NASA Technical Memorandum 102587

SIMULATOR COMPARISON OF THUMBALL, THUMB SWITCH, AND TOUCH SCREEN INPUT CONCEPTS FOR INTERACTION WITH A LARGE SCREEN COCKPIT DISPLAY FORMAT

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APRIL 1990

(NASA-TM-102587) SIMULATOR COMPARISON OF THUMBALL, THUMB SWITCH, AND TOUCH SCREEN INPUT CONCEPTS FOR INTERACTION WITH A LARGE SCREEN COCKPIT DISPLAY FORMAT (NASA) 31 p CSCL 01D G3/06 N90-21005 Unclas 0277028

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SUMMARY

A piloted simulation study has been conducted comparing three different input methods for interfacing with a large screen, multiwindow, "whole-flight-deck" (WFD) display for management of transport aircraft systems. One input methodology, the "thumball" concept, utilized a miniature trackball embedded in a conventional side-arm controller for cursor movement and numerical entry. The second method, the "Multifunction Control Throttle And Stick" (MCTAS) concept, employed a thumb switch located in the throttle handle for cursor control. The third method, the touch screen concept, provided data entry through a capacitive touch screen installed on the display surface.

The objective and subjective results obtained indicated that, with present implementations, the thumball concept was the most appropriate for interfacing with aircraft systems/subsystems presented on a large screen display. Not unexpectedly, the completion time differences between the three concepts varied with the task being performed, although the thumball implementation consistently outperformed the other two concepts. However, pilot suggestions for improved implementations of the MCTAS and touch screen concepts could reduce some of these differences.

INTRODUCTION

The rapidly increasing use of computer systems in the cockpit is providing more operational capability to the transport aircraft crew and, as a consequence, an increase of information that can be displayed and managed within the limited flight deck environment. Utilization of multiple (4 to 8) small-screen color cathode ray tubes (CRT's) as multimode, multifunction indicators appears to be the current solution for consolidating and integrating this information. A potential alternative for future application is a large screen, multiwindow, "whole-flight-deck" (WFD) display for the management of aircraft systems (refs. 1 - 3). A WFD display accommodates most aircraft information on one large CRT (ultimately to be replaced by one large flat-panel display) in the pilot's primary heads-down field-of-view. Figure 1 shows an example of a WFD display consisting of a primary flight display (PFD), a navigation display (ND), an Automatic Guidance and Control Unit (AGCU), a Navigation Control Display Unit (NCDU), engine displays, an Advisory Caution And Warning System (ACAWS), and a subsystem display area. To effectively interact with such a display, pilots must be provided with user-friendly, man-machine interface methods.

A piloted simulation study was conducted comparing three different input concepts as methods of interfacing with a large screen WFD display. The "thumball" concept utilized a miniature trackball embedded in a conventional side-arm controller; the "Multifunction Control Throttle And Stick" (MCTAS) concept used a thumb switch located in the throttle handle; and the touch screen concept utilized a capacitive touch screen installed on the CRT.

This paper describes each of the three input concepts and the experimental design in detail. Objective data as well as subjective results, garnered from pilot questionnaires and discussions, are also presented.

The authors would like to express their appreciation to United States Air Force pilots Bill Bishop, Joseph H. Ferry Jr., Craig E. Hoyt, Michael T. Martinez, Lisa L. Osterheld, and Walter Seeds for their time and effort in participating as test subjects in the study; Lucille H. Crittenden of Research Triangle Institute for development of the Boeing 737 aircraft model; Dean E. Nold of Purdue University for initial experimental design and thumball interface work; and Thomas W. Hogge and Lawrence E. Gupton for physical implementation of the three input technologies.

SIMULATOR CHARACTERISTICS

Simulator Cockpit

This study was conducted in the Crew Station Systems Research Laboratory using the Advanced Display Evaluation Cockpit (ADEC); a fixed-base, part-task research transport simulator outfitted with large cathode ray tube displays of the type which might be used on future transport aircraft (fig. 2, ref. 4, pp. 84 - 88). The equipment utilized consisted of the three study input devices, two cathode ray tube displays, a side-arm controller, and a throttle. A 19-inch CRT was positioned on the pilot side (left side) of the simulator cockpit and a 13-inch CRT, used for touch screen implementation, was located on the copilot side. It was necessary to utilize the copilot side of the simulator cockpit for the touch screen implementation of the study because there was not a touch screen available for the 19-inch monitor at the time of the subject experiment.

Aircraft Model

The aircraft model utilized for this study was a linear representation of the NASA Transport Systems Research Vehicle, a specially instrumented Boeing 737-100 (ref. 4, pp. 77 - 83). This airplane is a research aircraft that was modified to incorporate electronic displays and all-digital flight-control computers. The simulated aircraft was configured for low speed level flight and was flown using the "manual electric" control mode; consequently, attitude hold was not present. The aircraft model, implemented in FORTRAN, was hosted on a Digital Equipment Corporation (DEC) VAX-11/780 minicomputer at an iteration rate of 15 hertz. This model has been used for various other studies conducted at the NASA Langley Research Center (refs. 5 and 6).

Graphic Display

The visual display created for this experiment was a partial representation of a whole-flight-deck (WFD) display. A WFD display is one in which most of the aircraft state information is located on one large CRT, thus eliminating the need for specialized, dedicated instruments. The large screen was partitioned into multiple display formats in various window areas. The relative sizes of these areas were under computer control to allow selected areas to expand or shrink as a function of events. The display for this study consisted of a partial primary flight display, engine displays, an Advisory Caution And Warning System, a menu for displaying aircraft subsystems, and a menu for selecting symbology for presentation on a navigation display (fig. 3). There was also an area reserved below the PFD for displaying prompts to instruct the pilot which task to complete next.

The WFD display was produced on an Adage, Inc. Adage RDS-3000 programmable display generator using the Real-Time Animation Package (RAP). RAP is a high-level graphics programming language similar to the C language. This graphics software ran at an iteration rate of 2.6 Hz, approximately six times slower than the aircraft model. As a result, there was a delay between the time an input was introduced into the system and the updated information was displayed on the screen. Although the graphical iteration rate was slower than that desired for real-time simulation, it was anticipated that this rate would have approximately the same affect on pilot performance with each input concept and would create little or no concept bias in this study.

In order to obtain the 2.6 Hz graphical iteration rate of the WFD display, a navigation display was not included in this WFD implementation. The PFD was also stripped of all unnecessary information in order to further reduce the time required to render the entire WFD display. The information remaining in the partial PFD consisted of an aircraft symbol, pitch indices, and heading, roll angle, airspeed and altitude numeric indicators. This information was all that was required to perform the basic flying task used in this study.

The ACAWS was located in a window directly beneath the engine displays. This area was event driven. When a warning or caution was introduced into the system, the engine displays were automatically reduced in size and the ACAWS area was enlarged to list the subsystems containing failures. Additionally, the menu used to display the aircraft subsystems was reordered, listing the subsystems with warnings at the top of the menu in red and those with cautions below in yellow (fig. 4).

The navigation symbology menu of reference 5 was utilized in this study. The menu is generally used to select various symbology for presentation on the navigation display. In this instance, the navigation display was not included as part of the WFD display; however, the menu was used to provide a typical input task for the evaluation of the input concept.

INPUT CONCEPTS

Input Tasks

In order to evaluate the usefulness of each input concept as a means of interfacing with the WFD display, each pilot was asked to perform several tasks. There were four basic types of tasks (table I), which are described as follows:

Task 1 - Display a Subsystem. This task required changing the active menu (the menu that is currently in use) from the navigation symbology menu to the subsystem menu and then selecting the indicated subsystem.

Task 2 - Display the subsystems having a warning and caution, and clear those failures. This task required the subsystem containing the warning to be displayed and the failure cleared. The same would then be done for the caution failure.

