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THE EVOLUTION OF DISPLAY FORMATS FOR ADVANCED FIGHTERS USING MULTIMODE COLOR CRT DISPLAYS*

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Abstract

The evolution of display formats for advanced fighter aircraft using multimode color displays is described. A flight-test mission starting with preflight, takeoff, cruise, etc, and ending with postflight is simulated to illustrate the various display format changes experienced by the pilot. The use of color, pictorialism, and display declutter are illustrated.

I. Introduction

Military fighter cockpits have experienced an information explosion in recent years because of advancements in aircraft performance and armament and avionic subsystems, and the resulting increase in the kinds of missions performed. At the same time, there has been a tendency to reduce cockpit size, to increase aircraft performance, with the net result of reducing the space available for the placement of conventional dedicated electromechanical indicators, instruments, or displays. All of these factors have produced increased emphasis on the need to move away from dedicated displays in the direction of time-shared multimode displays. At the same time, advances in airborne digital avionics, including electronic cathode-ray tube (CRT) displays, have produced a significantly increased capability to provide multifunction time-shared displays.

Research and development activities on advanced fighter cockpits at North American Aircraft Operations (NAAO) required the extensive use of multimode displays (MMD) in the design of an advanced fighter demonstrator aircraft. The aircraft demonstrator placed emphasis on the flight demonstration of certain advanced aerodynamic and structural technologies not directly related to cockpit design. For this reason, mission avionics, stores management, and a head-up display were not included in the initial cockpit design.

Development of the MMD system architecture was NAAO responsibility, development of the hardware and software was a Bendix Flight Systems Division responsibility, while the development of display format was a joint NAAO/Bendix activity. Full-color shadow-mask CRT's were used for the multimode displays, and display format development took advantage of the color capability.

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II. Cockpit Description

Figure 1 shows the basic cockpit control display layout featuring a side stick controller on the right-side console and three multimode full-color CRT displays on the main instrument panel. Each CRT provides a 5-by 5-inch display surface which is pilot-controlled through a multifunction keyboard on the left-side console, just to the right of the throttle grip.

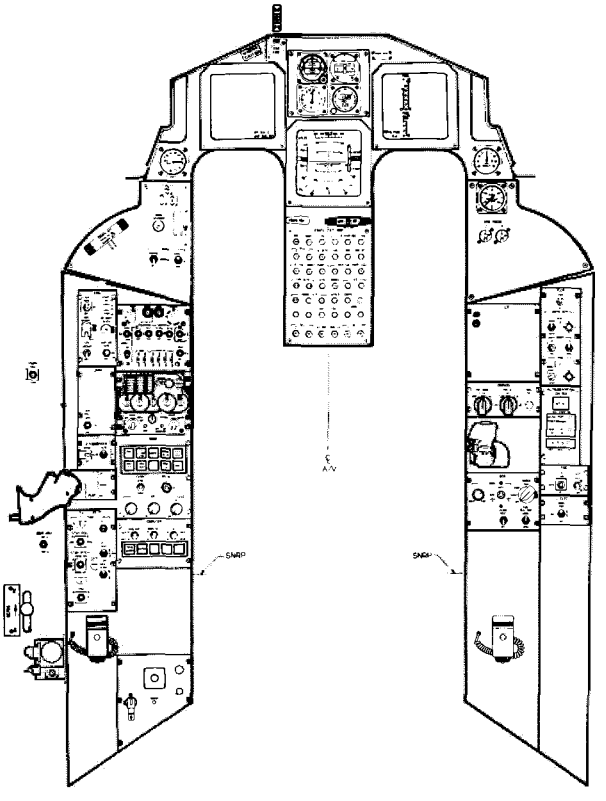

Figure 1. Advanced Fighter Demonstrator Cockpit Layout

Six electromechanical flight instruments are installed on the main instrument panel; four are immediately above the center MMD, while two are on the outboard tails of the main instrument panel. The first four were intended for the initial flights and would be removed shortly thereafter. The remaining two were part of a special flight-test instrumentation package. The lack of dedicated electromechanical instruments or indicators is one of the most noteworthy features of this cockpit.

III. Development of Color Formats

Ground rules

The major emphasis in the remainder of this paper concerns the evolutionary development of the display formats for the full-color shadow-mask CRT displays. A number of ground rules were established in advance of defining specific display formats:

1. Minimize use of dedicated displays of an electromechanical nature.
2. Display only that information required by the pilot for a given phase or operation.
3. Provide pilot option of calling up any information at any time.
4. Use color and formats to take advantage of prior usage in military cockpits.
5. Use pictorial formats where possible to replace symbols.
6. Use MMD capability of the CRT to present normal and emergency checklists.

To illustrate the implementation of these rules, a series of display formats will be presented to simulate the display conditions seen by the pilot as he performs preflight takeoff, climb, cruse, etc, finally returning to land and completion of postflight.

Preflight

The first 6 pages of the 10 page preflight checklist will be bypassed by starting the preflight checklist on page 7 shown on the left MMD (Figure 2). This mode was selected by the pilot depressing the PRE FLT switch on the MMD control panels. The aircraft has been preflighted to include the preset of specific switches. Engine start has been accomplished and the engine is at idle as can be seen on the right MMD (Figure 2). The engine parameters are displayed in a decluttered format where the horizontal lines represent upper and lower limits for normal operations. Digital readouts are provided at the bottom of each vertical scale when more exact information is required. The fuel quantity display is pictorial showing the aircraft fuel tanks in plan view.

The vertical situation display (VSD) shows attitude information, indicated airspeed, mach, altitude, heading, vertical speed, angle of attack, and acceleration. The 2,300-foot-altitude reading represents airfield elevation.

The blue cursor on the left side of the checklist display indicates to the pilot his current checklist item. The cursor triangular symbol may be filled in or empty. When filled in, this indicates the cursor will automatically advance to the next item when the pilot completes the current item. When empty, the pilot must activate the CHECK/ACK (Check/Acknowlege) switch, on the multifunction keyboard, to cause the cursor to advance to the next checklist item. On a production aircraft, very few empty cursors would be used, thereby speeding up performance of the checklist. In this case, the cursor would move from item to item at a predetermined rate while the pilot would perform an active monitoring role with ability to interrupt any time. The empty cursor is always used as the last item at the bottom of a checklist page. This insures pilot involvement in the semiautomatic checklist procedure.

The blue cursor shows the pilot is at item 6 of the preflight checklist, which requires the pilot to select one of several mission modes. The pilot selects the Takeoff/climb/letdown (TO/CLIMB/LTDN) mode to verify availability of the appropriate display and thereby check on the software programming.

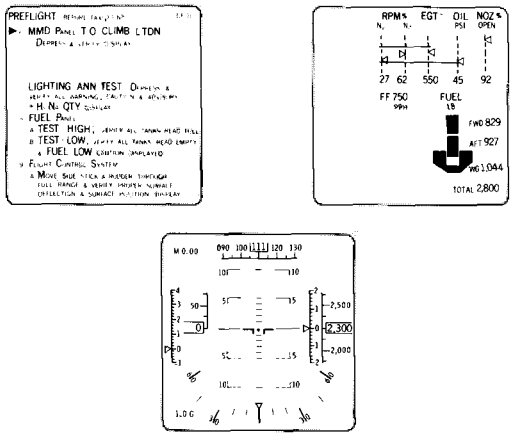

Figure 2. Preflight Checklist at TO CLIMB LTDN Select

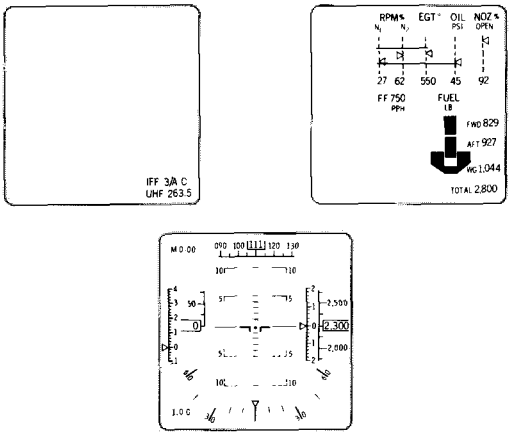

Figure 3. Left MMD Format for TO CLIMB LTDN Selection

The left MMD is the only display change (Figure 3), since the formats being shown on the center and right MMD are appropriate to all flight modes. The left MMD changes to show the UHF communication frequency or channel and IFF code (Figure 3). A second activation of the TO/CLIMB/LTDN pushbutton returns the checklist format to the left MMD (Figure 4).

