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Improved Navigational Technology and Air Traffic Control: A Description of Controller Coordination and Workload

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Improved navigational technology, such as microwave landing systems (MLS) or global positioning systems (GPS), installed in today's commercial aircraft enable the air traffic control (ATC) system to better utilize its airspace. This increased efficiency is essential if the ATC system is to meet its growing demand. Another approach to help increase airport capacity is to direct arrival traffic to final approaches with reduced lateral separations between parallel runways. Currently, efforts are already underway to increase airport capacity and efficiency by providing advanced automation to the ATC system. Research into ATC automation by NASA Ames Research Center in cooperation with the Federal Aviation Administration (FAA) has led to the development of the Center TRACON Automation System (CTAS). CTAS is intended to provide better traffic management and planning information for the ATC environment to reduce delay and increase air traffic control efficiency for both the TRACON and the ARTCC (Center) (Erzberger, 1992). The TRACON component of CTAS is known as the Final Approach Spacing Tool (FAST). The purpose of this study is to examine the effects of aircraft equipped with improved navigational technology upon controller coordination and workload under precision approaches to closely-spaced parallel runways within the CTAS environment.

BACKGROUND

Scott, Dargue, and Goka (1991) examined the effects of adding MLS-equipped aircraft to the traffic flow in a series of simulations contrasting the effects of ILS- versus MLS-equipped aircraft upon airspace operations. The study varied the mixture of ILS- and MLS-equipped aircraft and found that controllers experienced difficulty integrating the two disparate types of traffic. The task of controlling the aircraft proved easier when the composition of MLS aircraft in the overall traffic flow was very low or very high. Overall, however, Scott et al. determined that MLS-equipped aircraft produced reduced flight time from feeder fix to touchdown and increased maximum arrival rates. The controllers participating in the study felt that MLS approaches could improve operations overall.

An improvement in operations has also been demonstrated in the development of CTAS. The CTAS software has incorporated the input and active participation of controllers at all stages of the development process (Erzberger, 1992). Thousands of hours of simulations with controllers using FAST advisories has shown that FAST advisories increase airport capacity (Davis, Krzeczowski, & Bergh, 1994). Controllers themselves have often remarked that FAST advisories reduced their workload (Davis, Erzberger, Green, & Nedell, 1991).

Based on such studies, we expect that the ratio of advanced navigation-equipped aircraft and conventional navigation-equipped aircraft would affect the level of coordination and workload experienced by the controllers. In addition, the presence of automated assistance to the controllers (in the form of advisories) should reduce the need for coordination required during mixed traffic conditions and lower the controller’s workload. However, we also expect these issues to be complicated by the different approach types. Two different approach types were utilized: staggered and simultaneous. Staggered approaches require specific separations between aircraft on adjacent runways as well as between in-trail aircraft. Simultaneous, independent approaches have only in-trail spacing requirements (but do require final parallel monitors). Staggered approaches have been characterized as more complicated than simultaneous approaches (U.S. Department of Transportation, Federal Aviation Administration, 1991); consequently, we expect that greater coordination and workload will accompany staggered approach conditions. This study examined whether improved throughput could be observed under different approach types to closely-spaced parallel runways, and with aircraft that possessed advanced navigation devices.

METHODS

Two series of simulations were conducted at NASA Ames Research Center in the Advanced Automation Laboratory and the Terminal Area Productivity (TAP) Laboratory. The first series of simulations presented traffic based on live DFW radar data, without displaying advisories. The second series of simulations presented the same traffic data with a subset of FAST advisories. FAST advisories consist of two types: Passive and Active. Active FAST describes the overall FAST advisory system, providing runway assignment, sequence numbers, and turn, heading, and speed advisories. Passive FAST is a subset of the overall FAST system, consisting only of runway assignment and sequence numbers, and is currently undergoing field development. Passive FAST was used in this study. Both sets of simulations contrasted two traffic composition types: one group of "mixed" aircraft, comprised of both conventional aircraft and aircraft equipped with advanced navigation, and another group of advanced navigation-equipped aircraft only (hence referred to as "all-equipped").

Retired air traffic controllers and pilots participated as both controllers and pseudo-pilots. The controllers were assigned to one of four positions (two feeder and two final positions). The controllers were rotated through the different positions to evenly distribute their controlling styles. Controllers communicated with their pseudo pilots through a radio headset. The controllers and pseudo-pilots worked from Sun workstations, using high resolution color displays and making inputs with the keyboard and mouse. The displays used by the controllers are the current Planview Graphical User Interface (PGUI) displays upon which CTAS software is developed. All of the information typically viewed by a controller in the operational environment is available on the PGUI display in the same format. The airspace was modeled after the DFW TRACON airspace.

