NASA Ames Research Center

Contract Task Order – 59

Spacing Tool

Computer-Human Interface (CHI) Specification for Spacing Tool at the R-Position

Final Report

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INTRODUCTION

The purpose of this paper is to describe the Computer Human Interface (CHI) development work performed on the Spacing Tool as a part of NASA AATT Research Task Order 59. The Spacing Tool is an Air Traffic Management (ATM) Decision Support Tool (DST) designed for the en route R-side controller position. The Spacing Tool, proposed for Free Flight Phase 2, is designed to reduce user deviations in the presence of miles-in-trail (MIT) flow restrictions while maintaining separation. It is designed to assist controllers in managing MIT restrictions and enables "virtual" spacing without forcing controllers to place en route flights "in trail".

This paper describes the design of the Spacing Tool CHI, including the approach taken to design the CHI for implementation on the FAA's Display System Replacement (DSR). Descriptions of the different components of the Spacing Tool (Spacing List, trial planning functions and Range Data Blocks (RDB)) are included in the report. A Conflict List CHI, designed to support the Spacing Tool, is also presented. In addition, the paper includes descriptions of the Visual Basic (VB) demonstrations that are being delivered as a part of Research Task Order 59. The demonstrations include one dynamic, interactive demonstration where the trial planning concepts are demonstrated, one static demonstration that serves as walk-through of the Spacing Tool on the DSR Situation Display, and static, walk-through demonstrations of both the Conflict List CHI that was designed as a part of this task, and the Spacing List CHI. Issues and options associated with the operational implementation of Spacing Tool on the DSR are also included.

The R-position Spacing Tool CHI was designed to be consistent with currently fielded DSR capabilities and conventions (DSR release BBC10 – Flight Plan Readout View, Continuous Range readout function) as well as consistent with capabilities and conventions that have been engineered and are being introduced in the next three years into the DSR R-position. These capabilities that are being scheduled to be fielded in the next three years include textual and graphic annotations (fall/2001), 4th line of the FDB capabilities (fall/2002-currently being developed), interactive data block capabilities (fall/2002- CHI design complete and B—spec requirements being written) and data link capabilities for Controller Pilot Data Link Communications (CPDLC) Build 1A including line 0 of the FDB (fall/2003 - CHI design complete and B-spec requirements being written).

The CHI designed for the integration of the Spacing Tool into DSR contains the following elements: a Spacing List, Range Data Blocks (RDBs), a speed trial planning capability and a graphic trial planning capability. The Spacing List is a window on the DSR display that contains the aircraft identification, the projected spacing distance of the aircraft, and Spacing restriction information. RDBs are a separate data block located near the aircraft track symbol on the Situation Display that contain spacing distance information for that aircraft. Both speed and graphic trial planning capabilities can be accessed from the Spacing List and the RDBs. Each of these elements is described in more detail within this paper.

Since both the Spacing List and RDBs contain spacing distance and can be used to access trial planning tools, users have the option to run the Spacing Tool via the Spacing List, the RDBs or both the Spacing List and the RDBs simultaneously. The Spacing List contains more information than the RDBs, combines information at one location on the Situation Display, and contains secondary functions that cannot be accessed via the RDBs, yet are easily accessible through the Spacing List. The Spacing List, however, takes up additional space on the Situation Display while the RDBs were designed so that the Spacing Tool data and primary functions could be viewed, accessed, and incorporated into the controller's scans while taking up a minimal amount of space on the Situation Display. This multiple display-option design enhances the flexibility and options for how the DST capability is used.

The RDB option for displaying Spacing Tool information was chosen for three main reasons. First, the Full Data Blocks (FDB) on the situation display currently have a great deal of functionality tied to them, with new functionality already assigned in future releases of DSR. To add the Spacing Tool data and functionality would have made it more difficult for the controllers to decipher information contained in the FDBs. The use of RDBs simplifies the design. A second reason the RDB option was chosen was to isolate the Spacing Tool functionality from the multitude of functions in the FDB. The third reason the RDB was selected is because the RDB is already present as a part of the Continuous Range Readout (CRR) function in DSR. Using the RDB is a logical extension and serves as an upgrade to the CRR function.

NASA's concept of operations is for the Spacing Tool is to be used strategically. The paper, "En Route Descent Advisor (EDA) Concept", by Steve Green and Robert Vivona[1] discusses the strategic use of the Spacing Tool. However, a tactical approach is a reasonable first step in implementation of the Spacing Tool and does not preclude the use of the Spacing Tool as more of a strategic tool. This paper presents both options. The Spacing Tool VB prototype depicts a more tactical approach while more strategic CHI design options are provided in Appendix C.

DIFFERENT TYPES OF SPACING TOOL DATA

There are three different types of Spacing Tool MIT data discussed in this paper. The first is considered current state data. This data reflects an aircraft's current MIT data at the moment when the system refreshes and calculates spacing distance information. The second type of MIT data is trial plan data. A trial plan is only seen by the controller and represents a hypothetical, "what if" situation, that is, for example, what would happen if the controller reduced an aircraft's speed? What effect would reducing the speed have on the MIT data? Trial plan data represents the MIT that would be achieved if the trial plan were implemented. Trial planning methods are described later in this paper. If the controller implements the trial plan, that is, instructs the pilot to follow what was trial planned, then the aircraft will be on an active plan while the aircraft is transitioning. Active plan data therefore represents predicted end-state information.

For example, an aircraft flying at 350 knots is 7 miles behind another aircraft, but needs to be 10 miles behind. The controller trial plans a reduction in the aircraft's speed, to 300 knots, which results in a trial plan spacing distance of 10 miles. At this point, the aircraft's current state is 7 miles, while the trial plan value is 10 miles. There is no "active" plan yet. When the controller implements the plan, the pilot begins to reduce speed. As the aircraft slows and the data is read and displayed by the system, the aircraft's current state may be 325 knots and 8.5 miles, but the active plan value is 300 knots and 10 miles. There is no trial plan on the aircraft at this point.

Active plan information is not shown in this CHI but would be used by the Spacing Tool to calculate additional trial plans. Active plan data also forms the basis for conflict probe, a feature that would be integrated with the Spacing Tool. The data displayed in the Spacing List is either current state data, or trial planning data (the later is displayed in parentheses). Options displaying active data in the Spacing Tool CHI are depicted in Appendix C.

SPACING LIST VIEW (DSR R-Position Design)

The DSR Spacing List consists of a view header and a view body. The view expands/contracts as entries are added to the list or deleted from the list. The function of the Spacing List is to display each aircraft's predicted spacing distance and estimated time of arrival at or abeam the Miles-in-Trail reference, which can be a point, arc or boundary, when the first aircraft in the Spacing List is at or abeam the reference. The Spacing List can also be used to access both

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[1] Green, S.M., and Vivona, R., "En route Descent Advisor EDA Concept," Advanced Air Transportation Technologies Project Milestone 5.10 Report, September 1999, M/S 262-4, NASA Ames Research Center, Moffett Field, CA, U.S.A., 94035.

graphic and speed trial planning functions, as well as to control the color of the RDBs and the reference label. Figure 1: Spacing List identifies some of the data contained in the Spacing List.

