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APPLYING ADVANCED TECHNOLOGY TO FLIGHT STATION DESIGN

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Abstract

The Lockheed-Georgia Company is designing and building a new flight simulation research facility which will provide the capability to simulate advanced functional aircraft systems, develop conceptual crew systems, and test them in a full mission context. The flight station is designed to simulate 1990's aircraft technology using large electronic displays, touch panel controls, voice command, head-up displays and fly-by-wire/light flight and thrust controllers. The cab interfaces with experimenter consoles as well as simulation of the entire air traffic control system. The program is presently in the fourth phase of a five-phase program. The paper discusses the need for the program and Lockheed's crew systems development methodology. It also describes a unique and functional Pilot's Desk Flight Station, together with projected aircraft systems, controls, and display formats for the 1990's

Integrated Flight Station Designs Are Essential

Until recently, aircraft flight station design has been an evolutionary and fragmentary process. Controls and displays for evolving systems and equipment were added as they became available. When changes were introduced, care was used to ensure that these changes would not have a significant impact upon what was already familar to the pilot. There was sound reason to be cautious about change, but the resulting flight stations are a mass of knobs, switches, annunciations, and displays. The impression is one of complexity and clutter. Integration of crew systems, and a more orderly design approach is needed.

Many Forthcoming Air and Ground Systems Will Need To Be Integrated Into The Flight Station

Improved display/control techniques to reduce crew workload, performance computers for more efficient flying, as well as traffic resolution and collision avoidance systems that will provide improved safety are anticipated in the near future. Wind shear detectors and a microwave landing system will be added to improve the landing operation. The Global Positioning System may also offer improvements in navigation capabilities. The Mode-S transponder with data link is being implemented for improved air traffic control, and for the transmission of various types of data between air and ground. Cockpit-displayed air traffic information might also be made available to assist pilots in understanding traffic conditions around them. Incorporating these and other new systems without increasing the present crew workload is a challange facing aircraft crew system designers.

The new systems will not immediately replace any existing systems. The Microwave Landing System (MLS), for example, will continue to have the conventional Instrument Landing System (ILS) as a companion for years to come. The Global Positioning System, if implemented, would co-exist with VOR/DME, TACAN and other navigation systems which will be around for many more years. The presence of these overlapping systems must be considered in future flight station designs.

The prospect of greater on-board computer capacity provides opportunities to relieve the crew of simple memory chores, certain routine data processing tasks, and even procedural decision making. There is considerable challenge to identify the specific information that should be stored, the computational or integrating functions that should be computerized, and the decision logic that should be programmed.

Advances in electronics technology provide opportunities for more flexible and unusual communication between crew, machine, and ground controllers. How to develop cockpit controls, displays, and other interface devices to use this technology without increasing crew workload is one of the greatest challenges facing the designer of the flight station of the future.

The effects of increasing automation on operator performance in advanced systems is an extremely complex question that has certainly not been adequately investigated. In many cases, studying the effects of automation on overall operator performance has been secondary to the development of the system. This is, in part, a result of the dramatic advances in the applications of new technology that have occurred in the last decade. There are as many questions posed as have been answered by modern technology.

Lockheed-Georgia Response

Recognizing the need to test the impact of issues such as these on aircraft flight stations of the future and upon aircrew members, the Lockheed-Georgia Company is working with both the Advanced Transport Operating Systems Program (formerly Terminal Configured Vehicle Program), and the Man Vehicle System Research Facility Project of the National Aeronautics and Space Administration (NASA) to design and build new flight simulation research facilities. These facilities, being built at NASA's Langley and Ames Research Centers and at the Lockheed-Georgia Company, will provide the capability to develop conceptual crew systems, simulate advanced functional aircraft systems, and evaluate them in a full mission environment.

The flight station element of the facilities is being designed to simulate 1990's aircraft technology by using large high resolution color Cathode

Ray Tubes (CRTs) and flat panel displays, touch panel controls, voice command and response systems, head-up displays, and electronic, or fly-by-wire, flight and thrust controllers.

Design Methodology

The 1990's flight station is being developed in a five-phase program consisting of mission analysis, design, mockup fabrication and test, simulator design and fabrication, and simulator test.

Phase I - Mission Analyses and Requirements Development. Phase I, which began in 1979, consisted of forecasting information on 1990's transport aircraft with respect to user needs, operating environment and procedures, and electronics technology. Mission scenarios using this information were developed and validated by operationally qualified personnel. Detailed mission scenario time lines were used to develop aircraft functional requirements and to determine aircrew information and control requirements.

Phase II - Crew System Design And Mockup Fabrication. Phase II began with a description of system functions required to satisfy various missions and environments, and continued through the process of time lines, task loading, trade-off analyses, and reallocation of functions between crew members, and between the crew and the machine. Candidate crew systems were designed and selected. Technology forecasts, developed earlier in the program for displays and system operating controls, were used to guide the selection of the technologies suitable to the 1990 time period.

A full-scale mockup of the major components of the Pilot's Desk Flight Station was fabricated from Fome-Cor and enclosed in a shell representative of a generic, wide-body flight station. Layout studies on reach and vision were confirmed. The mockup was used during the design of individual crew systems panels to check the configuration for visual and physical accessability and ease of operation. Candidate layouts were mounted on Fome-Cor and placed in anticipated locations until the configuration was completed.

Phase III - Mockup Testing and Design Refinement. Three major areas of effort were included in Phase III. These included test plan preparation, data collection, and documentation. Using the mockup, the design was tested using a structured evaluation process which caused the test subjects to consider all aspects of the design in a mission context. Five two-pilot crews made up of experienced line pilots currently flying commercial transport aircraft, NASA test pilots, and Lockheed flight operations pilots were used as test subjects. They received comprehensive classroom training on the new systems and then evaluated the design by "flying" slice-in-time mission scenarios by pretending to operate the Fome-Cor control and displays in the flight station.

The flying sessions were structured to expose them to all elements of a circa 1995 transport mission. Examples of the tasks which they encountered during these flying sessions are shown in Figure 1. Detailed questionnaires that were developed address comprehensive design and workload issues. Comments and critiques were recorded during the two-to-three-day per crew evaluation and were later analyzed along with the questionnaire data. Upon completion of mockup testing, the design--including display formats, control and display locations, and system operational descriptions--was revised and refined to reflect the results of the test process. The results were documented for use in preparation of the simulator design.

