaps in pilots' understanding and functional operation of that particular system. With the expectation that flight crews will gain proficiency on the line, classroom and simulator training have focused on how to push the right buttons to make the aircraft do what is needed, rather than providing overarching automation theory and strategies for use. (Wiener, 1999 et al.; Holder & Hutchins, 2001). While advances in automation training have occurred over the past 20 years, flight crews have continued to make operational errors and frequently have not mastered basic automation concepts. An obvious conclusion is that additional emphasis should be placed on particular aspects of glass cockpit training to achieve desired levels of mastery.

The purpose of this study was to evaluate manual flight skills of pilots with both glass and traditional round-dial cockpit experience. Even though airplanes have traditionally been built with systems redundancy in mind, systems (including the autopilot and flight guidance systems) do fail, albeit infrequently. When failures of automated systems occur, pilots are required to manually fly the airplane, perhaps with traditional instruments. During this study, manual flying skills (without autopilot, flight director, or glass cockpit instrumentation) were evaluated by expert flight instructors during a one-hour flight simulator session. Subject pilots also evaluated their own simulator performance at the end of the session. In addition, participants were asked to report their levels of flight experience in glass cockpit and round dial aircraft. Data collected from these sources were analyzed to identify issues related to transitioning from glass to traditional instruments and vice versa.

Methodology

Subjects participating in the study were 110 high time, professional pilots with a wide variety of flight experience. Participants received initial flight training from a collegiate program (36%), a fixed base operator (26%), the military (15%), a flight training center (17%), or some combination of sources (6%). Average total flight time for all participants was 5,583 hours and 5,700 hours for those with at least 100 hours in glass cockpit aircraft (64%). Subjects with glass cockpit experience averaged 2,043 hours in glass cockpit aircraft. Glass cockpit aircraft were identified as those having electronic flight instrument

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displays integrated with a programmable flight management and alerting system, such as those found in regional jet and later model Boeing and Airbus aircraft.

Data were collected from participants during an arranged training session in preparation for an employment interview with a major air carrier. Training was conducted in an airline-category flight training device with "round dial" flight instrumentation. Duration of the flight profile for the session was one hour and included a takeoff, a complex departure procedure, rate climbs and descents, a holding procedure, and descent to a precision instrument approach. Additional instrument approaches were 'flown, time permitting, to complete the hour. Weather for the session was set to low ceilings and reduced visibility. Items evaluated during the training session included instrument crosscheck proficiency, flight within instrument test tolerances, smoothness of control, and correct completion of instrument procedures. Each of the above areas was rated on a five-point Likert scale.

Before the flight simulator session, each participant completed a biographical survey. Data collected included: age, gender, flight experience factors, and method of initial flight training. Upon completion of the training profile, each participant was asked to complete a performance self-evaluation in the areas of instrument crosscheck, ability to maintain established flight tolerances, smoothness of control, and knowledge of instrument procedures. Statistical Package for the Social Sciences (SPSS) software was used to identify descriptive aspects of participant biographical data. In addition, bivariate correlations were computed to identify variable relationships. Study findings describe participants' performance during the flight profile as well as their inputs concerning training in glass cockpit aircraft.

Results

A large portion of the sample (64%) reported qualification and at least 100 hours experience in glass cockpit aircraft. Those participants were asked to report likes and dislikes of glass cockpit training which they had received. Many of those participants (27%) liked the ease with which a consolidated instrument display and various glass components could be interpreted. Others praised innovative glass cockpit instructional methods and training staff (22%). A few glass-experienced participants enjoyed the challenge of training in a more advanced aircraft (9 %) and an improved ability to maintain situational awareness (8%). Participant responses to what they did not like about their glass cockpit training experience varied widely. Some participants (36%) did not like the classroom training methods which they felt were outdated and did not include enough hands-on material. Others (21%) did not like the overall training format and a reliance on computer-based instruction. Some (20%) felt that too much material was presented too fast. Some pilots (20%) reported that the flight management system was particularly difficult to master.

Experienced glass cockpit pilots were asked how frequently they used automated flight instrumentation features during flight. They were also asked which phase or phases of flight made them the most uncomfortable when using automated flight instrumentation features. Of those participants, 59% reported at least frequent use of automated flight modes during departures and instrument approaches. This factor may reflect company policy and manufacturer guidelines that promote maximum use of automatic flight modes. In addition, participants with glass experience indicated that they were not comfortable with the operation of automated flight modes during departure (13%) and approach (39%). It was unclear whether this lack of confidence was due to inadequate training, infrequent systems operation, or pilot skill level.

Many study participants expressed a concern with their instrument scan proficiency before the simulator session. However, participant feedback after the session, in the form of self-evaluation, indicated that 83% of glass experienced participants felt they were able to effectively scan their instrument after 30 minutes or less into the flight profile. Of the non-glass participants, 92% felt their scan was effective after 30 minutes or less. Only 43% of the glass experienced pilots believed they maintained flight tolerances of 10 knots, 10 degrees, and 100 feet altitude more than half the time, compared to 51% of non-glass pilots.

Based on the literature review, it was hypothesized that pilots with more glass cockpit experience would have a less effective instrument cross check, have difficulty maintaining tolerances, and generally perform poorer in a round-dial operating environment than those pilots with less glass cockpit flight time. A bivariate correlation procedure was conducted with study data to assess relationships between flight experience variables identified on the pre-flight survey (total flight time, glass-cockpit flight time, and frequency of manually flown approaches) and performance areas rated during the simulator profile flight (instrument scan, flight tolerances, control smoothness, instrument procedure knowledge, and overall performance). Results of the bivariate correlation procedure indicated significant relationships between: total flight time and an ability to maintain flight tolerances within practical test standards ($r = .292$), glass cockpit flight time and demonstrated knowledge of instrument procedures ($r = .290$), and frequency of

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manually flown approach activity and smooth aircraft control (r=-.238).