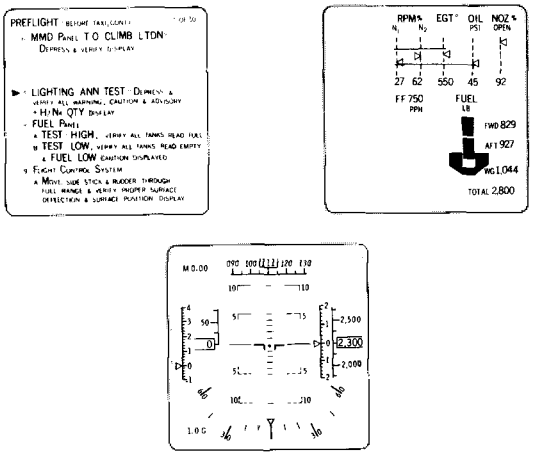

Figure 4. Preflight Checklist at Lighting Annunciator Test

Returning to the checklist on the left MMD (Figure 4), note the cursor is now on item 7 and the pilot has activated the ANN TEST (annunciator test) switch on the lighting panel to verify all warning, caution, and advisory messages. Successive activations of the annunciator test switch will cause three pages of annunciator test messages to appear on the center MMD. In Figure 5, page 1 of 3, 13 caution messages, four warning messages, and miscellaneous advisory information in blue, white, and green are presented. The boxed number 13 indicates to the pilot there are 13 caution messages on this page of test. During flight, the boxed numbered indicates the number of caution messages being held in active computer memory. Only the most recent four are displayed with the most recent messages displacing the older messages to storage memory. Under certain conditions the older messages are automatically recalled and displayed, while pilot option can provide recall at any time. The lack of a dedicated flap position indicator requires the presentation of flap information during preflight to verify softwave programming. Flap positions are shown as UP, INTMD (intermediate), and DN (down).

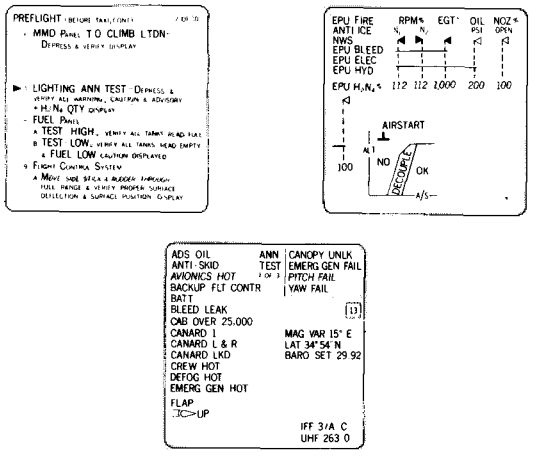

Figure 5. Lighting Annunciator Test, Page 1 of 3

On the right MMD the EPU (emergency power unit) fire warning and five green advisory messages are presented. The pilot checks to make sure the engine parameter and hydrazine quantity cursors are at maximum and the digital readouts in each case are correct. An airstart envelope format similar to that found in the pilot's handbook is also presented. The engine airstart envelope is a plot of altitude versus airspeed and is divided into three zones: NO, DECOUPLE, and OK. The first and last zones indicate airstart is or is not possible. The middle zone indicates airstart is possible only if the pilot decouples the accessory drive section from the engine. Each of the three airstart zones is color-coded red, yellow, or green, going from left to right. Color coding and a small aircraft symbol are used to indicate to the pilot his location in the airstart envelope.

The advanced fighter for which these display formats were being developed was single engine and had fairly significant energy requirements for the accessary drive section. This, coupled with negative aircraft stability, results in an increased emphasis on early engine restart. The airstart envelope display would take on less importance in a multiengine aircraft.

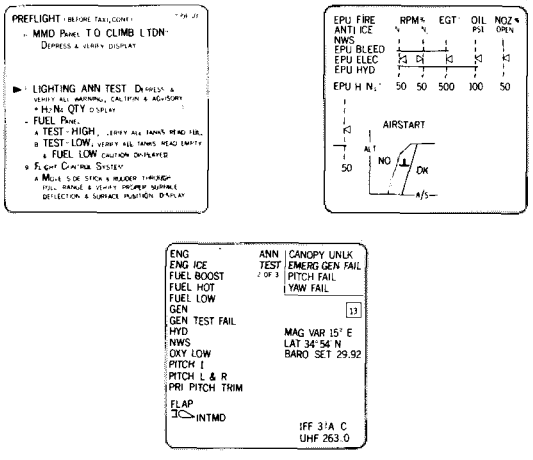

Figure 6. Lighting Annunciator Test, Page 2 of 3

Release and activation of the ANN TEST switch a second time removes page 1 of the annunciator test and replaces it with page 2 (Figure 6). At this point 13 new caution messages and the intermediate flap position are presented. The warning messages and the remaining advisory messages have not changed and are repeated for consistency of location. Again, the boxed number 13 indicates the number of messages on this page of the test. A missing message would be indicated by a sawtooth border around the blank

message space. Reference to a backup checklist would identify the missing message for subsequent maintennance action.

On the right MMD the engine parameters and hydrazine quantity displays are checked for midposition values.

The airstart envelope display is in the DECOUPLE zone, and the location of the aircraft symbol shows the pilot he may choose to trade altitude for airspeed, thereby moving into the OK zone and avoiding the need to decouple. Again, the digital values on the EPU and engine parameter formats in each case correspond to cursor midposition.

Release and activation of the ANN TEST test switch brings up page 3 of 3 of the annunciator test messages (Figure 7). Here 12 new caution messages, and the flap surfaces in a full-down position are shown.

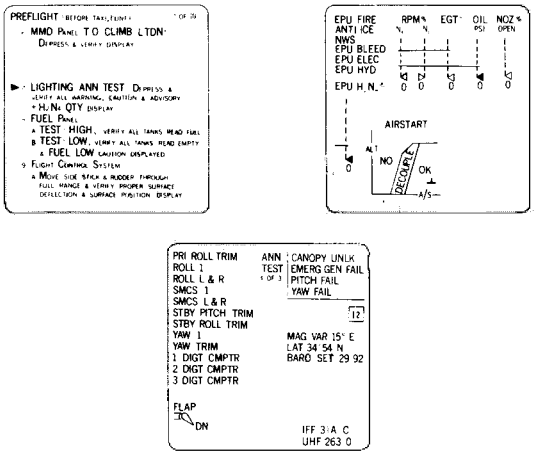

Figure 7. Lighting Annunciator Test, Page 3 of 3

On the right MMD, the third page of the engine parameter display with all cursors at minimum reading is presented. Versatility of programmable multifunction color displays is illustrated by the engine oil pressure and hydrazine quantity cursors having changed color from white to yellow, indicating a "low" condition. The color change also appears in the tick marks used to denote the vertical scales, as well as in the digital readout below each vertical scale. In the airstart envelope, the OK green zone with the small aircraft symbol well within this zone is presented.

Release of the annunciator test switch, on the lighting panel, for the third time restores the VSD format to the center MMD, the engine parameter/fuel format to the right MMD, and the checklist to the left MMD (Figure 8). The checklist cursor has moved to item 8 for fuel system quantity checks.

On the fuel panel, the pilot moves the fuel test switch to HIGH and verifies appropriate fuel system readings on the right MMD (Figure 9). The digital readouts for each tank, total quantity, and fuel flow are all correct. The pilot releases the fuel quantity test switch, and the engine parameter format is restored to the right MMD. (Figure 10).

