A HUMAN FACTORS EVALUATION OF ACTIVE FINAL APPROACH SPACING TOOL CONCEPTS

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Abstract

This paper summarizes the human factors aspects of the development of an air traffic control decision support tool known as the Active Final Approach Spacing Tool (aFAST). Active FAST will provide heading and speed advisories that will allow Terminal Radar Approach Control (TRACON) air traffic controllers to space aircraft more precisely on final approach. The human factors challenges include the design of the advisory format, timing of the presentation of advisories as well as the definition of the user interaction necessary for a daily-use operational system. Another key issue is the impact of the use of color displays on aFAST implementation. Initial shadow simulations were conducted to determine a nominal advisory presentation format. Findings from these studies are discussed and plans for further laboratory and field evaluations of aFAST are outlined.

Introduction

The Passive Final Approach Spacing Tool (pFAST), a component of the Center-TRACON Automation System (CTAS), is an air traffic control decision support system in daily use at Dallas-Ft. Worth TRACON (DFW TRACON). Passive FAST utilizes four-dimensional trajectory prediction algorithms and expert logic to perform runway allocation and sequencing of arrival traffic. Runway assignment and sequence advisories are displayed to TRACON Feeder and Final Approach controllers in the form of additional text in the aircraft's Full Data Block (FDB). The Passive FAST system has been demonstrated to provide a 9-13% increase in throughput at Dallas-Ft. Worth International Airport (DFW) [1].

Passive FAST was originally part of a more comprehensive FAST system that integrated runway and sequence advisories, with heading, speed and time-error (early/late) advisories [2]. In simulation, use of the FAST system reduced excess interarrival spacing by 0.4 nautical miles. Moreover, during a one-hour rush, controllers maintained a final approach course intercept length of 10-11 miles rather than the 18-20 mile final seen in baseline runs. Controllers commented that using FAST reduced their workload and that they did not have to issue additional vectors and speed control beyond those advised by FAST. Controllers indicated that the full advisory set, which included text in the FDB as well as advisory symbology on the planview display, would produce too much clutter on a monochrome display and that color display capability would be necessary to gain acceptance of the system. To alleviate this concern, as well as foster earlier controller acceptance, the heading and speed, or "Active," advisories were set aside for future research, while the runway and sequence, or "Passive," advisories, which are displayed only in the full data block, were developed for operational use first [1,3].

With a nationwide deployment of Passive FAST and the anticipated introduction of color displays into TRACON facilities in the United

States, NASA is continuing its development of active advisories. As part of NASA's Advanced Air Transportation Technologies (AATT) Project, research is underway to refine the sequencing and conflict detection and resolution algorithms in order to incorporate heading and speed advisories into the FAST system. Heading and speed advisories are referred to as "Active" advisories because they are more tactical in nature and provide control instructions by showing where the turns and speed reductions should begin. The "Passive" advisories are more strategic in nature because they provide a runway and sequence, but it is up to the controller to achieve the sequence. Passive FAST has been shown to increase throughput by means of more efficient runway allocation. Active FAST can further increase throughput by reducing excess in-trail separation on final approach [2,4]. At airports where there is a single runway, pFAST advisories will not demonstrate significant benefits because there is little to be gained through runway allocation and sequencing. Active FAST advisories are expected to improve throughput in all situations.

Figure 1 shows an example of the types of clearances that are presently issued by a controller to an aircraft on approach to DFW runway 17C from the southeast. The aircraft shown would follow a published standard arrival route (STAR) and then expect vectors to final approach. The aircraft should be on its STAR termination heading at 250 knots. The controller issues a speed reduction to 210 and a turn onto the downwind heading of 350 degrees. On the downwind leg, the controller slows the aircraft to 190 knots and then issues the base turn to 270 degrees. If necessary, the controller will further slow the aircraft to 170 knots before issuing the final approach course intercept heading of 200 degrees. The aFAST system will calculate where along the trajectory these clearances should be issued in order to achieve precise in-trail separation on final.

In addition to the technical challenges of developing the sequencing and conflict resolution algorithms [5], there are numerous human factors challenges involved in the development of aFAST. In order to implement aFAST advisories, it is important to understand the limitations of the human operator and design the advisories so that the information is readily available without creating excessive clutter. Specific human factors challenges include, but are not limited to, the physical characteristics of the advisories, procedural issues associated with the use of the advisories and the impact of controller and pilot performance on the aFAST algorithm performance. Physical characteristics include the size, shape and placement of advisory symbology, the use of additional text in the FDB, timing of the display of advisory information, and introduction of color to a previously monochrome environment. Procedural issues include determining which advisories should be presented to feeder controllers and which should be presented to final controllers, how advisories should be handled if an aircraft is in handoff status, and what type of controller interactions (slew entries, keystrokes) are necessary to achieve desired system performance. The human performance issues include the impact of early, late or missed advisories (on the part of the controller or pilot) on currently displayed aFAST advisories, and how the use of aFAST affects controller situational awareness.