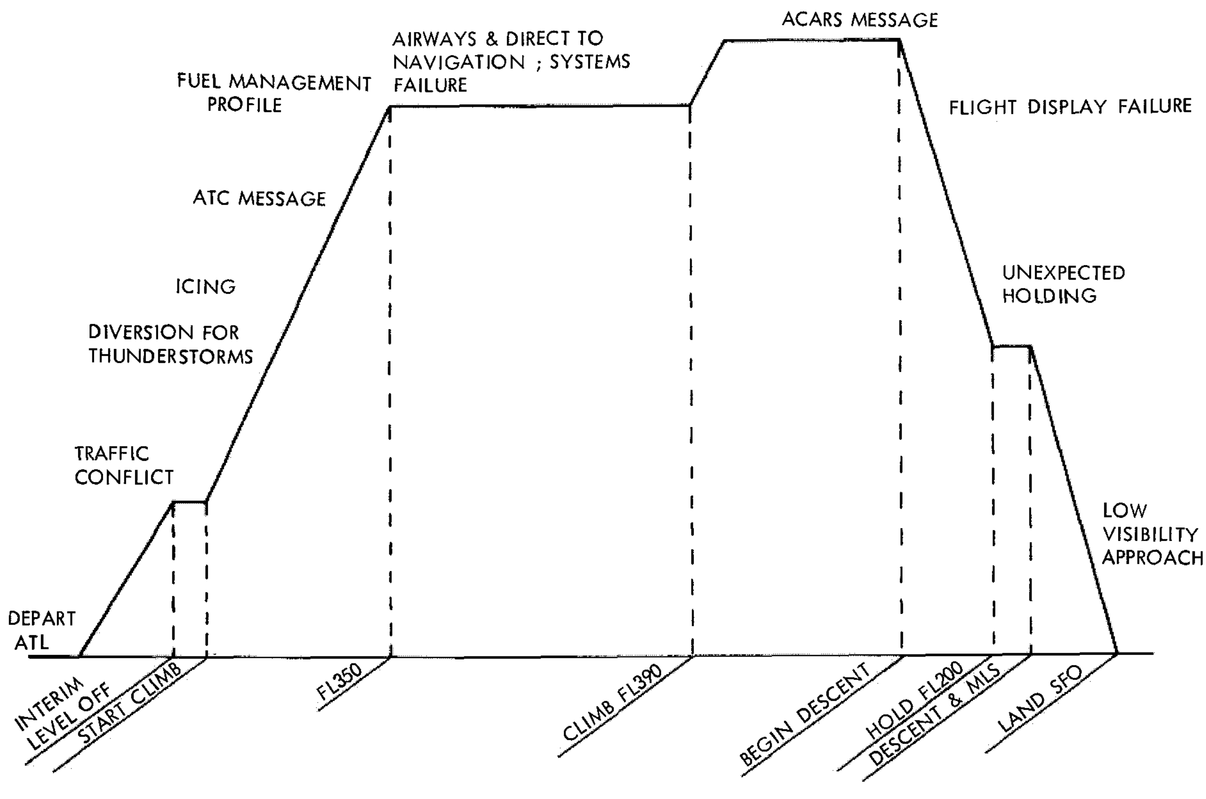


Figure 1. Mission Scenario Flight Profile

Phase IV - Simulator Design and Fabrication. The computer complex has been designed and the majority of its components have been received, installed and checked out. Figure 2 shows a block diagram of the architecture being used.

During early 1982, a generic, wide-bodied aircraft cab top and base were fitted with instrument panels and consoles, a side arm controller, throttles, and one 13" CRT. The capability to fly to an approach fix point and complete a curved path approach to landing using the large-screen CRT display system was demonstrated earlier this year. Also demonstrated was the control of aircraft functional systems by using a touch panel overlaying a CRT, rather than the conventional methods of controlling systems by pushbutton or toggle switches.

Hardware design and fabrication, and software development for all aircraft systems are currently taking place, and will continue throughout 1983, so that by the end of the year these research simulation facilities will be fully operational. The facilities will be adaptable to six-degree-of-freedom motion bases, with varying environmental conditions including ground effects and computer-generated imagery visual systems.

Phase V - Simulator Testing. Simulator testing will consist of the same basic tasks as Phase III: test preparation, data collection, and documentation. The crew systems will be tested in the same manner against the same mission scenarios by operationally qualified aircrews. The crews will evaluate the proposed flight control system, cockpit layouts, system control/displays design, display formats, and other crew systems for capability, applicability, and useability. During the process, the crew workload will be assessed. Specific tasks to be evaluated will be determined later in the program. Output from the simulation phase will interact with the entire program in a continuous feedback of refinements, improvements, and evaluation of new techniques for fulfilling the information/action requirements of the system, with results being applied to future aircraft.

The 1995 Flight Station

Using information from a comprehensive survey of technologies forecast to be available in the 1990s, design team members from each engineering discipline defined systems for the aircraft. This closely coordinated effort first performed preliminary design for the entire aircraft, then focused upon the flight station, and ultimately upon the crew systems. The use of fly-by-wire/ light flight and thrust control systems, without mechanical redundancy, eliminated the requirement for large and cumbersome columns, control wheels or center sticks, and throttle levers. This, in turn, permitted more efficiency in the use of the space presently occupied by those controls. Thus, the novel desk-top design was conceived, with small side-stick controllers and other controls/displays located much more conveniently for better reach and vision. Only small, easily accessible center-pedestal and overhead consoles are required. Figure 3 shows the mockup of the Pilot's Desk Flight Station design which was used in Phase III of the development program.

