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TEST PLANNING INFORMATION
AND
PROCEDURES FOR TESTING AIRCRAFT NAVIGATION SYSTEMS

PREPARED BY

CENTRAL INERTIAL GUIDANCE TEST FACILITY
6585TH TEST GROUP
HOLLOMAN AIR FORCE BASE, NEW MEXICO

OCTOBER 1975

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AIR FORCE SYSTEMS COMMAND - UNITED STATES AIR FORCE
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The designation of the Central Inertial Guidance Test Facility (CIGTF) as the DOD focal point for aircraft inertial navigator test and evaluation required that a generalized test plan be written to govern all future tests. This document outlines such a Standardized Test, including test philosophy and objectives, the test approach and an outline of the test procedure. It provides the reader with an understanding of the 6585th Test Group's aircraft navigator test capabilities, the types of test programs currently

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available, and the requirements necessary for an agency to enter systems in these programs.

Ten appendices which cover areas such as analysis methods, laboratory testing, and instrumentation, are included to provide the customer with additional detailed information.

FOREWORD

The 6585th Test Group's Central Inertial Guidance Test Facility (CIGTF) was established to provide a DOD capability to test and evaluate the products of the inertial navigation and guidance industry. The goals of the CIGTF are the following:

- o Unbiased evaluation of components and systems, to provide data from which the customer can select the optimum equipment for a given mission application.
- o Development of a single centralized test facility, to avoid the prohibitive costs of duplicated facilities.
- o Standardization of tests, to provide common yardsticks for comparative evaluations.
- o Competence in both personnel and equipment, to insure meaningful evaluation.

Originally established to provide test support for the development of early ballistic missile systems, the CIGTF has expanded its capability to cover the full spectrum of navigation and guidance equipment. The development of advanced precision test facilities and the acquisition of a hard core of experienced personnel have produced an unequaled facility for the evaluation of missile, spacecraft, and aircraft systems and components. This growing competence has resulted in increased emphasis on the role of the CIGTF as a national focal point for navigation system testing. The test facility is available to the three services, NASA, FAA, and private industry through government sponsorship.

Throughout any test program the customer is encouraged to observe the tests. He is kept aware of significant occurrences through immediate informal reports. Upon completion of the test, the CIGTF prepares a complete engineering and data analysis report for distribution by the customer.

The purpose of this document is to briefly describe the unique capabilities available for aircraft navigation system testing that exist within the 6585th Test Group, Holloman AFB, New Mexico. Test Planning Information Documents describing additional areas of capability are available and titled as follows:

. Sled testing of Guidance Components and Systems
Terminal Guidance Testing
Laboratory Testing of Guidance Components

Volume I	-	Gyroscope Laboratory
Volume II	-	Accelerometer Laboratory
Volume III	-	Environmental Laboratory
Volume IV	-	Celestial Inertial Laboratory
Volume V	-	Stellar Simulator Complex
Volume VI	-	260" Centrifuge

It is realized that a brief document cannot provide the detailed information necessary for complete test planning, and further inquiry is invited. The technical staff at the CIGTF stands ready to assist and advise in test planning or to design and conduct complete guidance test programs in fulfillment of any test requirements.

Request for test support or further information regarding test programs should be directed to the Central Inertial Guidance Test Facility, addressed:

6585th Test Group
Guidance Test Division (GDP)
Holloman AFB NM 88330

ABSTRACT

The designation of the Central Inertial Guidance Test Facility (CIGTF) as the DOD focal point for aircraft inertial navigator test and evaluation required that a generalized test plan be written to govern all future tests. This document outlines such a Standardized Test, including test philosophy and objectives, the test approach and an outline of the test procedure. It provides the reader with an understanding of the 6585th Test Group's aircraft navigator test capabilities, the types of test programs currently available, and the requirements necessary for an agency to enter systems in these programs.

Ten appendices which cover areas such as analysis methods, laboratory testing, and instrumentation, are included to provide the customer with additional detailed information.

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I. INTRODUCTION

A. Purpose

This document outlines the philosophy and procedures used to evaluate the performance and operational suitability of aircraft inertial navigation systems, and to provide for continuing Air Force implementation of DDR&E Directives regarding Test and Evaluation of Aircraft Inertial Navigators. The first such directive was issued in July 1965 by Dr. Harold Brown. This directive was sustained and clarified in April 1967 by Dr. John Foster. This later directive is quoted here in part:

> " . . .An Aircraft Inertial Navigator Test and Evaluation Program is established at the Central Inertial Guidance Test Facility (CIGTF), Holloman Air Force Base, which is the DOD focal point for aircraft inertial navigator test and evaluation. This CIGTF program will verify the expected performance of inertial navigators and will provide comparative results under the same test conditions. Through this process, avionics developers and/or Contract Definition (formerly PDP) contractors will have a number of inertial navigators to choose from whose performance has been verified, thereby minimizing the risks to the Government in their selection . . . ."

The standardized tests to be described here were established to fulfill the intent of the DDR&E Directive referred to above (Reference Appendix A) and provide a realistic basis for comparative analysis of systems or components prior to their selection for any specific DOD application. The resulting data enables the Air Force to select the best available equipment for either future weapon system development or modification of existing systems.

B. Background

The first Test Program Information (TPI) document was originally published in March 1966 to aid in implementation of Dr. Brown's memorandum concerning test and evaluation of aircraft inertial navigation systems. In April 1967, Dr. Foster reiterated the need for a central test agency (Reference Appendix A). The evaluation capability is an outgrowth of testing at the CIGTF of the XN-16 and MINS inertial navigation systems in 1964 under Program 663A, and tests of the AN/ASN-47, N-16, LN-14B, NIS-105, LCI, and Hipernas III inertial navigation systems under Program 698DF (Mark II) in 1965. The Mark II comparative evaluation was extended to evaluate the reaction time and accuracy under various pre-conditioning situations for the AN/ASN-47 and LN-14B. Between 1964 and 1975 the programs shown in Table I were tested or are currently under test.

In February 1975 a new division, The Aeronautical Test Division, was created within the 6585th Test Group to further improve flight test efficiency. The Aeronautical Test Division provides aircraft support in the form of scheduling, aircraft modification and documentation, and test system operation including maintenance. The Guidance Test Division (CIGTF) provides overall test management, data recording instrumentation, data reduction and analysis, and reporting of results.

TEST CODE: D=DEVELOPMENTAL V=VERIFICATION *=CURRENTLY UNDER TEST

TABLE -I INERTIAL NAVIGATORS FLIGHT TESTED AT THE CENTRAL INERTIAL GUIDANCE TEST FACILITY

PROGRAM	TYPE OF SYSTEM	SHORT TITLE	TEST CODE	CONTRACTOR	TYPE OF PLATFORM	GYROS NR	GYROS TYPE	ACCELEROMETERS NR	ACCELEROMETERS TYPE	TYPE OF COMPUTER A=ANALOG D=DIGITAL		TEST ENGINEER	TEST START	DDC ACQ NUMBER	
663E	MINIATURE INERTIAL	MINS	D	GPI	4-GIMBAL	3	KING II	3	KEARFOTT 2401	A		MR JAMES	1964		
663	INERTIAL NAVIGATOR	XN-16	D	AUTONETICS	4-GIMBAL	2	G-9	2	UM-8	D	VERDAN	LT HOOTEN	1964		
663	STELLAR INERTIAL DOPPLER	SIDS	D	LITTON	4-GIMBAL	2	G-300G	3	A200D	D	C-900	CAPT KUROWSKI	1965	AD383404	(C)
698	MARK II-INS	ASN-47	V	A-C	4-GIMBAL	3	SDF25 IRIG	3	GG-177B	D	MAGIC II	MAJOR ULSHAFER	1965		
698	MARK II-INS	LN-14	V	LITTON	4-GIMBAL	2	G-280	3	A200D	A	NCU	CAPT FOSSETT	1965		
698	MARK II-INS	HIPERNAS III	V	BELL	4-GIMBAL	2	BRIG IV	3	MOD-VIII	D	L-90-1B	MAJ ERI	1965		
698	MARK II-INS	LCI	V	GPI	4-GIMBAL	2	GYROFLEX	1	KEARFOTT 2414	D	DYDAN	MR JAMES	1965		
698	MARK II-INS	NIS-105	V	NORTRONICS	FLIP	3	GI-K7	3	AP-E4-10B	D	NDC-1050	CAPT KUROWSKI	1965		
698	MARK II-INS	N-16	V	AUTONETICS	4-GIMBAL	2	G-9	2	UM-8	D	D26J	LT HOOTEN	1965		
921	INERTIAL NAVIGATOR	LN-15	V	LITTON	4-GIMBAL	2	G-300G	2	A-200D	D	C-220	CAPT SORENSEN	1966	AD379888L	(U)
663	INERTIAL NAVIGATOR	PACE II	D	MIT	4-GIMBAL	3	2FBG-9F	3	16 PIGA G	D	VERDAN	CAPT ROROHA	1967	AD389179L	(C)
5201	LOW-COST INERTIAL	LOCATING	D	AFAL	4-GIMBAL	2	GYROFLEX	2	AUTONETICS/ KEARFOTT	D	NORTRONICS	MR JOHNSON	1967	AD810629L	(U)
698DF	STRAPDOWN INERTIAL	SIGN-III	V	HONEYWELL	STRAPDOWN	3	GG-334A	3	GG-177	D	HDC-501M	CAPT ROROHA	1968	AD503083	(C)
688G	INERTIAL NAVIGATOR	LTN-51	V	LITTON	4-GIMBAL	2	G-1	2	A-1	D	LC-720	MR JOHNSON	1968	AD507674L	(C)
8222	FLIGHT REFERENCE	FRSS	D,V	TELEDYNE	4-GIMBAL	2	TELEDYNE AIR BEARING	3	SINGLE AXIS	D	DDA	MAJ ULSHAFER	1968	AD843543L	(U)
921B	INERTIAL NAVIGATOR	P3C	V	KEARFOTT	3-GIMBAL	2	MOD II GYROFLEX	1	KEARFOTT 2414	D		CAPT KUROWSKI	1968	AD844809L	(U)
410A	INERTIAL DOPPLER	C-5A	D,V	NORTRONICS	FLOATED BALL	3	G1-K7G	3	KEARFOTT 2401	D	NDC-1051A	CAPT SORENSEN	1968	AD867681L	(U)
140A	CARRIER ACFT EQUIPMENT	SRAM(LN-15S)	D,V	BOEING/ LITTON	3-GIMBAL	2	G-300G2	3	A-200D	D	AUTONETICS	CAPT WOOD	1968	AD516448L	(S)
140A	AIRBORNE VEHICLE EQUIPMENT	SRAM	D	BOEING/GPI	4-GIMBAL	2	MOD-017 GYROFLEX	2	2401 & 2414	D		CAPT WOOD	1968	AD507564	(S)
139A	AMSA-INS	ASN-47	D	A-C	4-GIMBAL	3	1-AC 641G 2-AC 642G	3	2-GG 177B 1-4319	D	MAGIC 331	CAPT WETTERSTROM	1968	AD395066L	(S)

Table I Continued

PRO-GRAM	TYPE OF SYSTEM	SHORT TITLE	TEST CODE	CONTRACTOR	TYPE OF PLATFORM	GYROS NR	GYROS TYPE	ACCELEROMETERS NR	ACCELEROMETERS TYPE	TYPE OF COMPUTER A=Analog D=Digital		TEST ENGINEER	TEST START	DDC ACQ NUMBER	
139A	AMSA-INS	N-16	D	AUTONETICS	3-GIMBAL	2	G-9	3	UM-8	D	MARDAN	CAPT SORENSEN	1968	AD395066L	(S)
139A	AMSA-INS	LCI	D	GPI	4-GIMBAL	3	ALPHA III	1	2414	D	L-90-1C	MR MOYER	1968	"	(S)
69DF	CLOSE AIR SUPPORT SYSTEM	CLASS	D,V	LITTON	4-GIMBAL	2	G-300G2	3	A-200D	D	LC-728	CAPT HACKFORD	1970	AD516783L	(C)
69DF	INERTIAL NAVIGATOR	CAROUSEL IV	V	A-C	4-GIMBAL	3	AC-651G	3	AC-653A	D	MAGIC III	CAPT HEASLEY	1970	AD886564L	(U)
688G	STRAPDOWN KALMAN INERTIAL DOPPLER	SKIDS	V ,D	HONEYWELL	STRAPDOWN	3	GG-334A9	3	DGG-177	D	D201M	CAPT ROSE	1970	AD884579L	(U)
69DF	INERTIAL NAVIGATOR	CAROUSEL VM	V	A-C	4-GIMBAL	3	ZC-651G	3	AC-653A	D	MAGIC III	CAPT HEASLEY	1970	AD886564L	(U)
666A	DOPPLER INERTIAL LORAN	DILS(LN-30)	D	LITTON	4-GIMBAL	2	G-1200	3	A-1000	D	LC-728	MR JOHNSON	1970	AD519289L	(C)
328A	INERTIAL NAVIGATOR	F-15 INS ASN-109	D,V	LITTON	4-GIMBAL	2	G-1200	3	A-1000	D	DDA	CAPT HEASLEY	1971	AD892275L	(U)
666A	GIMBALLED ELECTRO STATIC GYRO INS	GEANS AN/ASN-101	D	HONEYWELL	4-GIMBAL	2	ESG	3	DGG-177	D	DBG 8196A1	LT GNIADY	1971	AD523446L	(C)
1559	INERTIAL NAVIGATOR	LN-12	V	LITTON	4-GIMBAL	2	G-200	3	A-2000	A	ASN 63 ASN 56	LT KING	1971	AD525467L	(U)
688G	INERTIAL NAVIGATOR	INS-61	V	KEARFOTT & COLLINS	4-GIMBAL	2	GYROFLEX KT-7E	2	KEARFOTT 2401	D	DDA	CAPT MOORE	1971	AD900352L	(U)
688G	INERTIAL NAVIGATOR	F-15 INS ASN-109 HELICOPTER	V	LITTON	4-GIMBAL	2	G-1200	3	A-1000	D	DDA	CAPT HEASLEY	1971	AD894139L	(U)
688G	INERTIAL NAVIGATOR	SKN-2400	V	SINGER-KEARFOTT	4-GIMBAL	2	SKG-2900	3	SKA-2900	D	SKC-3000	CAPT KING	1973	ADB005811L	(U)
688G	CIRIS	CAINS	V	LITTON	3-GIMBAL	2	G-300G2	3	A-2000	D	LC 728	CAPT BRINKER MR PEARSON	1973		(U)
666A	GIMBALLED ELECTRO STATIC GYRO INS	GEANS AN/ASN-101	D	HONEYWELL	4-GIMBAL	2	ESG	3	DGG-177	D	HDC-601	CAPT MONTGOMERY	1974	ADC001025	(C)
139A	DOPPLER-INERTIAL NAVIGATION SYSTEM	B-1(LN-15S)	D	BOEING/LITTONS SINGER-KEAR	3-GIMBALL	2	G-300G2	3	A200D	D	SKC-2070	MR PRESTON	1974		
688G	INERTIAL NAVIGATOR	LN-37	V	LITTON	4-GIMBAL	2	G-1200	3	A-1000	D	LC-4516	CAPT King	1974	ADB009271L	
666A	INERTIAL NAVIGATOR	N-57A-2	D	AUTONETICS	STRAPDOWN	2	MESG	3	EMA	D	D-216	CAPT PAYNE	1974	ADB009155L	
688G	INERTIAL NAVIGATOR	SKN-3000	V*	SINGER-KEARFOTT	STRAPDOWN	2	HYREX II	3	SKA-2900	D	SKC-3000	CAPT RITCHEY	1975		
688G	INERTIAL NAVIGATOR	HSDN-1020	V*	HAMILTON STD	STRAPDOWN	3	RI-1010	3	SUNDSTRAND Q-FLEX	D	AIDS	LT HAAS	1975		

Table I Continued

PROGRAM	TYPE OF SYSTEM	SHORT TITLE	TEST CODE	CONTRACTOR	TYPE OF PLATFORM	GYROS NR	GYROS TYPE	ACCELEROMETERS NR	ACCELEROMETERS TYPE	TYPE OF COMPUTER A=ANALOG	TYPE OF COMPUTER D=DIGITAL	TEST ENGINEER	TEST START	DDC ACQ NUMBER
688G	INERTIAL NAVIGATOR	LN-40	V*	LITTON	4-GIMBAL	2	G-4	2	A-4	D	LC-516	LT HAAS	1975	
688G	INERTIAL NAVIGATOR	LTN-72	V	LITTON	4-GIMBAL	2	G-2	3	A-2	D	C-4000	LT HAAS	1975	ADB009156L
666A	INERTIAL NAVIGATOR	LINS	D	HONEYWELL	STRAPDOWN	3	LASER GG1300AB04	3	SYS-DON 4841F-10	D	HDC-301A	CAPT PAYNE	1975	ADB008929L
670B	MISSILE INERTIAL NAVIGATOR	RACG	D*	SPERRY	STRAPDOWN	3	LASER 8000 SERIES	3	SUNDSTRAND Q-FLEX	D	DELCO MAGIC 362	CAPT RITCHEY	1975	

C. Potential:

A verification test program minimizes the risks of using newly developed inertial navigation systems. Evaluation of such systems at the CIGTF permits an assessment of performance and operational suitability. The resulting test reports are made available to the appropriate DOD agencies by direct and Defense Documentation Center distribution, thus providing data for the offices responsible for navigation avionics programs. Within the DOD, the Aircraft Navigation System Verification Program (Program 688G) provides for verification of systems other than those already selected for a specific aircraft application.

D. Organization:

The CIGTF with the support of other Test Group agencies and several test ranges provides the capability for complete test and performance evaluation of inertial navigation systems. This permits unbiased performance evaluation under conditions closely simulating an operational environment at a cost less than contractor testing.

The CIGTF manages the overall program during these tests. In addition to identifying resource requirements and preparing test plans and program documentation, the CIGTF performs laboratory tests, maintains all instrumentation support equipment, including the Completely Integrated Reference Instrumentation System (CIRIS), operates an extensive analog and digital computation facility for the reduction of test data, completely analyzes the test data, and prepares engineering and analysis reports.

The Aeronautical Test Division maintains and modifies the aircraft palletized testbeds on which test systems are flown (see Appendix C). In addition the Test Operations Branch of the Aeronautical Test Division is responsible for the operational conduct of the flight test programs in accordance with the test plans published by the CIGTF, and this test planning document.

The Test Track Division operates the 50,000 foot high-speed test track used to provide high vibration and acceleration environments. Ballistic missile inertial guidance systems and components have been tested in this environment. Although track testing is not normally required for aircraft navigation systems, it is available for special tests.

II. TEST OBJECTIVES

A. Philosophy:

A well-planned system development program will include testing from the component (gyros and accelerometer) level through system verification. Inertial instruments should be tested and evaluated on a component basis early in the program. These tests may reveal design deficiencies or performance characteristics which make the instruments unsuitable. Naturally, such findings must be made early so that redesign selections or substitutions do not delay the overall system development.

Similarly, developmental testing at system level in static and dynamic environments should be concluded before production plans are formalized. Finally, verification testing should be completed before the system is procured. This will insure that the best system is chosen for the application. Component testing of gyros, accelerometers and astro trackers is discussed in Appendix J along with system environmental tests. Developmental flight testing may take many forms, and test programs are usually tailored to meet special objectives. However, verification testing techniques and procedures are applied wherever feasible.

B. Types of Tests:

Flight test programs are divided into two categories: developmental programs and verification programs. Developmental tests of early prototype equipment provides information for design improvement and performance evaluation. Verification tests are performed on systems which are well along in the development cycle and which have normally undergone some previous dynamic testing. This document discusses primarily system verification tests; however, many of the concepts apply equally to developmental tests. It is Test Group policy to allow as much flexibility as possible on developmental programs, while following basic verification testing procedures as closely as seems reasonable.

C. Test Objectives:

The principal goal of a verification program is to provide a fair, impartial, and rigorous system evaluation under standardized conditions. The program determines the navigation performance and operational suitability of the navigation system through a series of ground and flight tests. The standardized test conditions correspond as closely as possible to those expected operationally. Strengths and weakness of the systems are identified. Other government agencies may use this information to compare systems of the same type and to choose the best system for new avionics applications.

D. Standard Test Phases:

The basic verification program for an inertial navigation system is outlined in Table II. It consists of four phases: Pre-delivery, ground, transport, and intended mission application test phases. Each system must advance through each of these phases in the above order. Systems intended for several potential applications may require testing in all three aircraft testbeds.

The basic program outlined in Table II is the minimum required to verify the primary alignment and navigation mode of the inertial navigation system. It is assumed that one alignment and navigation mode will be identified as primary. The objective of the verification is to establish a level of statistical confidence in the performance of the system for its primary operating mode in a typical operational environment.

TABLE II

BASIC VERIFICATION TEST OUTLINE

PHASE 0

Predelivery Ground Tests
2 - Static Nav Tests

PHASE I-A

I-A Standard Ground Tests
1-3 Functional Checkout Tests
2 Static NAV Tests
3 Scorsby Tests
1 Heading Sensitivity Tests

PHASE I-B

I-B Special Ground Tests
0-3 Special Analysis Tests
0-3 Special Application Tests

TOTALS:
7-15 Tests
4-8 Weeks

PHASE II

II Standard NC-141A Flight Tests
1-2 Functional Checkout Flights
6 West 84 Min Cruise Profile and Return
6 North 84 Min Cruise Profile and Return
3 East 84 Min Cruise Profile and Return
1-2 Terminate at a Distant Point/R.O.N./& Return
0-3 Special Analysis

TOTALS:
17-22 Flights
54-72 Flying Hours
8-12 Weeks

PHASE III

SPECIAL MISSION APPLICATION FLIGHT TEST PHASE

PHASE III

III-A UH-1H Helicopter Flight Tests
1-2 Functional Checkout Flights
6 East 42 Min Cruise Profiles and Return
6 North 42 Min Cruise Profiles and Return
6 East Terrain Mapping Missions
0-6 Special Analysis Flights

TOTALS:
19-26 Flights
29-39 Flying Hours
8-10 Weeks

PHASE III

III-B RF-4C Fighter Flight Tests
1-2 Functional Checkout Flights
6 West 42 Min Cruise Profiles and Return
6 West 42 Min Cruise/Simulate Ordnance Delivery Profiles and Return
6 West 42 Min Cruise/Simulate Air Combat Maneuvers and Return
2-4 Special Analysis Flights

TOTALS:
21-24 Flights
36-41 Flying Hours
8-12 Weeks

PHASE III

III-C Extended NC-141A Cargo Flight Tests
0 Functional Checkout Flights
2-3 West/NW 168 Min Cruise Profiles & Return
2-3 East 168 Min Cruise Profiles & Return
1 East/SE/terminate at distant point/ R.O.N./& Return
0-3 Special Analysis Flights
2-3 North 168 Min Cruise Profiles & Return

TOTALS:
7-13 Flights
48-84 Flying Hours
5-9 Weeks

PROGRAM TOTALS:
69-97 Tests
115-218 Flying Hours
32-50 Weeks
8-12 Months

The principal goal of a developmental program is to provide information for design improvement and evaluate test system performance. This is accomplished by subjecting the test specimen to the same operational test conditions and controls as those faced by verification test programs. By following the basic verification test outline and general test procedures as closely as possible, we insure basic day-to-day operational compatibility between developmental and verification flight test programs. Developmental programs are normally flown on the cargo aircraft only, and are flown on the helicopter and/or fighter aircraft only after demonstrating a potential capability for these aircraft. Again, it is Test Group policy to follow verification procedure on developmental programs where possible, and allow flexibility where obviously required.

III. TEST PROCEDURES

A. Test Definitions:

1. Only declared tests will be considered by the Air Force for evaluation. A test will not be declared unless the system and instrumentation are ready, and it will not commence until test objectives are established.

2. All declared tests will be classified as valid or invalid. As the term implies, an invalid test yields no useful performance information and will not be evaluated. (Invalid tests will not be counted in fulfilling the required number of tests as listed in the test outline.) The reasons for such an invalid test include:

a. System operator error.

b. Occurrence of some incident beyond control of the system: i.e., power failure.

c. Errors in the system computer program that seriously affect system operation or performance.

d. Failure of the test instrumentation or other testbed support equipment.

e. The system must be ready to navigate in 20 minutes or less after initial turn on for a valid test to be completed. Furthermore, the system must not have had power on for at least two hours prior to the start of the test.

3. Valid tests are further divided into two categories: data tests and no data tests. A test must meet the following criteria to be considered a valid data test:

a. The system must operate for at least 80% of the planned test time. Time is counted from switching to Navigate Mode.

b. The results must be representative of system nominal performance. For example, a test in which a significant identifiable system malfunction occurs will not be considered a data test. However, if maintenance or calibration is required the malfunction will be classified as a system failure.

c. The test engineer and system analyst must agree on adequacy and fulfillment of test procedures. CIGTF engineering judgement will be the final deciding factor in cases which are not clearly defined in items a and b above.

3. Reaction time is defined as the total time from turn on required for a system to complete alignment and go to the navigation mode. The maximum reaction time allowed is 20 minutes (unless a special waiver is granted) and once a characteristic system reaction time has been specified, it will be used on all declared tests.

B. Test Conduct:

1. A fair and valid verification test program can be conducted only by adhering to the following strict test discipline. The system will be calibrated and tested solely by Test Operations Branch (ATO) personnel. Also, Test Group personnel will determine the validity and usability of test data, and resolve all day-to-day operational test problems. This will include all test scheduling and declaring whether the system is ready for test or out for maintenance. All necessary maintenance and repair of the system and its support equipment will be controlled by ATO personnel. (See Appendix G for contractor field service and maintenance support requirements.) Additional shakedown flights will be permitted at the discretion of the Test Director, if extensive system repairs or modifications are required at the conclusion of the scheduled shakedown flights.