Task 3 - Select two navigation symbology items for presentation on the navigation display. This task required changing the active menu from the subsystem menu to the navigation symbology menu, selecting the first indicated item, and then selecting the second indicated item.

Task 4 - Change the reference altitude for the altitude range arc feature of the navigation display by 1700 feet. This task required engaging the numerical entry mode on the navigation symbology menu, changing the number to the indicated value,and then exiting the numerical entry mode.

Input Devices

Thumball.- The "thumball" is a miniature trackball embedded in a conventional side-arm controller (fig. 5, refs. 7 and 8). The trackball is rotated with the thumb to interact with the WFD display. It is an input device that provides position information in both the horizontal and the vertical directions. Output magnitude is directly related to rotation speed.

The thumball concept utilized the thumball combined with buttons located on the side-arm controller. With this system, the pilot was able to interact with all aircraft subsystems using one hand. Horizontal rotation of the thumball controlled the active menu designation (indicated by a magenta border surrounding the active menu), while vertical rotation of the thumball controlled the cursor within that menu. When the thumball was rotated to the right, the subsystem menu became active; when moved to the left, the navigation symbology menu became active. The cursor moved up or down through the active menu when the thumball was rotated up or down respectively. A quick rotation caused the cursor to move two positions, while a slower rotation moved the cursor one position at a time. Both menus had a cursor wrap-around feature which allowed the cursor to move from the top-most menu item to the bottom-most item and vice versa.

Task 1, displaying a subsystem, required a maximum of five inputs with the thumball system. First, the active menu was changed from the navigation symbology menu to the subsystem menu by rotating the thumball to the right. Next, the cursor was moved three menu locations to the desired menu item.

The item was then selected by pressing the right button on the control stick. During task 2 (subsystem failure), the cursor was initially positioned next to the warning item at the start of the task by the ACAWS. As a result, cursor movement was not necessary. The right button was pressed to display the subsystem containing the warning. The warning was then cleared by pressing the left button on the control stick. The same steps were conducted for the subsystem containing the caution (a total of four inputs). Selecting two navigation symbology items, task 3, required changing the active menu from the subsystem menu to the navigation symbology menu by rotating the thumball to the left. The cursor was then moved one menu location to the first symbology item. The item was selected by pressing the right button. Next, the cursor was moved three menu locations to the second symbology item. This item was also selected by pressing the right button (a maximum of seven inputs). The reference altitude value for task 4 was changed by moving the cursor three menu locations and then engaging the numerical entry mode by pressing the right button. The reference altitude was then changed by rotating the thumball up to increment and down to decrement the value. A slow movement of the ball changed the number by 100; a quick movement changed it by 1000. After the desired value was obtained, the enter-number mode was exited by pressing the left button (a minimum of nine inputs).

During the initial conceptualization of the thumball concept, there was some controversy concerning the direction of cursor movement with the vertical rotation of the thumball. Computer users familiar with mice, trackballs, and other cursor-control devices expect forward (or upward) motion of the device to be accompanied by upward movement of the cursor. However, pilots, when operating a hand-controller, expect a forward (upward) movement of the hand-controller to command a pitch down, or a lowering of the nose of the aircraft, and a backward (downward) input to command a pitch up. Thus, it was speculated that pilots might prefer a backward (downward) rotation of the thumball (located within the hand-controller) to result in moving the cursor up through the menu (or to increase the number in the enter-number mode) and vice versa. However, preliminary testing suggested that such was not the case. Several pilot subjects found that implementation to be more confusing than the computer-oriented version. As a result, for the experiment, the thumball was implemented such that an upward movement of the ball caused an upward movement of the cursor, or an increase in the number being entered, and vice versa. Provision was made in the subjective questionnaire to elicit further verification of the decision on this issue.

Multifunction Control Throttle And Stick (MCTAS).- The "Multifunction Control Throttle And Stick" concept was based on the "Hands-On-Throttle-And-Stick" (HOTAS) concept developed by the Air Force for fighter aircraft (ref. 9). The MCTAS system, which had evolved from the prior work reported in reference 6, utilized a thumb switch located in the throttle handle (fig. 6), together with buttons located on the side-arm controller. The thumb switch provided fine and coarse position information in the vertical direction.

The MCTAS concept operated in a manner very similar to the thumball concept. Each of the four input tasks was completed in exactly the same manner as for the thumball concept, except the throttle thumb switch was used for control of cursor movement and numerical entry (the thumball was still utilized to control the active menu). With this implementation, the subsystem menu did not differentiate between fine/coarse movement; the cursor only moved one menu location per input. In the navigation symbology menu, a fine input caused the cursor to move one menu location, while a coarse input caused the cursor to move to one of the starred menu items (fig. 3). This aided in speed of movement through that menu. When entering a numerical value, a fine input changed the number by 100 and a coarse input changed it by 1000.

Touch Screen.- The touch screen system utilized a 13-inch capacitive touch screen that required skin contact directly with the surface of the screen for activation to occur (refs. 10 and 11). It was necessary to use the 13-inch screen for this study since a 19-inch screen that would conform to the constraints of the simulator cockpit was not available. In developing the software for this system, an interactive editor was used to define the touch areas for the WFD display (ref. 12).

The touch screen concept operated in a conceptually intuitive manner. All that was necessary to activate a menu was to touch within the menu itself. To convey precisely which item was being pushed, the background color of a menu item was changed when it's touch-zone was being pressed. As long as pressure was applied to the screen, nothing was activated. A menu item was selected when the finger was released from the screen. Performing a selection by this method helped prevent inadvertent selection of an undesired item. Note that cursor moves were not required for the touch screen concept. A direct selection of the proper item was possible.

A subsystem was displayed for task 1 by touching the required item in the subsystem menu and exiting from the screen. To complete task 2, the subsystem containing the warning was displayed by selecting the appropriate menu item. At that time, a "delete" option would be listed in the ACAWS area (fig. 7). The warning would then be cleared by selecting this "delete" option. This process would be repeated for the subsystem containing the caution. The navigation symbology items (task 3) were selected by touching the first item in the navigation symbology menu and exiting from the screen, and then repeating this procedure for the second item. The reference altitude value was changed (task 4) by selecting the numerical menu item in the navigation symbology menu. As a result, arrows would be displayed at the bottom of the navigation symbology menu (fig. 8). Pressing the thicker arrows would change the number by 1000's, while pressing the thin arrows resulted in change by 100's. The numerical value was continually altered while pressure was placed on an arrow. After the proper value was obtained, the enter-number mode was exited by selecting the numerical menu item again.

EXPERIMENT DESCRIPTION

Experimental Design

A full-factorial design, with four replications for each condition, was used for this study. The factors of the experiment were pilots, flight condition, input concepts, input tasks, and versions of the various tasks (replicates).

Each pilot was given four versions of each of the four tasks while concentrating on flying the simulated aircraft (in-flight tasks) and also while focusing on just the tasks themselves (nonflying tasks). This resulted in a total of 32 tasks for every input concept. The versions within a task were designed to have the same number of cursor moves and selections, so each would take approximately the same amount of time to perform. The pilot was prompted to perform a particular task by a flashing message displayed in the center of the screen.

Objective Performance Measures

Performance data were collected for each in-flight and nonflying task. The time to complete each task, from the moment the prompt was displayed until the task was completed, was recorded. The average altitude, airspeed and roll angle during each in-flight task were also obtained.

Experimental Conditions

Five U.S. Air Force EC-135 pilots were used in this study. The EC-135 pilots had a cumulative total of 13,208 flying hours, with an 1350 hour minimum and a 4258 hour maximum flying time. Each pilot was asked to perform 16 nonflying tasks and then 16 in-flight tasks with each input concept. Table II shows the sequence of input concepts given to each pilot. The same 16 tasks were given in each instance but in random orders. For the in-flight conditions, the pilot was asked to perform a "Figure 8" maneuver, maintaining an altitude of 1500 feet, an airspeed of 130 knots, and a bank angle of 15 degrees. Care was taken not to initiate a task while the pilot was in the transition phase of the Figure 8 maneuver.

