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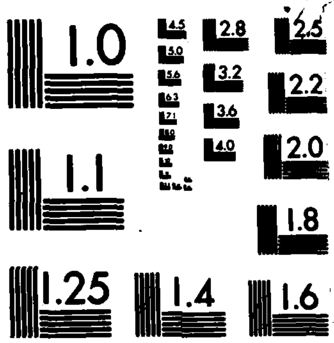

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AD-A140 870

COMMAND FLIGHT PATH DISPLAY

PHASE I AND II

FINAL TECHNICAL REPORT

R83-49

SYSTEMS ASSOCIATES, INC.
of
CALIFORNIA

Resource Management Systems Division

853 Atlantic Avenue
Long Beach, California 90813
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COMMAND FLIGHT PATH DISPLAY

PHASE I AND II

FINAL TECHNICAL REPORT

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This report covers the development of the Command Flight Path Display System and the actual Flight Test Operation of the System including the evaluation of the CFPD concept by analysis of flight test recorded data. It proves the validity of the CFPD concept which consists of a totally integrated pictorial presentation of the fundamental information necessary to effectively perform all of the normal basic flight operations with and without reference to the real world. The actual (cont. on reverse)

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Item 20 (cont) flight test: 1) Demonstrated that the CFPD was in fact a truly integrated display which provided the pilot with adequate information to execute take-off, climb, cruise/navigation, approach and landing, without reference to conventional parametric displays, or the real world.

2) Established that pilot performance with the CFPD was enhanced, demanding minimal concentration on the display, minimizing inadvertent departures, and requiring minimal training time, both initially and for maintaining flight proficiency, as compared to performance utilizing standard symbolic displays.

3) Proved that the electronic system required to generate the CFPD can be achieved by modifying current aircraft display and control systems through the utilization of computer graphics picture processing techniques.

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REFERENCES

1. Calspan Report No. 6645-F-12
2. Intermetrics Report No. IR-MA-244

GLOSSARY

AD - Analog to Digital
ANIP - Army Navy Instrumentation Program
AOA - Angle of Attack
ATC - Air Traffic Control
CDI - Course Deviation Indicator
CTOL - Carrier Take-off and Landing
CRT - Cathode Ray Tube
DCNO - Deputy Chief of Naval Operations
DIS - Discreet Word Input Sweep
DME - Slant Range Distance
FDL - Flight Dynamics Lab
FOV - Field of View
FPM - Feet per Minute
GFE - Government Furnished Equipment
HSD - Horizontal Situation Display
HSI - Horizontal Situation Indicator
HUD - Head-up-Display
HZ - Hertz
IAS - Indicated Airspeed
IC - Integrated Circuit
ICS - Intercommunication System
IFR - Instrument Flight Rules
ILS - Instrument Landing System
IMC - Instrument Meteorological Conditions
INS - Inertial Navigation System
I/O - Input/Output
KTS - Knots
MSL - Mean Sea Level
NADC - Naval Air Development Center
NATC - Naval Air Test Center
NAVAIRSYSCOM - Naval Air Systems Command
RC - Cross Range
RF - Forward Range
SDDL - Software Design and Documentation Language
SDI - Synchro to Digital Input
SIM TAPE - Simulation Tape
SPI - Serial to Parallel Input
TCN - Tacan (Tactical Air Navigation)
TIFS - Total In-Flight Simulator
TPS - Test Pilot School
VFR - Visual Flight Rules
VSD - Vertical Situation Display
VSI - Vertical Situation Indicator
VSTOL - Vertical/Short Take-off and Landing
VTOL - Vertical Take-off and Landing
WYPT - Waypoint

COMMAND FLIGHT PATH DISPLAY PROGRAM

PHASE I and II

FINAL REPORT

1.0 INTRODUCTION

The Command Flight Path Display (CFPD) program is a special focus program under the Aircraft Technology, 6.2 Exploratory Development Block. The purpose of the program is to develop a totally integrated pictorial aircraft display system and evaluate the concept by actual flight test consisting of take off, climb, cruise/navigation, approach and landing, with and without visible real world contact. If the results of the concept evaluation warrant continuation, then the procedure would be repeated for tactical operation in an operational aircraft.

1.1 This Final Report covers Phase I and Phase II of the CFPD program. Phase I consisted of the development of the Command Flight Path Display flight test system and Phase II was the actual Flight Test Operation of the system including the evaluation of the CFPD concept by analysis of flight test recorded data.

1.2 On 20 April 1982, a meeting was held with the Naval Air Systems Command (NAVAIRSYSCOM), the Naval Air Development Center (NADC), and principals from Systems Associates, Inc. of California, Resource Management Systems Division (SAI/RMS), at which time authorization was given to SAI/RMS to proceed with arrangements to initiate Phase I of the CFPD program. It was agreed that the program would utilize the U.S. Air Force NC 131H Total In-Flight Simulator (TIFS) aircraft located at Arvin/Calspan for installation and flight testing of the CFPD system as recommended by SAI/RMS, and including the services of Intermetrics, Inc. to develop the required display software.

1.3 On 23 April 1982, arrangements were made by SAI/RMS for the program kick-off meeting for Phase I which was held at Arvin/Calspan in Buffalo, New York, on 5 May 1982. Responsibilities were assigned as follows.

a. SAI/RMS would:

1. Define detailed program objectives and requirements concerning the CFPD concept and functional design of the system to produce the displays.

2. Through a subcontract to Intermetrics, define, produce and document all software in the host processor and the

display generator except that associated with definition of the airplane state as measured by the sensors.

3. Assure that software delivery was compatible with overall program milestones.

4. Define the CFPD evaluation flight test objectives and a suitable flight test program.

5. Analyze the flight test data and define the final system design to ensure its adequacy for subsequent NATC evaluation.

6. Document the flight test results.

b. Intermetrics, Inc. would:

1. Develop the algorithms for the generation of the CFPD, current HUD symbology, and display of WAD symbology on the Evans and Sutherland PS-300 display generator system.

2. Prepare the software specifications for the PDP-11 computer and the PS-300.

3. Coordinate the PDP-11 and PS-300 software specifications with the Calspan sensor data software specifications and prepare a total system software specification.

4. Define the sensor data input requirements for the PDP-11 computer jointly with Calspan.

5. Develop the software for the PS-300.

6. Develop the software for the PDP-11 as it relates to the PS-300.

7. Software checkout for the total system jointly with Calspan.

8. Specify the recording software requirements for the concept evaluation flight test as defined by SAI/RMS.

9. Reduce the recorded data from the evaluation flight tests as specified by SAI/RMS.

10. Provide software support during flight test.

11. Provide final report and software documentation.

c. Arvin/Calspan would:

1. Prepare software specifications for sensor data conversion for PDP-11 inputs, working in conjunction with Intermetrics.

2. Establish sensors and software required to provide data inputs to the PDP-11.

3. Define system integration and installation requirements.

4. Design the system installation.

5. Fabricate the system interconnections.

6. Install the system.

7. Checkout of the total system via a complete end to end systems test, jointly with Intermetrics.

8. Provide Flight Test Operation support and obtain AF approval for flight test.

9. Provide Flight Test Aircraft and System maintenance support except for SAI/RMS and Navy GFE equipment.

10. Provide pilots for the concept evaluation flight test.

11. Provide a "quick look" capability for evaluation of flight data after each flight from the TIFS recording system, if required.

12. Provide processed data tapes for subsequent analysis, if required.

13. Document all external meetings, phone conversations, conferences, etc., and submit to NADC, FDL, and SAI/RMS.

14. Notify NADC, FDL, and SAI/RMS of all critical situations existing or probable as soon as possible.

15. Design and implement provisions for WAD.

16. Provide input for final report.

1.4 It is important to point out that NAVAIRSYSCOM, NAVAIR 03B, at the 20 April meeting, established the deadline of 28 February 1983, for proof of concept by actual flight test of the CFPD. That deadline was met by conducting the first flight test of the CFPD on 9 February 1983, further flight test on 10 February 1983, and by Intermetrics' first data reduction results which were provided on 17 February 1983, just 9.5 months after start up and ten days before the deadline.

1.5 Although many problems were encountered during the execution of Phases I and II, the competence of the entire program team overcame these obstacles, and the program objectives were completely achieved.

1.6 The subject report is divided into Sections 2.0 through 6.0.

Section 2.0 consists of a general executive summary of the overall CFPD program including the major results achieved, conclusions drawn and recommendations for continued effort.

Section 3.0 describes Phase I with a detailed technical discussion of the CFPD system design. This section was to include the Intermetrics' report describing the development of the display software, and the Calspan report covering the sensor conversion software, the CFPD equipment hardening, the installation of the system in the TIFS aircraft, and the ground simulation system to accommodate the CFPD test program requirements.

Section 4.0 covers the Phase II Flight Test procedures, including the ground simulation, the actual in flight operation, and the data recording techniques.

Section 5.0 describes the observations resulting from the reduction of the recorded ground simulation and in flight data.

Section 6.0 consists of a group of appendices covering detailed specific data relative to the program schedule, cost, meetings, pilot comments, installation photographs, and flight test plots.

2.0 SUMMARY AND CONCLUSIONS

2.1 Command Flight Path Display Program Concept Definition

The Command Flight Path Display Concept is defined as a pictorial presentation of totally integrated real world visual cues which provides the pilot of an aircraft with the following information:

Orientation - Where am I and what am I doing?

Director - What should I do and when?

Quantitative - How am I doing?

All three categories of information are presented relative to the real world vertical plane on a cathode ray tube called the Vertical Situation Indicator (VSI), and relative to the real world horizontal plane, on a cathode ray tube called the Horizontal Situation Indicator (HSI).

The Vertical Situation Display Format should be displayed on a HUD(VSI) because this is one of the major requirements of the overall concept. It can also be displayed on a panel mounted CRT VSI. In both cases the display format consists of the following three independent elements (Figure 2-1).

a. A dynamic earth plane or "contact analogue" composed of external reference, linear perspective, texture, size and shape, and motion parallax visual cues, with the capability of angular and linear displacement relative to all three axes.

b. A dynamic flight path composed of the same visual cues as the contact analogue and with the same six degrees of freedom.

c. A command velocity indicator displayed as a three dimensional aircraft located by pilot selection, either to the left, right or center, placed above or below relative to the flight path, and with the capability of changing in size and perspective as the pilot alters his formation position.

The Horizontal Situation Display Format is always displayed on the HSI which should be oriented to the horizontal plane. The format consists of the following elements (Figure 2-2).

a. A topographical map or tactical plot depending upon the type of mission being conducted is provided covering the operational area of the aircraft including terrain characteristics, potential obstacles, navigational aid locations, operational bases, destinations, and targets.

b. A geographical Command Flight Path indicating the proposed or altered flight plan including all segments and way points,

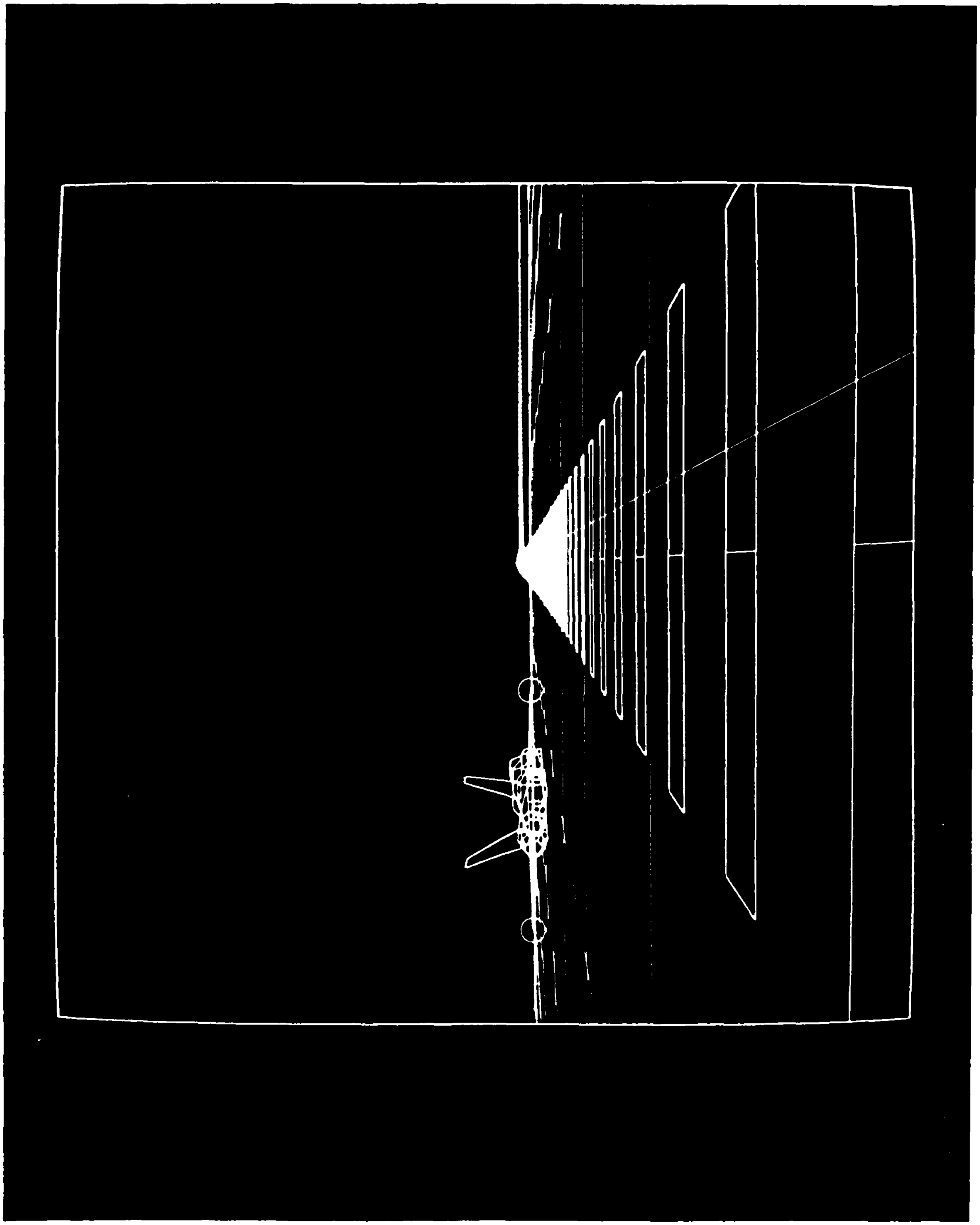


Figure 2-1

CFPD Vertical Situation Indicator

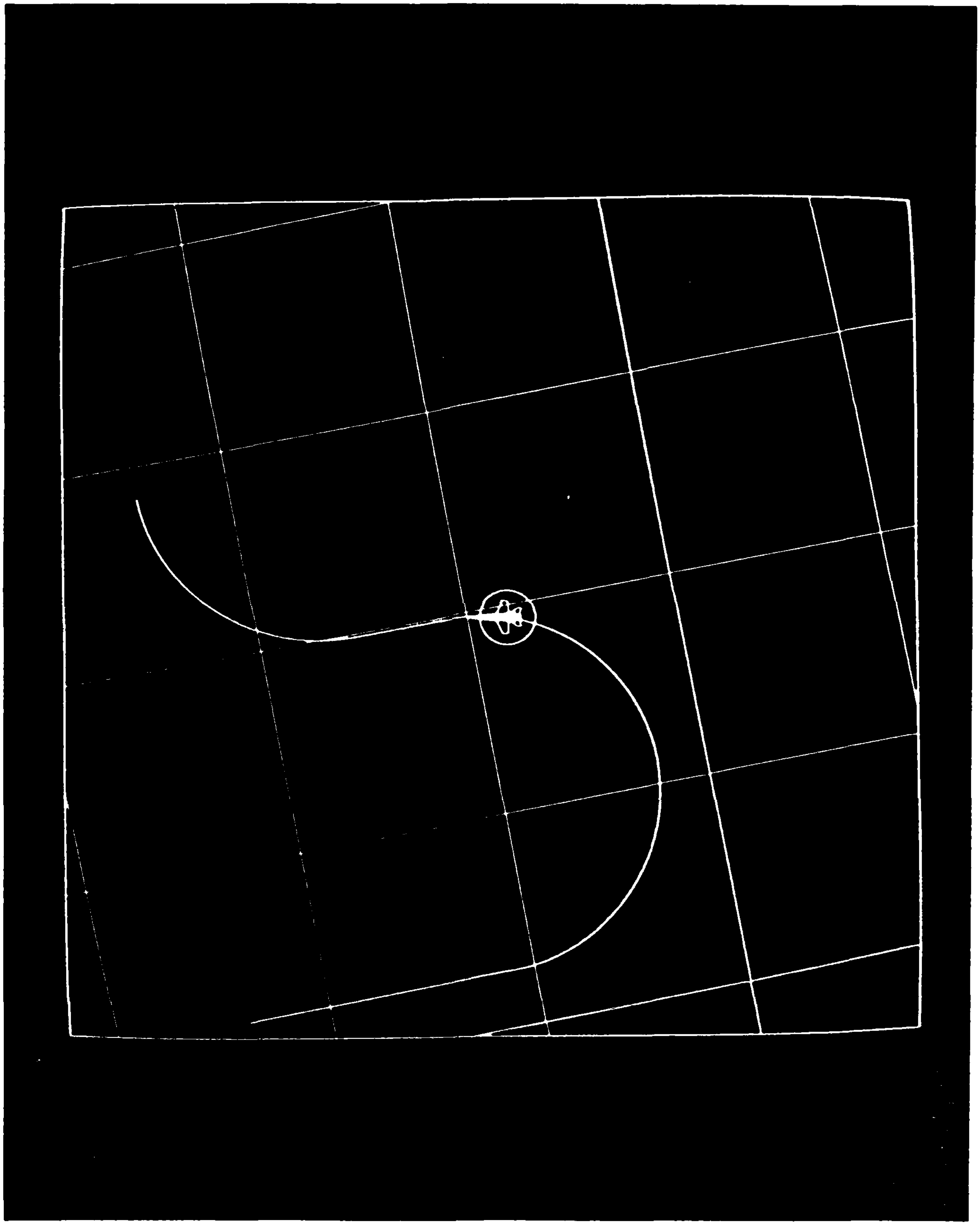


Figure 2-2

CFPD Horizontal Situation Indicator

the aircraft shadow representing present position relative to the flight path, an indication of where the aircraft should be on the flight path, and an ellipse which indicates range remaining relative to present power, altitude and velocity. (This ellipse was not included in the TIFS display during Phase II, but will be in Phase III.)

In the Phase II test program both displays were included, but emphasis was placed on the Vertical Situation Display with the HSI providing only the geographical Command Flight Path and the aircraft position relative to the Command Position. The program objective was more directed to determining the ability of the pilot to fly the aircraft effectively under IFR conditions, particularly with respect to take-off and landing, and normal flight operations rather than tactical missions. The above in brief, describes the overall basic Command Flight Path Concept. It must be stressed that all of the elements of the VSI display had to be included because all of the elements are necessary to provide an integrated display and present the required information.

2.1.1 Command Flight Path Display Program Objectives

The overall objective was to prove the validity of the Command Flight Path Display concept which consists of a totally integrated pictorial presentation of the fundamental information necessary to effectively perform all of the normal basic flight operations with and without reference to the real world.

The specific objectives were:

a. To demonstrate during actual flight that the CFPD is in fact a truly integrated display which does provide the pilot with adequate information to execute take-off, climb, cruise/navigation, approach and landing, without reference to conventional parametric displays, or the real world.

b. To establish that pilot performance with the CFPD is enhanced demanding minimal concentration on the display, minimizing inadvertent departures, and requiring minimal training time, both initially and for maintaining flight proficiency, as compared to performance utilizing standard symbolic displays.

c. To prove that the electronic system required to generate the CFPD can be achieved by modifying current aircraft display and control systems through the utilization of computer graphics picture processing techniques.

2.1.2 Contract Arrangements

The CFPD Program has been funded by the U.S. Navy through the Naval Air Systems Command (NAVAIRSYSCOM) and the Naval Air Development Center

(NADC), Warminster, PA. Funds were transferred by interservice funding documents to the U.S. Air Force, Wright Patterson Air Force Base, for application to an existing Air Force Contract with Arvin/Calspan Advanced Technology Center, Buffalo, NY. Under this contract, #F33615-79-C-3618, Arvin/Calspan provides continuing test, evaluation and other technical services to the U.S. Air Force and the U.S. Navy.

Systems Associates, Inc. of California was contracted by Arvin/Calspan, under subcontract #S-82-03, to develop, integrate and evaluate the CFPD and to provide subcontract management of software and hardware vendors. Intermetrics, Inc., Cambridge, Massachusetts, provided engineering and software services under Subcontract No. SAI-83-01. Engineering services were also purchased from Evans and Sutherland, Salt Lake City, Utah, by SAI/RMS purchase order.

Equipment was provided by the Navy or purchased by Arvin/Calspan, and SAI/RMS. Arvin/Calspan also provided engineering and installation services and the flight crews (safety pilots) during evaluation flights of the CFPD in the USAF NC 131H (TIFS) aircraft.

2.1.3 Phase I - Tasks

In accordance with the subject contract, the tasks performed under Phase I were as follows:

<u>Task 1</u>

a. The definition of the overall project objectives and the requirements to meet these goals.
b. The definition of the CFPD concept.
c. The functional design of the system to produce the CFPD.
d. Establishment of the project milestones, coordination of the Intermetrics subcontract, and monitoring of the project schedule, particularly software delivery.
e. The definition of the CFPD Concept Evaluation Flight Test objectives and the design of a suitable flight test program.
f. The preparation of the documentation covering Tasks 1, 2 and 3.

<u>Task 2</u>

SAI/RMS will provide engineering assistance for system integration and installation requirements.

<u>Task 3</u>

SAI/RMS will provide for the purchase of the following engineering services from Intermetrics, Inc.:

a. Development of the algorithms for the generation of the CFPD, current HUD symbology, and display of WAD symbology on a PS-300 Graphic Display.

b. Preparation of the software specifications for the PDP-11/44 computer and the PS-300.

c. Coordination of the PS-300 and PDP-11/44 software specifications with the Calspan sensor data software specifications and

d. Definition of the sensor data input requirements for the PDP-11/44 computer jointly with Calspan.

e. Development of the software for the PS-300.

f. Development of the software for the PDP-11/44 as it relates to the PS-300.

g. Software check-out for the total system jointly with Calspan.

h. Definition of the recording requirements for the CFPD concept evaluation flight test.

i. Document software to include algorithms, flow diagrams, definition of terms, etc., as well as the actual coding.

2.1.4 Phase II - Tasks

The tasks performed under Phase II were as follows:

Task 1 - Working with Intermetrics, check out the overall display system utilizing the ground flight simulator capability of the TIFS aircraft. Minor modifications of the displays will be made during this effort.

Task 2 - Brief the evaluation pilots before and during the flight simulator runs and conduct flight tests as indicated in the Flight Test Plan Schedule.

Task 3 - Modify the aircraft by replacing the VSI with the Hughes AIDS HUD and conduct ground simulation and check out system.

Task 4 - Conduct ground simulation runs followed by flight tests as indicated in the Flight Test Plan Schedule.

Task 5 - Reduce flight data and prepare a final report of the Command Flight Path Display concept evaluation.

