TECHNICAL REPORT

AUTOMATED TACTICAL AIRCRAFT LAUNCH AND RECOVERY SYSTEM MAN-MACHINE INTERFACE ANALYSIS

December 17, 1987

Prepared for

Electronic Systems Division
Air Force Systems Command, USAF
Hanscom AFB, Massachusetts 01731-5000

under Contract F19628-87-D-0013
Subcontract HH-C-FY87-001

by

Chris Boyd
Jean A. Gruhler

ARINC Research Corporation
a Subsidiary of ARINC Incorporated
2551 Riva Road
Annapolis, Maryland 21401

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
1987 Dec 17

3. REPORT TYPE AND DATES COVERED
FINAL

4. TITLE AND SUBTITLE
Automated Tactical Aircraft Launch and Recovery System Man-Machine Interface Analysis

5. FUNDING NUMBERS
F19628-87-D-0013

6. AUTHOR(S)
Chris Boyd, Jean A. Gruhler

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
ARINC Research Corp.
2551 Riva Road
Annapolis, MD 21401

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Hq Electronic Systems Division XR
Hanscom AFB, MA 01731-5000

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for Public Release; Distribution Unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
This document contains the results of a US Air Force contracted study to examine some of the Man-Machine Interface (MMI) implications of the Automated Tactical Aircraft Launch and Recovery System (ATALARS) concept.

14. SUBJECT TERMS
ATALARS, air traffic control, ATC, MMI, human factors interaction, displays, software, processing, airspace, optical engineering

15. NUMBER OF PAGES
37

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAR

NSN 7540-01-280-5500

Standard Form 298 (Rev 2-89)
Prescribed by ANSI Std Z39-18
298-102

Technical Report

Automated Tactical Aircraft Launch and Recovery System Man-Machine Interface Analysis

December 17, 1987

Prepared for:

Electronic Systems Division

Air Force Systems Command, USAF

Hanscom AFB, Massachusetts 01731-5000

Prepared by:

ARINC Research Corporation

Under Subcontract to:

HH Aerospace Design Co., Inc.

Sub-Contract HH-C-FY87-001

CONTENTS

CONTENTS (continued)

LIST OF ILLUSTRATIONS

LIST OF TABLES

CHAPTER ONE

INTRODUCTION

This document contains the results of a US Air Force contracted study to examine some of the Man-Machine Interface (MMI) implications of the Automated Tactical Aircraft Launch and Recovery System (ATALARS) concept.

1.1 BACKGROUND

Between 1982 ~~and~~ 1986, under the sponsorship of the Electronic Systems Division ~~(ESD)~~, Hanscom AFB, Air Traffic Control ~~(ATC)~~ survivability studies were conducted. These studies examined the major issues relating to ATC in a tactical wartime environment and identified a need for long range planning with survivability as the major thrust. The ATALARS concept evolved out of these efforts, ~~and was presented in ESD-TR-86-259.~~ Concepts, requirements, and design analyses were further defined in the "Advanced Air Traffic Control Concept Study" report prepared by ARINC Research Corporation, and Vanguard Research Incorporated under contract with ESD through HH Aerospace Design Company, Incorporated.

1.2 REPORT ORGANIZATION

~~The body of~~ this report focuses on four aspects of the MMI requirement:

~~Chapter 2~~ 1) The controller's display requirements (e.g. size, resolution, number of colors);

~~Chapter 3~~ 2) The controller's terminal, specifically display manipulation devices and hardware aspects of database input/output;

~~Chapter 4~~ 3) Display manipulation software functions, primarily utility functions and to a lesser extent application functions; and

~~Chapter 5~~ 4) The pilot's display requirements.

The report's conclusions and recommendations are contained in Chapter 6.

CHAPTER TWO

CONTROLLER'S DISPLAY REQUIREMENTS

2.0 INTRODUCTION

This chapter presents an analysis of the required characteristics of the controller's display. Characteristics examined include display size, resolution, colors, refresh rate, contrast ratio, pixel pitch, and raster versus vector scanning.

2.1 DISPLAY SIZE AND RESOLUTION

Display size and resolution are determined in conjunction with the relationship shown in Equation 2-1 with the variables defined as follows:

$$\frac{\text{maximum airspace dimension}}{\text{minimum feature}} = \frac{\text{display size}}{\text{resolution}}$$

Equation 2-1

Maximum Airspace Dimension - From Reference 1, Section 8.1.4, Coverage Capacity, states "ATALARS coverage zones would be on the order of 50 to 100 nautical miles maximum dimension."

Minimum Feature - For ATC purposes, we will define the minimum feature using aircraft separation minima. Table 2-1 presents these minima for various situations.

For enroute operations, Table 2-1 shows the most restrictive situation has a 4 mile minima.

If we assume a 10% variation in the distance between two points is the best, we can expect an operator to perceive without an adjacent reference line (Reference 2), then the controller needs to see at least 10 incremental steps between the acceptable minima (4 miles) and coincident targets. Therefore, a distance of 4/10 of a mile must be easily discernable on the display.

TABLE 2-1

AIRCRAFT SEPARATION MINIMA (REFERENCE 4)

SITUATION	SEPARATION
APPROACH AND DEPARTURE	
Diverging courses after departure	
Immediately after takeoff	1 minute
5 minutes after takeoff	2 minutes
13 miles Distance Measuring Equipment (DME) after takeoff	3 miles
Parallel runways	3,500 feet
Diverging runways	2,000 - 3,500 feet
Same course after departure	
Following aircraft climbing through lead aircraft altitude	3 minutes
Same, but both aircraft using DME	5 miles
Departing aircraft initial separation from arriving aircraft	4 miles
ENROUTE	
Minima on same, converging, or crossing courses	
Lead aircraft 44 knots faster	3 minutes
Same, but both aircraft using DME	5 miles
Lead aircraft 22 knots faster	5 minutes
Same, but both aircraft using DME	10 miles
One aircraft descending or climbing	5 minutes
Same, but both aircraft using DME	10 miles
Converging radials (90° or more) to same NAVAID	4 miles
Same, but using DME	5 miles

If we assume a 20 inch display with 100 miles full scale, then 4/10 mile would be shown as 0.08 inches. Reference 2 recommends an eye to display distance of 18 to 22 inches. At this distance from the eye, 0.08 inch represents 13 to 14 minutes of arc.

Reference 3 indicates that provided sufficient contrast this is well above the human eye's visual acuity threshold of one minute of arc.

Equation 2-1 therefore becomes:

$$\frac{100 \text{ Miles}}{0.4 \text{ mile}} = \frac{20 \text{ inch}}{.08 \text{ inch}}$$

Equation 2-2

Figure 2-1 presents the applicable geometry.

2.2 PIXEL PITCH

In Section 2.1 we found that a minimum feature of 0.08 inches or about 2 millimeters (mm) capability is a good first estimate of the resolution required to meet operational needs. However, as this value was derived from various separation minima, it represents a value where two targets should appear distinctly separate. In contrast, pixel pitch requirements should be based on the smooth generation of the various graphic symbology used on the controller's display.

Circles and diagonal lines, in particular, appear jagged if an excessively large pixel pitch is used. Figure 2-2 provides a representation of the relationship between pixel pitch and minimum feature resolution. As shown, the strain on the operator increases directly as the pixel pitch approaches the minimum feature dimension. At the other end of the scale, Figure 2-2 shows that the pixel pitch available with current display technologies (0.25 mm) approaches the visual acuity threshold for a display to viewer distance of 20 inches. With a 35% improvement in pixel pitch, the human eye would be incapable of distinguishing adjacent pixels. Graphic symbols would appear to be constructed from smoothly joined lines and geometric primitives. Therefore, a pixel pitch range of 0.25 mm (state-of-the-art) to 0.14 mm (visual acuity threshold) is recommended.

2.3 REFRESH RATE

The primary factor driving the display refresh rate is the availability of updated aircraft position information. To provide the controller with the most accurate information available the refresh rate for the controller's display should be at least as fast as the aircraft track data update rate. However, if aircraft track updates are based on exception reporting (deviations from intended flight profile) from intelligent terminals onboard the aircraft, then there is no inherent track update rate. In this case, ATALARS would synthesize aircraft position information based on a track predictive algorithm, and the track update frequency would be a function of the algorithm execution rate and the number of targets.

