U. S. ARMY
TRANSPORTATION RESEARCH COMMAND
FORT EUSTIS, VIRGINIA

TRECOM TECHNICAL REPORT 63-10

Automatic Light Aircraft Readiness Monitor

Project ALARM

VOLUME I

Project 9R89-02-015-16
Contract DA 44-177-TC-641

January 1963

prepared by :

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HEADQUARTERS
U S ARMY TRANSPORTATION RESEARCH COMMAND
Fort Eustis, Virginia

This report is a discussion of the results of an investigation to determine the feasibility of using an Automatic Light Aircraft Readiness Monitor at the first and second echelons of maintenance. The report also includes discussion of an onboard flight unit.

The report includes data derived from a limited test program and an analysis of these test results.

An adequate test program could not be accomplished because amplitudes of vibration, pressure, and temperatures representing or indicating a normally operating aircraft are not known. Go/no-go limits may not be established until the levels indicating normal operation are determined, especially the vibratory and temperature levels.

Therefore, the conclusions expressed by the contractor are not based on proven test results but rather on an indication of feasibility arrived at by review of engineering test data and by applying engineering experience for interpretation.

The recommendations made by the contractor are not concurred in by this Command. This Command recommends that, before any additional work is undertaken in the application of an ALARM system to Army aircraft, a test program be accomplished to establish the normal levels of a go/no-go condition for a specific model aircraft so that the value of an ALARM system may be truly established.

This Command recommends that these tests to establish normal levels be conducted on a late-model helicopter (UH-1B or CH-47A) to expedite future efforts of development required for incorporation of ALARM in the Army system.

FOR THE COMMANDER:

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Task 1D141812D18416
(Formerly Task 9R89-02-015-16)
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TRECOM Technical Report 63-10
January 1963

Project ALARM
AUTOMATIC LIGHT AIRCRAFT READINESS MONITOR

Phase II Test Program

VOLUME I

Prepared by:
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U. S. ARMY TRANSPORTATION RESEARCH COMMAND
FORT EUSTIS, VIRGINIA

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FOREWORD

This document, TRECOM Technical Report 63-10, Volume I, represents the final report for Phase II, Test Program, Project ALARM. The information includes discussions of program objectives, installation, test procedures and test results obtained during the course of this segment of the over-all ALARM program. In addition, specific conclusions and recommendations are presented, predicated upon the factual information derived from the various tests and technical research.

The complete report is published in three separate volumes. Volume I contains the detailed report; Volume II, Appendices; and Volume III, Addendum (Reinstallation).

The project code name, ALARM, is derived from the nomenclature for the electronic checkout system which is "Automatic Light Aircraft Readiness Monitor". The program was conducted by the York Division of The Bendix Corporation for the United States Army Transportation Research Command: C. A. Malami, project officer. The over-all operation of Phase II, Project ALARM, was under the direct supervision of D. E. Myers, project engineer.

The program was initiated 1 June 1960, under Contract DA 44-177-TC-641 and was organized to support the determinations set forth in Staff Study, Project 9R-38-01-017, House Task 12.129, dated February 1960.

Special acknowledgement is made of the technical support provided by all USATRECOM personnel during the course of Phase II, Project ALARM.

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SUMMARY

TRECOM Technical Report 63-10, Volume I, Volume II, and Volume III, describes in detail all results obtained during the course of Project ALARM test program. The documentation includes supporting data, graphs, photographs, and tables pertinent to the tests, together with miscellaneous observations made during the program. In addition, a complete schematic diagram of the ALARM control display system is incorporated as Figure 81, Volume I.

The fundamental objective of the Phase II test and report has been to establish and record the feasibility and utility of all concepts of aircraft condition monitoring provided in the breadboard ALARM experimental system. Based upon the results as detailed herein, conclusions and recommendations are provided as they relate to this objective.

For convenience, the information has been arranged in a manner considered to be the most practical for a report of this nature. In addition, a chronological summary of the test program effort is presented in tabular form. This documentation identifies significant program dates and events together with a summary of the total accumulated test time utilized in compiling the data described in this report. This information is identified in Table I, "Test Program Chronological Summary".

TABLE I

TEST PROGRAM CHRONOLOGICAL SUMMARY

Date	Project Phase or Event	Hours Accumulated Test Time: Data Flights	Ground Runs	Misc.
1/31/61	Arrival of A/C from USATRECOM			
2/1-28	ALARM System Installation			
3/1-8	Functional Testing		2.0	4.0
3/9-12	Operational Testing	5.0		1.0
3/13 to 4/12	A/C Grounded (TWX on T/R Slider)			
4/14-19	ASAP - Ft. Eustis			2.0
4/21-24	Operational Testing	3.0	1.0	
4/25, 26	DOD Briefing and BxY			1.0
4/27, 28	A/C Maintenance at NCGD			
5/1-3	A/C Grounded (EDP-T/R System)			
5/4-9	Operational Testing	6.0	2.0	4.5
5/10-6/5	A/C Grounded (EDP-T/R Hub Assy.)			
6/5-9	Operational Testing	8.5	3.5	8.0
6/12	A/C Maintenance at NCGD and Photos			
6/13-20	Flight Testing (24 Hour)	21.8	2.0	2.0
6/21	A/C Grounded (Exhaust Drain and Scissors Assy.)			
6/22, 23	Flight Testing (24 Hours)	2.0	0.5	
	SUBTOTALS	46.3	11.0	22.5
6/26, 27	ALARM System Modifications			
6/28	A/C to NCGD for Malfunction Tests			
6/28 to 9/22	Malfunction Testing	0.5	40.0*	10.0
9/25	Test Effort Halted at NCGD			

* 30 Hours recorded test time plus 10 hours unrecorded estimate.

TABLE I

TEST PROGRAM CHRONOLOGICAL SUMMARY (Cont'd)

Date	Project Phase or Event	Hours Accumulated Test Time: Data Flights	Ground Runs	Misc.
9/25 to 10/9	Preparations for Resumption of Testing at BxY			
10/10	A/C Arrival at BxY			
10/12 to 11/10	Malfunction Testing		26.0	10.0
11/21, 22	ALARM System Modifications			
11/27, 28	Concluding Malfunction Tests		1.0	1.0
	TOTALS	46.8	88.0	43.5
12/1/61	Transportation of A/C to NCGD for maintenance and return to Flight Status			
12/4/61 to 1/15/62	ALARM System Modifications at BxY			

CONCLUSIONS

It is concluded that the following areas of an HU-1 aircraft can be successfully instrumented for automatic electrical inspection:

1. All interlock arrangements with the exception of the Cabin Top Antenna Cover and the Crew and Cargo doors

2. Liquid Levels, (Engine Oil, Transmission Oil, 90° Gear Box Oil, 42° Gear Box Oil)

3. Chip Detectors, (Engine, Transmission, 90° Gear Box, 42° Gear Box)

4. Filter Bypasses (Fuel, Engine Oil, Transmission Oil)

5. All Temperature Channels (as modified)

In addition, pending results of current redesign investigations, feasibility is established for the following areas:

1. Transmission Pressure Relief Valve Monitor

2. Engine Over-Speed Detector

3. Engine Oil Flow (for leakage — 1 pint/minute, at 6400 rpm only)

4. All Vibration Channels (as modified)

In determining feasibility and adaptability to an ALARM System, factors such as weight, circuit complexity, reliability, repeatability, cost, and maintenance aspects have been considered.

Utility considerations, investigated as a separate aspect of the evaluations, involve factors including inspection time savings, increased safety-of-flight, improved inspection accuracy, and/or malfunction prediction capability (MPC). Utility of a channel is defined as having adequately satisfied one or more of these factors. It is concluded that this has been established for the following areas (utility factor involved is included in the parenthesis):

1. Interlocks (time saving, safety-of-flight)

2. Liquid Levels (time saving)

3. Chip Detectors (time saving, safety-of-flight, MPC)

4. Filter Bypasses (time saving)

5. All Vibration Channels (safety-of-flight, improved inspection accuracy, MPC)

6. All Temperature Channels (safety-of-flight, improved inspection accuracy, MPC)

7. XMSN Pressure Relief Valve Monitor (safety-of-flight, improved inspection accuracy)

8. Engine Over-Speed Detector (improved inspection accuracy)

9. Engine Oil Flow Monitor (safety-of-flight)

It is further concluded that the techniques involved in these areas apply equally well on any aircraft, fixed or rotary wing. Specific evaluation of each aircraft type would be required to permit proper definition of Go/No-Go levels in the areas of vibration and temperature, but basically the techniques apply.

It is difficult to accurately evaluate the amount of pre- and post-flight inspection time saved by the ALARM system. This is due to the fact that when comparing present checkout procedures with the procedure utilizing ALARM, it is necessary to include certain visual inspection steps with ALARM because of unmonitored inspection requirements. Time is saved since all channels identified previously as satisfying the "time saving" utility factor are direct, instantaneous automation of a visual inspection. It is difficult to stipulate time saved precisely because of the indirect condition-monitoring performed by such channels as vibration and temperature. These channels may, in fact, warn of abnormal conditions which may not be detected during visual inspection. Aircraft condition is better known through utilization of ALARM equipment, regardless of the time saving aspect.

Specific areas which have been determined to be incompatible to ALARM checkout philosophy are reported in detail in TREC Technical Report 60-49 for Phase I, Project ALARM.

RECOMMENDATIONS

It is recommended that all concepts as incorporated in the ALARM System be considered feasible, useful techniques for automatic inspection of aircraft.

It is further recommended that a minimum of two additional ALARM Systems be provided for installation and evaluation for each type aircraft to further substantiate and advance the capability of an automatic light aircraft readiness monitor.

It is also recommended that the magnetic chip detectors for the main transmission and the 42^{o} gear box of the HU-1A aircraft, be relocated in accordance with the finding of this report. In addition, it is recommended that the filter bypass setting be changed from the present 50% bypass flow to indicate bypass valve opening.

The recommendation is made to increase the scope and depth of the automatic light aircraft readiness monitor to include but not limited to the following:

1. Installation of additional temperature, pressure, interlock/continuity and vibration sensors.

2. Investigation of additional means to detect fuel and oil leaks at all engine rpm.

3. Addition of channels to monitor the following:

   (a) Engine over temperature (HOT START)

   (b) Engine flame out

   (c) Smoke and flame detection

   (d) Overtorque indication

4. Installation of strain gages to determine feasibility as an inspection tool.

5. A revised inspection procedure be evolved based on the capability of the ALARM System.

6. It is also recommended that a research and study program be initiated to implement sensors into the aircraft during the aircraft design stage.

INTRODUCTION

TEST PROGRAM OBJECTIVES

The objectives of the test program conducted on the ALARM breadboard system were primarily those involving a determination of the utility and reliability of the various monitoring techniques as applied to the HU-1 test-bed aircraft. A detailed discussion and analysis of the objectives are contained in TREC Report 60-49 for Phase I, Project ALARM. On ascertaining the aspects of each individual channel in the system, the over-all ALARM concept could then be evaluated with respect to the four primary objectives of the program, which were:

1. Automation of present pre- and post-flight inspection procedures.
2. Elimination of error and oversight in inspections.
3. Provision of in-flight monitoring capability for critical safety-of-flight items.
4. Detection of impending rather than actual failure in applicable areas.

Reliability observations were conducted during the entire test program, to determine the ability of all components of the system to continuously perform properly without any readjustment, relocation or replacement. Where failure to meet this objective occurred, immediate modifications were investigated and incorporated. If the modification became extensive and involved redesign which would have delayed the test program, appropriate documented recommendations were provided.

Utility testing of channels in some areas was a direct observation of channel operation which provided satisfaction of one or more of the system's primary objectives. This group included all interlock, liquid level, and filter bypass channels.

Another group of channels required evaluation of their adequacy to perform the intended monitoring function even though the technique satisfied one or more of the main program objectives. These included the chip detectors, engine speed monitor, and engine oil flow channel.

Finally, the major group of channels concerned with utility testing included those which monitored various dynamic parameters as a means of detecting deficiencies in the power plant and drive systems. Here part of the test objective was necessarily concerned with an evaluation of how these various parameters change as component deterioration occurs, then to determine whether or not the system's capabilities permitted these changes to be detected and used as aircraft "NO GO" indications. This group included the transmission pressure relief monitor, all vibration channels, and all temperature channels.

This report will relate the various procedures used and results obtained in the performance of the objectives.

SYSTEM INSTALLATION

The test-bed aircraft (JHU-1 S/N 57-6103) arrived at Bendix York on 31 January 1961. During the period 1 February 1961 through 28 February 1961 the entire breadboard ALARM System was installed by project personnel with the assistance of a qualified Army helicopter maintenance specialist.

Appendix I appearing in Volume II of this report provides installation locations and details of all ALARM sensors installed in the aircraft. For convenience, the installation drawings appear in the following order:

1. E1676475 - Installation, Interlocks, Control Display Box, Power Supply
2. E1676492 - Installation, Engine Oil Level Sensors
3. C1676474 - Installation, Fuel Filter
4. C1676468 - Installation, XMSN Pressure Relief Valve
5. D1676466 - Installation, 42^{o} Gear Box Sensors
6. D1676465 - Installation, 90^{o} Gear Box Sensors
7. C1676487 - Installation, Engine Sensors
8. D1676467 - Installation, XMSN Accessory Gear Box Sensors
9. D1676469 - Installation, XMSN Temp. & Vib. Sensors
10. C1677335 - Installation, Tail Vibration Sensor
11. C1677334 - Installation, Low Frequency Vibration Sensor
12. C1677339 - Installation, Engine Oil Flowmeter
13. D1677336 - Installation, XMSN Input Quill Temp. Sensor
14. C1676470 - Installation, Swashplate Brg. Temp. Sensor
15. C1676464 - Installation, Hanger Bearing Temp. Sensor

All drawings furnished in the Appendix provide location and configuration details of the various sensors with the exception of the drawing showing Interlock positions (E1676475). Table 2 is provided to clarify the interlock sensing devices' exact locations, and the subsequent grouping of these into the five legends of the Control/ Display Unit designated as ALARM Interlock Channels. Figure 1 shows the general location of all ALARM sensors. Table 3 lists all channels individually.

During the installation phase two major problem areas were encountered. The first involved the exact positioning of all interlock switches selected for use on the aircraft. Considerable investigation was required to determine the best positioning arrangement of each switch to provide the desired switch operation but with a minimum of aircraft frame modification. As amplified in the "TEST RESULTS" section of the report, these selections were generally satisfactory.

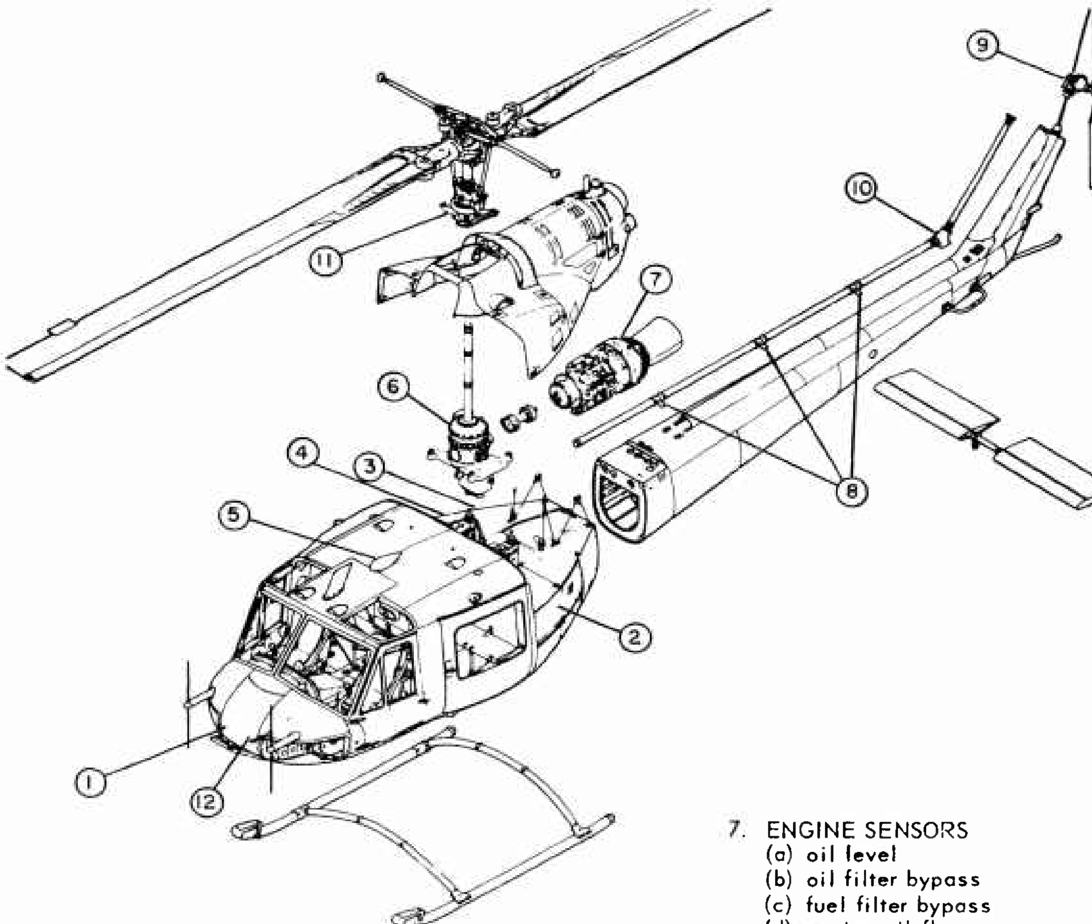
The second problem area involved the routing of main system cabling from the vicinity of the heater compartment on to the cockpit area. Original plans called for routing of this cabling beneath the right fuel cell and on beneath the cargo compartment to the pedestal. However, the heater and heat ducts as installed in the JHU-1 would have required additional holes through the main frame cross-members for the wiring to pass through as originally intended and this was recognized as an undesirable frame modification. The cabling ultimately was routed through the cargo hook compartment into the cargo compartment through the access window in the aft bulkhead, and then under the cargo deck to the pedestal.