At the start of each session, the pilot was provided with training time to become familiar with the aircraft simulator. Prior to data collection for each input concept, the concept was demonstrated and the pilot was allowed to practice until he was comfortable with it's operation. A sample prompt for each type of task was also furnished so the pilot would know what to expect when the data collection began. Next, the nonflying conditions were given for a concept, followed by the in-flight conditions for that same concept. Input errors were recorded, and those tasks that resulted in errors were repeated at the end of that session. A subjective questionnaire was given at the completion of data collection for each input concept. A final subjective questionnaire was also given at the completion of the session to get a comparative opinion. The questionnaires are shown in appendices A and B.

RESULTS and DISCUSSION

Objective Results

Analysis of performance measures.- Tables III and IV are summaries of the analyses of variance for the four performance measures recorded during the in-flight and nonflying conditions, with third order and higher interactions pooled into the error term. Results were considered statistically significant at the 95% confidence level. The following sections will discuss some of the significant sources of variation for the performance measures. The interactions that are not discussed were not considered to be a contributing factor in the analysis of the data.

Flight condition.- The flight condition factor was not significant for the completion time measure, which was an unexpected result. It was anticipated that the tasks under the in-flight conditions would, on the average, take more time to complete than the nonflying tasks. As shown in table V, however, the mean completion time for the in-flight tasks was slightly less than for the nonflying tasks. This could be attributed to the fact that the nonflying tasks were given prior to the in-flight tasks. Therefore, by the time the in-flight tasks were encountered the pilot was possibly more familiar with the operation of the input concepts for those tasks.

The flight condition term was not included in the analysis of the flight measures, since these measures were not available under nonflying conditions.

Input concepts.- The task completion time and average airspeed measures identified significant variability among concepts (see table VI). The thumball version recorded the lowest mean completion time across all tasks. This method enabled all input to be done with one hand from the side-arm controller. The touch screen concept took the longest mean completion time. This could be attributed to the fact that providing inputs through the touch screen required the pilot to take his hand from the throttle and reach forward to press the screen. The MCTAS implementation required both hands to accomplish certain tasks (since the thumball and buttons were utilized on the control stick), and cursor movements were slower compared to that of the thumball.

Since the hands were always on the controls, it was expected that the average airspeed held during the in-flight conditions would deviate from the designated 130 knots less when the MCTAS or thumball systems were used. This expectation held true for the MCTAS system; however, the data did not indicate this occurrence for the thumball concept. The airspeed deviation for the thumball tasks may have been caused by inadvertent control stick inputs when rotating the thumball. The airspeed variation for the touch screen concept may have also been caused by inadvertent control stick inputs when the pilot leaned forward to press the screen.

Tasks.- The task factor was statistically significant for the performance measures of task completion time and average airspeed. From table VII, it can be seen that changing the reference altitude took much longer than the other tasks. This was understandable, since entering a numerical value was the most complicated task to perform for each of the three input concepts.

The mean airspeed during task 2, handling cautions and warnings, deviated from the means of the other three tasks. This occurrence could be attributed to the fact that two of the four versions of task 2 included an engine failure, which affected airspeed by shutting down engine 2.

Pilot by flight condition interaction.- The significance of this second order term indicates that not all pilots responded in the same manner to the in-flight and nonflying conditions. In fact, two of the pilots recorded lower mean times for the in-flight tasks (see table VIII and figure 9). One of these pilots had a drastically lower mean time for the in-flight tasks. As mentioned previously, this may have occurred because the in-flight tasks were presented after the nonflying tasks, giving the pilot time to become more familiar with the input concepts. However, prior to the experiment, familiarization time with each concept and task had been considered ample for elimination of learning curve effects.

Pilot by input concept interaction.- The pilot by input concept interaction for completion time is presented graphically in figure 10 and numerically in table IX. In general, all pilots performed best with the thumball and worst with the touch screen. Pilot 2 was an exception, performing slightly better with the touch screen than with the MCTAS switch. Pilot acceptance or preference is one explanation why performance across pilots varied among concepts. Another reason may be the physical characteristics of the subjects. For example, a pilot with large fingers may not have been able to select items as well using the touch screen, since the items were located rather close together.

Input concept by task interaction.- Not unexpectedly, the completion time differences between the three input concepts varied with the task being performed, as indicated by the significance of the input concept by task interaction. The thumball performance was consistently as good or better than performance with the other two concepts. Figure 11 and table X shows that the touch screen concept was well suited for tasks which operated as an on/off toggle, such as tasks 1 and 3. Entering a numerical value (task 4) was much faster using the thumball method. Subsystem failures (task 2) were handled more effectively using the MCTAS and thumball methods since fewer steps were required and the hands remained on the controls. For this experiment, the subsystem failures tasks were completed in exactly the same manner for the MCTAS and thumball implementations because cursor movement was not necessary.

Analysis of input error data.- An input error was recorded for a particular task if the pilot incorrectly completed the task as stated in the prompt. There were 24 errors noted for the 480 tasks given during data collection. Table XI shows the number of errors by task and input concept.

The touch screen concept recorded the most input errors, particularly when entering the reference altitude. These errors were caused by exiting the enter number mode when the improper value was entered for the reference altitude. The location of the input arrows on the screen, along with the size of the touch zone for each arrow and the spacing between menu items, may have contributed to the error rate. The enter number mode was occasionally exited prematurely by accidentally selecting the reference altitude number menu item. Also, the improper numerical value was sometimes accepted because the number would be incremented/decremented one additional unit after the finger was removed from an arrow. This was caused by the delay in the system. Touch screen errors also occurred when an incorrect subsystem or symbology item was selected.

The MCTAS method of data entry recorded the most errors when selecting navigation symbology items. These errors could be attributed to the delay in the system or the fine/coarse feature of the throttle thumb switch. Much difficulty was encountered when trying to use the fine position to move the cursor one menu location at a time.

The thumball method of entry recorded errors for selecting an incorrect subsystem, selecting an incorrect navigation symbology item, and accepting an improper reference altitude. These errors could be attributed to the delay in the system and also to the rotation rate of the ball. This will be discussed in more detail in the subjective results section.

More errors were recorded for both the MCTAS and thumball systems for the nonflying conditions than for the in-flight conditions. Since the nonflying tasks were performed before the in-flight tasks, the pilots were probably more familiar with the input concepts for those tasks, which resulted in fewer errors while in-flight. However, more errors were noted for the in-flight conditions during touch screen entry. This could be attributed to the small screen size as well as the location of the screen, which could hinder input during in-flight conditions.

Any task that resulted in an error was deleted from the performance measure set and repeated at the end of that session to provide a complete data set of correctly performed tasks.

Subjective Results

This section discusses the comments obtained from the questionnaires shown in the appendices and observations made during data collection. The comments will be discussed according to input concept with general comments following.

Thumball concept.- The pilots responded favorably to the thumball as an input device. They preferred using one hand to provide all inputs necessary to interface with the aircraft systems. The hands were positioned in a normal flying arrangement and did not have to be removed from the controls during input. It was felt that the concept was easy to use and operation easy to learn. However, due to the location of the thumball, accidental inputs were sometimes made when moving the thumb over the ball, occasionally causing inadvertent inputs to the system. It was also commented that the movement of the ball was too "loose," with no feedback and not enough friction. The ball was also located where the trim switch would traditionally reside, although trim function could also be implemented as an additional thumball application. Therefore, additional redesign may be needed for actual flight applications.