The need for high display refresh rates is then driven by the need to portray smooth target motion on the display. Current ATC display refresh rates are usually based on the radar track information update rate. Target motion, as presented on the display, is incremental. While this

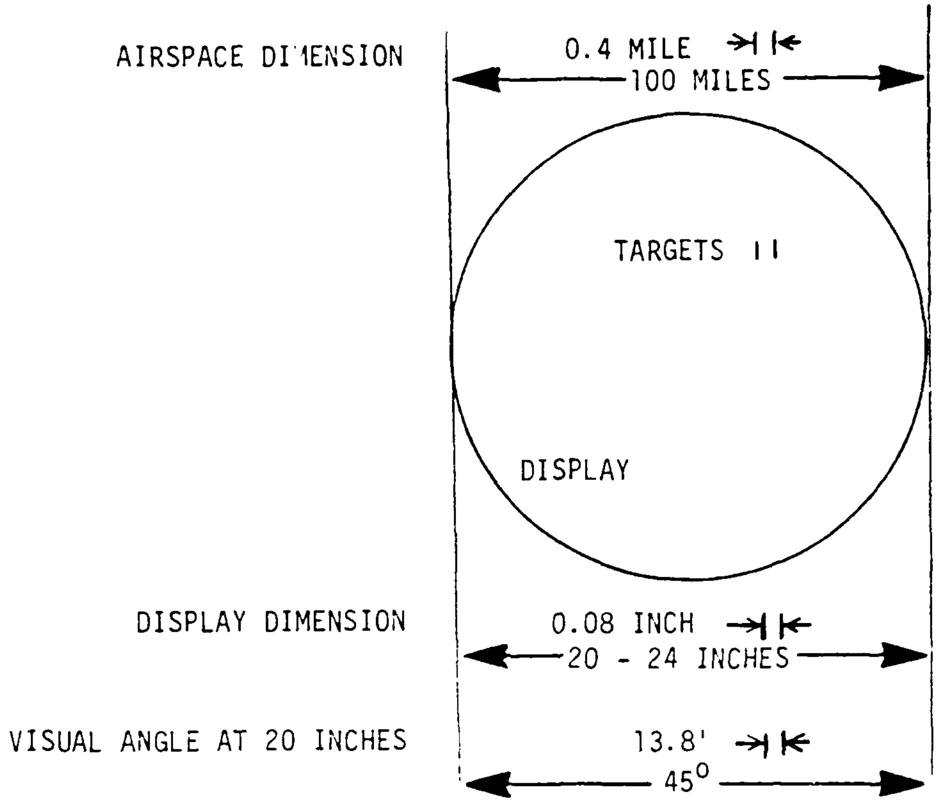

FIGURE 2-1

DISPLAY GEOMETRY

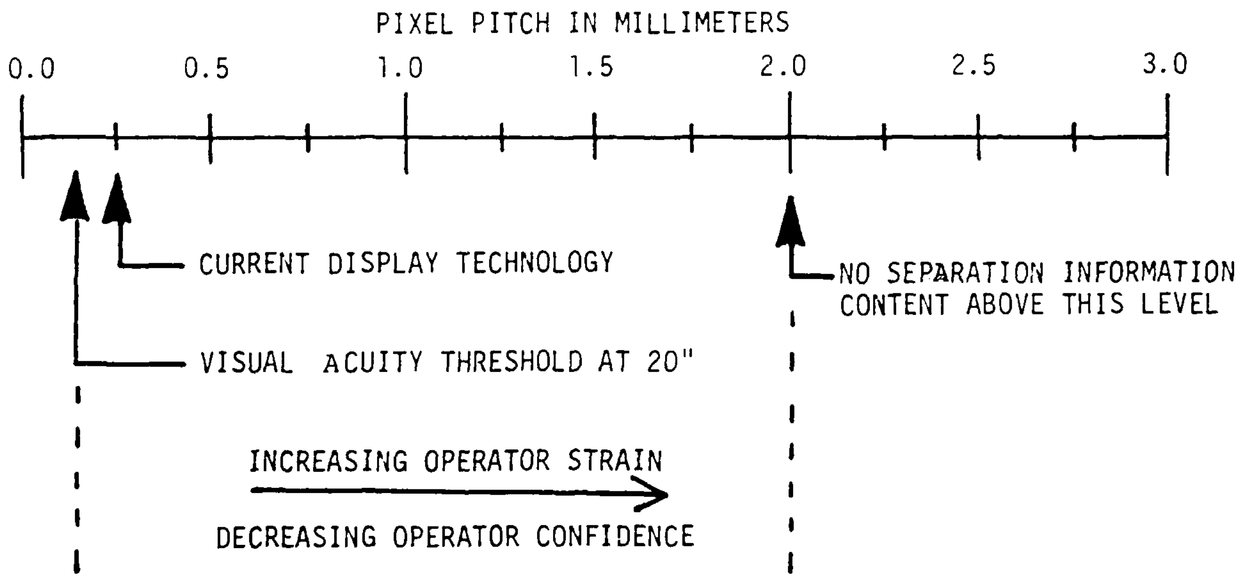

FIGURE 2-2

PIXEL PITCH AND RESOLUTION

has proven to be a workable situation, that is not to say it is optimal with respect to human factors. Smooth target motion provides the controller with important cues that are particularly helpful when visualizing course projection, clearance past an obstruction, and clearance past another aircraft. Figure 2-3 shows threshold values for display refresh rates that provide smooth motion under various conditions. Figure 2-4 graphs the relationship between aircraft velocity and display refresh rate for two different pixel pitches.

2.4 CONTRAST RATIO

The contrast ratio, as defined here, is the ratio between the light levels emitted from the brightest point on the display and the darkest point. Table 2-2 provides contrast ratios for various display technologies. In general, a plot of contrast ratio versus any visually dependent performance measurement is strictly monotonic, i.e., increased contrast ratios provides improved performance. Therefore, specification of the maximum available contrast ratio for the controller's display tends to be limited by cost and technical considerations. However, from a human factors standpoint, we can identify a minimum acceptable contrast ratio. Any increase above the minimum would be desirable. As shown by Table 2-2, a contrast ratio of 20:1, equivalent to a good Cathode Ray Tube (CRT) today, is the minimum acceptable.

TABLE 2-2

CONTRAST RATIOS OF VARIOUS DISPLAY TECHNOLOGIES

DISPLAY TECHNOLOGY	CONTRAST RATIO
Liquid Crystal Display (LCD)	3:1
Backlit LCD	7:1
Backlit Supertwisted Crystal	12:1
Gas Plasma	13 to 17:1
CRT	15 to 20:1
ATALARS Minimum	20:1
Flat Tension Mask CRT	25 to 30:1

2.5 COLOR

To some extent the discussions in Sections 2.1, 2.2, and 2.3 concerning resolution, pixel pitch, and refresh rate assumed raster scanning techniques. This was primarily due to the need for color display capability.