The system installation was completed with the mounting of the battery compartment chassis (Power Supply Modules) and the Control/Display unit. Special wiring revisions were incorporated for the Battery Test circuit, Master Caution light, and Engine Tachometer Generator input to the Engine Speed Channel.

TABLE 2

INTERLOCK CHANNEL GROUPING

Channel No.	Legend Title	Monitored Points
1	FWD Door Interlocks	Nose Door (2 Switches) Left Crew Door (1 Switch) Right Crew Door (1 Switch) Left Cargo Door (1 Switch) Right Cargo Door (1 Switch)
2	Left AFT Interlocks	Left AFT Access Doors (3) (3 Switches) Left Side XMSN Cowling (2 Switches) Left Side Engine Cowling (1 Switch)
3	Right AFT Interlocks	Right AFT Access Doors (3) (3 Switches) Right Side XMSN Cowling (1 Switch) Right Side Engine Cowling (1 Switch)
4	Filler Cap Security	Engine Oil Filler Cap (1 Switch) XMSN Oil Filler Cap (1 Switch) Hydraulic Filler Cap (1 Switch)
5	Lights/Antenna Security	Landing Light (1 Switch) Search Light (1 Switch) ARN 59 Loop Antenna Cover (Conductive Paint)



1. FWD DOOR INTERLOCKS (SEE TABLE 2)
2. LEFT AFT INTERLOCKS (SEE TABLE 2)
3. RIGHT AFT INTERLOCKS (SEE TABLE 2)
4. FILLER CAP SECURITY (SEE TABLE 2)
5. LIGHTS/ANTENNA SECURITY (SEE TABLE 2)
6. XMSN SENSORS
   (a) oil level
   (b) oil filter bypass
   (c) PRV
   (d) C.D.
   (e) vib upper
   (f) vib lower
   (g) mast brg temp
7. ENGINE SENSORS
   (a) oil level
   (b) oil filter bypass
   (c) fuel filter bypass
   (d) engine oil flow
   (e) C.D.
   (f) fwd eng vib
   (g) rear eng vib
8. SHAFT HGR BRGS TEMP
9. 90° G.B. SENSORS
   (a) oil level
   (b) g.b. temp
   (c) C.D.
   (d) tail vibration
10. 42° G.B. SENSORS
   (a) oil level
   (b) g.b. temp
   (c) C.D.
11. SWASH PLATE BRG TEMP
12. LOW FREQ FRAME VIB

FIGURE 1. ALARM SENSORS, GENERAL LOCATION

TABLE 3

CHANNEL IDENTIFICATION

Channel No.	Indication
1.	Fwd. Door
2.	Left Aft Door
3.	Right Aft Door
4.	Filler Cap Security
5.	Lights/Ant Security
6.	XMSN Oil Level
7.	Engine Oil Level
8.	90^{o} G.B. oil level
9.	42^{o} G.B. oil level
10.	Spare
11.	XMSN Chip Det.
12.	Acc. G.B. Chip Det.
13.	42^{o} G.B. Chip Det.
14.	90^{o} G.B. Chip Det.
15.	Spare
16.	XMSN Oil Filter
17.	Fuel Filter
18.	Engine Oil Filter
19.	XMSN Prv
20.	Spare
21.	XMSN Top Vib.
22.	XMSN Base Vib.
23.	Aft Engine Vib.
24.	Fwd. Engine Vib.
25.	Tail Vibration
26.	Lo Freq. Mast Vib.
27.	Spare
28.	Engine Speed
29.	Eng. Oil Flow
30.	Spare
31.	Swashplate Temp.
32.	Main Mast Brg. Temp.
33.	Fwd. Hgr. Brg. Temp.
34.	Mid Hgr. Brg. Temp.
35.	AFT Hgr. Brg. Temp.
36.	42^{o} G.B. Temp.
37.	90^{o} G.B. Temp.
38.	Spare
39.	Spare
40.	Spare

TEST PROCEDURES

This section will detail the various test procedures used during the course of the ALARM test program. It is presented in three sections in the following order:

1. Functional Tests. - Test sequences utilized to determine the basic functional operation of all channels to verify adequacy and proper installation of both sensors and electronic circuitry.

2. Operational Tests. - Tests of system with aircraft operating (either ground runs or flights) to observe system behavior, and to accumulate data of vibration and temperature for relation to system indications occurring during normal operating conditions.

3. Malfunction Tests. - Test various channel capabilities to detect abnormal aircraft conditions provided by deliberate introduction of malfunctions in the aircraft.

NOTE: Due to the nature of these tests, no flights were conducted after initiation of this series. All dynamic data observed and recorded are from ground runs only.

This section is arranged in this order rather than in a channel-by-channel sequence to avoid undue repetition of procedures. In this arrangement not all channels are involved in each of the three test groups due to the wide variety of types involved. However, each channel is included in at least one group.

Test data recorded in Appendices II and III are provided for reference. It is felt this is a logical method of test analysis in a limited test program. Comparative analysis refers to the relationship between test reference data and test malfunction data; reference data are the data recorded in normal aircraft operation and the malfunction data that recorded when the aircraft was subjected to known malfunctions. These are the considerations required to determine the detection capability of any given channel.

Although specific detection levels were set for each vibration channel, these levels were arbitrary and used only as a reference. It should be noted that the assumed detection levels were calibrated to a pure sinusoidal signal at specific frequencies. These calibrated limits hold no true relationship to the complex vibration spectrum encountered at any monitored point in the aircraft. The limits are relative to channel frequency response and an indication of percentage change in detection level.

On the basis of data accumulated during the test program, finite limits can be established for the test bed aircraft. Maximum detection capability of each vibration channel must be sacrificed because of the necessity of increasing the channel limit or threshold point to compensate for nominal vibration characteristic change in different dynamic components.

Test program results incorporate ground run-up and in-flight test conditions, with no attempt at comparisons. This is necessary because in actuality these two attitudes represent completely different conditions of dynamic aircraft operation. In-flight operation was considered normal in all cases with no known malfunctions. Variations, particularly in vibration, are considered to be the normal effects of various aerodynamic loads encountered. In contrast, all actual malfunction tests are referenced to the ground-run "normal" data for verification of changes in vibration signatures detected by the system. There is no attempt to compare these two conditions. The recognition of this difference is the underlying reason for automatic switching of detection levels on the vibration channels when moving from ground-run to flight.

FUNCTIONAL TESTS

Interlocks

An observer stationed in the cockpit noted the indications occurring on the ALARM Display panel as each interlock switch was operated manually at the various locations throughout the aircraft. The operation of the cabin top antenna cover sensor was observed by loosening the cover-holding screws. This Interlock series involved channels 1 through 5 of the ALARM System.

Liquid Level

The liquid level detectors (Channels 6-9) were checked by first observing that each channel was properly indicating "GO" inasmuch as all reservoirs were at proper fill levels. Each reservoir in turn was partially drained to the underfill condition and the channel observed for proper "NO GO" indication. Finally, each reservoir was refilled in excess of the proper level and each channel observed for "NO GO" indication.

Chip Detectors

The electric chip detectors (Channels 11-14) were tested by removing each detector from its plug location, shorting across the gap of the detector, and observing that the proper indicator presented the "NO GO" condition.

Filter Bypass

Functional test of the three filter bypass assemblies (Channels 16-18) was accomplished by utilizing an external magnet to close the magnetic switch built into each filter as it would do if the bypass valve were operated under pressure. Observations were made to verify that the proper ALARM legend was indicating the "NO GO" condition.

Transmission Pressure Relief Valve

The Transmission Pressure Relief Valve monitoring channel was tested by operating the microswitch incorporated on the valve manually and checking that Channel 19 was properly indicating.

Vibration

All vibration channels (Channels 21-26) were tested functionally by introducing a fixed frequency signal into the channel at the sensor locations and increasing the amplitude until indication occurred on the display. Frequencies used were 7.5 kilocycles for the two Transmission Vibration Channels and 125 cycles/second for the remaining four channels. These frequencies correspond to the self-check signals used internally in the ALARM System for checking the vibration channels. The vibration sensors were not functionally tested on the aircraft. These sensors had been tested and calibrated on a shake table just prior to installation and were assumed to be operating normally.

Engine Speed and Oil Flow

The same functional test procedure as employed for the vibration test was used for the Engine Speed and Engine Oil Flow channels (Channels 28-29), with the exception that a varying frequency was used. These two channels are by design sensitive only to frequency change rather than amplitude.

Temperature

The final functional tests performed were the temperature channels (Channels 31-37). At the last wiring terminal point leading to each of the thermal ribbons, a resistance was inserted to simulate increasing resistance of the sensor due to excessive heat and the proper "NO GO" indications observed. The resistance of the thermal ribbon was measured to verify that it was not open circuited or otherwise damaged during installation.

In all of the preceding functional tests, the operation of the Master Caution light was observed as each channel provided its "NO GO" indication. In addition, during this sequence, the test mode was periodically checked for correct operation. No functional test could be performed on the Battery Test Circuit other than to verify proper switching of the battery relay when the test button was depressed. This only provided a check of proper electrical installation.

OPERATIONAL TESTS

After successful completion of the functional tests on the system, a series of ground runs and flights were conducted and the following information accumulated:

1. All observed "NO GO" indications on the ALARM display during ground runs or in flight were noted and investigated as to cause.

2. The STATIC Channels (Interlocks, Liquid Levels, Chip Detectors) were observed prior to each A/C start for a ground run or flight and used as the inspection of those areas.

3. Data were recorded from all temperature sensors prior to and at the completion of each test run to determine normal operating temperature characteristics at each sensor location.

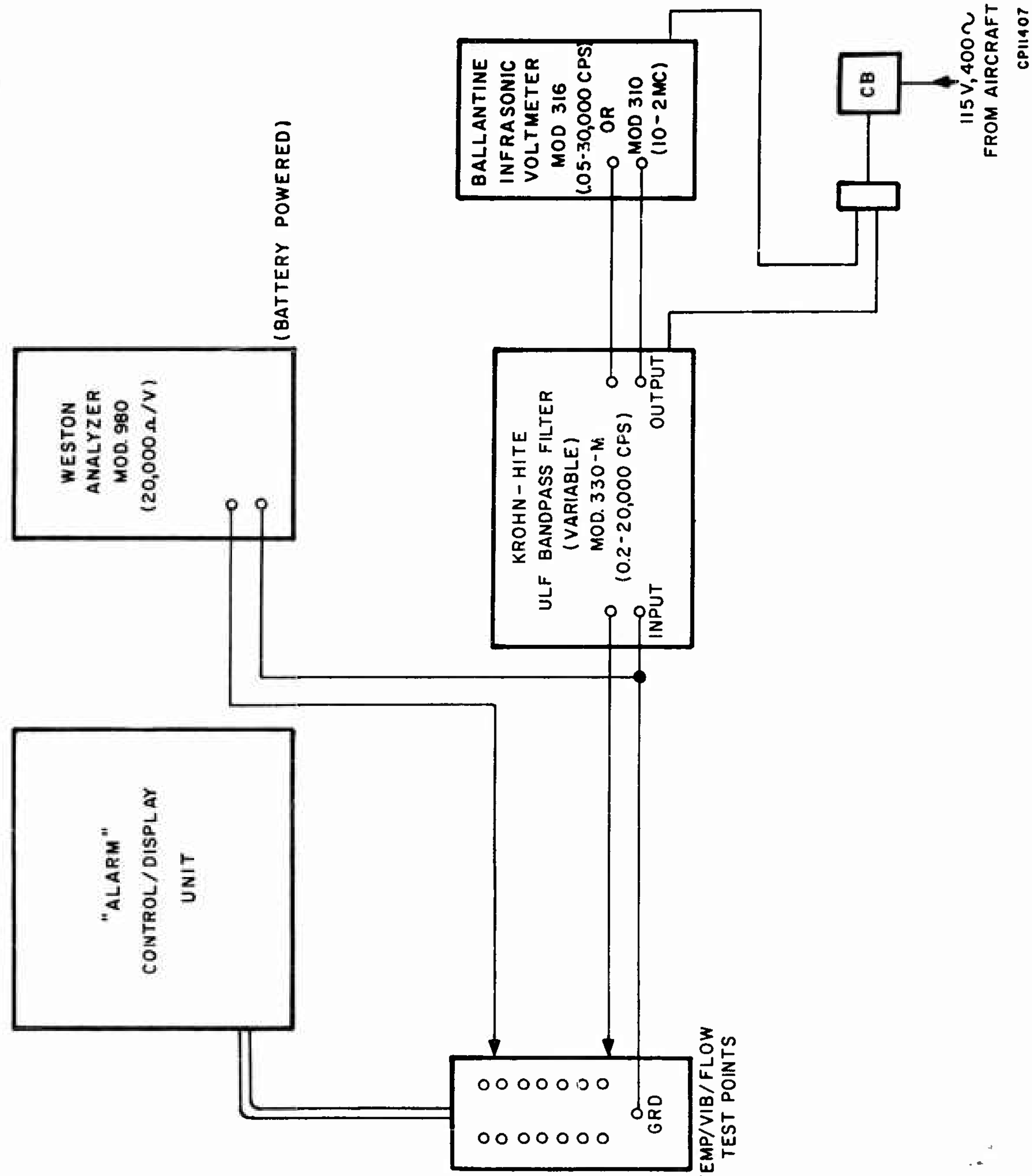


FIGURE 2. TEST EQUIPMENT INSTALLATION, BLOCK DIAGRAM

4. Data were recorded directly from all vibration transducers (over-all levels and frequency analysis data) to accumulate information on normal vibration patterns occurring at the sensor locations.

5. Over-all system operation was observed for reliability and stability at the various environments encountered during the test program. Any problems noted in this respect resulted in a subsequent modification study to remedy the condition.

Test Equipment

Test Equipment included the following:

Weston Analyzer Model 980 (20,000 Ω/v)

Krohn-Hite ULF Bandpass Filter Model 330-M (0.2-20,000 cps)

Ballantine Voltmeter Model 316 (0.05-30,000 cps) 100-130 Volts (60 cycles)

Ballantine Voltmeter Model 310 (10 to 2 mc) 1 mil-v-100v)105-125v 50-400 cps

Tektronix Oscilloscope Type 541A

Hewlett Packard Electronic Counter Model 521A

For purposes of recording the data referenced in Item 4 and Item 5, test equipment was installed in the cargo compartment of the JHU-1. Figure 2 is a block diagram of this test installation.

For recording temperature data, the Weston Analyzer was used to measure the resistance of the various thermal ribbons. The resistance value was converted to degrees Centigrade.

For vibration recording, the Krohn-Hite Filter was set to the various specified octave bands for each channel (sensor) and the peak-to-peak or RMS voltage amplitude in each band was recorded as measured by the Ballantine Voltmeter. This information was then converted to the proper vibration parameters. The bands recorded are listed in Table 4.

TABLE 4

VIBRATION PARAMETERS

Band No.	XMSN	Engine	Tail	Low Freq.
1	0.5-1 KC	20-40 cps	20-40 cps	3-6 cps
2	1-2 KC	40-80 cps	40-80 cps	6-12 cps
3	2-4 KC	80-160 cps	80-160 cps	12-25 cps
4	4-8 KC	160-300 cps	160-300 cps	25-50 cps
5	8-12 KC	320-500 cps	320-500 cps	50-100 cps
6	12-16 KC	500-1 KC	500-1 KC	
7	16-20 KC	1-2 KC	1-2 KC	
Over-all	0.5-20 KC	20 cps-2 KC	20 cps-2 KC	3-100 cps

In addition to these two main areas of data recording equipment, a portable oscilloscope and a frequency counter were used during ground runs for observations of the output generated by the Engine Oil Flowmeter (Channel 29).

A procedure was established for all dynamic runs to assist in coordinating the tasks of the A/C operator and project personnel. This procedure, or "Check List", is reproduced in its entirety.

Flight/Ground Run Test

Check List

I. Prior to Engine Start

   A. Record initial (cold) resistances of temperature channels
   B. APU "ON", Main Inverter "ON", Battery ON
   C. "ALARM" Self-Check
   D. "ALARM" Static Mode Test
   E. "ALARM" Mode Switch to Dynamic

II. Engine Start

III. Increase RPM to 6400, Hold Steady

   A. Record RPM when "Eng Speed" Channel goes off
   B. Observe "ALARM" dynamic indications
   C. Energize test equipment CB

IV. Increase RPM to Maximum

   A. Record RPM when "Eng Speed" channel energizes
   B. Record any "ALARM" dynamic indications
   C. "ALARM" mode switch to In-Flight

V. Proceed with take-off or hold for 6400 RPM ground run

   A. Instruct A/C operator on attitude desired
   B. Record data as assigned
   C. Record all "ALARM" indications

VI. After Shut-Down

   A. Record temperature data
   B. Record running time

The Operational Tests encompassed a considerable spectrum of varying aircraft attitudes, all of which were repeated at least twice. This permitted data accumulation in each attitude sufficient to verify measurement accuracies. In addition, this method resulted in more realistic observations of system behavior from a reliability and utility standpoint. The following is a summary of the attitudes and number of complete data-recording efforts relative to each:

1. 5800 RPM Ground Run - 2
2. 6000 RPM Ground Run - 3
3. 6400 RPM Ground Run - 4
4. 70K S/L Flight - 6
5. 80K S/L Flight - 6
6. 90K S/L Flight - 2
7. 100K S/L Flight - 6
8. 500 ft/min Climb - 5
9. 2500 ft/min Climb - 4
10. Hover - 7
11. Hover (1000 # load) - 4
12. Auto-rotation - 4
13. Max. T/O - 4
14. Maneuver (Rt. turn) - 4
15. Maneuver (Lt. turn) - 4

MALFUNCTION TESTS

Since the Operational Test Procedure involved observations and analyses of the aircraft in a normal operating condition, a Malfunction Test sequence was devised to provide evaluation of the ALARM System's capability to detect abnormal aircraft condition.