The task of entering numerical data was considered easy; however, an occasional reversal input would be given when changing the value. For instance, the ball would sometimes be rotated downward to increase the number or vice versa. Four of the five pilots felt that the direction of movement was appropriate and all believed errors would not occur if they were extremely familiar with the system.

Various other comments were made concerning the thumball rotation rate for obtaining coarse and fine inputs and for cursor movement. These concerns are application specific and should be adjusted accordingly.

MCTAS concept.- The MCTAS concept was the most unsatisfactory of the three concepts. This was mainly related to the design of the thumb switch located in the throttle. There was no feedback or detent to indicate when the switch was in the fine position. The coarse position had a physical detent at the end of possible switch travel. As a result, tasks dependent on fine movement encountered occasional input errors. For example, entering numerical data was somewhat difficult since the fine position was used to change the number by 100.

This concept was considered easy to learn. The location of the input devices was desirable since the hands would not have to be removed from the throttle or stick to complete a task. However, an implementation would be preferred where all input could be done with one hand from one location rather than using the thumball to control the active menu and the throttle switch for cursor movement. As with the thumball concept, the active menu was, on occasion, accidentally changed with the MCTAS system because of the location of the thumball.

Touch screen concept.- Several pilots felt that touch entry would be useful in a transport environment, dependent on error-free operation. With this 13-inch implementation, the touch areas were too small and located too close together. Therefore, all subjects were occasionally having problems selecting items, sometimes not being able to engage a desired item or choosing an incorrect item. Several suggestions were given to help alleviate this problem. For example, definite "on"/"off" areas located beside menu items or a timing delay that would require touching an item for a predetermined amount of time before it could be selected, were suggested.

Most pilots agreed the touch concept was easy to learn and understand. Menu items were selected merely by touching the desired item and releasing. The location of the touch screen was another matter entirely. Pilots did not feel it was a good idea to have to remove a hand from the throttle and reach forward to press the screen. This could result in erroneous control stick movements. A touch screen positioned near the throttles which did not require the operator to reach forward was suggested.

In general, the pilots considered this method of entering numerical data to be fairly difficult. The location and size of the input arrows appeared to be the major contributing factor. The arrows were positioned in the extreme lower left corner of the screen.

Other considerations when using a touch screen as an input device relate to the parallax problem. If a user's eye position is not in the same general vicinity as the designer's when the touch areas were defined, it may appear that to select an item the user must press below/above or left/right of the item. Also, touch areas should be designed large enough to accommodate fingers of all sizes. Finally, the touch screen technology utilized is dependent on the application. For instance, Air Force pilots must wear gloves during various phases of flight. Therefore, a touch screen activated by capacitance could not be used because direct contact must be made with the skin.

General comments.- Table XII shows the overall input concept preference of the pilots, obtained by tabulating the results from the final questionnaire shown in appendix B, for different situations. Although this particular implementation of the touch screen concept was not completely satisfactory, it is shown that these pilots would prefer touch screen input for most transport operations because of its intuitive simplicity, followed by the thumball, then MCTAS concept. Emergency flight conditions were an exception, with the thumball being the most desirable concept, reflecting its hands-on capabilities.

CONCLUDING REMARKS

The objective and subjective results of this study indicate that, with the present implementations, the thumball concept was the most effective interface. Pilots noted it was desirable to operate all aspects of the pilot interface from the control stick using one hand. This freed the second hand for other pertinent tasks and helped reduce pilot workload due to the centralization of the input device. Favorable reactions to all three input concepts, with suggestions for improved implementations, were expressed. In general, a large screen "whole-flight-deck" display concept, interfaced with an effective multifunction control concept, was seen as a promising method for managing aircraft systems.

Not unexpectedly, the completion time differences between the three concepts varied with the task being performed, although the thumball implementation consistently outperformed the other two concepts. However, pilot suggestions for improved implementations of the MCTAS and touch screen concepts could change some of these performance relationships.

A follow-on study is planned. This study would explore improved implementations of these concepts, including the evaluation of the touch screen method on a 19-inch diagonal CRT (the same size CRT used with the thumball and MCTAS concepts).

Appendix A

Subjective Questionnaire For Individual Devices

Check one of the following: Pilot # ______

MCTAS ________
Thumball ________
Touch Screen ________

For questions 1 - 4 answer with:

A - Strongly Disagree With Statement
B - Mildly Disagree With Statement
C - Neither Agree Nor Disagree
D - Mildly Agree With Statement
E - Strongly Agree With Statement

______ 1. Entering reference altitude was an easy task.

______ 2. Making changes (such as selecting subsystems, menus, etc.) was easy to learn.

______ 3. This system could serve a useful purpose in the air transport environment.

______ 4. This system could reduce my workload while flying in a "high activity" flight environment.

5. List two or more things (such as characteristics, etc.) you liked about this system.

____
____
____
____

6. List two or more things you did not like about this system.

____
____
____
____

7. Other comments regarding this system. (Thumball version only - comment on direction of cursor movement in relation to ball movement).

____
____
____
____

Appendix B

Final Subjective Questionnaire

Pilot #______

Please rank order the three systems under consideration for each situation as listed below (assume only transport operations).

A = MCTAS
B = Thumball
C = Touch Screen

	Potential Usefulness In Transports	Routine Flight Conditions	Emergency Flight Conditions
1st			
2nd			
3rd			

COMMENTS: ____________________

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12. Monroe, Burt L.; and Jones, Denise R.: An Interactive Editor for Definition of Touch-Sensitive Zones for a Graphic Display. NASA TM-89136, April 1987.

Table I. Description of Versions of Each Task

Task	Version	Description
1	1	Display electrical subsystem
1	2	Display fuel subsystem
1	3	Display secondary engine subsystem
1	4	Display enviroment system
2	1	Handle engine warning, electrical caution
2	2	Handle fuel warning, engine caution
2	3	Handle electrical warning, enviroment caution
2	4	Handle enviroment warning, fuel caution
3	1	Display straight vector and navaids
3	2	Display GRP and waypoint data
3	3	Display trend vector and local airports
3	4	Display navaids and staight vector
4	1	Change reference altitude by + 1700 feet
4	2	Change reference altitude by - 1700 feet
4	3	Change reference altitude by + 1700 feet
4	4	Change reference altitude by - 1700 feet

Table II. Sequence of Input Devices Given to Each Pilot

Pilot				
1	2	3	4	5
A	A	B	C	C
B	C	A	A	B
C	B	C	B	A

A=MCTAS B=Thumball C=Touch Screen

Table III. Summary of Analysis of Variance For Completion Time Metric

Factor	Degrees of Freedom	Significance of Performance Measure
P	4	* *
F	1	—
C	2	* *
T	3	* *
V	3	—
P x F	4	*
P x C	8	* *
P x T	12	* *
P x V	12	—
F x C	2	—
F x T	3	—
F x V	3	—
C x T	6	* *
C x V	6	—
T x V	9	—
Error	401	

Factors are as follows:
P - pilot; F - flight condition; C - concept;
T - Task; V - version.

Significance shown as follows:
— not significant at levels considered.
* significant at 5-percent level.
* * significant at 1-percent level.

Table IV. Summary of Analyses of Variance
For Other Performance Measures

Factor	Degrees of Freedom	Significance of Performance Measures		
		Altitude	Airspeed	Roll Angle
P	4	—	* *	—
C	2	—	* *	—
T	3	—	*	—
V	3	—	—	—
P x C	8	—	* *	—
P x T	12	—	—	—
P x V	12	—	—	—
C x T	6	—	—	—
C x V	6	—	—	—
T x V	9	—	* *	—
Error	174			

Factors are as follows:
P - pilot; C - concept;
T - task; V - version.

Significance shown as follows:
— not significant at levels considered.
* significant at 5-percent level.
* * significant at 1-percent level.