2.2 Development of the Command Flight Path Display Flight Test System

At the start up of Phase I it was jointly agreed by NADC, SAI/RMS, and Intermetrics that the major component of the CFPD flight test system would be the Evans and Sutherland PS-300 general purpose interactive computer graphic system. It was also agreed that in order to accomplish the type of flight test required to prove the CFPD concept, an inertial navigation system (INS) would be installed in the TIFS aircraft.

Using the above as a point of departure, many significant changes had to be made to accomplish the program objectives while maintaining the schedule within the proposed budget.

Purchase orders for the major hardware items were prepared by NADC. Calspan placed on order the lab peripheral accelerator (LPA-11K) and those components necessary to fabricate the input/output interface chassis. The software interface specifications were determined and agreed upon by Intermetrics and Calspan. SAI/RMS investigated available CRTs and initiated discussions with Xytron, Inc., manufacturer of the standard PS-300 display. The high writing speed of the PS-300 and available cockpit space dictated custom displays be built. In addition, the Naval Air Systems Command required the use of the Hughes AIDS Head-Up Display as part of the flight test. The compatibility of the PS-300 and the HUD as well as the HUD availability were in question.

Delays began to surface quickly. Purchase orders for the government furnished equipment were not received by the manufacturers to allow sufficient lead time to meet program delivery requirements. The INS from the Air Force Flight Dynamics Lab turned out to be unavailable and a search for another unit started. The Air Force requirement for ruggedization and vibration testing of the commercial equipment prior to installation in TIFS added a further squeeze on available time.

Discussions were initiated with Evans and Sutherland on ruggedization of the PS-300. Ruggedization of the unit by Evans and Sutherland personnel, as it was built would save valuable time. Initial response was favorable but Evans and Sutherland management would not consent to delivery of other than a standard unit. They would provide a kit that could be used for ruggedization and engineering services but would not modify the unit themselves. As a result, a second PS-300 was needed to allow software development to continue uninterrupted while the unit to be installed in the aircraft was ruggedized.

Magnetic tape recording equipment scheduled for use in the CFPD system began to develop reliability problems. A search for alternate equipment by SAI/RMS resulted in a purchase order from Calspan for a recording system from Western Peripherals.

Serious doubts began to develop concerning the PS-300 capabilities for the CFPD application. Software engineers were concerned about the ability of the PS-300 to update the required information at the required rate. Modifications to the PS-300 firmware were necessary and resulted in custom firmware that increased the processing capability of the unit.

NADC chose the F-18 standard symbology for use as the comparative symbology during the flight test. CFPD software development at Intermetrics and sensor software development at Calspan continued. The PS-300-HUD interface problem was solved but required a 50% reduction in writing speed of the PS-300.

A partial delivery of the first PS-300 to Intermetrics was made on September 7, 1982. Installation by Evans and Sutherland representatives was not completed until September 14. Calspan submitted the Class II Modification Part I to the Air Force and released purchase orders for the Xytron displays, magtape recorder, and the second PS-300. An inertial navigation system was located by NADC and delivered to Calspan on October 3, 1983.

Mr. Hoover continued discussions with Dr. Dave Evans of Evans and Sutherland concerning ruggedization of the PS-300. Evans and Sutherland agreed to provide a unit prepared for installation of a special back plane and edge connectors and to do the installation of the retrofit kit at Calspan. Sensor software was completed and delivered to Intermetrics for integration with the CFPD software. A flight plan was prepared and incorporated into a flight test program prepared by SAI/RMS.

Software development was completed and real time testing was accomplished at Intermetrics. The computer and accessories were then shipped to Calspan for system integration test. Evans and Sutherland provided a pre-production PS-300 with a modified card cage that eliminated the requirement for installing a retrofit kit. All commercial CFPD equipment was hardened followed by vibration testing. Results of the test were submitted to the Air Force in the Class II Part II Modification.

The CFPD System equipment was then installed and TIFS was prepared for ground simulation and testing.

2.3 Flight Test of the Command Flight Path Display/Concept Evaluation Flight Test Plan

The procedure for validating the CFPD concept consisted of comparing the flight performance of a number of pilots having different degrees of experience, while flying a specific flight plan, first utilizing a slightly modified current F-18 discrete symbol display, (Figures 2-3, 2-4 and 2-5) followed by flying the same flight plan with the command flight path integrated pictorial display.

The measure of the subject test pilots' performance was to be based upon the number and magnitude of inadvertent departures from the prescribed flight plan which were recorded relative to the three flight axes plus velocity control, when flying each type of display.

These procedures were performed first with VSI and HSI CRT displays with the test cockpit windows completely covered with translucent material to simulate zero-zero conditions, and then followed by replacing the VSI with the Hughes AIDS HUD and repeating the procedures under acceptable actual minimal weather conditions.

The flight test pattern consisted of a modified instrument flight training pattern composed of a series of interrelated maneuvers and performances basic to normal instrument flight rule (IFR) flight. (Figure 2-6)

The entire prescribed flight pattern was programmed to establish a virtual air space 3000 feet deep, covering approximately 27 square miles with a perimeter of roughly 78.5 miles. Since the pattern segments and way points were fixed, the coordinates could be oriented relative to any heading and barometric level selected. By initially setting the INS at

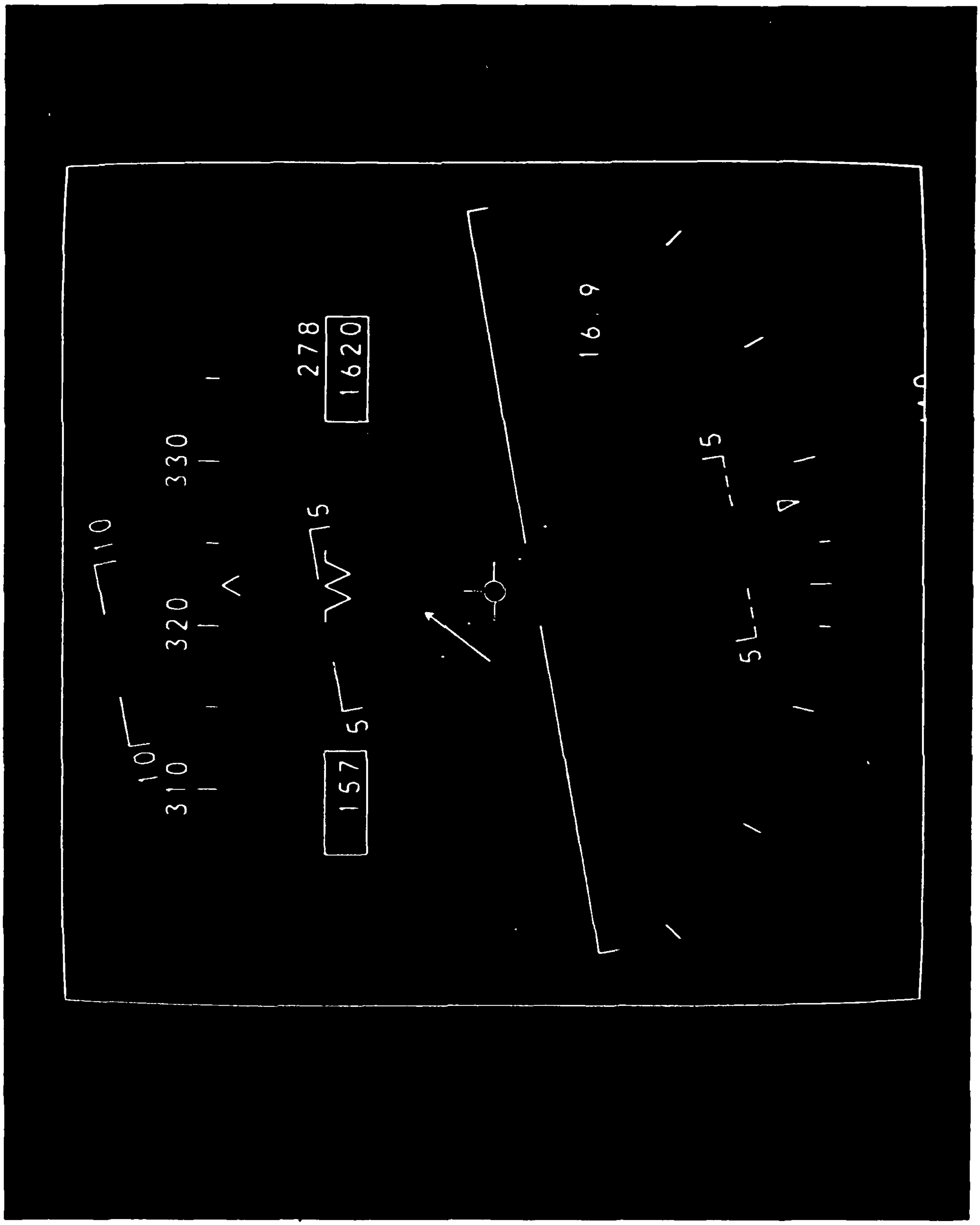


Figure 2-3
Modified F-18 Vertical Situation Indicator - Basic Flight

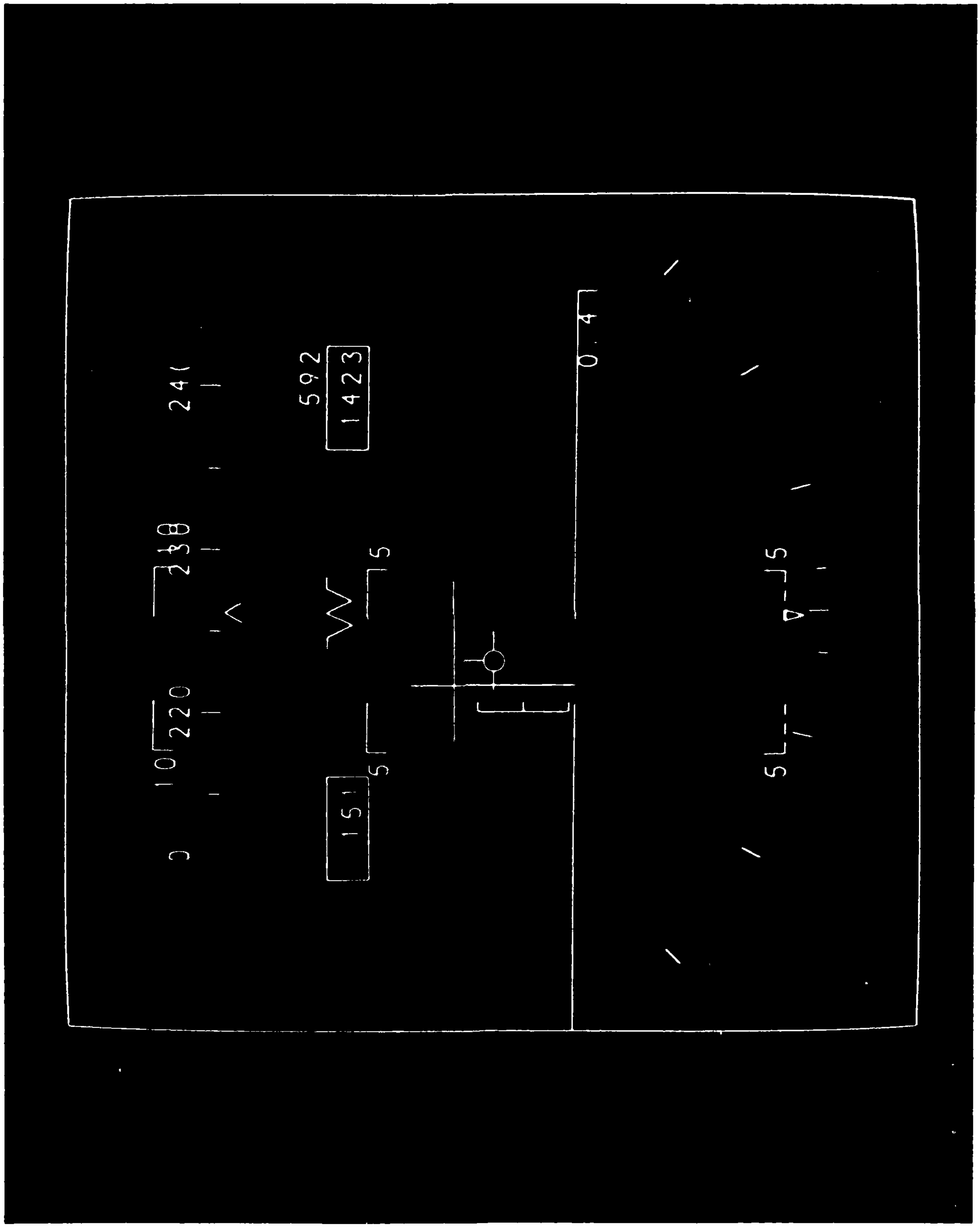


Figure 2-4

Modified F-18 Vertical Situation Indicator - During Approach

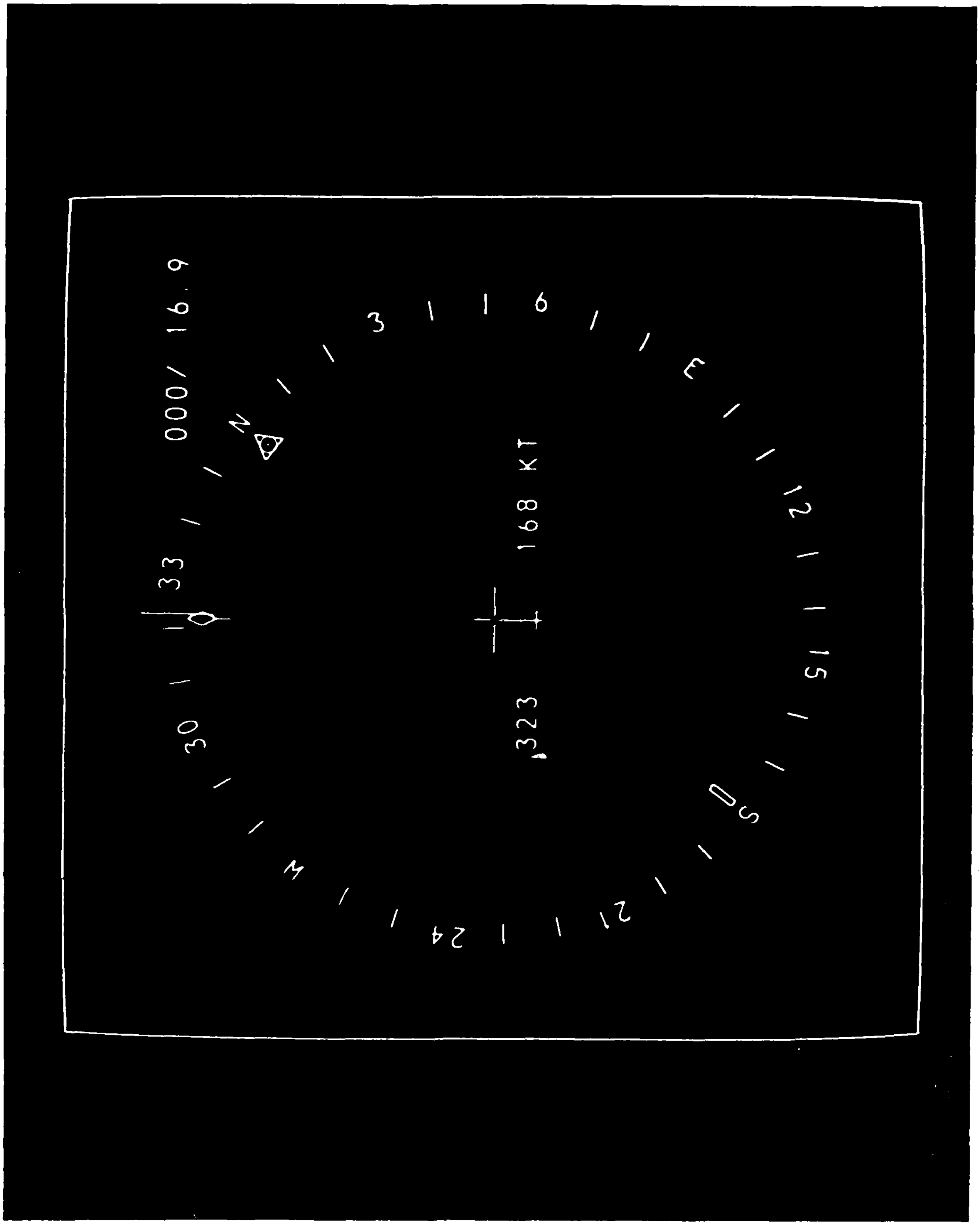
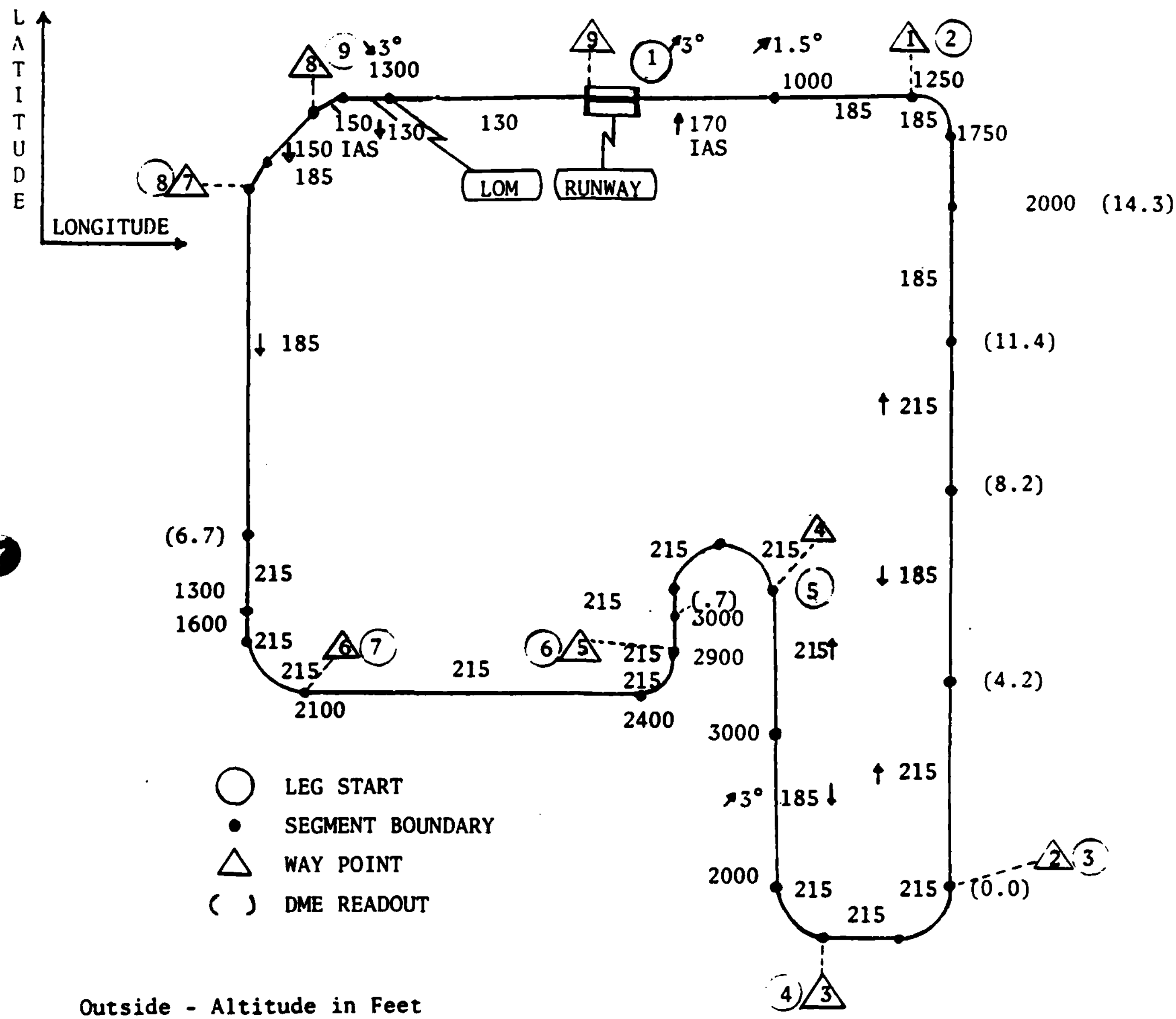


Figure 2-5

Modified F-18 Horizontal Situation Indicator



Outside - Altitude in Feet
Inside - Velocity in Knots
↑ accelerate to
↓ decelerate to

Total time ~ 25 minutes

All turns are standard rate turns under no wind conditions.

Figure 2-6

Flight Test Pattern

0 Latitude, 0 Longitude and 0 Altitude, any departure from the prescribed path could be measured, regardless of the magnetic heading and altitude flown. The selected heading, however, which was decided by the TIFS safety pilots was a cardinal heading and prescribed prior to any operation either for ground simulation or flight.

The procedure to initiate the flight test was for the safety pilots to depart Buffalo, climb to 6000 feet, turn to the prescribed heading at the selected test area, and indicate that the aircraft was in position to start the course. The only reason for establishing a cardinal heading was to make it easier, when using the F-18 symbology, to calculate a new heading when the initial heading was an even number.

When the safety pilot gave the signal that the aircraft was in position, the CFPD engineer initiated the flight plan by bringing up the F-18 symbology. At the end of the first pattern, if the evaluation pilot was off course, altitude or airspeed, the safety pilot would take over, bring the aircraft back into position and notify the CFPD engineer that he was ready to start the second pattern.

The geographical starting point of the flight test pattern was reasonably close to the Niagara airport because upon completion of flying the prescribed pattern, each evaluation pilot was required to make two instrument landing system (ILS) approaches to the flare point at Niagara, first with the F-18 display and then with the CFPD. This exercise was conducted by having the TIFS safety pilots bring the aircraft to an approach position outside the outer marker, engage the ILS and turn the control over to the CFPD engineer and the evaluation pilot.

The CFPD was programmed to portray all variations in the flight patterns and required no external information relative to way points. When the evaluation pilot was flying the F-18 display, the external navigation aids to provide bearing and DME for the way points were not available because of the requirement to use "virtual" airspace. In view of this, the CFPD engineer provided the evaluation pilots with the required way point information.

Upon completion of the above phase of the test program, the aircraft was modified by replacing the VSI CRT with the Hughes AIDS HUD.

Following the HUD display check-out, the evaluation pilots repeated the same operations performed during the first phase of the test program but using the HUD instead of the VSI, and under varying VFR and IFR conditions.

Mr. George Hoover was the first pilot to fly the Command Flight Path Display on 9 February 1983. Satisfied with the dynamics of the display, he requested Mr. Robert Harper fly the pattern on the CFPD. The following day Mr. Harper flew patterns on both the CFPD and the symbology and Mr. Victor Cronauer flew a partial pattern on the CFPD. Mr. Harper's patterns served as a baseline for performance comparison of the pilots to follow.

The remaining pilots who participated in the flight test program were from the Naval Air Systems Command, the Naval Air Development Center, and the Naval Air Test Center.

A breakdown of time in model for those pilots participating in the CFPD flight test is as follows. Data on all participants were not available.