All scheduled Phase 2 tests involving flight operation of the aircraft, including the extended normal operation during the period accepted as the "24-hour Test" (see Table 1, date lines 6-13 and 6-22), were completed and the aircraft was prepared for the Malfunction Tests.

Table 5 is a detailed listing of all malfunction tests conducted during this portion of the test program. As can be determined from this Table, the tests were directed toward evaluation of those channels which monitor aircraft parameters as an indirect method of detecting deficiencies, contrasted to the direct monitoring techniques such as used in the interlock and liquid level channels.

Since the test-bed aircraft had not yet been subjected to any deliberate abnormal operation, all dynamic components were assumed to be flight-worthy. Recognizing that damage to these components would definitely occur during the malfunction tests, it was considered desirable to replace the Engine, Main Transmission and both Tail Rotor Gear Boxes with like items due for overhaul. As a result of this decision, a series of dynamic component interchanges were performed. Table 6, Component History Table, provides serial numbers of the components involved in the effort.

TABLE 5

MALFUNCTION TEST AGENDA

Test No.	Malfunction	Procedure	Channels Involved	Result
1	Short-Shaft Misalignment	Remove shims under right rear engine mounts in 0.01" increments	XMSN Base Vib (22) Eng Vib (23, 24)	Inconclusive Page 61
2	Loss of Torque, Engine V-Band Coupling Clamp	Relieve torque on both clamps in 50 inch-pound increments.	Eng Vib (23, 24)	Negative Page 61
3	Loss of Torque, "Bishop's Hat" Mounting Bolt	Relieve torque on bolt	Aft Eng Vib (24)	Negative Page 61
4	Unbalanced NII Turbine Wheel	Remove combustion chamber, rotate turbine in 90° increments	Eng Vib (23, 24)	Increased Vibration detected Page 61
5	Loss of Torque, NII Turbine Wheel Mounting Bolt	Relieve torque on bolt	Eng Vib (23, 24)	Vibration Change Noted Inconclusive Page 63
6	Misaligned Input	Place 1/2" Plate under 42° Gear Box	42° GB Temp (36) Tail Vib (25)	Negative Page 72
7	Blocked Oil Collector in 42° Gear Box	Remove & disassemble 42° GB, inspect output side bearing, reassemble without collector.	42° GB Temp (36)	Negative Page 72
8	Defective Bearing and/or Gear 42° GB	Remove 42° GM Input Quill, disassemble, heat-treat gear and bearing, reassemble	42° GB Temp (36) 42° GB Chip Det (13) Tail Vib (25)	Temperature & Vib. Increase Page 72
9	Defective Bearing and/or Gear, 90° GB	Remove 90° GB Input Quill, disassemble, heat-treat gear and bearing, reassemble	90° GB Temp (37) 90° GB Chip Det (14) Tail Vib (25)	Temperature & Vib. Increase, Chip Det. Indication Page 76

TABLE 5

MALFUNCTION TEST AGENDA (Cont'd)

Test No.	Malfunction	Procedure	Channels Involved	Result
10	Defective Bearing and/or Gear, Main XMSN Input Quill	Remove XMSN Drive Quill, disassemble, heat-treat gear and bearing, reassemble	XMSN Base Vib (22) XMSN I/Q Temp. (Special)	Vibration Variation Page 76
11	Scored Lower Mast Bearing	Remove M/R System, place 0.015" Flat on inner race of lower mast bearing, reinstall	XMSN Top Vib (21) XMSN Base Vib (22)	Negative Page 80
12	Blocked Lubricating Jet(s), Main XMSN	Install blocked jets as required for evaluation	XMSN Pressure Relief Valve (19)	Inconclusive Page 80
13	Lack of Lubricant Swashplate Bearing	Expose bearing as required to remove lubricant by application of "penalene", resecure bearing.	Swashplate BRG Temp (31)	Negative Page 84
14	Blocked Oil and Fuel Filters	Block each filter (100%) using provided blocking elements.	XMSN Oil Filter (16) Fuel Filter (17) Eng Oil Filter (18)	No-Go Indication - No Significant change in sys. pressures Page 84
15	Ferrous Particles in 42° or 90° GB	Add (thru oil filler) measured increments of ferrous particles if required after tests 8 and 9.	GB Chip Dets. (13, 14) GB Temps (36, 37)	Immediate Indication W/90° GB - 42° GB indication after alteration Page 86
16	Unbalanced Tail Rotor Blade	Unbalance on a blade by application of tape as required to determine max. sensitivity of channel.	Tail Vib (25)	Vibration Increase Noted Page 86
17	Unbalanced Main Rotor Blade	Unbalance one blade by application of tape as required to determine max sens. of channel.	Low Frequency Mast Vib (26)	Vibration Increase Noted Page 90

TABLE 5

MALFUNCTION TEST AGENDA (Cont'd)

Test No.	Malfunction	Procedure	Channels Involved	Result
18	Main Rotor out of Track	Commencing with assumed intract cond., adjust pitch change link in one flat increments each test	Low Freq. Mast Vib. (26)	Vibration Increase Noted Page 90
19	Excessively Low Oil, Main XMSN	Remove oil as required to permit eval. of increased gear & bearing noises.	XMSN Top Vib. (21) XMSN Base Vib. (22)	Vibration Increase Noted Page 98
20	Loss of Oil, 90° GB	Gradual oil removal to eval. increases in gear & bearing noise vib., also temperature.	42° GB Temp (36) Tail Vib (25)	See Test #9 Page 76 and 98
21	Tail Rotor Out of Track	Draw blades out of track in increments by adjusting pitch change link, record vibrations.	Tail Vibration (25)	Negative Page 98
22	Ferrous Particles in Main XMSN	Add (thru oil filler) measured increments of ferrous particles if required after test 19.	XMSN Chip Det (11)	Immediate Chip Detector Indication After C.D. Relocation Page 102
23	Engine Oil Leakage	Install needle valve for inducing leakage in oil ret. line-measure max chan det. capability.	Eng. Oil Flow (29)	Inconclusive Page 102
24	Short Shaft Unbalance	Attach weight to short-shaft for eval. of engine vibration effect.	Eng. Vib (23, 24)	Vibration Increase Noted Page 102

TABLE 6

COMPONENT HISTORY TABLE

Component	Originally on A/C	Replaced by	Condition
Engine S/N (P/N T-53-L-1A)	LE-00346	LE-00112	TBO Component (495 hrs.)
Main XMSN S/N (P/N 204-040-001-13)	A12-20	A12-78	TBO Component (307 hrs.)
Main Mast Ass'y S/N (P/N 204-010-410-9)	B12-39	C12-50	Removed from crash-damaged A/C, S/N
Swashplate Support S/N (P/N 204-010-470-7)	F19-12	F19-12	(Not changed)
90° Gear Box S/N (P/N 204-040-004-25)	A13-15	A13-90	Removed from crash-damaged A/C, S/N
42° Gear Box S/N (P/N 204-040-513-1)	A13-12	A13-12	(Not changed)

It was recognized that some risk was involved in certain of these tests, consequently the following precautions were taken:

1. Installation of two 1/2" thicknesses of plywood against the aft cargo compartment bulkhead.

2. Aircraft located a minimum of 100' from buildings, tail pipe directed toward the most open area.

3. Outside observer provided for safety, all tests.

4. Provision of 3 fire extinguishers, one forward and one to each side of the aircraft.

The procedure employed for each test depended upon the particular test to be conducted. For tests concerning vibrations and temperatures, all normal maintenance procedures were followed with the intent of placing the aircraft in a normal, or reference condition. A brief aircraft ground run would then be conducted, during which reference data were recorded for all vibration and temperature channels. Following this, the necessary mechanical work was performed to induce the malfunction specified. In a few cases where no malfunction interaction would occur, two tests were conducted simultaneously, such as Test #14 and Test #16. Appropriate photographs were taken of the induced condition if there was sufficient visual difference from the normal condition.

The data-ground run was then conducted, during which the ALARM display was carefully observed at all times and all data recorded in detail relative to the channels under test. Where the particular malfunction specified incremental increases in the condition such as Test #15, after each test run it was necessary to shut down and repeat the preceding process for each increment.

In the test results section, the "raw" data obtained in all of these tests have been converted from the various voltage levels provided by the text instrumentation to the equivalent vibration parameters or temperatures. This has been done to clarify the test information and to assist in organizing it into the data forms contained in the appendices.

TEST RESULTS

FUNCTIONAL TESTS

The functional test procedures described in detail previously were performed in their entirety with most of the system installation verified as operational. During this effort, the system "Self-Check" (Test) Mode proved of considerable assistance, particularly in the testing of the Interlock/Continuity areas. A number of installation errors were rapidly isolated by observing indications (failures) in this Test Mode.

The major difficulties resolved during the Functional Test sequence were as follows:

1. Most of the Interlock switch arrangements required actuator adjustments for proper operation and, in a few instances, slight relocation of the switch position itself.

2. The Cabin Top Antenna Cover security sensor (conductive paint) required considerable adjustment and manipulation before it satisfactorily provided the indication that the cover holding-screws were properly secured.

3. Both the 42^{o} and 90^{o} Gear Box Chip Detectors indicated "NO GO" initially, and upon examination it was discovered that they had been installed improperly. The original magnetic plug valves had not been removed prior to installation of the new chip detectors (which have their own self-closing valve arrangement), causing a short across the detector gaps.

4. The Engine Oil Filter Bypass Channel indicated "NO GO" initially, and upon examination it was discovered that during installation the magnetic switch terminals had been damaged, causing the switch to short internally. A temporary repair appeared to remedy the condition; however, this experience caused concern over the basic design of the filter from a reliability standpoint. All three of the Filter Bypass Channels were observed closely throughout the test program because of this, and, as will be amplified later in this report, eventually were completely redesigned.

All other aspects of the system, including all Temperature, Vibration, Liquid Level, Oil Flow, and Engine Speed Channels tested satisfactorily, thus concluding this portion of the test program.

OPERATIONAL TESTS

Actual complete system operation commenced immediately following the Functional Tests, and, as detailed in the "Test Procedure" section of this report, involved normal aircraft operation both in ground run and flight. As a preliminary to this effort a number of brief ground runs and flights were conducted to permit final detection level adjustment of the Vibration and Oil Flow Channels. This consisted of setting these channels so that the ALARM legends just remained off (GO) when in both the Ground Run Attitude (Dynamic Mode) and in straight and level flight at about 70 knots IAS (In-flight Mode).

In order to provide a more concise treatment of the results of the test program, the following discussions are organized by individual channels or channel types rather than by particular tests.

Interlocks (Channels 1-5)

Functional tests of each monitored interlock and security point were performed periodically throughout the course of operational testing to insure the proper operation of each item throughout the period of long-term observation. This was accomplished by introducing the condition which was expected to cause indicated failure on any chosen interlock channel, such as unsecured doors, latches and cowlings; unstowed lights; and loose filter caps. Each one of the 23 monitor points was periodically checked in this manner.

Several occurrences which support the utility of these channels were noted during the course of operational tests. Two of these occurred during the flight test portion of the test program. In one instance, the hydraulic filler cap had been replaced but not turned down; and, in the other instance, the XMSN oil filler cap had inadvertently been left off after servicing. Both occurrences were indicated as filler cap security failures on the ALARM panel and enabled corrective action to be taken prior to flight.

An additional instance of the same nature occurred when the battery compartment access door had inadvertently been left unlatched after connecting the battery prior to flight. Here again, ALARM indication enabled corrective action to be taken prior to flight.

Over-all reliability of the concept used in monitoring the access doors employing the small Hartwell latches indicated a less than desirable level of performance, especially after many operations in long-term usage. Switch actuators at these points tended to bend or push aside rather easily when the latches themselves became loose and misaligned from repeated use.

Observations and periodic functional tests of the cowling interlocks showed reliable and consistent performance under repeated usage with the exception of the two switch interlocks on the top, forward transmission cowlings. The rather critical initial adjustment required at these points is a disadvantage; however, the operational reliability was not affected once these interlocks were adjusted to satisfaction.

Landing and searchlight interlocks were observed throughout the test program, although no fail indications were noted. The infrequent use of lights during normal daylight flight operation hindered observation under conditions of repeated use. Periodic functional test of these monitor points showed the consistent ability to detect unstowed conditions.

Security monitor of the ARN 59 loop antenna cover was observed to be unreliable due to the tendency of the conductive paint to crack under stress between points of fixed continuity. Utility of this monitor point was also questionable; as a result, it has been recommended that it be deleted from the system.

The present method of monitoring crew and cargo door security proved inadequate in observations over long-term use. Repeated adjustment of actuator alignment was necessary, resulting in low personnel confidence level. Utility of these interlocks was also questionable because of their proximity to the pilot and crew. They have been recommended for deletion.

Liquid Levels (Channels 6-9)

Operational testing was carried out in the form of observation of channel operation over the course of the test program. The varied conditions which exist over a long-term period of flight and ground operation were ideal with respect to evaluation of these channels against environmental and operational changes. All "NO GO" indications and the reasons for these failures were noted and recorded. Various examples of channel utility were observed during the test program. Several instances of "NO GO" conditions were indicated and subsequent visual inspection revealed either high or low fill levels in the component involved.

Early in the test program it was found that erroneous indications resulted on these channels when used in an environment of warm oil, such as after a flight. Corrective modifications were made and subsequent observations revealed that indicating response time was slower in a warm oil environment, but the decrease in response time was not sufficient to cause erroneous interpretation.

Chip Detectors (Channels 11-14)

The only indications that occurred on any of these four channels during Operational Testing resulted from a flight in heavy rain. Water accumulated on the terminal block connections to the 42° GB and 90° GB and caused those two chip detector channels to indicate "NO GO". The condition was corrected by applying a waterproofing compound over the terminals. No further erroneous indications were observed.

Periodic inspection of the four detectors revealed no accumulation of ferrous particles at any time. The detectors were not cleaned during these inspections to permit long-term observation of any particle build-up. The XMSN Detector eventually showed some slight traces of accumulation, but no abnormalities were observed.

Filter Bypasses (Channels 16-18)

As reported in the Functional Test Results section, difficulty with these channels was experienced at the beginning of the test program. At various times during the program, all three channels indicated erroneously; in one instance, a visual inspection of the XMSN Oil Filter revealed a severely clogged condition which Channel 16 (XMSN Oil Bypass) had failed to indicate. In every instance the failure was caused by damage to the magnetic switch terminals because of poor mechanical location.

Final disposition of this condition was to remove all three of the filter units and return them to the manufacturer for modification. The nature of the modification had been reviewed and concurred as sufficient to eliminate the problem of terminal breakage. Other tests were conducted in this area to establish feasibility of the concept; however, final tests of the modified filters will be conducted at a later date. This philosophy is discussed in greater detail in the Malfunction Test Section.

<u>Transmission Pressure Relief Valve</u> (Channel 19)

No indications were observed on this channel during the course of operational ground runs and test flights, and it was assumed that no abnormal valve motion was occurring. Later developments in this area revealed improper internal operation of the valve itself; thus no valid conclusions can be derived from this particular portion of the test program relative to this channel.

<u>Vibration Channels</u> (Channels 21-26)

Appendix II of this report contains summarized data accumulated on these channels during the course of the Operational Test program. All graphs presented and discussed in this section have been derived from these data. As before, it is necessary to assume normal operation of all monitored components; therefore, variations in vibration as shown are normal, environmentally influenced differences only.

Figure 3 presents the detection levels of the two transmission vibration channels, one each for the Dynamic Mode and the In-Flight Mode. These curves show the relationship between the two modes, and <u>should not</u> be referenced to graphs showing actual vibrations. These plots resulted from sinusoidal calibrations of the channel after their detection levels were dynamically set for the two modes, while actual vibration data presented in later graphs result from a complex vibration signature which is octave-analyzed. To be particularly noted on this graph are the higher settings on the XMSN Top channel. Normal vibrations at this point are about 50% higher than those occurring at the XMSN Base. This is attributed mainly to the damping effect of the transmission mounting arrangement which supports the housing at a point much nearer the base accelerometer. In addition, the difference in the two mode settings is shown. This difference is provided automatically by the ALARM Mode switching from Dynamic to In-Flight.

Figure 4 (Part 1 and Part 2) presents the data resulting from all flight attitudes, over-all (1-20 kc) readings only. The width of each area under the separate attitudes represents the variations recorded in these amplitudes. Sizeable increases occur on the XMSN Top during the 2500 ft/min climb and maximum take-off attitudes, and on the XMSN Base during the maximum take-off. This supports the ALARM indications that occurred during these attitudes representing a maximum torque condition on the transmission.