Table V. Means and Standard Deviations For Flight Conditions Factor Over Time

Flight Condition	Time (seconds)	
	Mean	Standard Deviation
In Flight	12.81	8.43
Not Flying	13.07	9.12

Table VI. Means and Standard Deviations For Statistically Significant Measures of Input Concept Factor Across All Tasks

Task	Time (seconds)		Airspeed (knots)	
	Mean	Standard Deviation	Mean	Standard Deviation
MCTAS	13.24	8.49	130.55	6.92
Thumball	9.42	5.00	127.58	6.69
Touch Screen	16.16	10.57	131.50	9.82

Table VII. Means and Standard Deviations For Statistically Significant Measures of Task Factor Across All Input Concepts

Task	Time (seconds)		Airspeed (knots)	
	Mean	Standard Deviation	Mean	Standard Deviation
1	7.58	2.83	131.32	7.69
2	10.54	9.88	127.70	8.71
3	11.40	3.84	129.72	7.26
4	22.24	8.06	130.77	8.29

Tasks are as follows:

1 - Display subsystem.
2 - Handle a warning and caution.
3 - Display two symbology items.
4 - Change reference altitude.

Table VIII. Means and Standard Deviations For Statistically Significant Measures of Pilot By Flight Condition Interaction

Pilot	Time (seconds)			
	In Flight		Not Flying	
	Mean	Standard Deviation	Mean	Standard Deviation
1	14.53	8.47	15.39	10.64
2	12.98	7.28	11.80	8.04
3	12.44	8.14	11.91	8.63
4	10.98	8.11	13.66	10.33
5	13.11	9.90	12.60	7.40

Table IX. Means and Standard Deviations For Statistically Significant Measures of Pilot By Input Concept Interaction

Pilot	MCTAS		Thumball	
	Time (seconds)		Time (seconds)	
	Mean	Standard Deviation	Mean	Standard Deviation
1	15.23	9.68	10.90	5.23
2	13.90	8.95	9.68	5.92
3	10.43	5.88	9.30	4.96
4	12.11	8.54	8.02	4.63
5	14.52	8.52	9.19	3.93

Pilot	Touch Screen	
	Time (seconds)	
	Mean	Standard Deviation
1	18.74	11.31
2	13.60	7.27
3	16.80	10.98
4	16.83	11.50
5	14.86	11.08

Table X. Means and Standard Deviations For Statistically Significant Measures of Input Concept By Task Interaction

Input Concept	Task 1 Time (seconds) Mean	Task 1 Time (seconds) Standard Deviation	Task 2 Time (seconds) Mean	Task 2 Time (seconds) Standard Deviation
MCTAS	8.74	2.79	5.36	1.57
Thumball	6.73	1.95	4.65	1.23
Touch Screen	7.27	3.25	21.62	10.25

Input Concept	Task 3 Time (seconds) Mean	Task 3 Time (seconds) Standard Deviation	Task 4 Time (seconds) Mean	Task 4 Time (seconds) Standard Deviation
MCTAS	14.24	3.77	24.63	7.15
Thumball	10.34	2.51	15.95	3.87
Touch Screen	9.61	3.44	26.15	8.36

Tasks are as follows:

1 - Display a subsystem.
2 - Handle a warning and caution.
3 - Display two symbology items.
4 - Change reference altitude.

Table XI. Number of Input Errors Recorded During Data Collection

Task	Not Flying			In Flight		
	MCTAS	Thum-ball	Touch screen	MCTAS	Thum-ball	Touch screen
Select Subsystem	0	3	1	0	0	1
ACAWS Alert	0	0	0	0	0	0
Select Symbology	5	1	0	1	0	3
Enter Reference Altitude	1	1	3	0	0	4

Table XII. Input Concept Preference of Pilots for Various Conditions

Preference	Potential Usefulness In Transports	Routine Flight Conditions	Emergency Flight Conditions
1st	Touch Screen	Touch Screen	Thumball
2nd	Thumball	Thumball	Touch Screen or MCTAS
3rd	MCTAS	MCTAS	MCTAS or Touch Screen

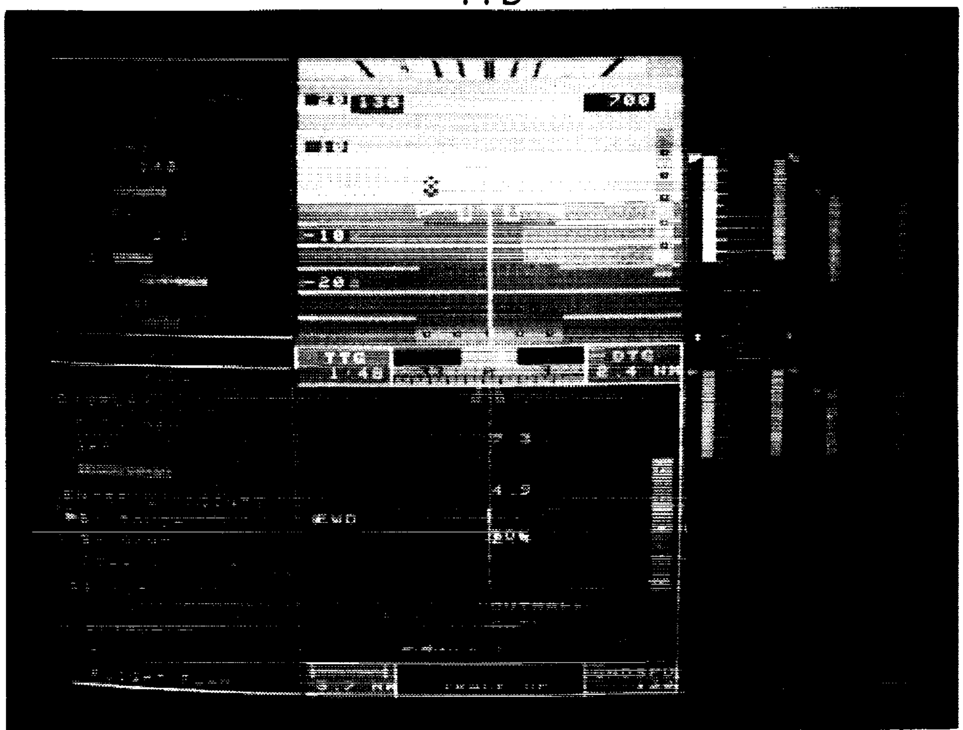

Figure 1. Whole-flight-deck display.

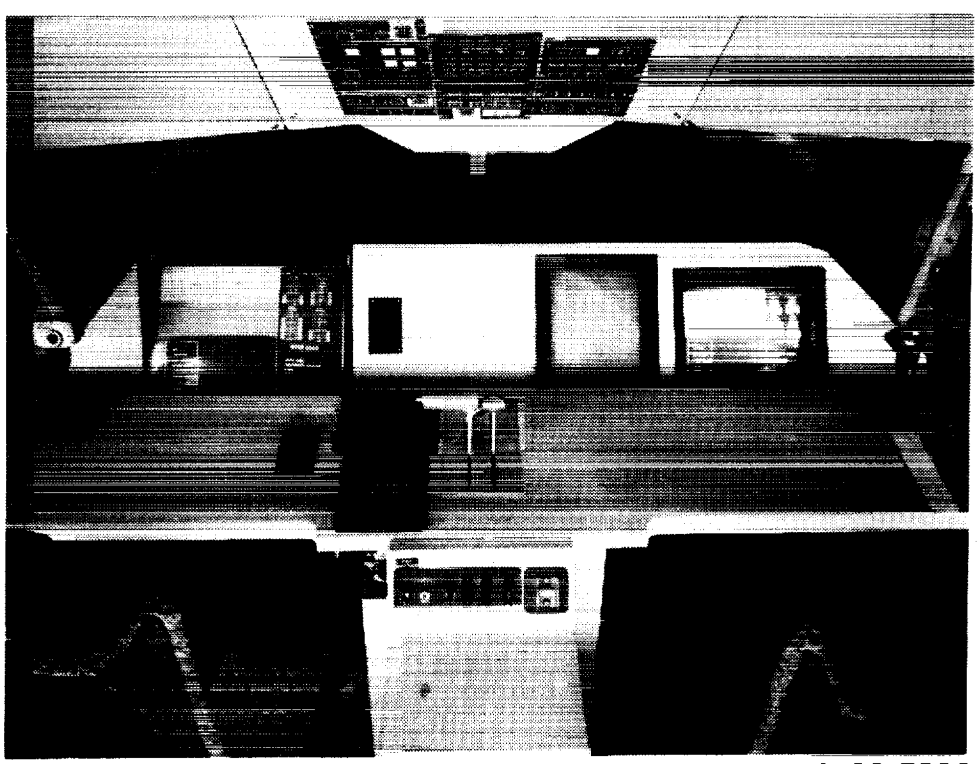

Figure 2. Research simulator cockpit.