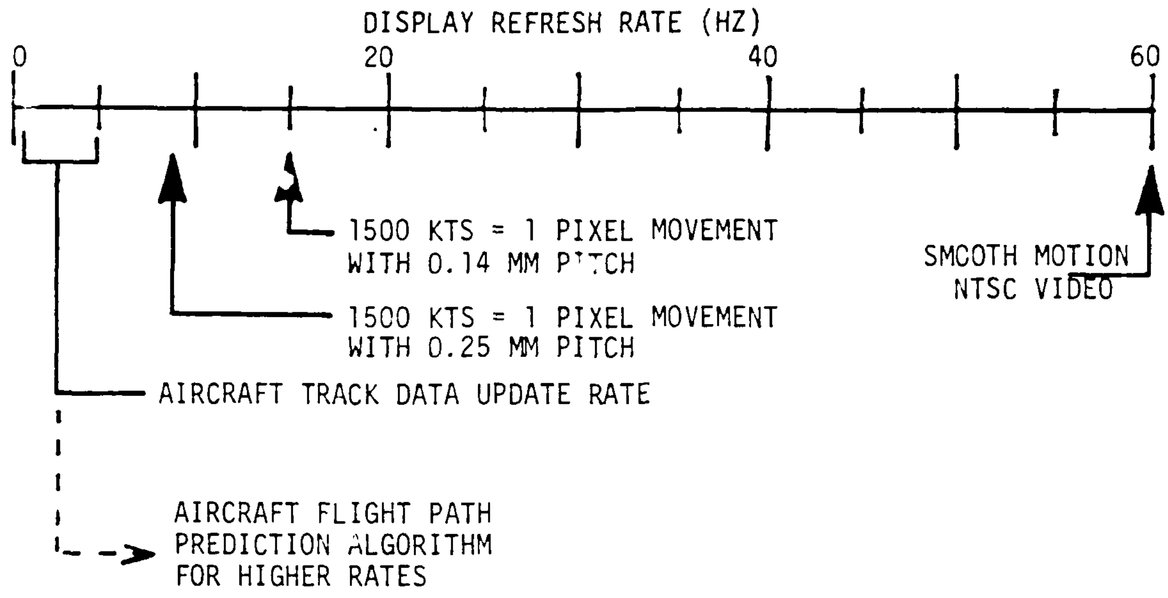

FIGURE 2-3

DISPLAY REFRESH RATE THRESHOLDS

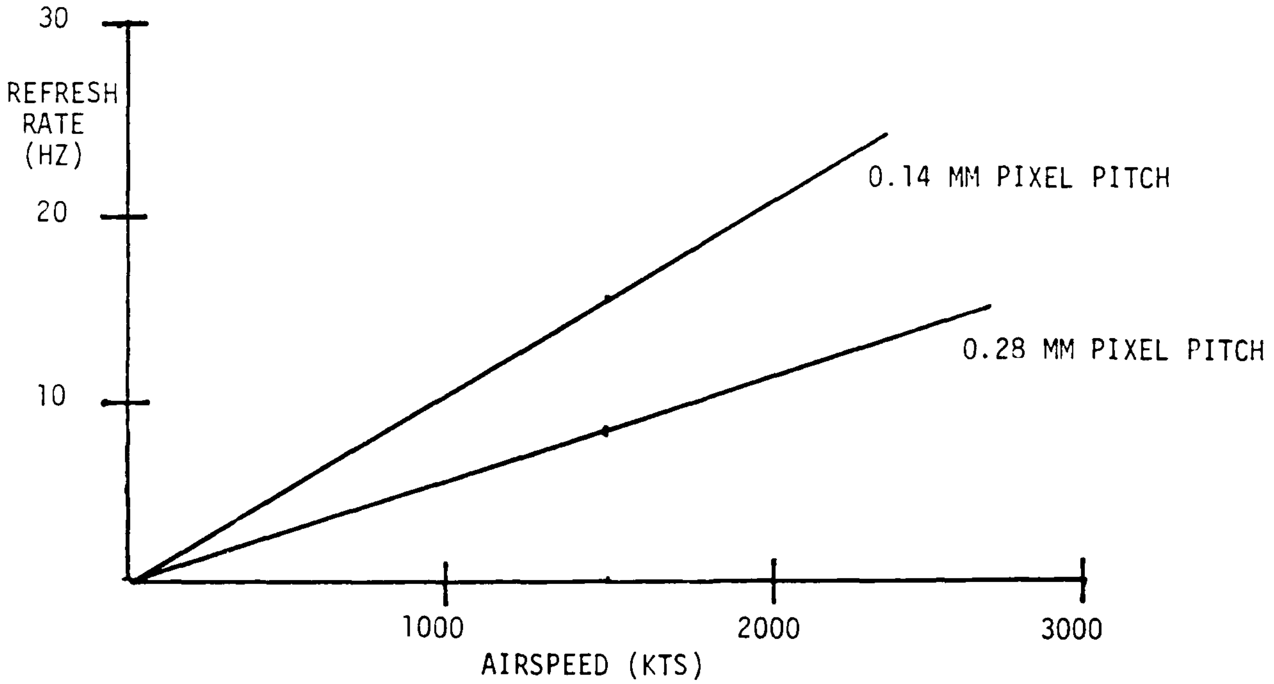

FIGURE 2-4

REFRESH RATE VS AIRCRAFT VELOCITY

The use of color at the MMI serves two purposes. First, an "alert" color is used to attract operator attention to an unusual or priority situation. Figure 2-5(a) is a chromaticity diagram standardized by the International Commission on Illumination. Colors are plotted in terms of the proportion of standard red or green in their makeup. Pure spectral colors (fully saturated) fall on the triangular solid line while pastels and "light" tints fall inside the triangle. Numbers along the line represent wavelengths in nanometers. An alert color should have good spectral distinction from other colors used on the display and should be saturated to the full display capability. When plotted on the chromaticity diagram against the capabilities of a hypothetical display, the display colors should be well spaced (from each other) around the perimeter that indicates maximum display intensity. As shown in Figure 2-5(b), such an arrangement could provide a maximum of five alert colors plus white and black.

The second use of color at the MMI is to increase information flow. A symbol, word, or number can have its intrinsic meaning augmented based on "information" colors. In this use of color spectral distinction is not as critical as with alert colors. The controller's attention is already focused, and the color conveys additional meaning. Figure 2-5(c) provides a color scheme with two alert colors, four information colors, plus white and black. The alert colors, red and orange, are close enough that a controller trained to look for either color will detect any occurrence of both colors. If more than four information colors are required, they should be spaced along the arc between 475 and 560 nanometers, away from the alert colors.

2.6 VECTOR SCANNED DISPLAYS

When a video picture is "painted" on the display screen, an electron beam is steered across the display. Variations in the intensity of the beam cause corresponding variations in the light emission from the phosphor coating on the screen. In raster scan displays, the electron beam scans the entire screen, row by row. With vector scan techniques, the electron beam traces only the symbols shown on the screen. This gives vector scanned displays, also called cursive displays or stroke writers, three inherent advantages over raster scanned devices.

First, the unlit area between symbols is not scanned at all. It therefore tends to be very dark, adding to the contrast and the readability. Second, higher intensity electron beams are feasible due largely to the longer beam switching time. This increases symbol brightness, contrast ratio, and readability. Third, diagonal lines are written with a single stroke of the electron beam instead of being assembled from a series of dots or short horizontal lines. Therefore, symbols appear smoother and more readable.

On the negative side, vector scanned displays have less color capability than raster scanned displays. Multiple layers of phosphor, each with different emission spectrum, are coated on the screen. Variations in the electron beam intensity cause variations in electron penetration of the phosphor layers and corresponding variations in the display colors.

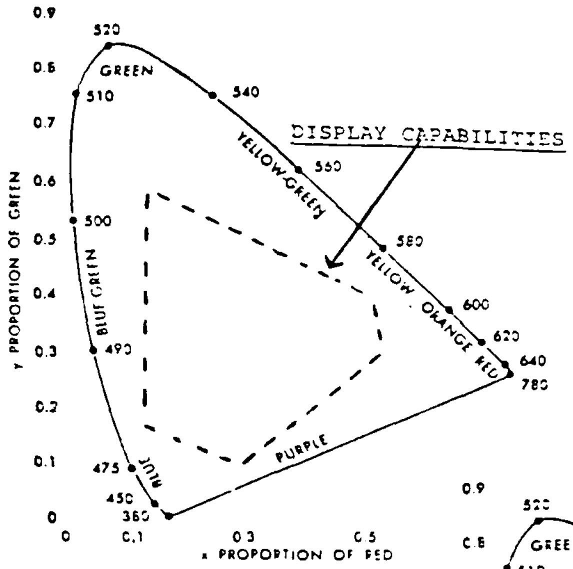

FIGURE 2-5(a)

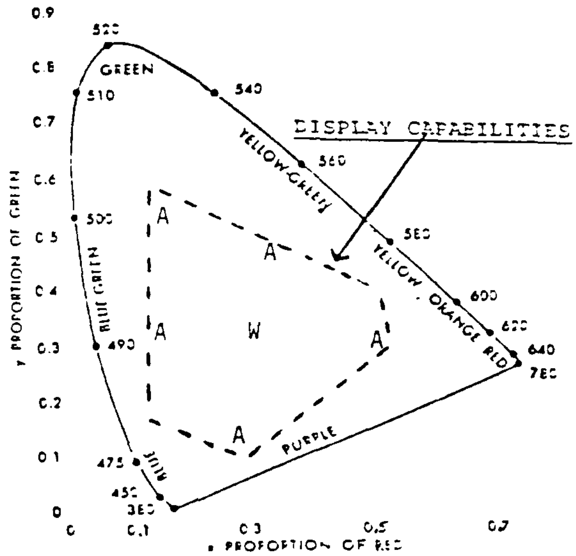

FIGURE 2-5(b)

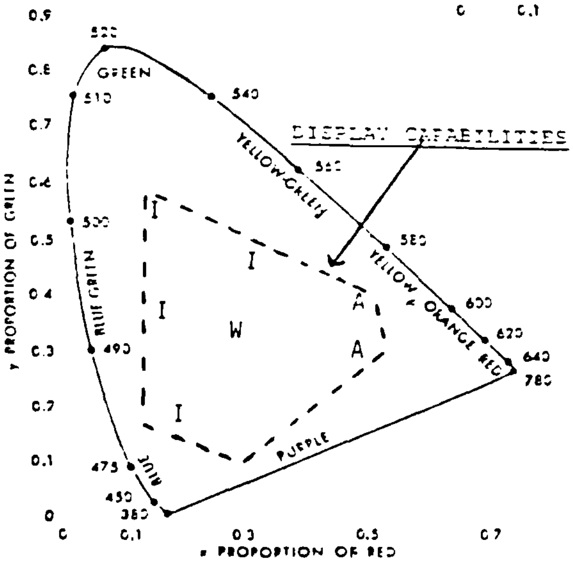

FIGURE 2-5(c)

A - ALERT
I - INFORMATION
W - WHITE

FIGURE 2-5(A, B, & C)
COLOR CHROMATICITY CHARTS

CHAPTER THREE

TERMINAL DEVICES AND CONTROLS

3.0 INTRODUCTION

This chapter presents an examination of various Input/Output (I/O) devices, display manipulation devices, and the hardware aspects of database I/O with respect to the controller's terminal. Terminal control devices fall into four functional areas: hardware activation and control, software function selection and control, data entry, and pointing. These areas will be examined in Sections 3.1 through 3.4 respectively.

3.1 HARDWARE ACTIVATION AND CONTROL

This category includes power switches; volume controls; display brightness, contrast, focus, intensity, and hue controls push-to-transmit switc.ies (if not voice activated); trim and sensitivity controls for the pointing device; and communications system controls.

While the placement of these controls is one of the primary concerns for a human factors analysis of the controller's work load, such an analysis must await a more detailed design definition than is currently available.