Pilot	Total Hours	Hours by Type							
		T-34	T-2	TA4	A-7	F9	T38	F/A18	F4
Lt R.J. O'Hanlon	1800			200	1200			20	
Lt J.D. Wetherbee	1700		150	150	1300			85	15
LCDR J.J. Walters	1275	25	100	100	900				
CDR F. Ameel	2758		150		2358	176	7	65	
VADM E.R. Seymour	N/A								
CAPT R.D. Friichtenicht	N/A								

Data recordings were made as part of the flight plan. Departures in all three axes from the planned flight path were recorded on magnetic tape. A video recording of the VSI display presented to the pilot in the evaluation cockpit was taped. TIFS intercommunication system (ICS) comments during the flight tests and post flight debriefs were also recorded. All original video and voice tapes were delivered to the Naval Air Development Center. The magnetic tapes of recorded flight data were utilized for generation of flight test plots.

2.4 Program Results

In general, it can be stated that each task proposed for Phase I and Phase II of the CFPD program was successfully accomplished, on schedule, and within the limits of the original proposed budget.

The significant specific results achieved were as follows:

a. The CFPD Flight Test System was developed by utilizing off-the-shelf commercial components primarily because they were the only units capable of meeting the system requirements and available within the timeframe and the budget limitations of the program. With special ruggedizing techniques and careful installation furnished by Calspan, the system (excluding the AIDS HUD) experienced no failures from the first start up through the completion of the last test flight.

b. The Flight Test of the CFPD system including 90 hours of ground simulation and 20 hours of in flight operations was accomplished as scheduled with only one flight cancelled due to inclement weather. From February 9, 1983, to April 20, 1983, eleven flights were made by nine evaluation pilots including VADM Seymour, COMNAVAIRSYSCOM, and Captain Friichtenicht, AIR 03. Four additional hours were flown with the system by two pilots from the U.S.

Naval Test Pilot School who flew only for syllabus requirements because the Calspan X-22 was down.

c. During all flight tests continuous recordings were made of three dimensional position data, flight path referenced position data, and altitude and lateral deviations. In addition, video tapes of the VSI were recorded along with TIFS intercommunication system (ICS) audio comments.

d. After each flight the debriefing of each pilot was recorded on audio tape and then transcribed. These are included in this report as Appendix D.

e. The recorded data from each flight were identified and separated, then coordinated with reference and timing information, and then analyzed to establish statistical parameters which were then utilized to draw the various plots to demonstrate the actual performance of the aircraft at any point along the flight plan. Analyses of these plots coordinated with each pilot's comments from the ICS and debriefing tapes were used as the basis for evaluating the CFPD concept.

2.5 Conclusions

The performance plots shown in Figures 5-1 through 5-6, and Appendix F, provide positive evidence that the flight test techniques which were used to evaluate the CFPD concept were indeed valid because the information displayed on these plots is a truly dynamic presentation of actual three dimensional aircraft operation. This method of evaluating displays by measuring actual performance relative to required performance provides specific answers as to how well pilots conduct selected missions, rather than just recording evaluating pilots' personal opinions of how the displays should be altered. As pointed out in Section 5.0, by comparing performance achieved with one display vs. another, but recorded relative to a command mission, the concept of paired comparison takes on a new meaning. In this instance, instead of just determining that one display is better than another, it is easy to establish <u>why</u> one is better.

2.5.1 Conclusions - Program Objectives

In view of the above, the analyses of the data generated the following conclusions relative to the objectives of the CFPD program:

a. Objective 1 - Flight test results demonstrated during actual flight that the CFPD is a truly integrated display which does provide the pilot with adequate information to execute take-off, climb, cruise/navigation, approach and landing, without reference to conventional parametric displays, or the real world.

b. Objective 2 - Analyses of the operational plots fully establish that pilot performance with the CFPD is enhanced, demanding minimal concentration on the display, minimizing inadvertent departures, and definitely requiring minimal training time (total training time prior to flight was one half hour with the CFPD), both initially and for maintaining flight proficiency, as compared to performance utilizing standard symbolic displays.

c. Objective 3 - The program results proved that the electronic system required to generate the CFPD can be achieved by relatively minor modifications to the aircraft display and control systems currently installed in operational aircraft, and by utilizing computer graphics picture processing techniques.

2.5.2 Conclusions - Command Flight Path Display Concept

In addition to meeting the objectives of the program, considerable knowledge was gained relative to the fundamental concepts of the Command Flight Path Display. The significant conclusions are as follows:

a. The concept of continuous command information is perhaps one of the most significant innovations that the CFPD format provides to man-machine systems displays. By having this information available, the necessity for memorizing each segment of the mission flight plan, or even referring to a navigation chart, is eliminated. This situation became evident during the actual flight test because the evaluation pilots either did not attempt to memorize the flight test plan, or they could not remember each maneuver while occupied with controlling the aircraft. Review of the ICS voice tapes clearly establishes that each pilot, while flying the symbology format, had to be coached by a second pilot in the right seat of the evaluation cockpit with regard to each upcoming event of the flight plan. If the evaluation pilot had not been informed of each required change to be made, he would have been required to read the flight plan chart which, in turn, would have seriously altered his scan pattern and the inadvertent departures would have been far greater than those which were actually recorded.

   In contrast to this procedure, no coaching relative to the flight plan was necessary when the evaluation pilot was flying the CFPD format because the required information was inherent in the display.

   The necessity for presenting anticipatory cues, which the CFPD provides, becomes much more critical during tactical operations requiring very exacting flight plans such as terrain following, even under VFR conditions, and are absolutely mandatory under IFR conditions. It is important to understand that this type of command information does not exist in current tactical aircraft displays.

b. Another concept inherent in the CFPD format is the requirement for an integrated display in lieu of combined discrete symbols. Since the word "symbol", by definition, is "something that stands for or represents another thing", it follows that symbols require interpretation, and interpretation, in turn, requires a learning process followed by mental integration.

If, as an alternative, the display consists of an integration of real world visual cues, no learning process or interpretation should be required and the information present in the display would be acquired through differentiation.

Examination of the performance plots of each evaluation pilot very definitely established four significant differences between the F-18 type symbology and the CFPD, which substantially influenced the obvious differences in performance.

1. Essentially no learning process or interpretation was required by the evaluation pilots when flying the CFPD with the exception of "flashing" the lead aircraft to indicate excessive velocity, and which will be replaced by real world visual cues during the next phase of the program. Each pilot saw the CFPD format for the first time on the evening before his evaluation flight, and flew the format in the ground simulator for only one half hour prior to his first actual flight. Each pilot, on the other hand, had flown a considerable number of hours with similar versions of the symbology format.

2. Another aspect of the comparison of discrete symbology relative to integrated visual displays which was examined was the effect of lag time inherent in the system. During the simulation phase, it became apparent that the data processing interface between the host computer and the picture processor had a lag time of approximately 200 to 300 milliseconds. Investigation of the probable cause of this delay revealed that the only interface available (non-real time DMR-11 DECnet) was the primary contributor to the system latency problem. In view of this situation, there was some concern by the Calspan pilots that such a lag time might negate the validity of the flight test results, and in fact, during debriefing sessions, some pilots indicated that the lag time was very noticeable when flying the symbology, <u>but not apparent when flying the CFPD</u>.

   Since both display formats were driven by the same data processing system we can only conclude that lag time in displays are amplified when discrete symbols are utilized, but minimized with integrated real world visual cue displays. (It has been learned just recently that a real time interface is now available.)

3. The third important difference between the symbolic format and the CFPD relates to disorientation. Several of the evaluation pilots indicated experiencing vertigo during some of the flight maneuvers while flying the symbology. None of the pilots experienced any form of disorientation that affected his operation of the aircraft or his understanding of the relationship of his aircraft to the Command Flight Path. This was further supported by the majority of the evaluation pilots' statements that there was never any question as to where they were, what they were doing, or what they should be doing while flying the CFPD format.

4. The concept of utilizing the VSI and the HSI with the CFPD format provides an excellent indication of the wind effect relative to take-off and climb, cruise, and approach and landing. The immediate indication of a change in wind direction becomes evident when corrections in heading are required to stay on the centerline of the flight path on the VSI. The drift angle also becomes apparent with just a glance at the aircraft position relative to the flight plan on the HSI. When the drift angle is minimal a head wind or tail wind can be determined by whether or not the velocity should be increased or decreased in order to maintain position with the "how goes it" circle. This is not the case with the symbology because displacement of the discrete symbols may be due to a variety of causes such as inability to maintain an accurate heading or attitude, or angle of attack and airspeed when making an ILS approach, or due to inherent lag in interpreting the information.

   In addition to the above, turbulence effects were no different visually in the CFPD than they would be when flying VFR. It is believed from what was observed during the flight test and the analyses of the performance plots, that indication of wind shear conditions can be integrated into the CFPD with very little effort. This will be considered during the next phase of the program.

c. One significant weakness in the CFPD format which became apparent during the flight test was the lack of realism in the presentation of the velocity control. Careful analysis of the video tapes and the ICS comments revealed that most of the evaluation pilots had some trouble maintaining formation position on the lead aircraft which suggests that the visual cues relative to the aircraft were inadequate. Further analysis of the display format itself indicates that the cues presented by the line drawing of the lead aircraft, without a hidden line algorithm, were not realistic enough to elicit a spontaneous response by the pilot.

Based on past experience with many simulated images, it is believed that if the lead aircraft is displayed as a shaded full color image in real time, the problem of the pilot maintaining formation position will be eliminated. In addition, anticipatory cues, such as torching of the tail pipe when power is required, the deployment of speed brakes on the aircraft image as a deceleration command, or the dropping of gear and flaps in the approach, will greatly enhance the pilot's performance.

Relative to the dynamics of the display, a variety of experiments with indicated airspeed, ground speed, and their derivatives, were conducted during actual flight tests. Although further investigation of these parameters will be carried out, it is fairly evident that the lead aircraft should represent indicated airspeed. In addition, further investigation and experimentation must be conducted to establish the most effective format for the lead aircraft in order for the pilot to maintain accurate altitude.

2.5.3 Conclusions - AIDS HUD

When the Hughes AIDS HUD was installed in place of the VSI, flights were made with and without the windscreen translucent curtain. When the outside world was obscured, there appeared to be little difference with either display format on the HUD or the VSI, with the exception that some pilots had trouble losing the display on the HUD because of the critical eye position and the restricted exit pupil. This was only true of pilots having limited experience flying a HUD.

Another exception was that line drawings of the CFPD on the HUD were incomplete with corners of the flight path trapezoids not being closed, thus producing a rather poor pictorial image.

In order to evaluate the display format when transitioning from IFR to VFR to IFR, it was intended that when flying the HUD, an altitude would be selected where the flight plan called for climbing and descending in and out of cloud levels, and with the translucent curtain removed. This phase of the flight test plan could not be achieved because the required weather conditions were not available during the duration of the flight test. When the translucent curtain was removed, particularly when making HUD approaches to Niagara, the pilots did indicate that the display was not bright enough against the background of white clouds and the snow-covered ground.

2.6 Recommendations

In view of the significant results and conclusions achieved during Phase I and II of the CFPD program, it is strongly recommended that further exploratory development be conducted to examine the feasibility of the CFPD concept for tactical operations, and for the development of a shaded, full color, real time display system compatible with current avionics systems.

Specifically, a program is recommended consisting of the following.

Task 1

Development and/or modification of existing CFPD algorithms to generate formats in real time and color for all modes of flight including:

a. VTOL, VSTOL and CTOL from shipboard and land bases.
b. Hovering/loiter flight.
c. Lateral flight.
d. Reverse flight.
e. Rotation.
f. Transitioning flight to and from vertical/hovering.
g. Cruise.
h. Terrain following/avoidance.

Task 2

Preparation of specifications that will be used to define the computer graphics display system hardware.

Task 3

Preparation and delivery of an engineering report that documents the detailed design analysis conducted on the CFPD system to be developed to meet the airborne operations listed in Task 1.

Task 4

Preparation and delivery of an Integrated Control Document which delineates the required characteristics for aircraft/system integration based on the Navy aircraft selected for the flight test.

Task 5

Design, development, and delivery, concurrently with Task 4, of the software programs that address and control the high speed graphic system used to generate the display formats.

Task 6

Preparation and documentation of an approved set of system check-out proceudres to be used during the conduct of bench and ground system checks.

Task 7

Preparation and delivery of a flight test plan to NADC for approval and technical support during the test program.

Task 8

Compilation and analysis of flight test data and the preparation and submittal of a report covering the overall project and test results.

3.0 TECHNICAL DISCUSSION

The Command Flight Path Display is the result of approximately 35 years of various Research and Development programs sponsored by the Navy in an effort to establish an optimal Man-Machine Systems interface.

The concept of a completely integrated pictorial display for aircraft was originally conceived in 1946 as a result of a study performed by the Flight Section, Special Devices Division, Navy Office of Research and Inventions, in conjunction with the University of Illinois.

It should be emphasized that in 1946, and for many years after, there was no known means for displaying the concept.

In 1952 the Office of Naval Research was charged by the Assistant Secretary of the Navy for Air to establish a program with the Bureau of Aeronautics to develop a new concept for aircraft instrumentation. This program was originally a Navy effort conducted jointly by the Office of Naval Research, Air Branch, the Bureau of Aeronautics, Instrument Branch, and the Naval Air Development Center. Later, the Army joined the program because of its interest in improving helicopter instrumentation at which time it was named the Army Navy Instrumentation Program (ANIP).

The generalized aircraft/Man-Machine system was identified. Although ANIP sponsored work in each of the system areas, those of the central computer and displays received the most concentrated research. However, the technology was still not available to produce the required display.

Many of the advanced systems now installed in current Navy aircraft came about as a result of the effort of this program which, over a ten-year period, produced the first airborne digital central computer, improved cathode ray tubes, and initiated the practicability of microelectronics. All of these advances, when properly integrated resulted in the initial demonstration of the concept of computer graphics generated display which was produced by General Electric under an ANIP contract.

It was not, however, until 1972-73 that computer graphics reached a point where real time, realistic computer generated images with relatively small computers was achieved. This break-through in technology was presented for the first time to the Navy at the First Advanced Aircrew Display Symposium held at the Naval Air Test Center (NATC), April 18-19, 1974.

As a result of the NATC demonstration and interest indicated by DCNO (AIR), Naval Air Systems Command (NAVAIRSYSCOM) through the Naval Air Development Center (NADC) sponsored a study to investigate the feasibility of generating a pictorial display employing real time computer graphics techniques. The study produced a demonstration by Northrop Aircraft Division in a flight simulator of the original concept of pictorial displays developed under the ANIP program.

Previous research and development efforts had clearly established visual display requirement information and the technical means for generating the displays. The only remaining unknown in proving the concept, currently referred to as the Command Flight Path Display (CFPD), was whether or not improved flight performance could be achieved during actual flight under real or simulated IFR flight conditions.

In an effort to solve the remaining unknown, an unsolicited proposal dated 15 April 1981 was submitted to the Naval Air Development Center by the Resource Management Systems (RMS) Division of Systems Associates, Inc. of California (SAI) for the development of a CFPD System. The proposal consisted of the following phases:

Phase 0 - Program Definition, Organization and Support Identification for Flight Testing the Command Flight Path Display.
Phase I - Development of the CFPD Flight Test System.
Phase II - Flight Test of the Command Flight Test System.
Phase III - Flight Test of the Command Flight Path Display in a current Navy Operational Aircraft.

In response to this proposal, a contract was awarded to SAI/RMS on 20 August 1981 by NADC, sponsored by NAVAIR-03, authorizing the execution of Phase 0.

On 20 April 1982, NAVAIRSYSCOM authorized SAI/RMS to proceed with PHASE I of the CFPD program.

On 5 May 1982 the kick-off meeting for PHASE I was held at ARVIN/CALSPAN in Buffalo, New York.

The System requirements in general are as follows:

- Computer Graphics Picture Processor
- Display Media (CRTs)
    - HUD
    - VSI
    - HSI
- Host Computer
- Peripheral Components (Writers, Recorders, etc.)
- Converters (A-D, etc.)
- Sensors
- Interconnections/Interfaces

3.1 System Design

The system design is shown in the CFPD system diagram (Figure 3-1). Few changes were made from the initial system diagram. In most cases, those changes made, were the result of delivery times being incompatible with the project schedule.

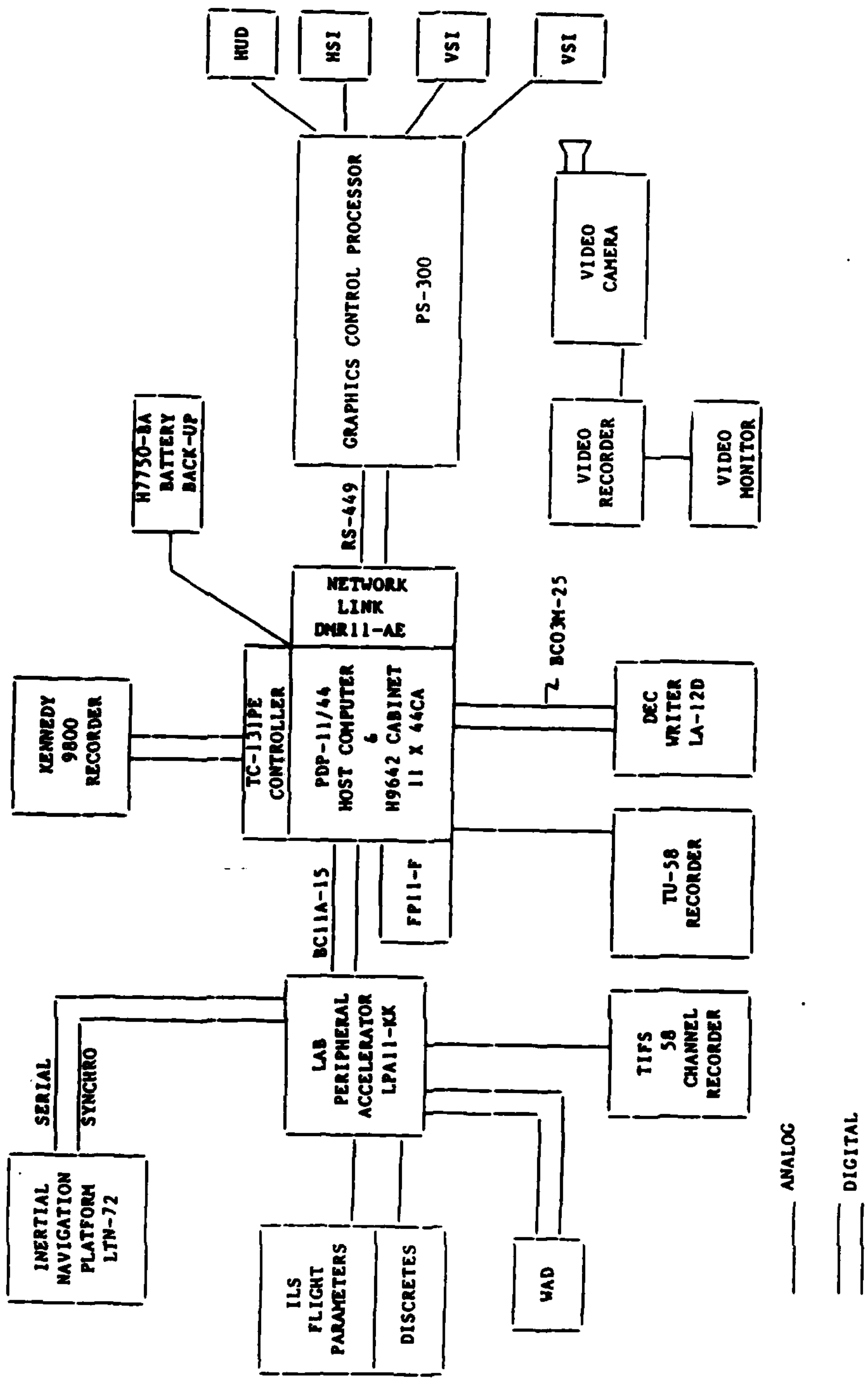


Figure 3-1

CFPD System Diagram

Only two pieces of equipment were militarized—the inertial navigation system and the Hughes AIDS HUD. The remaining components were commercial units. The commercial equipment was hardened and then vibration tested by Calspan prior to installation in the aircraft. The system was operational for over ninety hours of simulation and over twenty-three hours of flight time. The only component to malfunction from the start of the ground simulation to completion of the flight test was the HUD. In February the HUD overheated during ground simulation and a failed IC chip was replaced. On March 8th a high voltage problem prevented use of the HUD on the sixth CFPD flight.

3.1.1 Computer Graphics Picture Processor

The concept of a completely integrated pictorial display for aircraft required a powerful picture processor in order to generate realistic images in real time. The key to developing the CFPD system was the acquisition of the Evans and Sutherland PS-300. The PS-300 is a high performance, stroke writing system, capable of real time interaction computer graphics. It can accomplish its high speed by handling the graphics operations internally while the host computer runs the application program relatively uninterrupted. Short, dense bursts of information are passed through a low-bandwidth interface.

The specific requirements of the Command Flight Path Display Program necessitated the development of customized firmware by Evans and Sutherland. The CFPD and the Symbology displays required a much higher rate of input command processing than was possible with the standard unit. The modification allowed for binary data transmissions over the standard 56K baud interface.

The PS-300 was a commercial unit and required some modifications to ensure its reliability in an aircraft environment. Plans to install cards with standard card edge connectors after delivery of the unit, were changed when, after protracted negotiations, Evans and Sutherland was able to deliver a unit with that type card already installed. The floppy disc and power switch were relocated to allow access on the same side as the circuit cards when installed in the aircraft. In addition the cabinet was hardened to prevent as much movement as possible, as well as being shock mounted on a metal platform to the aircraft floor.

Manufacturer's warranties on the PS-300 were honored until modifications were made. Service agreements were arranged in the event engineering or repair work was required during the critical flight test period.

No provisions for alternate power sources were available. Major modifications to the PS-300 circuitry and external clock control would have been required. As a precaution a restart capability was included in the flight plan software to enable initialization at any location should power be lost to the PS-300 resulting in a program crash.

3.1.2 Display Media

The PS-300 can be equipped with as many as four displays. The standard 19" (48 cm) monochrome display was used during software development at Intermetrics Inc. Space constraints in the aircraft evaluation cockpit required utilization of much smaller displays to accomplish the flight test.

Three displays were required for information display in the aircraft at any one time. Information relative to the real world vertical plane presented on a cathode ray tube (CRT) called the Vertical Situation Indicator or VSI; and relative to the real world horizontal plane, on a cathode ray tube called the Horizontal Situation Indicator or HSI. Both the VSI and HSI were located in the cockpit. The third display was located in the aircraft cabin. It was a repeater of the VSI and served as a source for video taping of the display.

Three nine-inch CRTs with drivers were purchased from Xytron, Inc. of Sylmar, California. The three custom displays were compatible with the PS-300, and rugged enough to withstand the aircraft environment. The Advanced Integrated Display Systems (AIDS)/F-18 Diffractive Head-Up Display (HUD), developed by Hughes for the Naval Air Development Center, was also made available for the CFPD program. It replaced the Xytron panel mounted VSI when used. Integration of the AIDS HUD required a writing speed reduction of 50% in the PS-300 and doubled the brightness of the Xytron displays. The HUD line straightness and line segment closures were optimized for use with the McDonnell Aircraft Company F-18 ground simulator. This was done because the HUD was shared during the flight test with the ground simulator. Readjustment of the HUD would have meant replacement of capacitors each time the HUD was relocated.