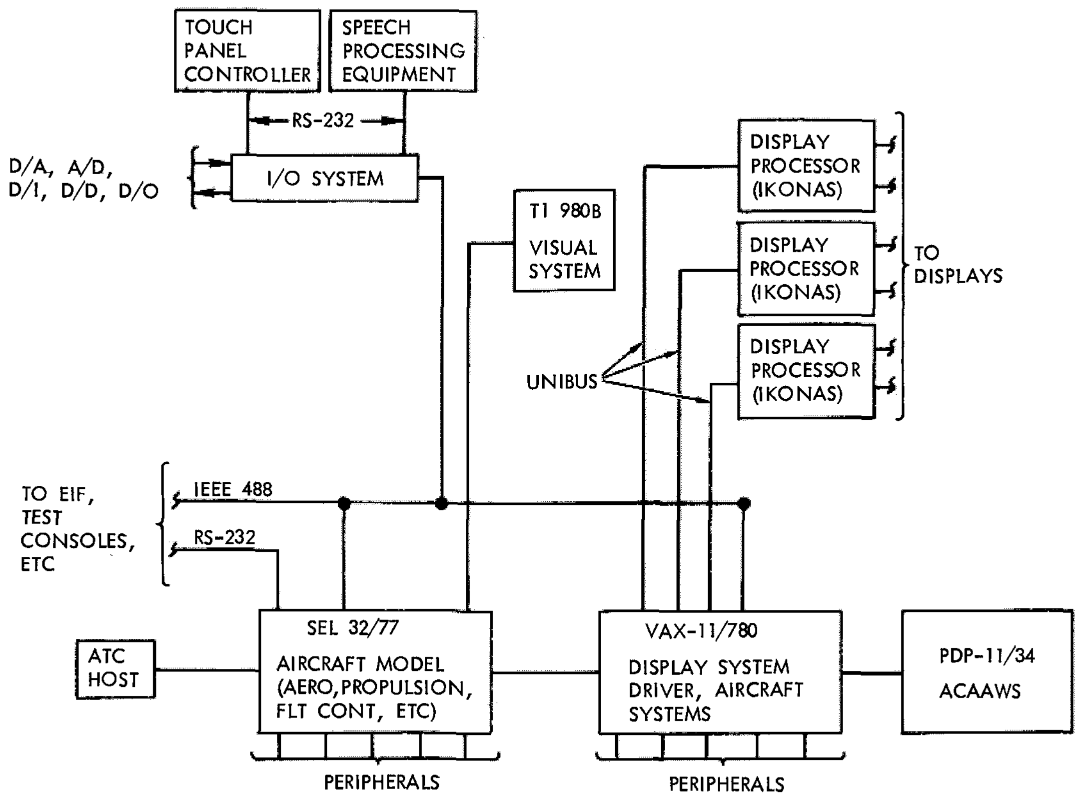


Figure 2. Computer System Architecture

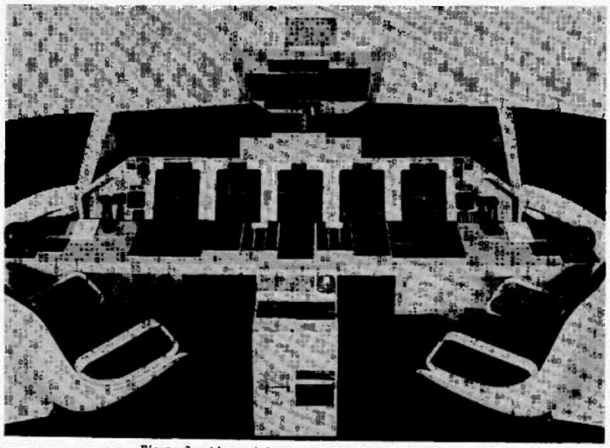


Figure 3. Advanced Concepts Flight Station Mockup

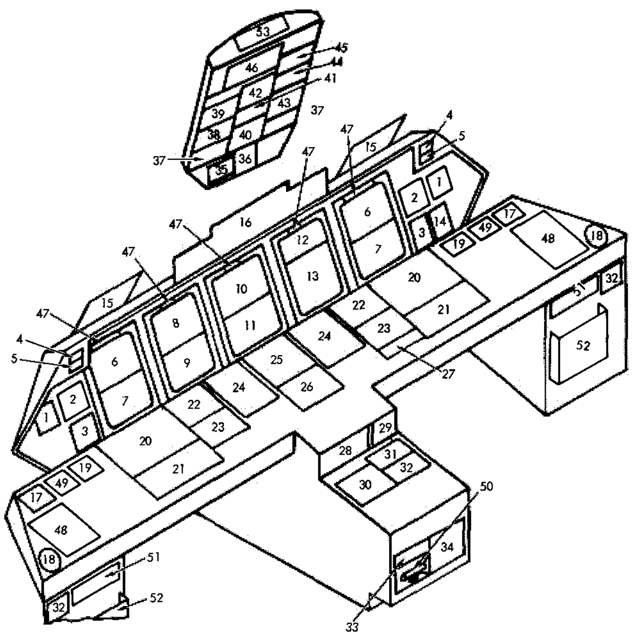
Within the next few years, advances in display technology will make possible the use of large, high-resolution, color, flat-panel displays. The simulators being developed by NASA and Lockheed, which contains the Pilot's Desk Flight Station design, will conceptualize these through installation of five vertically orientated 13-inch diagonal, color, Cathode Ray Tubes mounted side-by-side on the main instrument panel, as well as two monochromatic, flat-panel displays on the desk top. The center three displays and the two flat-panel displays will have touch-sensitive panels over their face to provide pilot control of the systems. Formats for the front panel displays, a large effort in the design process, are discussed later in this paper. Each pilot will have a head-up display to permit improved see-and-avoid opportunity during visual conditions, reduce head-down to head-up transition difficulties on landing, and possibly improve safety on very low visibility approaches.

The judicious use of advanced avionics technology permits the aircraft systems to automatically perform many systems monitoring functions. This relieves the pilots of that task, while providing them with data upon which to make decisions. This is very evident in the advisory, caution and warning system; however, the theme was used consistently in the design of all crew systems. This feature is necessary for safe worldwide operation by a two-pilot crew in view of the increasing amount of air traffic and air traffic control systems that will be in the flight station. Some other unique features of the design are: automatic loading of navigation and other operational data into the aircraft computers; performance management for most efficient/economical operation, integrated with a four-dimensional navigation system and the automatic flight control system; advanced air traffic control systems including Mode S data link of traffic and weather information, clearances, and collision avoidance; integrated control of communications, navigation systems, and transponders; a hard-copy printer for pilot selectable information; and a voice command and response system for announcing advisories, cautions and warnings, accessing/call-up of information, entering information into on-board computers, and controlling a limited number of systems. The layout of the flight station is shown in Figure 4.