2. A complete record will be kept of pertinent data such as system operating time, reaction times, system maintenance, and any special modifications to system configuration. Table III depicts a typical Test System Maintenance and Repair Log. Detailed operating and checkout procedures and test schedules will be established prior to each test. These include:

a. System operation and calibration instructions.

b. Signal conditioning and instrumentation checkout and calibration.

c. Integration checks.

d. Master checklists for all flight operations.

C. Phase Advancement Criteria:

1. The results of the valid tests during each phase will be the fundamental basis for allowing the test program to proceed during a phase, and for allowing advancements to the next phase.

TABLE III

TYPICAL TEST SYSTEM

MAINTENANCE AND REPAIR LOG - SYSTEM NO. 1

Date of Occurrence	Occurrence Number	System E.T.I.* at Occurrence	Required Contractor Trouble-shooting Time (Hr)	Time Required to Accomplish Corrective Action (Hr)	Discrepancy/ Symptoms	Corrective Action	Major Component	System Chargeable Reliability Failure Numbers	System Operating Time Since Last Failure	Remarks
12 Feb 1976	0	1055	N/A	N/A	Initial installation and system checkout on C-141A pallet, S/N No. 71-0010	Installation accomplished	N/A	N/A	N/A	
28 Mar 1976	1	1115	23.0	0.5	Nav attr failure and DS-7 (P/E) bite. Protective aluminum metal tape on inner gyro shroud came unglued causing mechanical interference.	Recement a gyro thermister wire to the gyro shroud to eliminate mechanical interference within the platform cover.	INU	N/A	N/A	Test #10017 on C-141A/ 776. Problem occurred shortly after T.O. on 1st cargo flight. CAUSE: Workmanship error.
11 Apr	2	1139	25.0	0.5	Nav attr failure and DS-7 (P/E) bite. Excessive 400 Hz noise levels on pitch and roll gyro pickoffs triggering INU BITE flag due to reduced reserve torquing capability.	Reduce amount of noise being "picked up" on the gyro pickoff leads by adding two jumpers to the platform electronics card and filtering out at least 6 db of excessive noise level.	INU	N/A	N/A	Test #1C025 on C-141A/ 776. System failed shortly after T.O. on cargo Flt #4. CAUSE: Design inadequacy.

* E. T. I = Elapsed Time Indicator

2. To advance to Phase II, the system must successfully complete the required tests in Phase I (Table II). The last two consecutive Scorsby tests must be valid data tests, and the system indicated radial position error must be below a 3 nautical mile per hour envelope shown in Figure 1.

3. Phase II contains the aircraft integration portion of the NC-141A flight test program. During this phase, missions are flown to collect the data necessary for an analysis of the INS performance. The system passes into Phase III after successful completion of the Phase II tests outlined in Table II.

4. In Phase III the system must successfully complete a series of special application performance flights in the testbed(s) selected. The CEP of radial position error for the valid data flights of Phase III must not exceed a growth rate of three nautical miles per hour. The system CEP for Phase III will be determined from quick-look and reduced data as available at the completion of Phase III tests.

5. If the system repeatedly fails to meet any of the above criteria for advancement, the system may be recalibrated as required and the test repeated. Should it be determined at any time during the test program that the system does not have sufficient merit to warrant further testing, the project will be terminated.

D. System Failure Criteria

Once a system starts undergoing testing, the following guidelines will define successful and/or unsuccessful system operation:

1. Every time the system is turned on for a test run, a standard alignment cycle will be followed, and the system must be ready to navigate in 20 minutes or less.

2. During any test run the radial error growth rate must not exceed 3 nm/hr from NAV.

3. The test system must navigate for 100 percent of every test mission, unless shutdown is accomplished due to and as a protection against external disturbances such as excessive heat, power fluctuations, etc. Test Group engineering judgement will be exercised and final in all cases.

E. System Calibration:

Under military operational conditions, avionics maintenance personnel will not have the benefit of error plots of previous flights to evaluate the adequacy of either the autocompensation or fixed IMU calibration factors. Also, they will not be able to calibrate on a flight-to-flight basis or to run numerous static tests. On the other hand, multiple systems are not available for CIGTF tests and it must be assured that performance results are not strongly influenced by poor system calibration. Therefore, the following general guidelines apply:

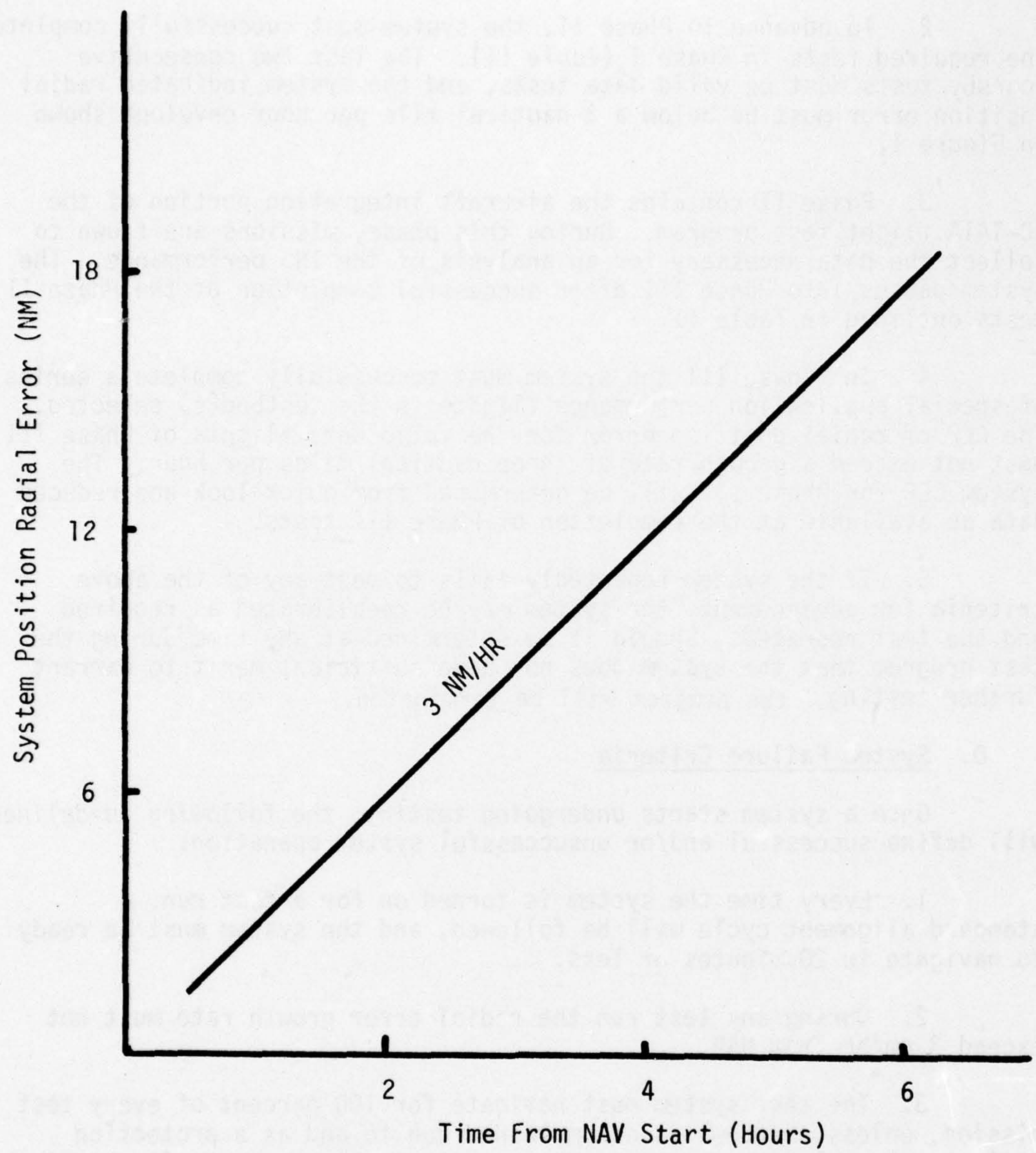


FIGURE 1

ERROR ENVELOPE FOR STATIC, SCORSBY AND FLIGHT TESTS

1. All calibrations will be performed under the control of the test engineer.

2. If available, the contractor's formalized operational procedures and schedules for calibrations will be followed insofar as is considered appropriate and feasible by the test engineer.

3. Performance data from flight navigation tests will not be used as a basis for changing inertial sensor compensation values. Changes to compensation constants will be derived only from calibrations performed within the guidelines of this section.

4. System calibrations may be performed before or after the checkout flights at the beginning of each flight test phase at the discretion of CIGTF Test Director. However, data obtained from the shakedown flight(s) may not be used to change inertial instrument constants.

5. If a major IMU malfunction occurs (e.g., an inertial component must be replaced) a system calibration will be permitted. If this occurs during the performance flight test segments of Phases II or III, additional ground tests or checkout flights may be conducted to assure correction of the malfunction.

F. System Substitutions and Repair:

1. The primary purpose of verification testing is to evaluate the performance and operational suitability of the test system, or systems, as accurately as possible in a minimum amount of time. It is also Test Group policy to gather as much maintainability and reliability information as can be obtained during this test process. Consequently, the Test Group exercises strict control over verification test systems configurations. Multiple substitutions are avoided whenever possible, and repair or replacement of minor subcomponents is preferred to major component substitutions.

2. Developmental test policies are not nearly as strict and efforts are primarily confined to maintaining correct documentation.

G. Flight Test Instrumentation and Data Collection:

1. Instrumentation for any given project will depend to a large extent on the type, quantity and accuracy of data required.

2. System data will ordinarily be recorded on magnetic tape. On some projects, however, paper tape or even manual recording may be employed. The type of data collected may be separeted into two categories. The first category is that required to determine quantitatively the system accuracy. Typically position, velocity, and attitude data are of interest. The second category is that required for analysis and troubleshooting the system. Data recorded for analysis purposes may be rather extensive for complex systems and may include any data available, internal or external to the inertial navigation system, which might aid in isolating individual system error sources.

3. In-flight reference data is ordinarily obtained from FPS-16 radars, cinetheodolites, DOVAP, onboard vertical cameras, or CIRIS. Table IV lists typical position, velocity and attitude accuracies and coverage available from these sources. Appendix D contains additional information on typical system and reference instrumentation.

4. The CIGTF recently accomplished a highly significant increase in the C-141 in-flight reference capability with the development of the Completely Integrated Reference Instrumentation System (CIRIS) (See Appendix I).

IV. PRE-DELIVERY GROUND TEST (PHASE 0)

A. Purpose:

The purpose of this test is to obtain a confidence that the system to be delivered to Holloman Air Force Base will function within the limits required. This test is designed as a functional check to be performed at the Contractor's facility prior to delivery to Holloman Air Force Base.

B. Test Objectives:

To determine the system's capability to function as an aircraft navigation system with respect to reaction time, accuracy, and test suitability.

C. Test Procedure:

1. The system will not have been operated for at least two hours prior to this test.

2. At laboratory ambient temperature, power will be applied to the system and the system will be sequenced to the navigate ready mode. This time period will be recorded.

3. The system is then placed in the navigate mode at Time T-00.

4. Present position latitude and longitude as displayed on the control panel will be recorded every five minutes starting from Time T-00.

5. A plot of radial error in nautical miles versus time will be made.

6. The test will extend for four (4) hours from the time the system was sequenced to navigate (T-00) or until the radial error exceeds the specified limit.

7. The above test will be repeated until two successful four-hour tests are achieved in a row.

8. The system will be mounted in the rack designed for the flight test (except for the control/display unit which may be separately

TABLE IV

REFERENCE SYSTEMS AND TYPICAL ACCURACIES AVAILABLE

	Checkpoint	Radar	Cine	DOVAP	CIRIS
Position (ft)	100-500	50-200	15-25	N/A	13
Velocity (ft/sec)	N/A	2-10	0.5-1	.3	.1
Attitude (min)	N/A	N/A	N/A	N/A	3
Data Available	2-5 days	1 week	6 weeks	1 week	Real Time
Weather Affects	Yes	No	Yes	No	No
Coverage Time (min)					
N-S Direction	>84	42	6	6	>84
E-W Direction	>84	84	4	4	>84

mounted but electrically connected to the rack for the accomplishment of the above tests.

D. Requirements:

1. The above tests must be witnessed by Air Force personnel.

2. The reaction time demonstrated in the laboratory tests shall not be greater than twenty (20) minutes for systems undergoing verification testing.

3. The demonstrated system performance in radial error shall not exceed, after the first 15 minutes, a line representing 3 nm/hr.

V. GROUND TEST PROCEDURES (PHASE I)

A. Initial Installation:

The purpose of Phase I is to insure that the test system is in a satisfactory operational condition after shipment to Holloman AFB and prior to entering the cargo flight test phase. During this phase initial system and instrumentation equipment installations are accomplished on the selected C-141 testbed pallet, and appropriate Class II modification documentation is started. The sequence of events is as follows:

1. The system and interconnecting cabling will be inspected to detect possible damage from shipment. The complete test system, cabling, and mounting plate or rack will be weighed and then mounted on the C-141 testbed pallet.

2. All system components will be inventoried and recorded by serial number. Elapsed Time Indicator (ETI) readings will be taken and recorded. Power on procedures will be determined. Appropriate check-lists and test summary data sheets will be constructed. After assignment of first standard test label (i.e., 1LC001-Sys), the system will be functionally checked on the C-141 testbed pallet.

3. Flight test instrumentation will be installed on the testbed pallet and connected to the test system. System outputs will be recorded on the magnetic tape recorder, and the resulting test tape will be delivered to the CIGTF for checkout of the data recording and reduction procedures.

4. After successful completion of the above steps, the system is ready to start the Standard Ground Test Series.

B. Test Procedures and Controls

1. All test, analysis, and evaluation functions are performed by Air Force personnel. The on site contractor field engineering personnel perform maintenance and repair functions only as directed by the test engineer, and report on actions taken and time required for such actions. Officers with graduate engineering degrees act as test engineers

and analysts, and Air Force technicians qualified in the guidance and control field maintain (with contractor technical support) and operate the systems.

2. Normally a two week training course, to be conducted by the contractor, will be required for each system prior to initiation of verification testing. The course content will cover a technical description of the system, including a survey of the developer's error analysis. Detailed instruction on hardware operation and malfunction detection isolation and correction will also be included. Attendance of this course is requisite for operation of the system on the ground and in the test aircraft.

3. Rigid control of test conditions is maintained at all times in order to insure that the resulting data will be a valid representation of characteristic system performance. Proper documentation and control allow some limited Reliability Analysis to be accomplished at the completion of the test program. Reliability testing techniques apply.

4. Reaction time, defined as total time from Power On to Navigate, will be monitored and controlled on all navigation runs. It should be noted that all tests will be conducted with identical reaction times, and that the reaction time utilized will usually be the system optimal reaction time recommended by the contractor.

5. To preclude the possibility of an inoperable navigation system remaining at the CIGTF for an extended period of time, an upper limit of 30 days will be allowed for return of the system to the test program after it has been withdrawn for maintenance or repair of any type. After this 30 day period, at the option of the Air Force, the system will be returned to the contractor's facility and will not be returned to Holloman until the difficulty is corrected.

C. Standard Ground Test Series:

1. All navigation systems undergoing verification testing will be subjected to a ground test series. Initial checkout testing will be accomplished at the Test Operations Branch. Note that Phase I tests can also be used in a competitive evaluation to disqualify those competing systems found to have insufficient accuracy to justify entry into flight tests of Phases II and III.

2. For preflight evaluation of system accuracy, the system will normally be operated for two 6-hour static navigation runs and three 6-hour Scorsby runs (See Figure 2). These runs will be performed with the system at nominal ambient temperatures. If necessary, platform cool down will be accelerated with refrigerated air. The Scorsby rate will be six cycles per minute at $\pm 3^{o}$ amplitude (6^{o} peak-to-peak swing). During one of the static tests and one of the Scorsby tests the system will be rotated to the four cardinal headings, at intervals of 84 minutes. During the Scorsby tests, the table amplitude will be gradually reduced to zero prior to turning the system to a new heading and then gradually increased back to $\pm 3^{o}$. Turning rate will approximate an aircraft turn rate of about 180 degrees/minute.

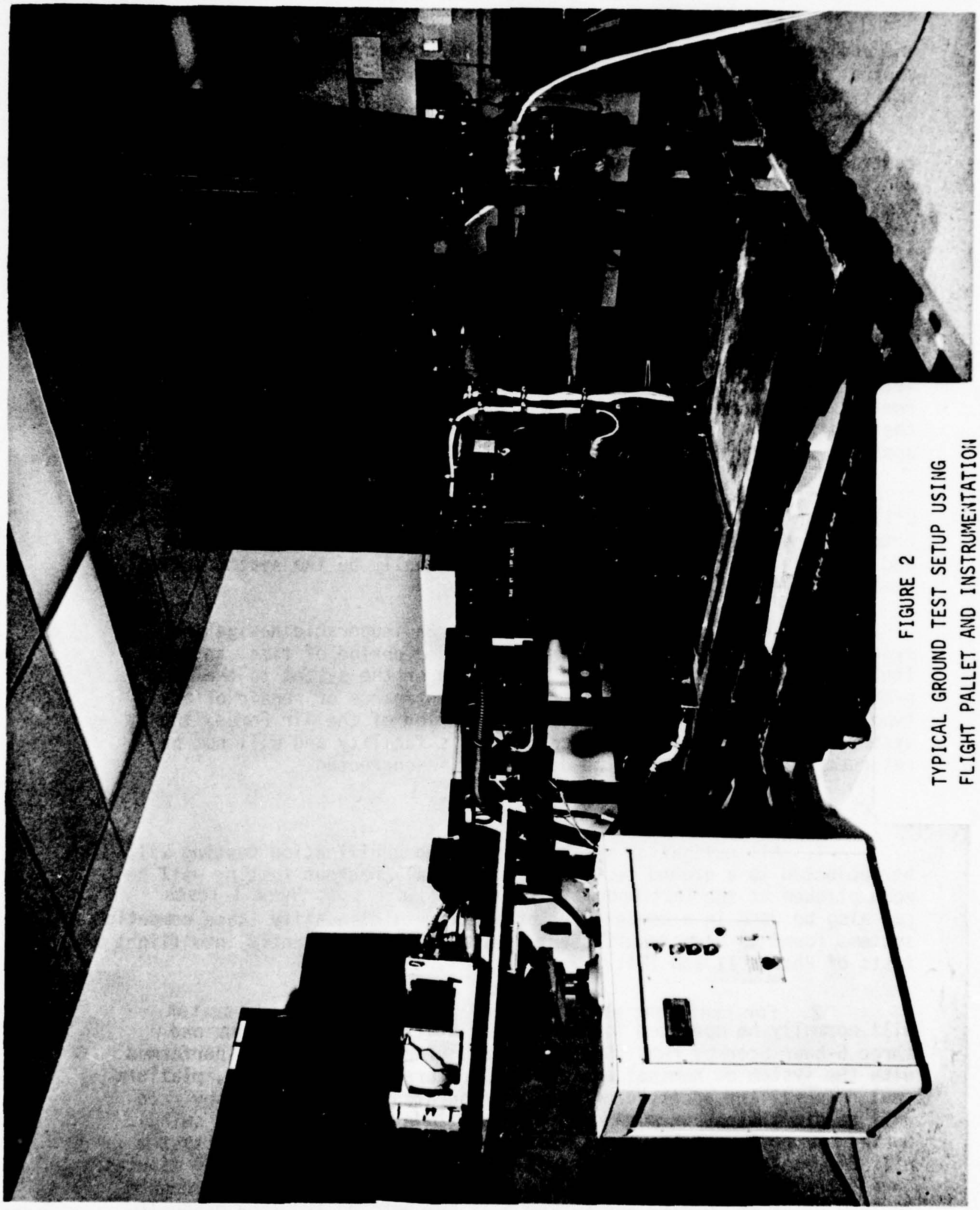


FIGURE 2

TYPICAL GROUND TEST SETUP USING FLIGHT PALLET AND INSTRUMENTATION

3. The heading sensitivity test described in the paragraph above will be complemented by a second form of heading sensitivity test for comparison purpose. This test will consist of 84-minute static runs at each of the four cardinal headings, with each cardinal run being preceded by a 20-minute realignment with the platform pointed northward. The initial alignment will follow a warmup period sufficient to preclude the effects of temperature transients.

D. Phase Advancement:

System performance as determined from the ground demonstration navigation runs will be compared with the criteria specified for advancement to the flight testing of Phase II. If the results are acceptable, Phase II testing will commence.

VI. CARGO TEST PROCEDURES (PHASES II AND III-C)

A. Class II Modification Acceptance:

1. Prior to initiation of the cargo test phase the C-141 palletized testbed (Figure 3) on which flight testing is to take place must satisfy a quality control inspection, IAW AFSCR 80-33. This regulation relates to documentation, operational procedures, and physical compliance with the documentation.

2. The project pallet will be installed in the NC-141A testbed, and power and signal interfaces will be verified. The system will be aligned and navigated in the aircraft during a 15-minute taxi test and a 90-minute post-taxi test, if deemed necessary by the project engineer and/or analyst. The system outputs will be examined and the tape will be sent to the analyst for reduction.

B. Test Procedures and Controls:

1. The flight test portion of this phase will begin with a limited number of checkout flights. When the data recording and system performance are acceptable, performance testing will commence.

2. Insofar as is possible each declared test attempted will have uniformity in the following parameters:

a. C-141 pallet-to-aircraft interface.

b. Reaction time.

c. Initial heading when starting alignment.

d. Pre-flight data period.

e. Taxi profiles.

f. Flight profiles

g. Post-flight data period.

FIGURE 3

NC-141A/776 - THE CARGO TESTBED AIRCRAFT

h. Mission documentation techniques.

i. System and instrumentation configuration.

C. Standard Cargo Aircraft Test Series

1. Table II (Page 7) outlines the number of tests to be conducted during this phase of testing. The number of valid data flights required is a function of system configuration and operating modes, normally in the range of from 17 to 22 sorties.

2. On cruise missions the system navigation performance on different headings will be tested. The number of turns will be minimized though altitudes and air speeds may vary. Missions will usually be out and back profiles although at least two will terminate at locations over 500 miles distance from the takeoff point. Some missions will consist of North-South profiles, others will be West-East or East-West profiles.

3. Many systems will have more than a single alignment and navigation mode. In addition, a system may be intended for a unique operational flight profile which is not adequately considered in the basic test program. Consequently, the test program will sometimes include additional flights beyond the requirements of Table II.

a. Possible additions to the basic test program include:

(1) Flight tests in secondary alignment and navigation modes.

(2) Flight tests over water for doppler aided systems.

(3) Flight tests over unique operational flight profiles.

(4) Special analysis flights.

b. Time, funding, and the desired level of confidence in the test results will be the major considerations in determining the number of additional flights. The particular type of additional flights will depend upon the individual operational requirements of the system, and must be specified on a system-to-system basis.

4. The principal goal of the verification test program is to generate test data on different systems, but under nearly identical and controlled conditions, in order to facilitate a comparative analysis capability between the various test systems. This is accomplished by standardization and rigid control of all possible parameters. Consequently, additional or special flights are to be avoided on verification test programs.

D. Phase Advancement:

System performance as determined from the flight sorties flown will be compared with the criteria specified for advancement, and if the test system has a potential for possible helicopter or fighter applications, the system will advance to the next test phase. If the system has a potential application as a long duration navigator it will undergo extended cargo testing (Phase III-C) prior to advancing to helicopter or fighter test phases.

VII. HELICOPTER TEST PROCEDURES (PHASE III-A)

A. Class II Modification Acceptance:

1. Prior to initiation of the helicopter test phase, the helicopter testbed pallet on which testing is to take place must be modified IAW AFSCR 80-33 and pass quality control inspection.

2. The project pallet will be installed in the UH-1H testbed (Figure 4). Power and signal interfaces will be verified. Quality Control Inspection will be performed.

B. Test Procedures and Controls:

Insofar as is possible, each declared test attempted will have uniformity in the following parameters:

1. UH-1H pallet to aircraft interface.
2. Reaction time.
3. Initial heading when starting alignment.
4. Pre-flight data period.
5. Taxi profiles.
6. Flight profiles.
7. Post-flight data period.
8. Mission documentation procedures.
9. System and Instrumentation configuration.

C. Standard Helicopter Test Series:

Table II (Page 7) outlines the number of tests to be conducted during this phase of testing. The number of valid data flights required is a function of system configuration and operating modes, normally in the range of 19-26 sorties. See Appendix E for helicopter flight profiles.

D. Phase Advancement:

System performance as determined from the flight sorties flown will be compared with the criteria specified for advancement; and if the test system has a potential for possible fighter applications, the system will advance to the next test phase.

