THE HUMAN FACTORS OF FMS USAGE IN THE TERMINAL AREA

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Abstract

The development of advanced automation for arrival aircraft into the terminal area is being investigated for both the air traffic control (ATC) and airborne environments. For the automation to be effective and provide the best advisory information, aircraft trajectories must be accurately estimated. One way to enhance the aircraft's adherence to the trajectories assumed by advanced ATC automation is to supply trajectory information to the pilots. Such information is currently provided by ATC to pilots through voice communication. Providing the advisories to the pilots via their Flight Management Systems (FMS) could help improve the timeliness of the advisories, especially in a time-critical terminal area environment. To successfully implement the FMS for use in the terminal area, human factors issues such as pilot workload and the usability and understandability of the information presented via the FMS must be addressed. This study examines the human factors aspects of FMS usage strategies by commercial airline crews flying a Boeing 747-400 full-motion simulator in a terminal area flight segment. Results indicate that FMS-guided flight in the terminal area creates significantly higher amounts of individual crewmembers' head-down time, and increased levels of self-reported workload compared to conventional navigational means.

Introduction

Current development of automation in the air traffic control (ATC) terminal area includes the Center-TRACON Automation System (CTAS).[1] Such automation requires the accurate estimation of trajectories in order to help provide useful and efficient traffic advisories and accurately predict arrival times of the aircraft in the system.[2]

One way to enhance the aircraft's adherence to the trajectories assumed by the advanced automation is to supply trajectory information to the pilots. Trajectory information is traditionally provided to the pilots by voice advisories from ATC. This would be the conventional means to ensure compliance with the trajectories and help to realize the benefits of increased fuel efficiency and reduced delays that are part of the CTAS automation. Another way to provide these trajectories to the aircraft is directly to the aircraft's flight management system (FMS). The time-critical nature of the terminal area may be an environment in which to enhance pilot accuracy by utilizing the FMS. The FMS would provide more complete routing information in advance of when the pilots would normally receive such information. There is the possibility, however, that providing such information would be too confusing or overwhelming for the pilots to incorporate into their flight planning and control activities.

The experiment described in this paper was conducted with three objectives: 1) to examine the variability of aircraft maneuvers for aircraft equipped with on-board automation; 2) to determine the impact of pre-stored FMS routes on cockpit crews flying in the terminal area (thus providing validation for the trajectories produced by the CTAS automation); and 3) to determine acceptability of utilizing the FMS in the terminal area. The results from the first objective are described in Reference 3. The second two objectives are examined primarily from a human factors viewpoint, and are the focus of this paper. "Impact" is defined by measuring the effects of using the FMS on pilot workload, describe how the FMS was utilized, and how the FMS was incorporated into flight planning activities and other cockpit operations. These questions are especially

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interesting given the fact that the FMS was not initially designed for use in the terminal area.

The benefits of the FMS can be obtained if two assumptions are met. First, the FMS database must be accurate. Second, from a human factors standpoint, it is critical that the FMS technology is easy to use under the constraints of terminal approach operations and is also acceptable to the pilots. Information should be easy to access, and inputs and changes should be achievable with minimum complexity. The means of conveying information from ATC to the cockpit crew, and the transfer of this information from crew to the FMS should be clear and concise. Within the cockpit, both the pilot flying (PF) and the pilot not-flying (PNF) should be aware of the planned flight route that is in the FMS, and what steps are needed to make changes and to monitor changes to that flight route.

When making changes to the flight systems in a conventionally-operated cockpit (not using the FMS), a pilot's actions are reflected in the physical setting of dials and switches, as well as the motions of reaching and turning. One pilot can be made aware of the other crewmember's actions by associating the movements with specific locations of equipment within the cockpit. If the cockpit tasks are distributed such that the PNF makes the majority of the operational changes to the aircraft systems as well as ATC communications,[4] the PF is still able to understand and observe the actions and settings of the PNF without taking attention away from the flying task. In contrast, using the FMS creates a situation in which changes can be made without obvious external feedback. Unless there is explicit discussion between the pilots during input of navigation settings in the FMS, there are no observable indications that modifications have been made to the pilot who did not implement the changes.