Display Format Coding. With the advent of large-screen color displays into the flight station, major human engineering research has been oriented toward the development and evaluation of the format requirements and basic formats for the five front-panel displays.

Guidelines were developed to define color coding: symbology, and font characteristics, such as sizes, stroke widths, etc.; and symbol logic. In each case the scheme employed is simple to learn and understand, and is applied in the same manner to all formats.

Color Coding. Three special-purpose colors (black, cyan and desaturated orange) and four primary coding colors (red, amber, white and green) are the maximum employed in any format to avoid the overuse and degradation of the benefits of color. They are assigned to reflect level of importance of coded information:



1. MASTER CRT BRIGHTNESS
2. CLOCK
3. WING FLAP INDICATOR
4. *MASTER WARNING LIGHT*
5. MASTER CAUTION LIGHT
6. FLIGHT DISPLAY
7. NAVIGATION DISPLAY
8. ENGINE POWER
   ENGINE STATUS
9. CDWI
   JEPP
   ENGINE STATUS
10. ACAWS
11. CDTI
    OBSTACLE CLEARANCE
12. CHECKLISTS
13. SYSTEMS SCHEMATICS
    ENGINE STATUS
14. FUEL QUANTITY INDICATOR
15. HEAD UP DISPLAY
16. GUIDANCE AND CONTROL PANEL
17. COFFEE CUP HOLDER
18. ASH TRY
19. SIDE STICK CONTROLLER
20. FMC CDU
21. CDU KEYBOARD
22. NAV DISPLAY CONTROL
23. TRANSMIT/MONITOR CONTROL
24. THROTTLES
25. COMM/NAV FREQ DISPLAY
26. COMM/NAV FREQ ENTRY
27. ACARS/SELCAL CONTROL
28. ALTERNATE TRIM CONTROL
29. WING FLAP CONTROL
30. GPS CONTROL
31. RADAR CONTROL
32. MIC.AND HEADSET JACK
33. DATA TRANSFER MODULE RECEPTACLE
34. PRINTER
35. LAND LIGHTS AND ADV WX
36. LANDING GEAR CONTROL
37. HEAD UP DISPLAY CONTROL
38. FLIGHT CONTROL SYSTEMS CONTROL
39. ENGINE START CONTROL
40. LANDING GEAR/BRAKE PANEL
41. CABIN ADVISORY LIGHTS
42. INTERIOR LIGHTING CONTROLS
43. APU/EXTERNAL POWER
44. OXYGEN/EMERGENCY DEPRESS
45. COCKPIT VOICE RECORDER
46. FIRE CONTROL PANEL
47. CRT ALTERNATE SOURCE CONTROLS
48. NOSEWHEEL STEERING & PARKING BRAKE
49. *RUDDER PEDAL ADJUST*
50. EMER GEAR RELEASE
51. STORAGE DRAWER
52. MAP CASE
53. EMER CIRCUIT BREAKERS

Figure 4. Advanced Concepts Flight Station Layout

Symbol Logic. The following examples of symbol logic were used across the various display formats. It should be noted that, in many cases, there is a direct interaction between the symbol logic, symbology, and color coding.

Symbology. A major coding requirement for symbology is the need for consistency, especially when there is a large group of related formats in the design, such as the functional systems formats. The symbology was also made compatible with the color-coding scheme and the symbol logic.

Figure 5 illustrates some of the symbology used in developing the various functional systems formats. Aspects of the symbol logic are inherent in the switch representations for ON and OFF illustrated in the figure.

One example pertains to the touch-panel menus on formats where the legend for the switch that has been selected is not shown. The rationale is to present only those options that are available for selection.

A second example is in the difference between flow and non-flow in fuel or electrical lines. Non-flow conditions are represented by non-filled lines, and flow conditions are represented by filled lines. Color coding of the lines indicate the status of the pressure or voltage in the lines.

Another example is the coding for failure conditions. Normally the inner square on a fuel pump switch is green. When the pump fails, the inner square turns red. When the pilot shuts the pump off, the normal OFF legend appears in the switch with a superimposed red X. This indicates that the unit is off because it has failed and should not be activated. The red X in all functional system formats indicates a failed system.

Color coding, symbology consistency, and symbol logic across the various formats was rated highly by pilots participating in the Phase III mockup testing of the flight station design, because information on the formats was easy to find, interpret, and understand.

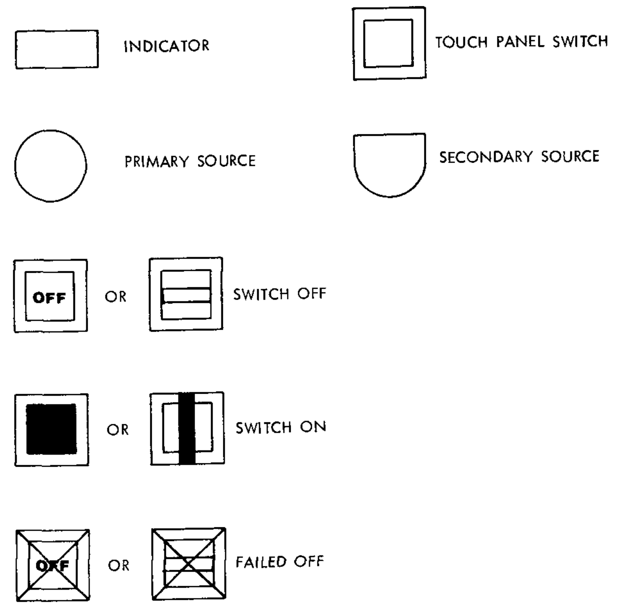


Figure 5. Examples of Symbology on Functional Systems Formats

Display Formats. A major area of research and design in 1981 was the development of the basic set of electronic display formats, shown in Figure 6. In total, 25 different types of formats, each with several variations, were developed. These formats and the switching logic associated with the touch panel overlays were examined as a part of the soft-mockup evaluation; comments obtained during the evaluation were incorporated. Some of the basic formats are discussed below.