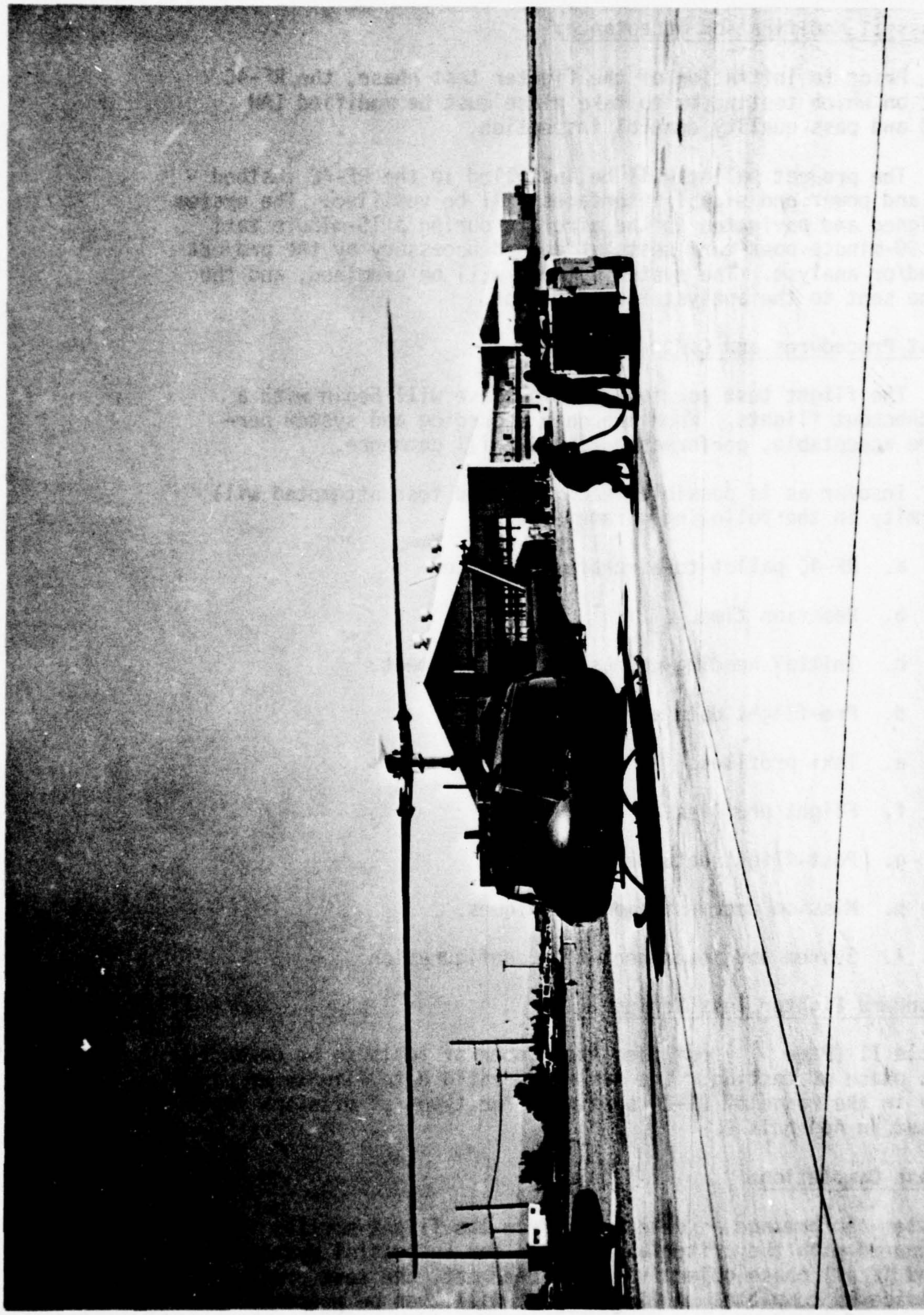


FIGURE 4
UH-1H HELICOPTER READY TO LAUNCH
TEST MISSION

VIII. FIGHTER TEST PROCEDURES (PHASE III-B)

A. Class II Modification Acceptance:

1. Prior to initiation of the fighter test phase, the RF-4C nose pallet on which testing is to take place must be modified IAW AFSCR 80-33 and pass quality control inspection.

2. The project pallet will be installed in the RF-4C testbed (Figure 5) and power and signal interfaces will be verified. The system will be aligned and navigated in the aircraft during a 15-minute taxi test and a 90-minute post-taxi test, if deemed necessary by the project engineer and/or analyst. The system outputs will be examined, and the tape will be sent to the analyst for reduction.

B. Test Procedures and Controls:

1. The flight test portion of this phase will begin with a number of checkout flights. When the data recording and system performance are acceptable, performance testing will commence.

2. Insofar as is possible, each declared test attempted will have uniformity in the following parameters:

   a. RF-4C pallet-to-aircraft interface.

   b. Reaction time.

   c. Initial heading when starting alignment.

   d. Pre-flight data period.

   e. Taxi profiles.

   f. Flight profiles.

   g. Post-flight data period.

   h. Mission documentation techniques.

   i. System and instrumentation configuration.

C. Standard Fighter Test Series:

Table II (Page 7) outlines the number of tests to be conducted during this phase of testing. The number of valid data flights required is normally in the range of 21-24 sorties. The types of missions flown are discussed in Appendix E.

D. Phase Completion:

System performance as determined from the flight sorties flown will be compared with the criteria specified for successful system performance;and if all phase objectives have been met, the test program will be considered complete. A final report will then be prepared.

FIGURE 5

RF-4C - FIGHTER TESTBED AIRCRAFT

IX. Data Reduction, Analysis and Reporting

All data are processed and controlled by Air Force personnel at the Central Inertial Guidance Test Facility except range tracking data which are processed by the US Army at White Sands Missile Range, New Mexico, Fort Huachuca, Arizona, and at the Space and Missile Center, California.

A. System Data Reduction:

1. Systems normally output data in digital form. The data are recorded on magnetic tapes making it possible to do the necessary processing directly using ground based computational equipment. If a system outputs data in analog form, these data are first digitized at the CIGTF prior to data reduction.

2. In either case, the contractor may be required to provide a buffer to permit proper interface between the system computer and data recording equipment. The importance of this buffer should not be overlooked; difficulties at the system/data recording interface could degrade or even prevent acquiring usable system data.

3. When radars or cinetheodolites are used as the position and velocity reference, system and reference data are normally compared at 10 second intervals. When a vertical camera is used for reference instrumentation, system position data are needed additionally at checkpoint times (usually every three to five minutes). *

4. The length of time required to reduce system data varies considerably depending on the method of data recording. Analog tapes usually require a week or more to digitize. Digital tapes may be placed directly on the land based computer for futher reduction. Hand recorded data are usually punched onto cards within one to two days for further reduction.

B. Reference Data Reduction:

1. During on-range flights, radar data are magnetically recorded at 10 or 20 frames per second. The data are thinned to one frame per second and a single station solution is used to find reference latitude, longitude, and MSL altitude. Cinetheodolite data are usually recorded at one frame per second. Film from two or more cinetheodolites are reduced using a multiple station solution to obtain reference latitude, longitude, and MSL altitude.

2. During off-range flights, aerial photographs are made of surveyed ground checkpoints. Miss distances are read from the film and added to checkpoint coordinates to obtain reference latitude and longitude.

* See Appendix I for a description of the CIGTF in-house developed CIRIS reference system.

3. The time required for reference data reduction is approximately as follows: 10 to 30 days for radar data, 20 to 40 days for cinetheodolite data, 2 to 5 days for photo data. The time required over and above the minimum quotes is primarily a function of the range workload and problems encountered in reducing the data.

C. Error Data Reduction

1. Position error information is obtained by computing the difference between system indicated data and reference data. Time synchronization is achieved by recording IRIG-B time with both system and reference data. Range reference time is derived from a master range timing station through land line and microwave relay. The system timing reference is recorded directly from an onboard IRIG-B time code generator. Using this method, a time synchronization within 1 millisecond between range reference data and system data is achieved.

2. During off range flights, system data are recorded as close to checkpoint photographs times as possible. Proper timing for error plots is accomplished in analysis and data processing.

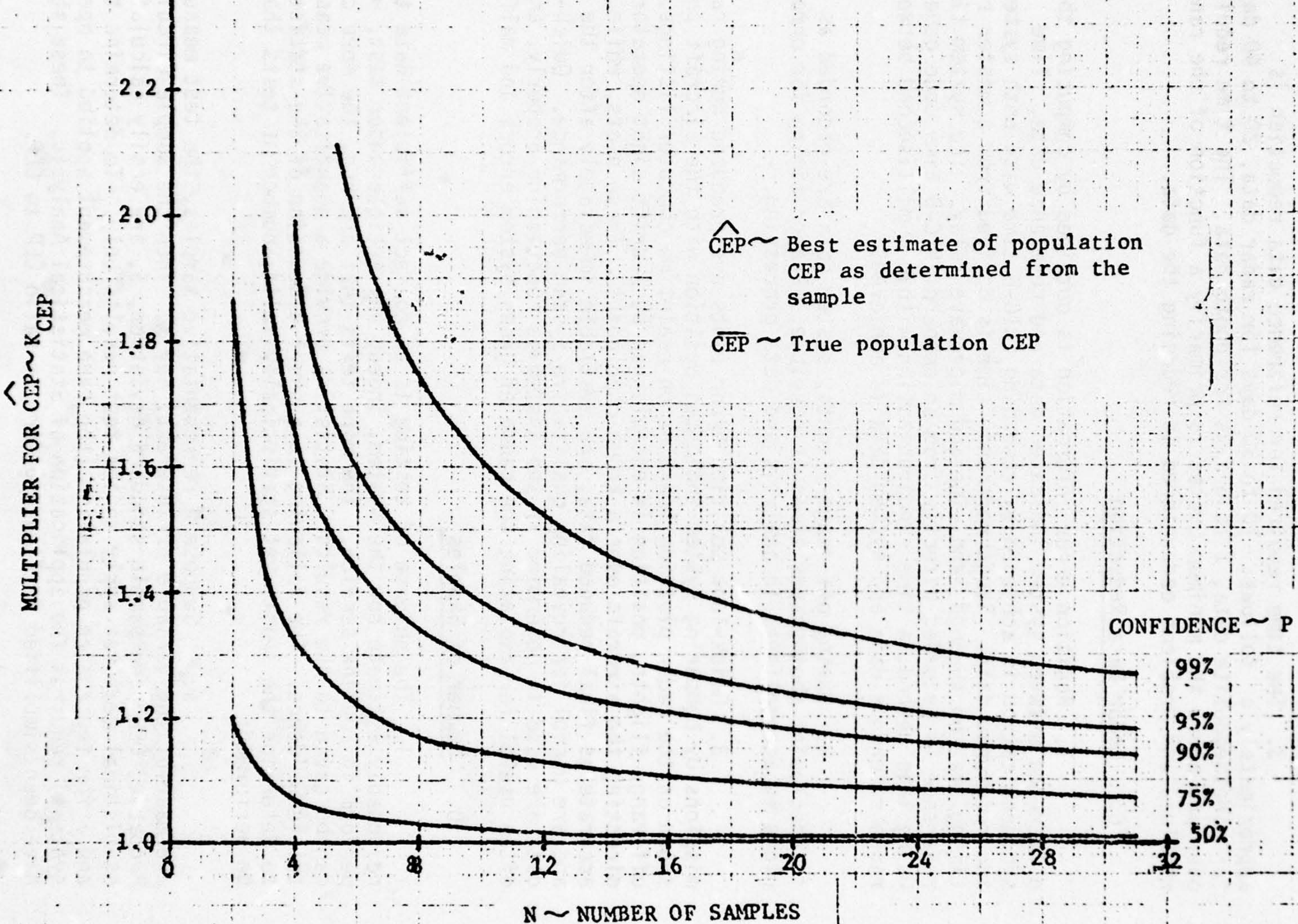
3. Quick-look position error plots are produced during radar missions by comparing system indicated position with the aircraft position shown on the radar plotting board or on real-time computer listings. During off-range flights, position is established by a drift sight operator directing the aircraft over a known checkpoint. These plots, while not as accurate as final reduced data, are available immediately after the flight and are useful for revealing qualitative system performance. Quick-look data are used to determine if the system is functioning properly, and is often useful for isolating the cause of gross system errors and malfunctions.

D. Number of Samples

1. The purpose of testing is to collect sufficient data to reasonably estimate how the system, indeed any article under test, will perform in routine service. The more tests that are run, the more confidence can be given to the results. Statistics provide a quantitative measure of this confidence. The following is a short discussion of the statistics used to determine the least, yet statistically valid, number of tests that should be performed:

a. Suppose N representative samples, the test measurements, are made of the variable of interest, say X. Then the sample Circular Error Probable, $\widehat{CEP}$, and sample standard deviation, S, are easily calculated. These statistical measures apply to the test results only. To determine the $\overline{CEP}$, and σ for the entire population (the same measurement applied to operational systems) requires the application of Statistical Analysis. These statistics have been simplified in Figure 6 for the ratio $\overline{CEP}$ to $\widehat{CEP}$.

FIG. 6 PROBABILITY (P) THAT $\overline{CEP}$ IS NO LARGER THAN K_{CEP} TIMES $\widehat{CEP}$.



b. Assume the same sample of N gives a value of $\widehat{CEP}$. From Figure 6, the value $\overline{CEP} \leq K_{CEP}\ \widehat{CEP}$ is determine to any level of confidence desired. For example, assume N = 6, $\widehat{CEP}$ = 1.0, then:

$\overline{CEP} \leq$ 1.04 with 50% confidence,
$\overline{CEP} \leq$ 1.22 with 75% confidence,
$\overline{CEP} \leq$ 1.60 with 95% confidence.

c. Furthermore, with N - 14 samples and $\widehat{CEP}$ = 1.0 (for simplicity, recognizing the computed CEP would probably change) Figure 6 gives:

$\overline{CEP} \leq$ 1.01 with 50% confidence,
$\overline{CEP} \leq$ 1.12 with 75% confidence,
$\overline{CEP} \leq$ 1.30 with 95% confidence.

d. Similar analysis can be applied to other measures of the sample statistics such as mean and standard deviation. However, each one has a separate confidence curve such as given in Figure 6 for CEP.

2. For good statistical confidence, a large number of samples should be used (20, 30 or more). In practice this would be prohibitive in cost and furthermore the "value" of additional tests (in terms of improved confidence) reduces rapidly as the number of tests increases. For these reasons and from the experience of many test programs, the rule of thumb has been adopted that six (6) samples are required for reasonable results This is tempered with cost and occasionally less samples will be accepted. Likewise, when the opportunity presents itself to collect additional data at minimum cost, more samples are used.

E. <u>Cumulative Radial Error Accuracy Results</u>

Cumulative radial error accuracy results will usually be derived by considering tests in different environments (static, Scorsby, C-141, RF-4C, or helicopter) as separate ensembles. Tests may be combined, however, if system performance is not significantly affected by different environments. For example, static and Scorsby tests may often be combined when making ensemble accuracy calculations. If more than one navigation or alignment mode is tested in the same environment, the tests in each individual mode will normally be considered as a separate ensemble.

2. Measures of performance calculated for inertial systems for ensembles of six or more tests include:

a. Mean and median errors.
b. 50th percentile (CEP), and 90th percentile error.
c. 85% confidence limits on the CEP.
d. Least squares position error rate (when meaningful).
e. RMS error (when meaningful).

These statistics will be calculated for position and velocity errors when sufficient data are available. Items a through c are calculated as a function of time, usually at 5 minute intervals. Items d and e are presented as single numbers when the statistics are meaningful. A least squares position error rate will ordinarily be presented only for pure inertial systems which have a position error growth which is nearly linear with time. The method to be used to calculate percentiles and confidence limits for radial* position and velocity errors is presented in Appendix F.

F. Estimation of System Error Sources

Error analysis will be focused on determining the principal sources of overall system position, velocity, and attitude errors. The technique used will depend upon the particular system mechanization. The extent of error analysis will depend on the time and manpower available to develop and implement the desired analysis.

G. Test Event Reports

Test data and preliminary test results will be available to the customer as soon as possible after each test. Normally, a quick-look error plot, to include any significant occurrences, is available immediately after each test event.

H. Data Packages

For test programs which require performance accuracy data to be released as soon as possible, data packages will be prepared two weeks after each phase of testing.

I. Final Report

1. After the completion of testing, a final report will be prepared. This will contain all results of the test program including the data presented previously in data packages. Information reported will customarily include:

* RSS of latitude and longitude channel errors.

a. Overall test program review.
b. Test objectives and procedures.
c. Physical characteristics of the system.
d. Performance accuracy results.
e. Error analysis results.
f. Operational suitability comments.
g. Data reduction and analysis techniques.
h. Test instrumentation.
i. Flight paths.

2. Position and velocity accuracy results will include plots of the following quantities as functions of time in the navigation mode:

a. For each flight - latitude, longitude, radial position and velocity errors.

b. Cumulative results -

(1) mean, median, 50th percentile (CEP) and 90th percentile of radial position and velocity errors;

(2) CEP and 85% confidence limits on the CEP of radial position and velocity errors;

(3) a composite of radial position and velocity errors for all valid data flights in each phase.

J. Data Distribution and Classification

1. Initial distribution of all data and test results will be controlled by CIGTF. Distribution lists (designated by the customer/CIGTF) will be contained in the specific system test plan. Contractor proprietary rights will be observed.

2. Test data and results will be accorded a security classification commensurate with the program and system under test.

X. RESPONSIBILITIES

A. 6585th Test Group

1. The 6585th Test Group, Guidance Test Division, Holloman Air Force Base, New Mexico, is the Responsible Development Organization (RDO) for Program 688G verification test programs and has primary responsibility for overall program management IAW AFR 80-14 and AFSC Supplement 1. The RDO for developmental test programs will be the customer. The Guidance Test Division:

a. Obtains the INS test specimens, ground equipment, and cabling required for testing from the contractor.

b. Obtains necessary documentation such as drawings, manuals, system descriptions, operation procedures, software descriptions, system limitations, etc., needed to plan, prepare, conduct tests and evaluate performance data.

c. Provides funds for reimbursable costs of the program.

2. The 6585th Test Group, Guidance Test Division, Holloman Air Force Base, New Mexico, IAW AFR 80-14 and AFSC Supplement 1, is also the Responsible Test Organization (RTO), and has the primary responsibility for planning and conducting this test project. The Guidance Test Division:

a. Provides a Test Director who will perform overall supervision of the entire test program to insure compliance with the Project Test Plan and this document. The Test Director serves as the point of contact between Test Group and outside agencies participating in the project.

b. Furnishes required equipment to record test data.

c. Provides a test analyst to analyze the test data and quantitatively evaluate system performance.

d. Coordinates the writing and publishing of the Final Report.

3. The 6585th Test Group, Aeronautical Test Division, Holloman Air Force Base, New Mexico, is the participating test organization and has primary responsibility for the actual conduct of the test program. The Aeronautical Test Division:

a. Provides a test engineer and guidance technicians to accomplish and perform detailed supervision of the tests.

b. Obtains White Sands Missile Range documentation to support the test project.

c. Prepares and maintains detailed documentation necessary to support the project: e.g., maintenance and repair logs, mission folders, aircraft schedule requests, Class II modification documentation, etc.

d. Provides at least one engineer and two technicians to each program and facilities for required maintenance and repair.

e. Maintains and modifies existing aircraft testbed pallets.

f. Defines any required aircraft testbed modification requirements to the appropriate agency.

B. Air Force Weapons Laboratory

The Air Force Weapons Laboratory (AD), Kirtland Air Force Base, New Mexico, provides the required computer center support for hardware (computer time, data link, etc.) and software (applications and programming).

C. 4950th Test Wing

The 4950th Test Wing, ASD, Wright-Patterson Air Force Base, Ohio, provides the following:

1. Maintenance support for the NC-141A testbed.

2. Procurement of necessary supplies and equipment for modification and maintenance support of the NC-141A testbed.

3. Aircrews to operate the NC-141A testbed.

D. Armament Development and Test Center (ADTC)

The Armament Development and Test Center (ADTC), Eglin Air Force Base, Florida, provides the following:

1. Maintenance support for the fighter aircraft testbed.

2. Procurement of necessary supplies and equipment for modification and maintenance support of fighter aircraft testbed.

3. Modification of fighter aircraft testbed IAW AFSWCR 80-33.

E. 3246th Test Wing

The 3246th Test Wing, Eglin Air Force Base, Florida, provides the following:

1. Engineering design, coordination, and approval of necessary Class II modifications to the fighter aircraft testbed.

2. A pilot to operate the fighter aircraft testbed.

F. USAF Range Operations Office

The USAF Range Operations Office, White Sands Missile Range, provides the interface between test ranges and the programs.

G. White Sands Missile Range

White Sands Missile Range, New Mexico, will be required for test range support. Details and coordination required is provided in WSMR National Range Documentation.

H. Customer

1. It is the responsibility of the customer to coordinate with the contractor to insure certain requirements are met. Many of the items listed below will be fulfilled by the contractor, but the CIGTF can levy responsibilities for these actions only on the customer.

2. The customer provides the test specimen, properly configured and documented for flight (See Appendix G) with proper signal buffering/ conditioning (See Appendix D). These items must be coordinated among the CIGTF, customer, and contractor.

3. The customer provides spares and contractor technical support. Usually one or two contractor personnel are required. These personnel do not fly during flight tests nor do they actively support ground tests.

4. The customer provides funds to cover the reimbursable program costs.

XI. SCHEDULE

A. Lead-Time Factors (preparation time before delivery):

The CIGTF requires approximately four to six months preparation time prior to delivery of a system to accomplish the following:

1. Modify the aircraft.

2. Develop data reduction programs.

3. Procure special test support equipment.

4. Document the program with Air Force Systems Command and supporting agencies.

5. Obtain training for project engineers, technicians and analysts at the contractor's plant on system technical and operating details. Normally a one or two week formal school is required.

6. Program aircraft and flying hour requirements.

7. Develop the specific system test plan.

B. System Flight Testing

A standardized verification test schedule is shown in Table II. The length of each phase and the general chronological sequence to be followed is indicated. It is anticipated that new cycles of the standardized test program will be initiated annually. Normally, an additional three months after completion of the last test flight will be required for data reduction and preparation of the final report.

APPENDIX A

FOSTER MEMO

DIRECTOR OF DEFENSE RESEARCH AND ENGINEERING
WASHINGTON, D. C. 20301

7 Apr 67

MEMORANDUM FOR THE ASSISTANT SECRETARY OF THE ARMY (R&D)
THE ASSISTANT SECRETARY OF THE NAVY (R&D)
THE ASSISTANT SECRETARY OF THE AIR FORCE (R&D)

SUBJECT: Test and Evaluation of Aircraft Inertial Navigators

Reference (a): DDR&E Memo to the Asst. Secy's of the Military Departments for R&D, dated 6 July 1965, Subj: T&E of Aircraft Inertial Navigators

The intent of reference (a) was to minimize the risks (i.e., in performance, reliability and cost of ownership) in the use of aircraft inertial navigators by establishing a Tri-Service T&E program at the Central Inertial Guidance Test Facility (CIGTF), Holloman AFB. Recently, questions have been raised about the interpretation of reference (a).

This Office considers that CIGTF test and evaluation of an aircraft inertial navigator's specified performance should be completed prior to the selection of that navigator for a specific aircraft avionics system engineering development, operational system development, or modification program. Otherwise, the Department of Defense and development contractors would continue to face possible development problems, poor reliability and performance, program delays, etc.

Therefore, reference (a) is hereby superseded by the following:

> An Aircraft Inertial Navigator Test and Evaluation Program is established at the Central Inertial Guidance Test Facility (CIGTF), Holloman AFB, which is the DOD focal point for aircraft inertial navigator test and evaluation. This CIGTF program will verify the expected performance of inertial navigators and will provide comparative results under the same test

conditions. Through this process, avionics developers and/or Contract Definition (formerly PDP) contractors will have a number of inertial navigators to choose from whose performance has been verified, thereby minimizing the risks to the Government in their selection.

Furthermore, the managers of the following types of programs (which require an airborne inertial navigator and which are intended for or are part of specific aircraft application) should select their inertial navigators from those that have had their performance capabilities tested and evaluated at the CIGTF:

Airborne inertial navigator engineering developments

Avionics system developments

Avionics modification engineering developments

This does not preclude any special or other inertial testing which a particular Service might wish to perform at its own or other facilities.

When the best interest of the Government is clearly served, the DDR&E may be requested to waive this requirement.

Furthermore, the Military Departments are strongly encouraged to anticipate their future inertial navigator needs and initate R&D programs, including the necessary T&E, prior to avionics system developments. Increased advanced development of aircraft inertial navigators is encouraged. Both the Navy and the Air Force are currently funding T&E at CIGTF and this Office strongly supports this effort.

/s/
JOHN S. FOSTER, JR.

Copy to:
ASD(I&L)
ASD(SA)
ASA(I&L)
ASN(I&L)
ASAF(I&L)

APPENDIX B

PHILOSOPHY AND APPROACH

VERIFICATION/RELIABILITY TESTING

I. PURPOSE

1.1 Verification Testing: The primary purpose of verification testing, as practiced by the 6585th Test Group, is to provide a basis for comparative analysis of the performance and operational suitability characteristics of a series of theoretically similar navigation systems, as accurately as possible, by obtaining comparative results under nearly identical test conditions, and in a minimum amount of time.

1.2 Reliability Testing: The purpose of reliability testing, is to establish in the shortest possible test time and at a mininum cost, whether or not the reliability of a component or system is equal to or better than a specified minimum value.

II. DEFINITIONS

2.1 Types of Failures: (Note: All follow individually specific statistical distributions)

2.1.1 Early Failures: Most cases can be traced to poor manufacturing or quality control techniques and can usually be eliminated by a "debugging or burn-in" process.

2.1.2 Wearout Failures: Symptomatic with age. Can be designed in or designed out. Can be controlled by correctly scheduled, good preventive maintenance practices.

2.1.3 Chance Failures: Sudden stress accumulations, random, unexpected.

2.2 Eliminating False Failure Indications:

2.2.1 Testing errors, errors in instrument reading, or faults or equipment damage caused by the test personnel;

2.2.2 Manufacturing errors, such as improper wiring, use of incorrect parts, material faults, etc. which can be corrected, for instance, by debugging procedures or by stricter quality control and production inspection so that they will not recur in service or in other lots to be shipped;

2.2.3 Secondary failures, caused directly by primary chance failures of other components or by failures of auxiliary equipment, such as external power supply failures;

2.2.4 Maladjustments, which can be corrected during normal operation without the use of test equipment or tools, i.e., when provisions for adjustment by the operating personnel are built into the equipment so that normal operation does not need to be interrupted. However, if maladjustments require interruption of operation to be corrected, they must be considered as failures.