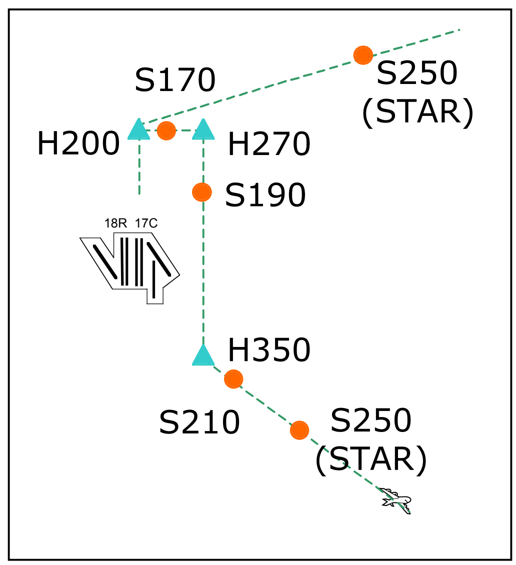

Figure 1. Example of Controller Clearances at DFW Airport

The design of aFAST advisories is being accomplished in two phases. In the first phase, the initial design of the advisories is being determined by a series of shadow simulations. The shadow simulation approach enables testing of aFAST interface designs (e.g., format, timing and use of color) in a realistic, moving traffic environment before the sequencing and deconfliction algorithms were fully developed. Once the aFAST algorithms are ready for evaluation, simulations will be conducted using the advisory formats decided upon in the initial phase. During this second phase, human factors research will be conducted to evaluate the acceptability of aFAST advisories, determine the impact of advisory presentation variables on controller performance, and assess the workload associated with using algorithm-generated aFAST advisories.

This paper describes the shadow simulation methodology employed to test the information format, use of color and timing of aFAST advisories and the results of these evaluations. The objectives of these simulations were to: 1) evaluate the format of the advisories, which includes such variables as FDB text, screen symbology, and use of color, 2) evaluate the timing of advisories and whether some indication of advisory priority is needed, and 3) begin to define the preliminary information requirements and user interactions necessary for an operational system.

Background

The initial design for the FDB text and screen symbology used in these aFAST simulations was based primarily on earlier FAST research as well as a review of other ATC automation systems under development in the United States and Europe. The original FAST interface provided a circled "X" for the speed advisory symbol and an arc for the turn indicator. The advised speed was provided in the FDB and the advised heading for the turn was drawn on the screen at the turn arc symbol. Studies of static display symbology and controller feedback from initial FAST simulations showed that placement of speed advisory text in the FDB was acceptable and the symbols chosen for advisory display were easily distinguished from the map symbology. Controllers gave feedback indicating that it was difficult to associate the turn advisory information with the correct aircraft when the turn information was placed at the turn indicator and suggested the information be placed in the FDB [6].

Previous studies by NASA Langley Research Center investigated performance of controllers using various final approach spacing aids. The formats investigated were a graphic indicator and "slot marker" on the planview display, as well as a countdown feature in the FDB indicating nautical miles to the turn. Controller performance, measured by interarrival spacing of aircraft, was best in the graphic indicator and slot marker conditions [4].

EUROCONTROL researchers in their PHARE Demonstration 2 (Programme for Harmonised Air Traffic Management Research in EUROCONTROL) used a graphical depiction of a trajectory with indicators along the path for descents. Speed reduction advisories were provided in the aircraft data tag [7].

The United Kingdom's National Air Traffic Services, Ltd. developed a tool to assist controllers with the timing of turns onto the ILS at Heathrow airport. In this system, also known as the "Final Approach Spacing Tool," the primary means of information display was a time-based countdown feature in the data block to indicate when to issue the turn and a chevron (>) in the data tag to indicate the direction of turn. In initial laboratory simulations, controllers found the display features easy to learn and to use [8].

In keeping with previous research findings and initial FAST FDB format evaluations, both heading and speed information were placed in the FDB for the human factors shadow simulations. In addition, graphical symbols were drawn on the display indicating the point at which the turn or speed reduction should begin. Though controllers in both the original FAST simulations and current aFAST shadow simulations indicated that color displays would be required for implementation of active advisories [1, 6], monochrome display of advisories was also investigated in order to document the design decision more completely. If monochrome display of aFAST advisories is acceptable, further research may explore the use of a limited set of monochrome aFAST functionality. This would likely be used in a less-complex airspace where more precise in-trail spacing could improve throughput.