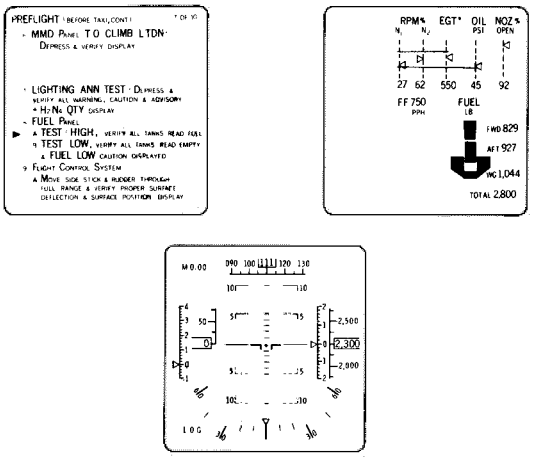

Figure 8. Preflight Checklist at Fuel Panel Tests

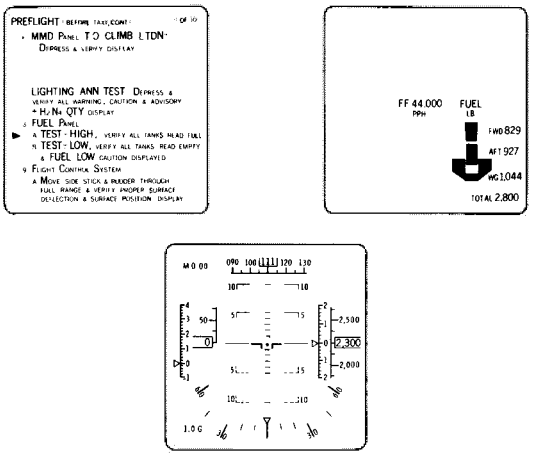

Figure 9. Fuel Test High

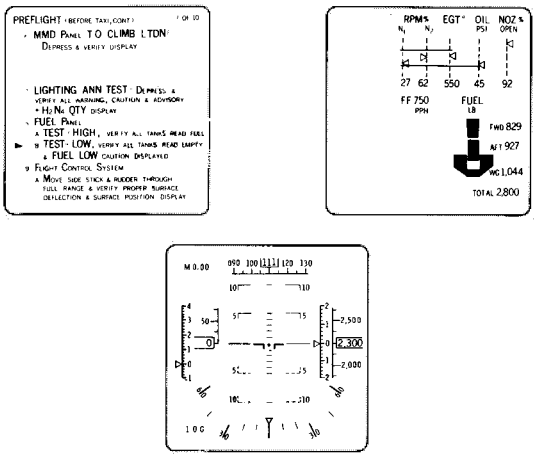

Figure 10. Prior to Fuel Test Low

The pilot now moves the fuel test switch to LOW, and the right MMD changes to show a fuel-empty condition, with the addition of yellow coding to indicate a caution condition (Figure 11). The center MMD has also changed to show the FUEL LOW caution annunciator.

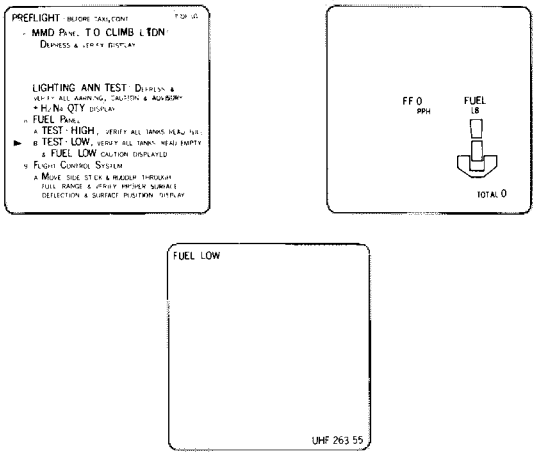

Figure 11. Fuel Test Low

Releasing the fuel test switch from LOW moves the checklist cursor to item 9A and restores the right MMD to the engine parameter format and fuel quantity format; and the center MMD shows the control surface position format (Figure 12). At this time, the pilot is directed to perform a flight control system surface position check by making inputs to the side stick controller and the force rudder pedals. While doing this, he observes the appropriate control surface movements on the center MMD. Flap movement is also checked at this time. The control surface position format, on the center MMD, is another example of the use of pictorialism to better convey information to the pilot.

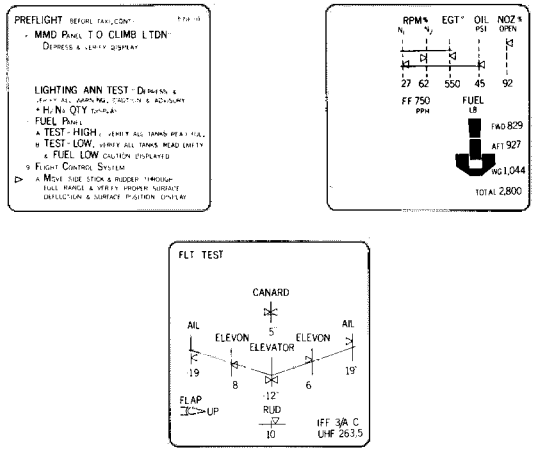

Figure 12. Flight Control Surface Checks

On completion of checklist item 9A, the control surface checks, the pilot depresses the CHECK ACK switch, on the multifunction keyboard, causing the checklist page to change on the left MMD and the center MMD to return to the vertical situation mode (Figure 13).

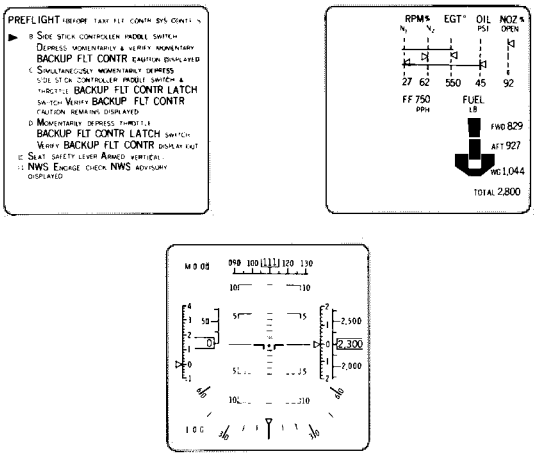

Figure 13. Prior to Backup Flight Control Checks - Momentary

At this time, the pilot depresses and holds the paddle switch, at the base of the stick grip, and verifies the appearance of the backup flight control caution message, on the center MMD (Figure 14). The flight control system is three-channel digital fly-by-wire, with a fourth analog channel as backup designed for use during the flight test program only. Automatic fault monitoring could produce a switchover from digitial to analog backup, or pilot selection could bring about the same result. The pilot releases the paddle switch and observes disappearance of the backup flight control caution message and reappearance of the vertical situation display (Figure 15). The blue cursor on the checklist automatically moves to item 9C on page 8.

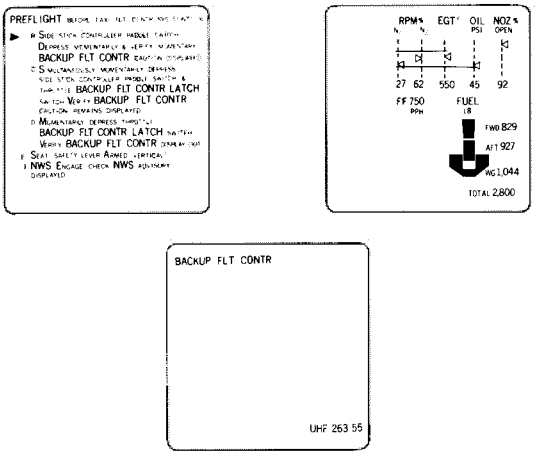

Figure 14. Backup Flight Control Check - Momentary

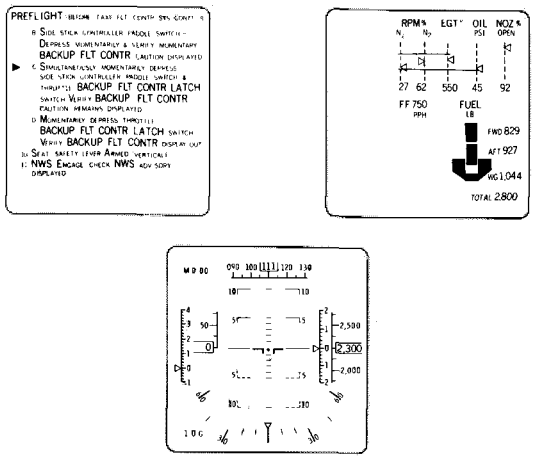

Figure 15. Prior to Backup Flight Control Check - Hold

For item 9C, the pilot again momentarily depresses the side stick paddle switch and simultaneously engages a throttle-mounted switch to latch the backup flight control selection (Figure 16). He releases both switches and observes the continued presence of the backup flight control caution annunciator, on the center MMD (Figure 16). The checklist cursor has automatically moved to item 9D (Figure 17).

For item 9D, the pilot again depresses the backup flight control latch switch, on the throttle, and observes the disappearance of the caution message, on the center MMD, and reappearance of the vertical situation display. The checklist cursor automatically moves to item 10 on page 8 (Figure 18).