Translucent material was used to completely cover the test cockpit windows to simulate zero-zero conditions while using the Xytron VSI and to screen the area outside the HUD field-of-view when not in actual minimal weather conditions.

3.1.3 Host Computer

Original intentions centered on the procurement of a militarized airborne computer. The Norden PDP 11/34 and 11/70 were leading candidates. The 11/70 could not be delivered in time to meet program schedules however. The capability of the 11/34 to meet program requirements was in doubt plus the cost of the unit was prohibitive.

Research into the use of commercial units indicated successful operation in an aircraft environment. The commercial PDP series was considered and the 11/44 was determined to be the smallest unit available to meet requirements. Delivery times were compatible with program schedules and the cost was well below the militarized version.

The PDP 11/44 was selected and configured with 256 KB memory, dual

TU 58 tape cartridges for ground check-out, RSX-11S 4.0 operating system, H9642 cabinet, and a battery backup that provided a minimum data retention time of twenty minutes in the event of power loss. A floating point processor (FP11-F) for the PDP 11/44 provided up to seventeen digits of precision as well as integer to floating point conversions. A DMR 11-AE network link and RS 449 cable provided the interface to the PS-300 along with the high-speed DEC interface upgrade option and the cross-interface compatibility software.

3.1.4 Peripheral Components

Peripheral components were used for interfacing with the host computer and for recording data deemed necessary for pilot performance comparison.

3.1.4.1 DEC Writer LA-12D

A Correspondent portable printing terminal, DEC writer LA-12D, with cable BC03M-15 was provided. The interactive terminal was mounted at the CFPD engineer's station in the cabin of the aircraft and supported the display and modification of program data during preflight loading, and in most cases, during actual flight.

Parameter modifications such as path segment dimensions and spacing, velocity indicator placement and size and symbol sensitivities could be changed easily with the LA-12D. It was also used to print out selected "quick look" parametric data while on the Command Flight Path Display.

3.1.4.2 TIFS 58 - Channel Recorder

The TIFS 58 - channel recorder was part of the aircraft and not required for the CFPD System. It was shown as part of the system because it was utilized for its "quick look" capability. Flight data of interest could be recorded and looked at after each flight if required.

3.1.4.3 Magnetic Tape System TS-131 PE

A commercial TS-131 PE Magnetic Tape System was utilized to record data during the flight test. The procedure for validating the Command Flight Path Display concept consisted of comparing the flight performance of a number of pilots while flying a specific flight plan, first utilizing a slightly modified standard symbology, followed by flying the same flight plan with the Command Flight Path Display.

The system consisted of a TC-131 PE magnetic tape controller and a Kennedy 9800 tape drive. The tape controller was imbedded in the PDP 11/44 computer. The tape drive was a ruggedized, dual density, 37.5 inch per second, 9 track configuration with a 1200 foot reel capacity, cabling, and diagnostics. The system was selected for its combination of size, weight, power requirements, dependability, and delivery schedule. Selected data was recorded without conditioning at a 3 HZ sampling rate.

The magnetic tape system also functioned as the loading mechanism for the bootable Command Flight Path Display software.

3.1.4.4 Video Recording System

A video recording of all test flights was made. The video portion showed the vertical situation display as seen by the pilot in the evaluation cockpit. The audio portion included ICS and radio communication.

The recording was accomplished by mounting a repeater VSI in the aircraft cabin. A Coho model 2810-200 video camera was mounted facing the repeater VSI along with a Sony VO 4800 recorder. A Sony CVM-115 video monitor was also mounted on the console in front of the engineer work station to provide in-flight check of recorded picture quality and ground playback capability.

3.1.4.5 Workload Assessment Device

Software provisions were made for the incorporation of a Workload Assessment Device (WAD). The device was used to measure pilot workload. The hardware was not installed after the flight time for proving the Command Flight Path Display concept was reduced to twenty hours.

3.1.5 Converters

Sensor information is channeled to the lab peripheral accelerator and Input/Output interface chassis for conversion. The smoothed sensor input data are then sent to the PDP-11/44.

3.1.5.1 Lab Peripheral Accelerator

The peripheral accelerator is an intelligent high speed, direct memory access microprocessor subsystem for realtime I/O devices. It is designed to increase realtime I/O throughput by reducing the high interrupt load on the CPU.

3.1.5.2 Input/Output Interface Chassis

The input/output chassis was a standard DEC expansion chassis equipped with a LPA11-K direct memory access subsystem and an array of purchased and Calspan-built circuit cards. The chassis electronic circuits were designed specifically to process the sensor data which was a composite of analog, discrete, and serial bit stream information.

The sixty-four analog input channels were wired to the TIFS Model Computer Patch Panel for sensor data input. Forty of the sixty-four single-wire analog inputs were filtered in a Calspan aliasing filter card. DEC multiplexer and twelve bit A/D converter cards were used to process the analog data.

The serial bit stream data from the INS was converted to labeled thirty-two bit parallel format in a Calspan-designed and fabricated circuit card.

Synchro outputs from the INS were converted to parallel digital data in a Calspan circuit card using two Data Device Corp. four channel multiplexer modules and a synchro-to-digital converter. INS and other aircraft sensor discrete inputs were level shifted and buffered in a Calspan-fabricated card. All digital data were controlled by a DEC LPA11-K Direct Memory Access system configured to conserve PDP-11/44 computer cycle time.

Provisions were made to couple a Workload Assessment Device (WAD) to the I/O chassis but the WAD was not used during the program. Four channels of D/A from the I/O chassis to the analog patch panels were also available for monitoring or recording.

3.1.6 Sensors

An inertial navigation system was required for position and inertial velocity input. Relatively high update rates as well as resolution requirements dictated a non standard system. A Litton Aero Products LTN-72 unit with 72-9-07 series programming, prewired pallet, battery, and cables was obtained. The unit provided +/- twenty foot resolution on latitude and longitude and updated the inertial velocities at 24 HZ.

On board sensor inputs from the TIFS aircraft included ILS signal during approach, radar altimeter reading, TIFS inertial data of yaw, pitch, and roll, airspeed, altimeter, angle of attack, rate of climb, and heading.

3.1.7 Interconnections/Interfaces

3.1.7.1 Host Computer/Graphics Picture Processor Interface

The link between the PDP-11/44 computer and the PS-300 graphics picture processor was a DMR11-AE high speed, synchronous, serial data link. The link consisted of two circuit cards which resided on the Unibus in the PDP-11/44 (each card was the full six connectors in length), and adaptor card mounted external to the PDP-11/44 but connected to the cards with ribbon cable, an RS-449 extension cable, an E&S RS-449 SYNC six-foot cable assembly, a RS-449 loop back plug and a DEC/DMR11 software package.

3.1.7.2 Display Interface

The Xytron interface was standard for the PS-300. Ninety-foot cables were installed to connect the cockpit-mounted displays to the picture processor. The two cables to the forward Xytron displays and the 25 foot cable to the cabin display from the picture processor used the E&S recommended Belden 9221 miniature coax cable. A thirty-foot coax cable connected the picture processor to the display repeater.

The HUD required interface circuits to be compatible with the PS-300 outputs. A chassis was fabricated at Calspan to enclose the interface hardware and was mounted in close proximity to the HUD.

The chassis contained:

1. Attenuators to adjust the X and Y signal scale factors.
2. An analog delay line for the Z signal with a range of 250 nanoseconds in ten steps.
3. Input and output isolation amplifiers for the delay line.
4. Relay control for HUD forced air cooling blower.
5. +/- fifteen volt regulators for delay line.
6. Attenuator circuit with potentiometer for Z axis amplitude matching.

The PS-300 with +/- 5V of output range was able to drive the HUD the maximum twenty degrees of vertical deflection (+/- 10 degrees) and twenty degrees (+/- 10 degrees) deflection in the X axis. The HUD was capable of thirty degree field of view (+/- 15 degrees) in the X direction.

The attenuators on the X and Y channels were for fine adjustment of the display size. The voltage divider in the Z axis reduced the 4V max drive signal to 1V max for the HUD. The relay allowed operation of the 115V 400 Hz HUD blower via a 28V control line from the HUD.

The delay line in the Z axis was required for time synchronizing the Z axis with the X and Y drive signals. X and Y deflection signals typically lagged the Z signals due to inductance of the yoke windings. The display generator had an unused zero to 500 nanosecond delay line in the Z axis but E&S current design practice was to use a zero to 250 nanosecond delay circuit installed in each display instead. Since the AIDS HUD was a prototype unit not equipped with a Z axis delay, Xytron Inc. provided a delay line assembly identical to their display delays. With the delay, the beam started writing line segments before the beam was stabilized at the start point and cut off the beam before the segment end point was reached.

The HUD signal cable from the PS-300 PORT 0 was made from two-wire shielded cable for maximum noise cancelling in the HUD. Although the HUD was capable of writing stroke over a raster scan it was used only in the stroke mode (calligraphic) for the CFPD program.

Before arrival at Calspan, the HUD input circuits were altered for compatibility with the current McDonnell Aircraft Company F-18 HUD installation. Modifications which affected the CFPD installation were:

a. Channel "B" inputs were used.
b. True differential inputs on UNBLANK were disabled. Only UNBLANK Hi was required.

3.2 Acquisition of Equipment

After several iterations of the matrix responsibilities, the Naval Air Development Center assumed responsibility for furnishing all hardware with the exception of minor interface components. A considerable delay in the release of the first two purchase orders to DEC and Evans and Sutherland resulted in a reevaluation of the situation. Similar delays on the remaining orders could not be tolerated if the program schedule was to be maintained. Approval was given to Calspan for the purchase of the magnetic tape system, the head down display, the second PS-300, the interface electronics chassis, and the second high speed interface.

The following hardware and software items were furnished for the CFPD program.

HARDWARE/SOFTWARE LIST

Item	Qty	Model	Description	Ordered By	Delivery Date
DIGITAL EQUIPMENT CORPORATION					
1	1	11X44-CA	PDP-11/44W256KB with TU58 Tape Cartridge and H9642 Cabinet	NADC	5 Oct 82
2	1	LPA-11KK	Lab Peripheral Accelerator with A-D Converter	Calspan	23 Jul 82
3	1	BC11A-15	Backplane Cable	Calspan	23 Jul 82
4	1	FP11-F	Floating Point Accelerator	NADC	5 Oct 82
5	1	DD11-DK	Expansion Backplane	NADC	5 Oct 82
6	1	KW11-K	Progressive Real Time Clock	NADC	5 Oct 82
7	2	DMR-11-AE	Network Link, RS422	NADC/ Calspan	5 Oct 82/ 16 Nov 82
8	1	H7750-AA	Battery Backup	NADC	5 Oct 82
9	1	LA-12D	Decwriter	SAI/RMS	4 Nov 82
10	1	BC03M-25	Null Modem Cable	SAI/RMS	4 Nov 82

11	1	QJ642-AN	RSX-11S Operating System	NADC	5 Oct 82
12	3	DR11-K	Digital Interface Package	Calspan	23 Jul 82
13	1	AM11-K	Multiplexer	Calspan	23 Jul 82
14	1	BA11-KE	Expander Box	Calspan	23 Jul 82
15	1	DD11-DK9	Expansion backplane	Calspan	23 Jul 82
16	1	DD11-CK4	Expansion backplane	Calspan	23 Jul 82
17	2		High Speed Interface Upgrade Option	NADC/ Calspan	10 Nov 82/ 1 Dec 82
18			Converters, Tools, etc.	Calspan	
19	1		RSX-11S Operating System Upgrade to Version 4.0	Calspan	5 Aug 82

EVANS & SUTHERLAND

1	1	PS-300	Std Config w/ RS/232 Interface w/o Cable & Connectors - Graphics Control Processor - 1MByte Memory - Display Processor - 19" Monochrome Display - Install & 60 Day Maintenance - User & Oper. Documentation	NADC	10 Nov 82
2	1	PS-300	Mod Config w/RS232 Interface - Graphics Control Processor - IMByte Memory - Display Processor	Calspan	1 Dec 82
3	1		Alphanumeric Keyboard/12 Functions Keyboard	NADC	10 Nov 82
4	1		LED Option for Keyboard	NADC	10 Nov 82
5	2		56KB Interface Upgrade Option (DEC)	NADC/ Calspan	10 Nov 82
6	1		Custom Firmware Functions	RMS	22 Oct/ 8 Nov 82
7	5		Programmer Training Course	RMS	21 Jun/ 2 Aug 82

WESPERCORP

1	1	TS-131PE	Magtape System	Calspan	5 Sep 82

XYTRON

1	3	X-1813	9" CRTs	Calspan	7 Dec 82
2	3	AB9R-7B	Drivers & Cables	Calspan	7 Dec 82

OTHER

1	1	LTN-72	Inertial Navigation Plat- form	NADC	3 Oct 82
2	1	Coho 2810-200	Video Camera	NADC	28 Oct 82
3	1	Sony AC VO-3800	Video Recorder	NADC	15 Dec 82
4	1	Sony CVM -115	Video Monitor	NADC	28 Oct 82
5	30		Magnetic Tapes	NADC	Nov 82
6	30		Video Tapes	NADC	Dec 82
7	1	Hughes	"AIDS" HUD	NADC	18 Nov 82
8	1	RS 449	Cable	Calspan	Nov 82
9	4		Cables (PS-300 to Drivers)	Calspan	1 Dec 82
10	2	UNITRON PS-62-66D	60 HZ Frequency Converters w/ Monitors & Relays	Calspan	Aug 82/ Sep 82

Delays were experienced when installation was required by the manufacturers' field representatives. In this case installation refers to unpacking, setting up, and diagnostic check-out. Scheduling for installation had to be arranged after delivery and was dependent on the field representative's priorities. In the case of the PDP 11/44 and the first PS-300, installation did not take place until ten and thirteen days after delivery respectively.

Warranties on the hardware were honored until modifications were made or the equipment was installed in the aircraft. Arrangements were made by NADC for priority service during the test flight timeframe in the event of a hardware failure.

3.2.1 Ruggedization of Equipment

The CFPD system was comprised mainly of standard commercial equipment. To ensure proper operation in the aircraft environment and to satisfy Air Force safety concerns the equipment was ruggedized by Arvin/Calspan. The two exceptions to the ruggedization were the inertial navigation system and the HUD, which were militarized units. Upon completion of the ruggedization the equipment was submitted to vibration testing under power. All equipment was successfully tested and certified safe for flight in the CFPD Class II Modification, Part II.

3.2.1.1 Ruggedization of the PDP-11/44 and I/O Chassis

The following steps were performed on both units.

a. The chassis were disassembled, including the internal power modules, and inspected for flightworthy hardware and wiring. Locking hardware including lockwashers, fibernuts, locktite and glyptol were added as required.

b. Wiring was inspected for security and support—especially near terminations. Support was provided as required.

c. Ribbon cables were routed to prevent chafing.

d. Clips were added across the tops of the DEC circuit cards to minimize flexure of the boards. Three-eighths inch thick closed-cell foam material was added between the outside boards and the chassis sides to rigidize the groups of circuit boards.

e. Strain relief clamps were used where cabling entered the chassis to prevent unnecessary tension on the internal terminations during flight or handling the chassis.

f. Each circuit card was inspected for components which could have leads broken, could become disconnected or, in the case of DIP switches, change state under vibration. A silastic type compound was used as required.

g. Foam rubber pads were installed in the upper cover to depress the circuit cards and prevent them from disconnecting from the backplane connectors. These same pads provided damping for circuit card lateral motion.

3.2.1.2 Ruggedization of the Computer Graphics Picture Processor

The Computer Graphics Picture Processor was electrically equivalent to a standard Evans and Sutherland PS-300. The following physical changes were made for this flight program.

a. Main system circuit cards were braced with strips of one-half inch closed-cell foam sheet to prevent circuit board flexure while minimizing disruption of cooling airflow.

b. Cabling from the backplane to the standard video output ports was stowed and new cabling and output connectors (CANNON Royal D type) were installed.

c. Circuit cards were inspected for items susceptible to breakage of component leads or disconnection under vibration. Silastic compound was applied as required.

d. Floppy disc drive and main system power switches were relocated for improved access after installation in the aircraft.

e. Front and rear cabinet panels were removed.

f. The cabinet top was replaced with a reinforced plexiglass plate.

g. Internal wiring and hardware were secured.

h. The unit was mounted to a support plate and Aeroflex Labs Inc. shock/vibration isolators chosen for shock load and the expected vibration environment.

3.2.1.3 Ruggedization of Displays and Display Drivers

The Xytron display chassis and the display driver chassis were modified as follows.

a. All hardware was checked for tightness and locking devices. Lockwashers, self locking nuts, glyptol and locktite were used where appropriate.

b. Wire mounting was modified where necessary to prevent chafing or binding and cables secured to minimize movement during flight.

c. Circuit cards were visually inspected for components susceptible to lead failure or disconnection under vibration. They were secured with silastic compound.

d. Circuit cards and heavy components were secured to prevent movement under vibration.

3.2.1.4 Ruggedization of the Magnetic Tape System

Ruggedization of the magnetic tape system was accomplished in three areas—the internal part of the transport, the interconnect cabling and the tape controller card. Internal to the transport, all hardware was checked for tightness, and lockwashers and locktite or glyptol was added where appropriate. All internal wiring was secured to prevent flexing—

especially near termination. The tape recorder was operated in the run and rewind mode while undergoing vibration testing to insure faultless operation in the aircraft environment.

Three ribbon cables provided the connections from the tape transport to the tape controller card. At the transport end, the cables attached to interface adapter cards that mated with a printed circuit card edge in the transport. Foam blocks were secured to the transport and the ribbon cables and adapter cards were attached to the blocks for support. The ribbon cables were secured with lacing cord and Adel straps to cabinet tie points.

The tape controller card was treated as part of the PDP-11/44 ruggedization. Special care was taken to support the tape controller card to prevent flexing of the board. Half inch thick strips of resilent closed-cell foam material were installed between the tape controller card and adjacent cards with care taken to minimize blockage of cooling air. The cables from the transport were connected directly to the controller card so strain relief was provided where the cables entered the computer. Protection against chafing or pinching the cables in the computer was also added.

3.3 Software Development

The CFPD software design and development effort was performed by three corporations--Intermetrics Inc., Arvin/Calspan Inc., and Evans & Sutherland Corp. Their contributions to the effort are described in the following sections. Additional information on the software interface can be found in Intermetrics Report No. IR-MA-244.

3.3.1 Intermetrics' Contribution

Intermetrics Inc. maintained overall responsibility for the software system design. In addition, Intermetrics designed and developed the Command Flight Path Display specific application software, generated the RSX-11S operating system, and integrated the Calspan and Intermetrics software into a "bootable" load tape for the runtime system.

The development approach adopted for this effort is described in Section 3.3.1.1. A high level description of the software developed is provided in Section 3.3.1.2.

3.3.1.1 Development Approach

The manner in which the CFPD project was approached consists of two parts: an overall philosophy of software development and the methodology of software development.

3.3.1.1.1 Philosophy

The manner in which a project is approached is normally determined by requirements. CFPD had three sets of "requirements": those outlined and defined by the contract, those derived from the nature of the project and those established by Intermetrics. Each of these, to a greater or lesser degree, directed the software development activities throughout the project and served to focus, and at times, refocus the developers' thought processes.

Contractually, the system was required to be functionally correct according to the project specifications. The CFPD display software was to accept sensor data as input, compute the necessary flight parameters and present graphical displays as output. The software needed to be reliable, in other words, barring any hardware problems the system remained functional and uncorrupted. Also in the event of a detected problem, recovery was necessary, at least to the extent of system re-initialization. The specifications included the aspect of "real-time" processing and synchronization of multi-tasks and multi-processors; it also established the low priority of such areas as fault-tolerance, maintainability and documentation.

There were also constraints and requirements derived from the unique specifics of the project as a research and development effort. It was recognized that there were areas in which answers to coding or implementation questions did not exist but these areas would be investigated as part of the project itself. The project, therefore, was approached as a one-pass task. The software was required to function as specified yet could be written as "throw-away" code; the best algorithms and fastest code were sacrificed for good, working algorithms and reasonably fast code. The idea was that this fact-finding project would answer some questions but it was not expected to produce a fully operational product at this time; in terms of phases, this was seen as the initial step which would be used for ideas on the next phase but could be thrown away after having served its purpose. This approach enabled the development to be completed within the project time constraints (9 months from design to implementation). Along the same lines, the lack of fault tolerance requirements minimized the need for recovery capability, error diagnostics, etc. and since it was not operational software, the system did not need to be user-friendly beyond the point at which the developers could operate it. Anticipating future system definition changes, a very modular (i.e., readily adaptable) programming style was used. Also, realizing that integration and in-flight testing would occur away from the Intermetrics development site prompted special consideration to avoid a long turn-around time for modifications. The division of the software between two companies was not considered a problem as long as the interface was established and maintained; each could develop their software independently provided that they comply with the protocol. This also facilitated the integration process.

The final group of requirements arose from standard software development practices and those developed during the course of the project. Prior development experience and programming expertise enabled individual yet directed concurrent efforts to diverge during development and converge to produce the final system. For instance, on any rapidly changing project, it is necessary to maintain an uncorrupted (i.e., working) system, along with exact knowledge of the current state-of-the-world (i.e., configuration management); these tasks were facilitated by the small staff and good communication. It was also recognized that, while documentation wasn't a major deliverable, the only way to maintain current information on project details was through decent documentation practices. The fact that at any given time only a portion of the development team would be on-site to locate problems and that a complementary portion of the team would be "back home" to initiate corrections reinforced the need for documentation so that everyone would have an overall understanding of the software.

3.3.1.1.2 Methodology

The CFPD software was developed and maintained in several phases for several reasons:

a. To divide a large task into more manageable parts; this incremental development aided the design, coding, testing and verification of the system.

b. To establish milestones which enabled tracking of the project.

c. By necessity due to the hardware involved (e.g., hardware availability, the operational versus developmental environments).

Development on the Intermetrics, Inc. PDP-11/70:

Development began in the PDP-11/70 under RSX. The CFPD task was initially divided into smaller, logical, manageable areas: display, computational, and data collection. Each member of the developmental team worked on a specific area with overlap into all other areas. Each was responsible for developing specific portions of the software, eventually merging it with the complete system during integration.

From the functional specification, an initial design specification was produced using SDDL, Software Design and Documentation Language; algorithms were developed and the interfaces between areas were established. During the design, certain elements were prioritized:

a. Functionality (system operated according to specifications)
b. Reliability (absence of bugs)
c. Speed (the integrated system needed to function in real-time)
d. Space (the integrated system needed to fit on the computer)
e. Modifiability (need for direct accessability to variables, etc.)
f. Documentation
g. Fault tolerance (at least a minimal amount of information)

Also at this time, operational specifications were evolved, also using SDDL, and informal design reviews were held. Knowing that the design specifications were high-level and that there was a high probability of future system definition changes, a very modular (i.e., readily adaptable) programming style was dictated.

Tested software was maintained in a specified area on the PDP-11/70. Access to this area was not restricted; instead communication between developers was sufficient to guarantee the integrity of the system during module testing. As a result, there existed a current working version of the system at any given time.