The Federal Aviation Administration (FAA) is in the process of performing upgrades to the TRACONs and En Route Centers to include color radar display systems. Active FAST research continues under the assumption that color will be available for the display of advisory information in the FDB and on-screen symbology. The two candidate systems that may be available in the TRACON facilities are the Color Automated Radar Terminal System

(Color ARTS) and the Standard Terminal Automation Replacement System (STARS). The interface standards adopted for these displays will affect the final presentation capabilities of aFAST.

Methods

Shadow Simulation

The development of shadow simulation scenarios is a two-step process. First, CTAS simulation data files are collected. Then, the actual aircraft turns and speed reductions are extracted from the data file and used to script aFAST advisories. During the shadow simulations, the CTAS simulation files are replayed with advisories displayed a variable amount of time prior to the point at which the aircraft changes speed or heading. While the controllers do not actively control aircraft in the shadow simulation, they were asked to perform handoffs and issue advisories for all aircraft in their sector.

Collection of CTAS Simulation Data Files

CTAS simulation data files were generated by recording the trajectories of simulated traffic actively controlled by facility controllers. The advantage of using simulated traffic, rather than recorded live traffic, is that during simulation, all controller clearances can be recorded, so the advisories can later be verified. A group of four controllers from DFW TRACON and five pseudopilots participated in controlling simulated arrival rushes into DFW. These test sessions occurred over a three-day period. The aircraft lists were generated by the Pseudo Aircraft System (PAS) [9] Pasgen program and were modeled after seven different rush periods at DFW. Arrival time errors were applied to the list of aircraft to create three different but statistically similar lists for each rush.

The simulation setup consisted of two Feeder and two Final Approach controllers controlling aircraft to DFW runways 18R and 17C using the CTAS Planview Graphical User Interface (PGUI). Five pseudopilots operating the PAS system made aircraft control inputs in response to controller commands. During each run, CTAS data and radar tracks were recorded so they could be used for playback during the shadow simulations, and PAS command files were collected for verification.

Generation of Advisories

Actual aircraft turns and speed reductions from the recorded data file were used to script the heading and speed advisories. Each simulation data file was run through a set of filters to detect the turns and speed reductions that occurred for each flight. These data were verified against the PAS command files, which recorded the actual clearances that were issued. The detected maneuvers were used to construct a list of advisories, each of which was time-stamped and tagged by aircraft callsign. Advisory messages were generated in order that the degree of turn or new speed could be presented in the full data block along with a screen graphic at the location where the aircraft was to begin its turn or speed reduction.

Conduct of Shadow Simulations

The 30-minute scenarios contained traffic to runways 17C and 18R fed from the four primary TRACON metering fixes. Advisories were simulated for a Feeder East controller, a Feeder West controller, a Runway 18R Final controller and a Runway 17C Final controller. Data were collected for the four controller positions independently, so simulations could be run without staffing all positions. During each run, the controllers were asked to perform handoffs and issue advisories to the aircraft. Data were collected by keypresses performed when the controller first noticed the advisory and when the controller issued the advisory. Pseudopilots were present to read back the advisories, though no aircraft control entries were required. After each run, controllers filled out a series of questionnaires to provide feedback on the aFAST advisory formats just presented.

Independent Variables

Three independent variables of advisories were examined in the shadow simulations: Symbology, Color and Timing. Due to the logistical constraints of human-in-the-loop testing with full-performance-level ATC specialists, it was not feasible to examine all permutations of each of these variables. A representative subset of the test matrix was examined across two shadow simulations.

Data Block Information Format

Figure 2 shows the format of the FDB for pFAST. The aircraft position symbol is shown as the letter "J". The aircraft ID is shown in the first line of the FDB. Runway assignment and aircraft type timeshare with reported altitude (in hundreds of feet) and ground speed (in knots) in the second line of the FDB. The pFAST sequence number is shown in the third line.

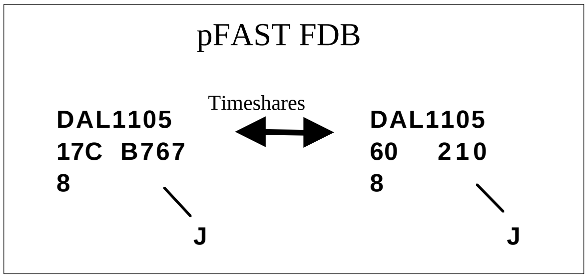

Figure 2. Passive FAST advisories

For aFAST, advised heading and speed (knots indicated airspeed) were added into the full data block. The possible formats for textual information include: the two or three-digit presentation of the heading or speed advisory value with the inclusion of a character "H" preceding the numeric value for heading or "S" for speed, and the degree to which information is timeshared with other information in the data tag. Feedback from early simulations indicated that the "S" could be confused with the number "5" and may not be necessary.