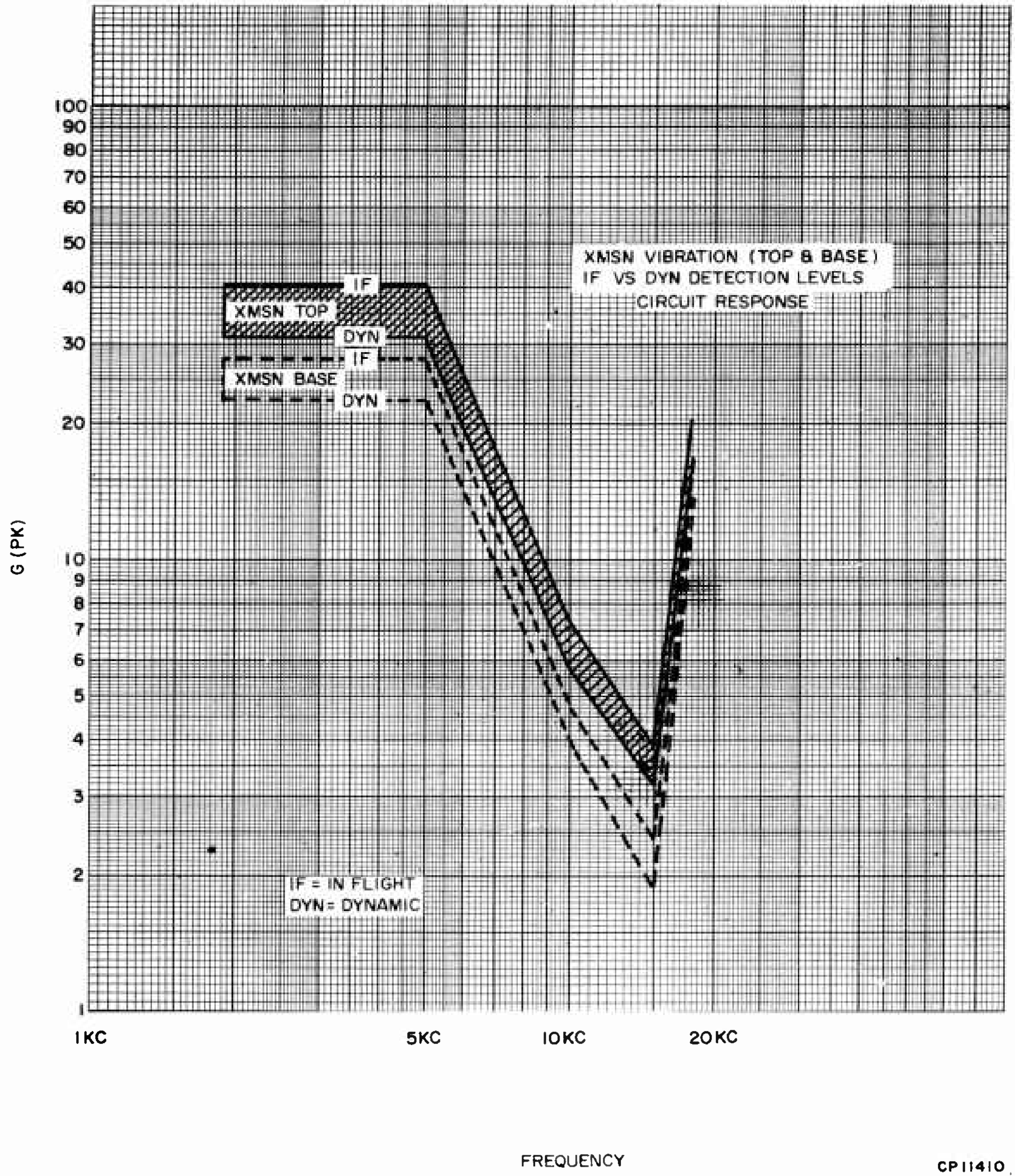


FIGURE 3. DETECTION LEVELS, PLOT

Figure 5 and Figure 6 are frequency plots of vibrations recorded during all Dynamic (ground-run) and In-Flight attitudes. Here the width of the in-flight area represents variations due to the various flight attitudes, with the highest g-levels at each frequency occurring during maximum take-off as had been indicated in Figure 4.

In general, Figures 3 through 6 illustrate the behavior of the transmission vibrations during normal aircraft operation. ALARM channel settings eventually established were such that no indications occurred at any time except those during attitudes of extreme torque. These indications were considered desirable since the attitudes are normally not to be held for extended periods of time.

The next five illustrations (7 through 12) show essentially the same categories of data concerning Engine Vibration Channels. Note particularly in Figures 7 and 8 the change made to the detection level; this resulted when it was realized the original detection level, as specified by the manufacturer, was too high to permit any realistic indication of any engine difficulty. At the same time, the ideal slope of this response was changed to a uniform response across the frequency band, at 3.2 inches/second. Even at this decreased detection level, at no time during the Operational Tests did an indication occur on these Channels, verified by observing the maximum amplitudes of plots on Figures 9, 10, and 11. This caused an even further decrease for the detection level used in the Malfunction Tests which are detailed in this document.

Figures 13 and 14 present data accumulated for the Tail Vibration Channel. Sensor Location #1 specified on these graphs refers to the 45^{o} orientation for transducing lateral and vertical vibrations occurring midway between the two Tail Rotor Drive gear boxes. Later investigations resulted in relocation of this pickup, and the data can only be used for comparing relative amplitudes rather than the absolute levels ultimately used to specify a final channel detection level.

The results of a 3-plane study of tail vibrations, shown in Figure 15, revealed predominate lateral vibration occurring, but it was suspected that the method of sensor mounting for this test resulted in some structural resonances. The sensor was mounted on a solid block of aluminum that had been welded to an aluminum sheet which replaced an inspection panel. This gave a large mass mounted to a thin and flexible base. The data collected while employing this mounting then had to be considered as questionable in value. Final changes were made to the location and mounting, predicated by qualitative analysis of all of these earlier tests. The sensor was eventually mounted on the 90^{o} Gear Box and oriented to transduce the vertical and fore-and-aft planes. This location (#3) was used for the subsequent Malfunction Tests.

Considerable study was made of the original engineering concept for the Low Frequency Mast Vibration area. This concept envisioned utilizing the XMSN Top accelerometer as the pickup to accept only the low frequency (100 cps) vibrations in this channel. Inconsistency became increasingly evident during Operational Testing and was attributed to the fact that at these frequencies the

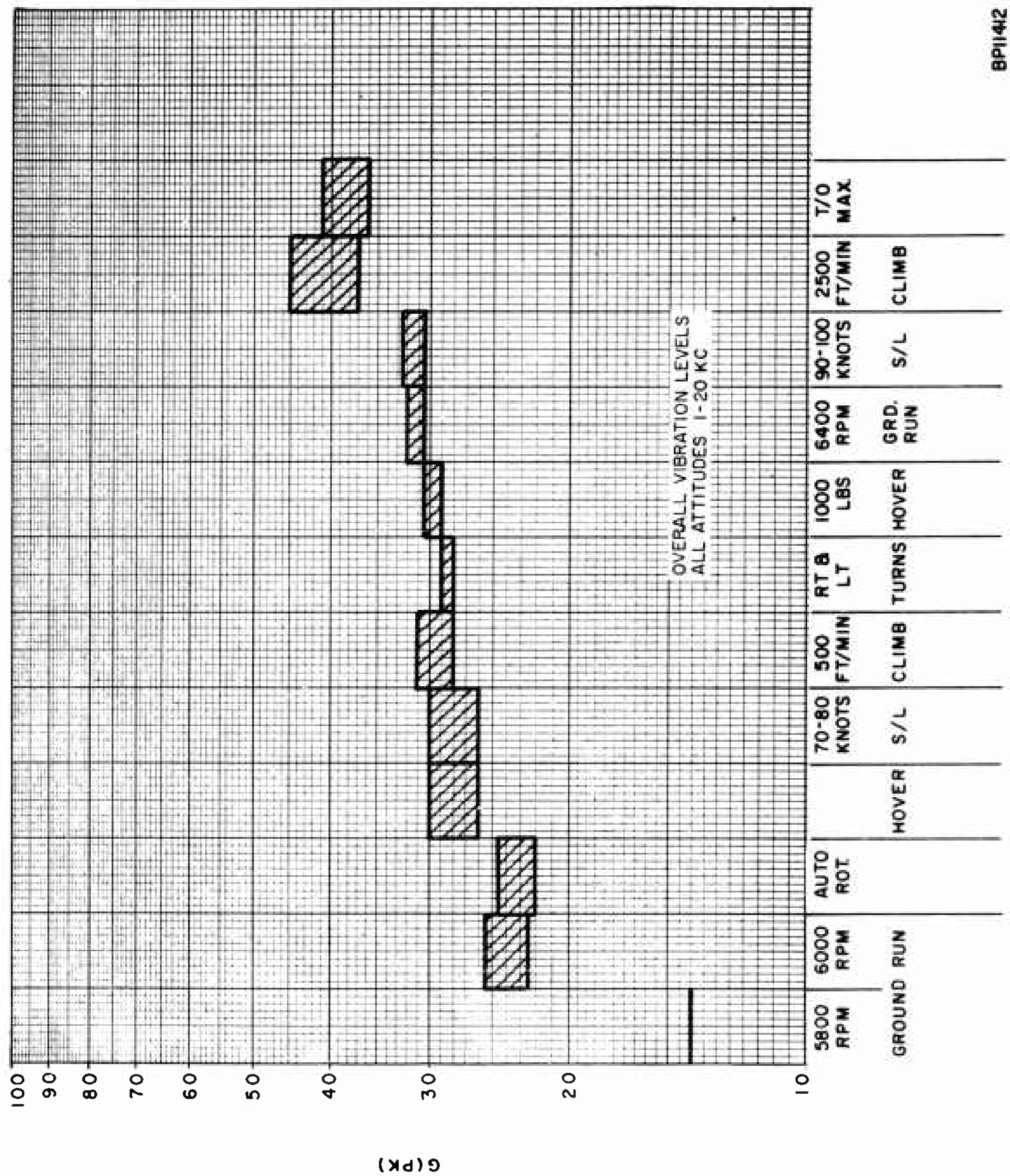


FIGURE 4. XMSN TOP, VIBRATION DATA, PLOT (PART 1)

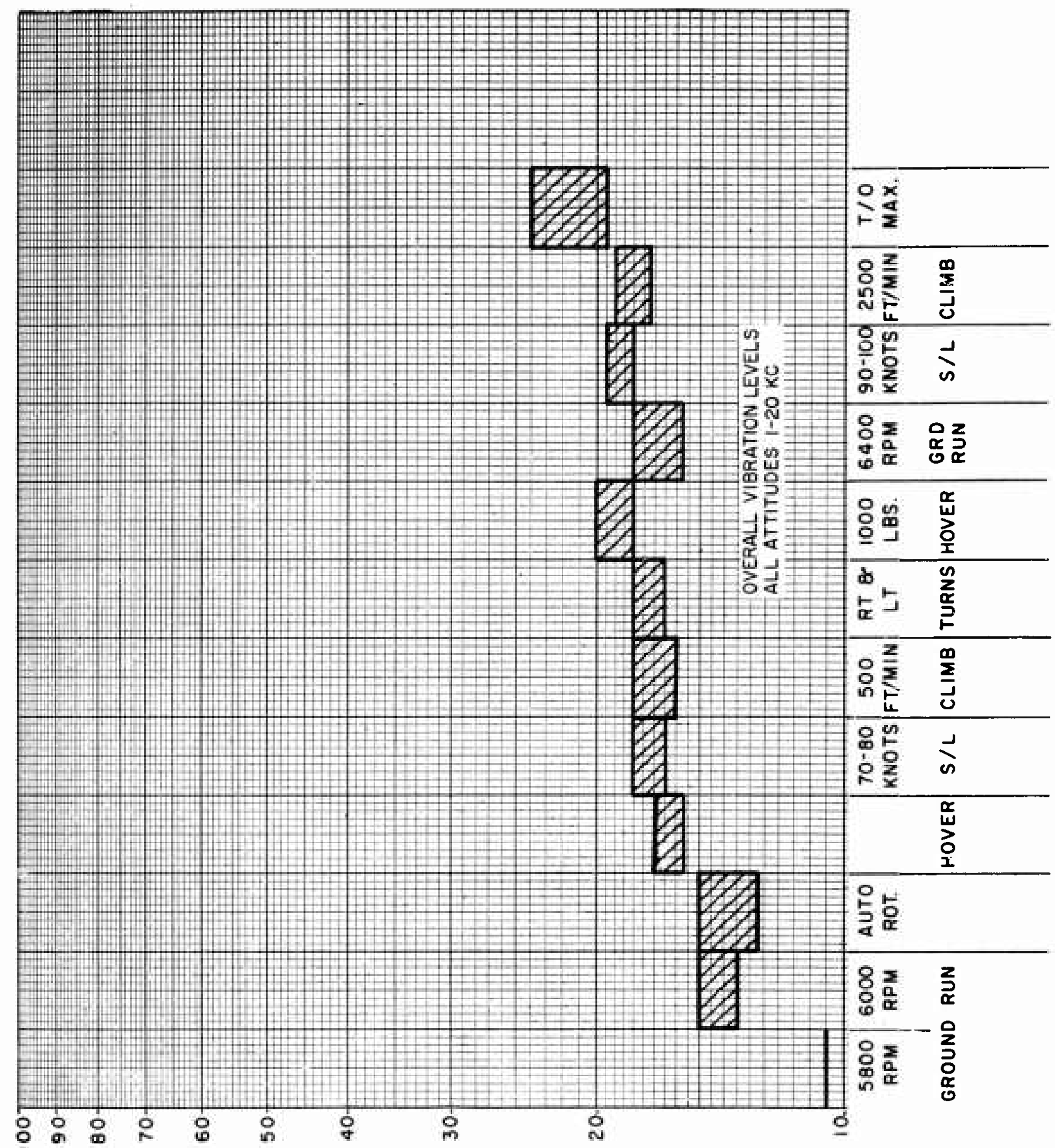


FIGURE 4. XMSN BASE, VIBRATION DATA, PLOT (PART 2)