Testing of software

For module testing and integration, various mechanisms were developed either specifically for the task or by modifying existing tools. They provided the means to exercise the computational, display and recorder software and served in varying degrees to simulate the integrated CFPD system.

Transfer to the PDP-11/44 system

At this time, final preparations were made to utilize the PDP-11/44 as the operational system; all CFPD tasks which would be performed during flight testing were made consistent with the system specifications. Intermetrics' tested portion of the CFPD software was transferred to the PDP-11/44 system via a bootable magnetic tape and the capability of down-loading the PS-300 with the flight plan was also accomplished in preparation for the flight tests.

System integration

The final system integration with the sensor software was performed at Intermetrics; all recognizable bugs were removed and a bootable system magnetic tape was created. The actual integration tests were performed on-site at Calspan with minimal problems.

System tests

During the intial testing of the system, many modifications were requested as changes in the implementation and the concept were mandated. As a result of the various design considerations, much of the "fine tuning" had been anticipated and corrections could be made, at times within seconds of the request. Despite the on-site modifications to the software, a current (albeit uneven) operational software specification was produced.

3.3.1.2 Software Description

The CFPD software system provides the computer processing for presentation of the Command Flight Path (CFPD) and conventional Symbology for normal (non-tactical) IMC flight through the following flight phases:

Take-off
Cruise (including turns and altitude changes)
Approach through flare.

All phases were pre-determined and programmed with no provision for online, inflight modifications to the loaded flight plan other than selection of various flight plan segments. Flight path "loops" were supported, with the selection of whether to exit or continue in the loop under operator control (via modification of the flight plan routing).

The CFPD software also provided for the display of conventional VSD and HSD symbology. This display commanded the same flight plan used by the CFPD software. The same restrictions to flight plan modification applied.

During actual flight test, data necessary for the post analysis and evaluation of the flights (CFPD and Symbology) were recorded. In addition, the display and modification of program data was supported from a hardcopy operator's terminal.

The ability to modify certain CFPD (and Symbology) parameters, such as path segment dimensions and spacing, velocity indicator placement, symbol sensitivities, etc., was supported during preflight loading, and in most cases, during actual flight.

A "Restart" Capability was provided which supported the resetting of the flight test data gathering to the current aircraft position. This function was utilized to pick up the flight test at a somewhat arbitrary point in case of an unintentional deviation from the flight plan (ATC, traffic, birds, system hiccup, etc.). In addition, the "fixing" of the aircraft at an arbitrary location in virtual space was provided, in essence moving the virtual space along with the aircraft.

The TIFS CFPD software system consisted of six major modules— Sensor, Sequencer, Recorder, Operator, Data base, and Format. The first four modules reside as separate tasks in the PDP-11, the Database Module was a shared data area in PDP-11 memory, and the Format module executed in the PS-300. The following sections describe the functionality of the six software modules and their interrelationships.

3.3.1.2.1 Sensor Module

The Sensor Module software, developed by Calspan, contained a number of special features and mode control options to facilitate the evaluation of the CFPD concept and to provide as accurate (and current) guidance and navigation data as possible from the available sensors. In particular, this software operated in one of two main modes—the flight mode or the ground simulation mode. In either case, the general processing functions were the same except that in the ground simulation mode additional analog data were input through the A/D channels from the ground simulation computers and an INS simulation was also performed in this subprogram. In addition, an ILS simulation was implemented.

Further information regarding the Sensor Module is contained in Section 3.3.2.

3.3.1.2.2 Sequencer Module

The Sequencer Module was responsible for the generation and update of the graphics displays. As such, its execution was tightly coupled to the Sensor Module, executing whenever the system was in run mode and data were available, the Sequencer also determined the data to be recorded by the Recorder Module. The functions provided by the Sequencer Module are described in the following paragraphs. In addition, the Sequencer major operational modes are described.

a. Initialization

During initial program load, the Sequencer module was responsible for "filing" the flight plan and down-loading the PS-300. Filing the flight plan entailed converting certain parameters in the Database flight plan to more convenient units and computing other derived data, e.g., path segment length, roll in and roll out points, center of turns, etc.

The PS-300 was down-loaded from both a predefined program tape and program code generated as a function of the flight plan (see Format Module). The PS-300 software generated by the Sequencer Initialization function provided the command flight path and runway outlines for the CFPD displays.

b. State Analysis

The State Analysis function of the Sequencer Module computed the ownship status relative to the flight plan contained in the Database Module. This task consisted of determining which part of the command flight path the aircraft was currently on (by geometric projection). The Command Position was also computed based on the previous command position, delta time, and command velocities and accelerations. Finally the location of the Velocity Indicator was determined as a function of the ownship's projected position on the command flight path, the distance from the ownship projected position, Command Position (if coupled), and velocity error.

The State Analysis had a secondary function of determining and updating the Sensor Module's control parameters. These parameters were based on information contained in the flight plan and determined the current flight mode, sensor usage (ILS, INS, etc.), and current runway data.

A special mode, called Restart, was supported by the State Analyzer function. Given a starting point (beginning of a flight plan route), the State Analyzer searched for the current location of the aircraft relative to the flight plan. This mode was used to initialize prior to a test run and for restarting at an arbitrary location.

c. Display Update

The Display Update function utilized the information supplied by the Sensor Module and State Analyzer function of the Sequencer Module to compute and format the PS-300 display update. Various rotation matrices and transformations were computed. This data were then converted to PS-300 internal binary format and transmitted via the PS-300 support routines to the PS-300.

d. Data Send

The Recorder Module was data insensitive; it was not aware of what it was storing on tape. As such, the Data Send function of the Sequencer Module was responsible for determining the data to be recorded during runtime, formatting the data into Send/Receive message packets, and sending the data to the Recorder Module. This software also controlled the frequency at which the data is recorded. A three Hz rate was used during flight test.

e. Operational Modes

The Sequencer Module supported three major operational modes—Live Sensors.

1. Live Sensors Mode—When operating in Live Sensors mode, the Sequencer depended on the Sensor Module for its input data. Sequencer activation was dependent on and synchronized with Sensor software execution. This was the mode under which the Sequencer operated during Ground Simulation and Flight.

2. Auto-track Mode—Auto-track Mode provided a built-in test and demonstration capability. During this mode of operation the Sequencer did not utilize Sensor generated data. Instead, the data computed by the State Analyzer function of the Sequencer were used as ownship data. In particular, the ownship location was set to the preceding cycle's Command Position. The ownship attitude was set equal to the attitude computed for the Velocity Indicator. Other values were derived (ILS) or estimated (angle-of-attack). This mode was used extensively during software development at Intermetrics prior to total software integration.

3. Sim-tape Mode--The Sequencer Module was also capable of accepting pre-recorded "sensor" values from digital magnetic tape. This mode was used early in the Sequencer development task as a means to record a flight using the Intermetrics F/A-18 simulation model and playback a given flight for testing purposes. In addition, one of the actual flight tests (during which data were recorded at fifteen Hz) has been used to generate a Sim-tape for demonstration, providing the capability to re-play an actual flight.

   To support this function, a software tool was developed which would accept a tape generated by the Record Module and reformat it for use as a Sim-tape. If desired, it would be possible to develop a program which would take the three Hz sampled data from flights, interpolate to a fifteen Hz frequency, and generate Sim-tapes for all of the flights.

3.3.1.2.3 Recorder Module

The performance of the pilots using the CFPD display versus the Symbology display was evaluated off-line using data recorded during the actual test flights. The Recorder Module provided this data recording function. The Recorder is capable of receiving data message (via the RSX-11S Send Data mechanism) from any of the other PDP-11 tasks for storage on digital magnetic tape (the Sensor Module did not utilize this capability). No processing or conditioning of the data received by the Recorder is performed. The data are recorded on the tape "as is."

The Send Data facility was chosen instead of using the Database Module to transmit data to the Recorder Module to avoid possible data integrity and synchronization problems. The Recorder can then operate as a background task, somewhat asynchronously with the Sensor and Sequencer Modules.

The actual data recorded during flight tests included the actual ownship "state vector" and certain command values. These data were passed to the Recorder Module at a 3 Hz sampling rate.

3.3.1.2.4 Operator Module

In order to provide online system monitoring and control without impacting the realtime software functions, the Operator Module was designed and developed as a separate task in the PDP-11. All data contained in the Database Module are accessible by the Operator Module.

To provide a general control and debug capability, the Operator software supported a memory display/modify command which allowed the display and modification of arbitrary memory locations in the Database. Multiple data formats were supported (integer, real, logical, octal). In addition, special commands were added to provide a friendlier, less error prone interface for common system functions. These included display format selection, system mode selection, current ownship state display, test 2 (see Sensor Module) setup and control, and test engineer annotation of the data recording.

The Operator Module also provided the capability to program the PS-300 from the operator's console. This function was provided by a system mode handshaking protocol between the Operator Module and the Sequencer Module. The Operator task notified the Sequencer through a system mode that a statement located in the Database was available for transmission to the PS-300. The Sequencer then transmits the statement to the PS-300 and resets the system mode.

3.3.1.2.5 Database Module

The Database Module was a shared data area located in PDP-11 memory. The Sensor, Sequencer, and Operator Modules mapped to this area for data communication and control. The Database provided storage for the display parameters and buffers, flight plan, flight state, Sensor Module control and output, and the global system status.

Initial values were provided for much of the data stored in the Database Module. This data (stored on the system boot tape) consisted of the flight plan, display parameters, and sensor filtering coefficients.

3.3.1.2.6 Format Module

The Format Module consisted of the programming down-loaded into the PS-300 by the PDP-11. This code consisted of a "static" portion which was independent of the flight plan contents and a "dynamic" portion which reflects the preprogrammed flight plan. The static portion was stored on magnetic tape and copied into the PS-300 by the PDP-11 during initial program load. The dynamic code was generated by the Sequencer Module based on the flight plan and also down-loaded during program load.

The Format program contained the entire graphical image. This included the complete command flight path and runway drawings. The data passed to the PS-300 during runtime consisted only of the current values for the image's degrees of freedom. For example, to move and orient the Velocity Indicator, the PDP-11 (Sequencer Module) transmitted the current location (latitude, longitude, altitude) relative to the eyepoint and the Velocity Indicator's current attitude (roll, pitch, heading). The lines which made up the actual Velocity Indicator image were NOT transmitted.

The following sections describe the display formats provided by the Format Module. These formats included the Command Flight Path Display Vertical and Horizontal Situation Displays and the Symbology Vertical and Horizontal Situation Display. The Symbology displays were modeled after the current F/A-18 NAV and approach mode HUD and HSD display formats.

CFPD Vertical Situation Display

The Vertical Situation Display was presented with a fifty degree field of view (FOV) and consisted of three major elements--Flight Path, Velocity Indicator, and Earth Plane. These elements are described below.

a. Flight Path

The flight path consisted of path plates which appeared to be rectangular plates 100' by 600' with a centerline. (Note that rectangular plates viewed at non-perpendicular angles appear as trapezoids due to the perspective transformation.) These plates, placed 300' apart, center to center, defined the command flight path. The plates were not necessarily parallel to the earth plane, as they were "banked" during command turns and "pitched" during command ascents and descents.

b. Velocity Indicator

The command airspeed was represented by a 3-D wireframe aircraft with which the test aircraft was to "fly formation." Deviations from the command velocity were indicated by a corresponding displacement of the velocity indicator relative to ownship. In addition, the command velocity driving the velocity indicator could be coupled to the Command Position, or "How goes it" circle. The instantaneous command velocity would then be the base command velocity (per the flight plan) plus or minus a velocity delta which would bring the ownship back/up to the Command Position. Velocity errors which would allow the ownship to overtake the velocity indicator resulted in the positioning of a blinking velocity indicator at a fixed distance of eight hundred feet in front of the ownship. Velocity errors which would allow the velocity indicator to disappear on the horizon result in a maximum distance for the velocity indicator of four thousand feet in front of the ownship. These artificial limits were imposed to prevent losing sight of the velocity indicator. The current position relative to the command position could still be determined by observing the horizontal situation display.

The velocity indicator position and size were selectable parameters and could be changed easily to meet pilot preference. The velocity indicator "flies" alongside of, and is oriented with, the command flight path. The majority of the test flights were flown with the velocity indicator at a distance of one hundred and fifty feet above the flight path and three hundred feet to the left of flight path centerline. The final version of the TIFS CFPD software permitted the operator to select velocity indicators which flew on the left or right side of the command flight path. Additionally, a formation of three velocity indicators could be called up, whereby the ownship would fly the "slot" position in a diamond. The velocity indicator on most flights was four hundred fifty feet.

c. Earth Plane

The earth plane provided a textured representation of the ground. The apparent size and detail of this texturing corresponded to the aircraft's location and attitude. The lines comprising the earth plane were spaced at an interval of fifteen thousand feet. In addition, a runway representation with standard markings was displayed for use during take-off and landing. The runway was at the same perspective as the corresponding earth plane. The dimensions were six hundred feet wide by nine thousand one hundred twenty-five feet long.

CFPD Horizontal Situation Display

The horizontal situation of the CFPD display consisted of three elements. These elements were the Command Ground Track, Current Position, and Command Position.

a. Command Ground Track

The command ground track defined by the flight plan was represented as a single solid line. While in the vicinity of the airport, a runway representation is displayed. The scale used for depicting the map was under operator control. The scale used during the flight test corresponded to a square map presentation 60,000 feet on a side.

b. Current Position

The current location of the aircraft was shown by a small plan view or shadow image of the aircraft, placed relative to the command ground track. The shadow image was equivalent to three thousand eight hundred fifty feet in length. Its orientation was fixed, with the underlaying elements rotating as per the ownship heading.

c. Command Position

During flight plan segments which commanded that the aircraft should be at a certain location at a certain time, the corresponding position was displayed as a small circle on the command ground track. This circle was visible during flight plan segments which command a given ground speed, and was not displayed during segments in which the command velocity was an airspeed. The circle had a radius of two thousand feet.

Symbology Vertical Situation Display

The Vertical Situation Display consisted of twelve parametric display elements. These elements are detailed below.

a. Heading

The aircraft's true heading was indicated by a moving tape scale at the top of the VSD display.

b. Air Speed

The aircraft's indicated air speed was displayed as a digital readout on the left side of the display. This value was enclosed in a box, the top of which was in line with the Altitude readout box.

c. Altitude

Barometric altitude was displayed as a digital readout enclosed in a box. The box was on the right side of the display, in line with the Air Speed readout.

d. Vertical Velocity

A digital readout, directly above the Altitude box, was used to show the aircraft's vertical velocity in feet per minute.

e. Velocity Vector

A velocity vector symbol was used to display the point towards which the aircraft was currently flying. The Flight Path/Pitch Ladder, Angle of Attack bracket, ILS needles, and Course Indicator were displayed relative to the Velocity Vector and would move around with it.

If the pilot desired, the Velocity Vector could be caged in either the horizontal (typical) or vertical (atypical) axes.

f. Flight Path/Pitch Ladder

The vertical flight path angle of the aircraft was indicated by the position of the Velocity Vector on the Flight Path/Pitch Ladder. The aircraft pitch attitude was indicated by the position of the aircraft Waterline mark with respect to the Flight Path/Pitch Ladder. Aircraft roll was indicated as the rotation of the Flight Path/Pitch Ladder around the Velocity Vector. Pitch lines were in five degree increments; above the horizon lines were solid, below the horizon lines were dashed.

g. Waterline Mark

A waterline symbol was located on the display to give a zero pitch reference mark for the pilot. This symbol could be removed at the discretion of the pilot.

h. Bank Angle Scale

A plus to minus 45 degree bank scale was located along the bottom of the display. Major tick marks were at 15 degree intervals, with a minor tick mark at plus and minus 5 degrees.

i. Angle of Attack Bracket

An AOA bracket was located along the left side of the Velocity Vector during Approach. The center of the bracket was intended to indicate the optimum AOA for approach. As this was never determined for the TIFS aircraft, the pilot was told to ignore this symbol. In later flights, the symbol was actually removed.

j. Course Indicator

Course steering data were displayed as an arrow showing a horizontal indication relative to the Velocity Vector. The rotation of the arrow indicated relative direction of the command course, while the offset of the arrow from the Velocity Vector indicated course lateral deviation. The scaling used during flight tests was 2000 feet per dot. This display construct was very similar to the CDI elements of a mechanical HSI.

k. DME Readout

Range to the waypoint (DME) was displayed as a digital readout on the right side of the display.

l. ILS

ILS elevation and azimuth needles were displayed relative to the Velocity Vector. The ILS display was only visible during Approach.

Symbology Horizontal Situation Display

The Horizontal Situation Display consisted of five display elements. These elements are detailed below. In addition to the display elements, the pilot could specify whether a Heading Up, Ground Track Up, or North Up display orientation was desired.

a. Heading

The true Heading of the aircraft was indicated by a heading marker (lubber line) on the periphery of the compass rose and a digital readout to the left of the center aircraft symbol. The orientation of the aircraft symbol in the center of the display corresponded to the heading marker.

b. Ground Track

The Ground Track of the aircraft was indicated by a Ground Track pointer on the periphery of the compass rose. This marker consisted of a diamond with a short "tail."

c. Ground Speed

The Ground Speed of the aircraft was displayed as a digital readout to the right of the center aircraft symbol.

d. Course

The Course heading of the current flight plan segment was indicated by a Course marker on the periphery of the compass rose and a digital readout in the upper right hand corner of the display. The course pointer consisted of a triangular head with an inscribed circle and dot and a rectangular tail at the reciprocal of the course.

e. DME

The range to the waypoint was displayed after the Course heading readout.

3.3.1.2.7 Operational Data Flow

The Sensor Module received the raw sensor values through the Lab peripheral accelerator (LPA-11K) hardware. The Sensor software was notified of data availability through the posting of an RSX-11S "significant event" by the LPA-11K support routines (provided by DEC). After processing this data, the Sensor Module loaded the data into the Database, notified the Sequencer Module that new data were available through another significant event, and "went to sleep" waiting for new sensor data.

The Sequencer Module utilized the data placed in the Database by the Sensor software to update the displays. As the Sequencer was at a lower priority than the Sensor Module, but higher than any of the other tasks, the Sequencer executed after the Sensor Module suspended itself.

The display update computed by the Sequencer software was transmitted to the PS-300 via the RSX-11S standard DMR-11 device driver. If at a three Hz interval, the Sequencer also transmitted (via the RSX-11S supported Send Data mechanism) selected data values to the Recorder Module. The Sequencer then suspended itself and waited for the next data ready significant event from the Sensor software.

3.3.1.2.8 Resource and Performance Statistics

The Intermetrics software contribution consisted of approximately

18,000 lines of PDP-11 Ratfor/Fortran source code (12,500 if comments were removed) and 1,000 lines of PS-300 source developed in about 11 manmonths. The PS-300 internal code, including the computer generated command flight path for the flight tests, required 580,400 bytes of PS-300 memory. The Database Module required 7,800 words of PDP-11 memory, while the Sequencer Module code required 33,500 words. While the software system was designed to support both the CFPD and Symbology display formats, plus data recording and online operator interfacing, approximately 720 lines of source code and 2,200 words of memory can be identified as Symbology specific. Therefore, the CFPD format can be considered to require 17,280 lines of Ratfor/Fortran source code and 39,100 words of memory. The reader is cautioned, however, against using these statistics as an estimate of flightworthy operational software requirements due to the design goals and objectives of this project (e.g., rapid prototype, minimal use of programmers, high level maintainability; see Section 3.3.1.1).

The runtime system executed during runtime at a 15 Hz. rate on a PDP-11/44 with floating point processor using the RSX-11S Version 4.0 operating system. The CFPD software was shown to be capable of a 20 Hz. cycle time, but the Symbology software was not able to attain this rate. It is expected that the PDP-11 to PS-300 interface through the DMR-11AE DECnet interface was the primary limiting factor, but this was not shown conclusively.

3.3.2 Arvin/Calspan's Contribution

The purpose of the CFPD sensor software was to provide the interface, as well as the requisite data processing functions, between the real world TIFS aircraft-related sensor systems and the display software. The primary function was to provide a set of smoothed and processed sensor input data to the display software that defined the position, attitude and velocities of the aircraft relative to an earth-referenced coordinate system (the guidance and navigation data) as well as other aircraft-related flight parameters. These data included input from an Inertial Navigation System (INS), an ILS receiver, a radar altimeter, the TIFS Air Data Computer, TIFS Inertial Sensors and other signals, and the Workload Assessment Device (WAD). A secondary function was to provide the required test functions, mode control, and sequence logic for the planned CFPD flight evaluation phases (e.g., take-off, cruise and approach/landing) in either a Flight or a Ground Simulation Mode.

The CFPD sensor software was developed by Calspan to satisfy the functional requirements defined in the CFPD Software Specification. This specification was written jointly by Calspan and Intermetrics early in the program to serve as a guide during software development, as well as to satisfy the communication requirements of the software design and documentation process. Calspan was responsible for the sensor software part of the specification.

The sensor software was developed at Calspan using a PDP-11/45 computer with a RSX-11M operating system. The software source code was then transferred to Intermetrics where it was integrated with the display and CFPD system software to run under the RSX-11S operating system on the PDP-11/44 computer. Because of task size constraints, the sensor software resides as a separate but high priority task in the system. Data communication between the tasks is through a resident common region, referred to below as the Global Database.

3.3.2.1 General Sensor Software Description

The sensor software resided as a separate task in the overall CFPD software. The program provided the real-time interface between the TIFS aircraft-related sensor systems and the display software. Its primary function was to provide processed sensor input data to the display software that defined the position, attitude and velocities of the aircraft relative to an earth-referenced coordinate system as well as other aircraft-related flight parameters such as air data. A secondary function was to provide the required test functions, mode control and sequence logic for the planned CFPD flight evaluation phases in either a Flight or Ground Simulation Mode.

All sensor data transfers to the PDP-11/44 were via the LPA11-K microprocessor peripheral accelerator. The sensor software controlled the LPA11-K through the use of standard LPA11-K FORTRAN support routines provided by DEC as part of the RSX-11M or 11S operating systems. The local databases contained all data and control parameters passed between the sensor subprograms, the LPA11-K and the support routines. The Global databases contained the control and data passed between the sensor software and the display software.

The sensor software also provided the real-time synchronization between the sensor inputs from LPA11-K and the rest of the display software. Since all sensor data transfers to main memory were controlled by the LPA11-K, sychronization was achieved by using the real time clock in the LPA11-K to control the update rate of the PDP-11/44 software. This was accomplished by initiating the sensor update loop at the completion of each A/D data sweep. At the completion of the sensor processing calculations, an event flag was set to synchronize the display software. The final update rate used was fifteen updates per second.

3.3.2.1.1 Sensor Software Modes

The sensor software contained a number of special features and mode control options to facilitate the evaluation of the CFPD concept and to provide as accurate (and current) guidance and navigation data possible from the available sensors. The main mode control and submode control of the sensor software was provided by the SENCTL database which was controlled by the display software. Prestored data needed for navigation purposes was also provided by this database. For instance, a runway data vector provided data for runway length, altitude, heading, glide slope angle, localizer position, glide slope intercept position, etc., which was used in the INS/ILS mixer processing functions. All processed data to be used by the display software was copied into the SENOUT database. This database provided the interface between all sensor software output and the display software.