For the shadow simulations described in this paper, advisory text was presented in three-digits with an "H" prepended to the heading advisory, as shown in Figure 3. Three-digit advised heading is shown in the third line of the data tag. It is prepended with an "H" to indicate that it is a heading advisory. Heading advisory information timeshares with sequence number. The three-digit speed advisory is shown on the right side of the third FDB line without prepended text.

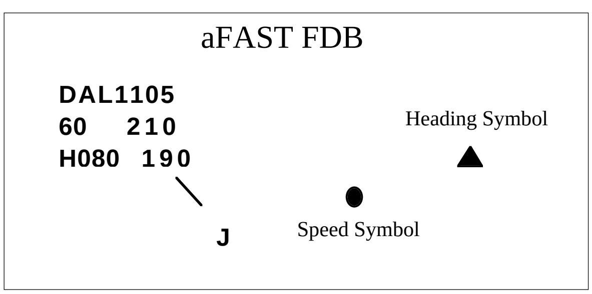

Figure 3. Active FAST advisories

Screen Symbology

Graphic indicators, both filled and open symbols, were used to represent where turns and speed reductions should begin. In Figure 3, a filled circle is used to represent the speed advisory and a filled triangle is used to represent the heading advisory. The full set of symbols used in the shadow simulations is shown in Figure 4 (note that the open circle was omitted due to the presence of a number of open circles on the video map). A Trajectory Preview function was also available to display the entire planned trajectory for a given aircraft. This function could also be used to connect an aircraft to its currently displayed advisories in cases where two aircraft had the same type of advisory displayed in close proximity. It was also expected that this feature could be used to help maintain situational awareness.

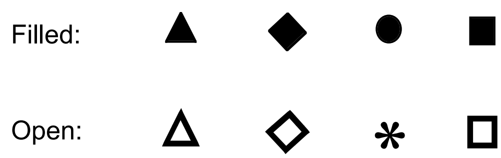

Figure 4. Screen Symbology

Figure 5 shows a full-color example of an aircraft FDB that contains both speed and heading advisories. The blue line represents the current aFAST-calculated trajectory as shown by the trajectory preview function.

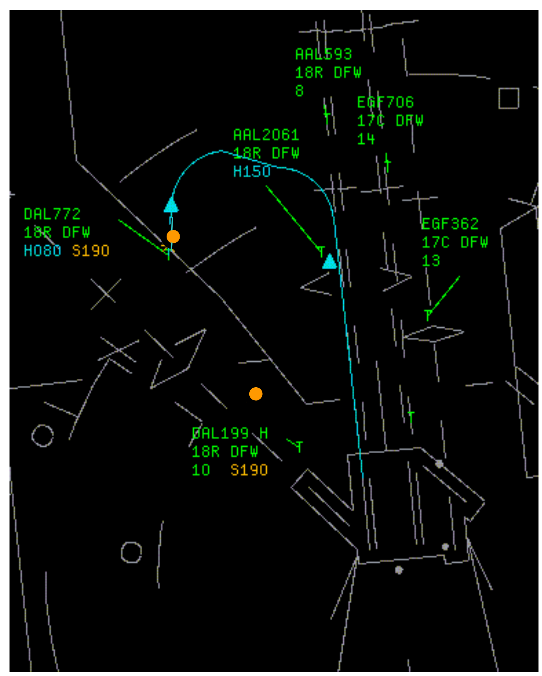

Figure 5. Active FAST example

Use of Color

It will be necessary to test controller acceptance of aFAST advisories in monochrome and color.

Under some circumstances, it may be possible to present a limited, but useful, set of aFAST advisories in monochrome depending on the complexity of the airport and airspace. In the monochrome condition, the videomap, FDBs, and advisories were presented in green. In the color condition, the videomap was presented in light gray, the FDBs were presented in green and the advisories were presented in cyan or yellow for heading and orange or magenta for speed.

Advisory Timing
Each advisory must be presented to the controller a certain amount of time before the controller needs to issue the advisory to the aircraft. The controller must have enough time to notice each advisory, comprehend its meaning, consider its implications and then, if acceptable, issue it to the correct aircraft. If the advisory is presented too late, the controller may miss the advisory or feel rushed in his decision-making process. If the advisory is presented too early, more advisories will be displayed at any given time and may result in excessive screen clutter. There is also a potential tradeoff between advisory display time and trajectory accuracy. Because each trajectory segment is frozen once its advisory is displayed, a shorter advisory display duration will produce more accurate trajectories and, in turn, more efficient traffic flows.