3.2 DATA ENTRY

Considerable effort should be made to reduce the amount of raw data entry required of the controller. This should include automated data links to provide weather information, flight plans, and facility status. The system should also prompt the controller with default or "best guess" values whenever data is required. The controller can then accept these values with a single keystroke. When no single value predominates, the controller may be able to select from a list of options with less effort (time and keystrokes) than required for full keyboard entry of the data. In addition, when keyboard entry is required, the system should be as fault tolerant as possible without allowing command ambiguities. For example, inconsistent spacing, incorrect spelling, and incomplete words or phrases should all be tolerated by the system provided there is a reasonable confidence level in what the controller meant to enter. Data entries should appear on-screen in the corrected form for controller verification.

The keyboard should have the standard "QWERTY" layout and be positioned directly in front of the controller for two-handed touch typing. In addition to alpha characters, the keyboard should include numbers in the usual positions along the top row to speed entry of alphanumeric strings. A separate 10-key number pad may be useful depending on the frequency of data entry tasks that are strictly numeric.

Voice recognition technology holds the potential for providing a major reduction in the controller's data entry work load. Although the controller's working vocabulary is fairly large, it is also well defined. This is largely due to the emphasis on standard phraseology and diction used to minimize transmission ambiguities.

Because the vocabulary is well defined, the technical risk in implementing a voice recognition system is significantly reduced. Table 3-1 shows the four major variations of the speech recognition problem.

TABLE 3-1

VARIATIONS OF THE SPEECH RECOGNITION PROBLEM

VARIATION NUMBER	LEVEL OF DIFFICULTY	NUMBER OF OPERATORS	CONTINUOUS SPEECH OR DISCRETE WORDS
1	HIGH	MULTIPLE	CONTINUOUS
2	MEDIUM	SINGLE	CONTINUOUS
3	MEDIUM	MULTIPLE	DISCRETE
4	LOW	SINGLE	DISCRETE

Even with the simplest variation, that of a single operation speaking discrete words, significant benefit could be provided for the controller. This is because the aural processes (speech and hearing) use a different area of the brain than vision and motor control. In control systems terminology, it is possible for the man-in-the-loop to become a parallel processor; eyes and hands coordinating on one task while giving voice commands for another. This represents a quantum step forward. Until now, most efforts to reduce the work load at the MMI were necessarily restricted to streamlining the operator's serial processing of the task queue.

3.3 SOFTWARE FUNCTION SELECTION

This section examines the requirements for terminal controls that activate all software driven procedures and functions, except for display manipulation functions to be examined in Chapter 4. Of the four functional areas of terminal control devices examined in this chapter, software function control represents the largest portion of the ATALARS controller work load.

Table 3-2 provides a partial list of software functions the controller must access. These functions were identified from an examination of several controller display mock-ups. From an MMI standpoint, it is necessary to identify those functions that require dedicated controls and those that can be accessed through multi-function controls. Multi-function controls help reduce control density on the console. If they are placed at the home position for the operator's hands, and on-screen definitions are provided, then many of the controller's tasks can be accomplished "head up", i.e., eyes on the display. An examination of the functions listed in Table 3-2 indicates that many functions would only be activated when a particular screen is displayed. These functions should be selected via multi-function keys with the key definition appearing on the appropriate screen.

3.4 POINTING

Pointing in this context refers to the controller positioning the display cursor coincident with a desired point, area, or target. This is usually followed immediately with the activation of a switch or control that indicates the cursor is in the desired position and the applicable procedure can be initiated.

An analysis of pointing device requirements must resolve two primary considerations: 1) what is the optimum hardware device, e.g., trackball, joystick, touch screen, etc.; and 2) what type of processing should be applied to the pointing device outputs to improve performance. These questions will be addressed in Sections 3.4.1 and 3.4.2 respectively.

3.4.1 Pointing Devices

This study has identified six types of pointing devices. They are the track ball, joystick, touch screen, light pen, mouse, and touch pad. Cursor keys (up, down, left, and right) were not considered, although for cursor movement during data entry and form filling they are very quick. Table 3-3 provides a summary of each device with respect to five performance characteristics applicable to the ATALARS application. These characteristics are console space claim, resolution, speed to position, simultaneous switching, and mobile operations compatibility.

Console space claim is an estimate of the console area required for mounting the hardware device. Hand, wrist, and forearm clearances were not considered. The touch screen and light pen were rated at zero space claim as they use the display screen and require no additional console space. The area estimate for the mouse is based on a 3:1 mouse to screen

TABLE 3-2

REPRESENTATIVE SOFTWARE CONTROLLED FUNCTIONS

AIRSPACE UTILIZATION CONTROL
- Add new airspace
- Delete existing airspace
- Show intersecting aircraft
- Control intersecting aircraft
- Show friendly air defense
- Create holding stack

AIRSPACE UTILIZATION DATA
- Define airspace boundaries
- Control intersecting aircraft
- Delete/cancel controlled area
- Confirm data entry

AIRCRAFT TRACK MONITORING
- Edit aircraft identification tag
- Show/hide aircraft track history
- Display current aircraft clearance
- Show airspace utilization
- Show weather
- Identify track source
- Overide route selection

ROUTE INTERRUPT HANDLING
- Select route
- Transmit route
- Automatic route selection enable
- Automatic route transmission enable
- Display aircraft route

AIRBASE STATUS REVIEW
- Designate landing/takeoff slot
- Adjust intervals
- Move block of landing/takeoff slots

CREATE STACK
- Designate navigation aid with pointing device
- Exit to stack control

STACK CONTROL
- Insert aircraft into stack
- Extract aircraft from stack
- Modify stack parameters

TABLE 3-3

POINTING DEVICE CHARACTERISTICS SUMMARY

	3.5 in. Track Ball	Isometric Joystick	Touch Screen	Light Pen	Mouse	Touch Pad
Console Space Claim	Fair, 25 in^2 (5"x5") Slightly more at back panel for shaft encoders	Good, 9 in^2 (3"x3")	Good, 0 in^2	Good, 0 in^2	Fair, 49 in^2 (7"x7"), Varies with required resolution	Poor, 100 in^2 (10"x10") Varies with required resolution
Resolution	Good, Software selectable	Good, Software selectable	Poor, One fat finger width	Fair, One pen point width	Good, Software selectable, provided sufficient area	Poor, $\frac{\text{Finger diameter}}{\text{Pad size}}$ Screen size
Speed to Point	Fair, varies with distance to point	Fair, varies with distance to point	Good, independent of distance to point	Fair to good, independent of distance to point	Fair, varies with distance to point	Poor to fair
Simultaneous Switching	None	One to four, plus palm switch	One on contact	One on contact	One to three	None
Mobile Operations Compatibility	Good, with proper wrist support	Good, with proper wrist support	Poor	Poor	None	Fair to poor

composite sensitivity ratio. Less sensitivity and greater resolution is available but will require more area. The touch pad area estimate is based on a 1:1 composite sensitivity ratio. Again, the pad could be larger or smaller depending on resolution requirements. Back panel space was not rigorously examined. In most cases it will not exceed the console space claim. However, because track balls often use digital shaft encoders mounted beside the ball, the back panel space claim can exceed that shown in Table 3-3 by typically 35% (MSI Model 625).

Resolution for a pointing device is defined as the smallest distance between adjacent targets that allows the operator to consistently and accurately select the desired target. For a touch screen or a light pen, the limiting factor is the diameter of the pointer (finger or pen), except that with a very fine pen point the limiting factor becomes the operator's manual dexterity and repeatability. The touch pad is similarly limited except that the dimensions of the touch pad can be changed according to the resolution required. Touch pad resolution then becomes dependent on the diameter of the pointer divided by the ratio of pad area to screen area. Outputs from the track ball, joystick, and mouse are processed (Section 3.4.2) before being used to position the cursor. With any of these three devices in the ATALARS application, resolution would not be a limiting factor.

Speed to position is defined as the time required to position the cursor coincident with a randomly placed target appearing on the screen. Given adequate resolution, the touch screen is a good performer in this category with the time required being independent of the target location on the screen. Similar conditions apply with the light pen except for the additional time required to pick up the pen. Figure 3-1, from Reference 5, provides a graph showing time to position for several track ball and joystick configurations. This figure indicates that at one part in a thousand required accuracy, a 3.5 inch track ball and an isometric joystick can be optimized to nearly the same time to position performance. Unfortunately, data was not available at lower accuracy levels that might be more typical of ATALARS requirements. Mouse performance should be similar to the track ball, perhaps slightly better in view of the better control of target overshoot tendencies with the mouse. Touch pad performance in time to position is rated poor as the operator must estimate the position on the touch pad that corresponds to the desired screen location, contact the pad, determine the initial error, and then drag his finger across the pad as required for final alignment.