In such an operating environment, should the PF wish to verify or access the flight route changes implemented by the PNF, attention would need to be diverted from flying to interact with the FMS to access the desired information. Another layer of difficulty is therefore added to the flying task. In the terminal area environment, where there is little time to input and evaluate clearances, the crew has less opportunity to assess changes to the flight plan and initiate and evaluate those changes. Thus, in order to use the FMS in the terminal area, the PF needs to be satisfied with the possibility of not having adequate time to confirm modifications made to the flight plan within the FMS. If this is the case, it might be expected that more time is devoted to discussing the overall flight plan between the crewmembers. FMS usage should also be reflected in more "head-down" time, or time spent referencing, programming, or reviewing information on the Control Display Unit (CDU), which is how the pilots interface with the FMS.

A previous study[5] reported that flight crews using the FMS saw the work of their flying tasks to be greatly eased, but the FMS was more difficult to use during low altitude phases of flight, such as in the terminal area. Previous research[4] has also found that in simulation, the pilot flying sometimes took the initiative to make inputs into the FMS.

In this study, commercial airline crews flew a Boeing 747-400 full-motion simulator in a terminal area segment of flight under conditions of manual flight, autopilot, and autopilot coupled with FMS. These three conditions represent differing levels of automation available to aircraft today. The influence of the FMS on the cockpit crew's flight planning activities and the effects upon pilot workload were examined. Different FMS-use strategies were documented.

Within this experiment the crews were provided with specific scenarios and their response to FMS route changes in the terminal area were documented. The data collected in this study includes head-down time, FMS programming strategies, flight planning discussion, self-reported workload responses, and a description of the distribution of responsibilities within the cockpit. It is hypothesized that a great deal of time spent in a head-down mode would be associated with less time devoted to routine flight tasks. The FMS programming methods that are observed may determine how the FMS is used by flight crews, and indicate pilot expectations with regard to how they would prefer to use the FMS in the terminal area. The discussions about the flight plan also could indicate how much information the crew had about their flight route. Extensive discussions regarding the flight plan could indicate a greater understanding of the flight plan, as well as problems encountered in the flight planning process. Self-reported workload should provide a more direct indication of how the crews perceive they are impacted by FMS usage in the terminal area. Finally, increased head-down time should also affect how the crew duties are distributed in the cockpit.

Methods

The simulated flights took place in a full-motion, Boeing 747-400 simulator at NASA Ames Research Center's Crew-Vehicle Systems Research Facility (CVSRF). The simulator includes a high-fidelity visual system and simulated ATC communications (see Figure 1). A full description of the simulator and its avionics capabilities and specifications can be found in References 6 and 7. A total of ten, two-person commercial airline crews, each crew consisting of a Captain (CA) and a First Officer (FO), flew simulated terminal area approach segments. The two crew

Figure 1. CVSRF 747-400 Cockpit

members alternated the flying responsibilities. Twelve simulated runs were scheduled for each day; due to equipment problems, one crew flew only 10 runs, for a total of 118 runs over all of the crews. The crews provided demographics data regarding their amount of flight experience and familiarity with the FMS and advanced automation as a whole.

After a training run, in which the flight plans and routes and basic FMS functionality were reviewed, the crews flew the terminal area arrival segment into the Dallas/Fort Worth (DFW) Airport. The flights' origination points alternated between the two East side meter fixes, Blue Ridge (see Figure 2) and Scurry (see Figure 3).

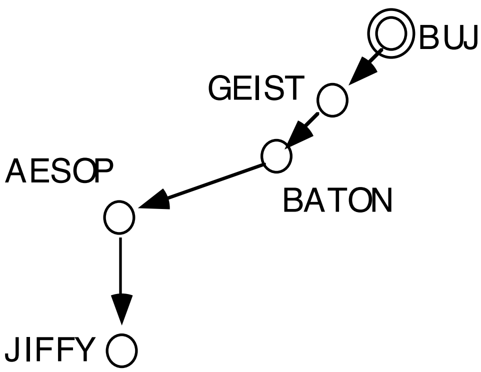

Figure 2. Blue Ridge FMS Arrival, BATNE1.