Experiment Design
The findings from two shadow simulations are summarized in this paper. The variables examined in those simulations are as follows:

Shadow Simulation I – Symbol/Timing
Three DFW Controllers simulated six 30-minute rush periods. Controller positions Feeder East, Feeder West and Runway 17C were staffed. Advisories were presented in color, using open and filled advisory symbols (circle/asterisk for speed and diamond for heading) as well as three advisory presentation durations: 15s, 30s, and 45s. The primary focus of this simulation was symbol type and timing of advisories.

Shadow Simulation II – Color/Mono
Three DFW Controllers simulated eight 30-minute rush periods. Controller positions Feeder East, Feeder West and Runway 17C were staffed. Advisories were presented in both monochrome and color, using open and filled advisory symbols (square for speed and triangle for heading) as well as two advisory presentation durations: 15s, 30s. The primary focus of this simulation was color vs. monochrome presentation of advisories.

Experimental Measures
Four types of dependent measures were collected during the simulations: reaction-time data, aircraft distance from advisory, self-reported workload and subjective ratings data.

Reaction Time Data
The time at which the advisory was displayed was automatically recorded. When the controller noticed the advisory, he was asked to dwell on the advisory symbol and press a key to acknowledge the advisory onset. At this keypress, the reaction time was recorded to determine how the advisory format affects detectability. This reaction time is a combination of the time it takes to perform both the cognitive task of recognizing the advisory and the physical task of the keypress.

Aircraft Distance Data
When the controller issued the advisory, he was asked to dwell on the aircraft symbol and press a second key. At this keypress, the time as well as the aircraft's distance from the advisory symbol were recorded. These data were used to assess the precision with which controllers issued the advisories.

It is anticipated that there will be no additional controller keyboard inputs required for using aFAST, but in order to collect response-time measures to evaluate the impact of increased screen clutter, controllers were asked to make keypress entries that would not be required with an operational system. Also, because the traffic is recorded, the controllers do not have to monitor the traffic as closely as they might for live traffic. The additional workload imposed by the keypresses may serve to bring the controllers' workload up to a more realistic level.

Self-Reported Workload
Following the runs, questionnaires and debriefing interviews were used to assess workload and usability of the advisories [10]. The modified NASA Task Load Index (TLX) [11] was used to measure workload associated with use of aFAST advisories. The modified TLX has been used to assess controller

workload in the development of both the Traffic Management Advisor (TMA) and pFAST.

Subjective Ratings
Usability questionnaires addressed the controllers' ability to detect the advisory symbology and text, the availability of advisory information when it was needed, effectiveness of advisory symbology and ratings of screen clutter. All questionnaire evaluations used an 11-point Likert scale for controller ratings.

Results and Discussion

Shadow simulations were conducted to evaluate use of color, type of symbology and timing of Active FAST heading and speed advisories. For each of these variables, the relevant reaction time data, workload ratings and usability questionnaire results are discussed. One-way analyses of variance (ANOVAs) were used to make statistical comparisons between color and monochrome, open and filled symbols, and the 15s, 30s and 45s display durations. Due to the limited scope of this paper, the comprehensive results from each simulation will be not be covered. Comparisons between symbol type and advisory timing represent data from Shadow Simulation I. The comparisons between color and monochrome represent data from Shadow Simulation II.

Use of Color
Controllers were able to detect color advisories more quickly than monochrome advisories (see Figure 6). Controllers averaged 7.4 with a standard deviation (SD) of 6.4 seconds to acknowledge color advisories compared to 9.4 (SD 7.2) seconds to acknowledge monochrome advisories [$F_{1,493} = 10.3$, $p < .002$].

Controllers rated monochrome advisories as contributing to workload more than color advisories. Differences in ratings of workload between color and monochrome were statistically significant on all five of the modified NASA TLX workload factors (Figure 7): Mental Demand [$F_{1,22} = 20.6$, $p < .002$], Time Pressure [$F_{1,22} = 10.2$, $p < .005$], Overall Effort [$F_{1,22} = 16.7$, $p < .0005$], Frustration [$F_{1,22} = 30.1$, $p < .0001$], Performance Support [$F_{1,22} = 11.0$, $p < .005$]. Means and standard deviations are shown in Table 1.