The sensor software operated in one of two main modes - the Flight Mode or the Ground Simulation Mode. In either case, the general processing functions were the same except that in the Ground Simulation Mode additional analog data were inputted through the A/D channels from the ground simulation computers and an INS simulation was performed using this data. In addition, an ILS simulation could be selected as an option in either the Flight or Ground Simulation Mode.

Selection of one of four primary modes (Preflight, Take-off, Cruise and Approach) which control the sensor software processing functions was via the SENCTL database. The functional requirements and submode control for the Preflight and Cruise Modes were straightforward; however, for the Take-off and Approach Modes, the sensor software was automatically advanced and latched through a sequence of guidance submodes for blending of INS, ILS and TIFS altitude and radar altimeter data. In addition, two Test Modes and a Position Reset feature were provided to initialize or update the position of the aircraft at a pre-specified location. The modes were as follows.

a. Preflight

In the Preflight Mode, all sensor software I/O and filter processing functions were executed, except that the blending of INS, ILS and radar altimeter data were disallowed. The navigation calculations to convert from geodetic latitude and longitude (from the INS) to Cartesian coordinates relative to the runway reference position were also performed. The main purpose of this mode was to allow time to stabilize any dynamic filters prior to engagement of the other modes. It could be entered from any other mode. The Test Mode and the Position Reset feature were also functional in this mode.

b. Cruise

All preflight processing functions were performed in this mode. Aircraft guidance in this mode was provided solely by the INS and the TIFS complementary filtered altitude. It could be entered from any other mode.

c. Take-off

Besides updating all Cruise Mode processing functions, selection of the Take-off Mode activated the radar altimeter and TIFS complementary filtered altitude mixer to generate a smoother altitude signal, whenever the appropriate criteria were satisfied. Knowing the runway altitude also allowed the radar altimeter to continually calibrate the altitude estimate from the TIFS complementary filter output. In addition, the runway localizer capture logic was activated. For instance, the criteria for localizer capture at take-off might be that the aircraft had moved to within +/- one hundred feet of the runway centerline, was within +/- five degrees of runway heading and the weight on wheel (WOW) signal was active. When the criteria were satisfied, a LOC/INS lateral complementary filter computation was initiated and utilized for precise lateral position determination. These data were also used to continually update the INS position data during the take-off roll. After lift-off (airspeed greater than rotation speed) and transition (not WOW), the sensor software computations would automatically revert to those in the Cruise Mode. In the Take-off Mode, the Test Modes and the Position Reset features were functional. In addition, a special Take-off Position Reset function was provided in this mode to update the INS at a prespecified take-off location on the runway. Also, this mode could be entered from any other mode.

d. Approach/Landing

Selection of the Approach Mode allowed a sequence of guidance submodes to be entered which were advanced by approach progress. In addition, all Cruise Mode processing functions continued to be executed and the radar altimeter/TIFS complementary filtered altitude mixer was activated (similar to the Take-off Mode) whenever the appropriate radar altimeter capture criteria were satisfied. The guidance submodes were defined by the following structure:

Guidance Submode	Requirement
INS Guidance	Approach Mode Selection
LOC/INS Guidance	Localizer Capture
LOC/Glide Slope/INS Guidance	Glide Slope Capture
Flare - LOC/INS	Terrain Altitude $<$ 50'
Rollout - LOC/INS	WOW set

Similar to the Take-Off Mode, the INS and the altitude complementary filter would be updated continually by the ILS and radar altimeter. The ILS and INS data were mixed in complementary filter fashion as were the radar altimeter and TIFS complementary filtered altitude data, whenever the appropriate capture criteria were satisfied. These complementary filters were the same as steady-state Kalman estimators. At some point during rollout, the Take-off Mode would automatically be engaged by the Sensor Software with the localizer capture. Also, this mode could be entered from any other mode, even though the normal mode advancement would be from the Cruise Mode.

During an approach and landing to an actual runway, the trajectory of the aircraft is defined primarily by the ILS and radar altimeter data; the INS merely performed a beam smoothing function. If, for any reason, the ILS was off or the appropriate capture criteria were not satisfied, guidance was from the INS and TIFS altitude data.

e. Test Modes

Two Test Modes were provided by the Sensor Software. Both of these modes simply added constant offsets to the position data from the INS and altitude complementary filter to initialize the location of the aircraft at a preselected position. The Test 1 Mode used the initial position defined by the runway data; the Test 2 Mode used another preselected location defined in the SENCTL database. The real ILS and radar altimeter were automatically disabled in the Test Mode, although the ILS simulation could still be enabled. The Test Modes were useful to initialize the aircraft at a particular position for approach and landing evaluations to a "virtual" runway at altitude or to simply initiate for airwork in Cruise to "find" the Command Flight Path. This was achieved by "fooling" the aircraft guidance systems. Therefore, offset Reset functions were also provided

f. Position Reset

This feature was useful to update the INS when the present position of the aircraft was known. It could be invoked at anytime except after localizer capture in Approach Mode.

g. Check-out Test Mode

This feature allowed input data from the LPA11-K to be replaced by pre-stored values. It was useful during check-out of the sensor software.

3.3.2.1.2 Sensor Software Processing Functions

The purpose of the major sensor software functions was to compute the best estimate of the airplane's state vector (position, velocity and attitude) from the various sensor inputs with enough precision and resolution so as not to compromise the evaluation of the CFPD concept.

The major sensor inputs were from the INS, an ILS receiver, a radar altimeter, TIFS sensor data and various signals from the gound simulation computers. Inputs from the INS included horizontal position (geodetic latitude and longitude), intertial velocity (North and East components), attitude (pitch and roll) and true heading. Vertical guidance was from the TIFS altitude data and from the radar altimeter. The ILS signals were conventional glide slope and localizer deviation errors. the TIFS altitude and vertical rate data were computed on the TIFS system computers by blending barometric altitude and vertical acceleration measurements in a complementary filter fashion. Other TIFS data included inputs from the air data computer and the TIFS pitch and roll attitude gyros.

All analog signals from the analog-to-digital (A/D) converters could be individually filtered to remove noise with a first order digital filter. The coefficients of the filter difference equations were computed using a Tustin transformation. The filter break frequencies were individually selectable or the filter could be bypassed. In the final software configuration, five relatively low frequency air data signals were filtered.

Similarly, data from the INS, which were transferred to the computer in a digital form, could be selectively filtered. In the Ground Simulation Mode, the data from the INS were substituted by the INS simulation calculations. Options were also available in the sensor software to use TIFS attitude data instead of the INS attitudes. Early in the CFPD flight evaluations the filters were used to eliminate pitch angle jitter in the display caused by synchro-to-digital converter noise. Later in the program, the attitude gyro signals from TIFS were used instead and the filters were bypassed.

The horizontal guidance computations consisted of three major functions. The functions are described in the following.

a. INS Complementary Filters

The purpose of the INS complementary filters was to provide high resolution, short-term, position data (latitude and longitude) to the display software. This was accomplished by blending longitude and V/E (East component of velocity) or latitude and V/N (North component of velocity) in complementary filter fashion to form composite longitude or latitude position measurements. The end result was that the low frequency information content in these composite parameters was from the raw INS position measurements, whereas the high frequency content was from the more accurate velocity data.

b. ILS/INS Mixer

The idea behind the ILS/INS mixer was basically the same, only the geometry and the low frequency data input were different. In this case, the position of the airplane was defined relative to the touchdown point on the runway in terms of forward ($\widehat{RF}$) and cross ($\widehat{RC}$) range to go in feet. The North and East components of velocity from the INS were simply resolved into this coordinate system as a function of runway heading. During an approach and landing, and after localizer and glide slope capture, RF was computed as a function of glide slope deviation error and altitude where RC was computed as a function of RF and localizer deviation. These position measurements were blended with forward and cross velocities from the INS to form the forward and lateral complementary filters. The outputs of these steady-state Kalman filters were smoothed estimates of forward ($\widehat{RF}$) and cross ($\widehat{RC}$) range to the touchdown reference point. Hence, in this mode, the low frequency horizontal guidance of the aircraft was defined by the altitude and ILS data; the INS essentially performed a beam smoothing function with the velocity data. After localizer capture, but prior to glide slope capture, $\widehat{RF}$ was computed from the updated INS position data (latitude and longitude) and used in the $\hat{RC}$ calculation to intialize the forward filter. Likewise, prior to localizer capture, both filters were initialized from the INS. In addition, appropriate capture, initialization, and edit by-pass logic was provided by the sensor software so that the mixer would work well in practice.

c. INS Updater

The INS updater simply calibrated the INS position data to $\hat{RF}$ and $\hat{RC}$ from the INS/ILS mixer. This was done by computing approriate offsets to be added to the INS latitude and longitude position data from $\hat{RF}$ and $\hat{RC}$. This calculation was performed anytime after localizer and/or glide slope capture. Consequently, the INS was continually being updated by the ILS and altitude data whenever possible. Likewise, the ILS simulation, whenever enabled, was simply a reverse calculation of localizer and glide slope deviation errors using the updated INS position data and altitude.

Vertical guidance was from the TIFS altitude and altitude rate data and a radar altimeter. The major blocks are described in the following.

a. Altitude Selector

The altitude selector was merely logic to select one of four A/D channels from which to select the TIFS altitude data. All four A/D channels were scaled the same but limited in range. This scheme allowed for a fine resolution altitude signal with a large dynamic range using twelve bit A/D converters. The resulting altitude signal had a resolution of approximately +/- one foot with a dynamic range of 0 to 15,250 feet.

b. Altitude Complementary Filter

The altitude complementary filter was implemented to perform the same function as the INS complementary filter discussed above; that is, to provide high resolution, short-term, altitude data to the display software. However, because the altitude selector worked so well, this filter was never enabled during the CFPD flight evaluations.

c. Altitude Blender

The altitude blender was used to continually calibrate the TIFS altitude signal whenever the radar altimeter data were flagged valid. The blender was a steady-state Kalman filter implemented to estimate a bias error in the TIFS altitude data using the radar altimeter. The blender could also be viewed as a complementary filter, which had the important property that high frequency information was obtained from the TIFS altitude, whereas low frequency information was extracted from the radar altimeter.

3.3.2.1.3 High Level Sensor Software Structure

The sensor software consisted of the main routine for the SENSOR task (called SENSOR), seven subroutines and four completion routines. The completion routines were called from the operating system when the LPA11-K had filled (or emptied) a data buffer. These routines were written to manage the buffer queue set up for the LPA11-K.

SENSOR was the main, but relatively small routine used to coordinate the sensor software. During program initialization or stopping, it called the SENINI subroutine; during the real-time program run loop, it called SENUPD.

The SENINI subroutine initialized the sensor software and initially configured the LPA11-K. This subroutine did not start the LPA11-K and was invoked only at system initialization and system stop. It was invoked during the system stop sequence to shut down the LPA11-K and display data on the hard copy terminal. In particular, this subroutine performed the following functions:

a. LPA11-K shut down and initialization
b. Initialization of data and control indicators
c. Pre-computation of sensor processing constants
d. Pre-computation of runway constants.

The SENOPT subroutine was called from SENINI during program initialization or program stop. It was an interactive, user-friendly, routine that allowed the sensor input and control data to be displayed and modified from the hard copy terminal prior to using the data during sensor intialization or stop. It prompted the operator; it read the required commands and data from the terminal; and it modified and/or displayed the data accordingly.

The SENUPD routine performed the main real-time processing functions of the sensor software. This routine started the LPA11-K, it set the update rate by waiting for an A/D buffer completion and it managed the buffer queue. In addition, all computations were done in this routine. After all sensor computations were completed, SENUPD called SENMOD; SENMOD performed all the real-time sensor software mode control functions. At the end of SENUPD, an event flag was set to synchronize the display software.

3.3.2.1.4 Sensor Software Databases

The databases were grouped as to whether they were Global or Local. The only difference between the two was that the Global databases were defined to be accessible to the Display software for data communication and control, whereas the Local databases were only available to the Sensor software. Each database consisted of one or more labeled common blocks and they were grouped together under a file name descriptive of how they were used in the program and consistent with the CFPD Software Specification

3.3.2.2 Timing

The update rate of the sensor software was controlled by the real-time clock in the LPA11-K. This was accomplished by initiating the sensor software update loop at the end of each A/D data input sweep.

All synchronous input/out (I/O) operations in the LPA11-K were driven and synchronized by the real-time clock overflow rate. This overflow rate was set by the sensor software and it applied to all active I/O requests. Control parameters were available to allow several concurrent requests to specify different sampling rates or sampling patterns, but the sampling rates had to be a multiple of the real-time clock overflow rate.

The sampling patterns set-up for the synchronous I/O date transfers for the CFPD system included the analog-to-digital (AD) input sweep; the synchro-to-digital output (SDO) control sweep; the synchro-to-digital input (SDI) sweep; and the discrete word input sweep (DIS). The SDI and DIS were "externally" triggered input sweeps which were controlled by the SDO output sweep. This was set up in the Calspan interface design so that a particular synchro-to-digital input channel or a discrete word input could be activated and its input synchronized to the other I/O under program control.

The AD sweep pattern was set up to convert and input forty consecutive A/D channels (one per each clock overflow), wait 460 clock overflows, and then repeat. Since the sensor software was activated after the forty channels of the A/D data are inputted to memory by the LPA11-K, the real-time loop time duration was equivalent to 500 clock overflows. Consequently, for a twenty Hz update rate the clock was set to overflow every one hundred microseconds, whereas for the fifteen HZ update rate the overflow was set for every 133 microseconds. An update rate of fifteen Hz was used for the CFPD flight evaluations.

The SDO sweep was set up to output data every ten clock overflows. However, only five of these outputs were coded to activate a SDI and DIS each update cycle and the first one started fifteen clock overflows ahead of the first A/D channel to be converted. This insured that all data input to the computer would be fresh (most recent) at the start of the real-time loop. This also insured that the maximum aggregate instantaneous throughput rate for all active requests on the LPA11-K, when in the multirequest mode, would not exceed 15K Hz.

The sensor software timing results were obtained with the PPD-11/44 computer system operating with the sensor test software. The sensor software took approximately 6-8 milliseconds to complete depending upon the sensor mode of operation. The Flight Mode was close to six milliseconds, whereas the Ground Simulation Mode was around eight milliseconds. It is estimated that it took approximately two milliseconds of system overhead time to service the buffer queue of each LPA11-K sweep. The remainder of the loop time was used by the display software and other system overhead.

The other sensor software system overhead came from managing the

I/O buffer queues for the SDO, SDI and DIS sweeps discussed above and the serial-to-parallel input (SPI) from the INS. The SPI was an "externally" triggered "asynchronous" digital input sweep from the INS which was inputted at a 24.16 Hz rate.

It was estimated that it took two milliseconds of system overhead time to service each I/O buffer queue. Since the SPI was an asychronous input to the computer, its buffer queue had to be serviced each time an input was received, and that could be as high as two per sensor software update time. To reduce the I/O overhead time, the SDO, SDI and DIS sweeps were implemented with long buffers, interleaved in such a fashion that only one of their buffer I/O queues had to be managed for every six updates of the sensor software. This scheme reduced significantly the amount of overhead time required to service the I/O buffer queues.

In the Flight Mode, the sensor software would use a minimum of ten milliseconds to a maximum of fourteen milliseconds of time for each update cycle. At a fifteen Hz update rate, 52.5 - 56.5 milliseconds would remain available for the display software.

With the final version of the overall CFPD software, a fifteen Hertz update rate was achieved with either the CFPD display or the F-18 symbology display. A twenty Hertz update rate could be maintained with the CFPD display, but it was marginal; twenty Hertz could not be achieved with the F-18 display. Consequently, all flight test evaluations were conducted with a fifteen Hertz update rate.

3.3.3 Evans & Sutherland's Contribution

The Evans & Sutherland PS-300 display system used in this project normally accepts command and data in the form of a high level, ASCII text stream with an effective bandwidth of about 1200 baud. (The interface hardware is capable of 56K baud transmission, but the standard PS-300 firmware is only able to process input commands at about 1200 baud.) CFPD requirements were more on the order of 30K baud. Consequently, Evans & Sutherland developed firmware customized for the CFPD and symbology displays which would support binary data transmission over the standard 56K baud interface. This firmware was incorporated into the control program loaded into the PS-300 during power-up.

3.4 System Installation

Installation in the NC-131H comes under the Air Force system of documentation and approval application to Class II Modifications, which are temporary installation for research, development, test, and evaluation purposes. The CFPD System, with the exception of the inertial navigation system and the HUD, was comprised of standard commercial equipment. To power the equipment, the existing 1500VA sixty Hz rotary inverter was permanently replaced with two 3500VA sixty Hz static frequency converters. To ensure proper functioning in a flight environment, the equipment was ruggedized and then subjected to vibration testing at Calspan. The system equipment successfully passed the vibration test, was certified safe for flight in the CFPD Class II Modification Part II, and was installed in the TIFS by Calspan personnel.

3.4.1 Frequency Converter Installation

The majority of equipment installed in TIFS for the CFPD program was standard office-type equipment not capable of operating on four hundred Hz line power. To accommodate this equipment, the existing 1500VA sixty Hz rotary inverter was permanently replaced with two 3500VA sixty Hz static frequency converters. The converters could not be paralleled, therefore, a two-bus distribution network was installed where either converter could supply either one or both buses. Both converters cannot be tied to the same output bus.

Two line filters were installed—one to filter the PS-300 power and the other to filter the PDP-11/44, I/O chassis and DEC writer power.

3.4.2 Vibration Testing

All CFPD equipment, except for the inertial navigation system and the HUD which are designed for airborne use, were exposed to vibration typical of the TIFS. A simple test was devised using a sinusoidal shaker input at frequencies and amplitudes observed on flight records in the cockpit and cabin areas. All equipment had been inspected and hardened by Calspan where needed. Each unit was under power during its test. All equipment passed the test without incident.

3.4.3 Hardware Mounting Location

The mounting locations for the major CFPD equipment items are identified in Figure 3-2. Except for the graphics processor and the video recorder and power supply, all CFPD equipment was hand mounted in the TIFS aircraft. Equipment locations, except cockpit displays, were selected for aircraft center of gravity considerations, ease of operation by crew members and accessibility for maintenance. The cabinets designated "CFPD Computer System" in Figure 3-2 are detailed in Figure 3-3. Photographs of the installations are presented in Appendix F.

3.4.4 Evaluation Cockpit Configuration

All standard instrumentation was removed from the evaluation pilot (left seat) instrument panel. A XYTRON display was installed in the HSI position and a Head-Up-Display (HUD) tray mounted above it. The tray was oriented for proper HUD viewing angle and would accept the Hughes "AIDS" HUD or a second XYTRON display. An adaptor was fabricated and secured to the removable XYTRON CRT display to provide the desired viewing position

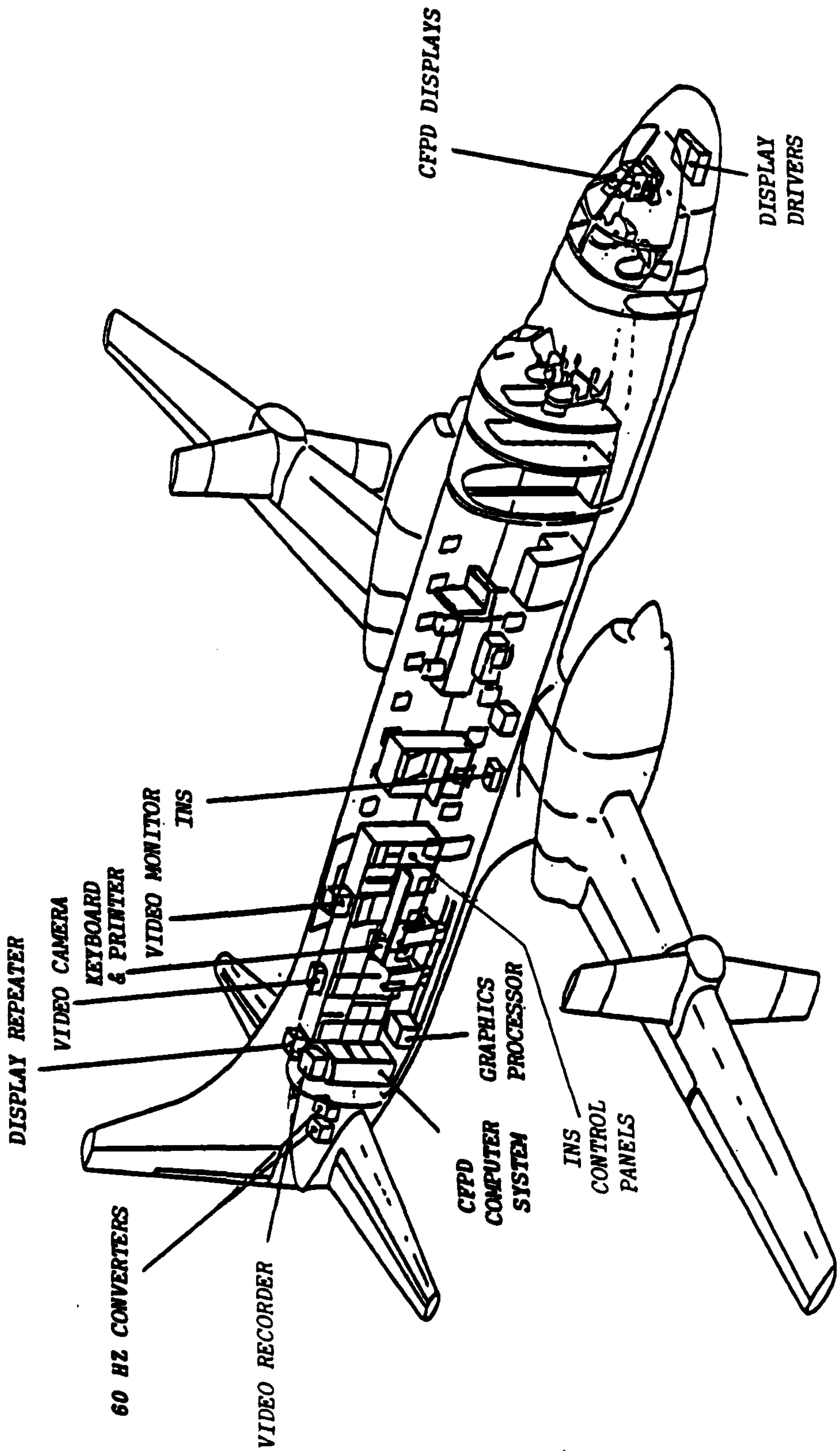


Figure 3-2

CFPD/TIFS General Arrangement

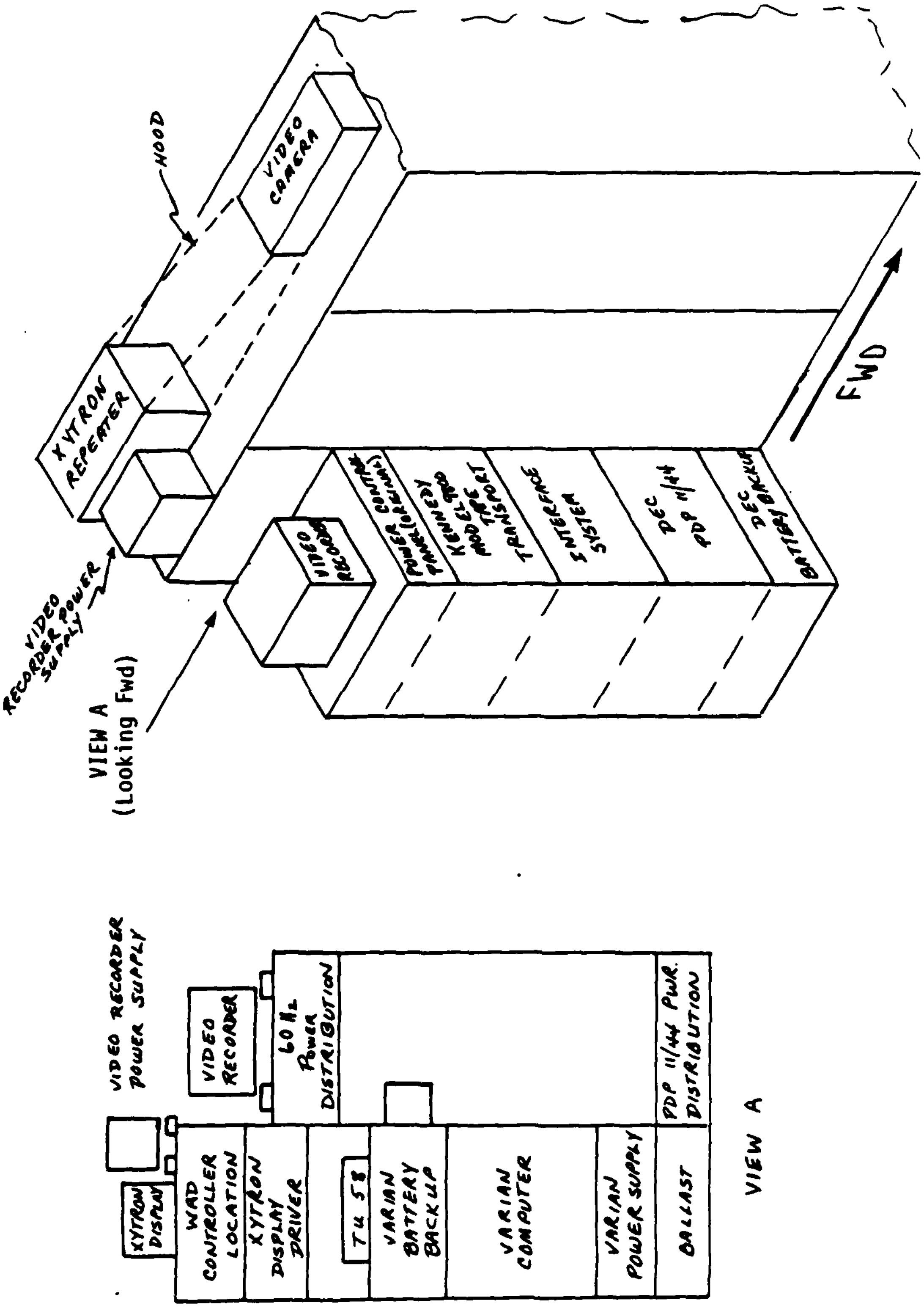


Figure 3-3

CFPD Computer System

when the XYTRON display was installed in the HUD tray.