Miles-in-Trail reference label   Miles-in-Trail restriction distance

Figure 1: Spacing List

Aircraft Identification
(ACID)   Spacing distance   Estimated time of arrival
                                    at or abeam MIT reference
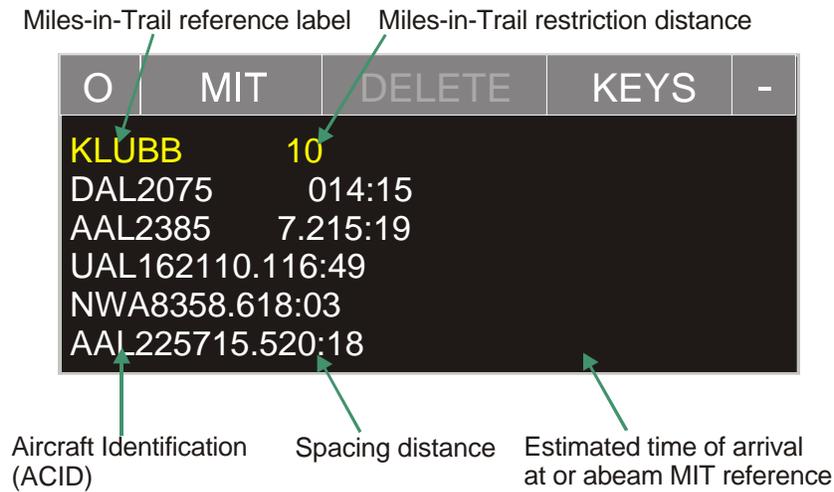
Spacing List View Header

The view header contains:

1. A toggle button to set the view to opaque or semi-transparent. The button is labeled "O" when the view is set to opaque and "T" when the view is set to semi-transparent. The view header is gray shaded when the view is set to opaque and has a black background when the view is set to semi-transparent. This feature is demonstrated in the Static Spacing Tool Demonstration, but not the Dynamic Spacing Tool Demonstration.
2. A view title button, "MIT" that allows the user to move the Spacing List window when MIT is selected.
3. A DELETE button to delete a user selected aircraft from the spacing list.
4. A KEYS button to toggle the display of a row of secondary function buttons on a line below the view header.
5. A view suppression button ("-").

Spacing List View Body

The row of secondary buttons (controlled by the KEYS button) that is displayed below the view header contains (see Figure 2: Spacing List – KEYS):

1. A button that enables the user to toggle between three different spacing distance display alternatives: REL for relative spacing between aircraft, TOTAL for the total spacing distance between an aircraft and the lead flight, and DELTA which indicates the difference between the current spacing distance and the spacing distance required.
2. A TIME button that enables the user to toggle the estimated time of arrival for each aircraft at the reference on and off for all aircraft or for each individual aircraft.
3. A LIST button that toggles the display of the reference headers and aircraft, spacing data and time. When the list is suppressed, only the view header and the restriction reference labels (reference and distance restriction) are displayed. When the list is displayed, each aircraft and its respective spacing distance and time (if time is on) are displayed.
4. A COLOR button that controls the display of the color palette. The color palette enables the user to assign a different color to the RDBs and the reference restriction. This allows the
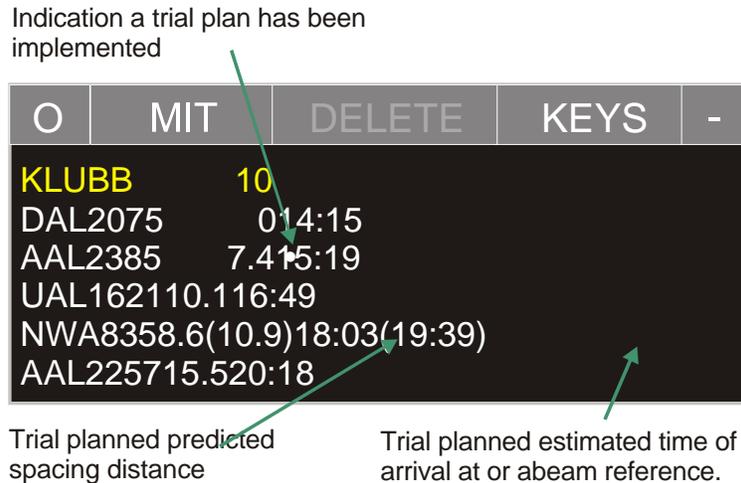
user to differentiate between separate spacing streams. In an implemented system, the brightness of the RDBs and the reference label will also be controlled through the COLOR button. When the Color pick areas are not displayed, the view contracts to save space.

Figure 2: Spacing List - KEYS

The view body below the secondary button row contains:

1. Reference label and the miles restriction imposed to the reference (e.g. KLUBB 10. See Figure 1: Spacing List)
2. Aircraft identification, current spacing distance, and when applicable, trial planning distance and time. (See Figure 1: Spacing List)
3. When TIME is on, the estimated time of arrival for the aircraft at the reference. (See Figure 1: Spacing List)
4. When the color palette has been selected (COLOR), the color brightness control (BCG) pick area appears. This area allows the controller to select one of four colors: white, green, pink, or yellow to assign to a reference and the RDBs or aircraft assigned a restriction to the reference. In the implemented system, the controller would be able to independently control the brightness of each of the four colors used for the spacing tool.
5. When a trial plan is being conducted, the trial plan spacing distance is shown in parentheses to the right of the current spacing distance reflecting the predicted end-state spacing distance if the trial plan were implemented (See Figure 3: Spacing List Trial Planning).
6. When a trial plan is being conducted and time is on, the estimated time of arrival for the aircraft at or abeam the reference if the trial plan were to be implemented is depicted to the right of the current estimated time in parentheses (See Figure 3: Spacing List Trial Planning).
7. After a trial plan is implemented, a check mark appears to the right of the spacing distance to indicate the aircraft has had a trial plan implemented. The check mark remains until the controller manually removes it, or it is automatically removed when the aircraft reaches the restriction distance imposed (See Figure 3: Spacing List Trial Planning).

Indication a trial plan has been
implemented

| O | MIT | DELETE | KEYS | - |

KLUBB   10
DAL2075   014:15
AAL2385   7.415:19
UAL162110.116:49
NWA8358.6(10.9)18:03(19:39)
AAL225715.520:18

Trial planned predicted
spacing distance

Trial planned estimated time of
arrival at or abeam reference.

Figure 3: Spacing List Trial Planning

Spacing List Posting Rules

Flights are assigned to restricted streams by the traffic management controller (TMC).

Spacing List Deletion Rules

Flights will be deleted from the Spacing List View when the flight has passed the reference, or the controller manually deletes a flight from the list.