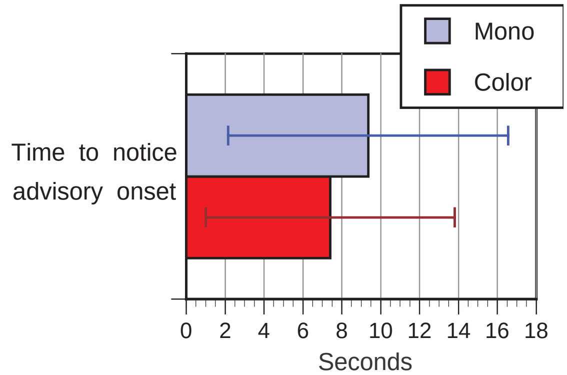

Figure 6. Controllers' reaction to advisory onset

Overall, controller ratings of workload were higher than might be expected from previous modified TLX ratings of pFAST [12]. Controllers explained that this was primarily due to the additional keystrokes required for data collection in the shadow simulations. In interviews, controllers reported that, though they preferred color presentation of advisories, it may still be possible to use monochrome advisories under certain conditions.

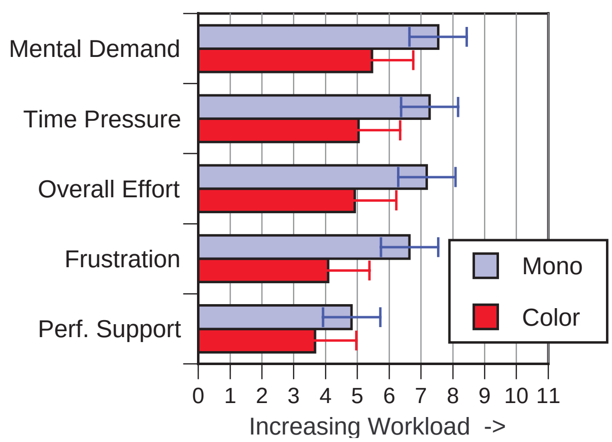

Figure 7. Controller ratings of workload

	Color	Mono
Mental Demand	5.5 (1.5)	7.5 (.5)
Time Pressure	5.0 (1.8)	7.1 (1.2)
Overall Effort	4.9 (1.7)	7.2 (.8)
Frustration	4.1 (1.3)	6.8 (1.1)
Perf. Support	3.7 (.9)	4.8 (.8)

Table 1. Means (SD) for workload ratings

Questionnaire data indicate that the use of color for the advisory symbology and text during the simulation made the advisories easier to detect than in the monochrome format. As shown in Figure 8, color advisory text was more easily distinguished from the data tag than monochrome text: Heading Text [$F_{1, 22} = 154.4$, $p < .0001$], Speed Text [$F_{1, 22} = 247.0$, $p < .0001$]. Color advisory symbols were more easily distinguished from the map background than monochrome symbols: Heading Symbol [$F_{1, 22} = 255.1$, $p < .0001$], Speed Symbol [$F_{1, 22} = 247.0$, $p < .0001$]. Means and standard deviations for these comparisons are shown in Table 2.

Color advisories were rated as contributing less to screen clutter than monochrome advisories [$F_{1, 22} = 4.7$, $p < .05$]. The mean rating for color on an 11-point scale was 4.5 (SD 1.6) and the mean for mono was 3.3 (SD 1.1), where 0 = "Excessive clutter" and 10 = "No perceptible clutter." Controllers preferred the presentation of advisories in color to presentation in monochrome and rated the use of color as, "Very helpful."

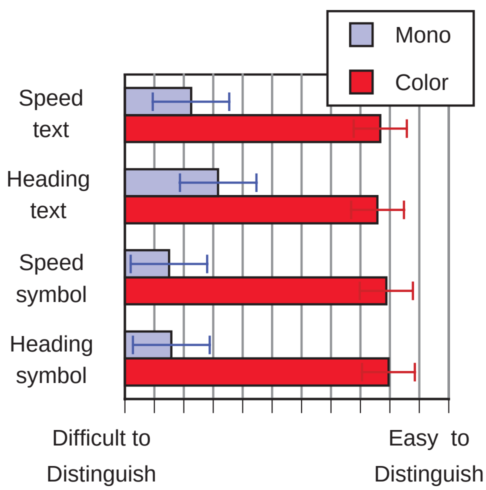

Figure 8. Ratings of advisory distinguishability.

	Color	Mono
Speed Text	8.7 (1.0)	2.3 (1.1)
Heading Text	8.6 (.9)	3.2 (1.2)
Speed Symbol	8.9 (.6)	1.5 (1.5)
Heading Symbol	9.0 (.7)	1.6 (1.4)

Table 2. Means (SD) for distinguishability ratings.