The CVSRF is capable of providing simulated background communications of other aircraft in the terminal area; these, in addition to ATC-issued clearances to the flight crew, were provided during each simulated flight. The crews flew the terminal arrival trajectories under three different flight conditions: manual flight (hand-flying using the flight director), autopilot (the typical way in which jet aircraft are currently flown into the DFW terminal area), and FMS

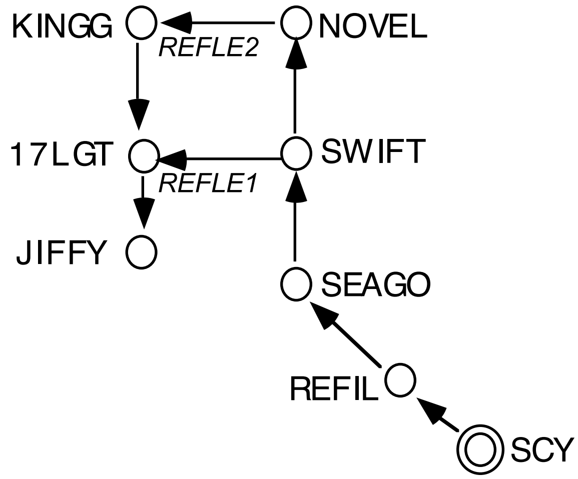

Figure 3. Scurry FMS Arrivals, REFLE1 and REFLE2.

(in which the autopilot was coupled with the FMS). When the simulated flight originated from the southeastern cornerpost fix, where the flight route was slightly longer than from the northeastern cornerpost fix, the crews were given a route amendment (REFLE2) to their original route clearance (REFLE1).

The simulated flights were videotaped, from a viewpoint behind the cockpit crew. After each simulated flight, the crews were debriefed and asked to provide ratings of their workload and contributors to their workload. Engineering data were collected on duration of flight, altitude, speed, and turn initiation; a report on pilot variability under the three flight conditions is described in Reference 3.

Each of the simulation videotapes was transcribed from the initiation of the flight to the touchdown on the runway. The transcripts included conversations between the cockpit crew and between the crew and ATC. Only conversations of an operational nature were transcribed. Due to recording problems, there were 6 runs that were not available for analysis.

The transcripts were coded to determine key events, noting the times within the simulation when certain events occurred, and where appropriate, the duration. The event data was then summarized and compared across the three flight conditions. Among the data collected from the transcripts/videotapes were: how the crews utilized/programmed the FMS (as determined by their communications), head-down time involved in using the FMS, and discussions about the flight plan.

The resulting data consisted of the following: questionnaire data and crew comments, discussions about the flight plan, head-down time spent programming the FMS, and a determination of the methods used in programming the FMS with the assigned route clearance.

Results

Demographics

The demographics data showed that the Captains had a mean of 17.2 years of experience as captains. The First Officers had a mean of 11.8 years of experience as first officers. On average, the Captains had 1895 hours of flight time in the 747-400, versus 1880 hours of flight time in the 747-400 for the First Officers; this difference was not statistically significant. Most of the flight crews typically flew long-haul flights between the U.S. and Pacific Rim destinations.

The crews were asked if they had personal computers in their homes, and also if they used computers on a daily basis. These questions were used to assess the crews' familiarity with automation. All of the captains reported having personal computers at home, and 7 of the 10 captains used computers on a daily basis. Nine of the ten first officers had personal computers in their homes and 9 out of 10 reported using computers on a daily basis. This suggests a good deal of familiarity with automation on the part of the flight crews that participated in this study.

Workload Ratings

Across all the simulations, the pilots did not rate their overall workload as excessive, nor were there significant differences in self-reported workload between the different East side fixes, or between the different pilots. In all of the data that were collected, the FMS flight conditions were rated as contributing the greatest amount to their workload, compared to the manual and autopilot conditions. In addition, the autopilot condition was associated with the lowest ratings of workload contribution.

Figure 4 depicts the significant differences found in the self-reported overall workload under the different flight conditions ($F[2,229] = 14.59$, $p < .001$). The average self-reported workload ratings are represented by the heights of the bars. The standard deviations are represented by the "T" lines on the top of each of the bars. The autopilot condition was rated significantly lower than the other two flight conditions ($t[235] = 8.86$, $p < .001$), at a value below the midpoint of the scale. The manual flight condition was rated significantly lower in workload than the FMS condition ($t[235] = -2.92$, $p < .01$).

The pilots were also asked about their satisfaction with their performance (see Figure 5). Overall, they reported mid-level to high ratings of performance satisfaction ($F[2,231] = 12.98$, $p < .001$). In addition, they reported significantly greater satisfaction in performance in the autopilot condition ($t[231]= -4.082$, $p < .001$). The

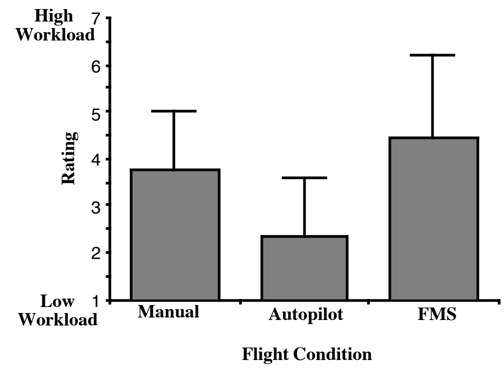

Figure 4. Self-Reported Workload.