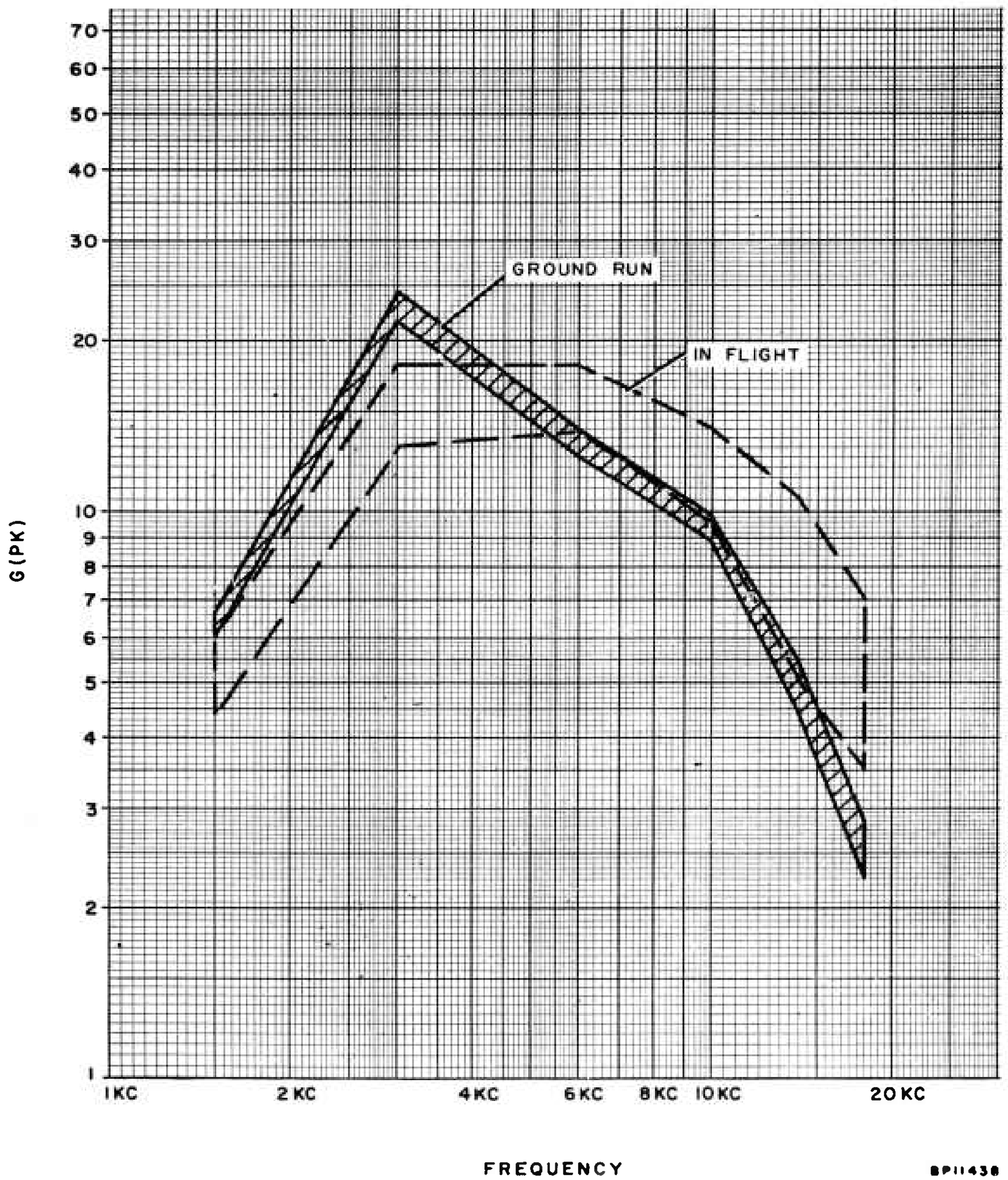


FIGURE 5. XMSN TOP, DYNAMIC VS I-F VIBRATION LEVELS, PLOT

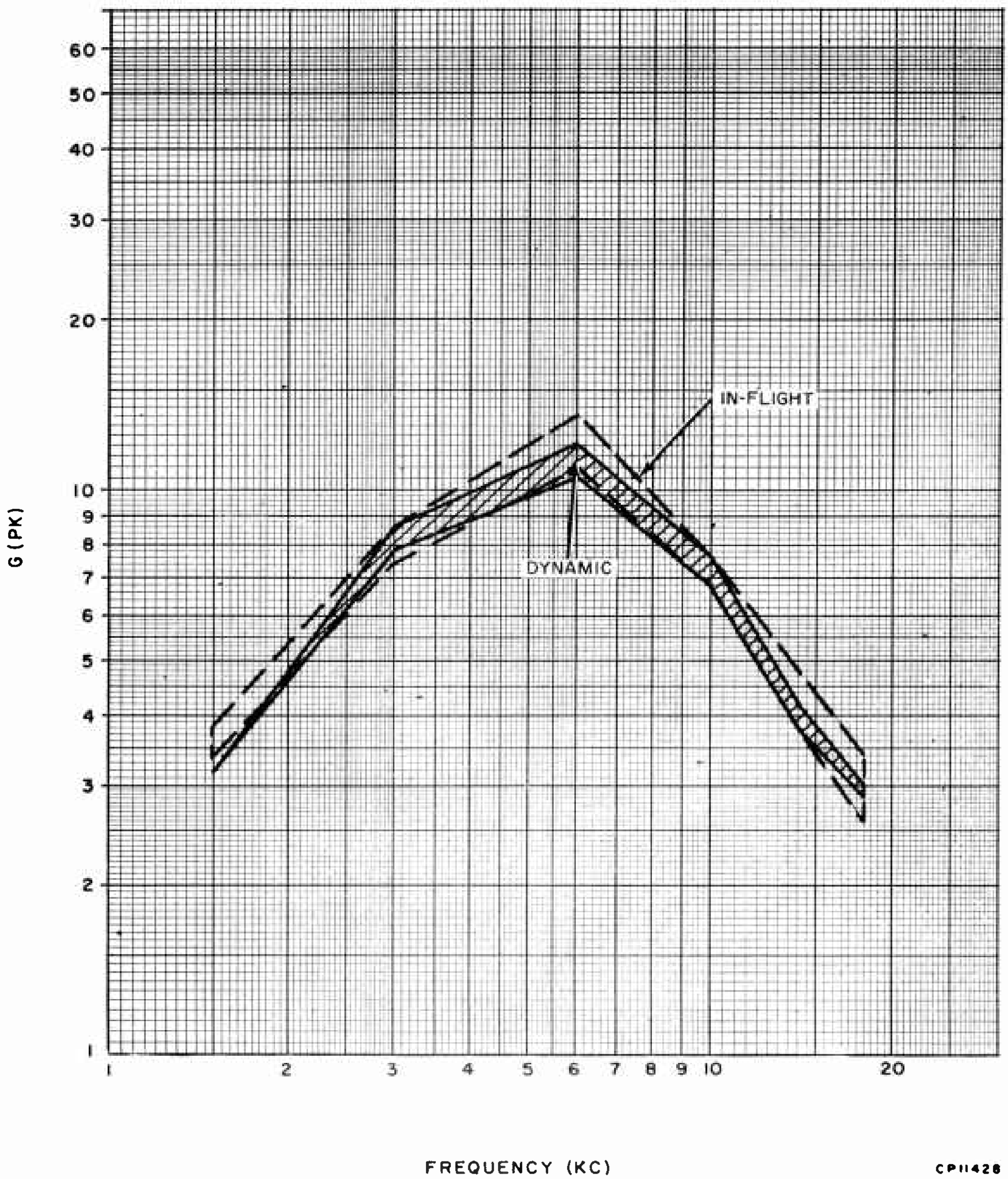


FIGURE 6. XMSN BASE, DYNAMIC VS I-F VIBRATION LEVELS, PLOT

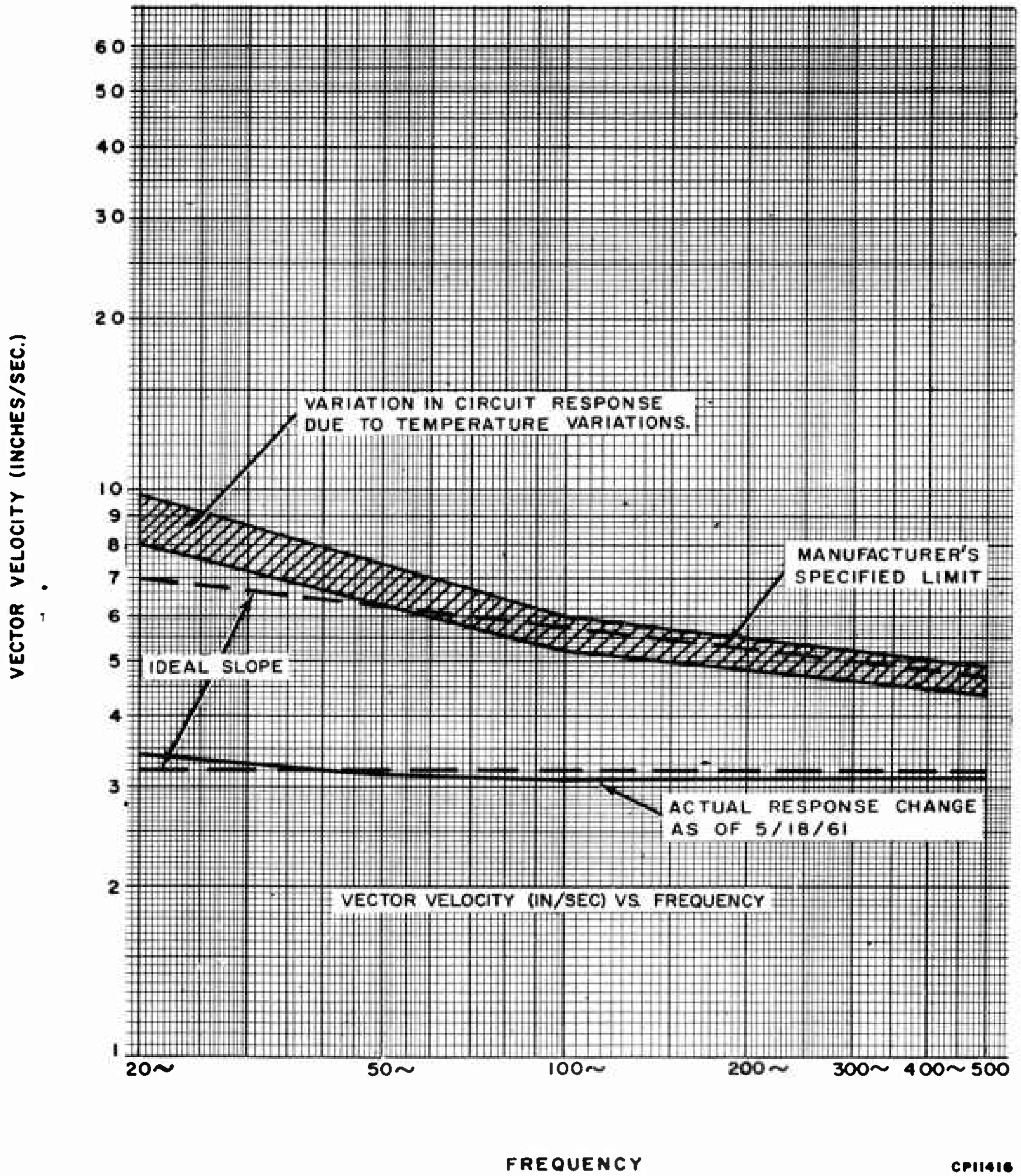


FIGURE 7. CHANNEL SENSITIVITY, AFT ENGINE VIBRATION, PLOT

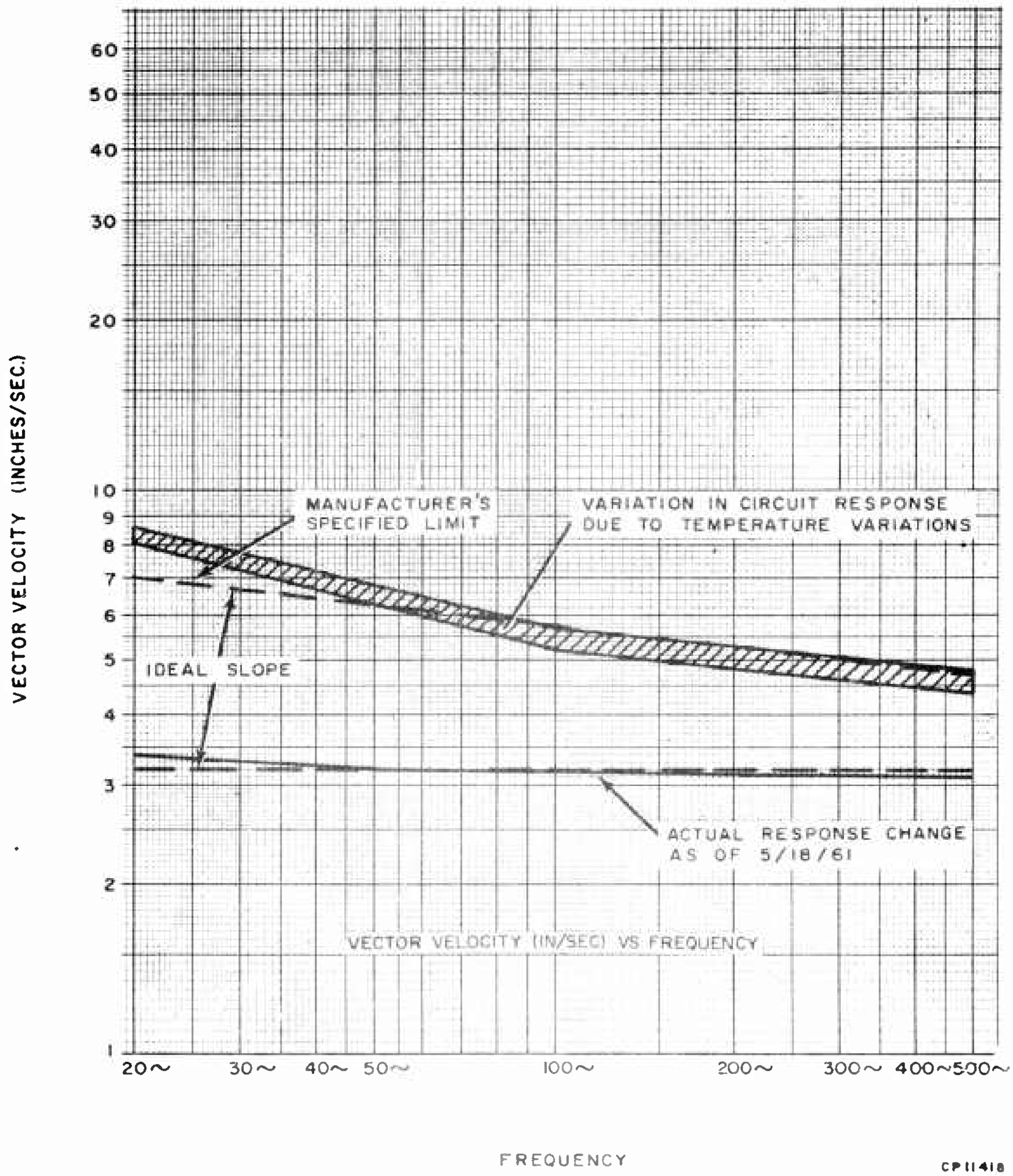


FIGURE 8. CHANNEL SENSITIVITY, FWD ENGINE VIBRATION, PLOT

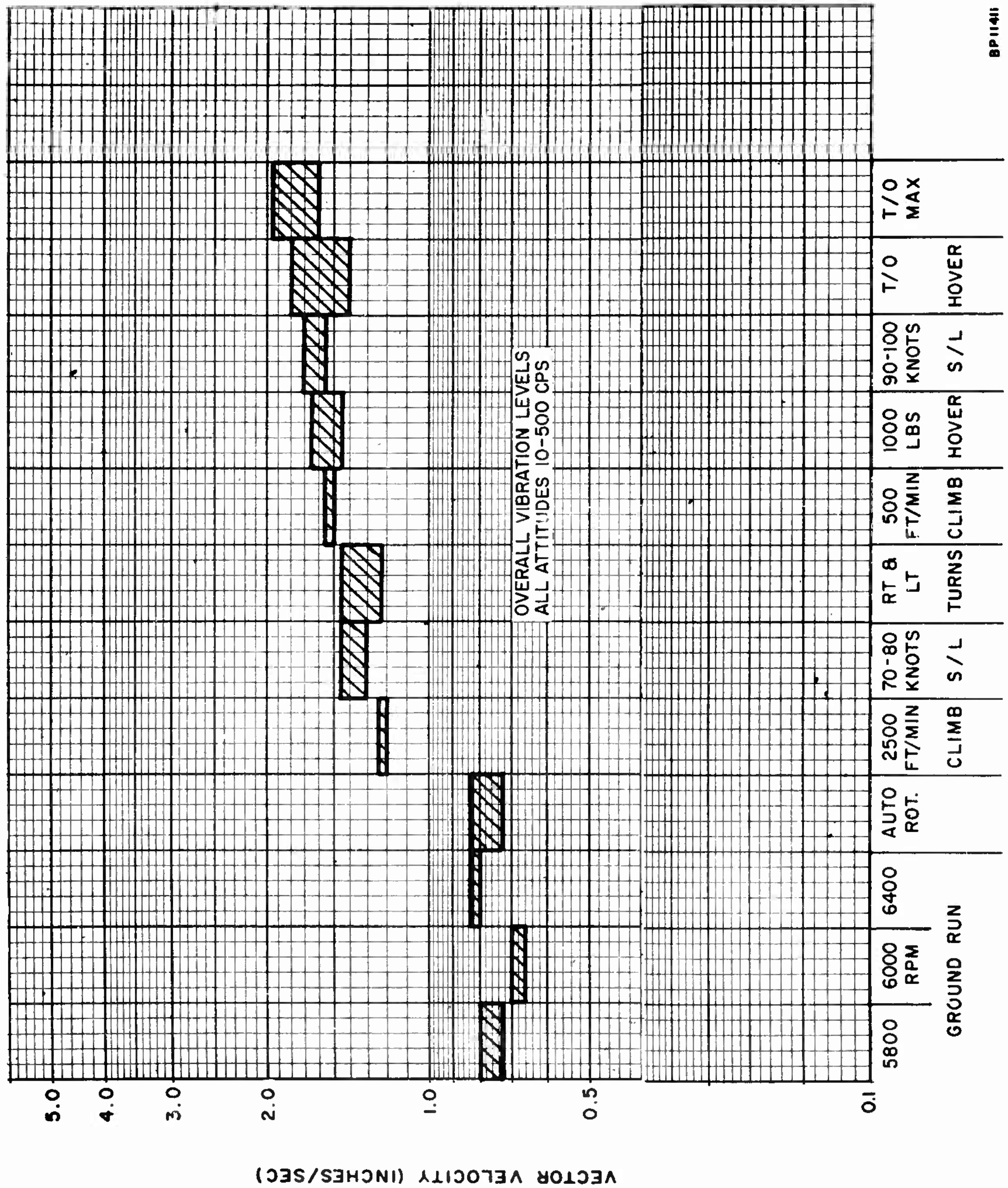


FIGURE 9. AFT ENGINE VIBRATION, OVER-ALL VIBRATION LEVELS

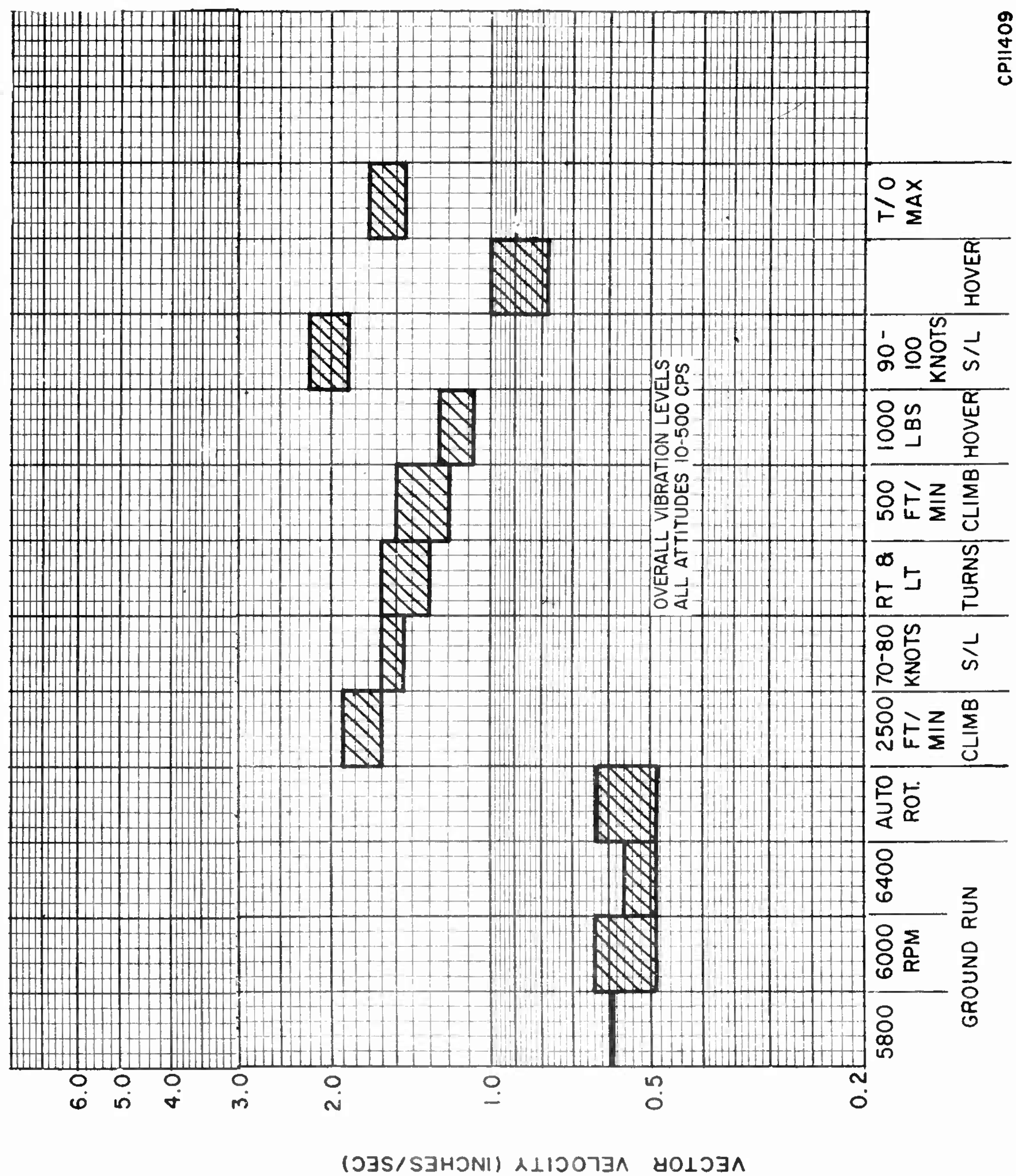


FIGURE 10. FWD ENGINE VIBRATION, OVER-ALL VIBRATION LEVELS

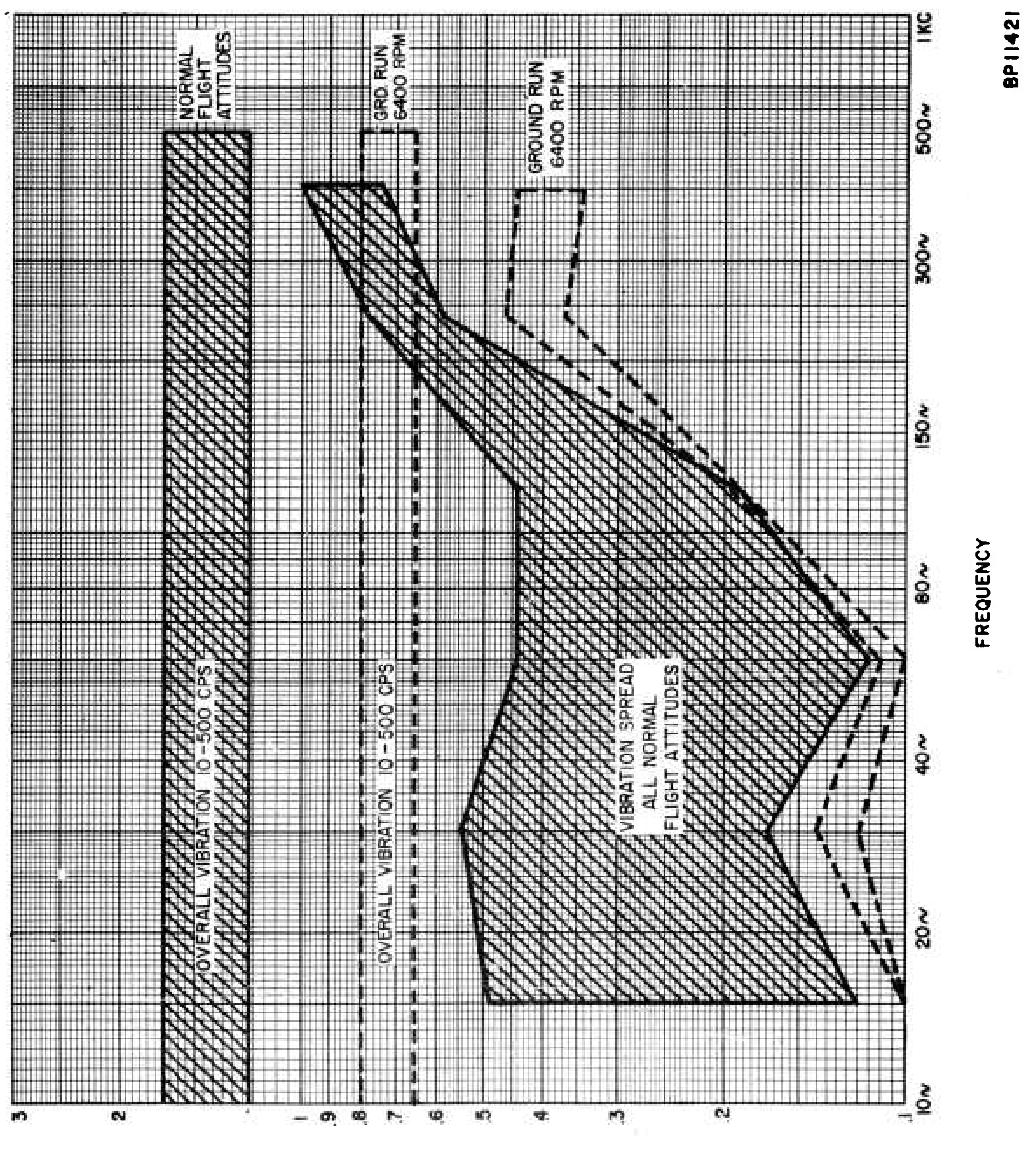


FIGURE 11. AFT ENGINE VIBRATION, VIBRATION LEVEL (IN/SEC) VS FREQUENCY, DYNAMIC AND IN-FLIGHT

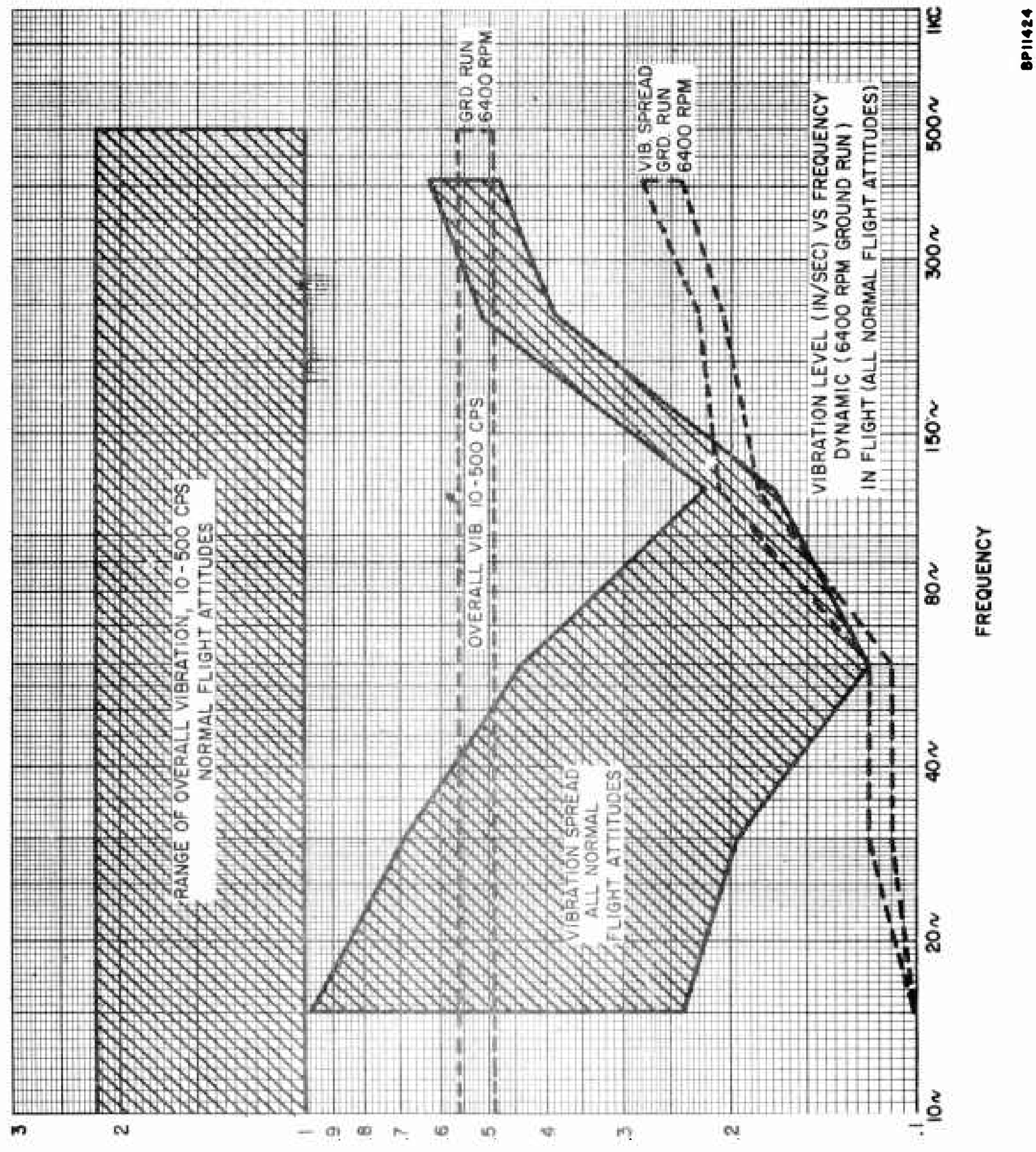


FIGURE 12. FWD ENGINE VIBRATION, VIBRATION LEVEL (IN/SEC) VS FREQUENCY

g-levels were so small that noise was adversely affecting the channel. This led to the adoption of a velocity-type pickup, which was located in the forward part of the aircraft fuselage to transduce low-frequency frame vibrations in the order of 1 and 2/rev. This effort was accomplished during the Malfunction Test sequence after the aircraft had been grounded, and no operational data were accumulated. Figure 16 shows the response curve of the modified channel used for the Malfunction Test.

In summary, the Operational Tests conducted on the vibration channels verified the validity of the techniques for monitoring with the exception of the previously discussed Low Frequency Mast Vibration channel. The transmission and Tail Vibration channels demonstrated their in-flight utility by repeatedly indicating to the pilot attitudes of high stress or uncoordinated flight. It is felt the Engine channels would have exhibited the same behavior (refer to Figure 9 and Figure 10); but because of the high detection level used, no indications occurred on these two channels. One important point