Type of Symbology

Controller acknowledgment of advisories did not differ significantly between the open and filled symbol conditions. Overall there was a trend for quicker response times to filled symbols than open symbols, but these differences were not statistically significant. Controllers also reported higher ratings of workload in the open-symbol condition for all scales of the modified TLX except Performance Support. Differences in ratings of Mental Demand and Frustration were statistically significant. These comparisons are shown in Figure 9: Mental Demand [$F_{1,12} = 15.4$, $p < .002$], Frustration [$F_{1,12} = 11.3$, $p < .006$]. Means and standard deviations for all scales of the modified TLX are shown in Table 3.

Questionnaire data showed that filled symbols were rated as contributing less to screen clutter than open symbols [$F_{1,16} = 12.5$, $p < .005$]. The mean rating for filled symbols on an 11-point scale was 6.3 (SD 2.0) and the mean for open symbols was 3.9 (SD 2.0), where 0 = "Excessive clutter" and 10 = "No perceptible clutter," as shown in Figure 10.

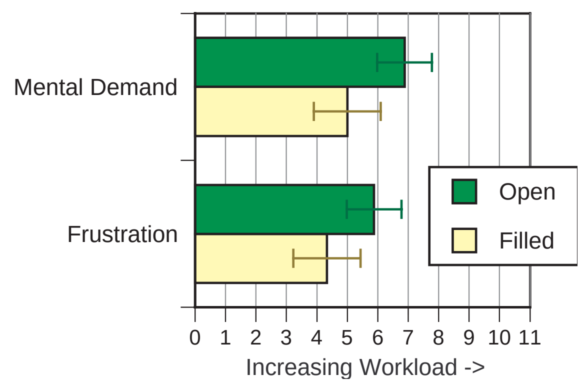

Figure 9. Controller ratings of workload

	Filled	Open
Mental Demand*	5.0 (1.2)	7.1 (.9)
Time Pressure	4.6 (1.4)	5.6 (1.3)
Overall Effort	5.1 (1.7)	6.3 (1.1)
Frustration*	5.8 (1.0)	4.3 (1.0)
Perf. Support	4.5 (1.5)	4.4 (1.7)

*Differences significant at the p < .01 level

Table 3. Means (SD) for workload ratings

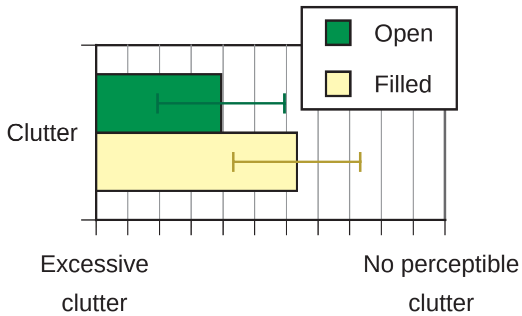

Figure 10. Controller ratings of screen clutter.

Controllers also preferred the filled symbols, indicating that the open symbols tended to blend in with the background videomap. When asked to choose which of the eight symbols used in the simulations they wanted to represent the advisories, the three controllers independently selected the filled triangle to represent headings and the asterisk to represent speeds.

Timing of Advisories

There was a main effect of advisory presentation duration for controller reaction to advisory onset; [$F_{1,344} = 8.9$, $p < .0002$]. The mean reaction times for advisory presentation duration were:15s=7.9 (SD 5.5), 30s=11.3 (SD 9.3), 45s=13.6 (SD 12.8). This showed that controllers took longer to react to advisories when they were presented for a longer duration. This result is expected, because for the longer presentation durations, there is more opportunity for longer reaction times. Also, because more advisories may be on at the same time, it may take the controller longer to react to them.

There were no significant differences in the ratings of workload over the three advisory presentation durations. Advisory presentation duration did not have any significant effect on ratings of Screen Clutter, Availability of Advisory Information, Use of Trajectory Preview Function, or Controllers' Attention to the Traffic.

Controllers rated the advisory presentation durations on an 11-point scale with 0 = "Too long" and 10 = "Too short," and 5 = "Just right." Though the ratings were not statistically different, the 30s and 45s conditions were rated as "Just right" [mean ratings: 5.7 (SD .8) and 5.5 (SD .8) respectively], with the 15s condition tending somewhat toward "Too short" [mean rating: 6.7 (SD 1.9)], as shown in Figure 11. In a separate rating, controllers reported that they preferred the 30-second advisory display condition.