In the baseline simulations, the aircraft tags were the same as the operational environment with the exception of an additional letter at the end of the aircraft callsign indicating the navigation equipment status of the aircraft. In the simulations with advisory information, the aircraft tags were also augmented with runway assignment and sequence numbers. The additional conflict alert advisories and non-transgression zone (NTZ) advisories appeared as the traffic situation warranted.

The controllers directed aircraft onto parallel approaches to runways 18R and 18L with 3,400 ft. of lateral separation between the approach paths, measured from their centerlines. The two approaches bounded a 2,500 ft. wide NTZ. The runway separations were 1,100 ft measured from their centerlines. The aircraft for runway 18L flew an offset approach by sidestepping to 18L approximately 3 nm from the threshold. Simulated aircraft were equipped with advanced navigation or equipped with conventional navigation. Aircraft which were equipped with conventional navigation were restricted to landing on runway 18R. Aircraft that were equipped with advanced navigation could land on either runway 18L or 18R.

The independent variables examined were: advisory condition (no advisories and Passive FAST advisories), traffic composition (mixed and all-equipped), and approach type (simultaneous or staggered). Both observational data (described in this paper) and technical data (examining issues of throughput and commands issued, described in Slattery, Lee, Sanford, & Pawlak, 1995) were collected from these simulations.

The experimenters gathered observations from the final and feeder controller positions, and manually recorded the communications that took place between the controllers. An audio recording captured the conversations between the final controllers as a backup and verification of the communication data. Questionnaires were collected from the controllers subsequent to each simulation. The questionnaires consisted of ratings of perceived overall workload, perceived coordination between controllers, and the helpfulness of the advisories (in the simulations with advisories). Ratings on a workload questionnaire based on a subset of the NASA Task Load Index (TLX) (Hart & Staveland, 1988) were also collected; controllers were asked to rate, on a 1 to 5 scale, their perception of mental demand, temporal demand, the helpfulness of the equipment, their level of frustration, and level of effort.

DATA ANALYSIS AND TREATMENT

Two sets of data were analyzed for this paper: questionnaire data, which was tabulated, and observation data. The observation data was first categorized into units of coordination and then coded for communication categories by three researchers, working together. The categories assigned to the coordination data were from the following 10 topics: heavy/757 aircraft; sequencing; runway assignment; simultaneous or staggered approaches; information about the aircraft's status; comments on performance; handoffs; go-arounds or missed approaches; overshoots; and a category into which unclear communications were classified. Each unit of communication could have multiple topic categories assigned. A more complete description of how the coordination data was categorized and coded is described in Lee, Pawlak, & Sanford (in progress).

Both the questionnaire and the coordination/communication data were analyzed by conducting multivariate analyses of variance (MANOVAs) examining the dependent variables under the 2 advisory conditions (baseline versus advisory), 2 levels of traffic composition (mixed versus all-equipped), and the 2 levels of approach types (simultaneous versus staggered). The specific questionnaire items of interest were the self-reported level of coordination required between final controllers, the self-reported level of workload experienced during the simulation, and the helpfulness of the Passive FAST and additional (conflict alert and NTZ) advisories.

RESULTS

A preliminary review of the data revealed that there were significantly more instances of coordination between final controllers than between feeder controllers or between feeder and final controllers. Due to this inequity in the distribution of the data, and because the goals of the study were to examine the effects of approach types and advisories which primarily affect the final controller, only the final controller questionnaire responses and coordination data are addressed. A more complete analysis of the data can be found in Lee, Pawlak, & Sanford (in progress).

Advisory Condition Effects

There was a significant effect of advisory condition on the self-reported level of mental demand required during the simulation ($F(1,30) = 11.716$, $p < .002$); greater mental demand was reported under the baseline over the advisory condition. There was also a greater mean rating of perceived final coordination required under baseline conditions over advisory conditions, but this result was nearly statistically significant ($F(1,30) = 3.419$, $p < .08$).

The analyses of the coordination data revealed a significant effect of advisory condition for the communication category of heavy aircraft/757 discussion ($F(1,9) = 16.879$, $p < .003$). Discussions about heavy aircraft included informing the other controller about heavy aircraft that were expected in the sector.

Traffic Composition Effects

The self-reported overall workload at the final positions was rated significantly higher for the traffic list composed of all-equipped aircraft over that of the traffic lists composed of a mixture of aircraft ($F(1,30) = 4.229$, $p < .049$). All of the mean ratings of the helpfulness of the advisories were higher for the mixed aircraft condition than the all-equipped condition. However, the only statistically significant result was found for the NTZ advisory ($F(1,14) = 5.393$, $p < .036$). The helpfulness ratings of the runway assignment and sequence number advisories were generally higher than those of the conflict alert and NTZ advisories.