The relationship between participant total flight time and their ability to maintain flight within practical test standards was expected. The strength of that relationship for glass-cockpit pilots was supported by a univariate ANOVA procedure (F= 6.12, p= .016). The finding was similar to that for non-glass cockpit pilots (F= 4.45, p= .02). The relationship between glass cockpit flight time and demonstrated knowledge of instrument procedures was also confirmed by a univariate ANOVA procedure (F= 7.52, p= .008). This finding may reflect better visualization of approach phases by participants due to experience with an integrated navigation display typically found in glass cockpits. Finally, the relationship between frequency of raw data approaches and smoothness of control was supported by an ANOVA procedure (F=5.13, p= .027). This finding suggests that more raw data flight experience enhances smoothness of control in manual flight modes. Relationships between flight experience factors and other performance areas were not found to be significant.

A further analysis was completed to detect relationships between self-evaluated ratings and those completed by an expert observer on the scored areas (crosscheck, flight tolerances, control smoothness, instrument procedures and overall performance). Results of ANOVA procedures suggest a strong relationship at the p = .01 level of significance for each pair of rating areas.

Discussion

This purpose of this study was to assess the manual flight skills of high-time pilots with extensive experience in advanced technology aircraft. Piloting skills, to include instrument scan, flight tolerances, control smoothness, knowledge of instrument procedures and overall performance, were evaluated in a "round dial" flight training device to identify levels of flight proficiency. Findings suggest significant relationships between: total flight time of study participants and their ability to maintain flight within established flight tolerances, glass cockpit aircraft experience of study participants and their knowledge of instrument procedures, and the frequency of raw data approaches flown by study participants and their level of flight control smoothness. No other significant relationships between study variables were identified.

The study illuminates a self-reported perception by participants in which there was a modest time lag in acquiring an adequate level of comfort with instrument scans using round dial instruments. This perception was expressed pre- and post-test, but did not seem to affect participant ability to perform within established standards, nor was instrument scan proficiency correlated with other experiential variables. There may be several reasons for an expressed concern over poor instrument scan: unfamiliarity with the type of aircraft replicated, currency of experience in an airline category aircraft with round dial flight decks, or insufficient preparation time for the flight simulator session that was conducted. Although some instrument scan time lag was expected for most, if not all participants, given a uniform unfamiliarity with the particular instrument system represented, it is noteworthy that nine percent more glass experienced pilots reported this lag (up to 30 minutes) than those who did not have glass experience.

Although the reason for this difference was not identified, the literature seems to suggest that a reliance on automated systems may engender a certain level of scan complacency among glass experienced pilots. This level of complacency may also contribute to a finding that 14% more glass experienced pilots than non-glass pilots identified a weakness in performing flight within expected flight tolerances of ten knots airspeed, ten degrees heading, and 100 feet altitude during at least half of the one-hour flight period. Despite such proficiency concerns, study findings suggest a significant positive relationship between total flight time of all study participants and an ability to maintain flight within expected tolerances. Further investigation into the impact of complacency fostered by advanced instrumentation operations, both in the areas of instrument scan and flight within expected tolerances, is recommended.

An additional study finding was that a significant relationship exists between the amount of glass experience and level of instrument knowledge. Data analysis suggests that participants with higher levels of glass experience have a better mastery of instrument flight procedures. During the current study, instrument mastery was evaluated during the holding and approach phases of flight. Although it is unclear from the current study which factors contributed to instrument mastery, one might conclude that sophisticated visualization during these flight phases, principally through advanced navigational displays, may facilitate enhanced understanding and retention of procedural information. Despite the finding of a positive relationship between glass experience and instrument procedural mastery, however, 33% of glass-experienced pilots remain uncomfortable with the operation of automated systems in the approach phase of flight. In addition, mastery of instrument visualization and procedures does not seem to influence control smoothness. As anticipated, findings from this study suggest that a lower

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frequency of manually flown "raw data" approaches contributes to a reduced level of control smoothness during manually controlled flight. Such findings may indicate that recurring psychomotor experience is essential to smooth aircraft operation in manual flight modes. If, as manufacturers of modern flight decks suggest, operation in manual flight modes is inefficient and undesirable, perhaps such a finding is of little concern. However, until such time as round dial aircraft are no longer in service and/or manually controlled flight is not essential, it would seem that control smoothness and manual operation within expected flight tolerances must receive appropriate attention during initial and continuing training.

Summary

Based on the literature review, it was hypothesized that pilots with more glass cockpit experience would have a less effective instrument scan, difficulty maintaining established flight tolerances, and poorer overall performance in a round-dial operating environment than pilots with less glass cockpit experience. Although participant self-evaluation data from the current study indicates some support for a reduction in instrument scan proficiency and flight within tolerance for the glass-experienced group, findings only suggest a significant positive correlation between glass cockpit experience and instrument knowledge. Further work is needed to address the potential impact of advanced technology instrumentation on manual flight skills of pilots who complete ab initio flight training in glass systems. Such research is necessary to ensure a smooth transition from the current round dial pilot training emphasis to one where fully automated flight decks are the new standard. ✈

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