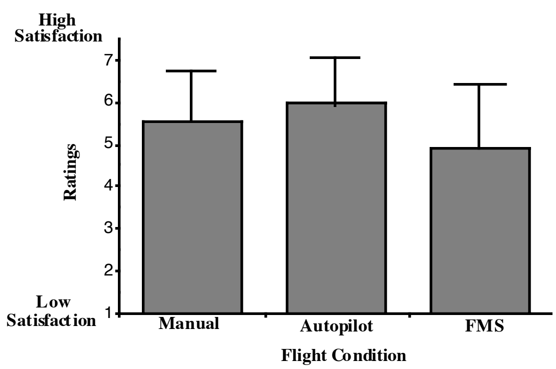

Figure 5. Self-Reported Satisfaction.

FMS mode was also rated significantly lower than the Manual mode in performance satisfaction ($t[231]= 3.078$, $p < .01$).

Figure 6 shows that the FMS mode was associated with the most self-reported frustration levels ($F[2,201] = 49.58$, $p < .001$). This is not surprising, given the lower satisfaction ratings (reported above) that were found in the FMS condition. The frustration ratings were significantly lower for the autopilot condition compared to the FMS and manual conditions ($t[201] = 8.321$, $p < .001$). The FMS condition was rated significantly more frustrating than the manual condition ($t[201] = -5.40$, $p < .001$). Again, these findings mirror the satisfaction ratings by showing that lower satisfaction is associated with higher frustration.

As shown in Figure 7, the activity of planning the flight route and its contribution to the overall workload was also rated significantly differently depending upon the flight mode ($F[2,177] = 21.33$, $p < .001$). The flight planning in the autopilot mode was rated as contributing the least to the overall workload ($t[177] = 4.61$, $p < .001$). The planning activity was rated

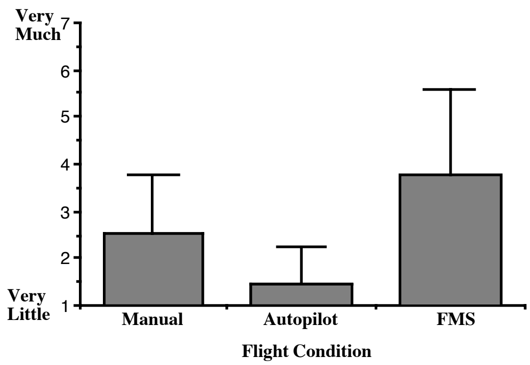

Figure 6. Self-Reported Frustration Level.

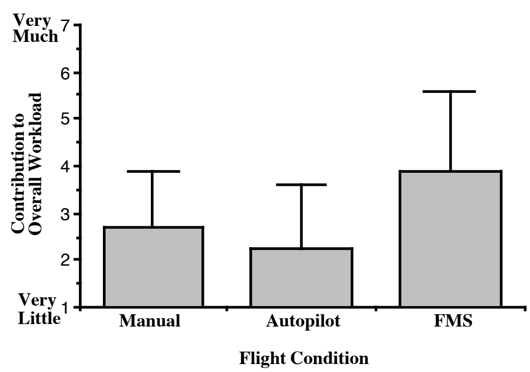

Figure 7. Planning the Flight Route.

significantly different and higher for the manual flight mode, and highest for the FMS mode ($t[177] = -4.58$, $p < .001$). As reported above, in the FMS conditions, where route amendments were issued, these route amendments were the greatest contributor to the overall crewworkload.

As shown in Figure 8, time pressure was rated significantly differently depending upon flight condition ($F[2,203] = 38.40$, $p < .001$). The crews rated the time pressure in the autopilot condition as contributing the least to the overall workload, compared to the other two flight conditions ($t[203] = 6.36$, $p < .001$). The FMS condition was again rated higher in time pressure as a contributor to overall workload compared to the manual condition ($t[203] = -5.93$, $p < .001$).