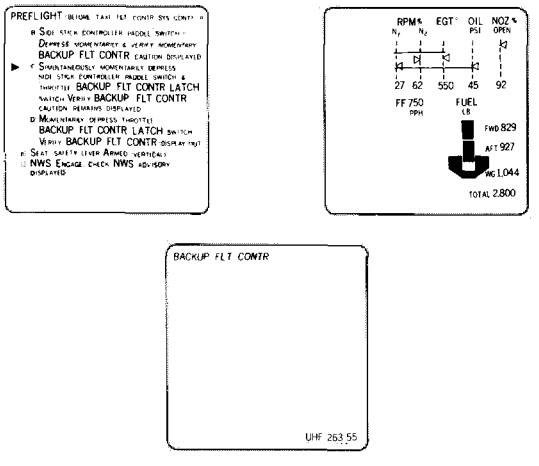

Figure 16. Backup Flight Control Check - Hold

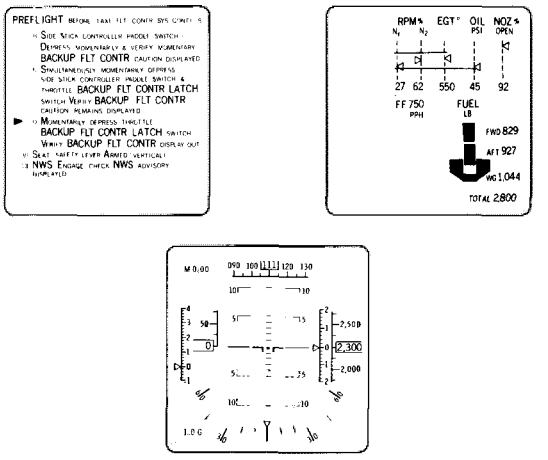

Figure 17. Backup Flight Control Check - Hold- Release

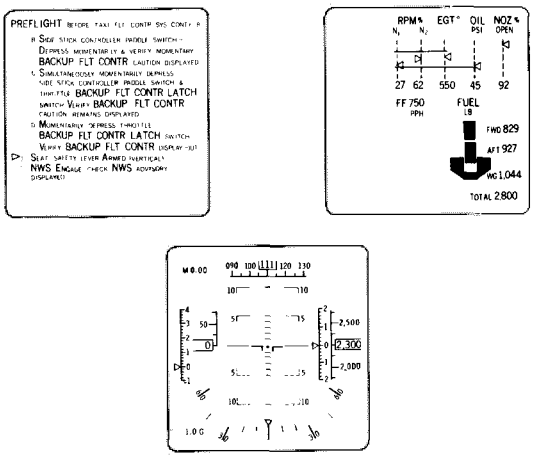

Figure 18. Ejection Seat Safety Lever - Check

For item 10, the pilot moves the ejection seat arming lever to the vertical position and depresses the CHECK/ACK switch, on the multifunction keyboard, causing the cursor to advance to item 11, nosewheel steering (NWS) engage (Figure 19). After momentarily pressing the NWS engage button on the side stick controller the pilot observes the green NWS advisory on the right MMD (Figure 20). He may also note some fuel burnoff. The pilot activates the CHECK/ACK pushbutton to advance the page.

At this time the final page of the preflight checklist is presented to permit completion of the "Before Takeoff" portion (Figure 21). Starting with item 4, IFF - set, (identification friend of foe), the pilot switches the IFF set from STANDBY to OPERATE and selects the appropriate code. As soon as he does this, he notes the appropriate IFF code in the lower right corner of the checklist display (Figure 22). Since the system cannot know if the pilot has selected the correct IFF code, the pilot must advance the cursor by activating the CHECK/ACK pushbutton (Figure 23).

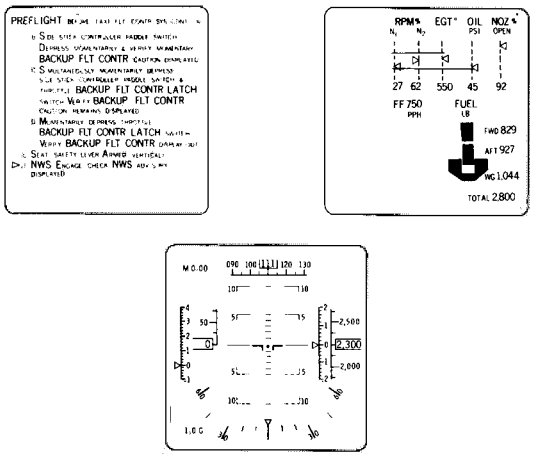

Figure 19. Prior to NWS Engage - Check

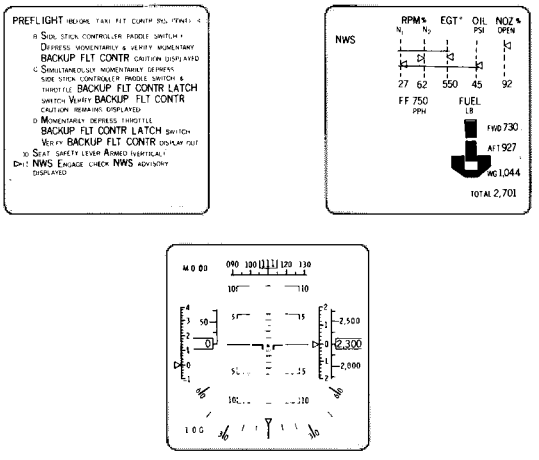

Figure 20. NWS Engage - Check

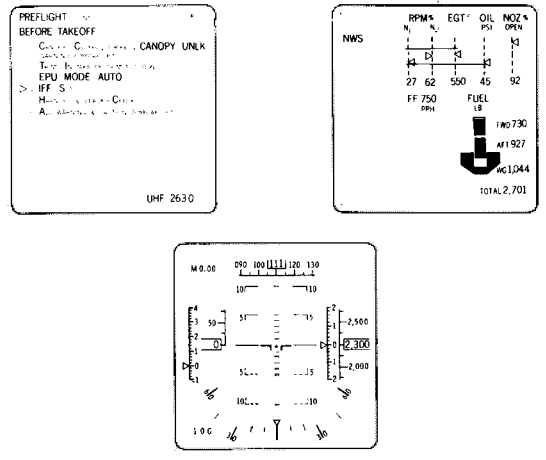

Figure 21. Prior to IFF Set

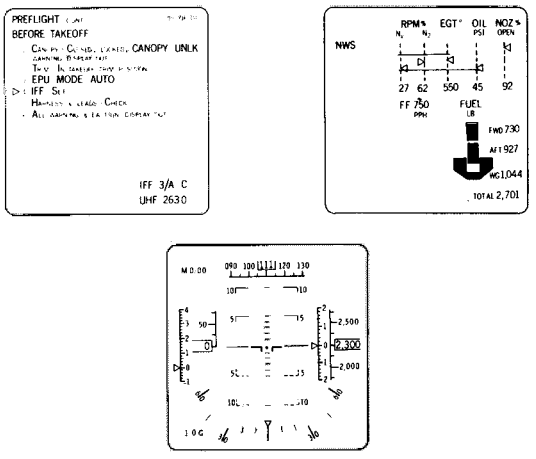

Figure 22. IFF - Set

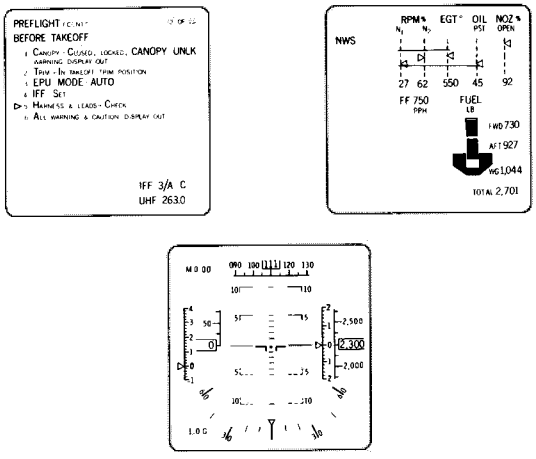

Figure 23. Restraint Harness Personal Leads - Check

The pilot next checks his seat harness and oxygen, communications, and anti-g leads to insure they are securely fastened. He again activates the CHECK/ACK pushbutton to advance the cursor to item 6 on the checklist (Figure 24).

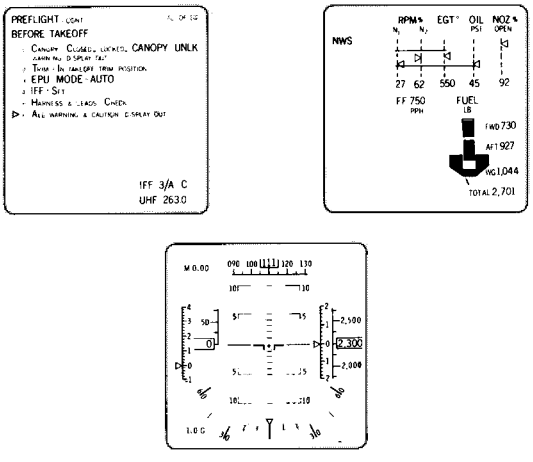

Figure 24. Warning, Caution - Check

On checking for warning and caution messages and finding none, the pilot activates the CHECK/ACK pushbutton, advancing the checklist cursor to the next page (Figure 25). The next page (Figure 25) indicates the preflight checklist is complete, and the pilot is ready for takeoff.