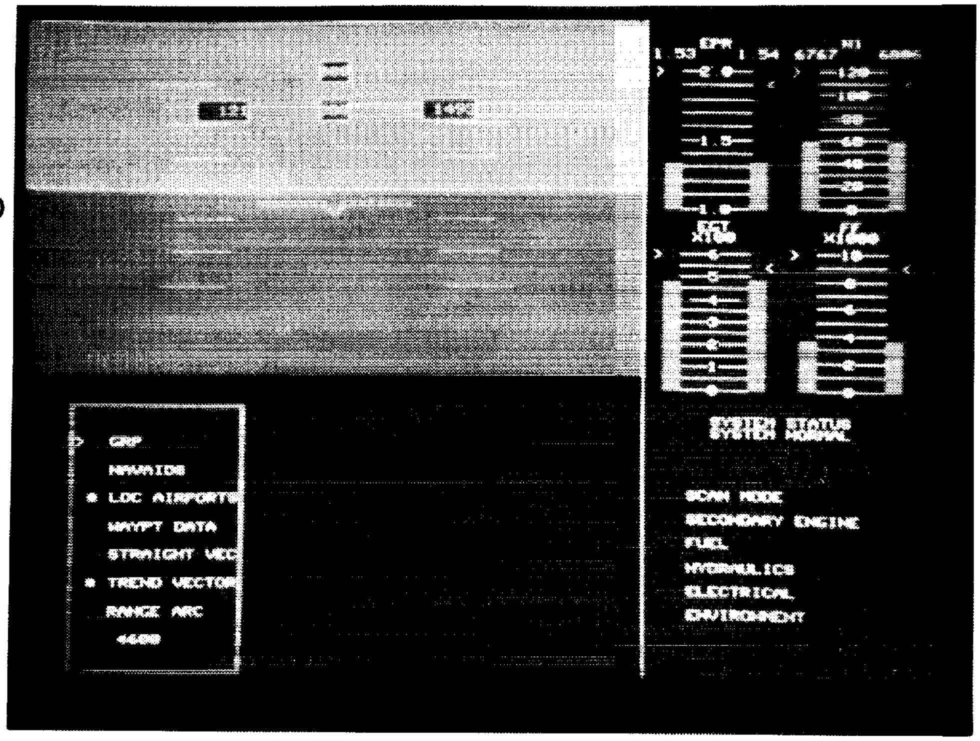

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Figure 3. Whole-flight-deck display utilized for present study.

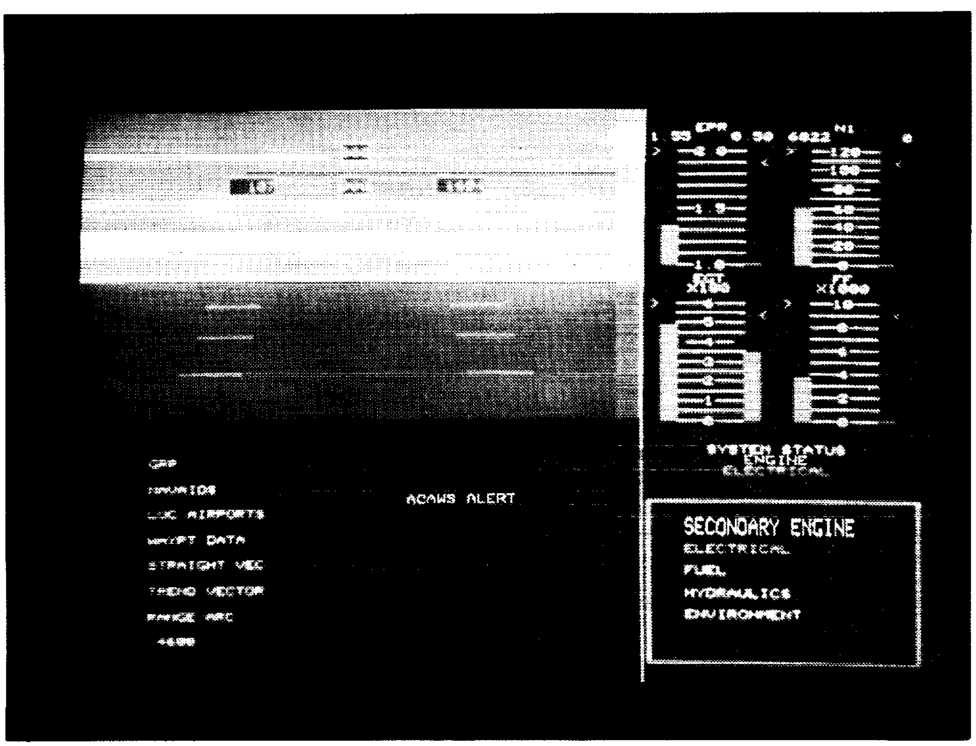

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Figure 4. Whole-flight-deck display emphasizing Advisory Caution And Warning System.

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Figure 5. Side-arm controller with thumball input device.

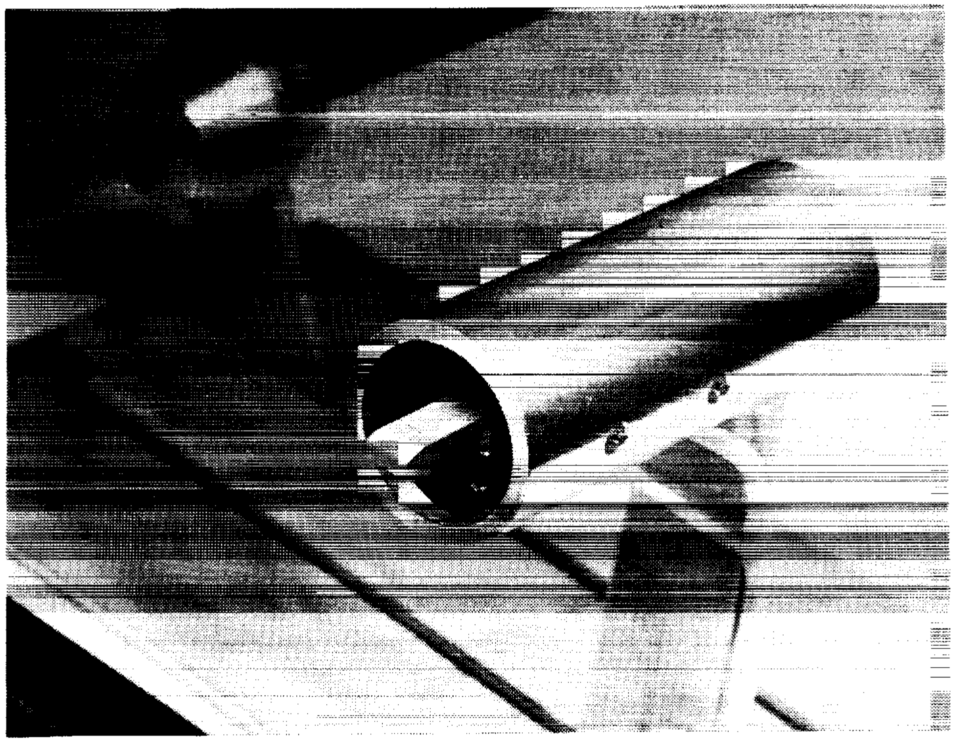

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Figure 6. Multifunction Control Throttle And Stick thumb switch located in throttle handle.