Spacing List Sort Order

Flights are displayed with the aircraft closest to the reference at the top of the list.

Spacing List – View Manipulation Functions:

The following is a description of how the Spacing List view can be manipulated. Refer to Figure 2: Spacing List – KEYS for the location of the buttons referred to in the following description. Appendix B contains a tutorial of the different buttons and their respective functions

1. The controller can move the view by picking the view title (MIT). The controller can drag the Spacing List to any position on the situation display screen.
2. The controller can set the view to opaque or semi-transparent.
3. The controller can delete an entry by selecting the aircraft identification field (left-click with mouse) and selecting DELETE (left- or right-click with mouse) [2]
4. The controller can toggle the display of keys (left- or right-click on KEYS)
5. The controller can toggle between three different spacing distance display alternatives: REL for relative, TOTAL for total, and DELTA for the difference between what is required and what the current predictions state.
6. The controller can toggle the estimated time of arrival at the reference on and off for all aircraft by toggling the TIME button, or, the controller can turn time on and off for individual aircraft by first selecting the aircraft identification, then selecting the TIME button.

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[2] In the prototype demonstrations, a mouse is used to select objects. In a DSR implementation of the Spacing Tool, a trackball would be used. The left-click and right-clicks of a mouse in the prototype demonstrations would be a trackball left-click and a center-click respectively in the DSR.

7. The controller can toggle between the display of the entire Spacing List, which includes reference labels, restriction distances, the aircraft identification and applicable spacing distance (distance, trial planning information and time), and just the reference header which contains the reference label to which the restriction is imposed, and the miles-in-trail distance requirement.
8. The controller can change the color of the reference header and RDB in the prototype. In a deployed system, brightness of the reference header and the RDBs would be controllable.

Spacing List Interactions

In order to access speed and graphic trial planning functions, as well as the delete feature, the controller must pick fields in the Spacing List view body. Table 1: Spacing List Interactions outlines the results of right- or left-clicking each of the pickable fields in the Spacing List view body.

Field	Left-click	Right-click
ACID	Selects aircraft for further action (deletion or to turn time on/off).	N/A
Spacing Distance	Open speed trial planning	Open graphic trial planning
Estimated time of arrival	N/A	N/A

Table 1 Spacing List Interactions

RANGE DATA BLOCKS (RDBs)

The purpose of the DSR Range Data Blocks is to display spacing data information and provide access to the speed and graphic trial planning functions. The standard RDB consists only of the spacing distance. The spacing distance is located on the first line of the RDB. Additional information may be depicted in RDBs as shown in Figure 4: Range Data Blocks.
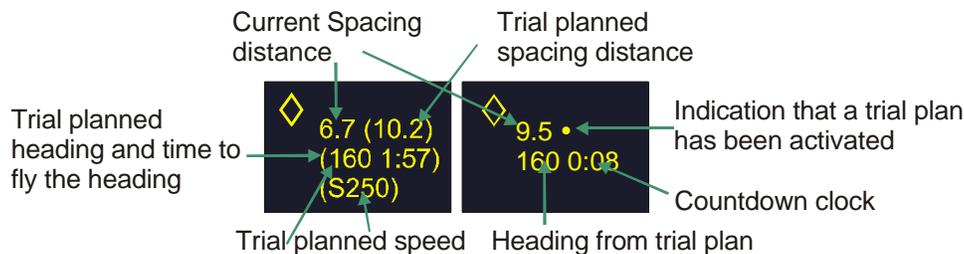
Figure 4: Range Data Blocks

When trial planning takes place, the RDB expands to incorporate trial planning information. This information will include the trial planning spacing distance. This trial planning spacing distance would be listed in parentheses to the right of the original spacing distance, depicted just like it would be in the Spacing List for consistency.

The second line would contain either the speed trial planning value preceded by an "S" (or "M" for Mach speed), or graphic trial planning information containing the heading the aircraft would need to fly to make the trial planned spacing distance reality, and the time the aircraft would have to fly that heading. If both a graphic trial plan and speed trial plan were being conducted

simultaneously, the graphic trial planning data would be in the second line and the speed data would be in the third line of the RDB.

After trial planning has taken place, the RDB will still contain the current spacing distance, which should change as the aircraft's route of flight or speed changes, and a check mark will appear to represent that a trial plan has been implemented. If a graphic trial plan was implemented, then the RDB would also contain the heading the aircraft should be flying along with a countdown clock which depicts how long the aircraft should fly that heading.

RDB Interactions

In order to access speed and graphic trial planning functions, the controller is able to pick fields in the RDB. Table 2: RDB Interactions outlines the results of right- or left-clicking each of the pickable fields in the RDB.

Field	Left-click	Right-click
Spacing Distance	Open speed trial planning	Open graphic trial planning
Trial planning data (in parentheses)	Implement trial plan	Implement trial plan
Check mark	Remove check mark	Remove check mark
Countdown clock (at 0:00)	Remove countdown clock and heading	Remove countdown clock and heading

Table 2: RDB Interactions

CONFLICT LIST (Spacing Tool Recommended Design)[3]

The Conflict List that was designed for integration into the Spacing Tool is designed to help controllers issue fewer, more efficient clearances, significantly reducing the rate of conflict-probe false alarms and missed alerts. The Spacing Tool Conflict List depicts aircraft pairs that are predicted to be in conflict with one another, the minutes to the closest point of conflict (MIN), along with the minimum amount of separation at the closest point of conflict in terms of both flight level (FL) and nautical miles (NM). Additional information depicted through symbology in the conflict list includes indications of aircraft that are subject to a Miles-in-Trail restriction, whether aircraft are under another sector's control, and indications of whether an aircraft is climbing, descending, or level. The Spacing Tool's Conflict List consists of a view header and a view body. The view expands/contracts as entries are added to the list or suppressed from the list. Figure 5: Conflict List, identifies some of the data contained in the Spacing Tool's Conflict List.

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[3] The Spacing Tool Conflict List is not intended to be another display of the Conflict Probe List separate from the CTAS D-2 conflict list. It was designed to meet the needs of the Spacing Tool CHI. The issue of different Conflict List designs is further discussed in the Open Issues section.

Figure 5: Conflict List

Conflict List View Header

The view header contains:

1. A toggle button to set the view to opaque or semi-transparent. The button is labeled "O" when the view is set to opaque and "T" when the view is set to semi-transparent. The view header is gray shaded when the view is set to opaque and has a black background when the view is set to semitransparent.
2. A view title button, "CP" that allows the user to move the Conflict List window when CP is selected.
3. A suppress button, SUP that enables a selected aircraft to be suppressed from the display. It is only active once an aircraft pair is selected. This button becomes the DISP, for display, when the display all pairs button, DISP ALL PAIRS, is selected.
4. A DISP ALL PAIRS (display all pairs) button that is selected when the user wants to see all aircraft pairs, suppressed and non-suppressed.
5. A KEYS button to toggle the display of a row of secondary function buttons on a line below the view header.
6. A view suppression button ("-").