2.2.5 Stress accumulations: In order to identify failures which might be caused by stress accumulations, strict control must be exercised over test conditions.

III. APPROACH

3.1 Both Verification Testing and Reliability Testing philosophy requires that the system be monitored continuously and its performance characteristics be compared with those specified initially for the entire test duration. This continuous monitoring is necessary because it helps to establish out-of-tolerance malfunctions which, from both the reliability and verification point of view, are failures in the same category as faults causing complete stoppage. Such malfunctions as well as complete failures must be recorded and correctly identified. A vital ingredient in the identification process is rigidly controlled test conditions, particularly with regards to stress and the operational environment.

3.2 During the test a failure log is maintained in which all failures and malfunctions, including the exempt ones, are entered and identified by the parts involved, nature of the cause, category of the failure, and time of occurrence. The failure log helps to check whether the test was correctly performed, whether the appropriate types of failures were entered in the graph, and gives valuable information as to the corrective actions which have to be taken in production to eliminate the occurrence of other than chance failures - or even in design if the chance failure rate is too high. The frequency of chance failures - and therefore equipment reliability - is basically decided during the design stage, but careless production and assembly can introduce a multitude of other failures which reduce reliability below the design level. This type of information would certainly be of value prior to purchasing a new type of system or prototype...both from a performance and maintenance viewpoint.

APPENDIX C

GENERAL SYSTEM INSTALLATION INFORMATION

I. GENERAL

A. Mechanical and electrical interfaces have been standardized as much as possible among the testbeds. This approach provides systems interchangeability among the transport and fighter aircraft, and facilitates the accumulation of a maximum amount of flight data in the minimum amount of time.

B. Palletization techniques provided in the testbed aircraft enable systems to easily be moved between the laboratory and the aircraft environment. This technique reduces aircraft down time, engineering effort, modification cost, program duration, and project maintenance time.

C. This attachment is offered to guide the contractor in his test planning. Important environmental, mechanical, and electrical factors are summarized. If the configuration or mandatory requirements of a particular system are not compatible with the standardized installation, the customer and contractor must coordinate changes with the CIGTF as early as possible.

II. NC-141A PALLET TESTBEDS

A. Aircraft NC-141A S/N 61-2776 will be utilized exclusively for CIGTF testing under formal agreement with Aeronautical Systems Division (ASD). Shown in Figures C-1 through C-5 are sketches of the latest universal NC-141A pallet testbed configurations currently being utilized. The NC-141A/776 has been modified to accommodate five system test pallets. Pallet Station 1 will normally be occupied by CIGTF's Completely Integrated Reference Instrumentation System (CIRIS). The remaining stations are available for systems under test.

B. Equipment Installation. The major components (excluding control/display units which are mounted adjacent to the system operator) are either installed on a contractor supplied flight rack or mounting plate, which is in turn installed on a pallet half. However, if it is determined early in the test planning cycle that some or all of the major system components could, or should, be installed in the standard 19-inch racks, this will be considered.

C. Electrical.

1. Maximum power provided to each pallet station:

28 VDC, 35 Amps

400 Hz, 3Ø Y, 115 VRMS, 35 Amps

2. Unitron 400 to 60 Hz Converters: Each unit can provide the following powers:

60 Hz, 1Ø, 115 VRMS, 30 Amps at 80 % Efficiency

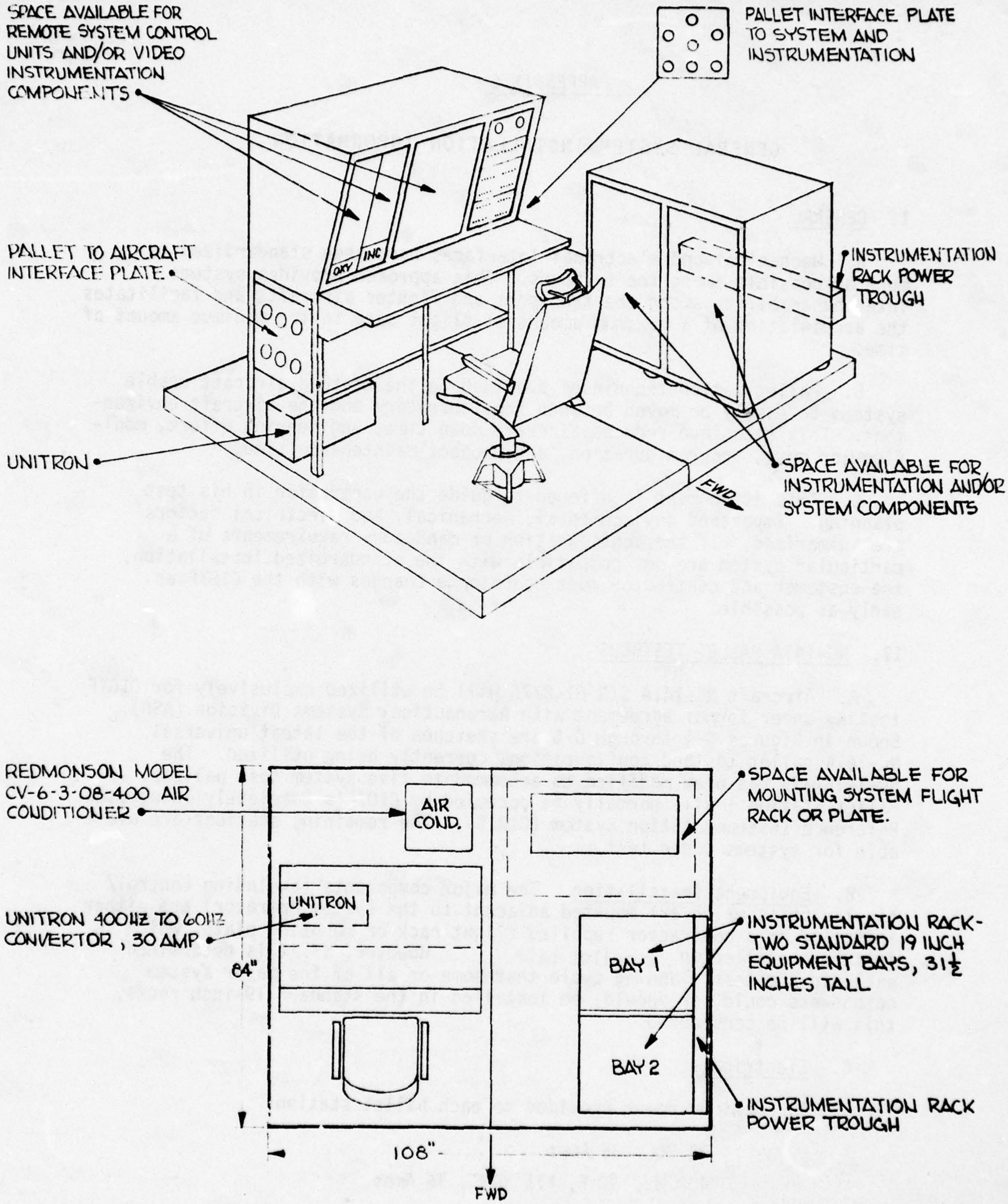
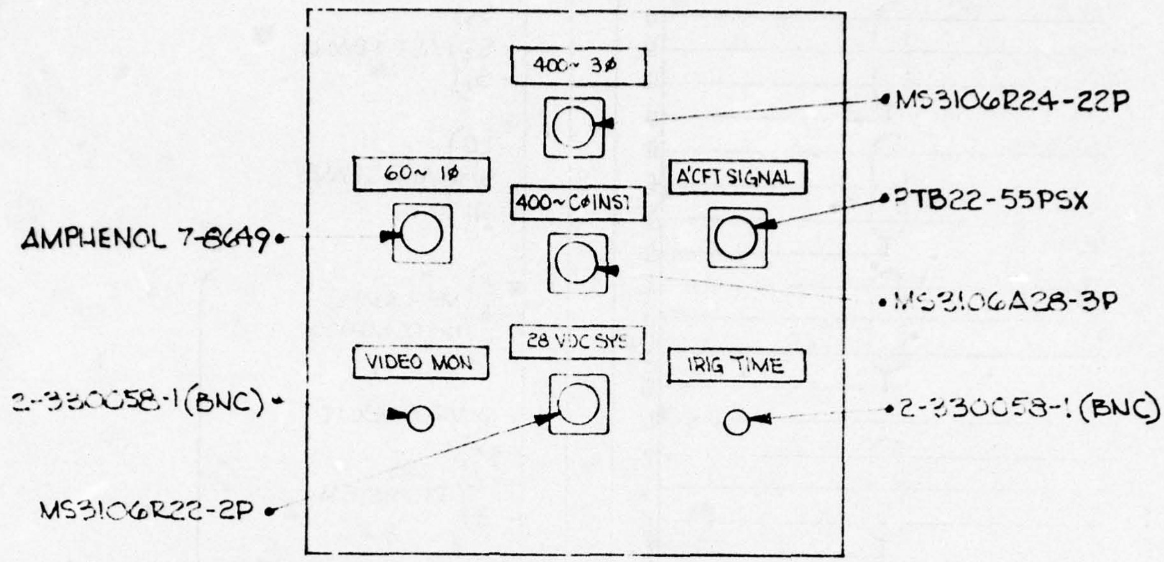
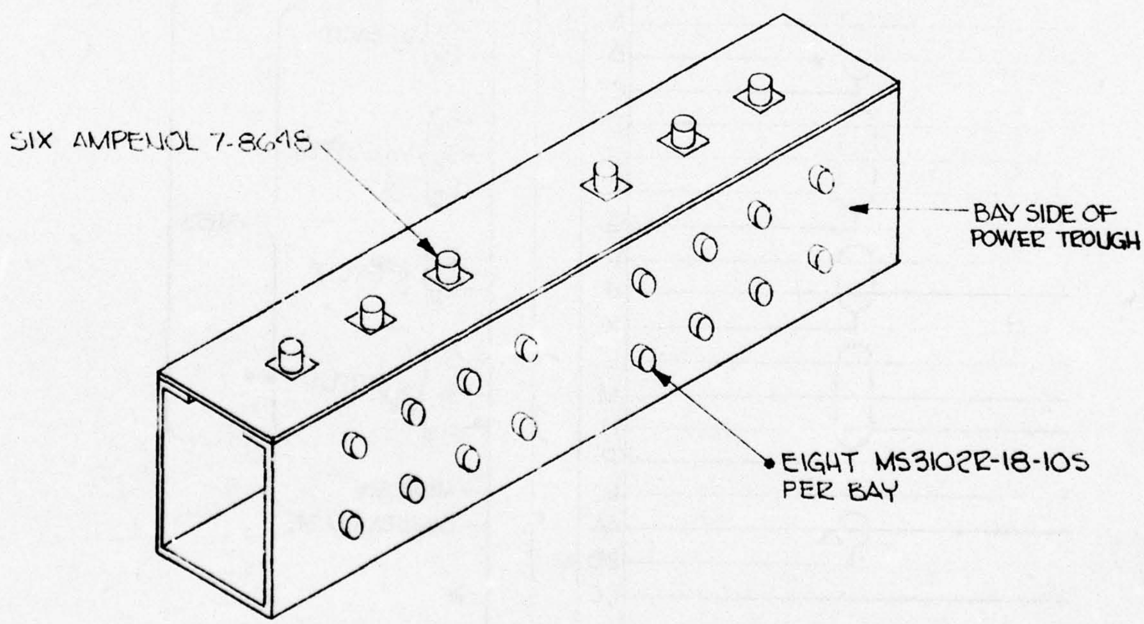

SPACE AVAILABLE FOR REMOTE SYSTEM CONTROL UNITS AND/OR VIDEO INSTRUMENTATION COMPONENTS
PALLET INTERFACE PLATE TO SYSTEM AND INSTRUMENTATION
OXY INC
PALLET TO AIRCRAFT INTERFACE PLATE
INSTRUMENTATION RACK POWER TROUGH
UNITRON
SPACE AVAILABLE FOR INSTRUMENTATION AND/OR SYSTEM COMPONENTS
FWD
REDMONSON MODEL CV-6-3-08-400 AIR CONDITIONER
AIR COND.
SPACE AVAILABLE FOR MOUNTING SYSTEM FLIGHT RACK OR PLATE.
UNITRON
UNITRON 400HZ TO 60HZ CONVERTOR, 30 AMP
INSTRUMENTATION RACK-TWO STANDARD 19 INCH EQUIPMENT BAYS, 31½ INCHES TALL
BAY 1
84"
BAY 2
INSTRUMENTATION RACK POWER TROUGH
108"
FWD

FIGURE C-1

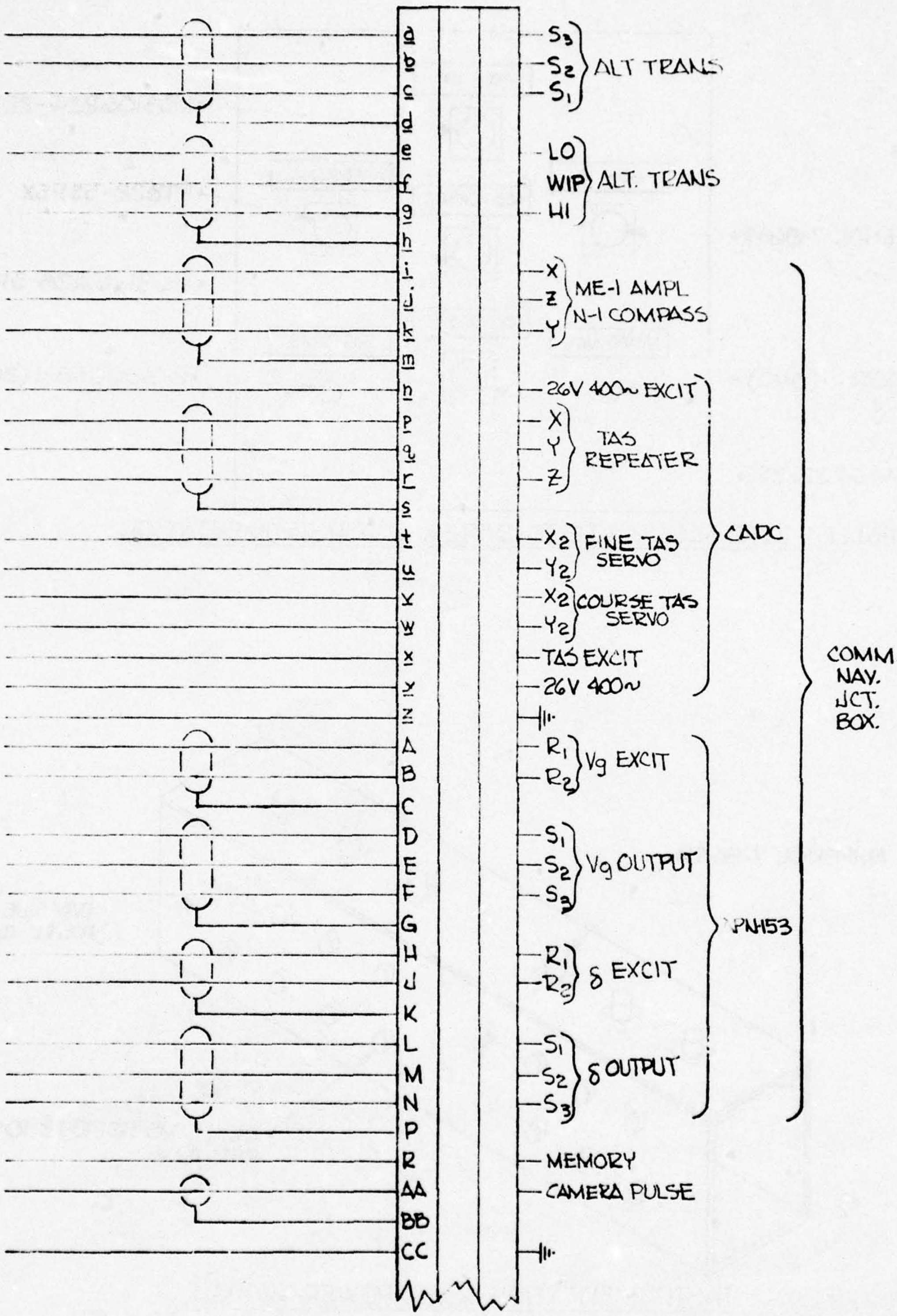


PALLET INTERFACE PLATE TO SYSTEM AND INSTRUMENTATION



INSTRUMENTATION RACK POWER TROUGH

FIGURE C-2



a
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P
R
AA
BB
CC
S3
S2
S1
ALT TRANS
LO
WIP
HI
ALT. TRANS
X
Z
Y
ME-1 AMPL
N-1 COMPASS
26V 400~ EXCIT
X
Y
Z
TAS REPEATER
X2
Y2
FINE TAS SERVO
X2
Y2
COURSE TAS SERVO
TAS EXCIT
26V 400~
CADC
COMM. NAV. JCT. BOX.
R1
R2
Vg EXCIT
S1
S2
S3
Vg OUTPUT
PNH53
R1
R2
δ EXCIT
S1
S2
S3
δ OUTPUT
MEMORY
CAMERA PULSE

FIGURE C-3

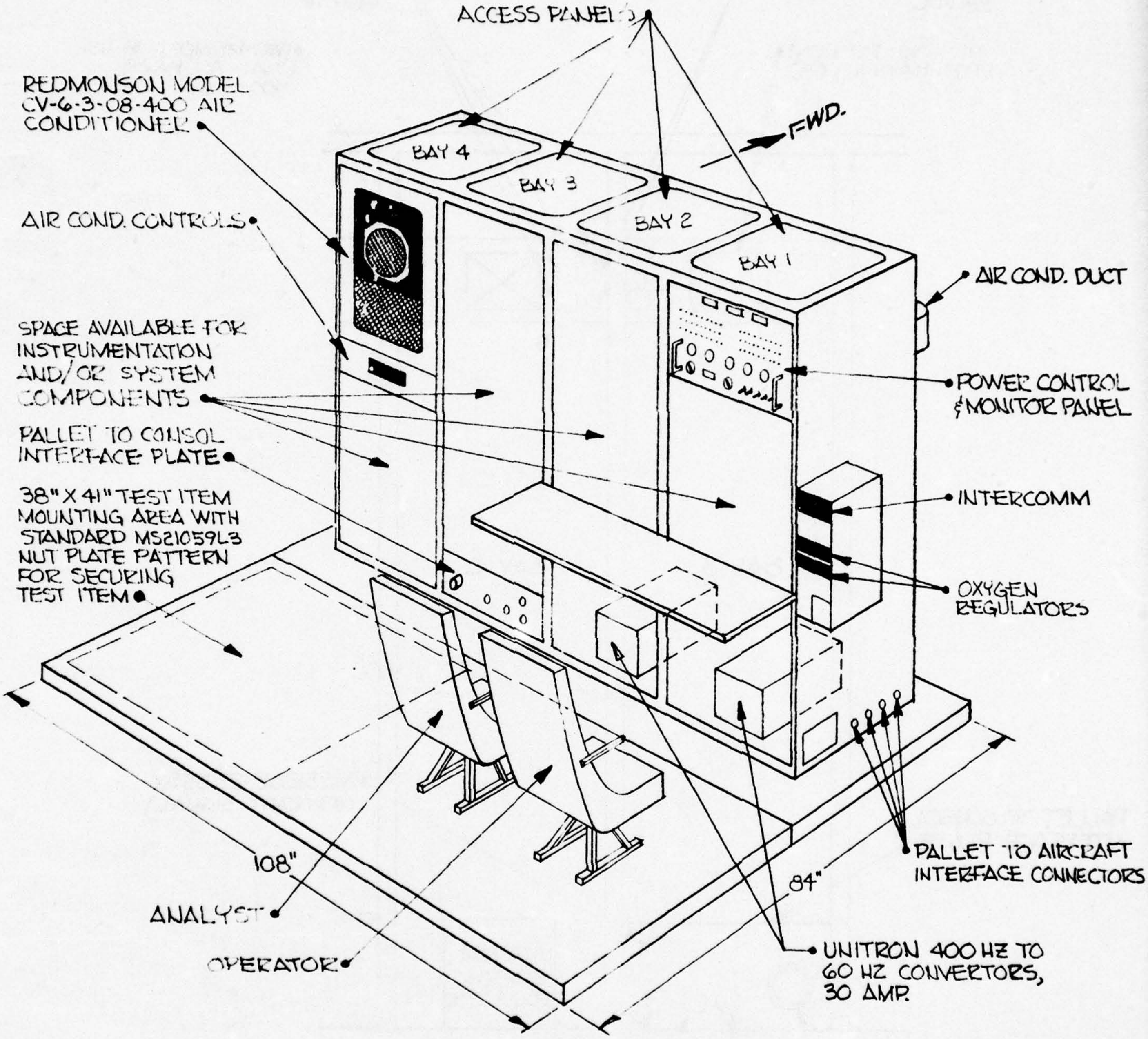

ACCESS PANELS
REDMONSON MODEL CV-6-3-08-400 AIR CONDITIONER
AIR COND. CONTROLS
FWD.
BAY 4
BAY 3
BAY 2
BAY 1
AIR COND. DUCT
SPACE AVAILABLE FOR INSTRUMENTATION AND/OR SYSTEM COMPONENTS
POWER CONTROL & MONITOR PANEL
PALLET TO CONSOL INTERFACE PLATE
38" X 41" TEST ITEM MOUNTING AREA WITH STANDARD MS21059L3 NUT PLATE PATTERN FOR SECURING TEST ITEM
INTERCOMM
OXYGEN REGULATORS
108"
84"
PALLET TO AIRCRAFT INTERFACE CONNECTORS
ANALYST
OPERATOR
UNITRON 400 HZ TO 60 HZ CONVERTORS, 30 AMP.

FIGURE C-4

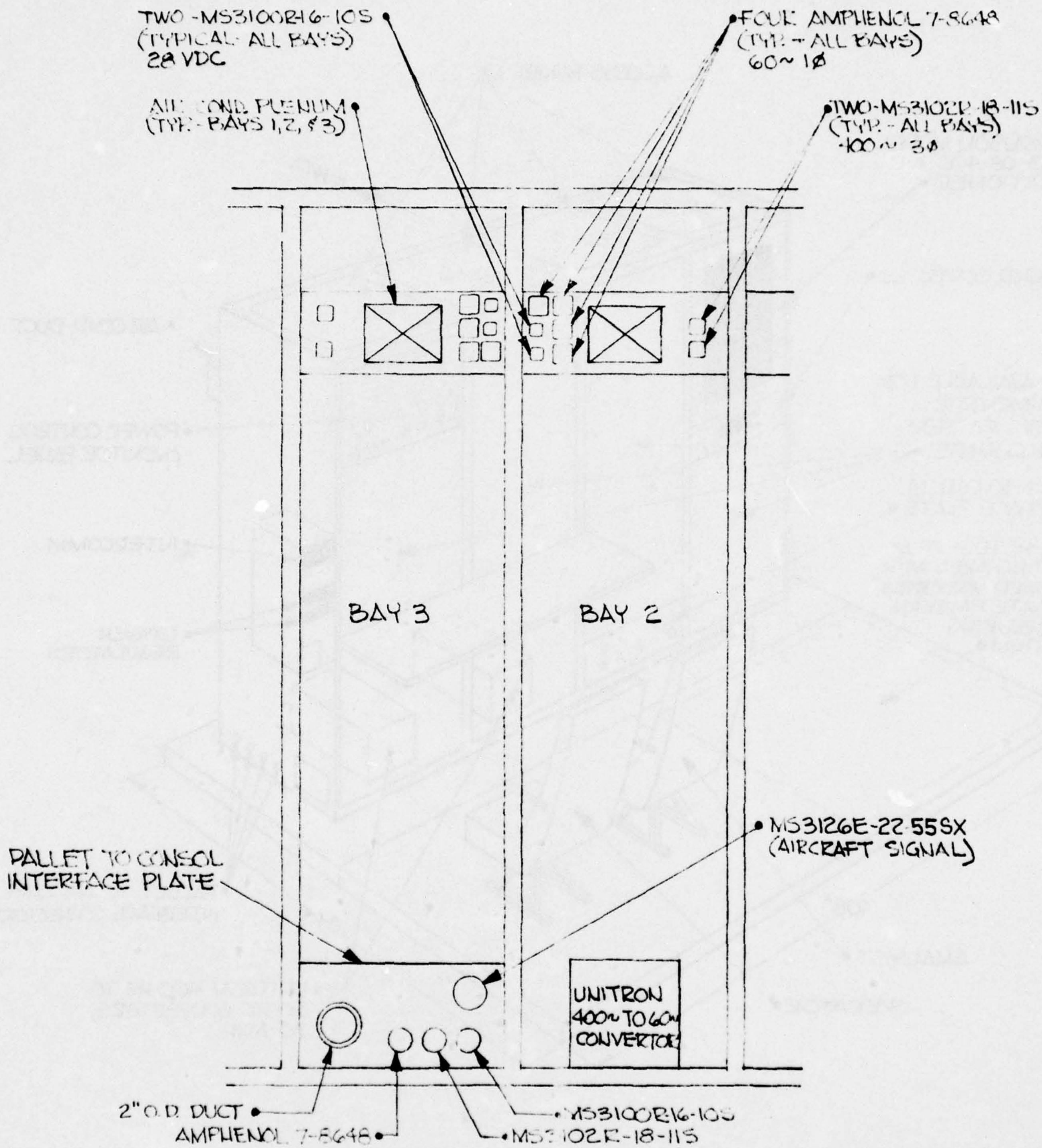

TWO-MS3100R16-10S
(TYPICAL ALL BAYS)
28 VDC
FOUR AMPHENOL 7-8648
(TYP - ALL BAYS)
60~ 1Ø
AIR COND PLENUM
(TYP - BAYS 1, 2, & 3)
TWO-MS3102R-18-11S
(TYP - ALL BAYS)
400~ 3Ø
BAY 3
BAY 2
MS3126E-22-55SX
(AIRCRAFT SIGNAL)
PALLET TO CONSOL
INTERFACE PLATE
UNITRON
400~ TO 60~
CONVERTOR
2" O.D. DUCT
AMPHENOL 7-8648
MS3100R16-10S
MS3102R-18-11S

FIGURE C-5

3. Power changeover time is 50 miliseconds or less: MIL-STD-704 applies. It is recommended that the contractor provide a power distribution box with the system. The box should contain fuses or circuit breakers to protect the system within its individual power requirements, and an ON/OFF switch. Reproducible mechanical and electrical drawings will be required for this unit.