Simultaneous switching is a determination of the number of binary switches that can be activated by the controller while moving the cursor. Single-handed operation only is considered. Use of the track ball precludes the activation of any switches with the same hand. Palm heel pads seen with some track ball configurations are not considered here due to excessive unintentional activation rates. The touch screen, light pen, and touch pad also offer no simultaneous pointing and switching capability. In some cases the touch screen or light pen is configured to position the cursor and activate a switch or screen contact. However,

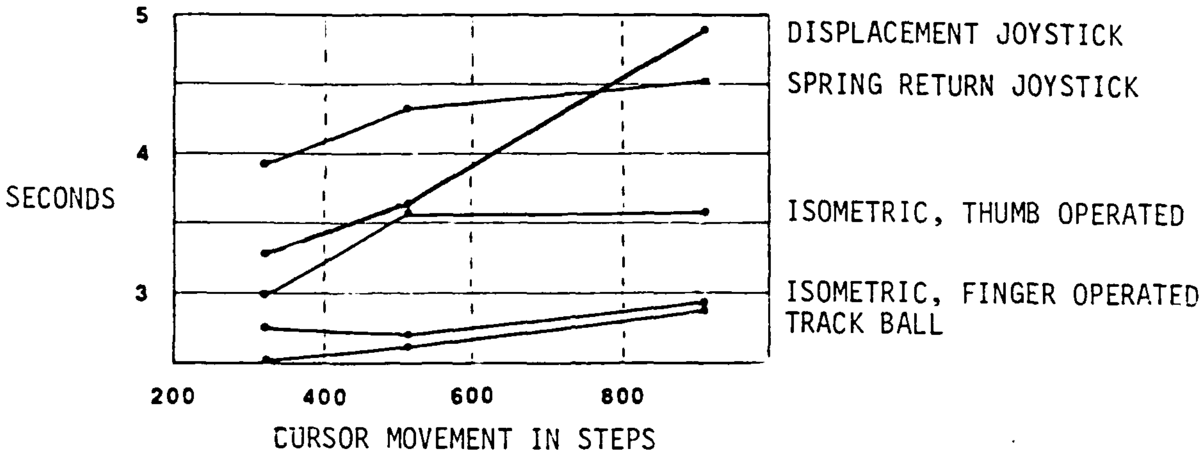

FIGURE 3-1

TIME TO POSITION

this does not allow cursor position verification by the controller prior to switch (procedure) activation. For some ATALARS functions and procedures this may be unacceptable. The mouse provides access to a maximum of three switches during cursor movement. These switches are positioned under the index, middle, and ring finger while the thumb and fifth finger grasp opposing sides of the mouse. The joystick can typically provide up to four hands-on switches when the joystick is ergonomically contoured. Three thumb-activated and one index finger activated switches is the most common configuration. With a simple post style joystick a single switch is mounted at the upper end of the post. An additional palm (deadman) switch can be configured for the joystick, the mouse, and possibly the light pen.

Mobile operations compatibility evaluates the performance degradation inherent in the pointing device during periods when the ATALARS van subsystem is in motion. Until the question of echelon employment versus mobile operations is resolved, this characteristic of a pointing device is a concern. Since maximum accelerations will be experienced in the vertical direction when in motion, the vertical orientation of the touch screen and light pen will induce translation errors. The horizontally oriented touch pad will induce inadvertant and intermittent contact. The mouse will roll off the table unless caged. The joystick and track ball should provide good performance provided proper wrist support is provided.

3.4.2 Output Processing

The touch screen, light pen, and touch pad are proportional displacement controls. That is, there exists a one-to-one correspondence between the placement of the pointer or pen and the cursor position. This is not necessarily the case with the track ball, joystick, or mouse. An increase in accuracy and a decrease in response time and fatigue is possible when various signal processing techniques are applied to the pointing device output prior to driving the cursor. In this section we will examine three aspects of classical control system theory, proportional control, rate control, and aided tracking, that are applicable to the ATALARS effort. In addition, we will look at two "smart" cursor control techniques, "snap" and "dead zone" that have recently seen increased use.

3.4.2.1 Classical Control System Techniques

Figure 3-2(a) provides a block diagram of a simple feedback control system. Figure 3-2(b) shows the same system as it is applicable to the ATALARS pointing problem. The reference input becomes the target position, the controlled variable becomes the cursor position, the actuating signal becomes the pointing device input, the feedforward element becomes the pointing device output processor, and the feedback element transfer function combined with the comparator are replaced by the "man-in-the-loop", that is, the controller.

It is convenient to view the controller simply as the transfer function in the feedback loop. However, it is difficult to describe the

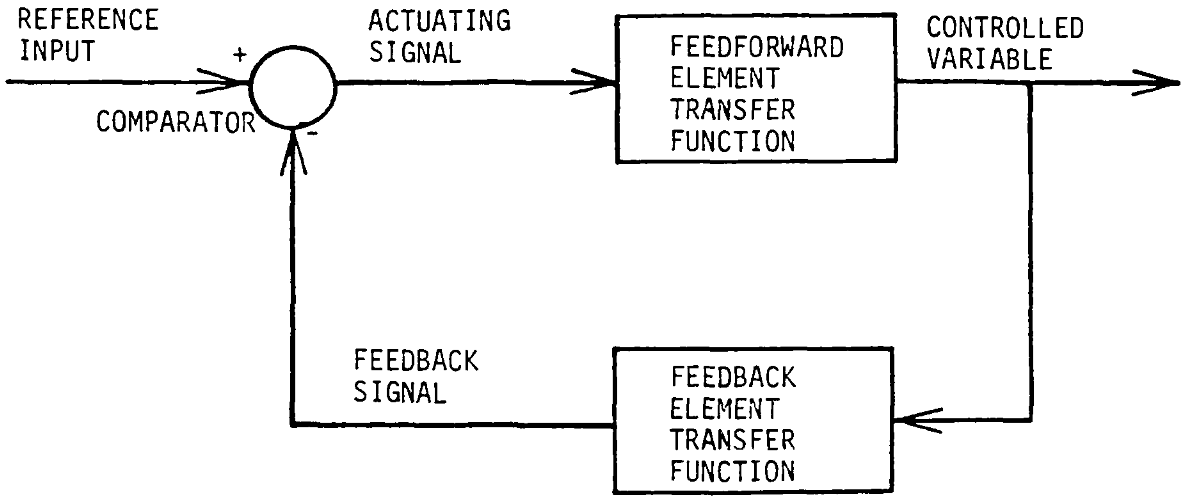

FIGURE 3-2(A)

FEEDBACK CONTROL BLOCK DIAGRAM

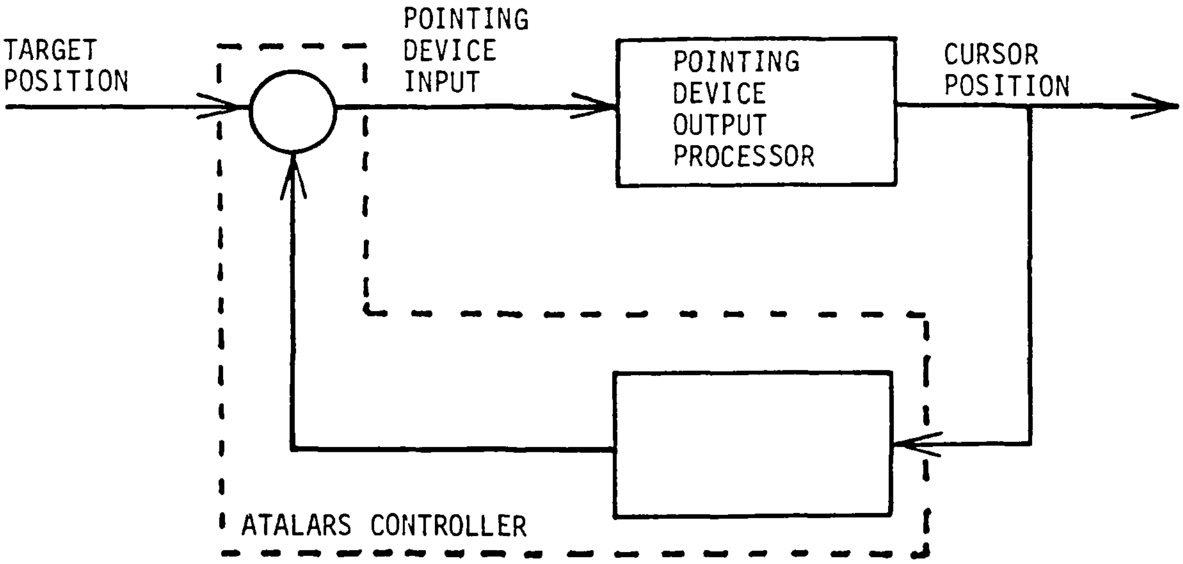

FIGURE 3-2(B)

CURSOR CONTROL BLOCK DIAGRAM

controller in terms of a single mathematical model because he is capable of changing his transfer function in response to varying conditions. For example, the human controller provides an adaptive, self-modifying transfer function in the feedback loop, i.e, he is capable of learning. The maximum effectiveness of the learning or training process represents a limit to system performance improvements available through the feedback loop. However, system performance can be further improved through selection of the proper feedforward elements or, in the ATALARS application, through selection of the proper signal processing to be applied to the pointing device input.

Proportional displacement control is perhaps the simplest signal processing option. The change in the cursor position is directly proportional to the position change of the joystick, track ball, or mouse. Self-centering and isometric joysticks are unsuitable in this mode as the cursor would return to center screen when the controller released the joystick.

