CONTROLLER-HUMAN INTERFACE DESIGN FOR THE FINAL APPROACH SPACING TOOL*

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ABSTRACT – The Federal Aviation Administration is developing a set of software tools, known as the Center-TRACON Automation System (CTAS), to assist air traffic controllers in their management and control tasks. CTAS originated at National Aeronautics and Space Administration (NASA) Ames Research Center, where prototypes continue to evolve. In parallel, Massachusetts Institute of Technology/ Lincoln Laboratory (MIT/LL) is refining and testing the software, including the Computer-Human Interface (CHI). This paper focuses on the CHI designed by MIT/LL for the Final Approach Spacing Tool (FAST) part of CTAS. The FAST design approach, CHI development and operational concept is presented.

Keywords: air traffic control; automation; human-centered design; human factors; human-machine interface.

1. INTRODUCTION

FAST comprises new computer automation software designed to assist radar controller teams in efficiently sequencing flight arrivals and precisely spacing aircraft on final approach during busy periods at terminals. Automation advisories generated by FAST are computed with respect to such real-world uncertainties as winds and weather conditions, pilot response times, aircraft performance, navigation accuracy, and communication delays. The FAST advisories include recommended sequence and runway assignment, accompanied by intelligently timed speed reductions and turns to specific vectors. They are displayed to controllers on Full Digital Arts Displays (FDADs). Whether or not the controllers can effectively interact with sophisticated automation aids presented to them on these older-generation, monochrome displays is a key human factors issue.

The FDAD workstations currently employed in terminal radar control rooms limit the Computer-Human Interface (CHI) design options. While some cryptic graphics are displayed on the FDADs (small arcs for vectors and splats for speed reduction points), most of the advisory information has been added as alphanumeric augmentation to the existing data blocks presented near each aircraft's radar symbol. Currently, only critical and timely information is displayed on the data blocks, to aid the controllers in their primary task of maintaining separation. The CHI design challenge was to augment the data block with an operationally suitable presentation of the advisories. Such human factors issues as target recognition, decision making, spatial perception, memory, use of cognitive maps, and minimal procedure modifications were considered in designing the output and associated inputs for the FDAD implementation of this interactive tool.

1.1 FAST CHI Output

The system used in Terminal Radar Approach Control rooms (TRACONs) today, known as Automated Radar Terminal System (ARTS), displays full data blocks comprised of five data fields presented on three lines. In consecutive order, these fields contain the conflict alert and/or low altitude alert indicator (usually not visible), the aircraft identifier, the Mode C altitude or runway number, status information (an asterisk indicates controller entry in Mode C field, which timeshares with the Mode C readout), and ground speed or the aircraft type and the aircraft's weight class indicator (e.g., H for Heavy). Our design proposal is to present FAST data on an additional fourth line comprised of three more fields, as depicted in Figure 1. We refer to this technique as data block augmentation.

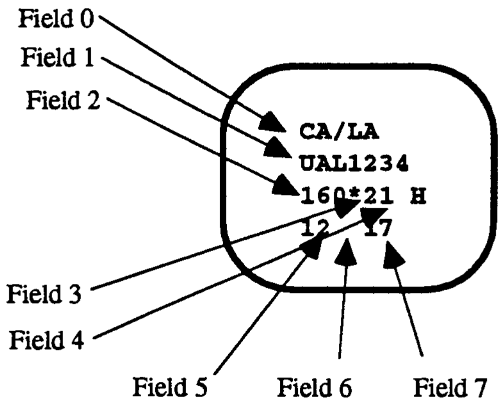
In the FAST CHI design, the added fields are sized and reserved for mutually exclusive advice (see Table 1). Certain advisories are mutually exclusive, that is, they do not time share with any other advisories. Rather, they exclude the display of each other as well as other possible advisories for a given field. This is important for precluding a cluttered look as data blocks typically surround one another on a busy radar screen and can overlap.

For example, the following advisories are mutually exclusive:

• Sequence number and resequence number, since the former is absolute and the latter is a relative number that is displayed briefly while the logic works on the request to change sequence.

• Controller discretion and the speed or heading number, since controller discretion logic inhibits generation of speed and turn advisories.