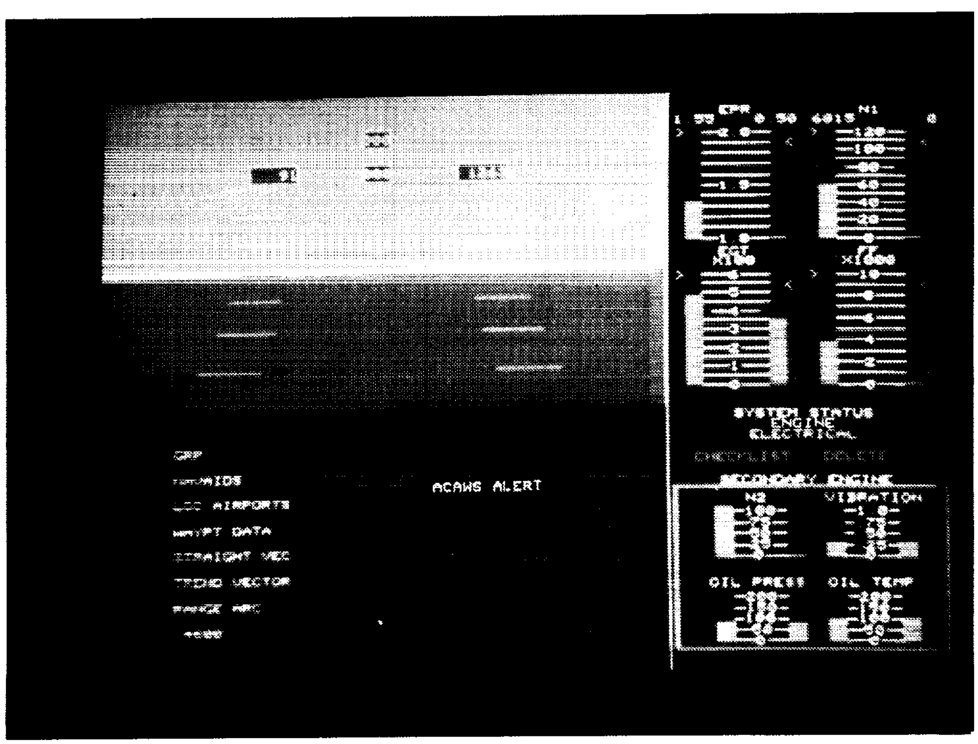

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Figure 7. Whole-flight-deck display featuring delete option for system failure for touch concept.

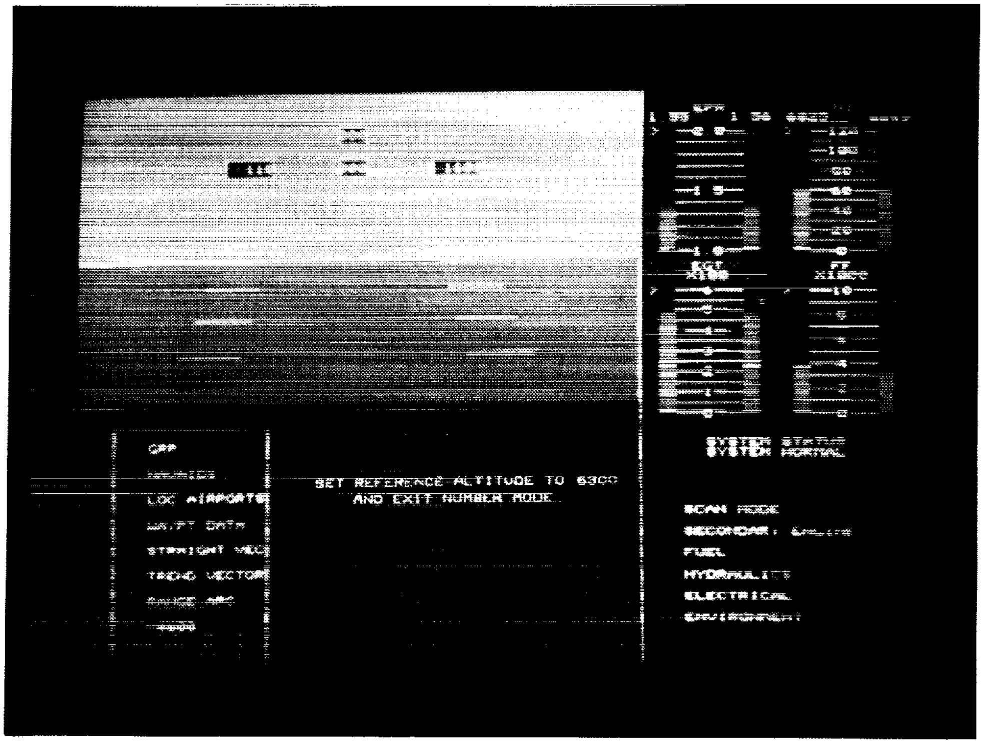

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Figure 8. Whole-flight-deck display showing method of numerical entry for touch concept.

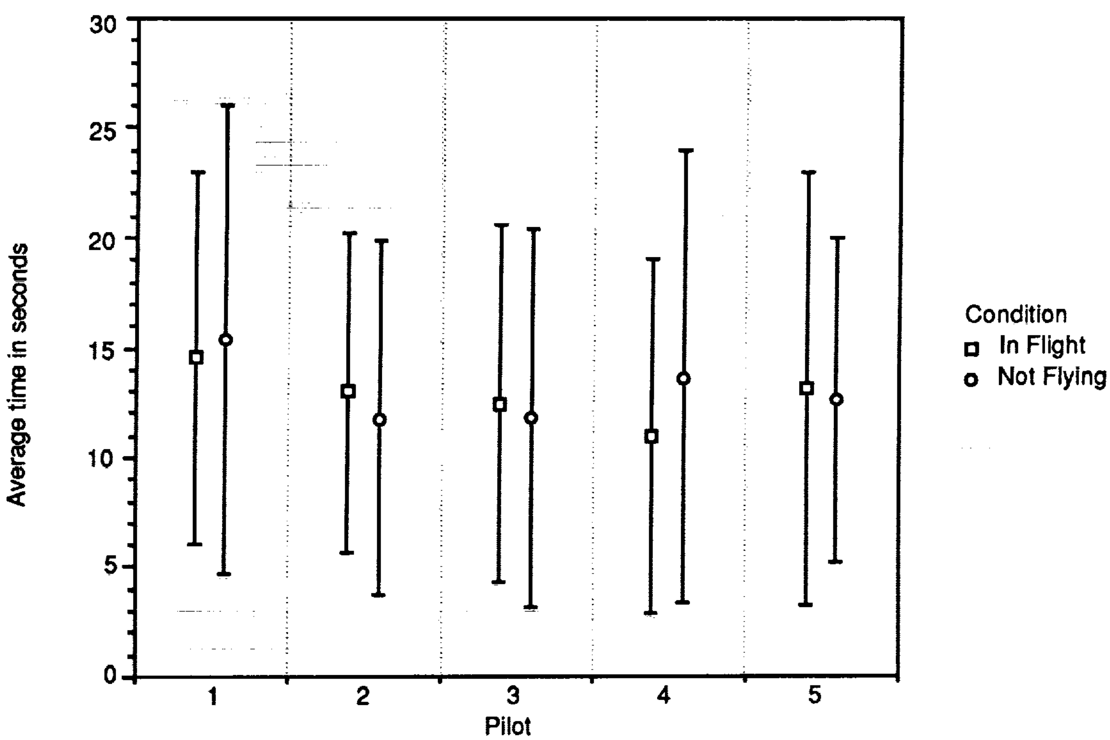

Figure 9. Average completion times of the flight conditions for all runs for each pilot.