to be emphasized is that in order to detect impending malfunction in the monitored areas, the channel detection levels must be set to just above the normal vibrational levels occurring during an average aircraft attitude such as 70-knot straight and level flight. This permits the indications of above-average attitudes; but at the same time, if considerable variations in normal vibrational levels are later found to occur from aircraft to aircraft, each channel would have to be calibrated to the aircraft on which it is installed to maintain its utility in this respect. Since no history is available on other aircraft, the variation of vibration levels is not known.

Engine Speed (Channel 28)

This channel originally was provided to indicate when Engine Power Shaft rpm (as generated electrically by the engine tachometer generator) dropped below the minimum safe flight level of 5800 rpm or exceeded the specified maximum. Operational test observations on this channel consisted primarily of determining its ability to operate consistently at the set rpm (repeatability).

Based upon pilot and observer comments, the utility of the lower limit (5800 rpm) was seriously questioned since its primary use would be as a warning of turbine "flame-out" at low altitudes. This warning did not prove fast enough to be of any practical value due to the coast-down delay of the shaft (3-5 seconds). Consequently, the lower limit was eliminated and evaluation was concentrated on the accuracy of the upper, or "over-speed", limit. The results of these observations revealed an excessive temperature drift of the channel rpm setting. It was felt that to be of value, the limit had to be held to 7000 rpm ± 1%. Design investigations have been conducted to determine the economic feasibility to provide this accuracy. Modifications of this circuit were submitted for approval. Due to economic and time factors involved, the decision was made not to modify this circuit.