Flight/Navigation Display. The primary flight display format, illustrated in the upper portion of Figure 7, is a modified NASA flight path angle display. The information contained in the display is tailored to the flight phase to simplify the format and improve interpretability. The example shown is for the approach and landing phase. As part of the development of the flight display format, relevant overlays, such as time-critical messages, were identified and integrated into the format structure.

Four basic navigation display formats, one of which is shown in the lower portion of Figure 7, were also developed. These formats can be divided into two classes: map formats and non-map formats. The basic map format is similar to other electronic navigation display formats, but it has improved information overlays and declutter capability.

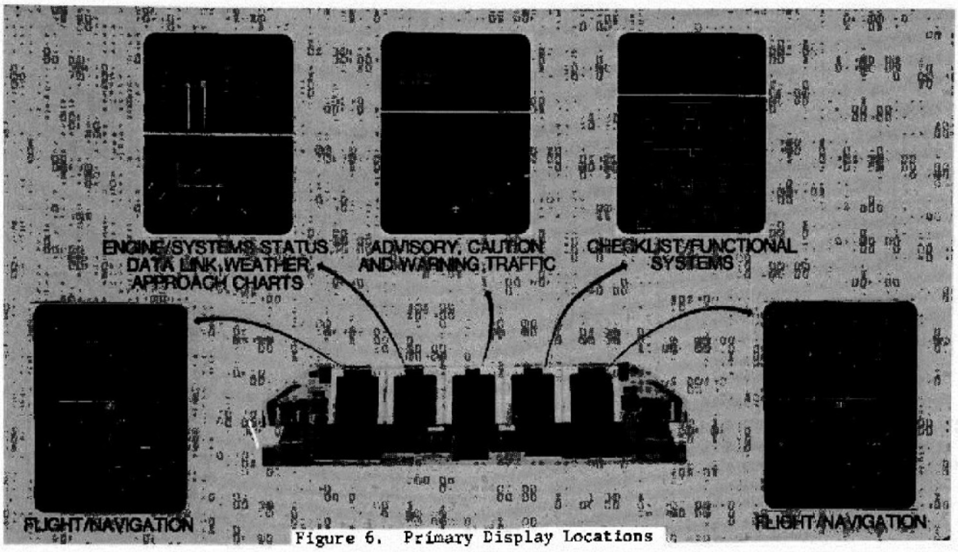


Figure 6. Primary Display Locations

Overlays include those for airfields, obstacles, and navigation aids, as well as unique weather symbology, filtered traffic, and decluttered range markers.

The three non-map navigation formats were developed for use when navigating on raw data information from VOR, VOR-DME, or ILS. They provide an improved representation of the horizontal situation through a more realistic pictorial format augmented by relevant digital navigation information.

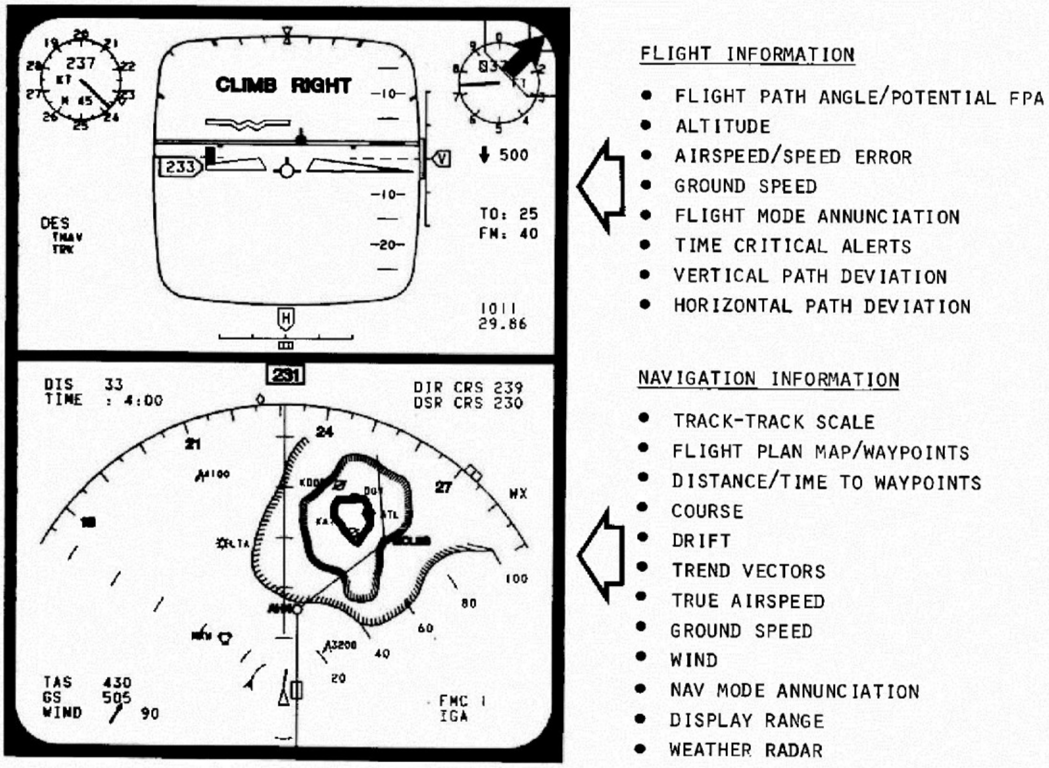


Figure 7. Flight/Navigation Display

Engine Power/Status, Approach Charts and Weather Display. Engine parameters are available in either bar graphs, as shown in the upper portion of Figure 8, or digital form. Switching permits both formats to be displayed simultaneously or individually. Unique features of these formats include integral limit indicators (bars divided along their length) for engine pressure ratio (EPR), exhaust gas temperature (EGT), and RPM; instantaneous throttle position and commanded values provided by the performance management computer; and digital values, color-coded to show systems health, which are automatically recalled from a blanked display, in event of a malfunction.

The lower portion of this display is used to present a variety of formats. The availability of the digital engine status in this location provides the capability to simultaneously present the bar graph and digital engine formats as mentioned above. Additional systems that may be displayed in this location are Cockpit Display of Weather Information (CDWI) or instrument-approach publications such as the Jeppesen chart, which is shown. The instrument approach chart formats are electronic display adaptations of standard paper charts.