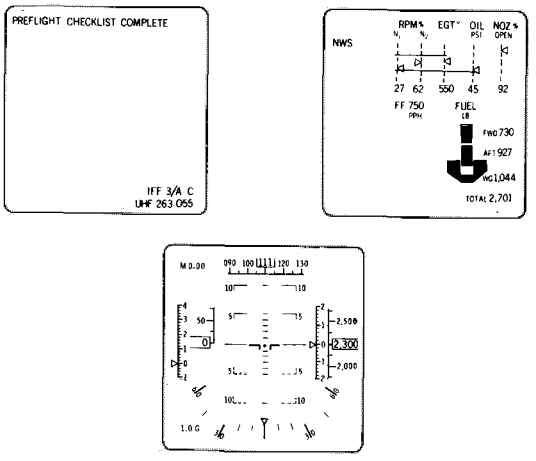

Figure 25. Preflight Checklist - Complete

At this time, the pilot selects TO/CLIMB/LTDN (takeoff/climb/letdown) and notes the display of flap setting, IFF code, and UHF communications information on the left MMD (Figure 26). Assuming he is on the active runway, he applies takeoff thrust, notes changes in the engine parameter display, and starts his takeoff roll. The pilot notes some additional fuel burnoff.

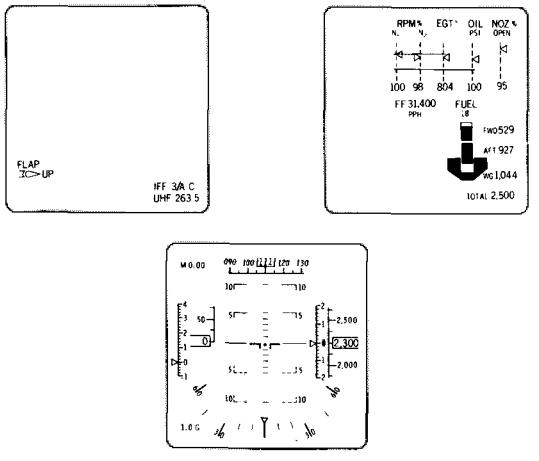

Figure 26. Display Formats at Start of Takeoff Roll

Takeoff/Climb

In Figure 27, on the center MMD the pilot notes the aircraft is climbing through 5,000 feet at 300 knots at 3,240-foot-per-minute rate of climb.

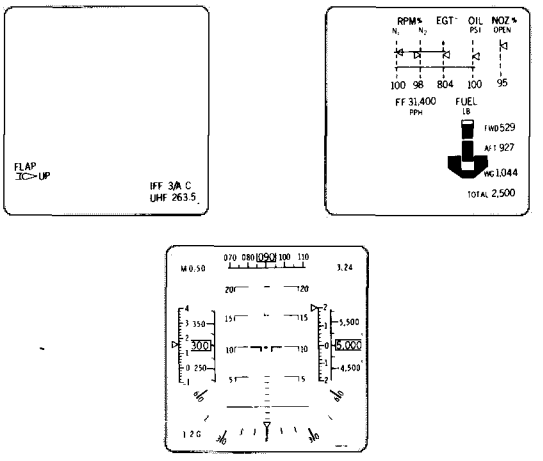

Figure 27. Display Formats During Climb

Cruise

At this time, the the pilot selects the cruise mode. In the next figure (Figure 28), on the center MMD, the pilot notes he is at 9,900 feet at an airspeed of 400 knots. On the right MMD, he notes some fuel burnoff and a reduced power setting. To further illustrate the principle of automatic decluttering, it may be noted that tank designation and quantity information are deleted when the tank reaches empty. The pictorial outline of an empty tank is retained.

In Figure 29, the pilot notes his indicated airspeed to be 390 knots, while altitude is about 10,150 feet with a rate of descent of 1,000 feet per minute. The sawtooth border around the digital altitude readout indicates to the pilot that the reading is suspect, and the pilot should use the reading with discretion. The pilot also notes additional fuel depletion on his right MMD.

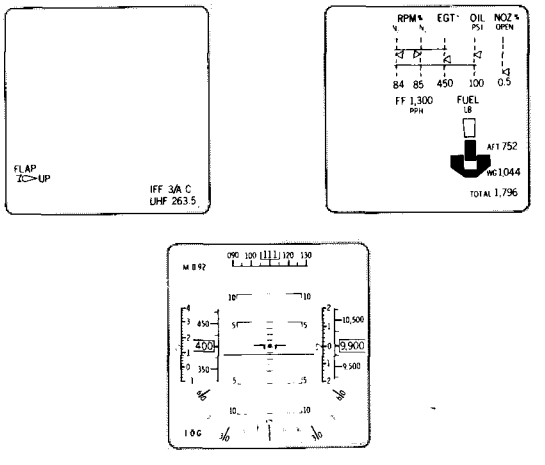

Figure 28. Display Formats During Cruise

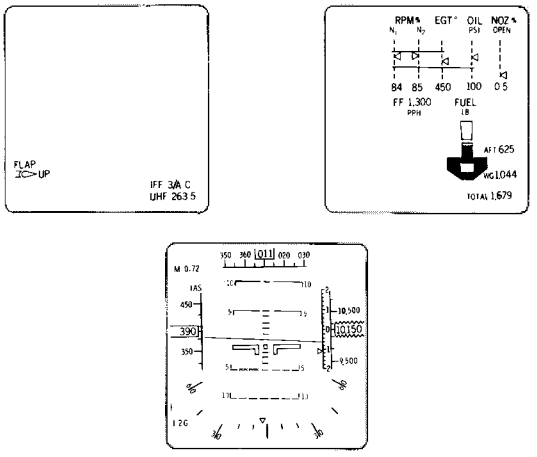

Figure 29. Cruise Formats With "Suspect" Altitude Readout

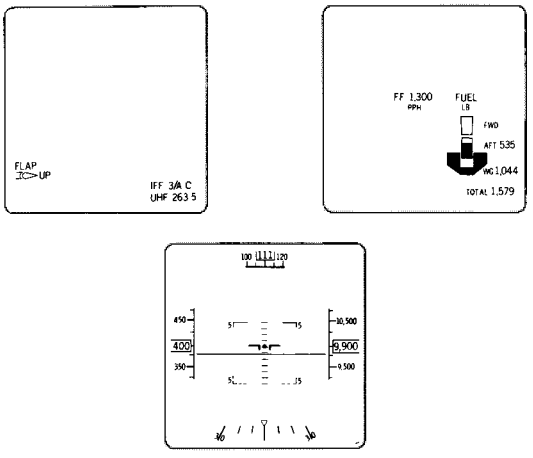

Figure 30. Cruise Declutter Formats

Cruise-Declutter

At this time the pilot selects the cruise-declutter mode, and notes the removal of a considerable amount of information from the center MMD (Figure 30). This includes pitch ladder information, the rate of climb scale, and digital read-outs for mach number, aircraft g, and vertical velocity. On the right MMD, all engine parameter information, except for fuel flow, has been removed. Again, additional fuel burnoff is indicated.

Emergency Conditions

In Figure 31, the pilot notes an engine caution message on the left MMD, and on the right MMD, he sees an engine flameout has occurred. The engine airstart envelope and the four engine parameters in the yellow indicate engine flameout. The reappearance of the engine parameter format was automatic as a result of the engine flameout problem. The EPU comes on-line automatically, and this is confirmed by the EPU electrical and hydraulic advisory messages. Hydrazine quantity is displayed automatically whenever EPU operation is ongoing.

In looking at the airstart envelope (Figure 31), the pilot notes he is in the DECOUPLE zone, meaning the accessory drive section must be disconnected from the engine gearbox to permit an airstart. The pilot decides against this action, and, instead, decides to trade altitude for airspeed in order to get into the OK zone of the airstart envelope.

In Figure 32, the pilot notes the aircraft is in the OK portion of the airstart envelope and that engine restart will occur shortly. To develop a "maximum information requirements" display condition and evaluate adequacy of the pilot-display interface, a second emergency is introduced prior to the engine flameout emergency being cleared. It should be noted that the pilot has as an EPU fire warning annunciator message on the right MMD and the corresponding EPU fire emergency procedures information on the left MMD (Figure 32).