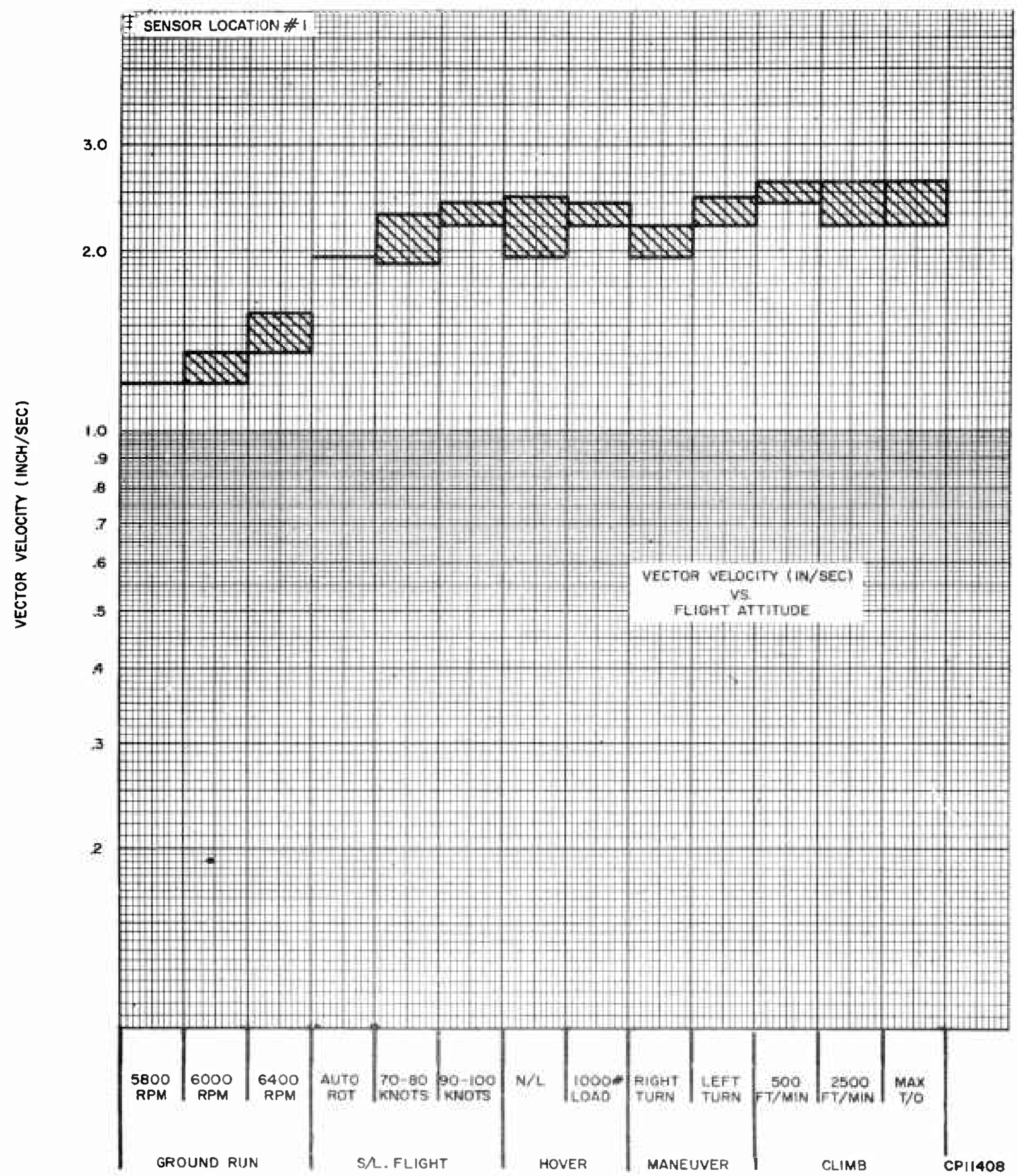


FIGURE 13. TAIL VIBRATION, OVER-ALL VIBRATION LEVELS, ALL FLIGHT ATTITUDES

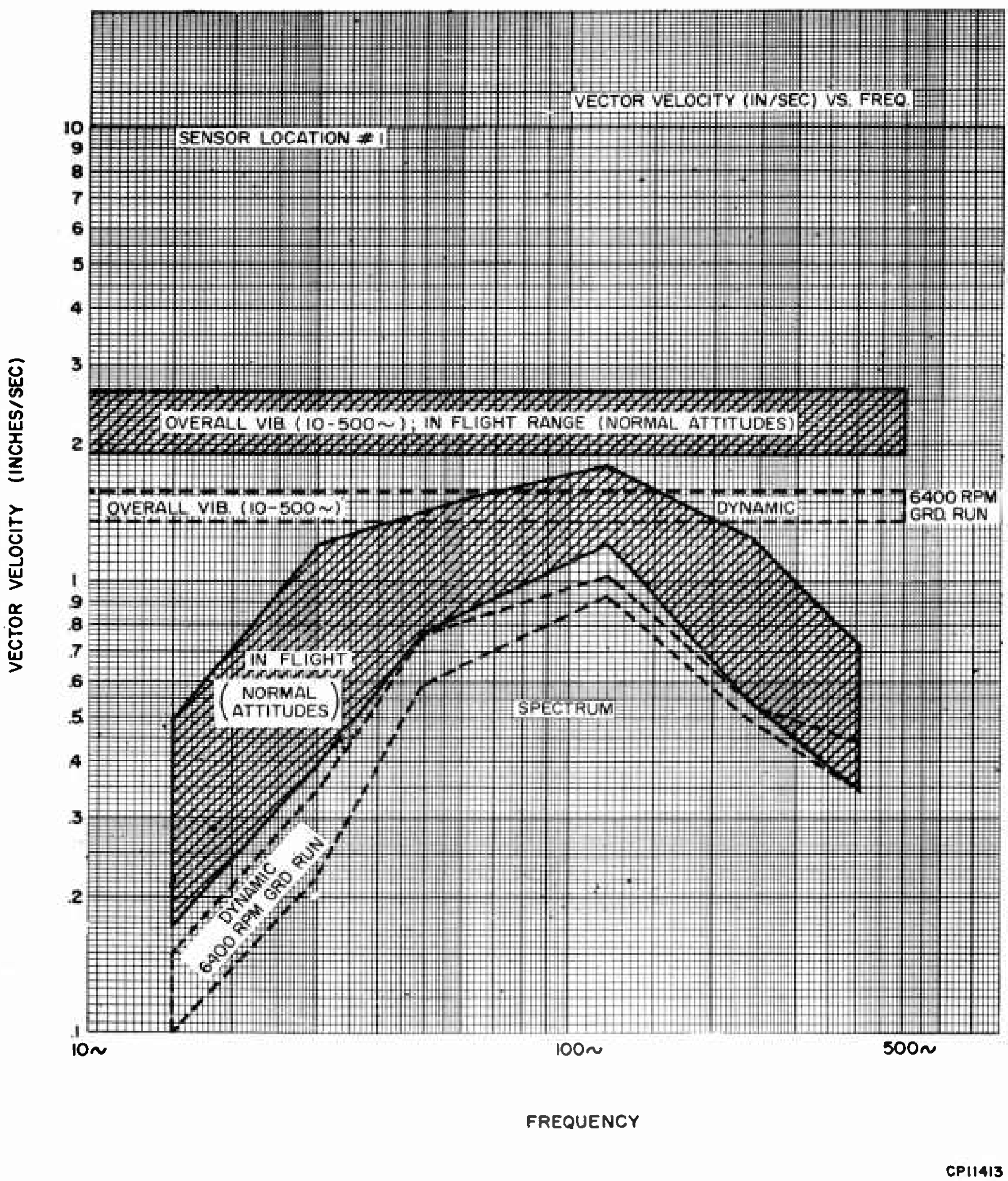


FIGURE 14. TAIL VIBRATION, VECTOR VELOCITY DYNAMIC AND IN-FLIGHT OPERATION

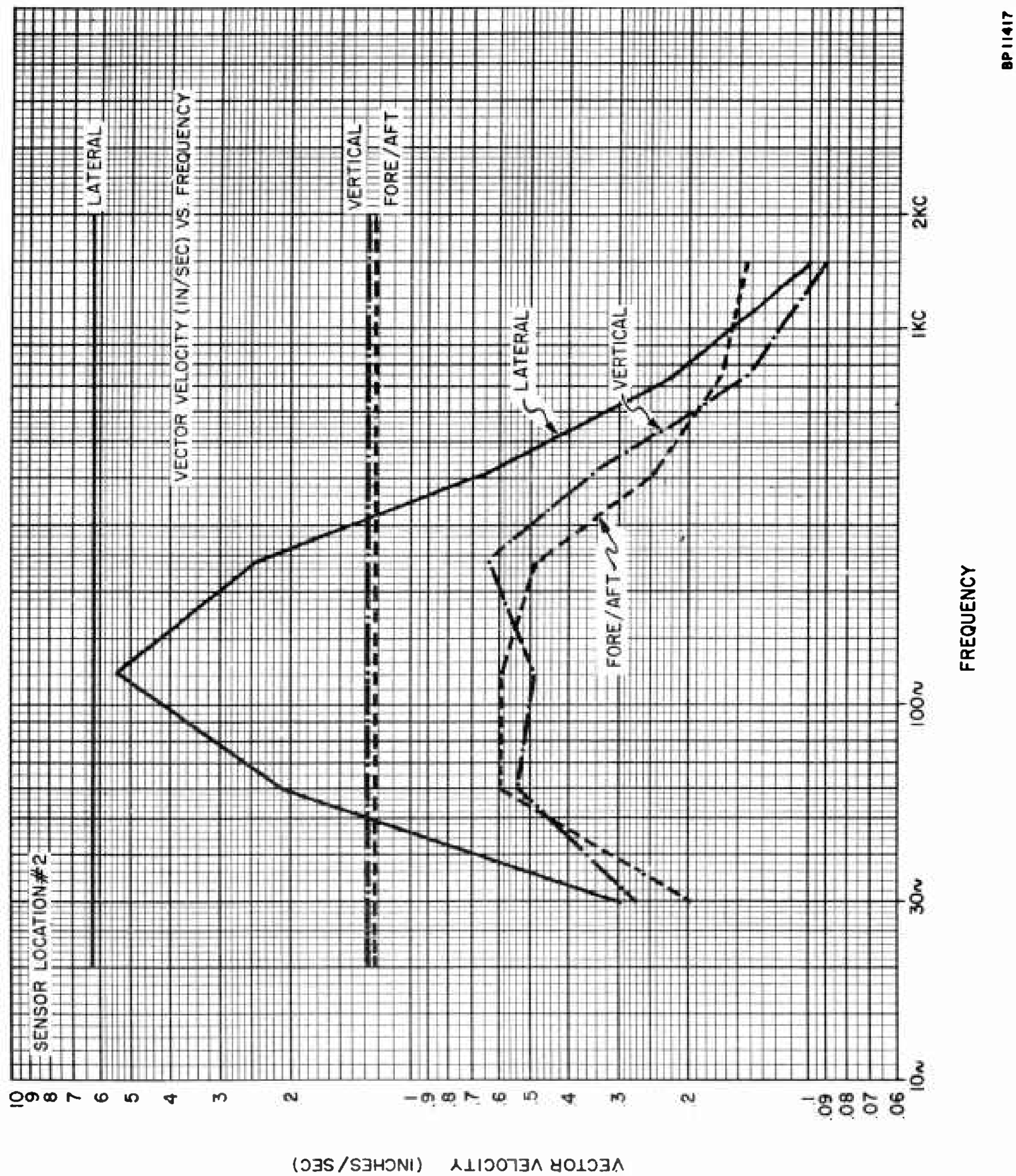


FIGURE 15. TAIL VIBRATION, VECTOR VELOCITY VERTICAL, LATERAL, FORE/AFT PICKUP ORIENTATION

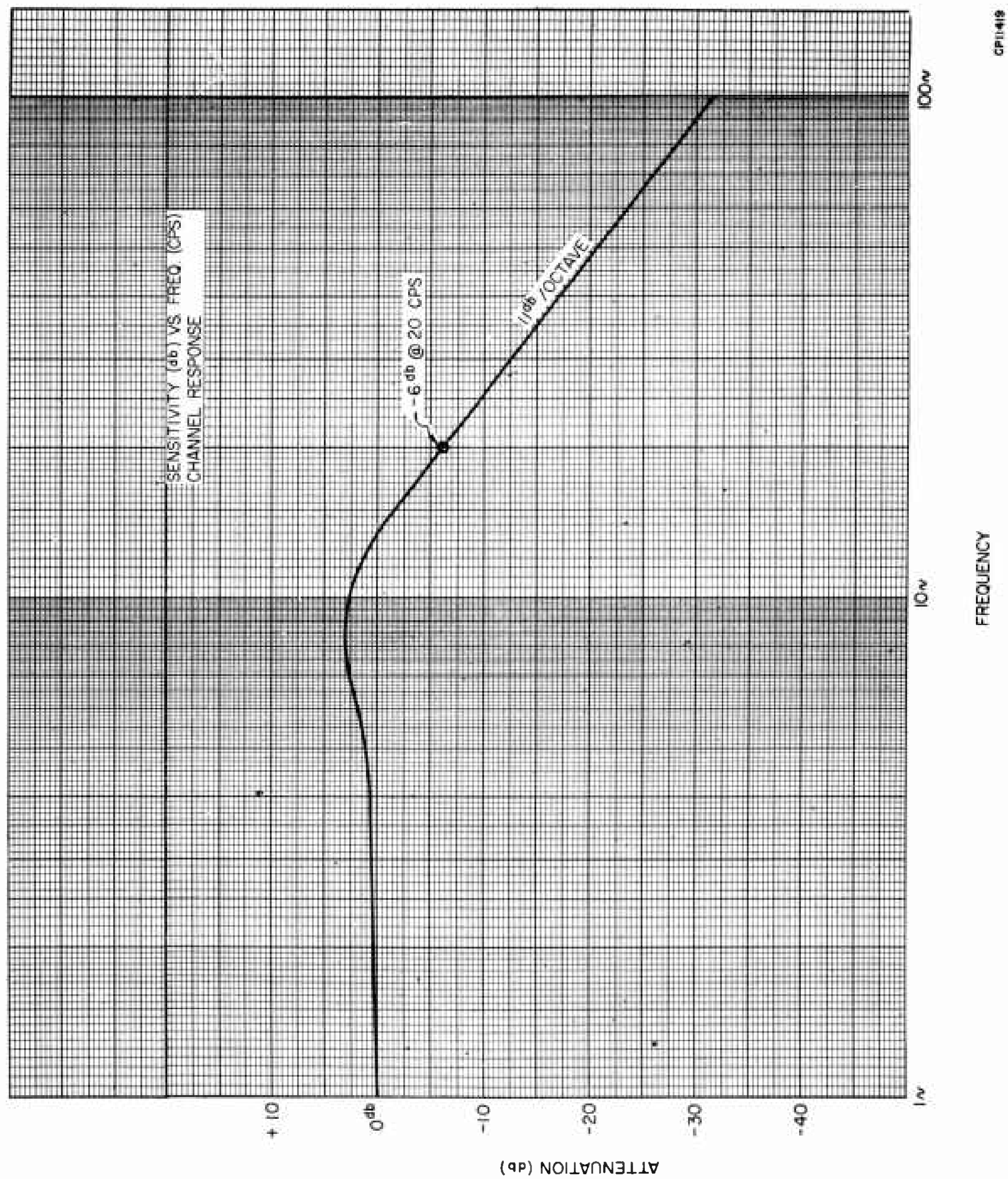


FIGURE 16. LOW FREQUENCY MAST VIBRATION, SENSITIVITY VS FREQUENCY, 1 AND 2 REV.

Engine Oil Flow (Channel 29)

Initial tests of this channel indicated that the original concept of monitoring the engine oil flow at the originally specified location would be inadequate. This was due to the excessive fluctuations at this point which forced setting the channel detection so high to avoid erroneous indications that it could then detect only very large increases in flow due to leaks in the system. In addition, in the original location, the flowmeter was not monitoring the entire engine oil system for leakage. This provided another factor leading to the decision to relocate the flowmeter. The flowmeter was installed at the present location in the oil return line adjacent to the oil reservoir (on the transmission deck). At this location, it monitors total flow, and leakage tests indicate a capability to detect leak rates of about 1 pint/minute in the system, which was the envisioned capability for the channel.

One important factor which came under consideration during tests of this channel was that of monitoring oil flow for external leakage at any engine rpm rather than at normal flight rpm only. This would be desirable during engine starts in the event a leak develops which could drain the system before normal flight rpm is attained. As a result of this consideration, further study was made of the flow characteristics of the test-bed aircraft engine oil system to determine if a technique could be devised which would detect leakage of at least 1 pint/minute at any rpm.

Two approaches were investigated, one involving "slaving" of the flowmeter output to engine rpm and the other utilizing two flowmeters and comparing reservoir input and output flow rates. The first approach was eliminated due to the prohibitive complexity involved, particularly in circuitry, to accomplish the compensation for the nonlinear relationship between engine speed and the flow rate. The second technique, utilizing two flowmeters, was thoroughly investigated and three different concepts considered. These were (1) proportional DC, (2) "Add and Subtract", and (3) Frequency Mixing. The first, proportional DC, was eliminated because of instability problems. The second and third were more promising but were considered to be of practical value only as a leak detector at full engine rpm. In addition to this restriction, the circuitry is complex.

Based on this knowledge, investigation of the leak detection channel involving measurement of oil flow rate determined that this method was impractical except as a monitor at full engine rpm. In order to maintain the necessary accuracy, the cost of the complete channel can become excessive compared to its utility. An evaluation of a completely different technique for monitoring engine oil leakage should be made (such as the vapor detection concept) in order to attempt to satisfy this critical area of aircraft maintenance.

Temperature Channels (Channels 31-37)

Figure 17 through Figure 20 are provided as a complete summarization of temperature measurements made during both Operational and Malfunction Test sequences. These graphs illustrate temperatures recorded for each sensor location during all flight attitudes, ground runs, and malfunction tests.

Channel detection levels are shown, and each temperature exceeding this level was an indicated "NO GO" on the system.

As can be observed in Figure 17, Part 1, no abnormal temperature conditions were encountered on the Swashplate Bearing throughout the Operational Tests. Measured temperatures ran somewhat below the detection level, and later malfunction tests supported the decision to lower the detection level 5^{o}C uniformly across the ambient temperature range.

The data on Part 2 of Figure 17 show the behavior of the temperatures recorded from the Main Mast Brg sensor. As a result of the Operational Tests, it was apparent that the t mperatures as monitored by the ALARM thermal ribbon were very closely related to the XMSN Oil Temperature as indicated on the aircraft instrument panel. ALARM indications would occur on this channel when the oil temperature reached "red-line" value of +110^{o}C during attitudes such as extended hover in hot, humid weather. It was resolved to eliminate this location for the reasons detailed in the Malfunction Test Results section of this report.

Data on the three Shaft Hanger bearing monitors are shown on Figure 18 and Part 1 of Figure 19. These data represent the accumulation during both Operational and Malfunction Testing. Early in the Operational Test programs, an indication occurred on the Mid Shaft Bearing and upon examination was found to have been caused by contaminated lubricant in the bearing. Upon removal and relubrication, the operating temperature dropped appreciably. This condition was repeated at various times and substantiated. Subsequent periodic indications during extended hovers in high ambient temperatures led to increasing the detection limit to avoid some of these conditions. The hover indication at high ambient temperatures is such that it should be heeded before catastrophic damage to the bearing occurs. It is suspected that the three hanger bearings were all operating at a higher than normal temperature because of the behavior experienced on the Mid Shaft Bearing. All three of these limits may eventually be reduced.

Figure 19 shows all data on the 90^{o} Gear Box channel as valid indications which occurred during the Malfunction Tests. None were observed during Operational Tests. The same is true of the 42^{o} Gear Box (Figure 20). In general, the detection levels are considered to be optimum for each two channels, although long-term observation of the 90^{o} Gear Box temperatures may permit reducing its level about 8^{o}C without encountering erroneous indications during less strenuous flight attitudes. The analog channels of the ALARM System were expected to exhibit some temperature drift due to environment. This was anticipated and compensation studies were performed early in the test program. Preliminary circuit modifications were found to be inadequate for the close tolerance channel operation that was required. Re-evaluation of the circuits for temperature compensation was made and redesign of thermistor compensating circuits for each channel was performed. Succeeding tests have shown the present temperature compensating technique to be feasible.

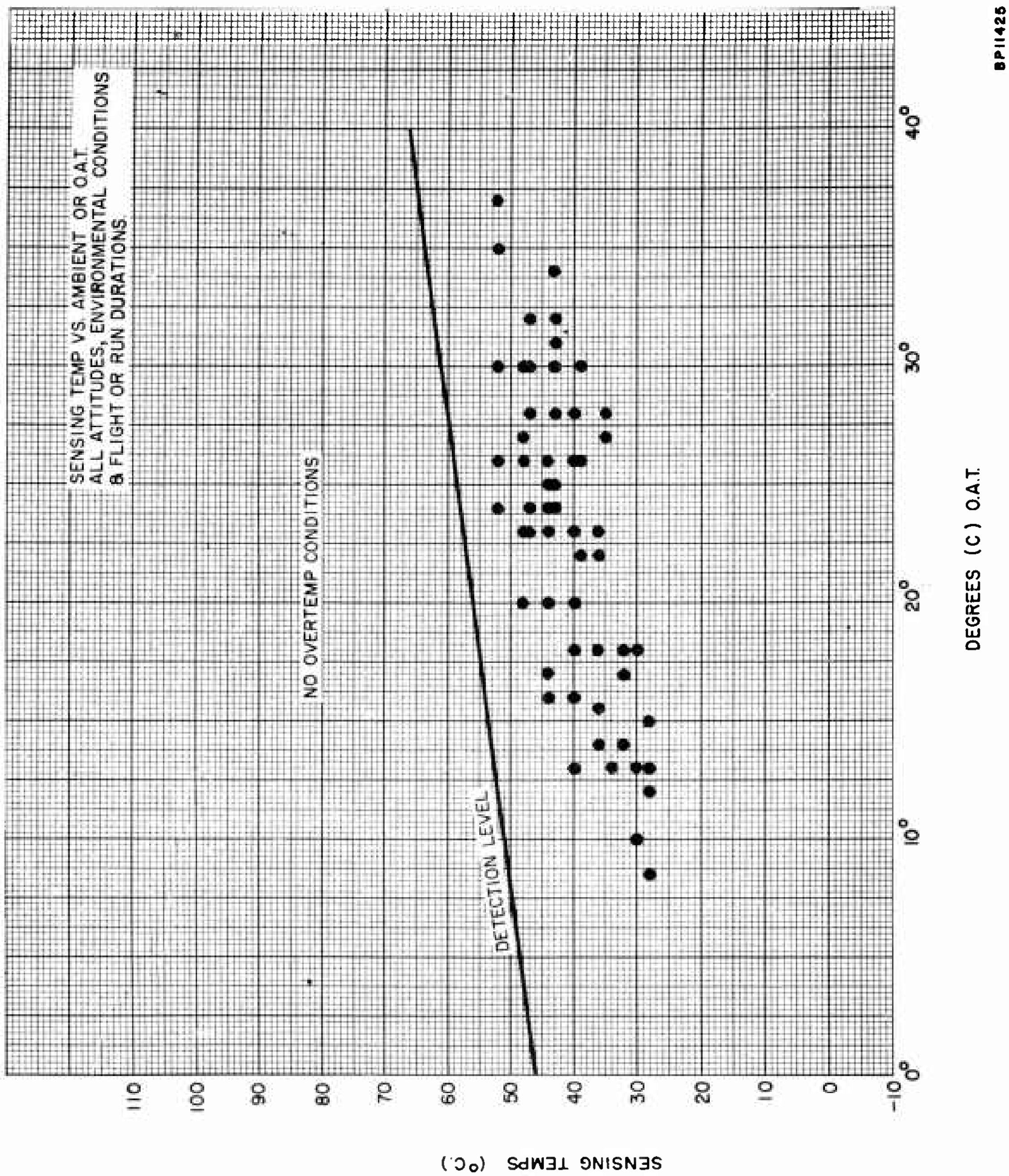


FIGURE 17. SWASH PLATE BEARING TEMPERATURE PLOTS (PART 1)