Conflict List View Body

The row of secondary buttons (controlled by the KEYS button) that is displayed below the view header contains:

1. A button that enables the user to toggle between displaying all conflict pairs and only those pairs of aircraft in conflict that have at least one aircraft subject to the spacing restriction.
2. A LBL (label) button that enables the user to toggle the labels, MIN, FL and NM on and off.
3. A FL/NM button that toggles on/off the FL (flight level) and NM (nautical miles) separation data.

The view body below the secondary button row contains:

1. Aircraft conflict pair data – aircraft identification for the two aircraft in conflict with each other.
2. A diamond symbol for each aircraft that is not under the control of the viewing controller,
3. A symbol to indicate whether an aircraft is subject to a Miles-in-Trail restriction (   )

4. Symbols to represent each aircraft's vertical status: "↑" for climbing aircraft, for "↓" descending aircraft, and "–" for aircraft that are level.

The above data is color-coded red or yellow to represent the level of conflict. The data contained below is white unless the aircraft is being suppressed and the controller has the "Display All Pairs" function on, in which case, the data will be gray for the suppressed aircraft:

5. Time to conflict in minutes (under MIN).
6. the horizontal separation at the closest point of conflict in flight levels (FL)
7. the lateral separation at the closest point of conflict in nautical miles (NM).

Conflict List Posting Rules

Flights are automatically added to the conflict list as the conflict probe identifies potential conflict pairs.

Conflict List Deletion Rules

Aircraft are automatically deleted from the list when a conflict has been resolved. The user may suppress any aircraft pair, but cannot manually delete a pair from the system.

Conflict List Sort Order

The Conflict List sort order was not defined during development of the prototype.

Conflict List – View Manipulation Functions:

1. The controller can move the view by picking the view title (CP). The controller can drag the Conflict List to any position on the prototype's situation display screen.
2. The controller can set the view to opaque or semi-transparent.
3. The controller can suppress an entry by selecting the aircraft identification field (left-click) and selecting SUP (left- or right-click). This hides the selected aircraft pair's information. The list automatically re-sizes when an entry is suppressed.
4. The controller can display the suppressed aircraft pairs along with the non-suppressed pairs by selecting the DISP ALL PAIRS button. Suppressed pairs, which are displayed after the DISP ALL PAIRS button has been selected, have their time to conflict and separation data depicted in gray.
5. Suppressed aircraft pairs can be returned to unsuppressed status from the DISP ALL PAIRS screen by the controller selecting the suppressed aircraft and then the DISP button, which is only accessible from the DISP ALL PAIRS screen.
6. The controller can return to viewing only non-suppressed pairs from the DISP ALL PAIRS screen by selecting the RETURN button, only accessible from the DISP ALL PAIRS screen.
7. The controller can toggle the display of keys (left- or right-click).
8. The controller can toggle between showing all pairs and just those pairs containing aircraft subject to Miles-in-Trail restrictions by selecting DISP RSTR ONLY (display restricted only) button available from the second row of buttons.
9. The controller can toggle between showing the labels, MIN, FL and NM by using the LBL (label) button.
10. The controller can toggle between showing the FL and NM data by selecting the FL/NM toggle key.
11. The controller can "show" an aircraft pair's route of flight on the situation display. To do so, the controller selects the aircraft pair and left-clicks. To turn off the "show" feature, the controller must select the aircraft pair again.

TRIAL PLANNING

Two types of trial planning can be invoked in the Spacing Tool: speed trial planning and graphic trial planning. Speed trial planning and graphic trial planning can be conducted independently or jointly.[4] . In either case, trial planning for an aircraft takes into consideration the type of plan the preceding aircraft is on. If the preceding aircraft has not been trial planned or is not on an active plan, then that aircraft's current spacing distance value is used in trial planning calculations. If the preceding aircraft has been trial planned, the trial plan value is used in the next aircraft's trial planning calculations. Finally, if the preceding aircraft is on an active plan, the active plan's end state value is used to calculate the trial plan data of the aircraft being trial planned.

Speed Trial Planning

The purpose of the speed trial planning feature is to allow the controller to trial plan different speeds to see how the new speed would affect either the spacing distance or the estimated time of arrival at the reference. If a trial plan is satisfactory, the controller can activate the plan. The speed trial planning feature can be accessed by either the Spacing List or the RDB via a left-click on the spacing distance value. This opens the Speed Pop-Up Menu (Figure 6).
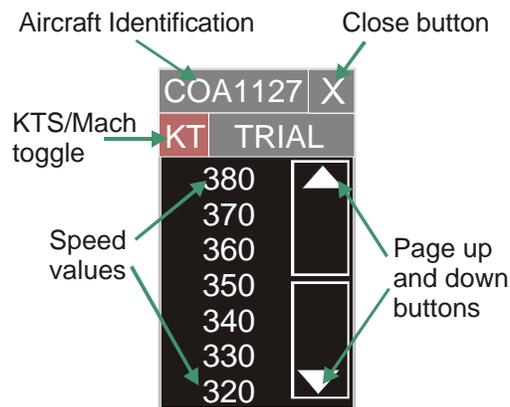
Figure 6: Speed Pop-Up Menu

Once the Speed Pop-up menu is opened, the user can select from a wide range of speeds. To select a value not depicted, the controller must page up or down using the page up and page down buttons.

While moving the trackball over the speed values, a dwell emphasis box appears to indicate which speed would be selected if the user performed a click action.

To perform a speed trial plan, the controller must select a speed value. Once a speed value is selected, a speed trial planned distance appears next to the current spacing distance in parentheses in the Spacing List and the RDB, depending on which is open. If TIME is on in the Spacing List, then a trial planned time for estimated time of arrival near the reference will be displayed to the right of the current time in parentheses.

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[4] It is a NASA requirement for trial planning to maximize the controller's flexibility in finding efficient and effective spacing-conformance plans.

There are two ways to select a speed value. A left-click on a speed value will leave the Speed Pop-Up Menu up and display the appropriate trial planning data.[5] A right-click will display the same trial planning data, but will result in the automatic closure of the Speed Pop-Up Menu. To activate a trial planned speed, the user must select the trial planning data in parentheses. To cancel a speed trial plan, the DELETE button must be selected. The DELETE button appears on the Speed Pop-Up Menu only after a speed has been selected. Selecting the "X" in the upper right-hand corner of the menu closes the Speed Pop-Up Menu.

When the trial plan is activated, the trial planning data is removed and a check mark is placed next to the current spacing distance. This check mark indicates that the spacing distance will undergo change because the aircraft is now on an active plan. In the implemented Spacing Tool system on the DSR, when the spacing distance reaches the restriction value, the check mark will be automatically removed from the display. Otherwise, the controller may manually remove it by clicking it.

Speed Pop-Up Menu

A detailed breakdown of the Speed Pop-Up Menu follows.