The window areas adjacent to the pilot seats were sealed with an opaque material and forward view was obscured by a translucent cloth hung from the overhead beam to forward of the HUD combiner glass to simulate IFR flight. For VFR flight conditions, the translucent cloth was removed from the Velcro attachments.

To prevent reflections from the CFPD installations onto the forward windscreen, a black cloth was installed forward of the instrument panel. A side view of the general layout of the evaluation cockpit is shown in Figure 3-4.

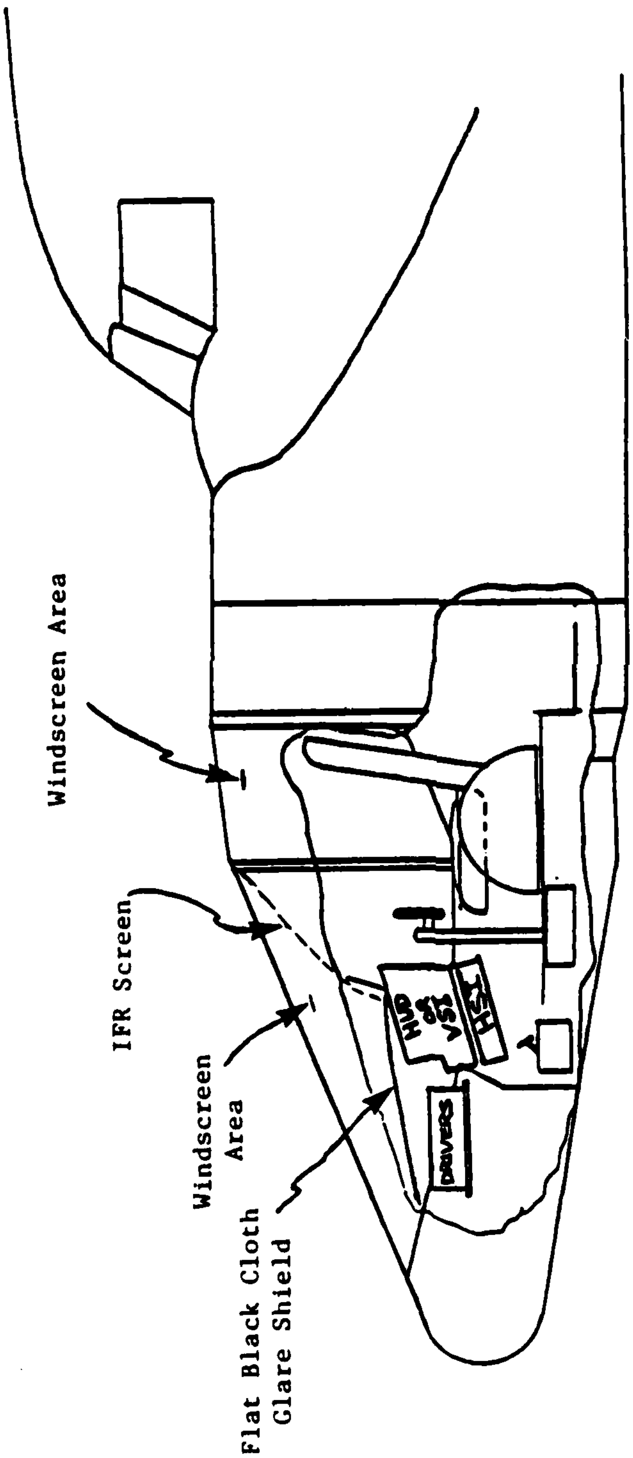


Figure 3-4

Evaluation Cockpit Layout

4.0 FLIGHT TEST

The overall objective for Phase II was to conduct flight tests of the Command Flight Path Display system in order to validate the display concept. Twenty hours of flight time were allocated for the validation. The target date for the first flight, established at the Phase I kick off meeting, was February 1, 1983. All milestones were established to accomplish this goal on time. A two month window for completion of the twenty hours of flight test was available but submission of flight data was promised to NAVAIR by the end of February.

The installation of the CFPD system was completed in mid January. Ground simulation commenced on January 27, 1983, following a short review meeting. The only open action item at the meeting was Air Force approval of the modifications to TIFS which was required prior to the first flight.

Verbal approval of the Class II Part II modification was finally received on February 8, 1983. The first flight was scheduled for the following day and was successfully executed. The second flight was flown on February 10, 1983. Data from the first two flights were prepared and provided to NAVAIR on February 28, 1983. No further flights were flown until March 3, 1983, due to pilot unavailability. Two pilots from the Naval Air Test Center and two from the Naval Air Development Center participated in the flight test during March.

The flight test window was extended into April to allow VADM E.R. Seymour, Commander, Naval Air Systems Command, to participate. VADM Seymour's visit had been postponed from February 9, 1983, when modification approval delay prevented system checkout in flight prior to his arrival. CAPT R.D. Friichtenicht, NAVAIR 03, accompanied VADM Seymour and also flew the flight test patterns. Two additional flights were flown on the CFPD system by U.S. Naval Test Pilot School pilots from Patuxent River. These pilots were not part of the flight test, but flew the system for TPS syllabus requirements when the X-22A aircraft at Calspan could not be flown.

Little cooperation was expected from the weather in Buffalo, New York, during the flight test. Fortunately it was a mild winter and only one scheduled flight was cancelled due to meteorological conditions. Snow, high winds, and turbulence were all encountered without adverse effect on the CFPD display.

4.1 Flight Test Plan

The development of the flight test plan was based on many critical factors. Criteria used were:

a. The Program Objectives
b. Total flight time available - 20 hours
c. Maximum time for a single flight - 2 hours
d. Maximum video tape recording time - 30 minutes
e. Evaluation of F-18 symbology relative to the CFPD

f. Evaluation of both displays on CRTs under simulated zero-zero conditions and on the Hughes AIDS HUD
g. Actual coupled ILS approaches under simulated zero-zero conditions on the VSI and with the AIDS HUD
h. Time to reach the flight test area and time to return to base
i. Indoctrination of the evaluation pilots
j. Calspan safety requirements.

A flight test pattern was developed that consisted of a modified instrument pattern. (Figure 2-6) It was composed of interrelated maneuvers and performances basic to normal IFR flight. The initial climbout to 1000 feet and the approach portion from completion of the first 45 degree turn to touchdown were flown on indicated airspeed (IAS). The remainder of the flight plan was flown on groundspeed. The following breakdown of the flight test pattern was provided to each pilot in the briefing guide.

<u>Leg 1</u>

1. Leg 1 begins at the rotation point.
2. Maintain runway heading, climbout at 3 degrees flight path angle and 170 kts IAS until reaching 1000 feet.
3. Raise gear and flaps as required.
4. Upon reaching 1000 feet reduce flight path angle to 1.7 degrees and continue to climb at 500 fpm and 185 kts groundspeed.

<u>Leg 2</u>

1. At waypoint 1 commence a 90 degree right turn continuing to climb and leveling off at 2000 feet, 185 kts groundspeed.
2. Maintain heading, altitude, and groundspeed.
3. At 11.4 DME start a level speed change to 215 kts.
4. At 8.2 DME start a level speed change to 185 kts.
5. At 4.2 DME start a level speed change to 215 kts.

<u>Leg 3</u>

1. At waypoint 2 commence a 90 degree right turn, maintain 2000 feet and 215 kts groundspeed.
2. After completion of the turn, maintain heading, altitude, and groundspeed until reaching waypoint 3.

<u>Leg 4</u>

1. At waypoint 3 commence a 90 degree right turn.
2. After completion of turn commence a 185 kts climb to 3000 feet. Upon reaching 3000 feet, level off and increase groundspeed to 215 kts.
3. Maintain heading, altitude, and groundspeed until reaching waypoint 4.

Leg 5

1. At waypoint 4 commence 180 degree left turn, maintaining 3000 feet, 215 kts.
2. At .7 DME commence a 500 fpm descent to 1300 feet.

Leg 6

1. At waypoint 5 commence a 90 degree right turn at 215 kts, continuing to descend at 500 fpm to 1300 feet.
2. After completion of the turn, maintain heading, groundspeed, and descent.

Leg 7

1. At waypoint 6 commence a 90 degree turn at 215 kts, continuing to descend at 500 fpm to 1300 feet.
2. After completion of turn, maintain heading and groundspeed. Level off at 1300 feet.
3. At 6.7 DME start a level speed change to 185 kts.
4. Maintain heading, altitude and groundpseed until reaching waypoint 7.

Leg 8

1. At waypoint 7 commence a 45 degree right turn.
2. At completion of turn commence level speed change to 150 kts IAS. Maintain heading and altitude. The ILS steering display will appear. (E.g. elevation and azimuth deviation needles referenced to the velocity indicator.)
3. Perform the landing checklist as required.
4. Waypoint 9 is the touchdown point.

This pattern served as the basis for the flight test plan. A schedule was prepared to cover the twenty hours of flight time available. Pilot availability necessitated changes to the original schedule and resulted in the actual schedule shown in Figure 4-1.

Each pilot selected to participate in the flight test was briefed the night before his first flight. He was asked to read a CFPD briefing guide which explained the program objectives, the concept definition, and the flight test plan. The following day the pilot was asked to fly the pattern in the ground simulation, first on the symbology and then on the CFPD.

When the simulation was complete, the aircraft was disconnected from the ground computers and prepared for flight. The pilot was briefed by the safety pilots on weather and safety. Following the brief, the aircraft was manned and the safety pilots departed Buffalo. When in position, and with the display ready, control of the aircraft was transferred to the pilot in the evaluation cockpit. The pilot flew the pattern, once on the symbology display and again on the CFPD display. At the completion of

PILOT	1983 DATE	GROUND		AIR									FLIGHT TIME (HRS + MIN)	
		PATTERN		CFPD Flight No.	VSI/HSI				HUD/HSI					
					PATTERN		ILS		PATTERN		ILS			
		F-18	CFPD		F-18	CFPD	F-18	CFPD	F-18	CFPD	F-18	CFPD	Flight	Total
G. Hoover	9Feb			1		X							1+50	
R.P. Harper	9Feb			1		X								1+50
R.P. Harper	10Feb			2	X	X							2+00	
V.T. Cronauer	10Feb			2		X								3+50
J. Wetherbee	3Mar	X	X	3	X	X	X	X					2+10	6+00
J. Wetherbee	4Mar			4					X	X	X	X	2+07	8+07
R. O'Hanlon	7Mar	X	X	5	X	X	X	X					1+46	
V.T. Cronauer	7Mar			5				X						9+53
R. O'Hanlon	8Mar			6	X	X	X	X					1+41	
V.T. Cronauer	8Mar			6				X						11+34
J. Walters	9Mar	X	X	7	X	X							1+10	12+44
J. Walters	23Mar			8					X	X	X	X	2+07	14+51
F. Ameel	24Mar	X	X	9					X	X	X	X	1+59	16+50
E.R. Seymour	19Apr	X	X	10	X	X	X	X					1+46	18+36
R.D. Friichtenicht	19Apr	X	X	11	X	X	X	X					1+36	20+12

Figure 4-1

Flight Test Plan Schedule

the pattern work the aircraft was repositioned by the safety pilots to intercept the ILS approach Runway 28 at Niagara. Control of the aircraft was again turned over to the pilot in the evaluation cockpit for one approach using the symbology display and one approach on the CFPD display.

The F-18 symbology was modified slightly to reflect TIFS performance parameters. Ground track up, heading up, and North up formats were available. The following details the differences from the standard F-18 symbology.

a. F-18 uses two different character sizes within the altitude readout box on the VSD. Our version used one size.
b. Characters on the compass rose of the F-18 HSD always remain upright, ours rotated with the compass rose.
c. The following were eliminated from the basic flight data:

    1) Angle of Attack Readout
    2) Mach Number
    3) Aircraft G
    4) Peak Aircraft G
    5) Ghost Velocity Vector

d. No Advisory Data Symbology was provided
e. No Steering (Waypoint Direct) Symbology was provided
f. Steering (TCN/WYPT Course) Symbology was provided with the following differences:

    1) Waypoints were predetermined and provided as shown in Figure 2-6 without station identifier.
    2) The CDI on the F-18 VSD shows angular deviation from course line, the modified version showed lateral displacement. If the needle is on the first (second) dot, ownship is 2000 feet (4000 feet) off of course centerline. Standard F-18 would have been 4 degrees and 8 degrees respectively.

g. The altitude presented in the box was barometric altitude. The runway was represented as 0' Mean Sea Level (MSL).
h. The Waterline symbol was always provided for pitch attitude reference. It was moved to correspond to TIFS HUD location or removed entirely when desired.
i. The landing display was presented on the approach leg only.
j. The AOA bracket was set up to correspond to TIFS parameters. The center of the bracket represented the optimum approach angle of attack (3.6 degrees true). The length of the bracket represents about plus or minus two degrees. No backup approach indexers were provided.

4.2 Ground Simulation

Ground simulation began on January 27, 1983. The simulation utilized the TIFS aircraft which was configured for control from the left hand evaluation cockpit seat. The left seat was arranged with left-hand throttles, a center stick and standard rudder pedals. Ground computers capable of reproducing the TIFS equations of motions were connected to the aircraft.

Initial simulation work was planned for display adjustments as well as software exercise. Immediate problems were encountered with aircraft control stability. A basic TIFS feel system was requested from Calspan. After several attempts, agreement was reached among the Calspan pilots that the feel system was configured for the basic TIFS. Final adjustments to the force feel system, gearings, trim rates, aileron to rudder interconnect, and Dutch roll damping were made on the first flight but no further changes were made for the duration of the flight test program. Actual values for the feel system gains and control system configuration of TIFS, used during the flight test, can be found in Calspan Report No. 6645-F-12.

Subtle adjustments to the CFPD display were made during the first week of ground simulation. These included size, position, and travel limits of the velocity indicator, coupling and uncoupling of the velocity indicator to the command position, horizon gradient, number of earth plane lines, amount of pattern visible, brightness contrast, dimension and spacing of plates, dimensions of runway, blending of plates and runway, and steepness of pattern turns. In most cases adjustments were made within a matter of seconds from the CFPD engineer's station. Software tapes with permanent modifications were prepared at Intermetrics and provided as required to support the simulation and flight test. Messrs. Steve Shelley, Neil Akiyama, and Paul Slonaker provided this support by rotating between Boston, Massachusetts, and Buffalo, New York. At least one of them was on site at Calspan as CFPD engineer for the entire ground simulation and on board TIFS for each test flight.

Use of the ground simulation continued for the duration of the flight test. Each pilot selected for participation flew the test flight pattern on the symbology and on the CFPD prior to actual flight.

Demonstrations of the CFPD for program participants were run on a non interference basis. Non pilots were able to fly the CFPD, without training. This provided additional proof that the display was truly integrated and had the necessary visual cues.

Approximately ninety-one hours of simulation time were accumulated during the course of the program.

4.3 Flight Test

The procedure to initiate the flight test was for the safety pilots to depart Buffalo, climb to altitude, and position the aircraft for the start of the flight test. The starting point depended on whether the evaluation pilot preferred to do the approaches at Niagara or the test pattern work first. He was given his choice. In addition he was given the option of which display format to start with, either the symbology or the Command Flight Path.

When the safety pilot was approaching the initial point, the CFPD engineer would bring up the display format to be flown and the evaluation pilot would engage the feel system in the evaluation cockpit. When all were ready, control of the aircraft was passed to the evaluation cockpit. Responsibility for visual traffic separation and radio communications remained with the safety pilots.

The evaluation pilot would execute his take-off in "virtual" airspace for the flight test pattern. The pattern covered approximately 27 square miles with a perimeter of roughly 78.5 miles. Approximately 25 minutes were required to cover the course which terminated with an approach to the same position that the pattern commenced.

When the first pattern was completed the safety pilot would take control of the aircraft and turn to reposition at the starting point allowing sufficient time for the CFPD engineer to bring up the display format for the second pattern and the evaluation pilot to engage the evaluation cockpit feel system again. The same procedure for transferring control of the aircraft would be followed once the aircraft was in position and all were ready.

The evaluation pilot would take control of the aircraft for the approach at Niagara after the safety pilot had engaged the ILS outside of the outer marker. He would fly the approach until control was taken back by the safety pilot, usually at an altitude of approximately 150 feet. The safety pilots would execute a missed approach and reposition the aircraft outside the outer marker for another approach.

A total of nine pilots participated in the flight test flying over twenty hours. Two additional pilots from the U.S. Naval Test Pilot School (TPS) flew the CFPD system for over three hours to complete TPS syllabus requirements when the X-22A aircraft at Calspan could not be flown.

On every flight a second pilot was in the right seat of the evaluation cockpit. The second pilot provided verbal cues to the evaluation pilot during the test pattern. Comments made while on the CFPD were limited as compared to a constant stream of prompting while on the symbology display. A much greater magnitude of departures would have been experienced on the symbology patterns if the evaluation pilot had relied strictly on the test pattern and not received verbal inputs from the second seat.

The last flight utilizing the CFPD system was flown on April 20, 1983. The system equipment was removed and shipped in accordance with NADC instructions.

4.4 Data Reduction

The Data Reduction for CFPD was performed at Intermetrics, Inc. on the data recorded during each flight by the Recorder task. Whenever possible, automated mechanisms were developed to facilitate the process and reduce the human interface. The reduction occurred in several phases, each identified by a specific function.

4.4.1 Phase I

Since the Recorder task performed no processing on the recorded flight data, the first phase involved identifying and separating the data sets associated with the various flight exercises (for each flight):

a. Flying the command path using the CFPD
b. Flying the command path using the symbology display
c. Flying the approach to Niagara using the CFPD
d. Flying the approach to Niagara using the symbology display

Throughout the flights, messages were generated automatically by the Operator task which signalled certain events (e.g., system initialization); these messages along with comments entered by the operator were sent to the Recorder task and formed a chronology which helped during this phase.

4.4.2 Phase II

The next phase involved obtaining reference and/or timing information used to coordinate and identify data within each data set. The information included three-dimensional position data (actual, projected onto the command path and command), flight path referenced position data (distance from take-off, "route" number) and deviations (altitude and lateral). Also during this phase, extraneous information (e.g., text messages) interspersed during the flights by the operator are removed. The end result is a data file containing all the information needed to perform the subsequent data analysis. The kinds of data recorded on the flight tapes and the data determined during this phase both evolved as a result of work on CFPD. During the initial flight tests, data were collected and reduced; from the preliminary plots, it was determined what data were needed (in addition to data being recorded) and what kinds of information were to be presented.

4.4.3 Phase III

The data were then analyzed to determine various statistical parameters, some of which were necessary for the plotting phase. These include the minimum, maximum, and average values of altitude deviation and lateral deviation. The statistical data also evolved to include such data as percent-time within certain deviations (e.g., within +/- 75 feet of the the command path).

4.4.4 Phase IV

Appropriate plotting data were extracted for each plot depending on the desired parameters; for example, altitude deviation versus distance along the command path. These data were then formatted so as to be compatible with the plotting package used during Phase V.

During the writing of this final report, it was determined that additional plots of a more integrated format were required as examples. These plots were generated by hand based on data generated during this phase.

4.4.5 Phase V

Finally, the ZCHART Plotting Package was used to actually generate the various plots, utilizing the data generated during Phase IV and the scaling parameters determined during Phase III. Each CFPD flight was represented by a set of data plots which presented various areas of interest as specified by the goals of the project. The plots included (for each pilot):

1. Altitude plots using the CFPD
2. Lateral deviation (from the Commanded Position) plots using the CFPD
3. Velocity plots using the CFPD
4. Altitude plots using the symbology display
5. Lateral deviation (from the Commanded Position) plots using the symbology display
6. Velocity plots using the symbology display

These plots are included in Appendix D of this report.

5.0 DATA REDUCTION RESULTS

In viewing the CFPD and Symbology plots resulting from the data reduction, it was noted that flight plan departures can be categorized into three error types--Anticipation and Reaction, Pilot Workload, and Non-linear Course Tracking. These generic categories are discussed in the following sections. Examples of these categories are derived from the plots contained in Appendix F and included for illustrative purposes. While they are not shown in the same format as the standard flight test plots, the examples in the following sections do represent actual flight test events and data. Plots containing more than one test case (i.e., both CFPD and Symbology) depict consecutively flown test cases by the same pilot during the same flight. On some of the examples, the altitude data were deleted as it did not pertain to the concept being discussed.