• Early/late indication, delay indication, and advice non-computable indication, since early/late is measured against the nominal route, delay is measured against the slowest route given the slowest time, and FAST is unable to compute advice when a trajectory error has been returned from CTAS.



Contents of fields (ARTS uses 0 through 4, FAST uses 5 through 7):

Field 0 - Conflict Alert, Low Altitude Alert

Field 1 - Aircraft Identifier (ACID)

Field 2 - Mode C Altitude/Scratchpad timeshared

Field 3 - Status

Field 4 - Ground Speed in knots and Heavy Indicator (if applicable)/Aircraft Type timeshared

Field 5 - Sequence Number/FAST Runway Indication possibly timeshared or Resequence Number or Missed Approach Advisory

Field 6 - Blank space

Field 7 - Non-Computable Indicator or Priority Aircraft Advisory or Controller Discretion Symbol or Delay Indicator or Speed Advisory Number/STAR Turn Advisory Number possibly timeshared

Figure 1. Existing ARTS data block augmented with FAST advisories.

Judicious use of time sharing succinct bits of information is also used for displaying some of the FAST augmentation to the data block. Controllers have become accustomed to viewing information that is continuously updated but abbreviated in both presentation and length of time interval. In the existing ARTS, three of the full data block fields are capable of time sharing displayed information. These fields can time share independent of one another. The unit time is 1/2 second. The number of 1/2 second intervals for the duration of each field is controllable via software. ARTS time shares fields 2 and 4 in the third line of the data block while FAST will time share augmentation fields 5 and 7 in the fourth line. FAST displays advisories at the same rate as the vertically aligned ARTS data, although different rates are technically possible.

If some advisories are not available at a given time, then the corresponding reserved data fields will remain blank. This is consistent with display of the ARTS' fields directly above, where information is presented in reserved spaces. Representative samples of augmented data blocks are presented in Figure 2.

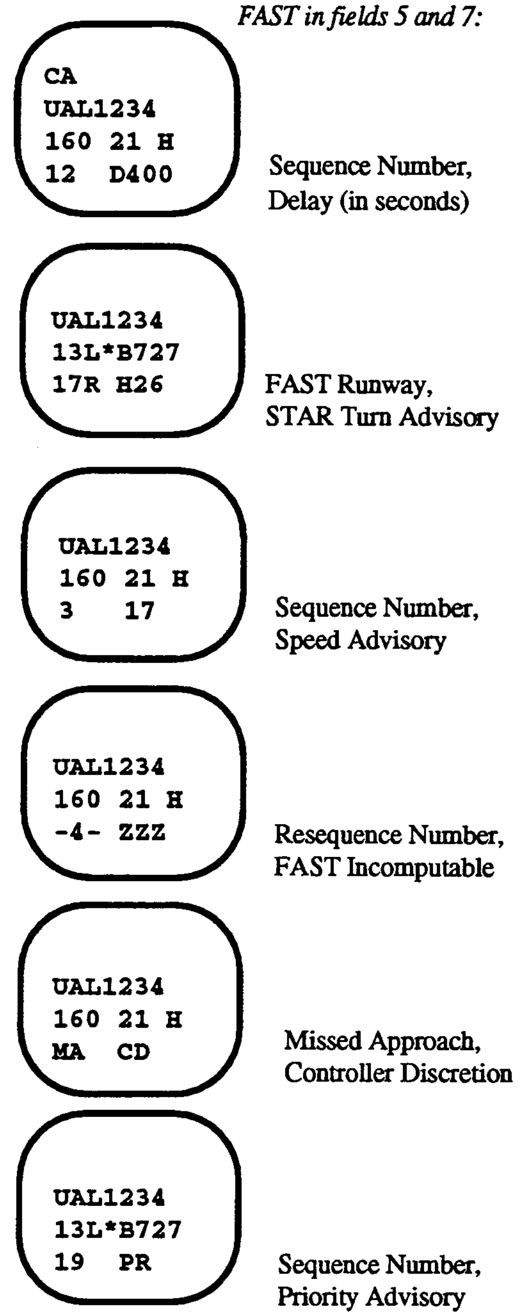


Figure 2. Sampler of FAST data block fields with advisories.