The CDWI formats provide the pilot, through Mode S data link, a variety of weather information relevant to the projected flight path. The types of information available include enroute weather advisories, thunderstorm, icing and wind information, and destination weather. The selectable range feature, from 600 miles to 50 miles, permits the pilots to plan required diversions well ahead, and yet tailors the symbology so that more detailed weather representations are available at the shorter ranges.

ACAWS/CDTI Display. The Advisory, Caution and Warning System (ACAWS) and Cockpit Display of Traffic Information (CDTI) format, shown in Figure 9, are available on the center CRT display. The ACAWS format is a nine-line message area that presents information from a very complex monitoring system. The messages are prioritized for display by color and relative position. One unique feature is the offsetting of caution and advisory messages to provide interpretability for this critical display in the event of color gun failure. Displayed information can be removed from view and/or recalled through touch panel menu switches.

The CDTI, shown in the lower portion of Figure 9, represents an integrated presentation of traffic information derived from the advanced air traffic control systems, and provides filtered traffic information showing only traffic relevant to the "own" aircraft. The symbology indicates whether depicted traffic is above or below "own" aircraft, distance above or below, predicted track information and proximity warnings. Special data available includes information on aircraft with non-functional altitude encoding transponders and identification readouts of the pictured traffic. The identification data is obtained by touching the aircraft symbol for which information is required.