There was a significant interaction between advisory condition and the traffic composition for the TLX-based rating of temporal demand ($F(1,30) = 7.997$, $p < .008$). The means show that under the mixed traffic conditions, the time pressure was about the same under both advisory conditions. However, under the all-equipped aircraft list, there was significantly more time pressure reported under the baseline conditions than the advisory conditions. Figure 1 illustrates this interaction.

Approach Type Effects

The analysis revealed a significant effect for approach type for discussions about the sequence and the aircraft status. In both communication categories, there were significantly more communications about these topics during staggered approaches over simultaneous approaches. The sequence discussion describes the controllers working out the sequence that the aircraft will take, and making adjustments to fit the sequence. There was a mean of over 17 sequence communications per simulation during staggered approaches and 7.5 communications per simulation during simultaneous approaches ($F(1,9) = 6.329$, $p < .033$). The aircraft status discussion describes providing information about the altitude, speed, or heading of an aircraft. There was a mean of 13.9 aircraft status communications per simulation during staggered approaches and 5.6 communications per simulation during simultaneous approaches ($F(1,9) = 8.141$, $p < .035$).

The results indicated that, for both the perceived and actual amount of coordination instances between final controllers, there was no significant difference in baseline over advisory conditions. There was also no significant effect of the traffic composition or the approach types upon perceived and actual amount of coordination instances for the final controllers.

DISCUSSION

Overall, our results suggest that the presence of Passive FAST advisories result in lower self-reported mental demand, and less observed coordination between final controllers. The baseline (no-advisory) conditions are also characterized by more discussion about heavy aircraft. This result is unexpected; while in-trail spacing required behind heavy aircraft is larger than that for conventional jet aircraft, it is unclear what the advisories under the advisory condition were able to provide the controllers that reduced their discussion of heavy aircraft. This result would have been expected under conditions where Active FAST (with turn, heading, and speed advisories) is utilized, because precise information about where to make turns and change speeds for heavy aircraft and all other traffic is provided. The advisories presented in this study provided sequencing and runway allocation information, and indications of NTZ violations and impending conflicts. NTZ violations were indicated by the aircraft tag change in color from green to blue. Impending conflicts were indicated by the aircraft tags of the potential conflicting aircraft changing to a red color. Perhaps sequence and runway advisories used by the TRACON controller reduces the time-critical nature of planning for heavy aircraft, and requires less exchange between controllers about this topic.

The NTZ advisory was found to be more helpful under mixed traffic conditions over that of the all-equipped traffic conditions. This indicates that advisories are more helpful when the traffic composition is less certain. The Passive FAST advisories (sequence number and runway assignment) were not rated significantly more helpful under different traffic composition or approach types. We have two possible explanations for the lack of a stronger finding in favor of the Passive FAST advisories. The first is that our study focused on the coordination and workload of the final controller, but it is the job of the feeder controller to merge traffic from outside the TRACON into the final sectors. Final controllers may discuss very little about the sequences and runway assignments unless they disagree with the sequence or runway assignment plan set up by the feeder controller. The feeder controller data may provide information about the use of sequence and runway assignment advisories. A second explanation is that our subject population has worked extensively with the Passive FAST advisories and they may be experiencing a plateau effect in how helpful they find the advisories. Perhaps collecting ratings from the controllers subsequent to the baseline simulations, and asking them to rate how they feel they could have utilized advisory information would have added more insight into the usefulness of the advisories.

The controllers reported less overall workload under the mixed traffic conditions than when all of the aircraft were equipped with advanced navigation. This result is contrary to the previous study (Scott et al., 1991), in which controllers reported a higher workload level under mixed traffic conditions. The interaction between advisory condition and the traffic composition for the temporal demand rating provides a possible explanation for this result. Under baseline conditions, the controllers indicated a higher temporal demand for the all-equipped list over the mixed aircraft list. When there are no advisories, and all aircraft are capable of landing upon either runway, the controller must make an additional decision to assign runways. This, in effect, creates more planning and strategizing on the part of the controller, and could contribute to a higher temporal demand rating. Under advisory conditions, however, the runway decision is provided for the controller in both mixed and all-equipped traffic conditions. The data show that the all-equipped condition produced a rating of less temporal demand than under the mixed aircraft condition. Further, the coordination observed also supports this reasoning. We observed more discussion regarding runway assignments under the mixed aircraft conditions over that of the all-equipped conditions, though this difference was not statistically significant.

There were a few significant results for the approach type and self-reported workload and observed coordination. There was more communication regarding the sequence and the aircraft status under staggered approaches versus simultaneous approaches. Previous studies (U.S. D.O.T., FAA, 1991) have shown that staggered approaches are more complex than simultaneous approaches because of having to meet both diagonal and in-trail separation requirements. Our results demonstrate that discussing the aircraft sequence and the current state of the aircraft are important to coordinating and achieving a staggered approach.