Table 1 ARTS data block augmentation fields of FAST advisories

Field #	# of Characters	Sample Content	Meaning
5	3	-4-	Resequence Number or
		2	Sequence Number or
		MA	Missed Approach Advisory
		13L	*possibly time shares with*
			FAST Runway Indication
6	1	*blank space*	none
7	6	ZZZ	FAST advice incomputable or
		CD	Controller Discretion or
		D400	Delay (in seconds) or
		PR	Priority Aircraft Advisory
		17	Speed Advisory Number
			time shares with
		H26	STAR Turn Advisory Number

CLEAR	**BACK SPACE**								**ENTER**
TRK START	**TRK REPOS**	**TRK SUSP**	**TRK DROP**	**HND OFF**	**FLT DATA**	**MULTI FUNC**	**F8**	**Δ**	**.**
F9	**F10**	**F11**	**F12**	**F13**	**F14**	**F15**	**F16**	**IFR +**	**VFR /**
A	**BCN B**	**CFG C**	**DIS D**	**EMG E**	**FIL F**	**G**	**1**	**2**	**3**
H	**I**	**J**	**K**	**LDR L**	**MOD M**	**N**	**4**	**5**	**6**
OFF O	**PRE P**	**Q**	**R**	**SYS S**	**TAB T**	**U**	**7**	**8**	**9**
V	**W**	**X**	**Y**	**Z**	*****	**∀**	**◊**	**0**	**□**

Figure 3. ARTSIII Keyboard Layout Diagram

1.2 FAST CHI Input

As discussed above, the amount of output from FAST onto the FDAD – already crowded with such critical information as radar targets, data blocks, range rings, weather areas, satellite airport symbols, and tabular lists – was intentionally kept clear and concise. The same guiding principal holds for the additional input needed to support controllers' communications with FAST. Although the human factors design goal was to build a system as transparent as possible to the user, some essential FAST-specific keyboard entries were necessarily added as part of the CHI. In keeping with the development approach of introducing automation that is unobtrusive and easy to use, we determined that the existing ARTS keyboard (see Figure 3) and trackball be used for FAST input, which is consistent with our recommendation of augmenting the existing display for FAST output. The CHI design for FAST related input/output, therefore, should result in minimal impact or change to the controller's current operational concept.

Specifically, a currently unused function key (F12), and some unused shape keys (inverted triangle, square), were chosen to initiate the FAST inputs and differentiate them from the existing ARTS inputs. Within ARTS, certain keys have over the years been patched into the software to abbreviate frequently used functions. (Some of these are actually labelled on the keys and the same could be done for FAST inputs once acceptance is determined). For FAST inputs the number of keystrokes was kept down to one or two wherever technically feasible, with the exception of turning the transmission of ARTS data to FAST on and off since inadvertent activation is not desirable. Each input is echoed (i.e.,0 printed out verbatim as it is typed) in the ARTS preview area, already established for the purpose of echoing ARTS related inputs. The limited set of editing features in ARTS (clear, backspace) work consistently with FAST inputs. A separate small area called the FAST information list (FIL) is displayed to indicate the status of FAST (a simple rotating arrow reflects the system is alive), provide feedback for FAST-specific inputs and relate system messages.

The ENTER key on the ARTS keyboard has the same effect as using the ENTER key attached to the trackball (which is mounted near the keyboard on the FDAD console's shelf). As with the existing ARTS, either method may be used for most inputs. Table 2 presents the FAST-specific inputs currently supported by the software. The abbreviation "slew" refers to the action of moving the cursor (with the trackball) to cover the control position symbol of the desired data block or to pinpoint a spatial location on the FDAD. The acronym "ACID" is used to indicate the aircraft identification number may be keyed in. Where two input methods are listed for a given function, as in the ARTS either method will work. The FAST-specific output resulting from these inputs can be "quick looked" which is an ARTS feature that allows a neighboring controller in the same facility to temporarily view data blocks under the control of other radar positions. These outputs that are supported by the quick look feature are marked with an asterisk in Table 2.