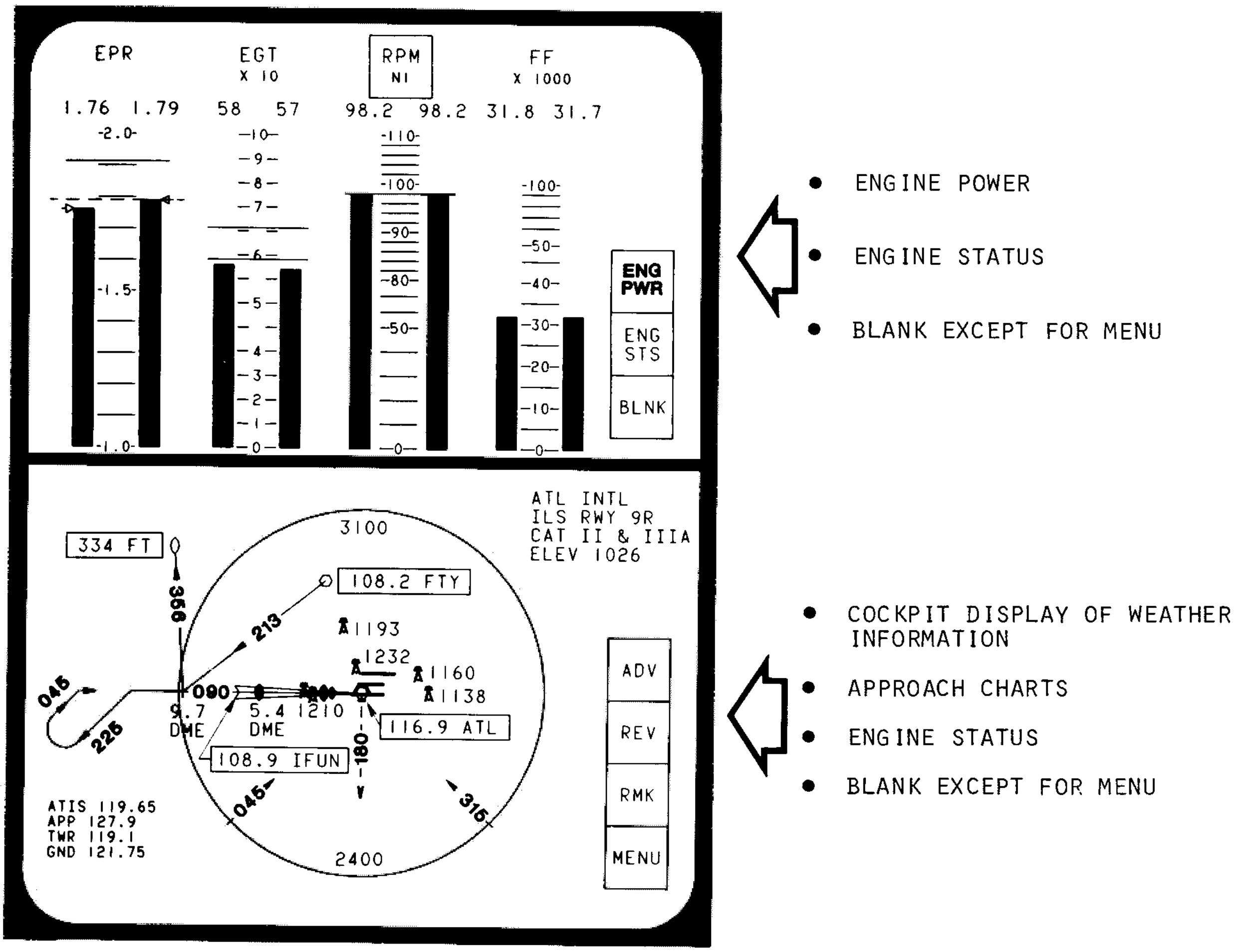


Figure 8. Engine Power/Status, Approach Charts, and Weather Display

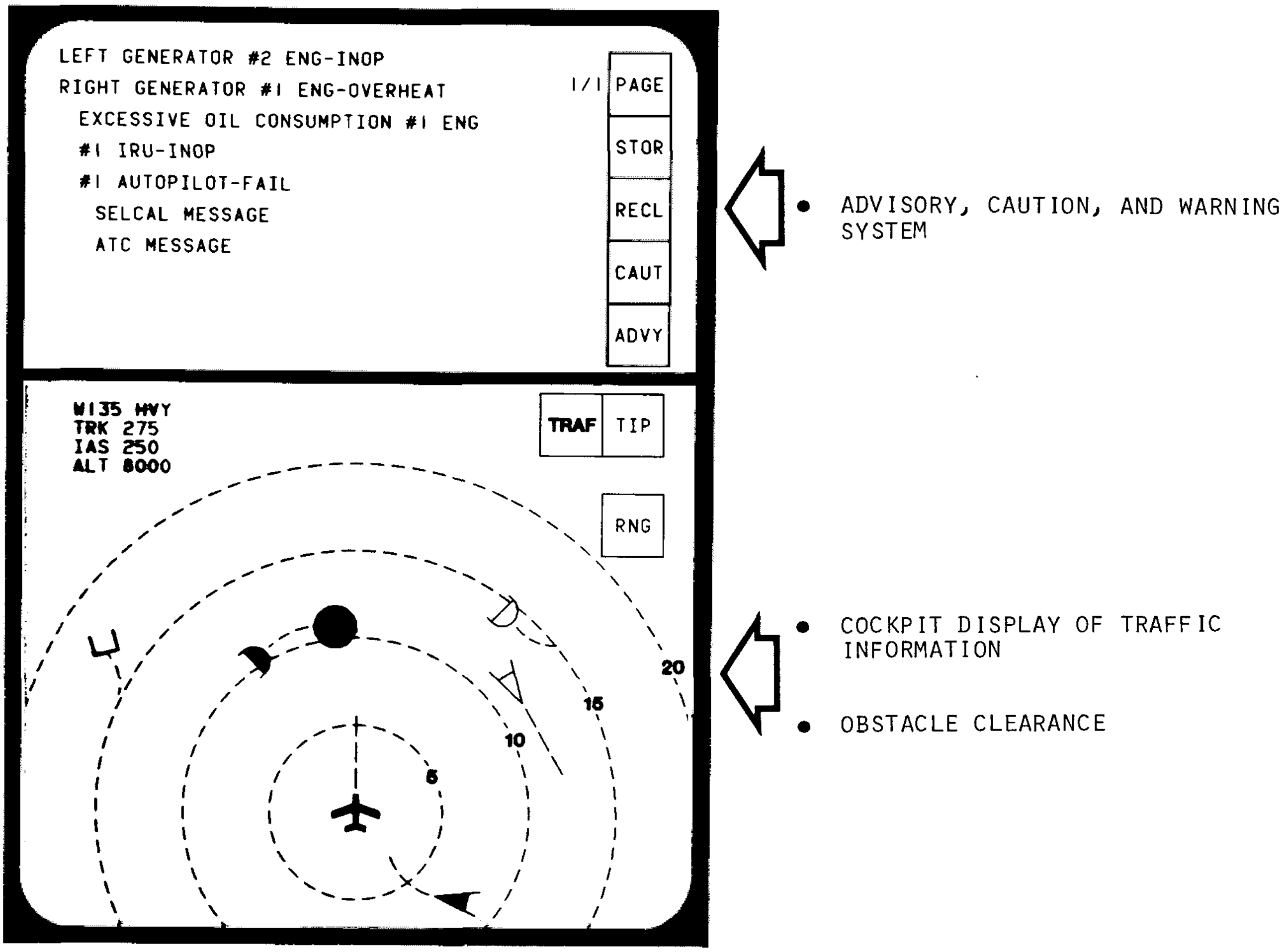


Figure 9. ACAWS/CDTI Display

Checklist/Functional Systems Display. The checklist shown in the upper portion of Figure 10 represents an electronic system that offers a variety of automatic and semiautomatic sequencing and call-up features. Checklist items may be advanced, reversed, or cleared through the touch panel switches. Items may be checked-off by touching the line item. Pilots are reminded of skipped items with a "checklist incomplete" message, which also serves as a touch panel switch to recall the skipped item. A novel feature is its integration with the functional systems schematics, described below. When an item associated with a functional system reaches the top line of the checklist, the schematic of that system automatically appears so that its controls can be operated through the touch panel. The checklist is also integrated with the ACAWS system. When a warning or caution message appears, pressing the appropriate abnormal or emergency touch panel switch displays the checklist for that malfunction along with the proper systems schematic.

All aircraft functional systems and associated crew systems have been defined. Many are displayed on the lower portion of the #4 display, and are controlled through touch panel overlays. Operation of the systems was kept simple by exploiting advanced methods of monitoring and automatic control where feasible. In the interest of brevity, operation of the systems is not discussed here.

The lower portion of Figure 10 illustrates one of the functional system formats developed. The coding consistency discussed earlier is used in similar formats, such as the three electrical systems, the environmental system, and the fuel system. Similarly, formats for the lights, adverse weather, and Comm/Nav are consistent. These formats are especially designed to be compatible with touch panel operation.

Advanced Air Traffic Control System Allocation. Among the studies conducted in 1981 was one concerned with the integration of information from the advanced air traffic control systems, currently under development by the FAA, into the baseline design. This effort involved the determination of the information that is projected to eventually be available from the various systems, the interrelationship of the various types of information, the appropriate methods of accessing the information, and the appropriate location of the various types of information within the design constraints. Each of these steps was a prerequisite to the integration of advanced air traffic information into the set of basic display formats. Figure 11 indicates where the various types of advanced air traffic control information are displayed.