The pilots were also asked about the overall impact of communicating with ATC during the flight scenarios. It would be expected that typical ATC communication would be considered more intrusive as the cockpit tasks increased. However, in the FMS condition, the ATC communication overall is reduced because more

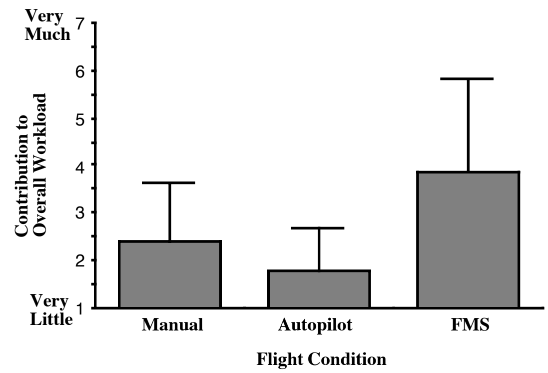

Figure 8. Time Pressure

information on the flight route is provided to the crews via the FMS (rather than by voice). Under all three flight conditions, the crews rated the ATC communication effect on their workload as low to mid-range on the scale (see Figure 9). The crews rated the overall task of communicating with ATC as contributing little to the overall workload under the autopilot condition, followed by being rated as a greater contributor in the manual condition ($F[2,203] = 5.77$, $p < .01$). While the communication with ATC was less demanding under the autopilot condition than the FMS and manual conditions ($t[203] = 2.77$, $p < .01$), the difference between manual and FMS conditions was not statistically significant. Thus, the workload impact of ATC communications under FMS usage was higher than the autopilot "baseline" despite the overall reduction in number of clearances issued by ATC to the crew.

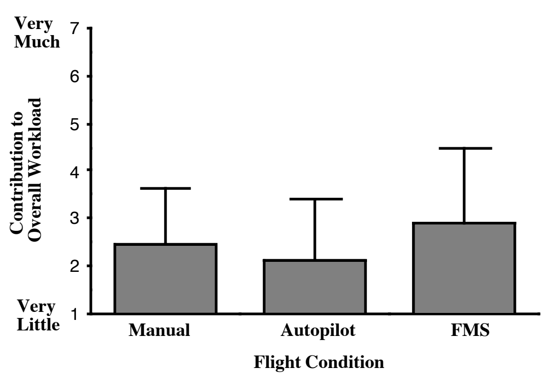

Figure 9. ATC Communication.

Transcript Data

The simulation transcript data was analyzed in three ways: 1) the amount of time devoted to discussions of the flight plan; 2) the amount of head-down time on the part of the pilots; and 3) the different strategies employed by the crews to implement route changes in the FMS conditions. Results from each of these areas will be discussed in detail below.

Flight Plan Discussion

The activities of a flight crew in the terminal area are traditionally tactical in nature. Crews are provided with instructions from ATC to meet airspace restrictions and are guided to touchdown. In this experiment, the crews were briefed on the flight plan prior to the beginning of the simulations. In addition, under the FMS condition, the planned flight route information was explicitly available to the crew through their route clearances as well as additional approach plates specific to the experiment.

The number of times that a crew discussed the flight plan was tabulated within each of the different flight conditions. Flight plan discussion was characterizedas any discussion regarding upcoming waypoints, future plans for dealing with route amendments, and flight route restrictions. This included discussions when the crews were programming the FMS and discussing the upcoming waypoints and restrictions. Flight plan discussions were not categorized when the crew merely stated their current location along the flight path, or any discussion of their current status in relation to the overall flight path.

As shown in Figure 10, the FMS flight condition resulted in significantly more discussion about the flight plan than the manual and autopilot conditions ($F[2,110] = 56.85$, $p < .001$). There was also greater variability in the amount of discussion about the flight plan in the FMS condition. The manual and autopilot conditions were not significantly different from one another. This suggests the crews discussed the flight plan information more extensively in the FMS condition than in the traditional, more tactical flight environment. This finding also suggests that the crews were more aware of their flight route under the FMS conditions.

Head-downTime

The videotaped data were reviewed to determine the amount of time that the crews were "head-down," or looking at the FMS/CDU to accomplish programming or referencing activities during the flight. The types of head-down activity were classified into 3 categories: Captain (CA) head-down, First Officer (FO) head-down, and both pilots head-down. Over all the flight conditions, the FO head-down category comprised an average of 79.4 seconds of head-down time, followed by the CA head-down category, with an average of 66.4 seconds of head-downtime. There was relatively little overall time in which both crewmembers were categorizedas head-down: 29 seconds on average, over all the simulated flights.