1.3 Progression of CHI design and development

The CHI for FAST, indeed for all of CTAS, is being designed and developed in an iterative fashion with respect to the overall project philosophy of "human-centered" automation. Many different controllers from each major region in the United States, as well as some from other nations, have been exposed to FAST on the monochrome FDADs (and on color SUN workstations that will not be delivered into the field). The FAA has supported this design effort by providing System Development Teams (SDTs) who tested the early prototypes in the laboratories at MIT/LL and NASA Ames (Davis, et al., 1990). Additional controllers continue to experiment with FAST in a non-operational mode at the field development sites of Denver and Dallas/Fort Worth (DFW) where Cadres of their peers are trained to teach them the tool. Currently, a FAST Assessment Team is conducting a final review of "passive" FAST, i.e., sequence numbers and runway assignments. Formal training of all controllers at DFW will follow.

Close contact with the users of this product has allowed us to propose a design that was conceived and tested with human factors in mind. The first test of FAST on FDADs was conducted by MIT/LL using static symbology as part of a risk reduction series geared toward discovering if the tool could successfully migrate from a laboratory platform to a display used in the "real-world" of ATC. Up to this point, the SDT had seen FAST only on smaller color raster displays. Results from this risk reduction test, done at the FAA Technical Center (FAATC) confirmed that the CHI of the FAST data block augmentation was readily acceptable to the SDT (Picardi, 1992). Responses revealed strong agreement that the added FAST symbology does indeed appear distinct from the existing ARTS and videomap symbology. Therefore, confidence was gained that the passive advisories are being presented in an operationally suitable manner.

For further investigation of the CHI and other engineering aspects, increased simulation fidelity was needed. Therefore, a FAST System Test Environment was conceived and built by MIT/LL (Spencer, 1993). We used the FSTE to conduct a shake-down test of FAST with dynamic simulations using realistically heavy traffic scenarios and highly experienced full performance level controllers from Level V (the busiest) facilities The results from this dynamic real-time simulation where consistent with the SDTs initial favorable reaction to the FAST CHI. Based on the increased information displayed for FAST outputs, and timeliness required for FAST inputs, the controllers suggested limiting the number of advisories able to be quick looked and abbreviating the longer keystrokes (e.g., resequence). A copy of the FSTE was then delivered to NASA Ames to support their continued use of real-time simulations with the SDT (Picardi, 1992), and to FAATC where functionality demonstrations are conducted before each incremental field deployment to the development sites.

One key finding during tests conducted on the FDADs has been that the active advisories, which included the display of turn arcs and speed splats, are not as discernable to the SDT and they have commented on their perception of screen clutter, with suggestions for alleviating it. Based on the SDTs suggestion resulting from the potential for confusing the turn advisory with other ARTS symbology, the vector number presented adjacent to the detached arc was removed and placed only in the data block.

Table 2 FAST-specific inputs supported on the FDAD keyboard

Entry Format	Function
F12, ON, Enter	This enables transmission of ARTS data to FAST.
F12, OFF, Enter	This disables transmission of ARTS data to FAST.
F12, E, Enter	This enables the display of FAST advisories at all positions. The FIL rotating indicator is shown when advisories are enabled.
F12, I, Enter	This disables the display of FAST advisories at all positions, but ARTS data is sent to FAST. The FIL rotating indicator is not displayed.
F12, O, Enter	This toggles FAST advisories on/off at the entering position. When FAST advisories are off, the letter O appears in the FIL as a status indicator. The FIL rotating indicator is not affected by this entry.
F12, ⊟, Enter	This toggles turn and speed advisories on/off at the entering position. Other FAST advisories/displays are not affected. When turn and speed advisories are off, the character ⊟ appears in the FIL as a status indicator.
F12, X, ACID, Enter (or Slew)	This toggles scheduling status of specified aircraft between suspended and scheduled. These changes in scheduling status must be acknowledged at the traffic management display. When an aircraft is suspended from the schedule, the indicator X replaces the sequence number in the data block.*
F12, F, Enter	This clears the FIL display of any error messages or resequence messages.
F12, F, Slew	This relocates the FAST Information List.
F12, Δ, ACID, Enter (or Slew)	This toggles the priority scheduling status of the aircraft. When an aircraft is being given priority scheduling, the indicator PR appears in its data block augmentation.*
F12, •, ACID, Enter (or Slew)	This designates the flight as a missed approach to FAST. The indicator MA will appear in the data block augmentation, replacing the landing sequence number. FAST may display MA automatically as well.*
F12, A, ACID, Enter (or Slew)	This causes FAST to schedule a missed approach aircraft.
Rwy, Slew	This assigns a landing runway to the aircraft. The ARTS initially assigns a default landing runway to DFW arrivals based upon the entry fix, and displays this runway in the scratchpad area of the data block. If FAST agrees with this runway assignment, it will not issue any runway advisory. If FAST recommends a different runway, it will display a runway advisory in the data block augmentation. The controller only needs to make this keyboard entry if the default runway assigned by ARTS is unsatisfactory, or if FAST advises a different runway and a choice must be made. FAST will accept any runway assigned by the controller. Rwy is a single keystroke. For DFW arrivals the keys are as follows: + for **13R**, / for **31R**, • for **17R/35L**, Δ for **18L/36R**, ◊ for **17L/35R**, ∇ for **18R/36L***.
F12, 5, ACID, Enter (or Slew)	The identified aircraft is given the landing sequence number 1, and all subsequent aircraft assigned to the same runway are renumbered accordingly.
F12, 5, Rwy, Enter	All aircraft assigned to the indicated runway have their landing sequence renumbered starting with 1. Rwy is a single key as for the runway assignment entry.
F12, R, ACID, Enter (or Slew)	This resequences aircraft. The aircraft are entered in the order of their new sequence. The first aircraft entered retains its current landing sequence number, and the other aircraft are sequenced behind it in the order they are entered. All entered aircraft must be assigned to the same runway. An aircraft can be removed from the sequence by entering it again, even though other aircraft have been entered in the meantime. While the aircraft are being resequenced, their sequence number is replaced by their relative sequence number in the format -n-. To facilitate the multiple entries, the ARTS multiple entry feature may be used by prefixing the first F12-R with M. This eliminates the need to enter F12 for subsequent entries, but the R must still be entered.