Rate control is a signal processing technique where the application of a force or deflection on the control produces a corresponding velocity or rate at the cursor. Pure rate control is unsuitable for use with the mouse, track ball, or non-centering joystick as the controller has to return to the device to the null position in order to stop cursor motion.

Aided tracking is a processing technique that is a combination of the first two techniques, that is, an input to the pointing device produces a corresponding position change in addition to a resulting rate. The ratio of position to rate control is called the aided tracking time constant. This technique was initially implemented to compensate for a demonstrated tendency to overshoot the target.

While pure proportional displacement control is unsuitable for certain hardware devices, and pure rate control is unsuitable for other devices, aided tracking with an adjustable tracking time constant provides the flexibility to meet the ATALARS controller's pointing requirements with a variety of devices.

3.4.2.2 Smart Cursor Control Techniques

A smart cursor control technique with the potential to favorably impact controller response times and fatigue levels is known as "cursor snap." With this technique the cursor does not move smoothly and continuously about the screen. Instead, it snaps or jumps from one valid target to another in response to the controller's input. There is virtually no time that the cursor is between targets. The controller never has to decide if the cursor is close enough to the desired target to activate a function. This is a simple concept but the impact, particularly to reduce controller's fatigue, can be significant.

A second technique that may be useful for the ATALARS pointing function is a controller variable dead zone. The initial cursor response follows a step function with no cursor movement when the input is below a threshold value. This allows the controller to rest his hand on the pointing device without causing unintentional cursor movement.

CHAPTER FOUR

DISPLAY MANIPULATION FUNCTIONS

This chapter examines the software implementation of various display manipulation functions. These functions include display pan, zoom, cropping, transfer, and scoping.

4.1 DISPLAY PAN AND ZOOM

Figure 4-1 provides a display screen in context with a three axis frame of reference. The ATALARS controller should be able to pan the display perspective (point of view) left and right along the x-axis, up and down along the y-axis, and zoom in and out along the z-axis. This is a total of three "degrees of freedom"; that is, three axes of translation. In addition, the need for cursor control with two degrees of freedom (x-and y-axes) has been previously established. Altogether there are possible requirements for control of up to five degrees of freedom. However, since simultaneous control of all five will not be required, there exists relatively simple hardware solutions.

One such solution would use a track ball and a three position, spring-centered rocker switch. A track ball provides control of two degrees of freedom, that is, it can be configured to move a cursor along the x-and y-axes. A three position rocker switch could effectively multiply that capability to six degrees of freedom, one more than required. Push the rocker switch forward and movement of the track ball pans the display left, right, up, and down. Release the rocker switch and the track ball is in the cursor control mode. Pull the rocker switch back and the track ball controls display zoom with forward and backward movement of the ball.

A joystick, substituted for the track ball, would provide a functionally equivalent control solution. However, the rocker switch could be mounted on the joystick crown for thumb operation.

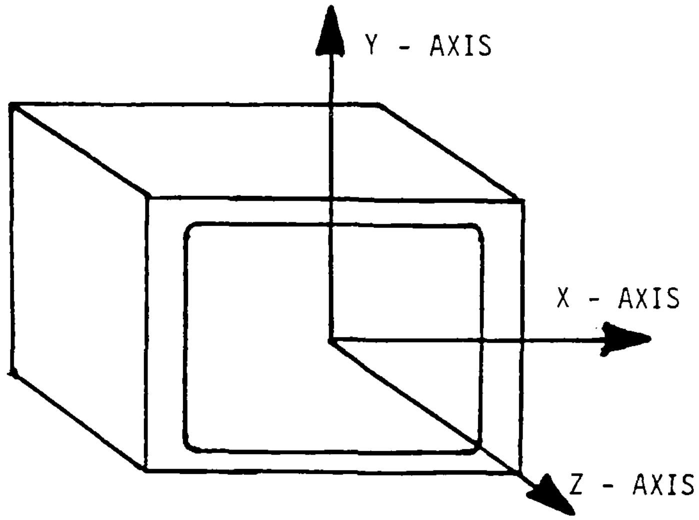

FIGURE 4-1

DISPLAY FRAME OF REFERENCE

4.2 DISPLAY CROPPING

Display cropping involves trimming the non-pertinent portions of the borders of the display and expanding the remaining image to full-sreen size to provide maximum detail with minimum eye-strain. Display cropping should be software controlled and automatically implemented. No controller action should be necessary. However, since this will cause variations in distance scaling on the display that were not specifically activated by the controller, a distance reference scale should appear on the display at all times.

4.3 DISPLAY TRANSFER

Display transfer is defined here as the process by which the controller erases the current graphic display and replaces it with the appropriate display required for the next action. That is, any one of a number of graphic or textual "displays" can appear on the same "screen." In most cases display transfer will occur along predictable lines. In this case the best implementation of the display transfer function is to provide an on-screen prompt that defines one of the hands-on multi-function keys (Section 3.3) to provide direct transfer to the route selection display.

In addition to making smooth display transfers along predictable lines, the controller should have direct, single keystroke access to any display. However, if a dedicated control key is assigned to each display, the console space claim becomes too large. Also, as software upgrades provide more features and displays, additional display selection keys would be required. An acceptable alternative would be to assign a unique key on the alphanumeric keyboard to each display. To the extent practical, the key selected would provide a mnemonic clue for the corresponding display (e.g., "I" for route interrupt, "S" for route select). If the ATALARS system and data base does not utilize case sensitivity (upper versus lower case letters), then the two standard keyboard "shift" keys can be replaced with display transfer keys. Immediate transfer to any display is then accomplished by typing the "uppercase" letter corresponding to the desired display (e.g., "shift" - "I" for route interrupt).

4.4 LIMITED SCOPE DISPLAYS

A single ATALARS system may be responsible for controlling up to 300 aircraft launching from and returning to up to 10 airbases. Although many of the displays will contain alphanumeric information and statistics about the aircraft in the airspace, there will also be the more typical geographic displays showing aircraft position and flight information. Display scoping refers to the software controlled process that would limit or reduce the scope of such a display to a particular subset of all the aircraft in the airspace. The purpose is to reduce the clutter on the display. For example, an airbase is closed due to runway damage.

Aircraft inbound to that airbase need to be advised and rerouted. During this process the controller may want to display just those aircraft. Table 4-1 provides a list of other possible scoping constraints.

TABLE 4-1

LIMITED SCOPE CONSTRAINTS

- One aircraft designated by the controller
- All aircraft from a specific external ATC authority
- All aircraft returning to a designated airbase
- All aircraft on a particular mission (ATO/FRAG)
- All aircraft of a particular type (A-10, C-130, etc.)
- All aircraft with specific capabilities (Radar navigation, night ops, etc.)
- All aircraft belonging to a specific unit or squadron
- All aircraft projected to transit a designated area
- All aircraft

CHAPTER FIVE

AIRCRAFT DISPLAY REQUIREMENTS

5.0 INTRODUCTION

The ATALARS data link and aircraft terminal will replace some of the ground-to-air communications now accomplished with voice radio. Information that is currently received by the aircrew via their earphones will be presented on a visual cockpit display. This is a potential problem, particularly for single seat aircraft, where the pilot's cockpit environment is already visually saturated. This chapter examines the requirements for the ATALARS cockpit display. Section 5.1 identifies the current ATC traffic. Section 5.2 identifies a set of data and data types common to many of the individual messages. Section 5.3 presents an existing cockpit display that handles these data types.

5.1 ATC COMMUNICATIONS TRAFFIC

Table 5-1 identifies some current ATC ground-to-air message traffic. The traffic listed in Table 5-1 is meant to be representative, not exhaustive.

TABLE 5-1

REPRESENTATIVE ATC MESSAGE TRAFFIC

<u>GENERAL ALERTS, ADVISORIES AND INFORMATION</u>

- Safety alert
- Clearance alert
- NAVAID malfunction advisory
- Wake turbulence advisory
- Traffic advisory
- Bird activity information
- Weather and chaff advisories
- Radio communications transfer
- Altimeter setting
- Runway visibility value / runway visibility range
- Operational procedures

TABLE 5-1 (continued)

REPRESENTATIVE ATC MESSAGE TRAFFIC

TERMINAL AREA TRAFFIC (DEPARTURE)

Departure control directions
Departure clearance
Departure clearance void time
Departure restrictions
Hold for release and release time
Standard instrument departure clearance
Takeoff clearance and cancellation

EN ROUTE TRAFFIC

Route clearance
Clearance items
Route and altitude amendments
Through clearance
Altitude reservation (ALTRV) flight plan clearance
Visual Flight Rules release to Instrument Flight Rules departure
Altitude directives (intercept, hold, cross, cruise, etc.)
Anticipated altitude changes
Altitude confirmation
En route descent clearance
Advance descent clearance
Advance approach information

HOLDING TRAFFIC

Clearance to holding fix
Holding instructions
Holding deviations
Holding delay estimate

TERMINAL AREA TRAFFIC (APPROACH)

Braking advisories
Runway in use
Vehicle traffic and equipment on runways
Wind shear advisories
Observed abnormalities
Landing area conditions
Closed/unsafe runways

TABLE 5-1 (continued)

REPRESENTATIVE ATC MESSAGE TRAFFIC

Wheels down check
Sequencing and spacing instructions
Clearance information
Radio frequency changes and radar beacon code changes
Airport conditions
Approach information
Approach clearance
Low approach clearance
Overhead approach clearance
Practice precautionary approach clearance
High altitude instrument approach clearance
Circling approach clearance
Missed approach wave off
Landing information
Landing control directions
Landing clearance

5.2 COMMON DATA TYPES IN GROUND TO AIR TRAFFIC

Table 5-1 identified 57 types of ground to air ATC messages in five areas. As stated previously, this was not an exhaustive list. In addition, no analysis of the relative frequency of occurrence among the various message types has been performed. However, of the 57 message types, at least 10 could include a command course, 13 a command altitude, 9 a command speed, and 9 a command rate to altitude. An additional 19 messages included predictable data types, e.g., runway visibility value, radio communications transfer, altimeter setting, chaff advisory, clearance void time, etc. A predefined waypoint or fix could be incorporated in at least 10 message types. A final 16 of the messages could contain information of a sufficiently unique character that voice or text may be the only transmission option.