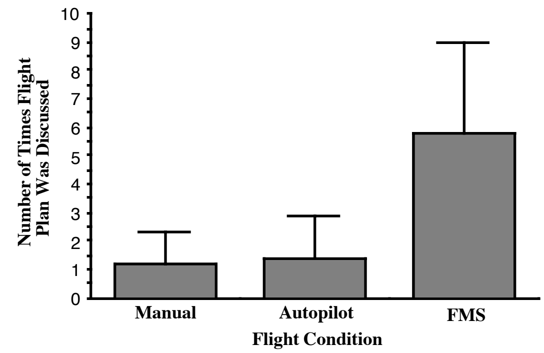

Figure 10. Discussion of Flight Plan.

Head-downtime is necessarily influenced by the flight duties assigned to the PF or PNF. Traditionally, the PNF is responsible for talking on the radios and non-control-related tasks during flight. Given the difficulties that some of the crews appeared to experience in the FMS condition, and based on crew comments, it was expected that there would be some significant sharing of the PNF programming duties between the crewmembers in order to accomplish the necessary programming tasks. Figure 11 depicts the head-down time for both crewmembers in the FMS conditions only. The figure shows that the head-down time did not increase significantly for the PNF. Which crewmember was flying did not significantly influence the amount of head-down time for both crewmembers at the same time. Also, when the CA was flying, the FO did significantly more of the programming and referencing of the FMS ($F[1,87] = 15.64$, $p < .001$). When the FO was flying, the CA did significantly more of the programming and referencing of the FMS ($F[1,85] = 7.77$, $p < .01$). This finding coincides with the traditional duty assignments as requiredby most airline standardoperatingprocedures.

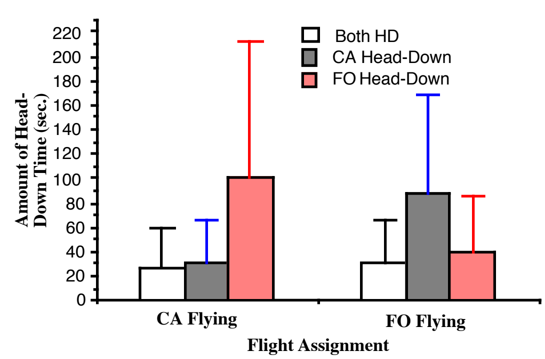

Figure 11. Head-Down Time by Flight Assignment

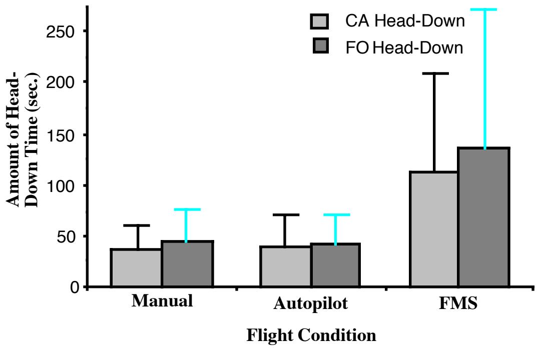

Figure 12. Head-Down Time.

Figure 12 depicts the head-downtime across the flight conditions, partialling out the effects of the PF. There was nearly three times as much head-downtime on the part of the CA under the FMS conditions than the manual and autopilot conditions; this finding is statistically significant ($F[2, 85] = 27.272$, $p < .001$). Similar results were found for the FO head-down time ($F[2,83] = 15.668$, $p < .001$); there was again nearly three times as much head-downtime on the part of the FO in the FMS condition than the manual and autopilot conditions.

FMS Programming Strategies

The FMS programming strategies were examined for the FMS runs. There were five out of the available 46 cases of FMS observations in which no strategy could be determined from the videotaped data.

Two strategies were observed in dealing with the route amendment introduced in the FMS flight conditions. When the crews were provided with the route clearance, they generally followed one of two ways of starting the aircraft along the new route. In the first strategy, the crews got the arrival route information first, before starting the aircraft along its new route. In the second strategy, the crews started the aircraft along the route first, and then completed accessing the arrival information from the FMS descent page. The functional differences between the two strategies appeared to be that the first strategy reduced the number of keystrokes necessary to interact with the FMS. The second strategy required more steps to program the FMS, but started the aircraft along its new clearance sooner. One of the crews indicated that the second strategy was one that was taught in training, and they understood it was the method they were expected to use.