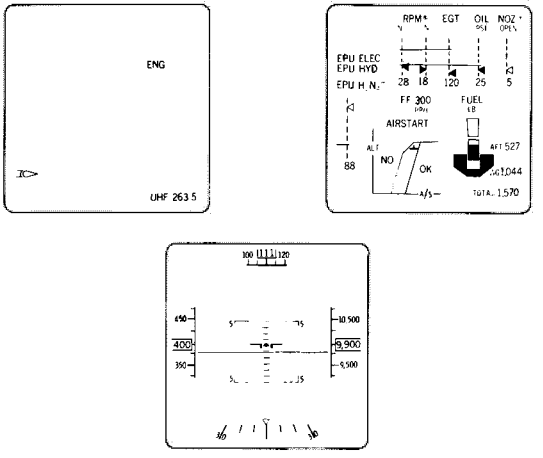

Figure 31. Emergency Conditions - Engine Flameout

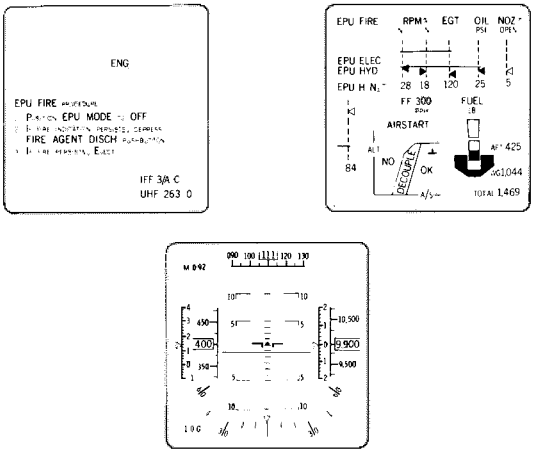

Figure 32. Engine Flameout and EPU Fire

In Figure 33, the pilot notes that engine restart has occurred as indicated by the engine parameter values and removal of the airstart envelope and EPU data. We also note removal of the engine caution message and EPU fire procedures information from the left MMD, since engine restart was successful and the EPU fire was extinguished.

Figure 33 also shows a return to normal cruise condition, with the aircraft flying at 20,100 feet at an indicated airspeed of 460 knots. In returning to a normal cruise condition display format after an emergency, the displays are not decluttered automatically. Under these conditions, it is left to the pilot to reselect a declutter mode. Fuel burnoff has continued, with the total remaining slightly above 1,000 pounds. The pictorial fuel display shows the forward tank empty, the aft tank about half full, and the wing tanks full. The alphanumeric labels for each tank are removed when the tank is emptied.

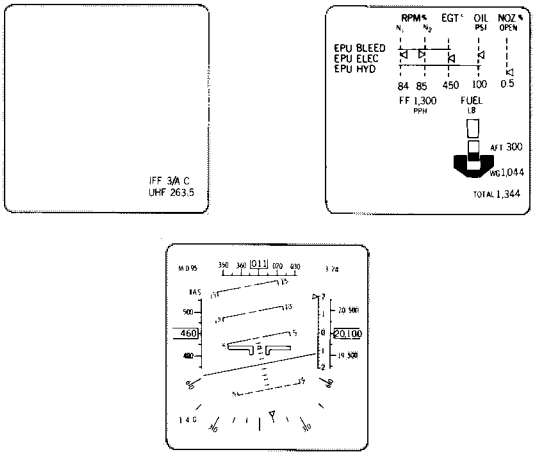

Figure 33. Return to Normal Conditions

Flight-Test Mode

At this time, the pilot selects the flight-test mode on the multifunction keyboard, and the left MMD (Figure 34) now shows a data format that might be used for flutter testing. The right MMD shows pilot has gone into afterburner operation (Figure 34).

While still in a flight-test mode, the pilot is going to perform some aircraft handling qualities tests and he therefore calls up the control surface position format on the left MMD (Figure 35). On the right MMD, we note that the engine is out of afterburner operation and the fuel supply is down to 800 pounds.

More Emergency Conditions

In Figure 36, the left MMD shows the onset of a warning condition (canopy unlocked) and a caution condition (engine ice). On the right MMD, fuel supply is down to 700 pounds (Figure 36).

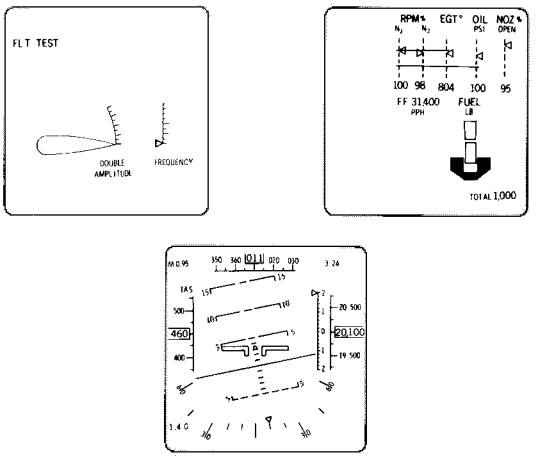

Figure 34. Tailored Format for Flight Test

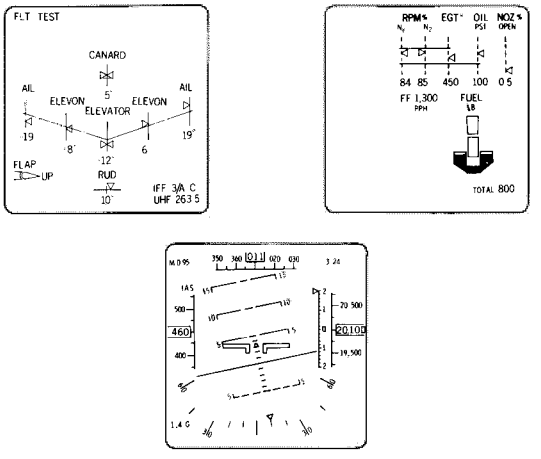

Figure 35. Format for Handling Quality Tests

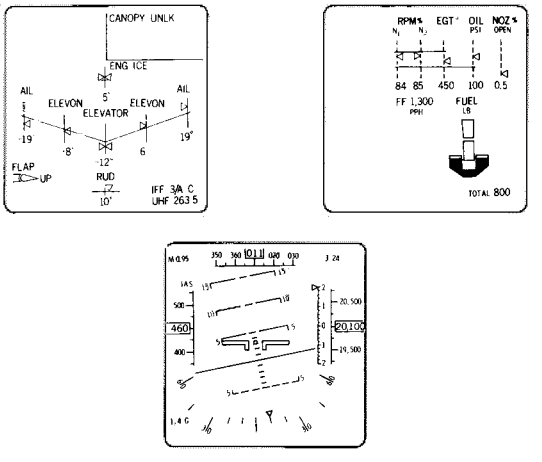

Figure 36. Emergency Information Annunciation With Normal Flight Data

In Figure 37, we see the pilot has corrected the canopy unlocked condition and three additional caution conditions have been announced. Since warning and caution messages have a higher priority than the control surface position information, portions of the control surface displayed information are removed to permit display of the warning and caution messages. While attending to these four caution messages, the pilot decides to recall all other caution messages stored in memory in order to better evaluate a course of action (Figure 38). Meanwhile, the pilot has initiated a letdown, and we note on the center MMD the aircraft is at 9,900 feet at an IAS of 400 knots (Figure 38).

Letdown/Landing

At this time, the pilot has selected the TO CLIMB LTDN mode, on the multifunction keyboard (Figure 39). For purposes of this paper we assume the caution message problems facing the pilot a few moments earlier have been corrected. The aircraft is at 5,000 feet at an IAS of 300 knots. On the right MMD, we note the engine is at IDLE, and the fuel supply is down to 700 pounds as the aircraft turns on the final approach (Figure 39).

On the final approach, the flaps are lowered to INTMD, as can be seen in Figure 40.

Figure 41, shows landing has occurred, the aircraft is at 2,300 feet (field elevation), the engine is at idle, the fuel supply is down to 500 pounds, the flaps are retracted, and nosewheel steering is engaged.

As the pilot taxis (Figure 42), a FUEL LOW caution has appeared on the left MMD, while the right MMD pictorial fuel display also reflects this condition by changing the fuel supply color from blue to yellow. The digital readout for fuel quantity (400 pounds in this case) also changes color from white to yellow.