Based on experience with the development of CTAS (Davis, et al., 1991; Davis et al., 1994) and previous studies (Scott et al., 1991), we expected more robust findings in favor of the helpfulness of automation. There may be methodological reasons why the advisories were not found to be more helpful. One reason was the limited number of data available in this study. The data collection was limited to one (or, at most, two) simulation sessions per experimental condition. In addition, three-quarters of the simulation data were under the mixed aircraft traffic condition. A future study would benefit from a more balanced experimental design, so that an equal number of simulations between the two traffic composition conditions are run, as well as an increase in the number of simulations per experimental condition.

Another methodological concern is that the levels of traffic in the simulations may not be sufficient to detect measurable differences in coordination or workload. The simulation traffic levels were 30-40% lower than the traffic levels used to assess CTAS (which reflects the traffic load at level 5 facilities such as Dallas/Ft. Worth and Denver). A lower traffic level can blur the distinction between a task made easier by advisories, and a task that the controller is able to effectively manage alone. It would be important for a future study to examine the "right" level of traffic at which the controller feels is an adequate test for a new automation tool.

Feeder controller coordination and communication was not addressed in this paper; but the feeder controller does impact the overall operations and such data would provide a better overall picture of the experimental conditions' impact upon controller communication and coordination. Future study would benefit from more data to examine the feeder controller's influence upon the traffic situation and how that affects the final controller.

CONCLUDING REMARKS

This study showed that the coordination, communication, and workload of the final sector controller is impacted by aircraft equipped with advanced navigational technology on closely-spaced parallel runways under conditions with and without CTAS advisories. Lower self-reported mental demand and less observed coordination between final controllers were found when advisories were presented. An effect of traffic composition under different advisory conditions was also observed; the advisories were shown to reduce perceived temporal demand for the all-equipped condition, but increase perceived temporal demand in the baseline condition, when compared to mixed traffic.

Overall, our results are encouraging for the use and development of Passive FAST. Our results echo the comments from visiting field controllers who have reported that they are able to run higher levels of traffic with advisories than without them (Davis, et al., 1994). The results also indicate interactions between advisory conditions and advanced navigation operations. Additional study, including the effects of the feeder controller's actions, is warranted to further define the effects of operations on closely-spaced parallel runways.

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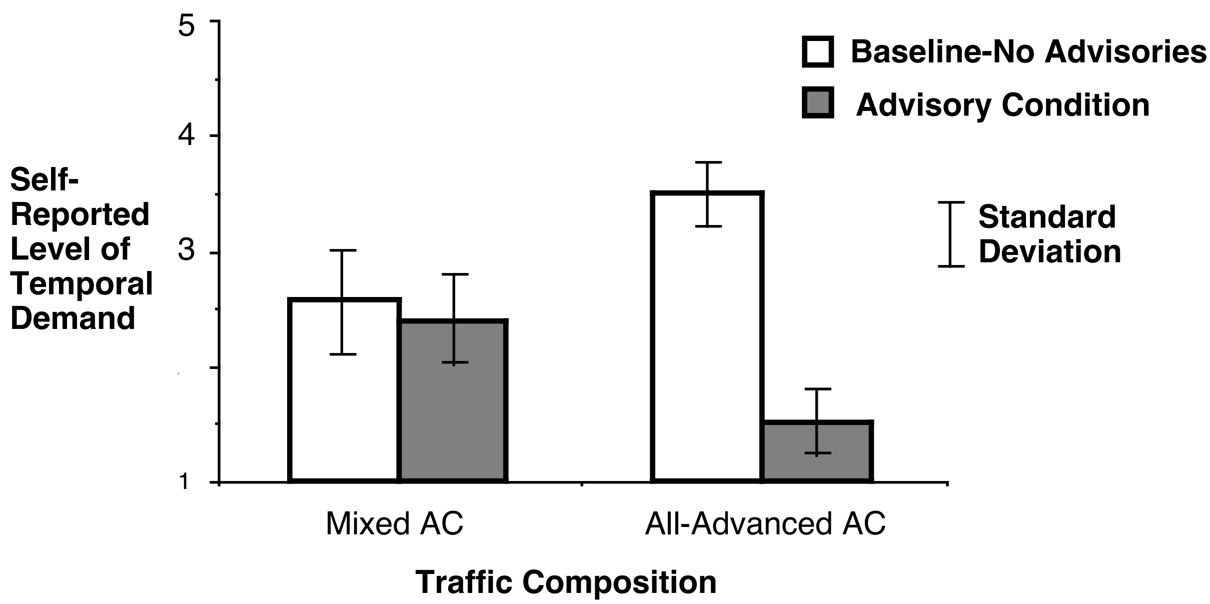

Figure 1. Controller rating of temporal demand under traffic composition and advisory conditions.