Speed Pop-Up Menu View Header

The view header contains:
1. The selected aircraft's identification (ACID)
2. A button to close the Speed Pop-Up Menu, "X".
3. A toggle button that in an implemented system would toggle between KT for knots, and M for Mach speed (in the prototype system, only KT is used),
4. The word TRIAL to indicate that the selection will be used for trial planning purposes.

Speed Pop-Up Menu View Body

The view body contains:
1. Seven speed values at a time. These values range from 250 knots to 310 knots when the Speed Pop-Up menu first appears. The lowest speed value is always displayed at the bottom of the list, and the highest value is always displayed at the top of the list.
2. Page up and down arrows on the right-hand side to allow the controller to scroll through speed values above 310 and below 250 knots.
3. A DELETE button used to delete and close the speed trial planning function. This button only appears after a speed value has been selected via a left click.

Keyboard Inputs

An alternative to the use of the Speed pop-up menu is the use of keyboard inputs for speed trial planning. The DSR R-position keyboard contains 24-hard-labeled function keys that when pressed display text into the R-Position command line (preview area) of the R-CRD (Computer Readout Device) View. The text that these keys display is facility adaptable. In DSR, this text is usually the command verb and it is followed by a set of parameter values that can be entered via the keyboard or with the trackball. The command-input string may then be entered into the system for further processing via the keyboard Enter key or via the trackball Enter key if the parameters are specified with the trackball. Therefore, it is technically feasible to assign the speed control trial planning capability to a function key for use with keyboard inputs for speed value and aircraft id. When entered, the Spacing Tool would process this keyboard-input sequence. It should be noted, however, that recent enhancements to the DSR CHI have focused on using the full data block and the trackball for message entry rather than on keyboard inputs. Further analysis of the operational need for keyboard inputs should be done as the Spacing Tool

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[5] Another NASA requirement is to enable controllers to quickly iterate on trial plans to find a spacing solution.

matures and it becomes clearer as to the DSR baseline into which the Spacing Tool might be integrated.

Graphic Route Trial Planning

The purpose of the Graphic Route Trial planning feature is to allow the controller to see the effects of a route change on an aircraft's spacing distance and/or estimated time of arrival at the reference.

To access the graphic route trial planning feature, the controller must right-click on the spacing distance in the Spacing List or the RDB. Upon the right-click, a route line will be drawn from the aircraft track symbol on the situation display along the aircraft's current route of flight to either the reference or abeam the reference. The cursor is automatically moved to the center of the route line.

The controller must activate the line by clicking on the line in order to be able to drag the route. If the RDBs are off, an RDB appears for the aircraft being trial planned (refer to Figure 4: Range Data Blocks). Graphic route trial planning data, which includes the aircraft's trial planned heading and time to fly this new heading, is automatically displayed on the Situation Display. This data is depicted in one of two graphic route trial planning information locations that are available to view in the dynamic VB demonstration of the Spacing Tool. One depicts the data in the RDB; the other displays the data near the cursor on the graphic trial planning route line. This second option is called the graphic RDB.

When the line is first selected, the trial planning heading is the current heading, and the time displayed is 0:00 since no route change has been planned. As the route line is dragged, the heading, time to fly the heading and trial planning spacing distance values change to reflect the trial planned route.

A right-click of the mouse enables a graphic-trial plan. In the dynamic VB demonstration of the Spacing Tool, to exit the graphic trial planning feature without implementing it, the space bar should be pressed. In the implemented system, a "CLEAR" key would be used to complete the same action.

In an implemented system, the conflict probe feature would be integrated into the Spacing Tool. This feature would change the trial planning route line and trial planning data to red to indicate a conflict. This feature is demonstrated in the static VB demonstration of Spacing Tool.

SPACING TOOL CHI ASSUMPTIONS

The following assumptions were made in the design of the Spacing Tool integration into DSR:

• Picking on the trial planned distance (value in parentheses in the RDB or in the Spacing List) activates the trial plan. It is assumed that this picking action either results in the clearance being uplinked to the pilot, if CPDLC is available, or that the controller would voice the clearance to the pilot if CPDLC was not available for that aircraft.

• No special coding is provided in the CHI prototype to alert the controller to turn back conditions. It is assumed that the controller is scanning the Situation Display and may not require special emphasis to alert them to the turn back condition.

• The CHI design for the Spacing Tool should be independent of the trial-planning engine driving it (e.g. URET CCLD, CTAS/D2). That is, the CHI for the R-position is not predicated on a specific conflict probe implementation.

ADVANTAGES/DISADVANTAGES OF THE SPACING TOOL CHI

The approach taken for the Spacing Tool CHI design was based on the approach that has been taken for the integration of the Continuous Range Readout function and the Controller-Pilot Data Link function into DSR. One of the main tenets of this approach is that the controller should be able to execute the function and view data associated with the function either via a list or via the FDB and Situation Display or via a mixture of both. The application of this guiding principle to the Spacing Tool led to the CHI design described in this paper. The Spacing Tool CHI design allows the controller to use the Spacing List to interact with the Spacing Tool, or use the RDB, to present Spacing Tool data and interact with the tool, or use both the list and the RDB in combination. This approach offers the controller the maximum flexibility in managing glass space while also offering the flexibility to use a list and reduce the amount of data presented on the Situation Display that is associated with a given flight.

The CHI approach to depicting MIT in the RDB builds on the current use of the RDB for presenting continuous range readout data in DSR. The use of the RDB for Spacing Tool builds on the habits that will be established with the DSR Continuous Range Readout with respect to focusing on the RDB for MIT information. Extending the RDB to contain additional data for Spacing Tool, as well as building Spacing Tool functionality into the RDB, seems to be a logical extension to the DSR capabilities for Continuous Range Readout. The controller may invoke the Spacing Tool functions from the RDB fields where their eyes are focused for MIT data, similar to invoking CPDLC or altitude, heading, and speed clearance functions from the associated fields/portals in the FDB.

No obvious disadvantages to the CHI design approach have been identified at this point in time. Certainly it can be argued that additional lists to the display will exacerbate the issue of where the controller will place all the lists that have been fielded, or that are being developed for fielding in the near-term future. The CHI design attempts to address this issue by providing the RDB option. It can be argued that the RDB option adds additional data blocks to the Situation display already covered with FDBs and Limited Data Blocks (LDBs). The CHI design tries to minimize the amount of data displayed and does offer the list approach for controllers who have that glass space available. A consequence of providing the controller with additional tools is that the data from the tools have to be displayed at some location on the physical display surface. A good CHI design offers the controller the flexibility to not use the tool or to use the tool and display the data associated with the tool in a manner that best meets the constraints of the situation.

There are certainly many issues that need to be resolved (see below) and many CHI details that will need to be addressed as the Spacing Tool CHI matures and is briefed to controller teams. Disadvantages to the CHI approach taken in this paper may arise as future steps are taken to implement the Spacing Tool and as higher fidelity prototyping and controller-in the loop simulations are conducted. It is expected that the Spacing Tool Visual Basic CHI prototype will serve as a stimulus for discussions and that further operational and CHI issues will arise from these discussions.