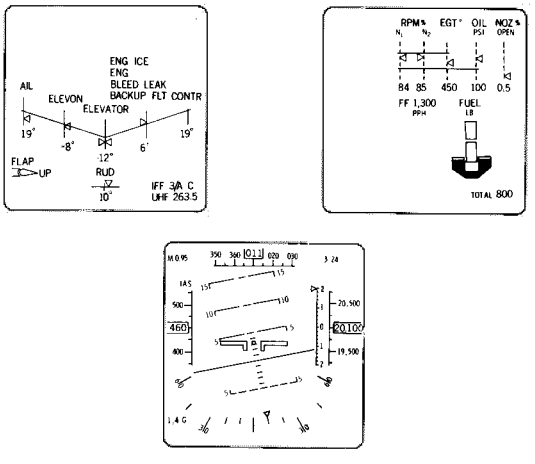

Figure 37. Displacement of Normal Formats by Caution Messages

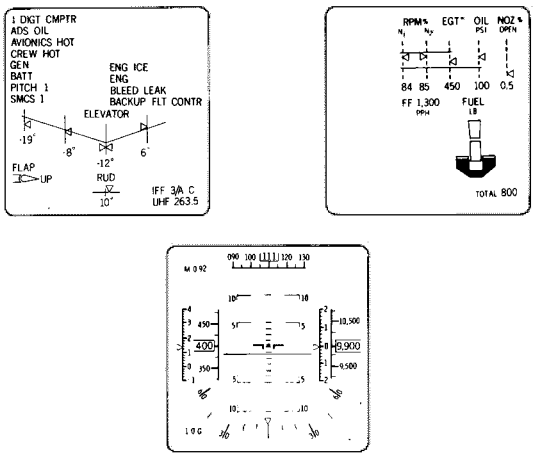

Figure 38. Effect of Caution Recall on Normal Data Displacement

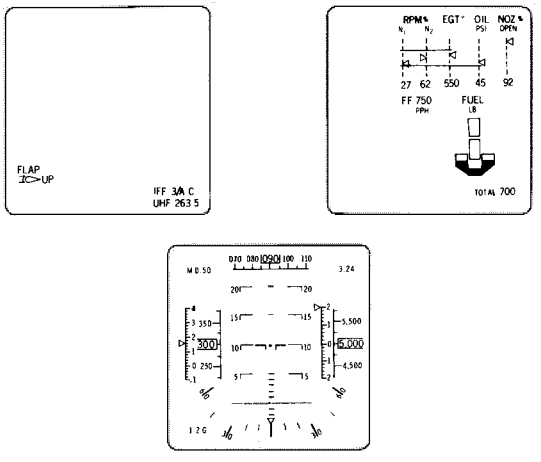

Figure 39. Letdown/Landing Display Formats

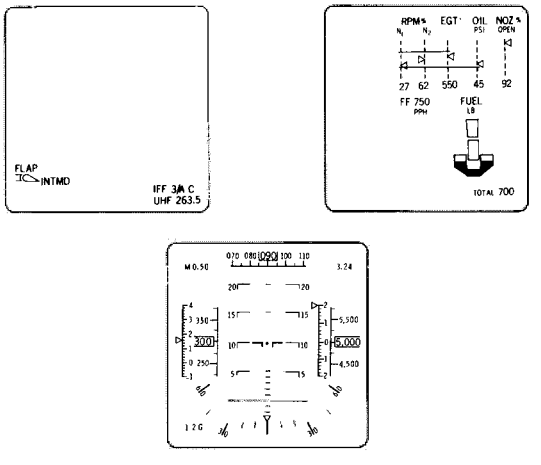

Figure 40. Final Approach Formats

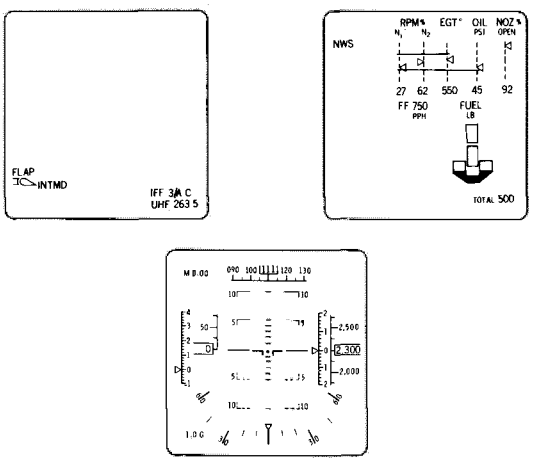

Figure 41. Immediately After Landing

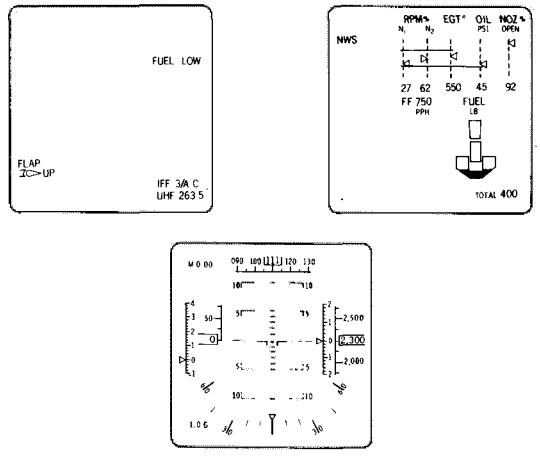

Figure 42. Displays During Taxi

Postflight

In Figure 43, the aircraft is in its parking space on the ramp and the pilot has selected the postflight mode on the multifunction keyboard. The left MMD shows page 1 of the postflight checklist, while the right MMD shows the decreasing fuel supply, down to 300 pounds at this time. Returning to the checklist, (Figure 44), the pilot has turned the IFF off. This is revealed in Figure 44 by the absence of the IFF code. Fuel supply has decreased to 250 pounds. Meanwhile, the checklist cursor has automatically advanced to item 2 in Figure 45.

Item 2, page 1, of the postflight checklist, requires the pilot to safety the ejection seat by moving a seat-mounted lever from a vertical to a horizontal position. Having accomplished this, the pilot activates the CHECK/ACK pushbutton, on the multifunction keyboard, causing the checklist cursor to advance to the "Engine Shutdown" section of the checklist (Figure 46).

In Figure 46, the current checklist item requires the pilot to check that the EPU is off. Having completed this the pilot activates CHECK/ACK to advance the checklist cursor.