5.3 EXAMPLE COCKPIT DISPLAY

The carrier based F/A-18A aircraft incorporates certain capabilities that are functionally similar to those required in an ATALARS controlled aircraft. For example, there is a ship to air data link (link 4) that in certain modes of operations provides ATC instructions to the aircraft. These instructions include holding information, approach clearance, command heading, command altitude, command rate of descent, and command speed. A multipurpose cockpit display and a Head Up Display (HUD) provide these instructions to the crew.

Figure 5-1, from Reference 8, depicts an aircraft's flight path during an approach to and entry into a holding pattern. Figures 5-2(a through e) show the cockpit (link 4) display and the HUD at designated points throughout the maneuver.

In Figure 5-2(a) the aircraft is at point 1. The pilot has activated the onboard system and is in the test mode as noted on the link 4 display. Data link command information may appear on the link 4 display and the HUD during test.

In Figure 5-2(b) the aircraft is at point 2. The test is complete and the link 4 display shows the test results and system capability in the upper right corner - "T/C" for traffic control capable and "ACL1" for automatic carrier landing, mode 1 capable. The command airspeed of 270 knots, command altitude of 35,000 feet, and command rate of descent of 0 feet/minute are shown at the upper left. The double chevrons indicate a command heading of 320°. The HUD shows the aircraft in a right bank to pick up the command heading, indicated by the heavy vertical line below 305°, which is full scale to the right on the HUD.

In Figure 2-5(c) the aircraft is at point 3 and has captured the command heading.

In Figure 2-5(d) the aircraft is at point 4 and has just received a command altitude change. The word "DATA" flashes on the right side of the HUD for about 10 seconds indicating the receipt of new ATC guidance data. "Command altitude 20,000" and "command rate of descent 4000 feet/minute" are underlined on the link 4 display indicating new data.

In Figure 2-5(e) the aircraft is at point 5 and has just received a command airspeed change to 375 knots. Again the flashing "DATA" prompt is on the HUD, and the command airspeed is underlined on the link 4 display.

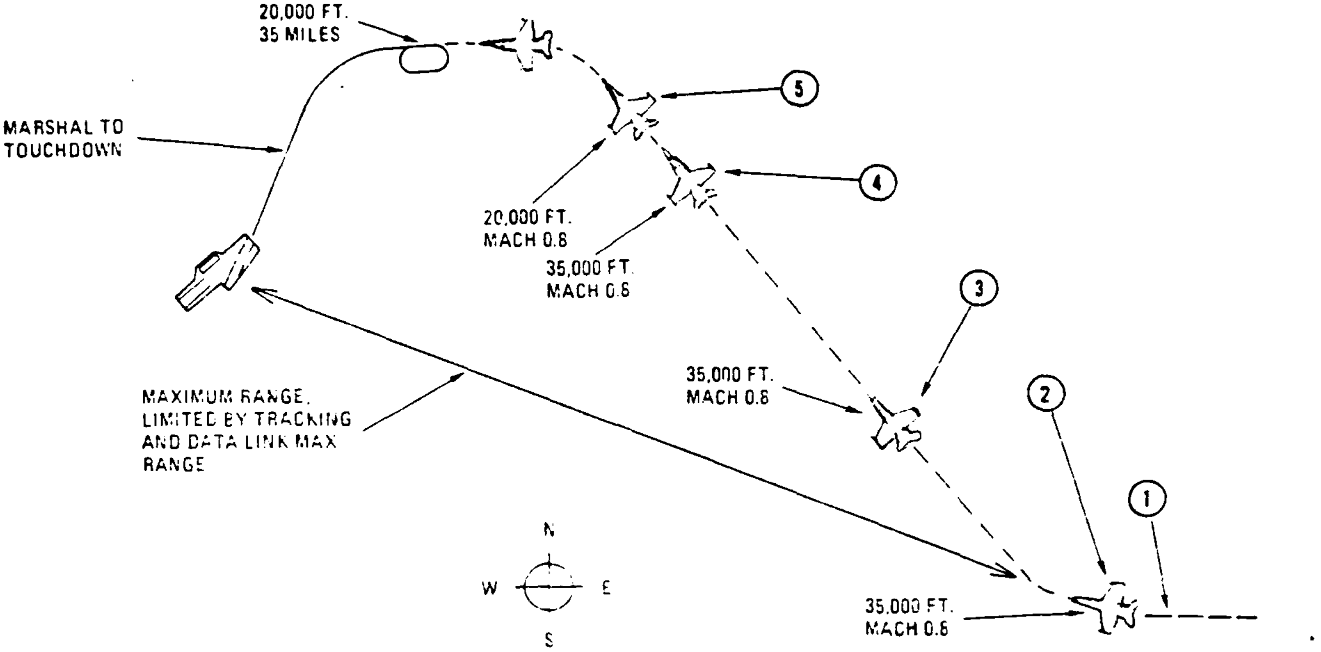

FIGURE 5-1

FLIGHT PATH, ENTRY TO HOLDING

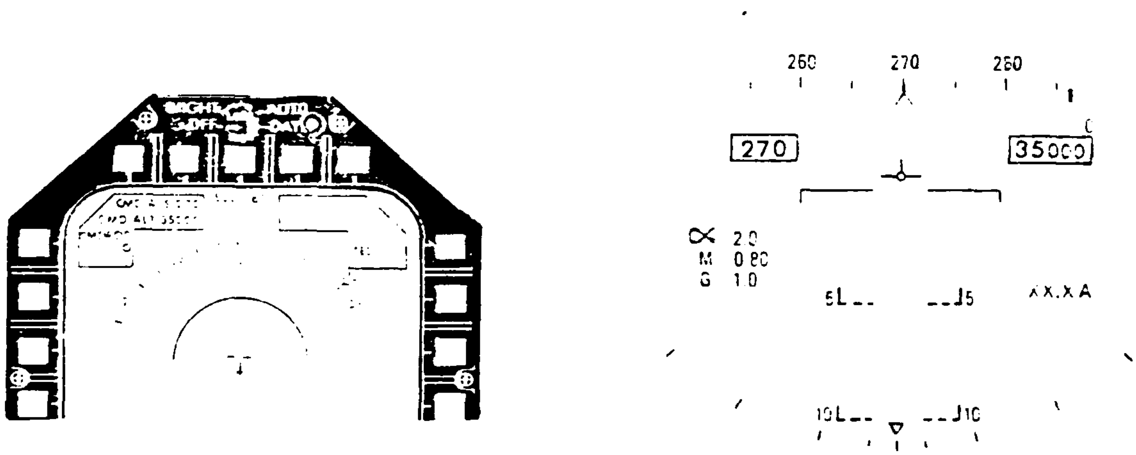

FIGURE 5-2(A)

POINT 1

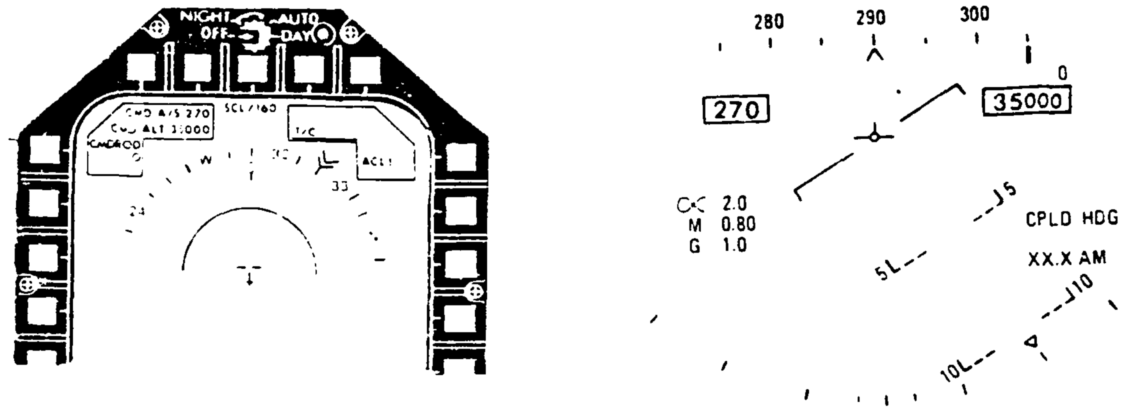

FIGURE 5-2(B)