OPEN CHI ISSUES FOR FUTURE ANALYSIS AND DISCUSSION

1. Further higher fidelity prototyping may be needed to examine whether dwell emphasis that is already applied to the DSR FDB needs to be extended to the RDB. The RDB may need dwell emphasis to enhance the readability of RDBs on busy Situation Displays.

2. Further analysis needs to be done with respect to the Conflict Probe List. The first issue is whether this list provides operationally useful information for the R-position. Conflict probe data is available at the D-position and the operational need for conflict probe data at the R-position needs to be analyzed and discussed with controller teams. The presentation of conflict data to the R-position need not be an all-or-none decision. A subset of conflict probe data (e.g., conflict feedback while dragging the graphic route) may be valuable to the

controller for the real-time feedback provided the controller when planning a particular route clearance.

3. A second issue related to the Conflict Probe List is that the Conflict Probe List for Spacing Tool and the Conflict Probe List for D2 need to be integrated into a single presentation. There should not be two versions of the Conflict Probe List at the R-position. Currently, the CHI design for the Spacing Tool Conflict List differs from the D2 Conflict List. The CHI designs differ in terms of coding data, and functionality. These differences reflect the different emphasis of the two tools as well as differences in the operational concepts for conflict data at the R-position.

4. The CHI prototypes developed for this Spacing Tool Task (TO-59) display the current value for miles in trail. This value increments/decrements after the trial plan is invoked. This is a more tactical representation of the data (how far are the planes apart now, rather than how far apart will they be once the aircraft reaches the desired speed or completes the graphic route adjustment). In the short-term, this may be a more logical extension to the DSR Continuous Range Readout capability. However, it can be argued that showing both the current MIT value as well as the active plan value (predicted end-state) or showing just the active plan value is more desirable from a strategic point of view. These options need to be further analyzed and discussed with the controller team (ATDET).

5. No special coding is provided in the CHI prototype to alert the controller to turn back conditions. It is assumed that the controller is scanning the Situation Display and may not require special emphasis to alert them to the turn back condition. The validity of this assumption needs to be validated with controller teams and controller-in-the-loop prototype activities.

6. Future system development should examine the capability for the controller to have more flexibility in the return leg of a graphic trial plan. In the prototype system, it is assumed that the controller will return the aircraft to the original route further downstream, and that the operation will be completed before reaching the restricted reference.

ALTERNATE CONTROLLER ROLES (D-POSITION)

The focus of the discussion in this paper has been on the integration of the Spacing Tool into the DSR R-position. The primary display at the DSR R-position is the radar-based Situation Display. The Situation Display was used as the base for integrating the Spacing Tool. The Continuous Range Readout concept in DSR based on the concept of RDBs was extended to display additional Spacing Tool data as well as provide a portal for Spacing Tool functionality such as speed and graphic route trial planning. The DSR D-position currently exists in two versions: a URET version and a non-URET version. The non-URET version contains a 15" color CRT primarily supporting the display of a D-CRD (Computer Readout Display) window for entering messages and viewing system responses and a Time View. The URET version contains a 20" inch diagonal color flat panel supporting the display of the URET Aircraft List, Graphic Plans Display, DCRD and other URET windows.

A fundamental question is whether an operational need exists for Spacing Tool functionality at the D-position. This paper will defer that operational discussion and focus briefly on how the Spacing Tool functionality might be integrated into the D-position if the operational need existed. The current D-position CHI without URET offers little possibility for displaying additional data at the D-position. For the most part, strip bays cover most of the 15" monitor except for a tunnel where the time and the DCRD are visible. Therefore, it is assumed for the remainder of this discussion that the Spacing Tool would be integrated into a D-position with URET and the 20" flat panel.

The Spacing Tool could be integrated as a separate window much like the Spacing List at the R-position. Visually, the Spacing List at the D-position would look similar to the Spacing List at the R-position except for cosmetic changes brought about by the use of Motif at the D-position.

There is no Situation Display at the D-position. However, the RDB concept used with the Spacing Tool at the R-position could be integrated into the URET Graphic Plan Display. The Graphic Plan Display displays the trajectory-based locations of the flights (no radar returns). Since the Graphic Plan Display is an existing URET display, the Spacing Tool data and functionality presented via an RDB extension would take up no additional display space. This is a significant advantage. The Aircraft List is the primary display at the D-position and minimizing the display of additional windows that may cover the Aircraft List is key. Visually, the RDBs would look similar to the RDBs at the R-position. The RDBs at the D-position would be displayed relative to the associated Graphic Plan data blocks (instead of the Situation Display FDBs).

Finally, the Spacing Tool data and functionality could be integrated into the Aircraft List itself. The Aircraft List contains an entry for each aircraft with conflict probe data, altitude data, heading and speed data, route data, type and code data. There are many tradeoffs to examine in how to best integrate the Spacing Tool functionality into the Aircraft List once it has been decided that there is an operational need for the Spacing Tool at the D-position, in addition to the R-position.

DEMONSTRATIONS

Four demonstrations in Visual Basic are being delivered as a part of this task order. All four demonstrations focus on the R-position integration of the Spacing Tool. One is a static demonstration of the Situation Display depicting a scenario where a miles-in-trail restriction is implemented and the Spacing Tool is invoked and used to space aircraft according to the restriction. This demonstration is entitled "Spacing Tool Static Demo". Screen captures of this demonstration are included in Appendix A. A description of each screen capture is also included in Appendix A.

The second demonstration is a dynamic, interactive demonstration of the Spacing Tool as it would be integrated onto the DSR Situation Display. This demonstration is the "Spacing Tool Dynamic Demo". In this demonstration, aircraft symbols and their associated data blocks are set in motion. The demonstration allows the user to interact with the Spacing List, the RDBs, and the speed and graphic trial planning capabilities. The dynamic demonstration also allows the viewer to compare the Continuous Range Readout (CRR) information to the Spacing Tool RDB and gives the viewer the option of viewing the graphic trial planning data in the location of the RDB or near the cursor when the route line is being manipulated (Graphic option).

Both the Spacing Tool Static Demonstration and the Spacing Tool Dynamic Demonstration have the same background. Each represents airspace containing a fix called "KLUBB" and a center boundary, ZME-ZFW. The aircraft in the beginning of the static demonstration are flying in parallel and will pass abeam KLUBB while the aircraft in the dynamic demonstration are flying independent paths but will each pass over KLUBB. It should be noted that a Miles-in-Trail restriction is not always implemented in reference to a fix. In the static demonstration, a second MIT restriction is imposed over the center boundary.

The last two demonstrations are essentially tutorials for the Spacing List and the Conflict List, titled "Spacing List Tutorial" and "Conflict List Tutorial" respectively. Both are static demonstrations that demonstrate what each button does. A detailed description of the buttons is included earlier in the paper. Screen captures of both the Spacing List and the Conflict List are included in Appendix B.