D. Cooling. The cabin temperature in the NC-141A can reach 115° F on a hot summer day; therefore, cooling air is provided for on each pallet.

1. Figure C-1 Cooling air is ducted directly to the system and instrumentation racks as required.

2. Figure C-4 Cooling air is available from the air conditioner located in Bay 4 and distributed to all bays through an air plenum. The plenum has removeable plates for adapting peculiar supply hoses to instrumentation and system components. Air may also be directed to the system installation area via the auxiliary panel in Bay 3.

3. Flow Rate. Specific air flow rates would, of course, vary according to the number of components being cooled. Generally adequate cooling air is always available: occasionally an in-line fan for the flow rate requirement of a particular unit must be added.

4. Signals. Aircraft and support instrumentation signals avialable on each pallet testbed are routed via a standard connector, Bendix PT06E (5R)-22-55P; and the pin assignments are as shown in Figure C-3.

III. UH-1H HELICOPTER TESTBED

A. Helicopter INS testing is accomplished on helicopters belonging to US Army. UH-1H type helicopters are assigned daily; therefore INS testbeds must be interchangeable with any tail number assigned. Testbed provisions are available to simultaneously test two inertial navigation systems at once in the same helicopter. Under these controlled testing conditions it provides the capability of testing both inertial navigation systems under the exact same test condition. For comparability see Figure C-6.

B. Equipment Installation. INS components and data acquisition components are installed in racks mounted on the pallet testbed in the laboratory (see Figures C-6 & C-7). The pallet testbed is then installed in the helicopter using a loading dolly and a retractable caster-roller system integral to the pallet. The pallet testbed (maximum total weight 1200 pounds) is secured to the helicopter floor cargo tiedowns by steel cables and turnbuckles to safely withstand G loading factors (4.0 g's FWD, 20 g's AFT, 1.5 g's LATERAL, 2.0 g's VERTICAL) (see Figure C-8).

C. Electrical. Helicopter power (28VDC) is furnished to the pallet interface connector from the ship's standby generator. The following electrical power is available on the pallet testbed:

115 VAC/400 Hz/ 3 Ø	5 KVA
115 VAC/ 60 Hz/ 1 Ø	1 KVA
28 VDC	25 AMPS

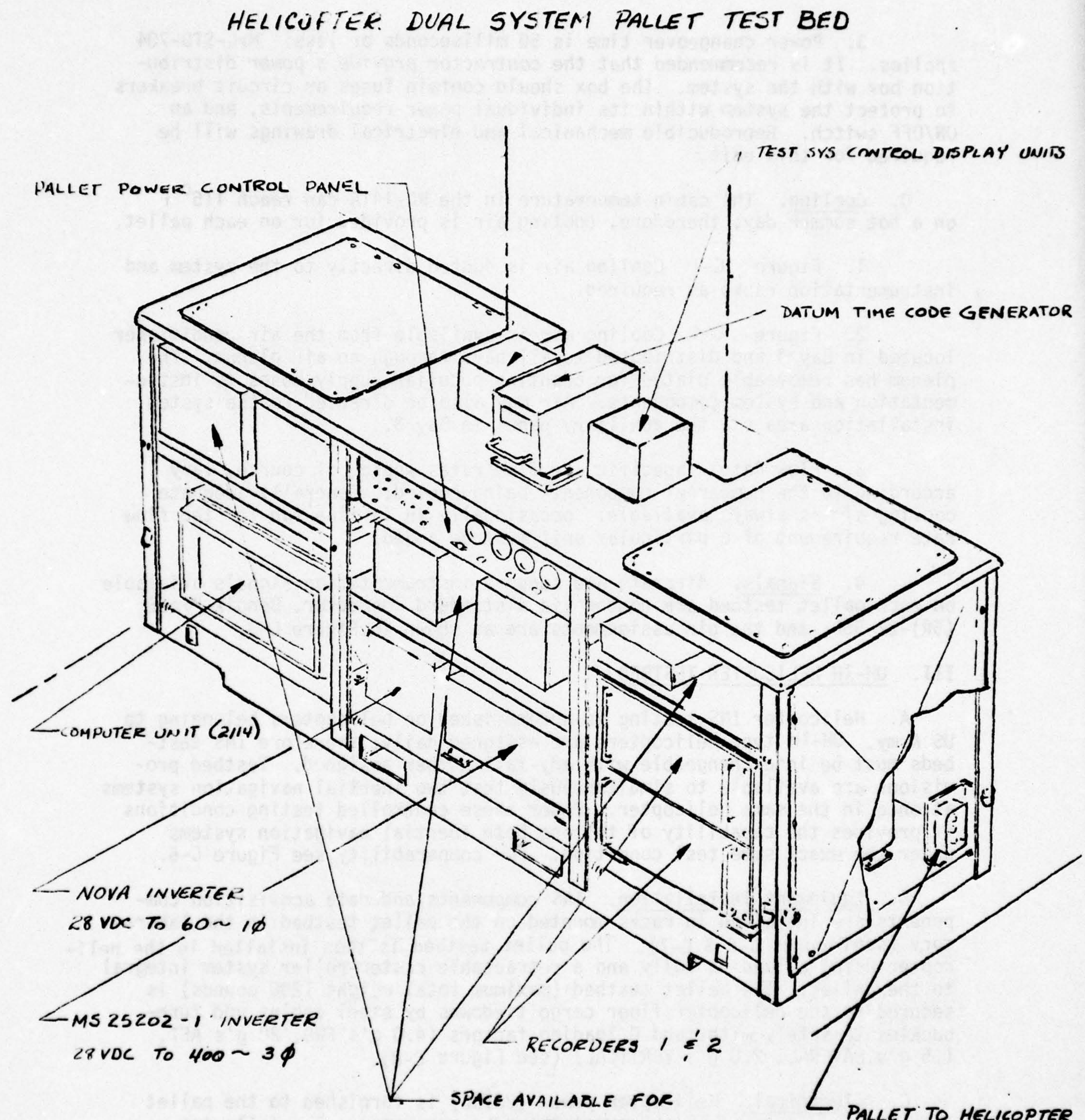

HELICOPTER DUAL SYSTEM PALLET TEST BED
TEST SYS CONTROL DISPLAY UNITS
PALLET POWER CONTROL PANEL
DATUM TIME CODE GENERATOR
COMPUTER UNIT (2114)
NOVA INVERTER
28 VDC TO 60~ 1φ
MS 25202-1 INVERTER
28 VDC TO 400~ 3φ
RECORDERS 1 & 2
SPACE AVAILABLE FOR
SYS COMPONENTS
TYPICAL SHOWN
PALLET TO HELICOPTER
INTERFACE CONNECTOR
28 VDC FRM STANDBY GEN.

FIGURE C-6

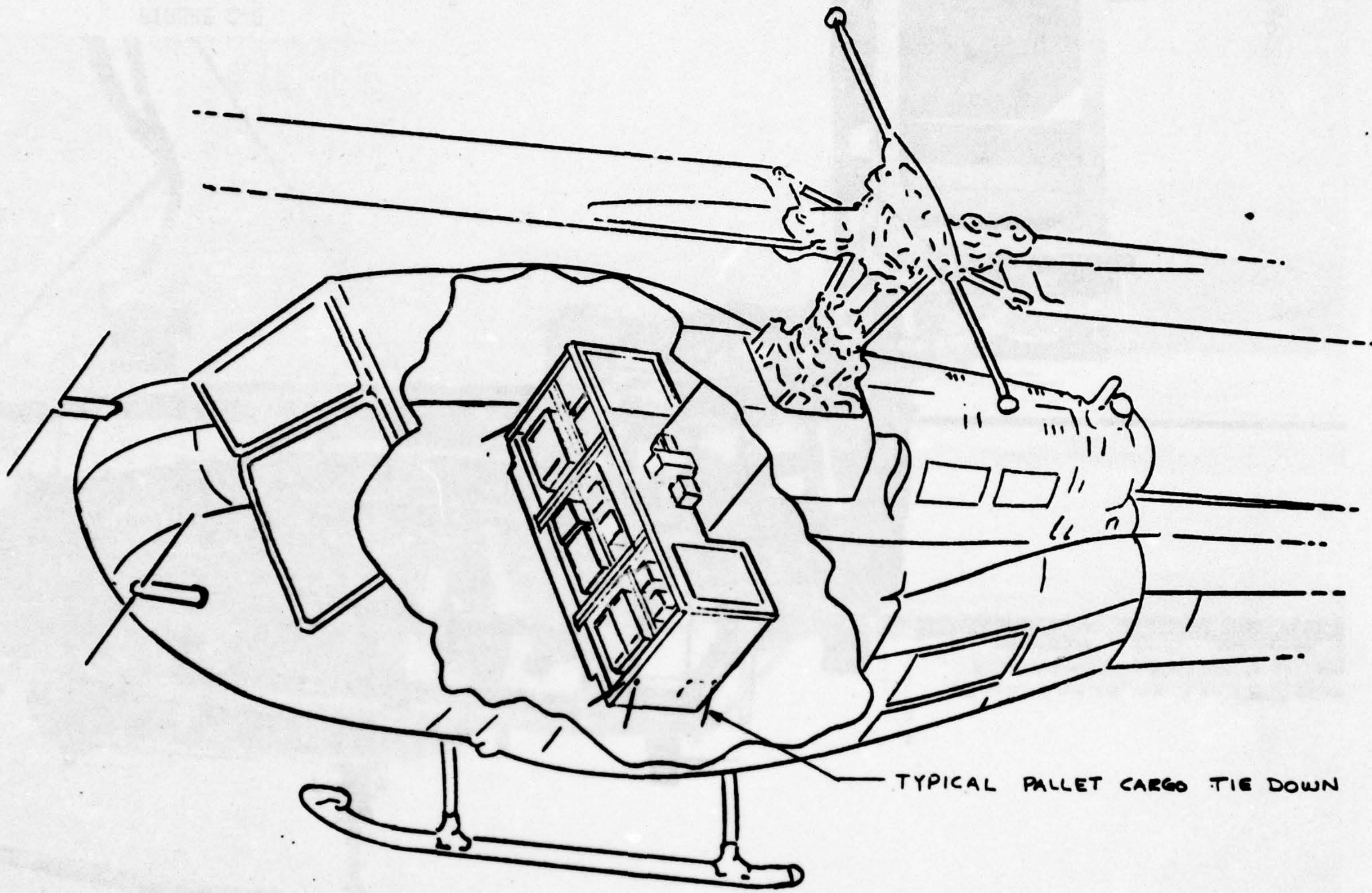


FIGURE C-7

UH-1H HELICOPTER WITH PALLET TESTBED INSTALLED

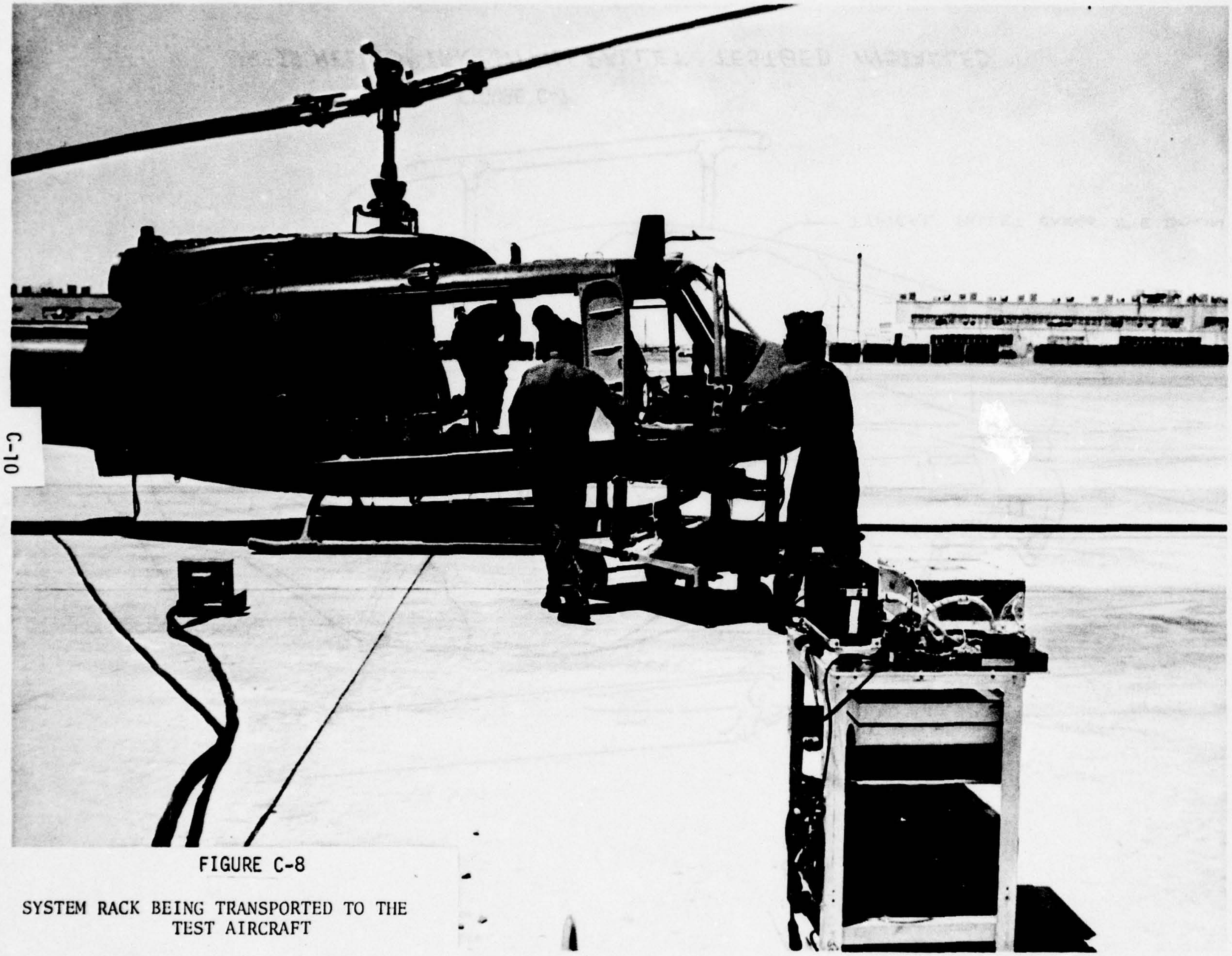


FIGURE C-8

SYSTEM RACK BEING TRANSPORTED TO THE TEST AIRCRAFT

D. Cooling. No equipment cool capability exists from the helicopter. It is recommended that an auxiliary 400 Hz air blower be furnished to provide test system component with acceptable flow rate of ambient compartment air (40 to 120°).

IV. RF-4C FIGHTER TESTBED

A. Normally, RF-4C S/N 66-7743 will be utilized. Figures C-9 through C-13 depict the basic modification design currently installed in the space available for future projects.

B. Equipment Installation. The major components (excluding control/display units which are mounted in the aft cockpit) will be installed in the fighter flight test rack shown in Figure C-12. Some relocation of components may be required from program to program; however, this problem will not normally be addressed until it appears certain that the test system will successfully pass the cargo phase advancement criteria.

C. Electrical.

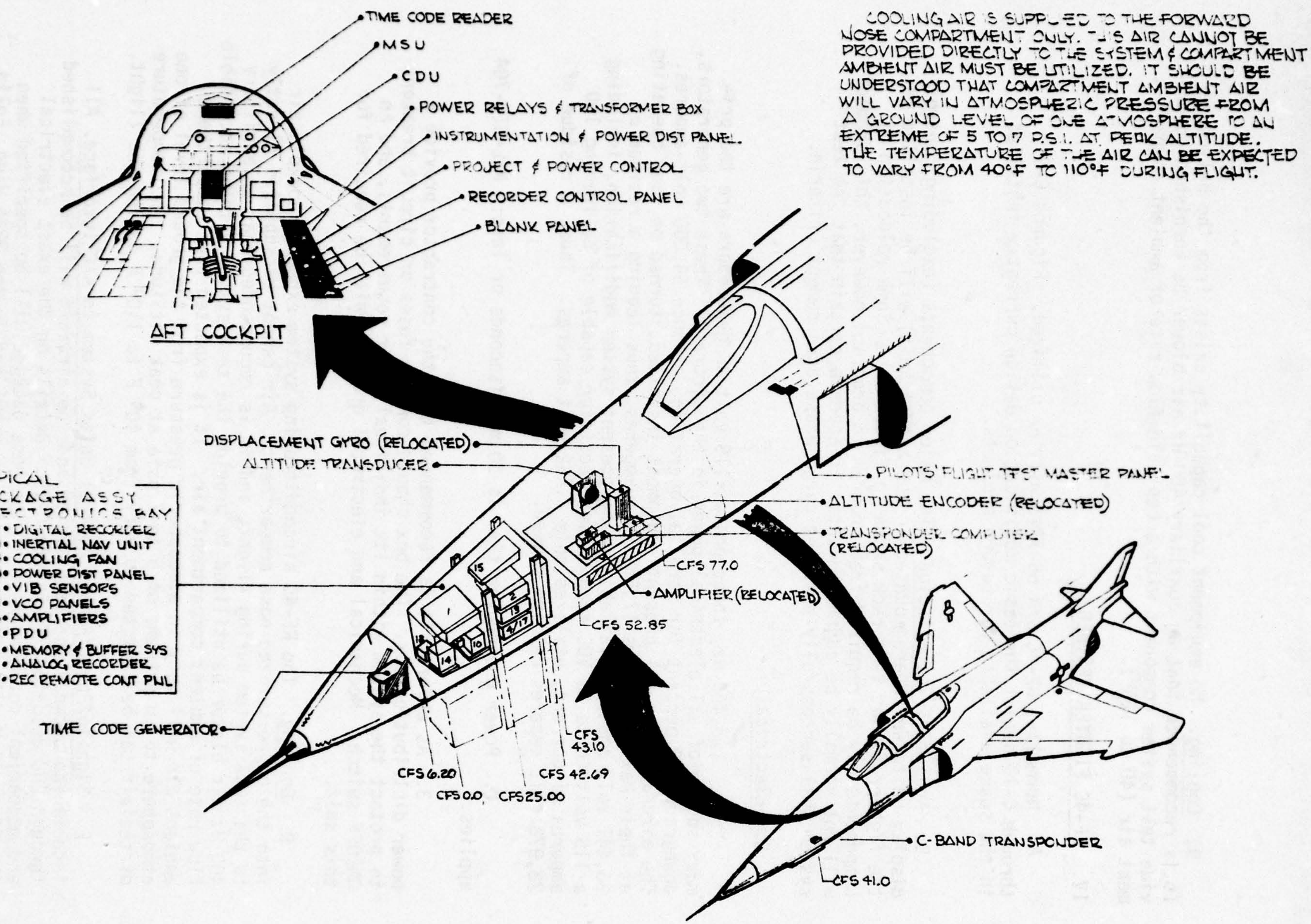
1. Two 400 Hz, three phase, 115 volt AC generators are the primary source of all electrical power in the aircraft. These two generators, downgraded 10 percent for parallel operation, produce 54,000 volt-amperes. The aircraft with all present equipment installed, turned on, and operating at their maximum, draws 17,559 volt-amperes, thus leaving a residue of 36,441 volt amperes available. The present system modification, including a 115 volt AC to 28 VDC transformer-rectifier capable of delivering 100 amperes of current, utilizes only 7,462 volt amperes. Thus, a residue of 28,978 volt amperes remains unused.

2. Power changeover time is 50 milliseconds or less: MIL-STD-704 applies.

3. As before, it is recommended that the contractor provide a power distribution box. The box should contain fuses or circuit breakers to protect the system within its individual power requirements, and an ON/OFF switch. Mechanical and electrical drawings will be required for this unit.

D. Cooling. The RF-4C airconditioning system exhausts cockpit air into the unpressurized nose compartment. Air cannot be supplied directly to the test system during flight, and it is recommended that an auxiliary 400 Hz air blower be utilized to provide the test system with an acceptable flow rate of ambient compartment air. It is expected that compartment ambient air will vary in atmospheric pressure from the ground level of one atmosphere to an extreme of 5 to 7 psia at peak altitude. The temperature of the air can be expected to vary from 40° F to 110° F during the flight.

E. Signals/Power/Remote Control Units System to A/C Interface. All interfacing between the test system and the aircraft will be accomplished through PDU described in Figure C-10. Details on the exact electrical and mechanical configuration of the nose package will be specified when the Class II Modifications Proposal is submitted to the 3246 Wing, Eglin AFB, FL.



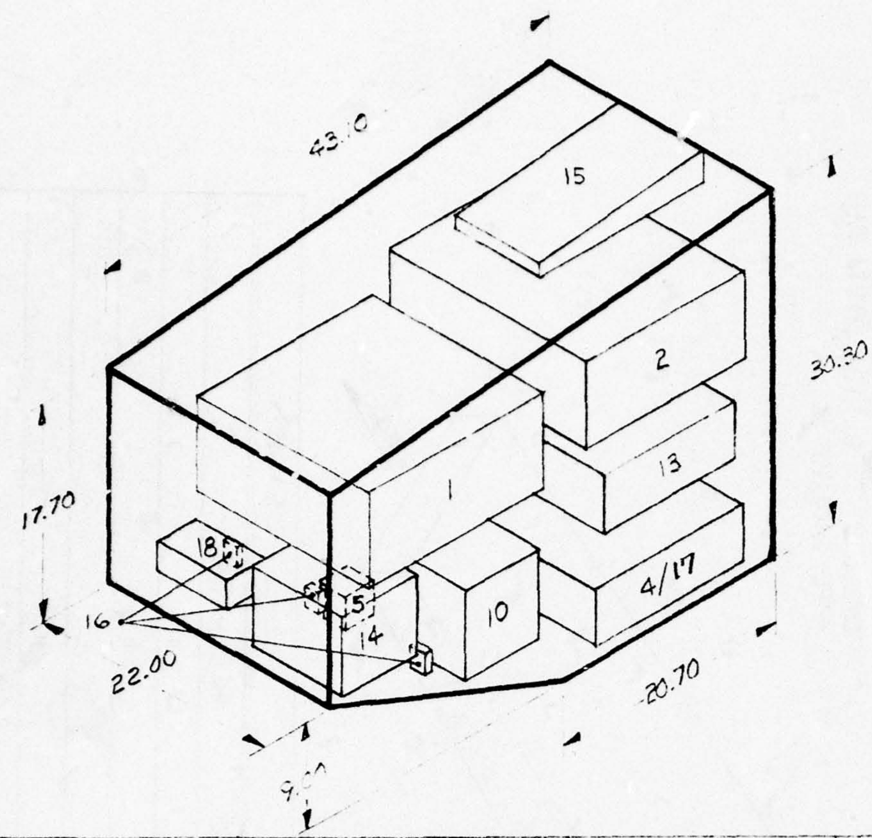
GENERAL ARRANGEMENT : CLASS II MOD TO RF4C/37743

FIGURE C-9

FIGURE C-10
NOSE PACKAGE READY FOR LOADERS

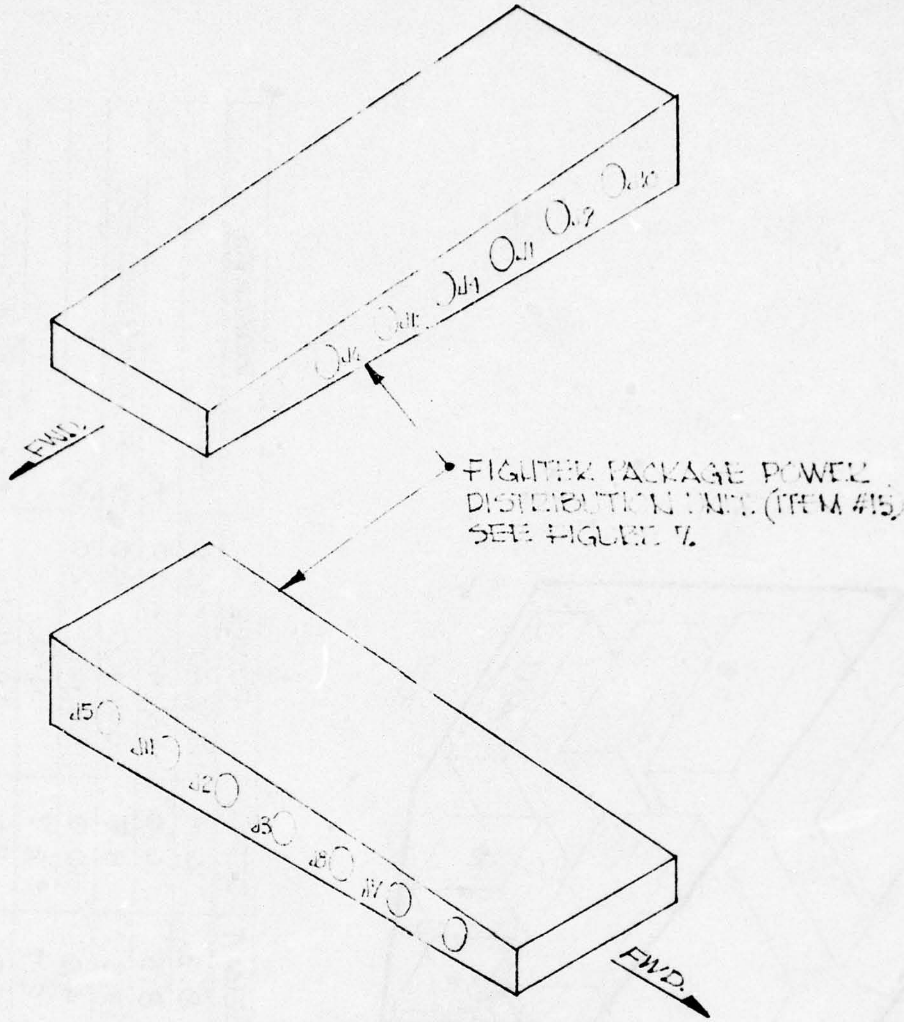
FIGURE C-11

NOSE PACKAGE BEING LOADED INTO TESTBED AIRCRAFT



ITEM	DESCRIPTION	WIDTH	HEIGHT	DEPTH	POWER	REMARKS
1	DIGITAL RECORDER	17.0	8.3	16.4	115 V, 400~, CØ	341 VA
10	INERTIAL NAV UNIT	7.6	8.5	16.0	115 V, 400~, ΔØ	*
14	COOLING FAN	7.5	7.5	8.5	115 V, 400~, ΔØ	* → 1600 VA (COMBINED)
13	POWER DIST PANEL	12.2	4.0	10.0	115 V, 400~, ΔØ	*
5	VIB. SENSORS	3.0	2.7	2.7	N/A	
18	V.C.O. PANELS	4.6	3.0	9.0	28 VDC	* → 0.5 AMP (COMBINED)
16	AMPLIFIERS (3)	1.0	2.3	2.0	28 VDC	*
15	P. D. U.	15.5	2.2/3.5	8.0		SEE FIGURE 9
2	MEMORY & BUFFER SYS	14.7	9.3	18.5	115V, 400~, CØ	330 VA
4	ANALOG RECORDER	12.2	6.0	16.0	28 VDC, 5 AMP	
17	REC REMOTE CONT PANEL					

FIGURE C-12



CONNECTOR	TYPE	USAGE
J1	MS3102R-18-10S	400 ~ 3φ
J2	"	"
J3	"	"
J4	"	"
J5	"	"
J6	MS3102R-16-10S	28 VDC
J7	"	"
J8	"	"
J9	MS3126F-22-21P	INPUT POWER TO PACKAGE
J10	MS3126F-24-61S	SIGNAL
J11	MS3126F-22-55S	"
J12	MS3126F-16-26P	"

FIGURE C-13

F. Full Scale Mockup. It is requested that the contractor supply one full scale mockup of each major system component, complete with dummy connectors. to facilitate the Class II modification work to be accomplished at Eglin AFB, FL.