In 63.4% of the available FMS runs, the pilots chose to use the second strategy. Further analysis was conducted to see if there were any statistically significant correlations between the strategy utilized by the flight crews and other experimental conditions (discounting the possible training effects). There were no statistically significant associations between strategy and: the originating fix, amount of head-downtime, the duration of the head-down time, or the PF.

FMS programming time is documented in Reference 3. An analysis was conducted to see if there were significant differences between the programming times associated with the two strategies. The mean programming time was 86.55 sec (SD = 53.35) for the first strategy, while the mean programming time for the second strategy was 117.85 sec (SD = 42.64). Although the perception of the amount of actions required and the mean programming times suggest a definite reduction in programming time for the first strategy, the means were not statistically different from one another.

Pilot Acceptance

Pilot acceptance of the FMS procedures was not explicitly collected with any kind of acceptance rating scale. Acceptance data is therefore inferred from the extensive debriefing discussions held with the pilots following the simulation runs, and at the end of each day of simulation.

Although the crews were largely successful with utilizing the FMS in these terminal-area experimental scenarios, overall, the pilots reported dissatisfaction, and emphasized the extra workload that was required during arrival operations. The additional route clearance change that was issued on runs which originated from the southeastern cornerpost was especially difficult to accommodate. Pilots felt that they had insufficient time to prepare and program for the additional route change. One pilot said that if a change was required late in the approach phase, the change should simply consist of runway headings, speed, and altitude, rather than an entire new route clearance. Another pilot said that when there is low workload, utilizing the FMS reduced the workload even further; however, under higher workload, utilizing the FMS made the overall tasks "impossible."

Discussion

The demographics data show that there was a good deal of familiarity with automation on the part of the flight crews who participated in the experiment. However, this familiarity with automation and the occasional use of the FMS during the cruise portion of long, trans-oceanic flights suggests that the crews' familiarity with programming may not translate into the pressure of utilizing the FMS in a more high-workload environment, such as in a terminal approach segment of flight.

The questionnaire data show that the pilots reported workload to be the greatest in the FMS condition. The crews reported the least amount of workload under the autopilot condition, which could represent a baseline of how they normally perform their flight tasks in the terminal area. One reason for the increased workload in the FMS condition can be attributed to the amount of head-down time in the terminal area. The time needed to refer to the FMS for programming purposes suggests that there was less time available to perform other required tasks. It was frequently mentioned by the pilots that there is a lot that the crews need to take care of in the final phases of flight, and that monitoring and programming tasks removes a crewmember from being able to participate in these tasks. The impact of ATC communications were expected to be reduced with the use of the FMS in the terminal area, but even though fewer clearances from ATC were issued in the FMS conditions, the impact of communicating with ATC was still considered by the pilots to be higher than the autopilot condition, and about the same as during manual operations.

The amount of time the pilots spent discussing the flight plan was significantly increased in the FMS condition over the other two flight conditions. This result could be attributed to both an increased awareness of the flight plan in general, or indicate problems encountered due to the FMS programming activity. This increase in flight plan discussion was somewhat expected, given that the crewmembers are no longer able to share information in the same way that they would under conventional autopilot operations, such as viewing the setting of switches and dials and associating these motions with intended actions. This increased discussion and awareness of the flight plan might be expected to be associated with greater satisfaction with the overall flight, since more information is being provided to the pilots on what to expect. However, ratings of satisfaction were not positively associated with the FMS conditions. Crews were the least satisfied with their performance in the FMS conditions. In addition, the crews also rated the flight planning as being a greater contributor to the workload under the FMS condition. Reference 3 describes in detail the errors in pilot adherence to trajectories during these simulations: of the nine significant route errors over all the runs, eight were under FMS conditions. The errors consisted of incorrect FMS procedures being entered or the inability to enter the procedures in a timely manner.

From crewmember comments, the head-down time appeared to be a significant issue in the acceptability of the FMS procedures in the terminal area. They perceived that the use of the FMS required too much head-down time, and that it caused both crewmembers to become involved in referencing and programming the FMS regardless of flight condition. Contrary to their perceptions, however, it appeared that the PNF still accomplished the majority of the FMS interactions and the PF was able to devote his attention to the flying tasks. Given the pilot concerns, it might have been expected that both PF and PNF would have experienced more closely equivalent times devoted to referencing and programming the FMS. In contrast, the results showed that the pilots maintained relatively significant differences in head-down time, suggesting that they were able to adhere to standard operating procedures.