To view the demonstrations, install the demonstrations from the CD-ROMs provided by Lockheed Martin ATM by following the directions for installation and operation as provided below. Two CDs have been provided to NASA as a part of this task order. One, is for installation on a PC desktop computer, the other is for installation on a laptop computer. The demonstrations were designed to be run on computers that have Windows as their operating system.

Installing the demonstrations

To install the demonstrations onto a computer:

1. Place CD into the computer's CD-drive
2. Open "My Computer" (usually this icon is on the desktop but it may be found in Windows Explorer as well).
3. Double-click on the CD drive in the "My Computer" window
4. A window titled "Spacing Tool" should appear containing four folders. Open the first folder in the window with a double-click.
5. Double-click on the "setup" icon.
6. Select "OK" when prompted.
7. If necessary, change the directory of where the programs will be stored, and then click "OK", otherwise, proceed to step 8.
8. Click the computer icon
9. Click "Continue" in the Choose Program Group window
10. Choose "Yes" if prompted
11. Click "OK"

To install the remaining demonstrations, return to the "Spacing Tool" window that contains the four demonstration folders, open the next folder then follow steps 5-11. Continue this process until all four demonstrations have been installed.

Operating the demonstrations

To access the demonstrations once they have been installed:

1. Click "Start"
2. Select "Programs"
3. Position the cursor over "Spacing Tool Demo"
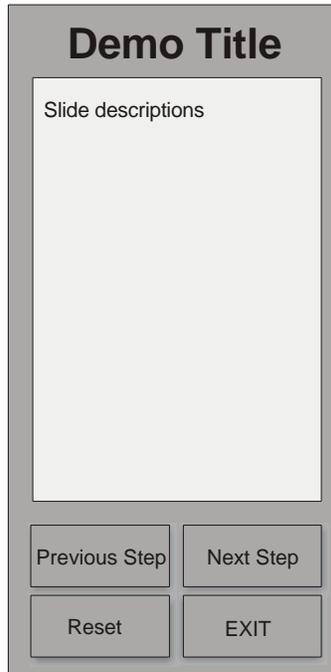4. Then select the Spacing Tool demonstration you wish to run.

Once the demonstration is opened, a control panel operates each demonstration. The same control panel operates the three static demonstrations (see Figure 7: Static demonstration control panel), while a different control panel operates the dynamic demonstration (see Figure 8: Dynamic demonstration control panel).

The control panel for the static demonstrations contains the title of the demonstration at the top of the control panel, a listing of all the slides contained in the demonstration, and buttons to control the operation of the demonstration. "Next Step" takes the user to the next picture in the list, acting similar to a forward button of a slide projector; "Previous Step" returns the user to the previously viewed slide, acting like a reverse button of a slide projector. "Reset" opens the first picture in the list, while "EXIT" closes the demonstration. The user can select any slide in the list and that slide will be depicted.

The dynamic demonstration is operated differently. To start the demonstration, the user must select "Play". Selecting "Play" starts the aircraft in motion on their independent paths to the fix "KLUBB". The demonstration may be paused at any time by selecting the "Pause" button. To resume play, the "Play" button must be selected. The demonstration can be reset via the "Reset" button, and it can be exited using the "Exit" button.

The radio buttons are available to the user to control the viewing of different features contained in the dynamic demon. When "List" is selected, the Spacing List will appear on the screen and the RDBs will be off. Selecting the "RDB" radio button closes the Spacing List and displays the RDBs. "Both" enables the user to view both the Spacing List and the RDBs simultaneously. The

"Graphic" radio button changes the location of the graphic trial planning data block from within the RDB to the one o'clock position of the cursor during graphic trial planning. This feature was discussed earlier. The "CRR" radio button controls the display of the continuous range readout feature. This data is contained on the first line of the RDB and is followed by an "R". This feature was also discussed earlier.

Demo Title

Slide descriptions

| Previous Step | Next Step |
| Reset | EXIT |

Figure 7: Static demonstration control panel

Control Panel

00:00:00

◉ **LIST**
○ **RDB**
○ **BOTH**
☐ **Graphic**
☐ **CRR**

Pause

Play

Reset

Exit
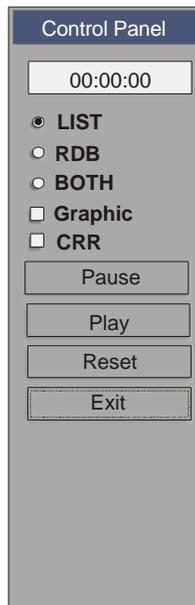
Figure 8: Dynamic demonstration control panel

The demonstrations have limitations due to the fact that they are initial prototypes of the Spacing Tool and are built in Visual Basic. The following are limitations of the dynamic demonstration:

1. the opaque function is not supported,
2. multiple-graphic trial plans on the same aircraft cannot be completed without error in the MIT calculations,
3. trial plans on multiple aircraft cannot be open simultaneously without error in the MIT calculations,
4. trial plans use current state information, not active plan data,
5. conflict probe is not supported, and
6. the toggle between knots and Mach value is not operational.

The static demonstration, however, illustrates the interaction between Conflict Probe and the Spacing Tool. It also shows trial plans that take into consideration active plan information, not current state information.

To simplify the dynamic demonstration, the following rules were programmed into the demonstration:

1. The check mark representing an active plan is removed after a period of time, not when the spacing restriction value is met or when the controller removes the check mark manually.
2. The turn back clock is removed after it reaches zero and ten seconds have passed. In the actual system, the controller would have to manually remove the countdown clock.
3. The aircraft turns to a heading to rejoin its original course once the countdown clock reaches zero. In the implemented system, the controller would have to issue a clearance by voice or datalink for the aircraft to resume its original course.
4. When a trial plan is implemented, the changes in the spacing distance value time are not modeled with real-time calculations. This shortens the time required for the changes to be made and displayed in the demonstration. For example, when a speed trial plan is implemented, the amount of time it takes for that flight to achieve the trial plan speed is not indicative of the real world performance characteristics of an aircraft.

As for the Spacing Tool static demonstration, there are only a few limitations. The first is that the DELETE button in the Speed Pop-up menu is not present. The second limitation is that the static display sometimes displays some of the data on the situation display in bold. This is not the intent of the CHI design but is rather a result of the software used in development of the demonstration. Finally, the scale used in the static demonstration is smaller than that used in the dynamic demonstration, resulting in a more tactical representation of the Spacing Tool. The scale was used since it is more convenient for illustrating purposes. The dynamic demonstration uses a larger scale and can be used to demonstrate more of a strategic approach.

Other issues may arise while running the programs. These issues usually result from the machine the software is being run on. For example, due to screen differences, colors on the prototype are approximate representations of the colors that will be seen on a DSR console, and the colors may appear different when run on different computers. Changing the size of the screen's resolution may be necessary to improve the viewing of the Spacing Tool Static Demonstration. This should be done with the program closed. If the arrow symbols disappear in either the Conflict List Tutorial or the Spacing List tutorial, the computer should be shut down completely and rebooted before running the demonstration again.