APPENDIX D

INSTRUMENTATION AND SUPPORT EQUIPMENT

This appendix is intended only as a guide to the customer. The requirements of each test program for instrumentation and support equipment will be considered on an individual basis. Early identification of special requirements for instrumentation and support equipment is mandatory to allow for lengthy procurement cycles.

Digital instrumentation is accomplished in one of two ways dependent on the type of data available from the system under test. For a serial data type system, a digital buffer is used. For a parallel data type system, a digital computer is used. Analog recording is also used with the types of equipment available listed in paragraph 5 of this appendix.

1. EQUIPMENT AVAILABLE AT CIGTF

1.1 Ground

1.1.1 Oscillograph recorders

1.1.2 General purpose test equipment

1.1.3 Ground stations, analog, and digital

1.1.4 Power measuring equipment

1.1.5 Theodolites

1.2 Airborne

1.2.1 Digital buffers/tape recorders

1.2.2 Analog magnetic tape recorders

1.2.3 Oscillograph recorders

1.2.4 Voltage controller oscillator complexes

1.2.5 Analog signal conditioners

1.2.6 Vibration and altitude transducers

1.2.7 Time code generators, IRIG

1.2.8 PCM schronizers

1.2.9 Analog to digital converters

2. CUSTOMER SUPPORT

In general, the customer is responsible for insuring that the contractor properly conditions the signals to be recorded. It is a test requirement that the contractor provide to the CIGTF a detailed description of the system outputs as soon as practicable after acceptance of the test program. This description will be accomplished at a technical meeting held at theCIGTF.

3. DIGITAL RECORDING REQUIREMENTS - SERIAL DATA

Generally a digital buffer system is used for the recording of serial digital data although in some special cases a computer system may be used. These cases are usually determined by a size constraint or the requirement for data processing before recording. Since a buffer system is only able to take in data and write directly or magnetic tape, no data manipulation is possible. GDOI is retiring buffers. Computer based DAS is considered the standard, with buffers used as alternates.

3.1 System Output Format

3.1.1 Data may be continuous, gated word, or gated frame of either Manchester, RZ, or NRZ code. (A gate signal must be provided for gated data.)

3.1.2 A 50 percent duty cycle clock must be provided coincident with the data. The maximum frequency can be no greater than one megahertz.

3.1.3 A sync word (unique bit combination) must occur once in each frame of data. For recording purposes, the sync word will be considered the first word in the frame and IRIG time will be frozen upon its detection.

3.1.4 The word length must be constant and no longer than 48 bits.

3.1.5 The maximum frame lengths are as follows:

a. 254 words for words 24 bits or less.

b. 127 words for words 25 - 48 bits.

3.1.6 Word and frame lengths must be constants.

3.2 Interface

3.2.1 System outputs to the digital buffer system should be DTL compatible.

3.2.2 If any outputs are not DTL compatible CIGTF requires the following information:

a. A timing diagram of clock and data which specifies logic levels.

3.3 Digital Recorder Outputs

The techniques applied in buffering and formatting result in an IBM compatible 7 or 9 track digital tape record.

4. DIGITAL RECORDING REQUIREMENTS - PARALLEL DATA

A computer type data acquisition system is used to collect parallel data. The use of the computer allows data acquisition from multiple sources and also permits manipulation of the data before recording. In some special cases, real time data display, including graphics is available.

4.1 System Output Format

4.1.1 Data must be in a parallel form up to 32 bits although 16 bits or less are preferred.

4.1.2 A data strobe pulse must be supplied with the data and must be true when the data is valid.

4.1.3 The rate of transfer for parallel words should not exceed 100 KHZ, if possible, although higher rates can be handled by use of special drive routines.

4.2 Interface

4.2.1 System outputs to the computer should be TTL compatible, either POS or NEG true, if possible although other signal levels may be used.

4.2.2 A timing diagram showing the relationship between the data and data strobe pulse is required.

4.2.3 A list of the words in the system output format and the scale factors to be applied to each word is requested.

4.3 Digital Recorder Outputs

The techniques applied to the formatting of data result in an IBM compatible 9 track digital tape record.

5. ANALOG RECORDING

5.1 Tape Recorder

5.1.1 Transport Aircraft

Mfg. and Model	Min-Com PC-500
No. of Tracks	14
Tape Load	9200 Ft. of 1 Mil Mylar
Input Signal Levels	0-5 Volts or ± 2.5 Volts Referenced to A/C Ground

5.1.2 Fighter Aircraft

Mfg. and Model	Astro-Science M-14
No. of Tracks	14
Tape Load	9200 Ft. of 1 Mil Mylar
Input Signal Levels	0-5 Volts or ±2.5 Volts Referenced to A/C Ground

Table D-I lists pertinent recording parameters applicable to the above equipment. VCO's and discriminators are available for the FM recording frequencies specified in Table D-I. Complexes using other standard IRIG subcarriers are available on request. Input impedances vary according to the recording techniques and equipment in use. Table D-II is a typical listing of tape recorder channel assignments. Table D-III is a typical triad of VCO complexes using standard IRIG VCO's.

5.2 Visicorder

5.2.1 Voltage levels; zero to ±5 v.

5.2.2 Input impedances into galvo amplifiers: 47 kohms in parallel with 300 pico farads.

5.2.3 Maximum frequency: 4.8 KHz.

5.2.4 The visicorders are most useful for recording trouble-shooting functions. The recorders are typically run at a low speed (0.2 ips) and detailed observation of signals above 200 Hz can be made for only short periods and at paper speeds of 10 to 40 ips.

5.3 Altitude Transducers

5.3.1 These barometric devices are manufactured by the Wallace O. Leonard Company. The outputs are analog. Several different outputs are available. The units, PN 503654-39, which are more readily available are described below.

5.3.2 Altitude range: Zero to 80,000 feet.

5.3.3 Potentimeter output, externally excited, with resistance zero to 5,000 ohms, or 6.25 ohms per 100 feet.

5.3.4 Maximum excitation: 75 vdc or VRMS.

TABLE D-I

SELECTED RECORDING PARAMETERS

Tape Speed (IPS)	Nominal Frequency Response Direct Record	Center Frequency (KHz) FM Record	Intelligence Bandwidth (KHz)	Recording Time (Hr) per 9200 Ft Reel
120	1 KHz-2MHz	*	*	0.25
60	1 MHz	*	*	0.5
30	500 KHz	*	*	1.0
15	250 KHz	*	*	2.0
7-1/2	125 KHz	54	10 KC	4.0
3-3/4	62.5 KHz	27	5 KC	8
1-7/8	31.25 KHz	13.5	2.5 KC	16

*Future Procurement

TABLE D-II

TYPICAL TAPE RECORDER TRACK ASSIGNMENT

TRACK	TYPE	FUNCTION
1	Direct	System No. 2 Data
2	FM	Camera Sync Pulse
3	Direct	System No. 2 Data Clock
4	FM	System No. 1 Data
5	Direct	System No. 2 Frame Marker
6	FM	System No. 1 Data Clock
7	Direct	Tape Speed Compensation
8	Direct	Tape Speed Compensation
9	Direct	Spare
10	FM	X Vibration
11	Direct	Spare
12	FM	IRIG-B Timing
13	FM	Z Vibration
14	FM	Y Vibration

TABLE D-III

TYPICAL VCO CHANNEL ASSIGNMENTS

VCO (KHz)	Information Bandwidth (Hz)	A Complex	B Complex	C Complex
10.5	160	X-gyro Torquer ±2.5v	Y-gyro Torquer ±2.5v	Z-gyro Torquer ±2.5v
7.35	110	X Accelerometer ±2.5v	Y Accelerometer ±2.5v	5vdc Precision No. 1
5.4	81	Altitude No. 1 0-5v	Altitude No. 2 0-5v	28vdc Precision No. 1 0-5v
3.9	59	Doppler Memory 0-5v	Doppler "On" 0-5v	Temp Monitor No. 1 0-5v
3.0	45	No-Go Monitor No. 1 0-5v	No-Go Monitor No. 2 0-5v	Temp Monitor No. 2 0-5v
2.3	35	Computer 400 hz Amplitude 0-5v	Aircraft 400 hz Amplitude 0-5v	Line Voltage Detection 0-5v
1.7	25	Aircraft 28vdc	Spare	Spare
Direct		Computer No. 1 400 Freq		Aircraft 400 Freq

6. MINICOMPUTERS AFFECT TEST RESPONSE

6.1 Recent advances in minicomputers and peripherals have provided the tools which had a significant impact on the quality of test instrumentation. The improvements have not been limited to the flexible and reliable data acquisition, control and display capabilities of computer control instrumentation, but has been an important tool to provide what is referred to as "quick-look" capability. "Quick-look" is essentially the ability to obtain timely information concerning the results of a test (what has been recorded on magnetic tape) which affect the schedules and/or quality of further tests.

6.2 The time constraints imposed on flight testing due to aircraft scheduling and support coordination affect at least three distinct activities of the test team. Each test mission records data on magnetic tape that can provide information concerning

6.2.1 The performance of the test data acquisition equipment

6.2.2 Test system operation

6.2.3. Test system performance

This information car affect decisions to repair equipment, alter mission schedules, perform calibrations, change test plans, repeat or change test profiles and numerous other decisions that lead to timely and cost effective testing.

6.3 Software has been developed that effectively utilizes the capabilities of minicomputers and peripherals post-flight in a ground station to provide the "quick-look" capability described. It is important to note that this post-flight capability does not duplicate the real-time data display which may also affect decisions of a similar nature, but is totally dependent on recorded data which must be used for system evaluation by test analysts. The important features of a large magnetic tape dump program are:

6.3.1 Data is read directly from a "raw" or unprocessed magnetic tape produced by the data Acquisition System.

6.3.2 Generalized and often used data unpacking and formatting features provide scaled listings or plots from "any" system test.

6.3.3 Specific features for detecting typical events or malfunctions are switch selectable.

6.3.4 Analysis aid such as statistics generations, differentiation, differencing, and condition testing can be invoked.

6.3.5 Tape searchers, positioning, duplicating, and formatting can be accomplished.

6.4 Quick-look can be accomplished easily on a new system by first listing data records in 16, 32 or 48 bit octal form or hexidecimal form. Bit hang-up, data parity, and record length tests are also automatically performed. Record skip features allows selective scanning of the entire tape to insure consistent data acquisition throughout the mission. This binary form of data listing can be compared with data format specifications which are used to generate unpack specification files. These files are used to obtain listings which have discretes and data words that are unpacked and scaled in engineering units for columnar presentation with meaningful labels. The third step is selection of specific variables for plot generation. Often used plots can be specified on plot files so that only six keyboard inputs are required to produce a scaled plot with annotation from data tapes. The simplicity of operation can best be illustrated for a recent test program. Thirty minutes after the first data tape had been recorded, a plot of position versus time had been generated.

6.5 The minicomputer is an effective tool for generating needed information in a timely manner. Analysis of data tapes for the purpose of test quality control had advanced the flight test capability providing significant improvements in response time to events that might have otherwise gone unnoticed prior to the next mission.

7. INSTRUMENTATION POD

7.1 The instrumentation pod, currently in use by the 6585th Test Group, is a modified 600 gallon fuel tank carried at the centerline station of an F-4 aircraft. The pod is unique in that it has the capability of recording analog, digital and video signals simultaneously.

7.2 The heart of the data acquisition system is a HP 2100 computer used in conjunction with a Digi Data 1457 digital recorder and an Analogic AN 5800 digitizer. The analog system consists of a MARS 1000 analog recorder along with three Dorsett VCO packs with the capability of recording 36 analog signals. The video system is comprised of a Sony EV 320 video recorder, a video processor and sync stripper to condition the video data, and a screen splitter and character generator to provide alpha-numeric data both real-time and as part of the video recording. All recorders are remotely operable from the aft cockpit of the aircraft.

7.3 Signal conditioning consists of an EMR 515 synchronizer for PAM data and a signal distribution/conditioning panel to route the data to the digital and analog systems. Test item signals and F-4 attitude functions, along with weather data (dew point and total temperature) are also available for recording. A Motorola TAC NAV system provides range to target through a ground based transonder. All recorded data is referenced through the use of a Datum 9150 time code generator.

7.4 The instrumentation pod is essentially a palletized data acquisition system which releases the aircraft for greater utilization by other projects. A specially designed dolly/cradle permits lab and/or hanger checkouts with test items under test which greatly reduces the downtime of the aircraft for project preparation. The pod is designed so that it is easily adaptable for other test items with minor revisions. Through its unique recording capability, along with onboard time code generation and ranging, range requirements are limited to air space only. Through the use of a digital and video ground station operated by 6585th Test Group personnel, quick-look data can be generated within minutes of mission sortie completion.

APPENDIX E

REPRESENTATIVE FLIGHT PATHS

I. CARGO CHECKPOINT FLIGHT PATHS

a. In Phase II testing, the system is installed and flown in an NC-141A testbed aircraft. Following initial shakedown sorties, data flights are performed over specially designed flight paths where accurately surveyed checkpoints are photographed using a vertically stabilized camera to provide reference information.

b. The reasons for including the transport phase even for systems intended for fighter applications are as follows:

(1) The transport usually provides a more economical vehicle in which to checkout system performance. This is especially true for systems with complex software mechanizations.

(2) Longer flight times can be provided more economically in the transport than in the fighter. Routes (See Figure E-1) over precision surveyed checkpoints exist across the entire country providing a transcontinental flight test capability. Established checkpoints routes are also located in Alaska for high latitude tests.

(3) Present fighter aircraft require the extensive use of range facilities for radar tracking. Transport aircraft can often use off range vertical photography as a position reference. This can be especially efficient for the checkout portion of system testing, and is often accurate enough for verification testing.

(4) Continuous radar coverage is available from Holloman AFB to the West coast using the tracking facilities of White Sands Missile Range, Ft Huachuca, Az and SAMTEC, Vandenberg AFB, Ca.

II. HELICOPTER FLIGHT PATHS

Two basic types of flight profiles are flown during this test phase: both North-South and East-West navigation profiles, and terrain mapping profiles. The navigation flight profiles will be flown in order to obtain baseline navigation data in straight and level flight. These flights are made at 750-1000 foot altitudes above ground level. They are made with 180^{o} turns coinciding with a half Schuler period (42 minutes). The terrain mapping profiles are designed to simulate operational conditions as closely as possible. Specific maneuvers include: low level cruising, low level hover, landing between maneuvers, autogyro descent from altitude, attack and evasion profiles, and mapping profiles. The normal duration of each mission is 1½ - 2 hours. Figure E-2 is an outline map of the helicopter flight paths.

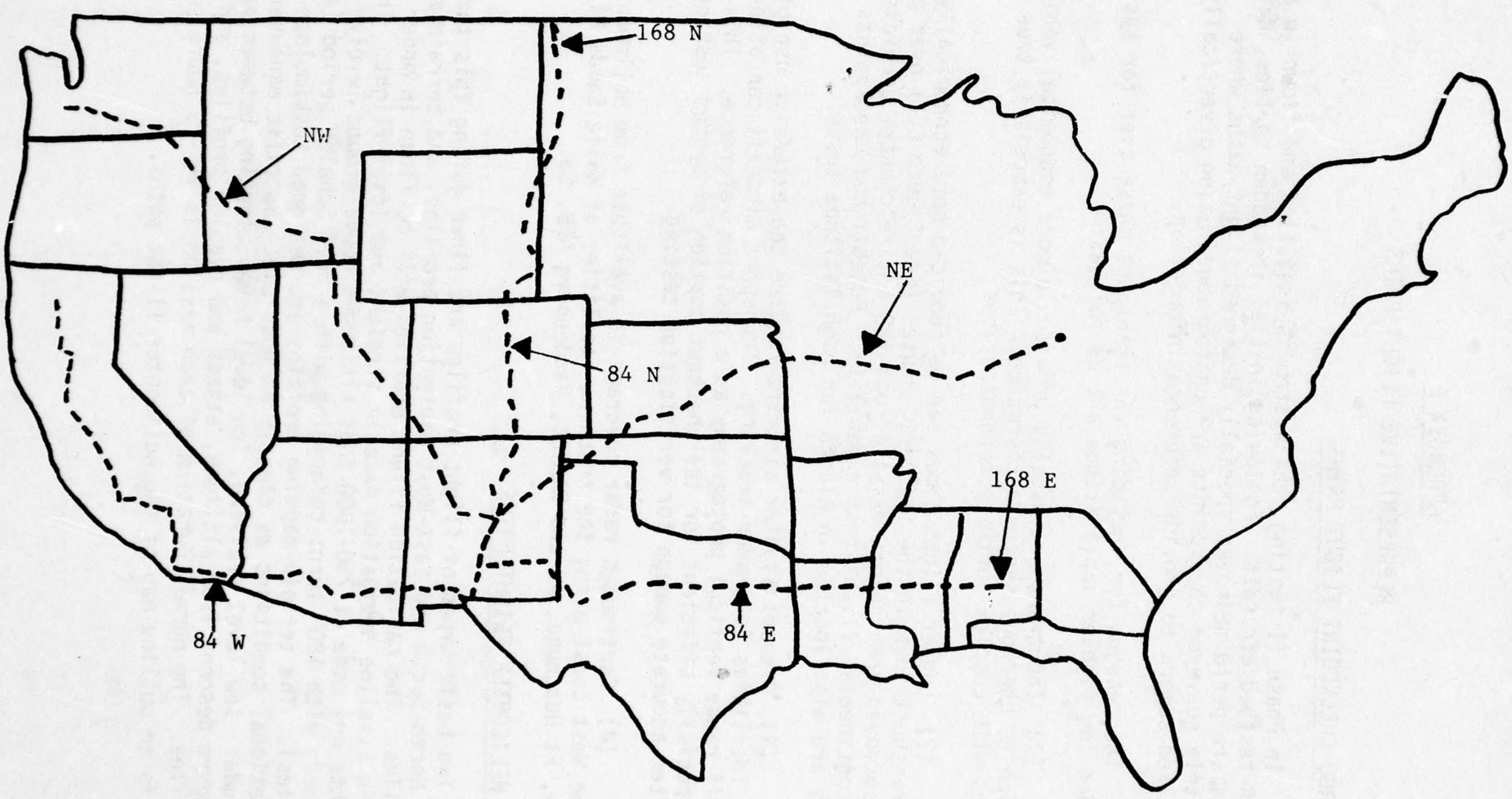


FIGURE E-1
CHECKPOINT PATHS

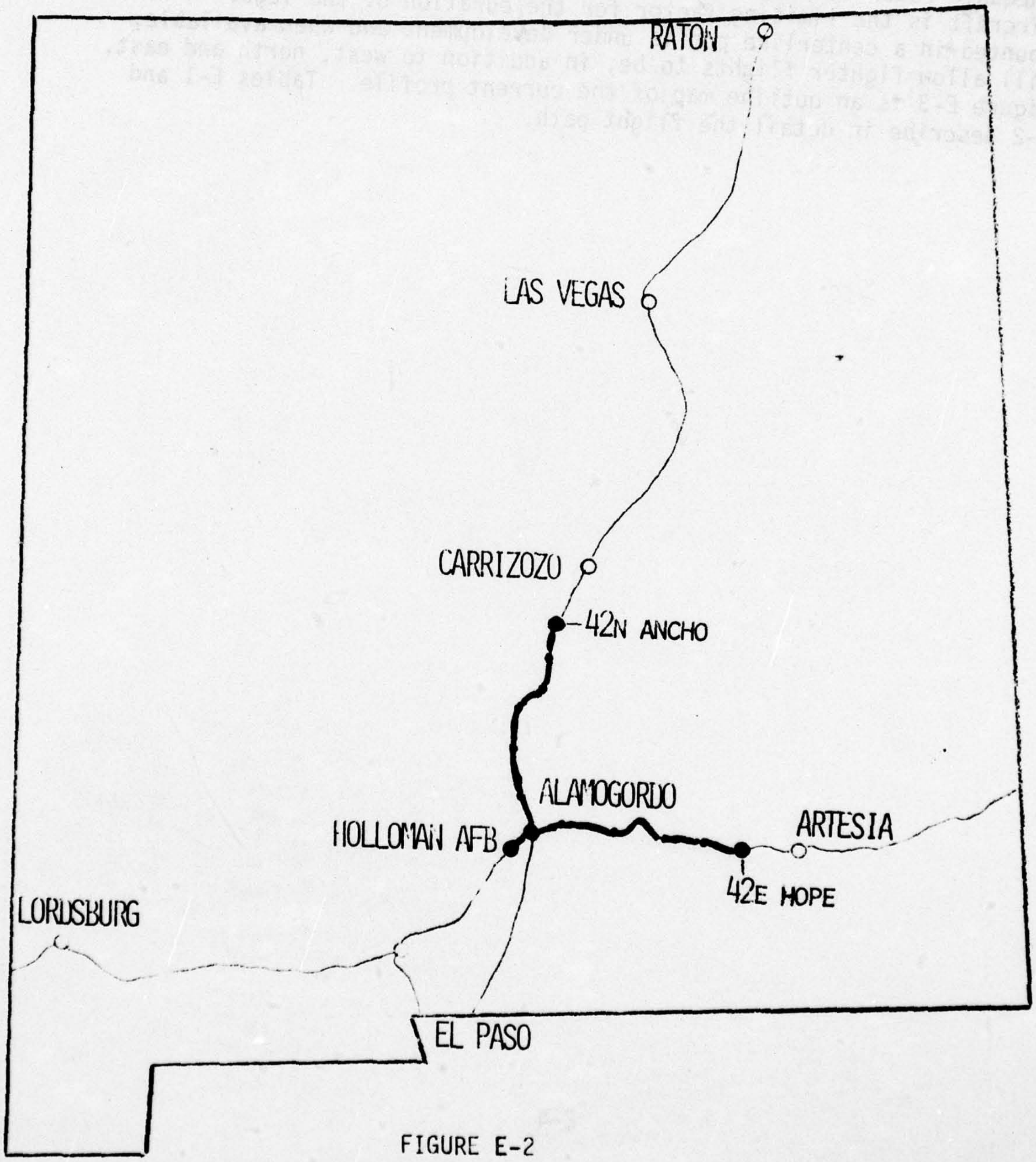


FIGURE E-2

HELICOPTER CHECKPOINT
FLIGHT PATHS

III. FIGHTER FLIGHT PATHS

Currently, the only available flight path for fighter aircraft is a west-east path from Holloman. West is the only direction with adequate radar coverage for the required 42 minute legs. The fighter aircraft is the limiting factor for the duration of the legs. A CIRIS mounted in a centerline pod is under development and when available, will allow fighter flights to be, in addition to west, north and east. Figure E-3 is an outline map of the current profile. Tables E-I and E-2 describe in detail the flight path.