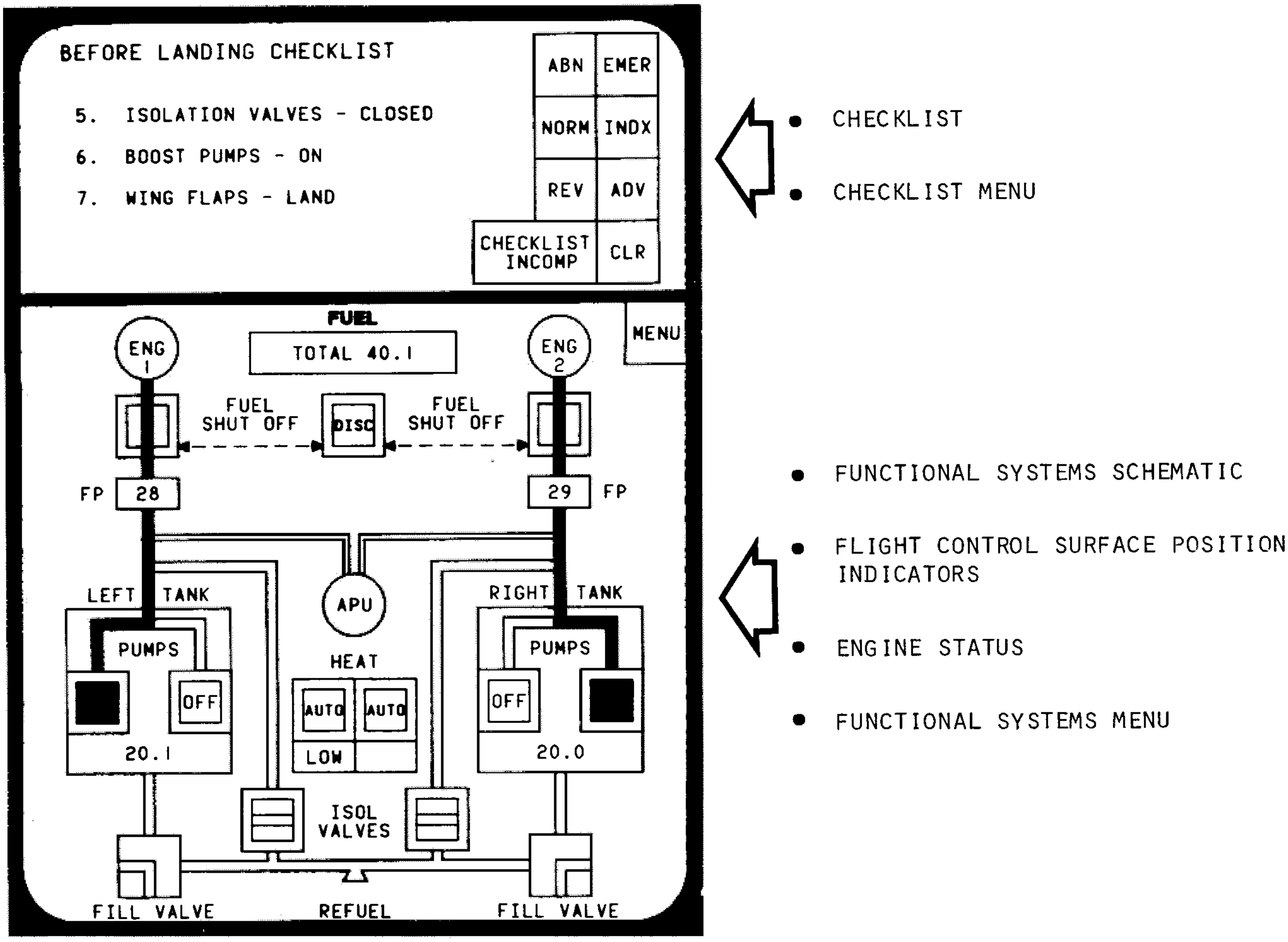
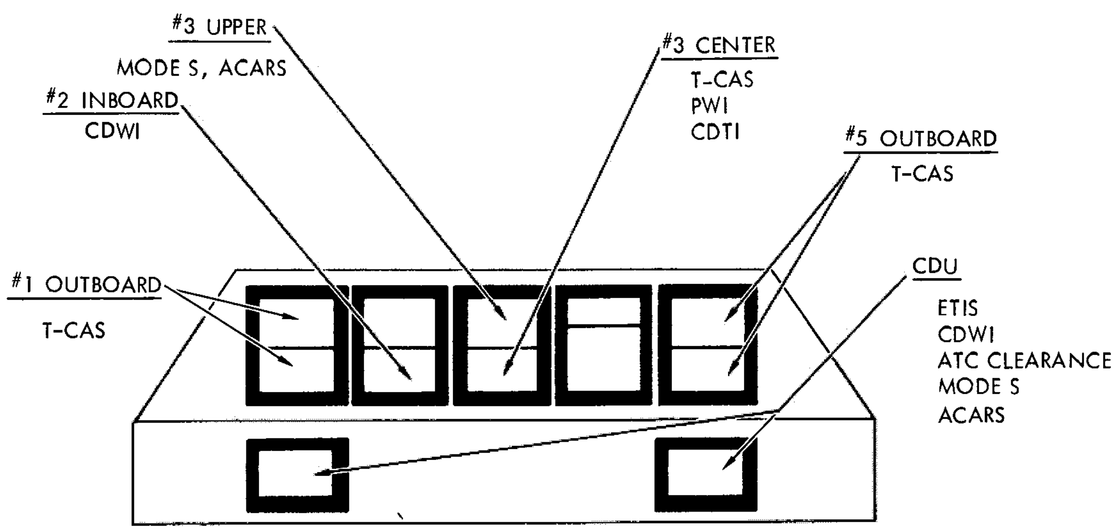


Figure 10. Checklist/Functional Systems Display



ACARS	AIRINC COMMUNICATIONS ADDRESSING AND REPORTING SYSTEM
ATC	AIR TRAFFIC CONTROL
CDTI	COCKPIT DISPLAY OF TRAFFIC INFORMATION
CDWI	COCKPIT DISPLAY OF WEATHER INFORMATION
ETIS	ENHANCED TERMINAL INFORMATION SERVICE
MODE S	TRANSPONDER WITH DATA LINK
PWI	PROXIMITY WARNING INFORMATION
T-CAS	THREAT-ALERT AND COLLISION AVOIDANCE SYSTEM

Figure 11. Advanced ATC Systems Display Locations

FUTURE RESEARCH

Upon completion of the Lockheed and NASA Research Simulator facilities in early 1984, an intensive research program is being planned that will validate and further refine the design. Development and test of new concepts and advances in technology will be conducted, for application to aircraft of the future.

Many areas for research projects have been identified, including:

- Integration of advancing aircraft and air traffic control systems concepts
- Optimization of controls and displays for advanced air traffic control systems and information transfer system
- The applicability of touch panel controls in transport aircraft
- The effect of automation on pilot performance
- The adaptability of head-up displays to transport aircraft
- The evaluation of advanced flight display formats, such as Path-in-the-Sky
- The effect of total or partial display failure on pilot performance
- The comparison of various flight control modes -- velocity vector, attitude and manual

It is exciting to consider the endless possibilities for research in facilities that will be as flexible and easily adaptable to new technologies as these are planned to be.