ISSUES AND OPTIONS ASSOCIATED WITH THE OPERATIONAL IMPLEMENTATION OF SPACING TOOL ON THE DSR

The process for the deployment of a new en route Air Traffic (AT) capability involves concept development, requirements definition, CHI prototyping and user team involvement. The first step in the process is to identify functionality and develop the related operational concept. Next comes the development of a low fidelity prototype of the capability.

At this stage it is critical to obtain support for the capability from the FAA. Most likely, new AT capabilities should be coming through the free flight program office – AOZ. AOZ should make arrangements to have the concepts evaluated by the Air Traffic DSR Evolution Team (ATDET). AOZ will work with the FAA's requirements branch, ARU, to help in the definition of requirements for the capability to hand off to the implementers. (Draft requirements are helpful in this stage). AOZ will mostly likely request AUA (as the en route implementers) to define the approach for implementation based on the requirements provided by ARU.

The next step is to perform an architectural study to determine how the proposed capability best fits into the en route system (e.g. part of CTAS vs. part of conflict probe). Depending on the complexity of the idea and the clarity of the operational concepts, a more robust prototype of the function will be developed. This prototype is further reviewed with ATDET. Depending again on complexity, this may also serve as a platform for air traffic procedure development activities. This is usually performed by the FAA with broad field representation.

After the above have been completed, an implementation decision is made, a Change Request (CR) is written against the en route requirements baselines (e.g. DSR or URET CCLD) and the function is scheduled for implementation against a particular system release. With this release come the full gamut of final tested software, technical manuals, training, specification updates, software design updates, etc.

When a release is completed, it is given to a key site for testing. Once any relevant Program Trouble Reports (PTRs) are worked out, the system release is given to all the field sites, who then tests the release and upgrades it to the operational version. Part of the cycle is to accomplish any required training for the controllers on the new capability.

TRL 2-3 TRANSITION: PRELIMINARY HUMAN FACTORS ASSESSMENT AND RESEARCH PLAN

1. Review the concept description for the DST or DAG-TM concept.
    *   Several papers and presentations (see below) on the Spacing Tool concept, provided by NASA Ames, were reviewed by LMATM and were discussed in a technical meeting between NASA Ames (S. Green) and LMATM (M. Tarka and C Schulz) at LMATM in Rockville the week of 6/18/01.[6]
    *   "En Route Descent Advisor (EDA) Concept" S. Green & R. Vivona, 9/30/99
    *   "En Route Spacing Tool: Efficient Conflict Free Spacing to Flow Restricted Airspace", S. Green, 6/13/00 (paper)
    *   "En Route Spacing Tool: Efficient Conflict Free Spacing to Flow Restricted Airspace", S. Green, 6/13/00 (viewgraphs)

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[6] This meeting focused on reviewing the Spacing Tool functionality and discussing high level concepts for how the functionality could be incorporated into the DSR CHI.

2. Describe the existing or proposed computer-human interface (CHI) design.
   - This paper, "Computer-Human Interface (CHI) Specification for Spacing Tool at the R-Position", T0-59, 9/28/01, describes the proposed CHI for the Spacing Tool integrated into the DSR R-position. The paper describes each Spacing Tool view as well as integration of the Spacing Tool data into the Situation Display. In addition to the paper, four Visual Basic demonstrations are provided to depict the prototype CHI. Three of the demos are static step-through demos that walk the viewer through a canned series of events, depicting the proposed Spacing Tool CHI at each step. The fourth demo is a more interactive demo where the viewer will be able to interact with the Spacing Tool functions in a limited fashion using the proposed Spacing Tool CHI. The purposes of these demonstrations are to educate the viewer and to promote discussion of the Spacing Tool CHI and the integration of the tool at the DSR –R-position.

3. Identify modifications to controller and pilot procedures that may be needed when the DST or concept is deployed.
   - The FAA, with broad field representation, usually performs procedure development. A representative from the procedures branch is usually involved in all ATDET meetings so that the procedural implications of new functions are identified as the CHI design evolves and is reviewed with the ATDET team.

4. Discuss how the DST or concept might be integrated into the target system and identify related human factors issues.
   - This paper, "Computer-Human Interface (CHI) Specification for Spacing Tool at the R-Position", T0-59, 9/28/01, describes how the Spacing Tool concept would be integrated into the DSR CHI by describing the CHI design for the Spacing Tool when it is integrated into DSR. As mentioned above, four Visual Basic demonstrations are also provided depicting the Spacing Tool integrated into the DSR CHI.

5. Identify any other human factors issues and research questions that should be addressed during DST or concept development up to and including the target TRL.
   - This paper, "Computer-Human Interface (CHI) Specification for Spacing Tool at the R-Position", T0-59, 9/28/01, identifies several CHI issues for future analysis and discussion. These issues need to be reviewed with the ATDET.

6. Outline recommended human factors involvement in research and development.
   - Human factors should continue to be involved with the Spacing Tool CHI as it evolves through user team feedback and further higher fidelity prototyping. Human-in-the-loop simulations should be included in future research and development efforts of the Spacing Tool CHI. In the LMATM/FAA model for the DSR CHI, human factors is involved from concept development, through requirements development, CHI design and prototyping, and user review and feedback activities, including user testing. Human factors continues to be involved during software development to answer questions, as well as during system testing and training to assist those groups in understanding the CHI.

7. Suggest a strategy for user involvement in DST or concept development.
   - This paper, "Computer-Human Interface (CHI) Specification for Spacing Tool at the R-Position", T0-59, 9/28/01, suggests a strategy for user involvement in the CHI design. The process for the deployment of a new en route AT capability involves concept development, requirements definition, CHI prototyping, and user team involvement. The first step in the process is to identify functionality and develop the related operational concept. Next comes the development of a low fidelity prototype of the capability. At this stage it is critical to have the Spacing Tool functionality and the instantiation of that functionality in the Spacing Tool CHI evaluated by ATDET. Depending on the complexity

of the functionality and the clarity of the operational concepts, a more robust prototype of the function may need to be developed. This prototype is further reviewed with ATDET. Depending again on complexity, this prototype may also serve as a platform for air traffic procedure development activities. The FAA, with broad field representation, usually performs procedure development.

8. Discuss a plan for human factors work to support future TRL transitions.

   • Human factors should continue to be involved with the Spacing Tool CHI development to analyze and resolve human factors issues and to evolve the CHI through user team feedback and further higher fidelity prototyping, Human-in-the-loop simulations should be included in throughout this process. As functions move from concept development to initial deployment, more detailed and more numerous CHI issues arise that need to be analyzed and resolved to completely integrate a new function or set of functions into an existing system like DSR. These detailed issues can be deferred during the concept development and initial prototyping phases but must be addressed before functionality can be fielded. To ensure continuity of design principles and goals, and consistent resolution of detailed CHI issues, it is essential to have the continued involvement of human factors during later TRL transitions.