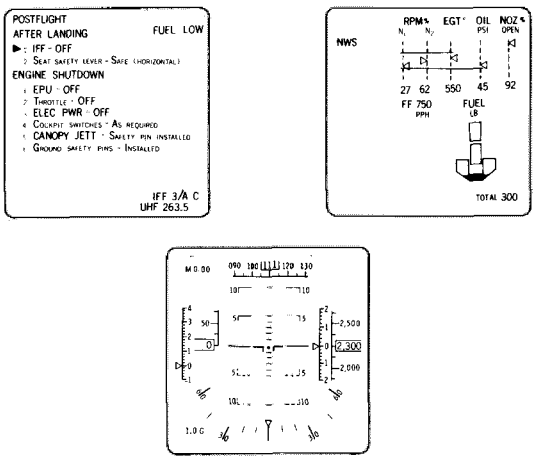

Figure 43. Postflight Checklist - IFF Off

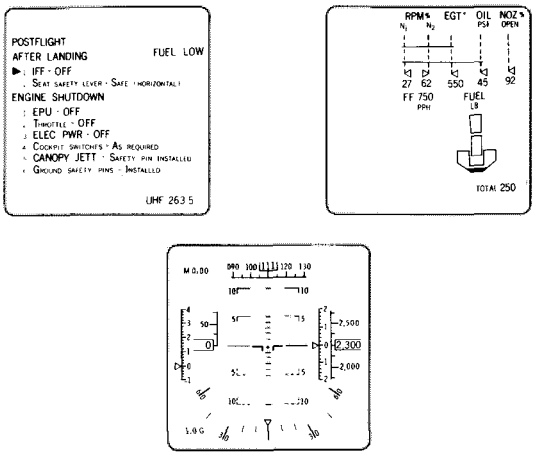

Figure 44. Postflight Checklist - IFF Code Removed

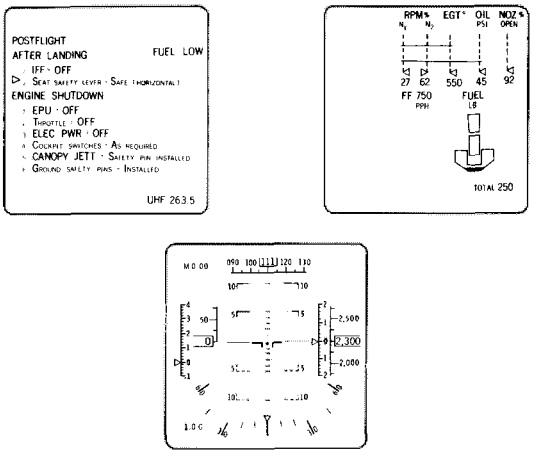

Figure 45. Postflight Checklist - Ejection Seat Safety Lever

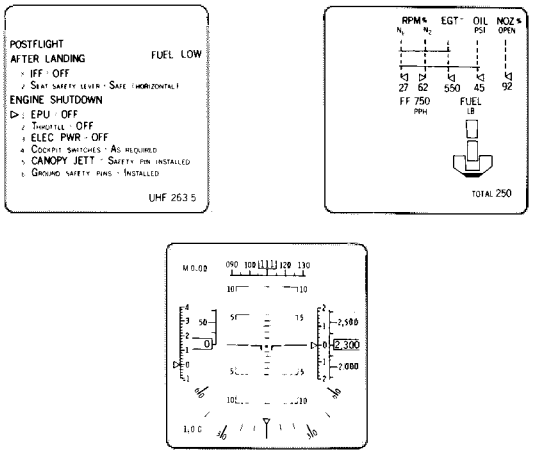

Figure 46. Engine Shutdown - EPU Off

In Figure 47, the solid cursor at item 2, "throttle-off," indicates that when the pilot moves the throttle to OFF, the cursor will automatically advance to the next checklist item. On the right MMD, the engine parameters are at zero in response to the throttle being moved to OFF (Figure 47).

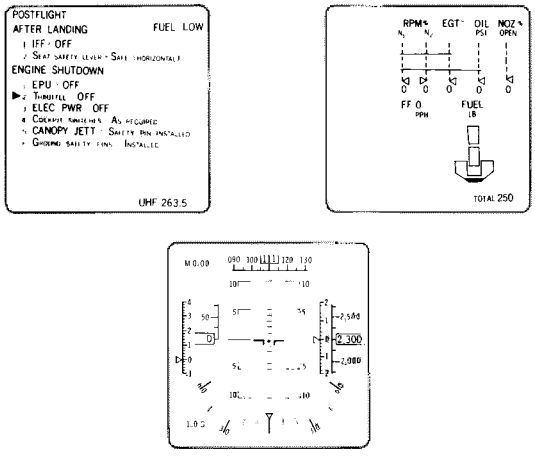

Figure 47. Engine Shutdown - Throttle Off

In Figure 48, the pilot responds to the ELEC PWR OFF checklist item, which automatically advances the cursor to the next checklist item and also removes power to the center and right MMD's (Figure 49).

The pilot performs the checks required by the remaining postflight checklist items (Figure 50), and, for each item, activates the CHECK/ACK pushbutton to advance the checklist cursor. The completion of the last item ground safety pins installed (Figure 51) is signaled by the crew chief, with the pilot activating the CHECK/ACK pushbutton to advance the cursor to the next page.

The next page (Figure 52) shows the postflight checklist has been completed, and the pilot turns the power off to the left MMD (Figure 53) and leaves the aircraft.

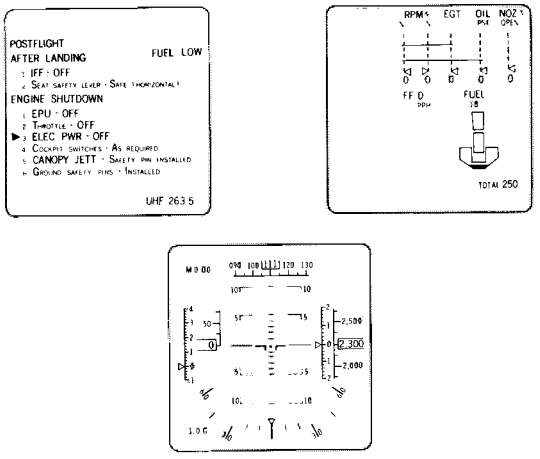

Figure 48. Engine Shutdown - Electric Power Off

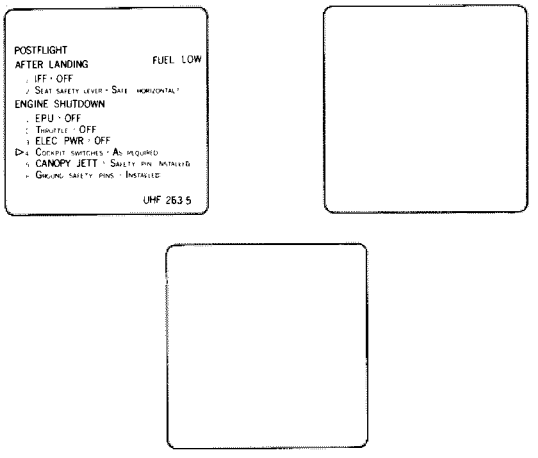

Figure 49. Cockpit Switches - As Required

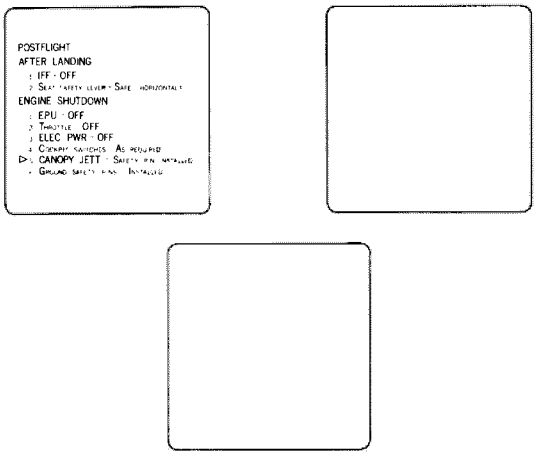

Figure 50. Canopy Jettison - Safety Pin - Installed

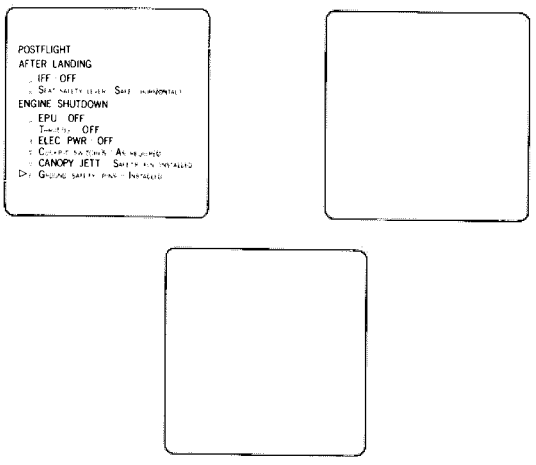

Figure 51. Ground Safety Pins - Installed

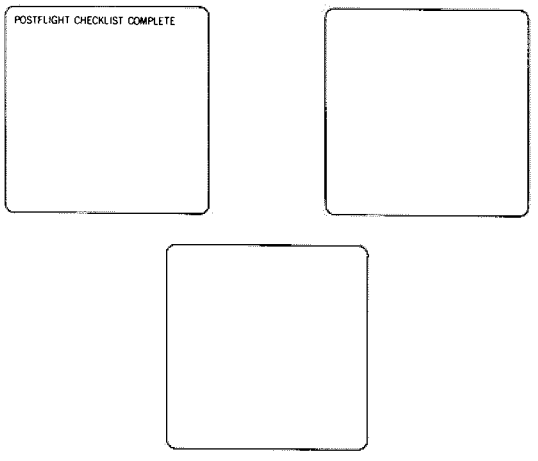

Figure 52. Postflight Checklist - Complete

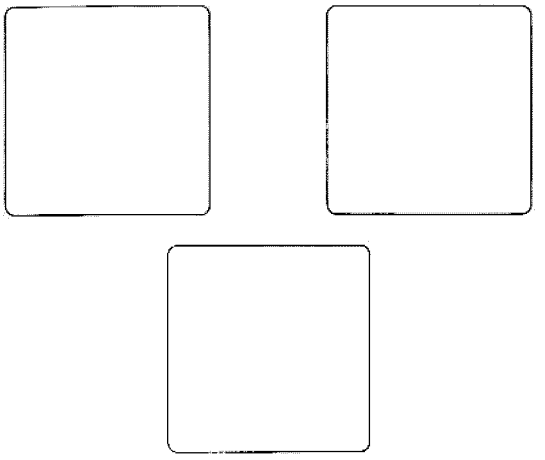

Figure 53. MMD Formats During Power Off

IV. Conclusions

The changeover from dedicated electromechanical instruments to multifunction electronic displays offers an opportunity to implement significant human engineering improvements in aircraft cockpits. These improvements include the use of pictorial formats, the presentation of information only when required, and the flexibility to change format as a result of flight-test data and changes in operational mission requirements. Through the use of specific examples, this paper has attempted to illustrate these principles.