POINT 2

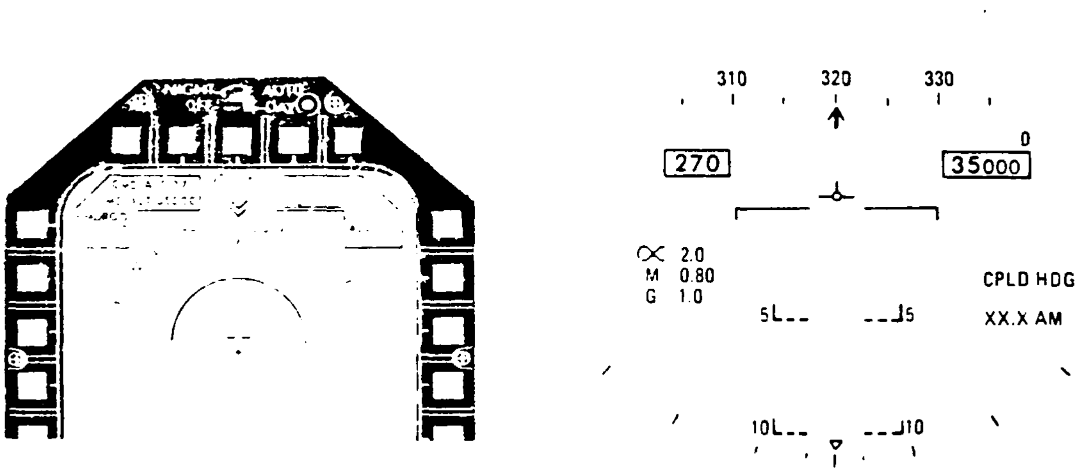

FIGURE 5-2(C)

POINT 3

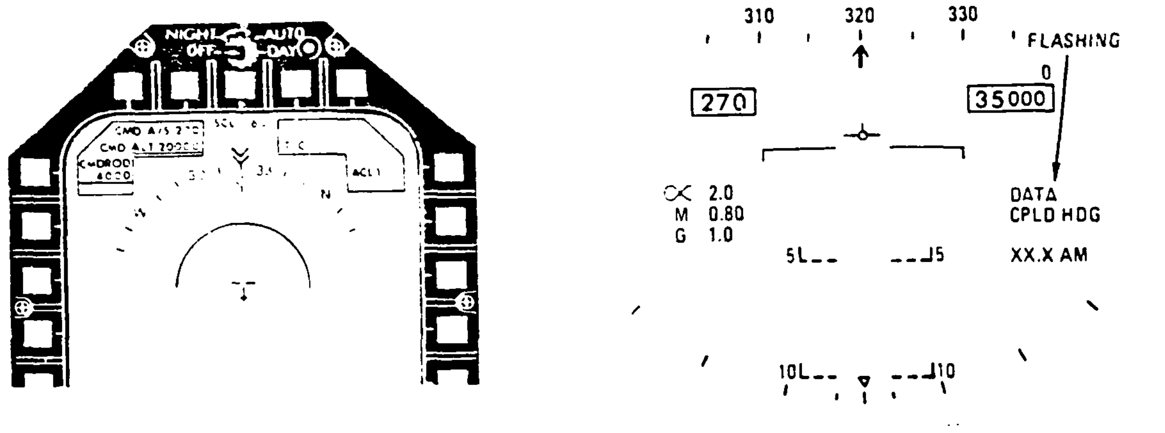

FIGURE 5-2(D)

POINT 4

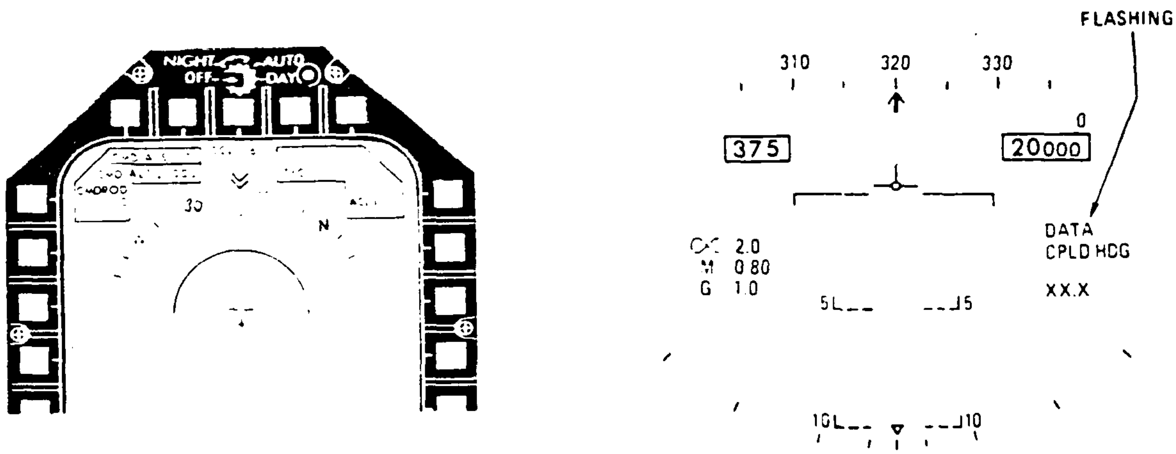

FIGURE 5-2(E)

POINT 5

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

Table 6-1 provides a summary of features identified for the controller's console and the aircrew displays. It is recommended that these features be included in the design of the MMI for the controller and pilot displays.

TABLE 6-1

CONSOLE AND DISPLAY FEATURE SUMMARY

Section	Feature	Value
2.1	Screen size	20 to 24 inches
2.2	Pixel pitch	0.14 to 0.25 millimeters
2.3	Refresh rate	15 Hertz or greater
2.4	Contrast ratio	20:1 or better
2.5	Color capability	Minimum of six colors plus black and white
2.6	Scanning	Raster scan unless vector scanned with improved color capability is available
3.1	Hard controls	Organized by common purpose
3.2	Data entry	Full alphanumeric keyboard; 10-key number pad; possible voice recognition
3.3	Soft controls	Two banks of four keys each, positioned under each hand; or one 10-key pad positioned for opposite hand from pointing device

TABLE 6-1 (continued)

CONSOLE AND DISPLAY FEATURE SUMMARY

Section	Feature	Value
3.4.1	Pointing device	Contoured joystick with three thumb and one index finger switches
3.4.2	Pointing device post-processing	Aided tracking with operator selectable tracking time constant; cursor 'snap' and low level signal dead zone
4.1	Pan and zoom	Thumb activated rocker switch on joystick
5.2	Cockpit display	Command course, speed, altitude, and rate to altitude; waypoint display with relay to mission or navigation computer
5.3	Head up display	Command course, speed, and altitude; or a 'new data' flag to direct attention to the cockpit display

REFERENCES

1. Advanced Air Traffic Control Concept Study for the Automated Tactical Aircraft Launch and Recovery System (ATALARS), ARINC Research Corporation and Vanguard Research, Inc., March 2, 1987.

2. Woodson, Wesley E. and Conover, Donald W.; Human Engineering Guide for Equipment Designers, Second Edition; University of California Press, California; 1966

3. Smith, Warren J.; Modern Optical Engineering; McGraw-Hill, Inc., New York; 1966

4. 7110.65E Air Traffic Control (Handbook), including Change 1 (7/30/87); U.S. Department of Transportation, Federal Aviation Administration, Air Traffic Operations Service; April 9, 1987

5. Mehr, Morton H. and Mehr, Ethan; "Manual Digital Positioning in 2 Axes; A Comparison of Joystick and Track Ball Controls"; reprinted by Measurement System, Incorporated (MS) from the Proceedings of the 16th Annual Meeting of the Human Factors Society; October 1972

6. Mehr, Morton H.; "Aided Tracking Circuits. Explanations and Applications"; reprinted by Measurement Systems, Incorporated (MS)

7. Raven, Francis H.; Automatic Control Engineering, Third Edition; McGraw-Hill, Inc., New York; 1961

8. NATOPS Flight Manual, F/TF-18A; February 15, 1980

ACRONYMS

ATALARS	Automated Tactical Aircraft Launch and Recovery System
ATC	Air Traffic Control
ATO	Air Task Order
CRT	Cathode Ray Tube
DME	Distance Measuring Equipment
ESD	Electronic Systems Division
HUD	Head Up Display
IFR	Instrument Flight Rules
I/O	Input/Output
KTS	Knots
LCD	Liquid Crystal Display
MM	Millimeter
MMI	Man-Machine Interface
NAVAID	Navigational Aid
NTSC	National Television Standards Committee
VFR	Visual Flight Rules