The head-down time was much more pronounced in the FMS cases than under the manual or autopilot cases. This suggests that under the more time-critical tasks required of the crews during the terminal approach phase of flight, utilizing the FMS often means that not only is the PNF spending a great deal of time attending to the FMS, but much more time than is customary under autopilot or manual flight conditions. This may contribute to the increased time pressure that the crews reported under the FMS conditions. The resulting effect may be that under FMS usage in the terminal area, the PF may have to take on more tasks that are usually completed by the PNF. It is critical that further studies examine this issue of sharing of duties. If the FMS programming process is so unwieldy that that PNF must spend too much time programming, the PF will be negatively impacted by having to assist either in traditional PNF flying duties, or in the programming activity itself.

The strategy that the crews employed most frequently in programming the FMS reflects what they have been trained to utilize and may also indicate the more intuitive means of integrating the FMS into the flying duties. In the majority of the cases, the crews chose to use the method which sent the aircraft along its (new) route more quickly, rather than use the quicker way to program the FMS, despite the increase in the amount of keystrokes. Improving the FMS interface through decreasing the amount of keystrokes, or enabling the aircraft to be started along its new route more quickly (with fewer complex FMS programming actions) would probably be a welcome design change. It would also be useful to investigate the different ways that different airlines may train their pilots in FMS usage. This might provide some clues as to airline priorities and how better FMS interfaces would influence their training procedures.

Training itself may also influence the effective use of the FMS in the terminal area. Because the pilots in this study were chosen for their familiarity with the 747-400, they were more likely to have used the FMS only in the cruise phase of trans-oceanic flights. Thus, they may not have had enough familiarity using the FMS features, or identifying and correcting entry errors.

Future studies may wish to provide more training runs to the pilots to familiarize them with the FMS.

Pilot acceptance of the FMS clearances in the terminal area was generally not positive. While the crews were clearly able to accomplish the flying tasks under the FMS conditions, time pressure and crew resource issues contributed to their general dissatisfaction with using the FMS in the terminal approach phase of flight. Other aids may be needed to successfully implement widespreaduse of the FMS in the terminal area. One such aid is datalink, which could reduce some of the difficulties encountered with programming and entering in route changes that are received by voice. Use of other such devices should consider whether there is an added impact upon head-down time and time pressure experienced by the flight crews.

Conclusion

Previous studies have indicated that the FMS reduces workload, primarily in the cruise phase of flight. In the arrival phase, FMS usage was reported to increase workload.[5] The results of this experiment support these findings. In this study, among the three flight conditions examined, the FMS mode was rated highest in self-reported workload, with the lowest levels of performance satisfaction. The FMS workload levels were rated higher than even flying with minimal automation. Some variables which were assumed would be benefits of using the FMS, such as reduced ATC interaction and possibly more efficient flight planning, were found to actually be more difficult under FMS flight conditions. These expected advantages did not outweigh some of the other problems experienced by the crews.

The self-reported workload under the autopilot condition was the lowest of the three flight conditions. The greater amount of pilot performance satisfaction in the autopilot condition provides an indicator of a baseline level of workload to which pilots are accustomed. This level should probably be considered as a target in the development of cockpit automation and the integration of advancedATC automation, to help reduce the pilot workload in the terminal area. Strategies observed in the use of the FMS from this study suggest that for future development of FMS interfaces, there should be an examination of what is more intuitive and expedient for the pilots in dealing with route clearances. The time pressure involved in the terminal area is another reason why there should be attention paid to improving the nature of the FMS interface if pilots are to be expected to use the FMS in the terminal area. In addition, training issues should also be addressed in future simulation to help identify whether the terminal area is itself a barrier to FMS usage, or if greater proficiency using the FMS (together with a more intuitive human-computer interface) would be sufficient to allow effective FMS use in the terminal area.

It is clear from this study that while benefits may be expected from FMS usage, further work needs to be done to examine how the pilots can most effectively incorporate this information into their work environment without negatively impacting workload and smooth, safe flight operations. To do so will help to ensure greater accuracy for meeting trajectories introduced by advanced ATC automation. Providing route information to the pilots via datalink could streamline this process in the terminal area, and allow for the efficient use of the FMS.

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