5.0.1 Description of Example Plots

The plot figures included as examples in the following sections were designed to depict lateral, vertical, and longitudinal errors along a common axis (distance along the flight path). Lateral and vertical departures are shown as line graphs indicating the distance left or right of the flight path for lateral errors and the actual altitude flown for vertical errors.

Note

> While flying the CFPD flight tests, pilots tended to fly above the command flight path at some personally comfortable height. This offset was not removed from the altitude plots in the examples.

Longitudinal errors are depicted by taking "snapshots" of the flight data and plotting where the aircraft was positioned relative to the start of the flight plan and the commanded position. The distance between the Command Position and the CFPD/Symbology Position markers for each snapshot indicate how far ahead or behind flight plan the pilot is at that particular moment.

5.0.2 Anticipation and Reaction

Anticipation and Reaction type errors relate to the inability of the pilot to anticipate maneuvers and control corrections and to react in a timely and correct manner to indicated deviations. The most graphic examples of these types of errors occurred while intercepting and tracking a given course line or setting up and executing an ILS approach. When flying the Symbology format, pilots typically experienced difficulty in anticipating the correct time to "roll-out" of a turn and the correct heading to hold. The general tendency is to "bracket" the desired course line or glide slope, eventually converging on the correct control inputs to maintain course. Lateral deviation plots showing these cases can be easily recognized as they exhibit a damped oscillation towards zero error. However, when flying the CFPD format, the same pilots never really "lost" the command information. (The single exception is discussed in the next paragraph.) In fact, they never deviated far enough to demonstrate any bracketing-like tendency. Figure 5-1 demonstrates this.

During one flight, a pilot flying the CFPD format intentionally departed from the command flight path to investigate how easy it is to re-intercept the commanded course. Figure 5-2 shows that the pilot did not appear to have to "search" for the correct control inputs to intercept and maintain course. The pilots "convergence" on the correct control inputs was extremely rapid when compared to the performances using the Symbology format.

Another very common flight plan deviation involved the interception of the Localizer and/or Glide Slope during an ILS approach. (Figure 5-3) A large majority of the pilots exhibited an overshoot of the localizer course. Similar difficulties were not experienced by the pilots flying CFPD. Whether these difficulties could be attributed to the change in format (Cruise to Approach) with its attendant change in sensitivities or the change in command type (fly at a given altitude digital value to follow the glide slope needle) was not determined.

Note

> Data for longitudinal errors (the position plots) were not included as the velocity being commanded during approach was Indicated Airspeed, not Ground Speed. In other words, there was no pre-determined geographic command position for the aircraft; "how goes it" was instantaneous, not cumulative.

5.0.3 Pilot Workload

It is widely accepted that operator performance of a given task is directly related to the operator-perceived workload. This workload is not only a function of the required control inputs, but is dependent on the quality (accuracy, timeliness, completeness, presentation medium, etc.) of the information presented to the operator. These human factors concepts are applicable to the piloting task incorporated into the CFPD flight tests. While not measured quantitatively, evaluation pilot assessments of their perceived workload was collected during the debriefing sessions (see Appendix D).

When faced with a relatively high workload task, a typical tendency of the pilots flying the Symbology was to "fixate" on tracking one or two of the commanded flight parameters (to the detriment of the remaining parameters). An example of this observation is shown in Figure 5-4. The pilot was commanded to roll-out onto a new course and immediately de-accelerate and climb to a new altitude. The pilot was to maintain a given flight path angle. In this case, the pilot apparently concentrated on intercepting the new course line, possibly due to difficulties in establishing the preceding leg. Meanwhile, the aircraft was slowly descending, when in fact a climb

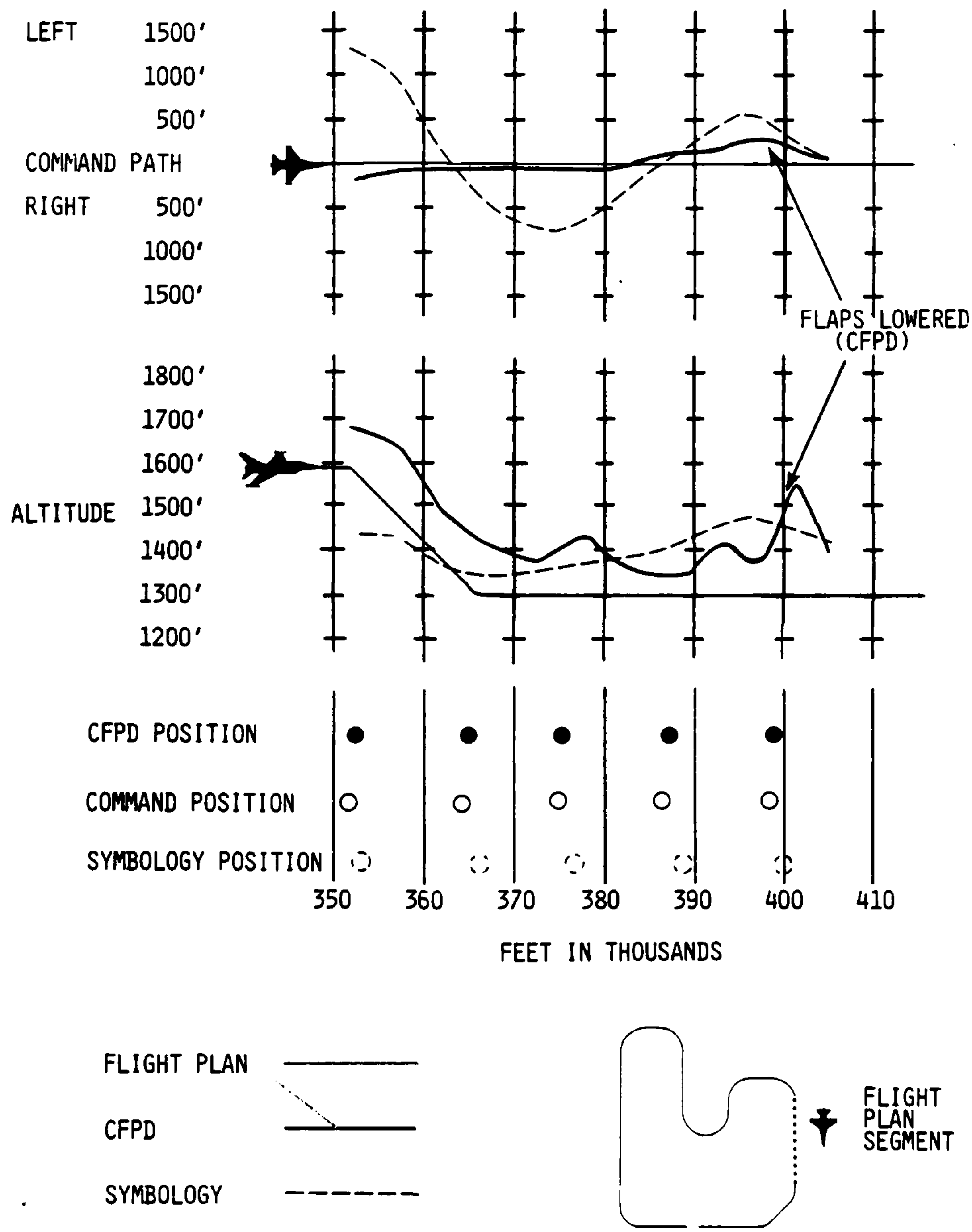


Figure 5-1

Lateral Bracketing Deviation

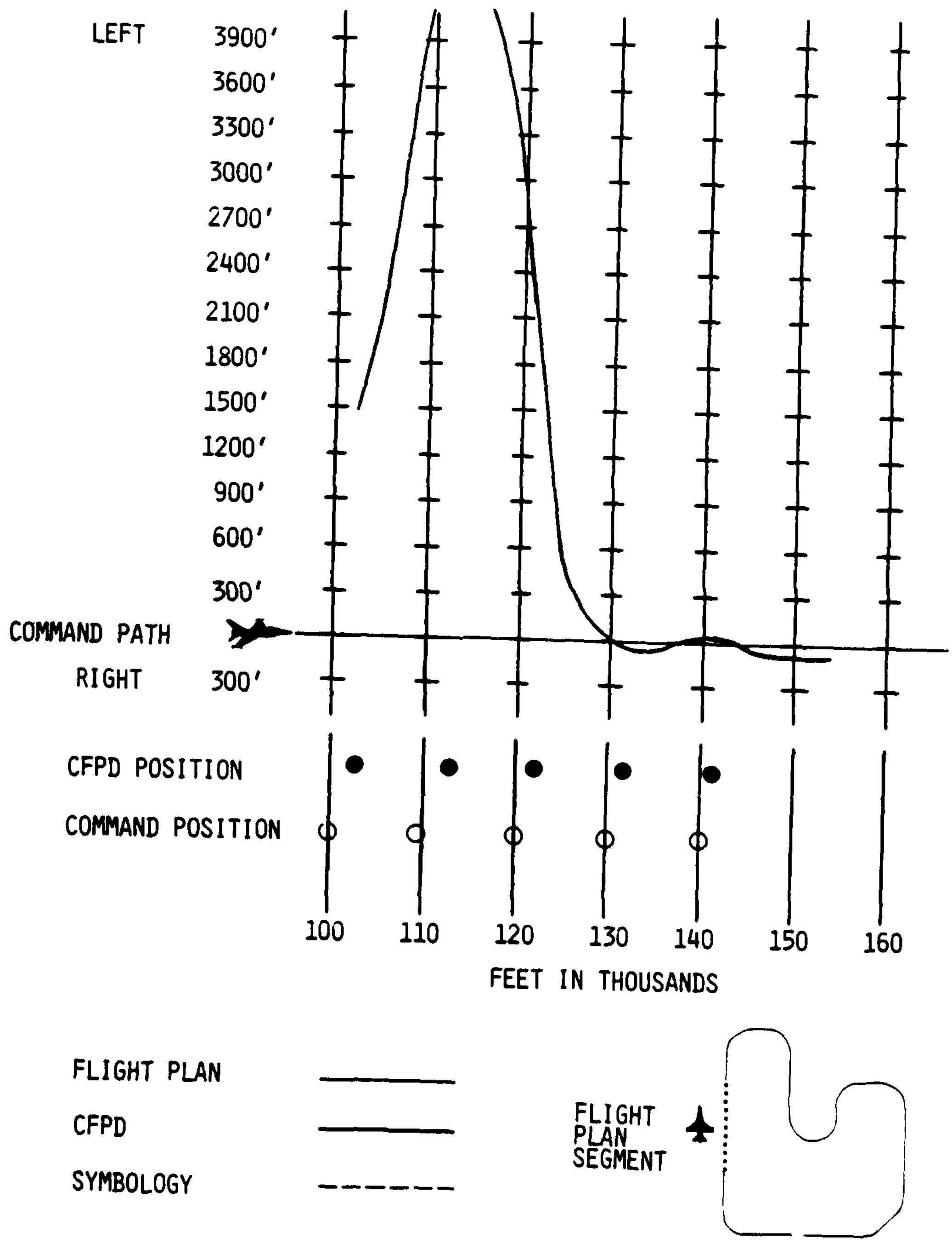


Figure 5-2

Intentional Departure and Interception on CFPD

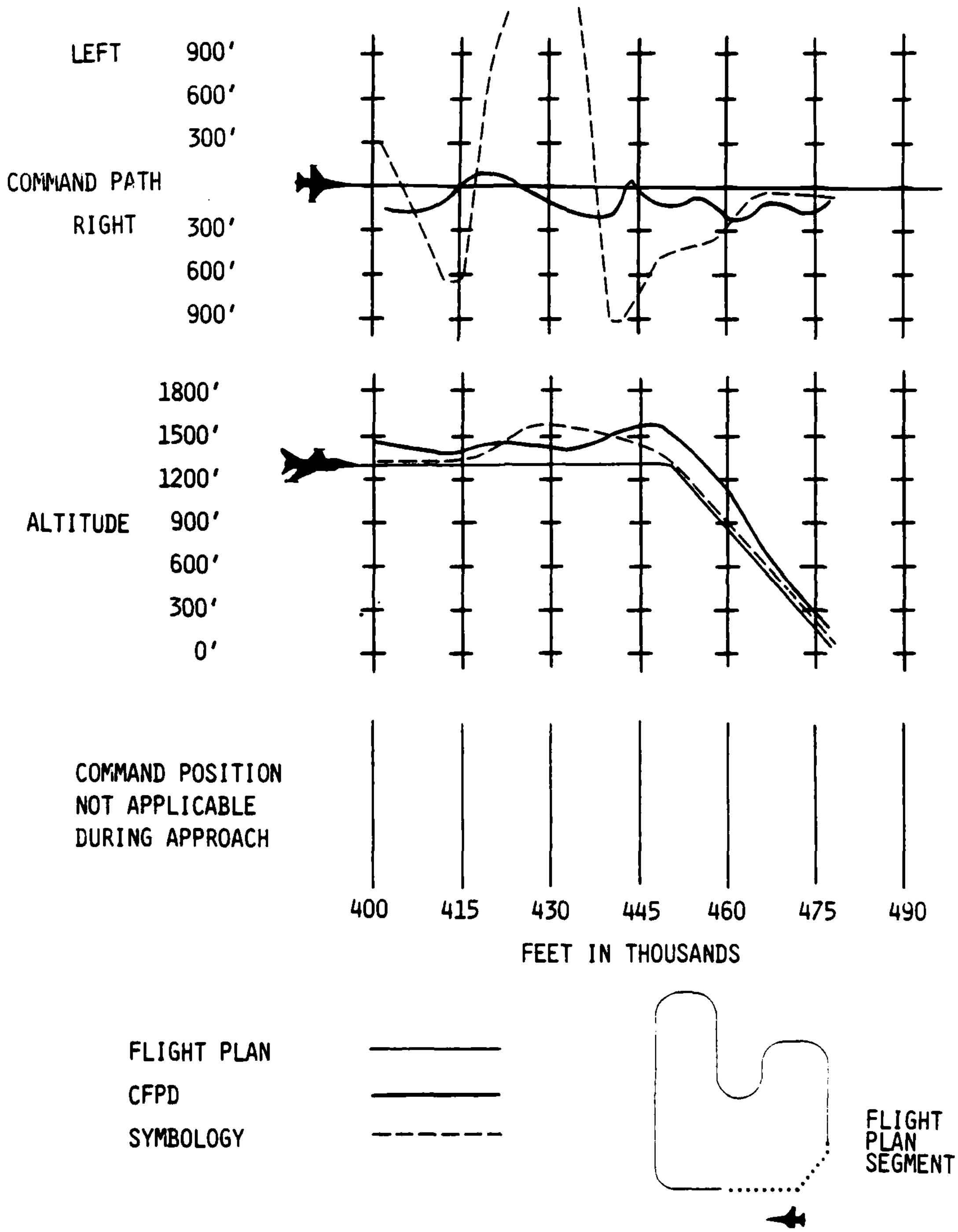


Figure 5-3

Deviation During Interception of ILS Localizer

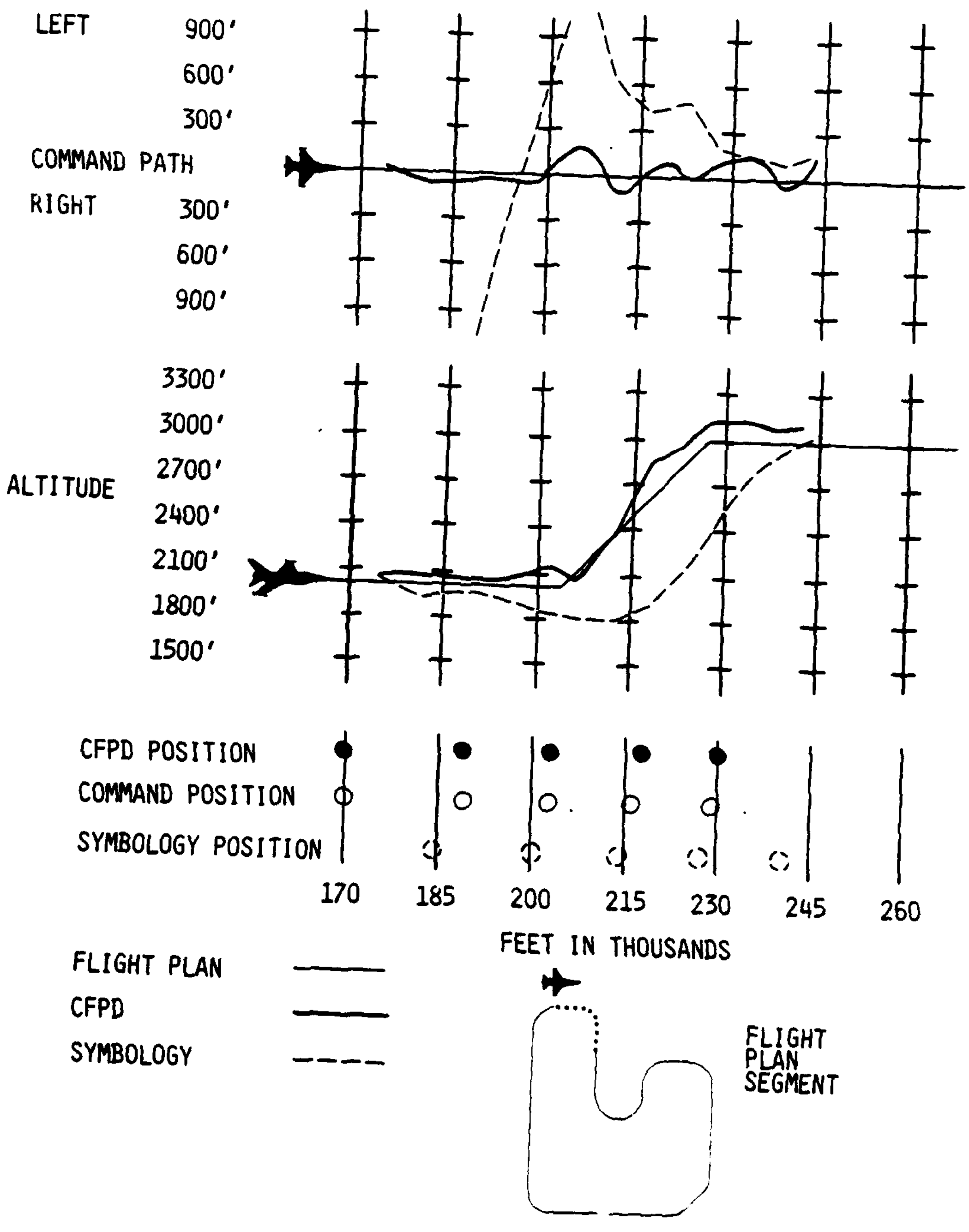


Figure 5-4

Deviation During High Pilot Workload Task to 3000' should have commenced. During this flight, the pilot was actually prompted to start climbing.

5.0.4 Non-linear Course Tracking

"Standard" symbology display formats do not provide for the presentation of curved or non-linear flight paths. Flight plans consist of connected straight legs; the pilot has to "round off" the corners by executing some manner of a standard turn. Errors in determining and maintaining the correct bank angle result in a horizontal course deviation. Errors of this nature are typically not apparent to the pilot until the new course leg is (or is not) intercepted. Problems in tracking a non-linear flight path were most apparent during the 180 degree turn portion of the flight plan (Figure 5-5). Notice that the pilot did not show the same degree of difficulty in executing the turn while flying the CFPD format.

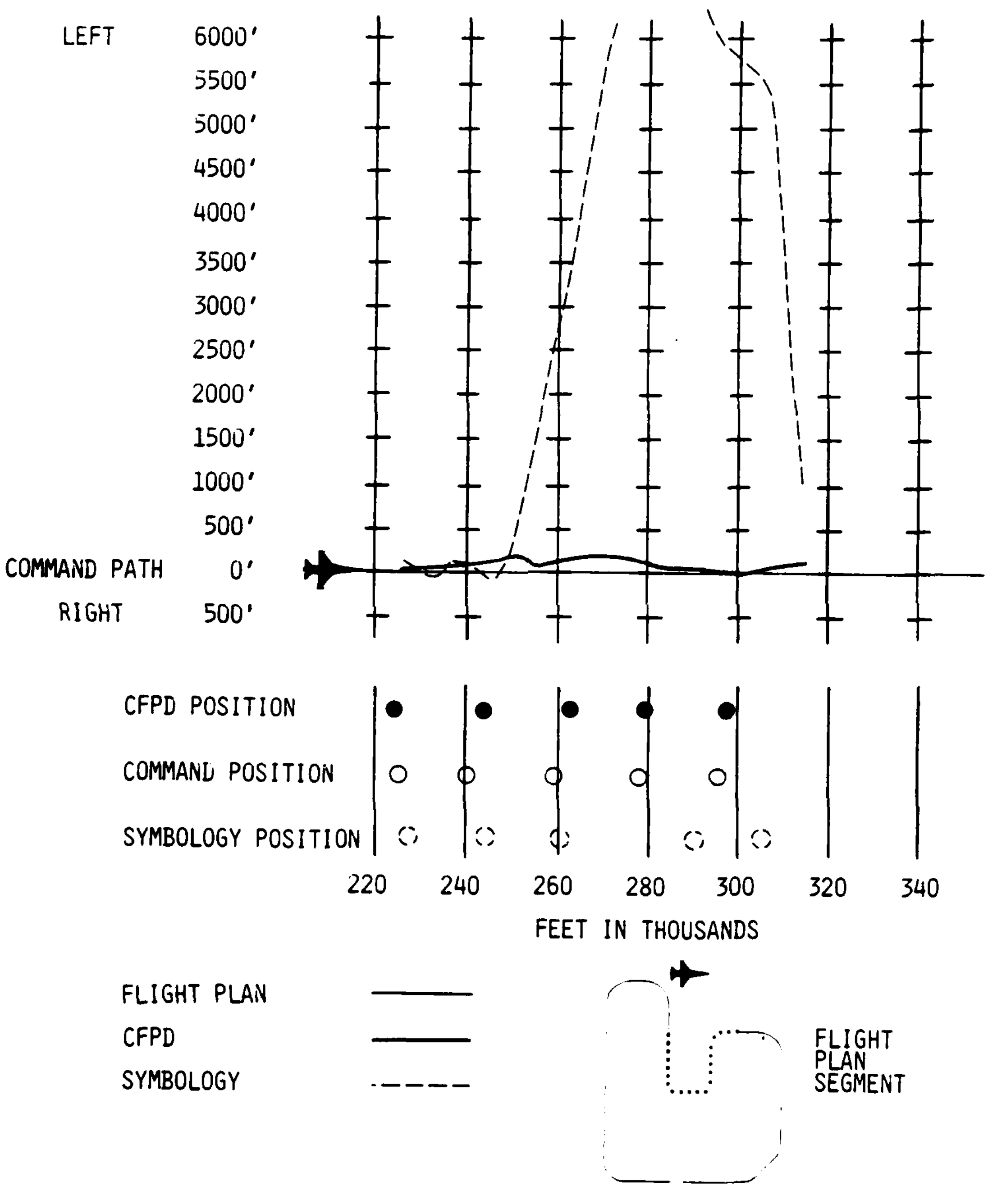


Figure 5-5

Deviation During Non-Linear Flight Path Tracking

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