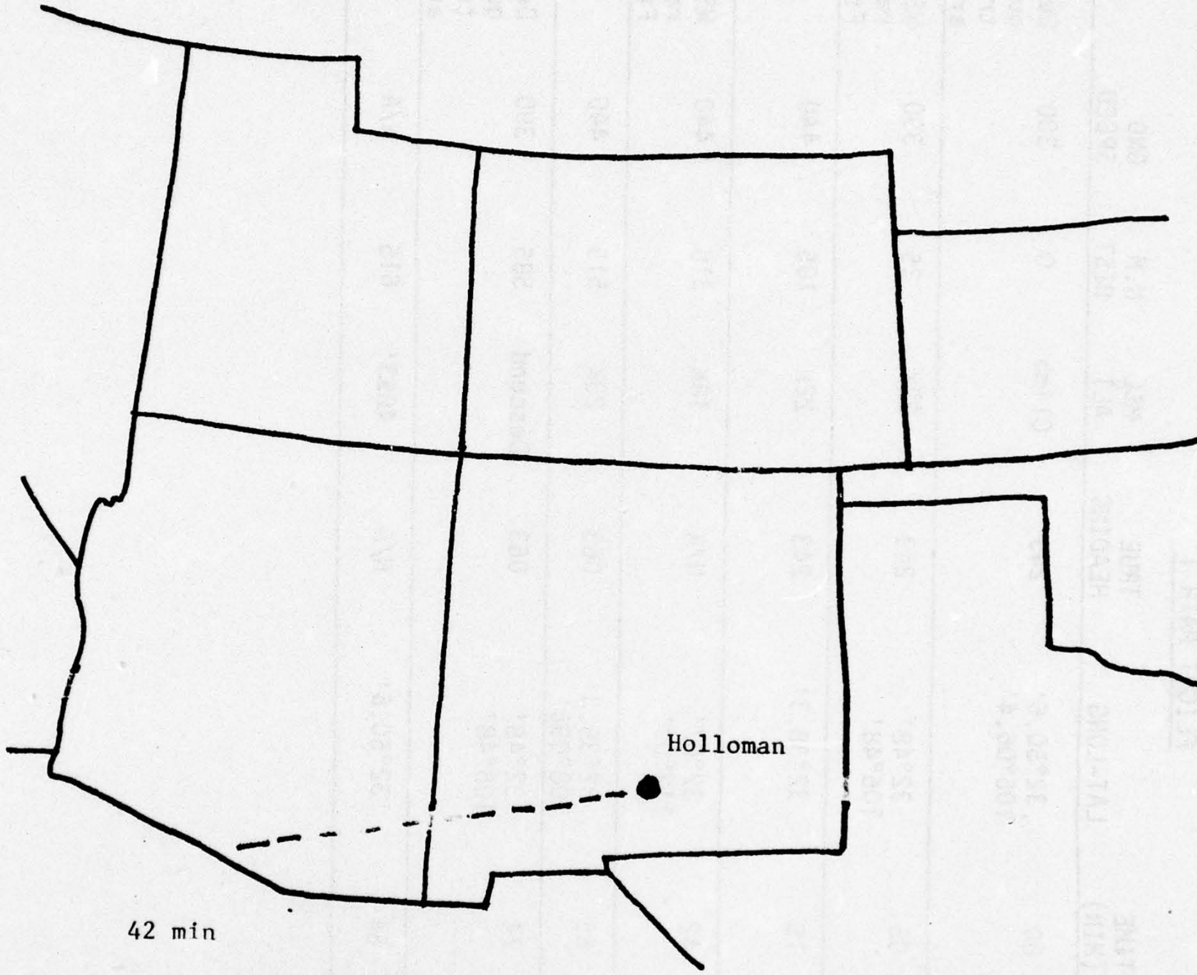


FIGURE E-3
FIGHTER FLIGHT PROFILE

TABLE E-I

FLIGHT PATH 1

EVENT	TIME (MIN)	LAT-LONG	TRUE HEADING	MSL ALT	N.M DIST	GND SPEED	REMARKS
1. Takeoff Holloman AFB Radar Coverage Begins	00	32°50.6' 106°06.4'	243	Climb	0	300	Deviations may be required in order to transit restricted area. R5107B.
2. Level off and exit R5107B	05	32°48' 106°48'	243	22K	35	390	WSMR coordinates for radar. Hand off with Ft. Huachuca.
3. Crossover Silver City VORTAC - Radar hand off to Ft. Huachuca	15	32°38.3'	243	22K	105	440	
4. Begin turn for return to Holloman	42	32°07' 112°09'	N/A	18K	310	440	WSMR coordinates for radar hand off with Ft. Huachuca.
5. Radar hand off to WSMR	65	32°38.3' 108°096'	063	23K	515	440	
6. Enter R5107B and Begin Descent	74	32°48' 106°48'	063	Descend	585	390	Deviations may be required in order to transit restricted area R5107B.
7. Land Holloman AFB Radar Coverage Ends	84	32°50.6'	N/A	4093'	615	N/A	

TABLE E-II

FLIGHT PATH 2

EVENT	TIME (MIN)	LAT-LONG	TRUE HEADING	MSL ALT	N.M DIST	GND SPEED	REMARKS
1. Takeoff Holloman AFB Radar Coverage Begins	00	32°50.6' 106°06.4	243	Climb	0	300	Deviations may be required in order to transit restricted area R5107B.
2. Level off and exit R5107B	05	32°48' 106°48'	243	22K	35	390	WSMR coordinates for radar hand off with Ft. Huachuca.
3. Crossover Silver City VORTAC - Radar hand off to Ft. Huachuca	15	32°38.3'	243	22K	105	440	
4. Initiate turn and begin ordnance delivery or air combat maneuvers.	42	32°97' 112°09'	N/A	10K to 18K	310	N/A	Max 5 g's, 9 minutes duration.
5. Return to Holloman	51	32°07' 112°09'	063	23K	310	440	WSMR coordinates for radar off with Ft. Huachuca.
6. Radar hand off to WSMR	74	32°38.3' 108°09.6'	063	23K	515	440	
7. Enter R5107B and begin descent	83	32°48' 106°48'	063	Descend	585	390	Deviations may be required in order to transit restricted area R5107B.
8. Land Holloman AFB Radar Coverage Ends	93	32°50.6'	N/A	4093'	615	N/A	

APPENDIX F

COMPUTATION OF PERCENTILES AND CONFIDENCE LIMITS OF RADIAL ERROR

1. The method of calculating the percentiles of radial errors and confidence limits for the means and standard deviations are presented in this appendix. Latitude and longitude errors are assumed to follow a normal distribution. The chi-square and t distributions as well as the theory of sampling statistics form the basis of these developments.

2. Definitions

X	latitude error
Y	longitude error
r	radial error
m	number of tests (sample size)
μ	population mean
σ^2	population variance
$\bar{q}$	sample mean
S^2	sample variance
n	degrees of freedom
R_p	p^{th} percentile of radial error
Z_p	p^{th} percentile point of a zero mean normal distribution

3. Estimate of the Percentiles of Radial Error

a. The first method used to calculate percentiles of radial error is based on the CIGTF Working Paper "Maximum Likelihood Estimate of the Distribution of Radial Error" by Francis J. Mason. The following is an outline of the method for obtaining the percentiles at each time point. Suppose at some point in time there are m radial errors (r_i; i=1, m) from the m corresponding flights in the sample.

(1) Calculate the geometric mean (GM) of the radial errors:

$$GM = \sqrt[m]{\Pi r_i} \quad \text{(F-1)}$$

(2) Calculate the root mean square (RMS) of the radial errors:

$$RMS = \sqrt{\frac{\Sigma r_i^2}{m}} \quad \text{(F-2)}$$

(3) Use Figure F-1 to compute R_p, the radial error corresponding to the p^{th} percentile.

(4) Figure F-1 is constructed in the following manner. Assume that the probability element for (r^2/a^2) is:

$$dp(r^2/a^2) = \frac{1}{2^{\frac{n}{2}} \Gamma(\frac{n}{2})} e^{-\frac{r^2}{2a^2}} \left(\frac{r^2}{a^2}\right)^{\frac{n-2}{2}} d\left(\frac{r^2}{a^2}\right) \quad \text{(F-3)}$$

This is a chi-squared distribution for the variable (r^2/a^2) where "a" is a normalizing factor and n is the number of degrees of freedom. $\Gamma(x)$ is of course the gamma function of x. To obtain the probability of a set of m observations (r_i) the product of the individual probabilities is formed.

$$P(\leq r) = \prod_{i=1}^{m} \frac{1}{(2a^2)^{\frac{n}{2}} \Gamma(\frac{n}{2})} e^{-\left(\frac{r_i^2}{2a^2}\right)} (r_i^2)^{\frac{n}{2}} \frac{d(r_i^2)}{r_i^2} \quad \text{(F-4)}$$

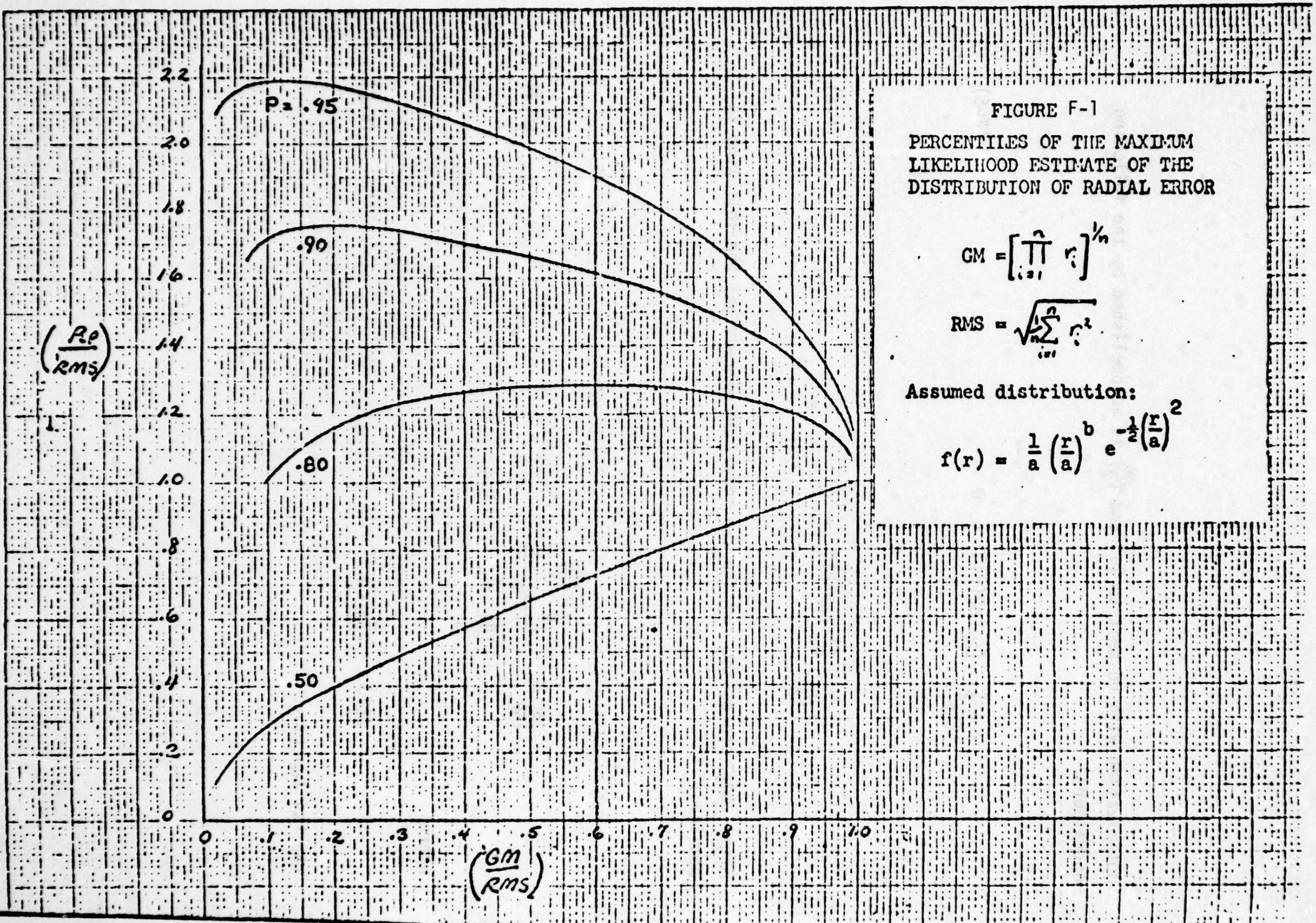


FIGURE F-1

PERCENTILES OF THE MAXIMUM LIKELIHOOD ESTIMATE OF THE DISTRIBUTION OF RADIAL ERROR

$$GM = \left[\prod_{i=1}^{n} r_i\right]^{1/n}$$

$$RMS = \sqrt{\frac{1}{n}\sum_{i=1}^{n} r_i^2}$$

Assumed distribution:

$$f(r) = \frac{1}{a}\left(\frac{r}{a}\right)^b e^{-\frac{1}{2}\left(\frac{r}{a}\right)^2}$$

Optimization with respect to $2a^2$ and $(\frac{n}{2})$ is accomplished by the following operations.

$$\frac{\partial}{\partial(2a^2)}\left[\frac{1}{m}\, \mathrm{Ln} P(\overset{<}{r})\right] = 0 \qquad \text{(F-5)}$$

and

$$\frac{\partial}{\partial(\frac{n}{2})}\left[\frac{1}{m}\, \mathrm{Ln} P(\overset{<}{r})\right] = 0 \qquad \text{(F-6)}$$

After some processing of the two resulting expressions the following is obtained:

$$\frac{GM}{RMS} = \frac{e^{\frac{1}{2}\psi(\frac{n}{2})}}{(\frac{n}{2})^{\frac{1}{2}}} \qquad \text{(F-7)}$$

where

$$\psi(Z) = \frac{d}{dz}\, \mathrm{Ln}\, \Gamma(Z) \qquad \text{(F-8)}$$

the Psi function.

It is further observed that since

$$\frac{r^2}{a^2} = \text{a chi-squared } (\chi^2) \text{ distribution}$$

and

$$\chi = \sqrt{\frac{\chi^2}{n}} = \text{a chi distribution}$$

that

$$\frac{r}{RMS} = \text{a chi distibution.}$$

The desired percentiles of this function are plotted versus n. The final step is to eliminate n between this plot and the plot of equation (F-7). The result is Figure F-1.

(5) For the 50th and 90th percentiles the following approximation may be used:

Let

$$R = \frac{GM}{RMS} \qquad \text{(F-9)}$$

then

$$R_{50} \approx \begin{cases} RMS\ (.89\ \ \sqrt{R}\ ) , & R \leq 0.2 \\ RMS\ (.78R + .25) , & R > 0.2 \end{cases} \qquad \text{(F-10)}$$

and

$$R_{90} \simeq \begin{cases} RMS[R + 1.6(1 - R^2)] \quad , \quad R \leq 0.6 \\ RMS(1 + \sqrt{1 - R}) \quad , \quad R > 0.6 \end{cases} \tag{F-11}$$

b. The second method used to calculate percentiles of radial error is based on a paper by L. L. Fosen and D. L. Harmer titled "Inertial System Performance Evaluation" which was presented at the Third Inertial Guidance Test Symposium at Holloman AFB, New Mexico, 1966.

(1) At each time point the percentiles of radial error are calculated from:

$$R_p = \sigma_y \sqrt{a(Z_p \sigma_z + \mu_z)^3} \tag{F-12}$$

σ_y, a, σ_z, μ_z are calculated from the following set of formulas:

$$\sigma_x \simeq S_x \sqrt{\frac{m}{m-1}} \quad ; \quad \sigma_y \simeq S_y \sqrt{\frac{m}{m-1}} \tag{F-13}$$

$$\mu_x \simeq \bar{x} \quad ; \quad \mu_y \simeq \bar{y} \tag{F-14}$$

$$K = \frac{\sigma_x}{\sigma_y} \quad ; \quad d = \sqrt{\mu_x^2 + \mu_y^2} \tag{F-15}$$

$$n = K^2(2-K^2) + 1 + \frac{2}{\sigma_y^2}(d^2 - \mu_x^2 \quad K^2 - \mu_y^2) \tag{F-16}$$

$$\lambda = K^2(K^2 - 1) + \frac{1}{\sigma_y^2}(2\mu_x^2 K^2 + 2\mu_y^2 - d^2) \qquad \text{(F-17)}$$

$$a = n + \lambda \quad ; \quad b = \lambda / a \qquad \text{(F-18)}$$

$$\mu_z = 1 - \frac{2}{9}\,\frac{1 + b}{a} - \frac{40}{81}\,\frac{b^2}{a^2} \qquad \text{(F-19)}$$

$$\sigma_z = \sqrt{\frac{2}{9}\,\frac{1 + b}{a} + \frac{16}{27}\,\frac{b^2}{a^2}} \qquad \text{(F-20)}$$

(2) The 50^{th} and 90^{th} percentiles are calculated from:

$$R_{50} \approx \sigma_y \sqrt{a\mu_z^3} \qquad \text{(F-21)}$$

$$R_{90} \approx \sigma_y \sqrt{a(1.28155\sigma_z + \mu_z)^3} \qquad \text{(F-22)}$$

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4. Confidence Limits on Means and Standard Deviations

At each time point the 100 (1 - α) percent confidence limits on the CEP are approximated by computing the upper and lower limits of the means and standard deviation as follows:

The statistic $\frac{\bar{q}_x - \mu_x}{\frac{S_x}{\sqrt{n}}}$ follows the "t" distribution.

Then the confidence limits on the means are set by:

$$\left| \frac{\bar{q}_x - \mu_x}{\frac{S_x}{\sqrt{n}}} \right| < t_{\frac{\alpha}{2}} \qquad \text{(F-23)}$$

where $t_{\frac{\alpha}{2}}$ is the appropriate percentage point of the "t" distribution.

It follows then that the limits are:

$$\bar{q}_x - \frac{S_x}{\sqrt{n}} t_{\frac{\alpha}{2}} < \mu_x < \bar{q}_x + \frac{S_x}{\sqrt{n}} t_{\frac{\alpha}{2}} \qquad \text{(F-24)}$$

Also the statistic $\frac{S^2}{\sigma^2} n$ follows the χ^2 distribution. Since the percentage points of the χ^2 and χ distribution are related by $\chi = \sqrt{\frac{\chi^2}{n}}$ the confidence limits for the standard deviations are set by

$$X_{\frac{\alpha}{2}} < \frac{S_x}{\sigma_x} < X_{1-\frac{\alpha}{2}} \quad \text{(F-25)}$$

or

$$\frac{S_x}{X_{1-\frac{\alpha}{2}}} < \sigma_x < \frac{S_x}{X_{\frac{\alpha}{2}}} \quad \text{(F-26)}$$

The upper and lower limits of the CEP (R_{50}) are computed by using the appropriate values of the mean and standard deviation in Equations (F-13) through (F-21).

5. References

a. Mason, F. J., Maximum Likelihood Estimates of the Distribution of Radial Errors, Working Paper, Central Inertial Guidance Test Facility, September 1965.

b. Rosen, L. L. and Harmer, D. L., Inertial System Performance Evaluation, Proceedings of the Third Inertial Guidance Test Symposium, Holloman AFB, New Mexico, October 1966.

c. Li, Jerome C. R., Introduction to Statistical Inference, The Science Press, Inc., PA, 1957.

APPENDIX G
CONTRACTOR SUPPORT

I. CONTRACTOR SUPPORT

a. The concept of operation for aircraft inertial navigation systems tests at the Test Group is "in-house." Air Force personnel not only manage and conduct the programs, but they also maintain (with contractor support) and operate the system. Successful operation and maintenance are dependent upon two factors:

(1) A minimum of two weeks schooling on the system is required at the contractor's plant. This training may be contracted and funded by Air Training Command for one engineer, one analyst, and two technicians. The course content should basically consist of (1/4 of time) system fundamentals and unique features, complete with navigation equations and transformation matrices; (2/4 of time) detailed and complete block diagram instruction, error analysis and troubleshooting techniques, all built-in-test-equipment (BITE) capabilities; and (1/4 of time) maintenance, calibration, and operation.

(2) Contractor technical and spares support is required at the Test Group. Air Force personnel cannot be experts on a specific system after a minimum amount of training; thus, one or two contractor personnel are required to support the test effort. Contractor personnel do not fly on test aircraft, nor do they become actively involved in the conduct of the test program. Spares support is necessary to aid completion of the tests in a timely manner.

b. Contractors supporting cargo and/or helicopter flight test programs at the Test Group should supply the following:

(1) The test system and interconnecting cables.

(2) A letter certifying that the system has been system safety engineered, that it meets or surpasses pertinent military standards and specifications, and that it represents no hazards for the proposed operational environment.

(3) A complete project equipment listing of all major system components. Weight, length, height, width and power requirements.

(4) A reproducible pin-to-pin system wiring interconnecting diagram is required. This drawing should clearly indicate any power carrying wires and their sizes.

(5) It is recommended that a power distribution box, complete with fuses or circuit breakers, an ON/OFF switch, and any other circuitry necessary to protect the system within its own individual power requirements, be supplied. If used, reproducible mechanical and electrical drawings are required for this unit.

c. Contractors supporting fighter flight test programs must furnish the Test Group with all of the above items, plus:

(1) One set of system major component 'mockups' complete with 'dummy' connectors. These 'mockups' should be outwardly identical to the test system.

(2) One complete set of system mating connectors. These items are used to facilitate the accomplishment of the fighter Class II Modification, in progress during the cargo or helicopter test phase.

d. In the eventuality that the test system must be returned to a contractor facility for calibrations or repairs, an Air Force representative is required to accompany it on verification test programs. On developmental programs this normally is not required. However, the Test Group requires a report on what was accomplished or discovered.

e. In the eventuality that a system subcomponent is returned to a contractor facility for repair or analysis, the Test Group requires that a detailed report be returned describing what was determined.

APPENDIX H

METHODS OF ENTERING FLIGHT TEST PROGRAMS

I. The basic requirement to initiate formal action by the 6585th Test Group is for the Government sponsor to send a letter, TWX, or preferably Universal Documentation System Forms 1 thru 9 requesting testing. Prior to the submission of a formal request for testing, informal communications via telephone, visits, etc., is highly encouraged. The current Autovon number for Guidance Test Division Operations Office is 349-2174 or 867-1110, Ext 5-2174. The commercial number is (505) 479-6511, Ext 5-2174. The mailing address is 6585th Test Group/GDP, Holloman AFB, NM 88330. The TWX address is 6585TG/GDP, HOLLOMAN AFB, NM.

II. Once communications is established with a customer, a Test Director from the Guidance Test Division Operations Office will be assigned. He will then be the focal point for communications and correspondence with the customer.

a. Upon receipt of formal request for testing by a customer, the Test Director, with the help of participating Test Group Divisions and/or outside agencies, will generate a Statement of Capability, Management Plan, or Engineering Services Plan (as appropriate) and will estimate the reimbursable expenses for the test.

b. Upon acceptance of the Statement of Capability, etc., by the customer and the receipt of a Project Order, MIPR, OA, etc., then active work in the project can start. Non-AFSC customers are required to obtain an AFSC Form 56 authorizing the 6585th Test Group to perform the test.

c. Help in preparing any of the documentation can be obtained by contacting the Guidance Test Division, Operations Office (GDP).

APPENDIX I

DESCRIPTION OF THE COMPLETELY INTEGRATED REFERENCE INSTRUMENTATION SYSTEM (CIRIS)

I. The Completely Integrated Reference Instrumentation System (CIRIS) (See Figure I-1) provides a highly accurate position, velocity and attitude reference over long flight paths for real-time use in testing guidance and navigation systems. The CIRIS is an airborne automated system that is operationally independent due to integration of all the reference measurement sources by minicomputers. CIRIS advances flight testing of navigation systems in two areas:

a. Highly accurate continuous reference data is usable for aircraft testing over long periods of time.

b. Real-time data provides immediate evaluation of systems under test.

II. CIRIS generates the reference data by using four measurment devices that are controlled and time-coordinated by a minicomputer to provide inputs to a 15-state Kalman filter. The real-time filtered reference data which is generated in a second minicomputer is distributed to test data acquisition computers and recorded with the raw measurement data on magnetic tape. Further processing (backward filtering and smoothing) can be done post-flight as required.

a. CIRIS data meets the following specification:

(1) Position accuracy to 13 ft (1 sigma) in three-axis.

(2) Velocity accuracy to .1 ft/sec (1 sigma) in three-axis.

(3) Attitude accuracy to 3 arc min (1 sigma).

(4) Real-time reference points every 10-15 seconds.

(5) Post-flight reference points every 2-4 seconds.

(6) Continuous reference for longer than 84 min in any direction (limited only by hardware availability).