Currently, detached arcs are presented a short distance in front of the associated data block along the predicted flight path for the aircraft that will be issued a turn advisory. In laboratory testing on the development color workstations, both the arc and the data block are briefly painted in a unique distinct color to indicate their relationship. We suspect the lack of color to associate these detached advisories with their respective data blocks nearby on the monochrome FDAD and/or simply to call attention to them, i.e., situational awareness, is being reflected in the controllers' reaction.

A movement is underway in the FAA, known as the Stand Alone Replacement System (STARS), to deploy color consoles into TRACONs which may address one issue of acceptability when using active FAST advisories. We will examine the CHI design issues such as this one as the product continues to be re-engineered in preparation for eventual field deployment. MIT/LL recently began the process of Development Test and Evaluation (DT&E) on the re-engineered software for the Demonstration and Validation (D&V) phase of the project, during which the CHI of FAST and other parts of CTAS will eventually be formally verified. Meanwhile CHI design and requirements specification is undergoing final analysis and documentation by a team of researchers and users.

2. CONCLUSION

FAST, including the CHI described here, has been tested extensively by controller teams in laboratories at MIT/LL and NASA Ames and is currently being evaluated for use by controllers in Dallas/Fort Worth and Denver terminals. Technically, FAST data presentation and interaction has been shown not to interfere with the presentation or operation of the primary system, ARTS, as demonstrated at the FAA Technical Center (FAATC) during "noninterference" tests. Important human factors issues regarding the FAST CHI, such as workload, distribution of automation access between controller teams and traffic management coordinators, and maintenance of situational awareness, remain to be fully determined and addressed when the software is deployed for ATC operations. In the future, the potential use of data link between the pilot in the cockpit and the radar controller in the TRACON with respect to ATC automation will be an interesting challenge to consider. For now, early research and development experience accompanied by simulation testing results has indicated that the CHI successfully communicates the FAST concept to the user community and that, in turn, the concept appears a viable one for automating a carefully chosen portion of the air traffic control task.

In summary, the FAST CHI design retains consistency in appearance and behavior of data block items, while minimizing clutter and distraction. To enhance usability, spatial cues are provided for advisory placement on a single added line in the data block. Data presentation is abbreviated and presented to the controller only when timely. Controller input back to FAST was also designed to be minimal and consistent with their existing ARTS keyboard and trackball method. Progressively more robust testing with FAA-supplied controller teams has consistently shown that the CHI design for at least the first increment of this new automation (known as passive FAST) will be acceptable for operational use by air traffic controllers at the major TRACON facilities throughout the United States.

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