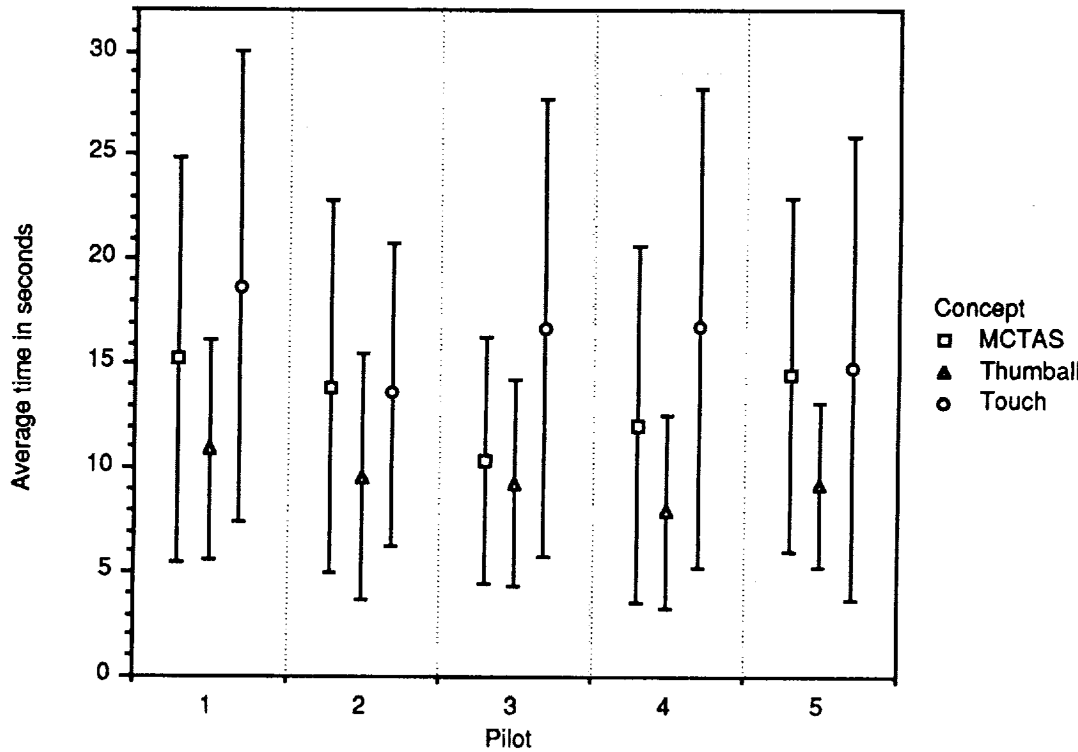

Figure 10. Average completion times of the various tasks for the three input concepts for each pilot.

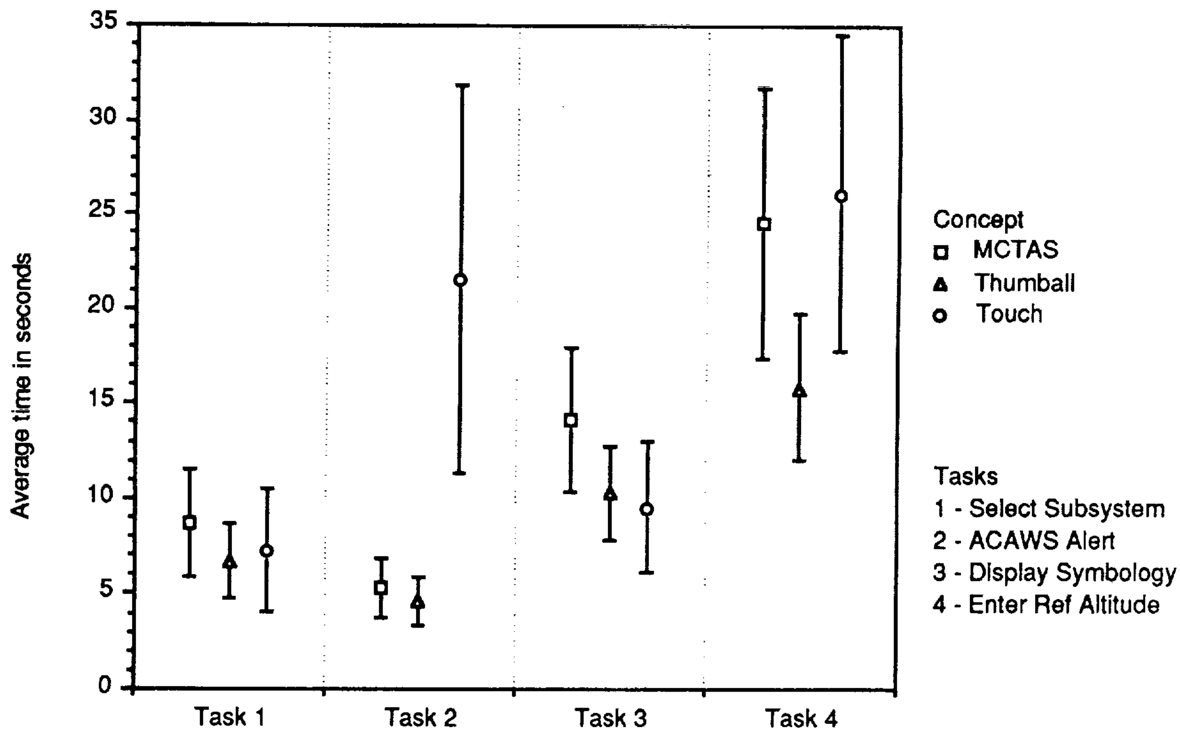

Figure 11. Average completion times of each input concept for all pilots for each task.

Report Documentation Page

National Aeronautics and Space Administration

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TM-102587		

4. Title and Subtitle

Simulator Comparison of Thumball, Thumb Switch, and Touch Screen Input Concepts for Interaction with a Large Screen Cockpit Display Format

5. Report Date

April 1990

6. Performing Organization Code

7. Author(s)

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8. Performing Organization Report No.

10. Work Unit No.

505-66-11-02

9. Performing Organization Name and Address

NASA Langley Research Center
Hampton, VA 23665-5225

11. Contract or Grant No.

12. Sponsoring Agency Name and Address

National Aeronautics and Space Administration
Washington, DC 20546-0001

13. Type of Report and Period Covered

Technical Memorandum

14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

A piloted simulation study has been conducted comparing three different input methods for interfacing to a large screen, multiwindow, "whole-flight-deck" display for management of transport aircraft systems. The "thumball" concept utilized a miniature trackball embedded in a conventional side-arm controller. The "Mulifunction Control Throttle and Stick" (MCTAS) concept employed a thumb switch located in the throttle handle. The touch screen concept provided data entry through a capacitive touch screen installed on the display surface. The objective and subjective results obtained indicate that, with present implementations, the thumball concept was the most appropriate for interfacing with aircraft systems/subsystems presented on a large screen display. Not unexpectedly, the completion time differences between the three concepts varied with the task being performed, although the thumball implementation consistently outperformed the other two concepts. However, pilot suggestions for improved implementations of the MCTAS and touch screen concepts could reduce some of these differences.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Display Systems Man-Machine Systems Aircraft Instrumentation Input Systems	Unclassified-Unlimited Subject Category 06

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of pages	22. Price
Unclassified	Unclassified	30	A03

NASA FORM 1626 OCT 86