Some of the specifications can experience slight degradation in some flight conditions which can be controlled if necessary. This data can be used for time correlated comparison with systems under test in their data acquisition computers. Real-time display and plot generations of test and reference data provide laboratory capabilities in a flight test environment.

b. The measurement hardware includes an inertial navigation system stabilized by barometric altitude from an Air Data Computer, a Doppler

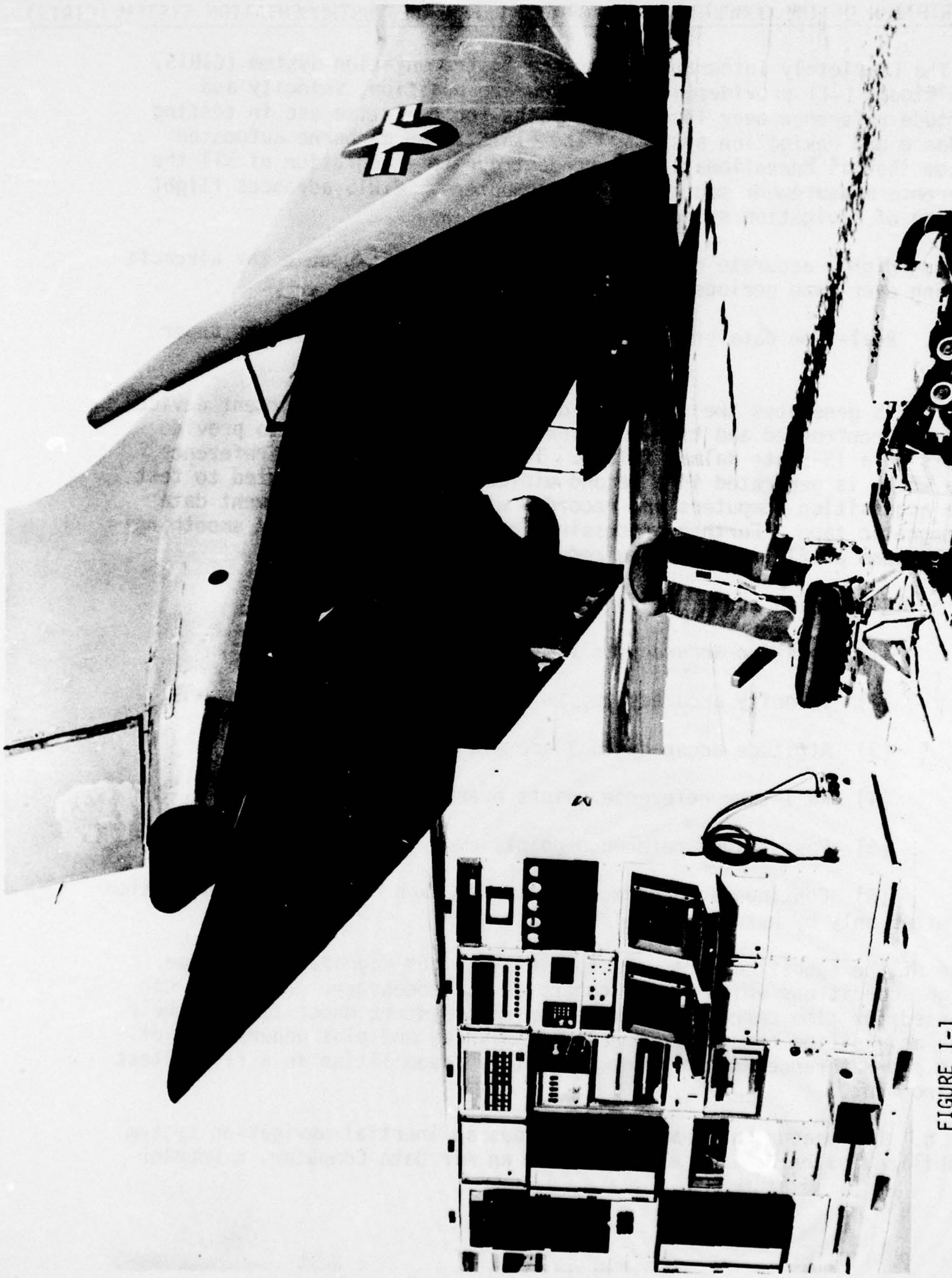


FIGURE I-1
COMPLETELY INTEGRATED REFERENCE
INSTRUMENTATION SYSTEM (CIRIS)

radar, and a precision radio range/range-rate system. The inertial system data is used in the filter as continuous reference for data propagation and reference for the filter error states. The error states are updated by incorporation of barometric altitude, doppler velocities, and precision range and range-rates to precisely surveyed ground sites. The CIRIS accuracies are directly dependent on the measurements obtained from the range/range-rate system which includes an airborne interrogator that is used to selectively interrogate one ground-base transponder every two seconds. A set of the four transponders nearest the current aircraft location is used to provide one redundant measurement in a time-phased triangulation scheme. The transponders and associated omni direction antenna are portable and are designed for remote operation. They are deployed in a triangular pattern separated by approximately 150 miles in a line along the flight path. CIRIS degradation can occur when flight paths leave areas of radio range coverage which extends to 200 nautical mile line-of-sight. Incorporation of doppler radar data will minimize degradation until radio coverage is resumed.

III. In summary, the CIRIS has provided a new dimension to planning navigation system flight testing. The advances in reference accuracies have influenced the methods of data analysis that are still being investigated. Real-time data comparison can impact test duration and operational independence has had a positive affect on schedules for testing state-of-the-art aided inertial navigation systems which require this precision reference.

APPENDIX J

CIGTF LABORATORY CAPABILITIES

1. INTRODUCTION

a. The accuracy demanded in aircraft inertial navigation systems requires a complete, detailed evaluation of all the components of the system. The CICTF has facilities available to test and provide meaningful laboratory evaluation of each component received for testing. This appendix provides test information on both gyroscopes and accelerometers. In addition, Section 4 and 5 define environmental system and star tracker tests.

b. The Guidance Test Laboratory has a capability to test strap down inertial systems on a precision two axis test fixture. Precision rate inputs about two axis can be put into the systems which are capable of checking the strap down system gyro torquer linearity and accuracy and also its maximum rate capability. These type tests are the only way in which a strap down system can be accurately evaluated to determine the gyro scale factor, and torquing linearity.

2. GYROSCOPE TESTS

a. In order to acquire a high level of statistical confidence in the evaluation of a specific type of gyroscope, it is advantageous to test more than one gyroscope. A typical gyro test program will last between one and three months, assuming three specimens are available and are tested simultaneously.

b. Subsystem Concept. To make testing conform as closely as possible to actual conditions, the subsystem concept is employed. A gyro mount is fabricated to simulate the actual navigator mounting structure in terms of mass, heat transmissability, and physical location of components. The navigator heater blankets and temperature controller are used to control mount temperature. In addition, where practical, excitation electronics identical to those to be used in the aircraft are used in testing.

c. Laboratory Tests. The following tests have been designed to investigate gyro performance in light of specific operational requirements of an inertial navigator. A single-degree-of-freedom gyro is assumed throughout; however, tests for a two-degree-of-freedom gyro are usually identical except for the additional orientations required for the two sensitive axes.

(1) Preliminary Tests. Preliminary tests consist of all tests necessary to check out the gyro, the gyro electronics, and the mating of the gyro to its mount and to the test table.

(2) Standard Torque-to-Balance (STB) Test. The standard torque-to-balance (STB) test is a tumbling test in which a rate-drive table is driven at a constant angular velocity such as twenty Earth rate. The gyro signal generator and torque generator are connected in the torque-to-balance mode. Sampling of the torque generator current provides data which yields the following information: drift coefficient magnitudes, wheel-on instabilities, and wheel-shutdown instabilities. This drift coefficient information can be used to computer compensate gyro drift in a navigator.

(3) Non-Compensable Drift Test:

(a) This test is performed with the gyro connected in the servo mode so that the signal generator output controls rotation of the test table. The table axis and the sensitive gyro axis are both horizontal or both vertical; thus, usual navigator component orientations are simulated.

(b) Compensation is applied for Earth rate and gyro drift. Then without any further adjustment of compensation, the gyro is allowed to drift for several hours. The drift rate measured after compensation is the non-compensable drift of the gyro which indicates the fixed position total drift rate wheel-on instability. This information could be used to establish optimum filter weights in a Kalman mechanization.

(4) Sensitivity Test.

(a) The sensitivity test indicates how variations in gyro operating and environmental parameters affect fixed position total drift without compensation for Earth rate and gyro drift. Again, the gyro is oriented as it would be in a navigator.

(b) The following parameters are varied one at a time above and below the normal values while the others are held at the normal value: wheel supply frequency, wheel supply voltage, gyro temperature, signal generator excitation voltage, external magnetic field, and gyro temperature gradients. The fixed position total drift rate is recorded at each parameter value and the results are usually displayed graphically.

(5) Environmental Tests.

(a) A gyro is subjected to three types of environmental tests while non-operating. These test simulate conditions that a gyro might undergo during shipment or between flights. The tests are: hot soak, cold soak, and mechanical shock. Immediately prior to and immediately after each environment an STB test is performed to measure any changes in the gyro drift coefficients caused by the environment.

(b) A fourth environmental test, mechanical vibration, is performed with the gyro operating in order to simulate aircraft vibration. The drift coefficients are evaluated before and after vibration to measure the effect of the test.

(6) Warmup Test.

(a) The purpose of this test is to determine the warmup characteristics of the gyro and, in particular, to determine the time required for the gyro to achieve stable operation after turn-on.

(b) The gyro is connected in the torque-to-balance mode and oriented with one axis vertical. Fixed position total drift rate and gyro temperature are recorded as a function of time while the gyro is heated to normal operating temperature. This information can be used to compute a warmup time, or to computer compensate the gyro output during warmup.

(7) Autocorrelation Test.

(a) The purpose of this test is to determine the autocorrelation function of the gyro fixed position total drift rate. The gyro is operated in the torque-to-balance mode with the spin axis vertical and the sensitive axis north. A compensation current is applied to hold the signal generator at its null position. After gyro temperature and drift rate have stabilized, the torque-to-balance current is sampled periodically. From this information the autocorrelation function can be computed.

(b) Typically, this autocorrelation function plotted versus time takes the form of a decaying exponential. The time constant of such an exponential is defined as the autocorrelation time of the gyro. This value determines the amount of time necessary to predict, with a known confidence level, the mean value of the gyro drift rate.

(8) Fixed Position Total Drift Rate and Torque Generator Scale Factor Test.

(a) This test gives information from which the fixed position total drift rate and torque generator scale factor magnitudes, wheel-on instabilities, and wheel-shutdown instabilities are obtained for navigator orientations.

(b) With the gyro connected in the torque-to-balance mode and the spin axis vertical, the sensitive axis is directed alternately north and south while the torque-to-balance current is recorded. Repetition of the test with the wheel-on and then with wheel-shutdowns allows computation of the above quantities. The test is repeated with the spin axis horizontal and the sensitive axis vertical to obtain the fixed position total drift rate for the other gyro orientation used in navigators.

(9) Torque Generator Scale Factor Long Term Instability Test. Since the torque generator scale factor is not frequently updated, it is important that this scale factor be stable. The standard deviation of all determinations of the torque generator scale factor during a test series is computed and defined as the scale factor long term instability.

(10) The TTCRP is an experimental device in which a gyroscope may be precisely counterrotated up to a level of approximately 8 g's. This test is designed to determine if the gyroscope has linear of non-linear g^2 terms in this G range. If it is suspected that the gyroscope will be used in an application above 8 g's for any time period the instrument may be placed on the 260 inch centrifuge and the g^2 term and possibly the g^4 term may be extracted from the data. The 260 inch centrifuge accuracy is in a continuous improvement program and testing accuracy is constantly improving.

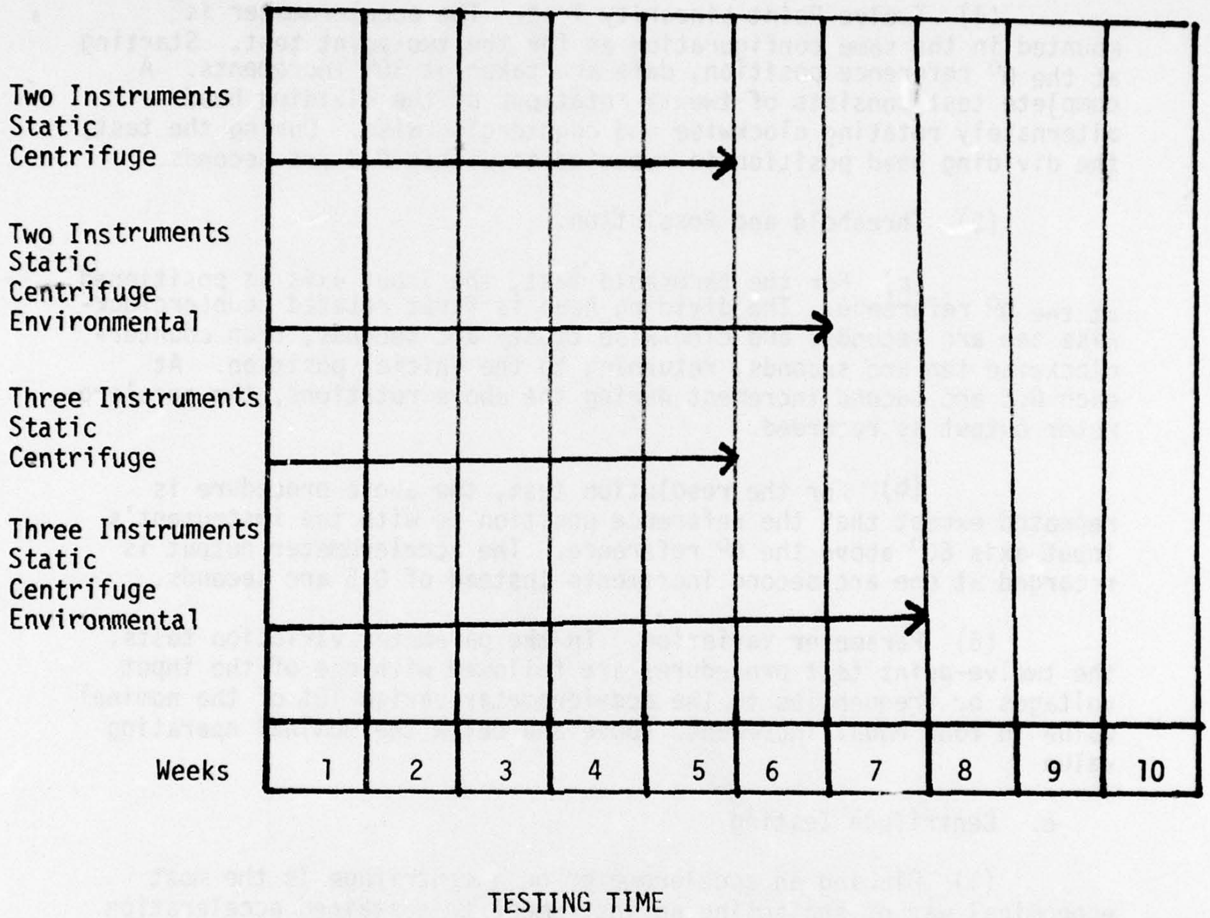
3. ACCELEROMETER TESTS

a. In order to acquire a high level of statistical confidence in the evaluation of a specific type of accelerometer, it is advantageous to test from two to three accelerometer specimens. A typical accelerometer test program, as described below, will last between one and two months (see Figure B-1).

b. Static Testing. Static testing consists of conducting the following tests in a 1g environment.

(1) Initial Checkout. The initial checkout consists of a visual check for damage in shipment, a continuity check for any open or shorted electrical circuits in the instrument, and an operational check where power is supplied to the instrument and the output is monitored.

(2) Input Axis Alignment. The accelerometer is mounted on a dividing head with its input axis nominally in the dividing head plane of rotation and its output axis nominally perpendicular to that plane. In this configuration, the input axis is constrained to rotate in the local gravity field. The dividing head is then rotated $180^{\circ} \pm 0.3$ arc seconds and the output again recorded. The dividing head position is then adjusted until the accelerometer output equals the average of the above two recorded outputs. The above sequence is repeated until equal outputs are obtained, indicating that the input axis is horizontal. The final position with the input axis horizontal and the pendulous axis directed down is noted as the 0° reference position, and the dividing head angle is noted as the reference angle.


Two Instruments
Static
Centrifuge
Two Instruments
Static
Centrifuge
Environmental
Three Instruments
Static
Centrifuge
Three Instruments
Static
Centrifuge
Environmental
Weeks
1
2
3
4
5
6
7
8
9
10
TESTING TIME

(3) Two-Point Test. The accelerometer is mounted on the dividing head in the same position as for the input axis alignment sequence and an input axis alignment is performed. The accelerometer output is then recorded with the input axis positioned alternately at the 90^{o} and 270^{o} reference positions (corresponding to +1 and -1 g acceleration inputs, respectively). Twenty rotations are performed per test.

(4) Twelve-Point Linearity Test. The accelerometer is mounted in the same configuration as for the two-point test. Starting at the 0^{o} reference position, data are taken at 30^{o} increments. A complete test consists of twenty rotations of the dividing head, alternately rotating clockwise and counterclockwise. During the test, the dividing head position is repeated to within 0.3 arc seconds.

(5) Threshold and Resolution.

(a) For the threshold test, the input axis is positioned at the 0^{o} reference. The dividing head is first rotated counterclockwise ten arc seconds, and clockwise twenty arc seconds, then counterclockwise ten arc seconds, returning to the initial position. At each 0.5 arc second increment during the above rotations, the accelerometer output is recorded.

(b) For the resolution test, the above procedure is repeated except that the reference position is with the instrument's input axis 60^{o} above the 0^{o} reference. The accelerometer output is recorded at one arc second increments instead of 0.5 arc seconds.

(6) Parameter Variation. In the parameter variation tests, the twelve-point test procedures are followed with one of the input voltages or frequencies to the accelerometer varied 10% of the nominal value in four equal increments above and below the nominal operating value.

c. Centrifuge Testing

(1) Placing an accelerometer on a centrifuge is the most economical way of subjecting an instrument to sustained acceleration above 1 g. Also, by accurately controlling the rotation of the centrifuge arm, very precise readings of the accelerometer output can be obtained.

(2) The accelerometer output is recorded over a 20 g range in increments of 1 g to determine departure from linearity. However, the centrifuge has a 25 g range with an infinite number of steps to 25 g's.

d. Environmental Testing. Environmental tests are accomplished to determine if the accelerometer can operate correctly after being subjected to established extremes in temperature, vibration, and mechanical shock. The test extremes are set by military specifications as follows:

(1) Hot Soak, MIL-E-5272C, Para 4.1.2.

(2) Cold Soak, MIL-E-5272C, Para 4.2.2.

(3) Vibration, MIL-T-5422E, Para 4.2.1, Part II.

(4) Mechanical Shock, MIT-T-5422E, Para 4.3.2.1.

4. SYSTEM ENVIRONMENTAL TESTS

a. These tests determine the sensitivity of a system to selected environmental factors. Tests are conducted with the system in both operating and nonoperating conditions. Calibrations are performed prior to and after environmental testing, and between individual tests. Performance degradation is determined by comparison of these calibrations and by comparison of position and velocity error plots made during navigation runs in operating condition tests.

b. Because the environmental specifications to which systems are designed vary, these test outlines include only the ranges of environmental conditions which can be achieved. Tests will be tailored to meet specific equipment design specifications. Low pressure altitude tests are run if the operational configuration makes this type of test meaningful. Dynamic performance coefficients or other non-linear (G^2 terms) are evaluated at appropriate vibration levels and discrete frequencies with a sine wave input. Thermal shock is run to simulate takeoff and rapid ascent to high altitudes where the temperature is low.

(1) Temperature Variation (Non-Operating System)

(a) Low Temperature. The entire system is placed in an environmental chamber and the temperature reduced to the specific level. After thermal stabilization, the temperature is returned to room ambient. System warm-up time is recorded and plotted.

(b) High Temperature. The entire system is placed in an environmental chamber and the temperature increased to the specified level. After thermal stabilization, the temperature is returned to room ambient. System cool-down is recorded and plotted.

(c) Maximum Temperature Variations: -100°F to +200°F.

(2) Temperature-Altitude Simulations (System Operating)

(a) Low Temperature. With the system operating in an environmental chamber, the temperature is reduced to the specified level. Pressure is then reduced to the equivalent of the specified altitude. After thermal stabilization, system performance is monitored during a bench navigation run. The temperature and pressure are returned to room ambient.

(b) High Temperature. With the system operating in an environmental chamber, the temperature is increased to a specified level. After thermal stabilization, system performance is monitored during a bench navigation run. The temperature is then returned to room ambient.

(c) Maximum Variations: Temperature, -100°F to +200°F, Altitude, 0 to 220,000 feet.

(3) Vibration Tests

(a) Magnetic Shaker.

1. This test determines the effect of linear vibration on the system in both operating and non-operating conditions.

2. The tests are performed with one major unit of the system at a time on the vibration table.

3. In the operating condition, the major unit being vibrated is connected and operated with the remainder of the system.

4. Prior to this test, a sweep is made at a reduced vibration level to identify critical resonance frequencies.

5. Vibration Capacity: 0 to 5,000 pounds force

(b) Angular Vibration.

1. This test is designed to evaluate the response of the system to simulated low altitude flight conditions. The system is operated on the Controlled Platform Test Stand which produces angular vibration about three axes simultaneously.

2. Frequency Range: 1/2 to 21 cps

3. Amplitude of Vibration: ± 4°

4. Phase and amplitude of vibration about each axis are independently adjustable.

(4) Mechanical Shock Test. This test is designed to evaluate the ability of the system to withstand mechanical shock, and is performed by arresting major units after a specified period of free fall. Shock is applied along specified axes of the units.

(a) Shock Pulse Shape: Half sine wave.

(b) Duration: 11 ± 1 milliseconds

(c) Capacity: 800 pounds - 12 g maximum
25 pounds - 200 g maximum

(5) Centrifuge Test. A 260-inch centrifuge with a counter-rotating platform is available for special tests. This facility provides the following capability:

(a)	Acceleration	0.25 - 85 g (5.8 - 106 rpm)
(b)	Accuracy	5 ppm
(c)	Payload	800 lbs

5. STAR TRACKER TESTS

a. Standard star tracker tests are listed below in terms of the capabilities of the CIGTF Stellar Simulator. The simulator consists essentially of a fixed Dual Star Simulator (DSS) and a movable Single Star Simulator (SSS).

(1) Spectral Response. This test determines the electro-optical sensitivity of the sensor to energy contained within defined wave length bands.

(a) The Stellar Simulator provides radiation between 0.35 and 1.0 micron wave lengths at 0.02 micron increments.

(b) To perform the test, the simulator intensity is set at a calibrated level and relative output of the sensor is plotted versus wave length as the simulator wave length is varied.

(2) Window Refraction. The refractive properties of the window (housing) are determined by repeating the spectral response test for different orientations of the sensor line of sight with respect to the position of the simulated star.

(3) Sky Background Polarization. This test determines the effect on performance of noise due to sky background polarization. The simulator can simulate a star on a sky background polarized between 0° and 180°.

(4) Sensitivity to Star Fluctuation. Sensitivity to "twinkling" is measured by plotting sensor response against the frequency of modulation of star intensity. This modulation frequency is variable between 0 and 100 cps.

(5) Star Magnitude Discrimination. The simulator can simulate two stars of variable magnitude and separation. Magnitude discrimination is evaluated by positioning two stars within the sensor's search field. Star magnitude is variable between -2.0 and +5.0 VM. The magnitude of one star is set at a programmed value which the sensor is commanded to seek. The magnitude of the other star is then adjusted until the sensor is unable to detect the difference in magnitude.

(6) Star Magnitude Versus Background Tracking Ability. This test is performed by positioning stars of various magnitudes against sky backgrounds of various intensities. The star brightness is then decreased until the system can no longer acquire and track the star. A plot is then made of star magnitude versus sky brightness at which the system fails to track the star.

(7) Sky Gradient Rejection Capability. The sky background of the DSS can simulate brightness gradients of 0, 2.5, 5.0, 10.0 and 20.0 percent per degree. The system is evaluated on its ability to sense and subtract sky gradient by requiring it to acquire and track stars against various gradients.

(8) Search Rate. Search rates are measured by plotting tracker angle encoder angle versus time for various star magnitudes.

(9) Mechanical Pointing Resolution. This test determines the minimum star displacement that can be detected by the star tracker. It is performed by allowing the tracker to acquire a stationary star and then displacing the star in one arc second increments along elevation and azimuth axes until the tracker realigns itself.

(10) Tracker Pointing Accuracy. This test determines the readout accuracy of the azimuth and elevation angle encoders. The test is performed by recording and plotting encoder output versus position of a simulated star.

(11) Field of View Size. This test is designed to evaluate the field of view of the tracker through the system (platform) housing. A star is positioned near the edge of the assumed field of view. The elevation angle is then reduced until the star is no longer detected by the tracker. This procedure is repeated at 30° increments through a 360° azimuth rotation of the tracker, and a polar plot made. A similar procedure is followed to determine the field of view at the upper elevation angle limit of the tracker.

(12) Telescope Line of Sight (LOS) Stability. The tracker is positioned with the LOS collinear with the optical path to a simulated star. Angle encoder output is monitored during warm-up and changes in the ambient environment.

(13) Misalignment of Star Tracker Reference Frame to System (IMU) Coordinates. The platform gimbals are locked with X and Y accelerometers horizontal. The tracker LOS is then aligned with a simulated star. Encoder outputs are recorded as the platform is rotated through 360° in 30° increments. The turntable on which the platform is mounted can be positioned to an accuracy of better than one arc second.

(14) Double Star Detection. The DDS can simulate two stars of different magnitudes from superposition to a separation of 4^{o}. This test evaluates the ability of the star tracker to detect, acquire, and track dual stars of varying magnitudes and separation.

(15) There is a capability within the laboratories to test star tracker equipment against actual live stars in Room 14 of the Celestial Inertial Laboratory. A cylindrical hydraulic cylinder can be positioned vertically and locked in position on which the star tracker can be mounted. The base motion of this locked cylinder is in a region of a few micro inches. The CIL also has a very precision north reference system with which a star tracker pointing accuracy can be checked periodically. Being at an altitude of approximately 4,000 feet allows an excellent opportunity to check star tracker's against actual stars with their sky background. This in conjunction with the star simulator, provides a very excellent combination of simulation and actual star tracker operation.