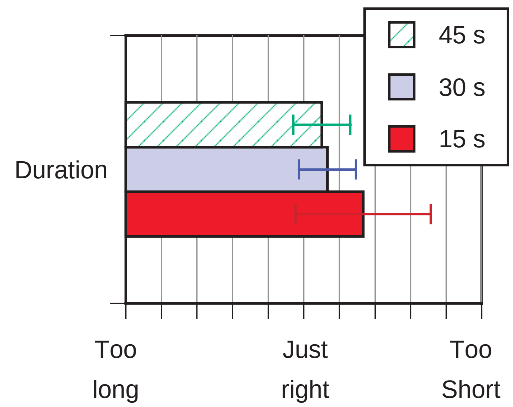

Figure 11. Controller ratings of advisory presentation duration.

Distance from advisory

An important part of the development of the Active FAST algorithm is to understand the precision with which controllers respond to the advisories. The aFAST algorithm must be able to handle a certain amount of variability in both controller and pilot responses. The issues of pilot and controller variability will be investigated more thoroughly in later simulations using algorithm-generated advisories. In the shadow simulations, controllers were asked to make a key entry when they issued each advisory. At this time, the aircraft's distance from the advisory was calculated. This value is an indicator of controller performance but also takes into account controller "comfort zones". For the two simulations, means for aircraft distance from advisory at advisory issue were 0.59 nmi (SD .65) and 0.47 nmi. (SD .40). There were differences between individuals and across controller positions, but no significant patterns emerged from these data.

Conclusions

Feedback from the controllers indicates that the shadow simulation methodology provides a realistic moving traffic display that is effective for evaluating candidate interface designs. The methodology is being used to test other CTAS tools under development, such as Expedite

Departure Path (EDP)[13]. Findings from these studies show that the simulation method and experimental measures collected are helpful in making and documenting design decisions.

Controllers preferred the color presentation of advisories and their reaction time data indicate that they are able to detect the color advisories more quickly than the monochrome advisories. Workload was rated higher in the monochrome condition than in the color condition across all five workload dimensions. Use of color will be a requirement for aFAST and the colors used to represent the advisories will need to be integrated with existing color use schemes for STARS and Color ARTS displays.

Controllers preferred the filled symbols and rated them as easier to detect than open symbols. Trends in the reaction time and workload data also support this. The final design of the screen symbology however, will depend on the symbols used to represent radar targets and other air traffic control data on the STARS and Color ARTS displays.

There were no differences in workload related to advisory display duration. This indicates that the tested range of presentation durations was within the capability of the controllers. Controllers reported that they rarely used the trajectory preview function, which indicates that there was little confusion as to which advisories were associated with each aircraft, even with advisory presentation durations of 45 seconds. Controllers indicated that 30 seconds was the preferred presentation duration and that, depending on traffic, feeder controllers may require a different advisory presentation duration than final controllers.

From the results of these studies, a candidate interface has been finalized for use with algorithm-generated advisories. Advisories will be presented in color, using filled symbols and will be presented for 30 seconds. The final design of the advisory presentation format may be modified for compatibility with FAA hardware. The FAA's long-term platform for TRACON radar displays is the STARS system. DFW TRACON, however, will likely receive Color ARTS displays prior to the STARS upgrade. At present, the color schemes for these two systems are not finalized, but they do differ in several respects, including the colors used to display owned and unowned traffic and the symbols used to represent different categories of radar targets. The aFAST system will be designed for implementation on STARS, but it is likely that the first field evaluation may be at DFW TRACON, so the system must be able to accommodate both platforms. Future controller-in-the-loop simulations at NASA Ames will be conducted using the Sony 2K x 2K monitors that are part of the STARS system.

These findings are based on a limited number of simulations conducted with a small group of controllers from a single facility. As work on aFAST continues, a cadre of controllers from multiple facilities will be formed to participate in the refinement and testing of the algorithms and interface. Though the differences described above may not be representative of the entire controller population, it is important to look at the trends in the data and understand how various design decisions may impact controller acceptability of advisories in terms of self-reported workload and perceptions of clutter.

The current plan for aFAST development is to begin extensive testing of the sequencing and conflict resolution algorithm, which will include closed-loop simulations as well as controller-in-the-loop simulation. Once evaluations of aFAST algorithm-generated advisories are underway, FDB features and advisory timing may be revisited and evaluated in terms of their impact on controller performance. The human factors focus of these later studies will be the evaluation of the accuracy and stability of advisories, the impact of early, late or missed advisories on currently displayed advisories as well as controller situational awareness and failure recovery strategies. As the algorithms are determined to be reliable and the advisories are deemed acceptable to controllers, the research will move to a more operations-focused phase that will include simulations at the FAA Technical Center and an eventual field demonstration. In this final phase, human factors researchers will focus on operational and procedural issues associated with aFAST implementation.

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