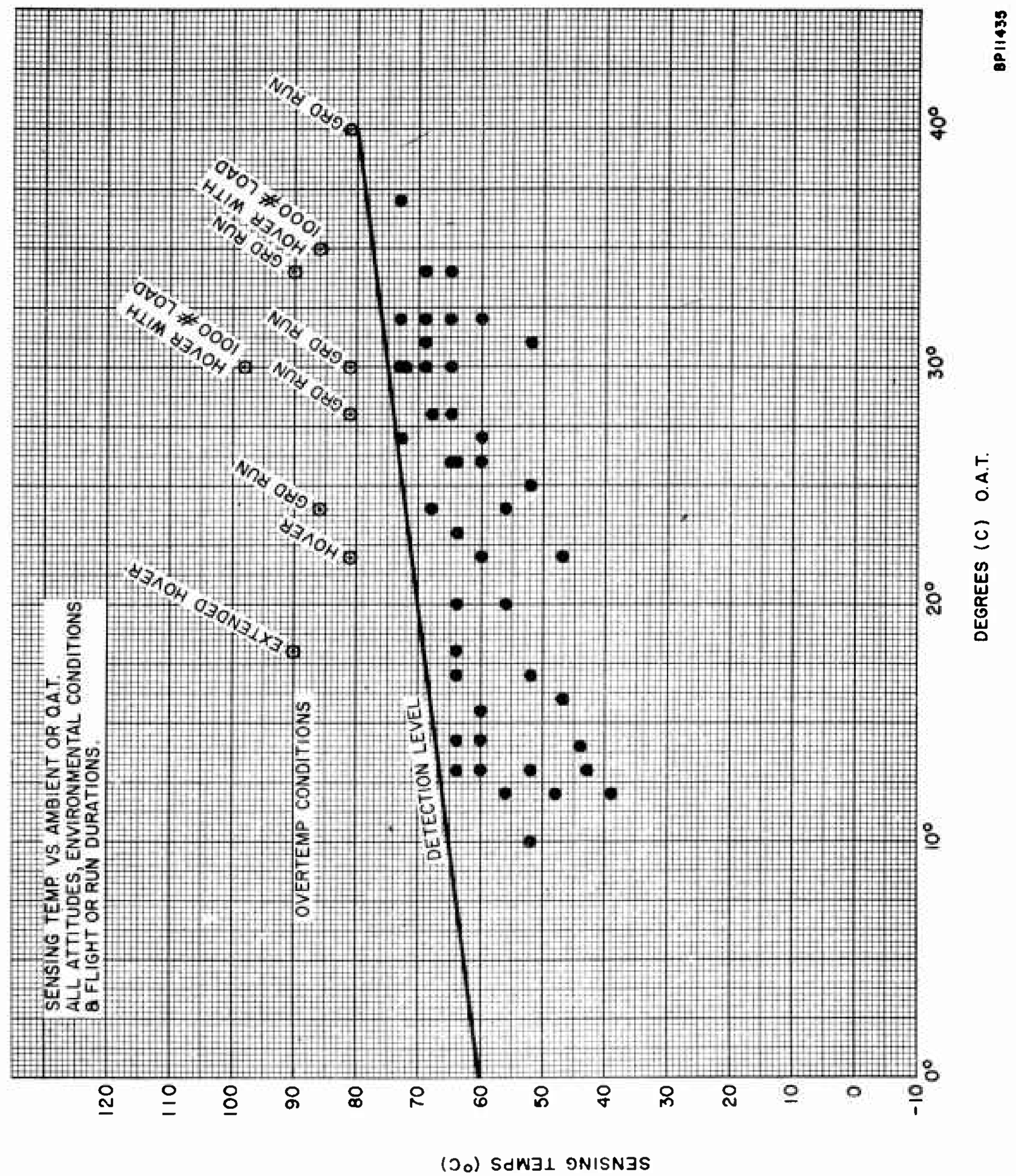


FIGURE 17. MAIN MAST BEARING TEMPERATURE PLOTS (PART 2)

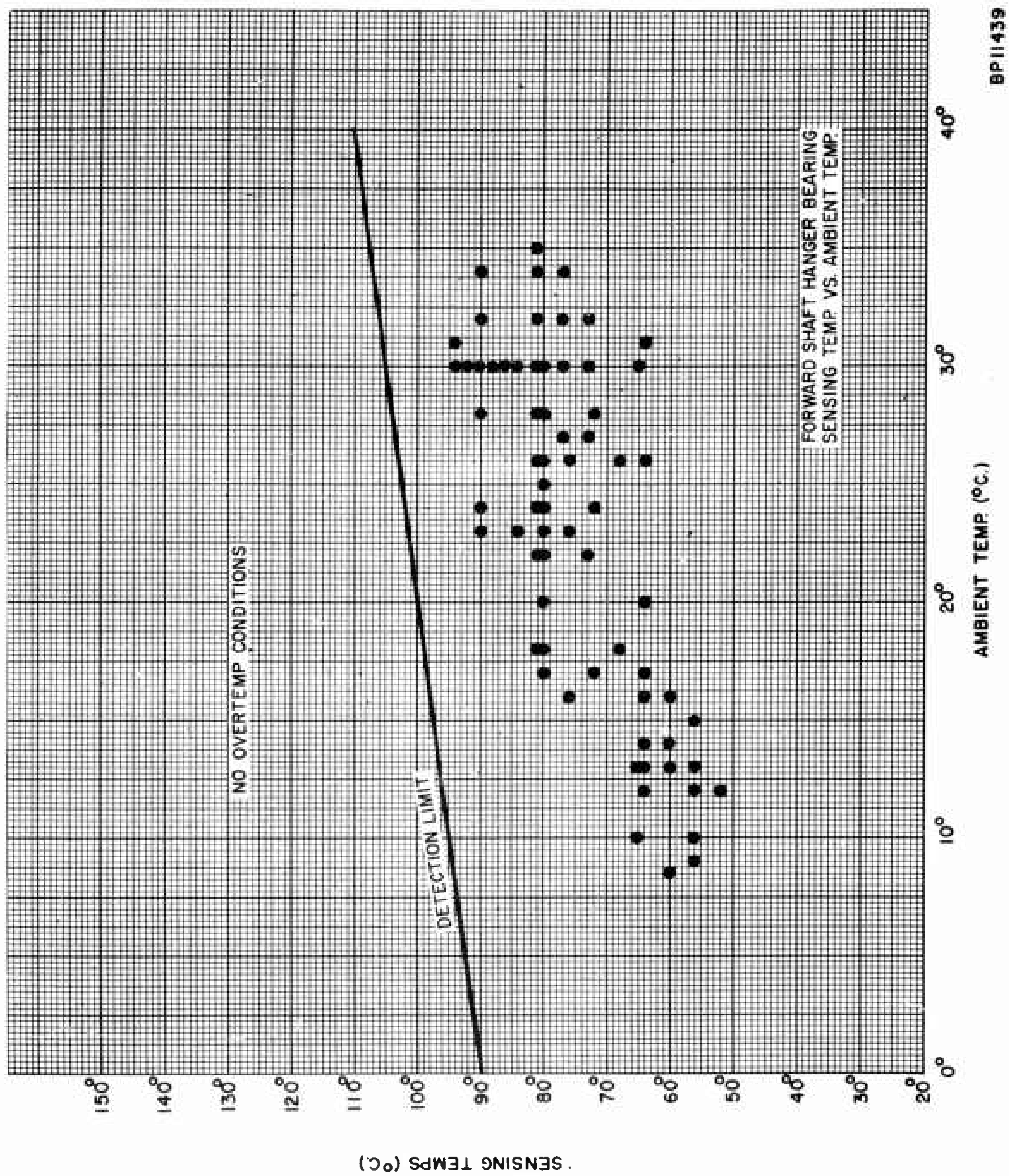


FIGURE 18. FWD SHAFT HANGER BEARING, SENSING TEMPERATURE VS AMBIENT TEMPERATURE (PART 1)

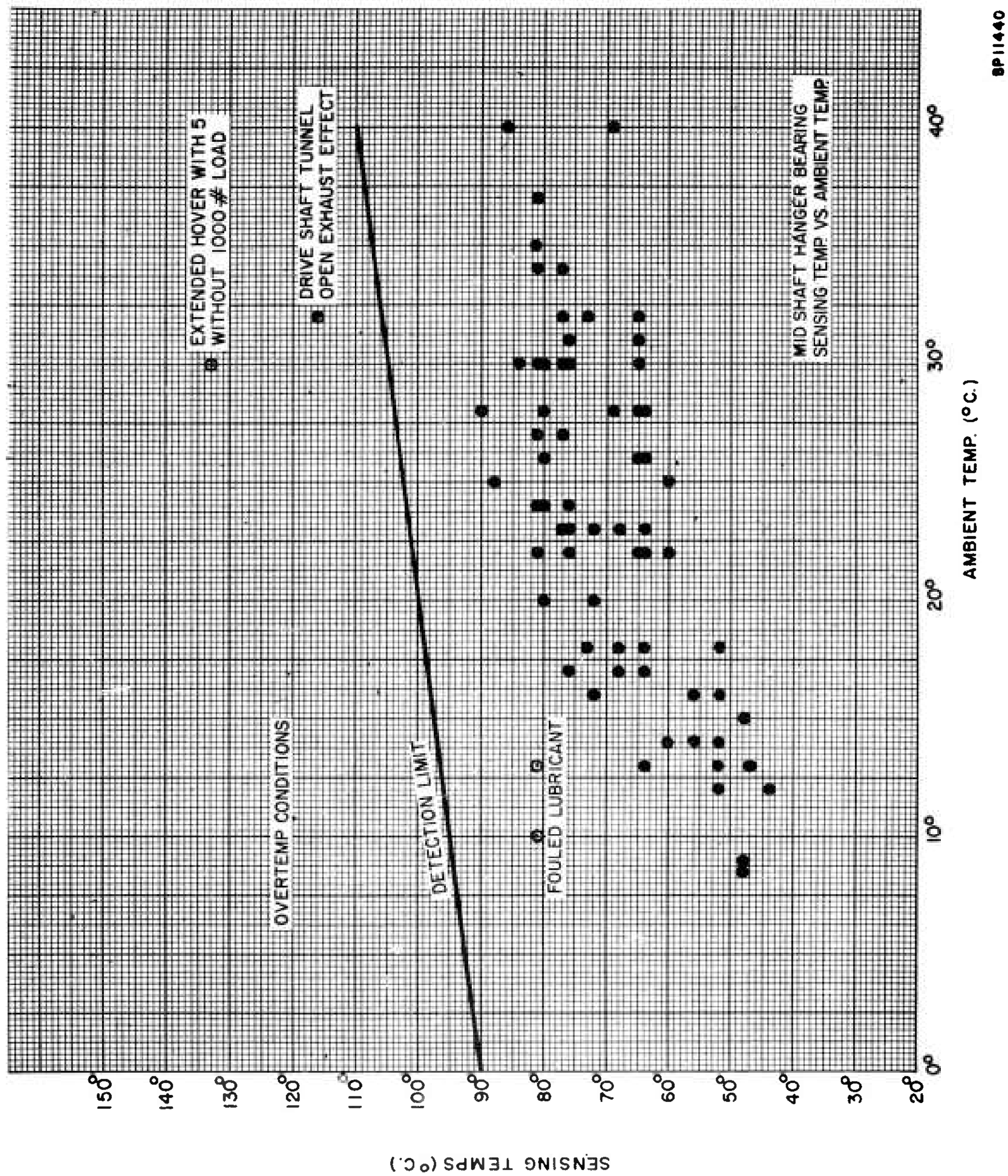


FIGURE 18. MID SHAFT HANGER BEARING, SENSING TEMPERATURE VS AMBIENT TEMPERATURE (PART 2)

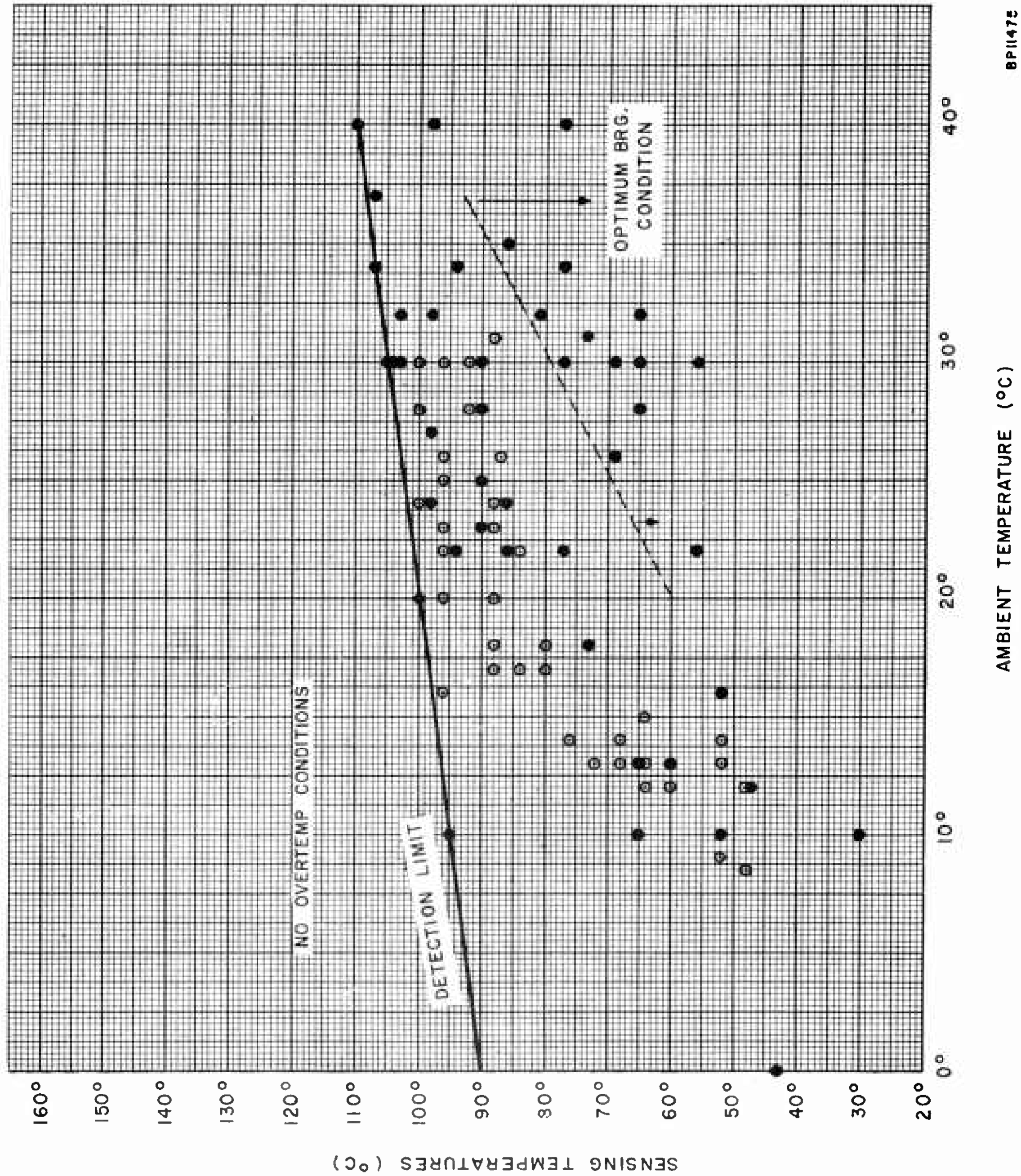


FIGURE 19. AFT SHAFT HANGER BEARING, SENSING TEMPERATURE VS AMBIENT TEMPERATURE (PART 1)

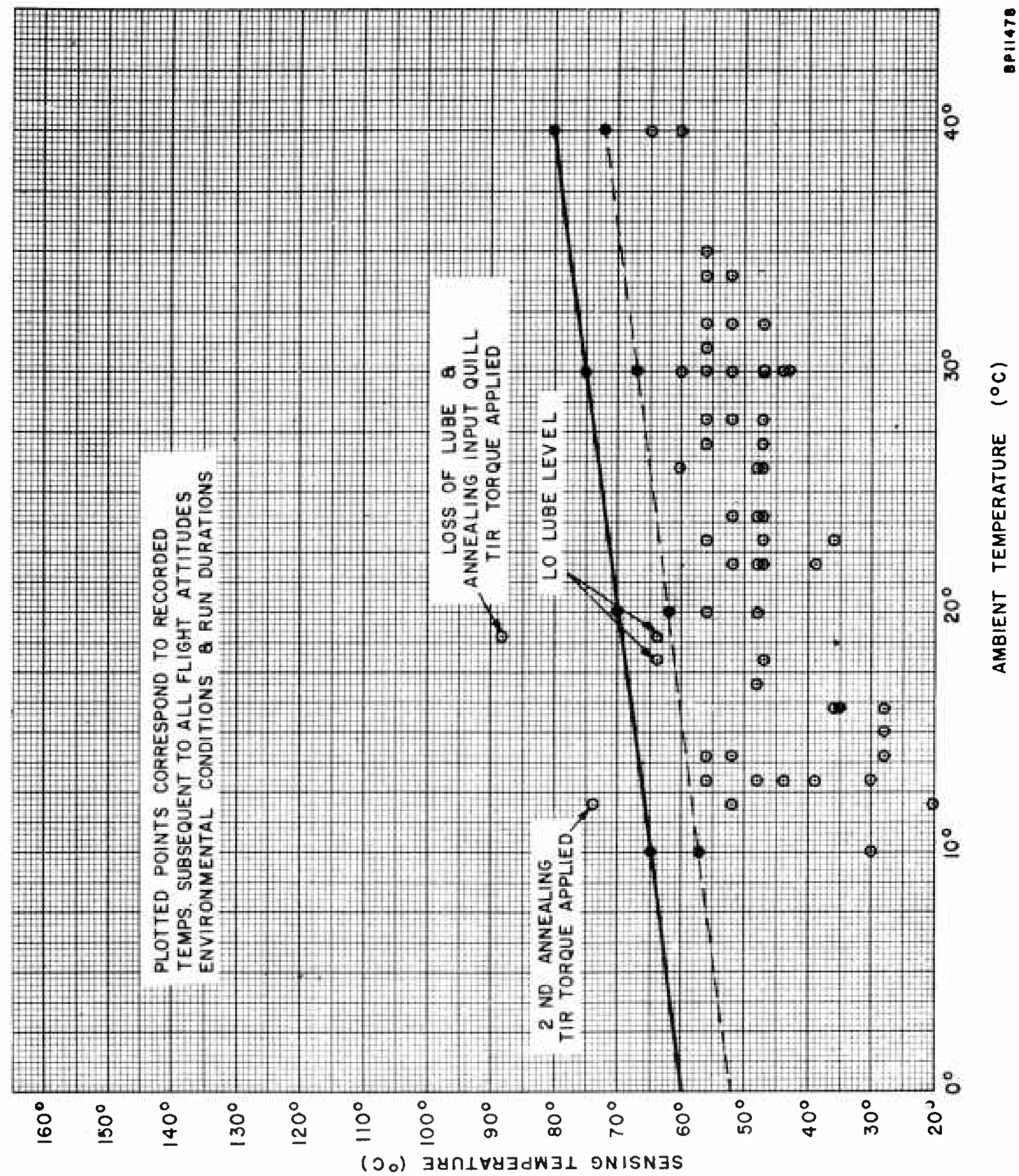


FIGURE 19. 90° GEAR BOX, SENSING TEMPERATURE VS AMBIENT PLOT (PART 2)

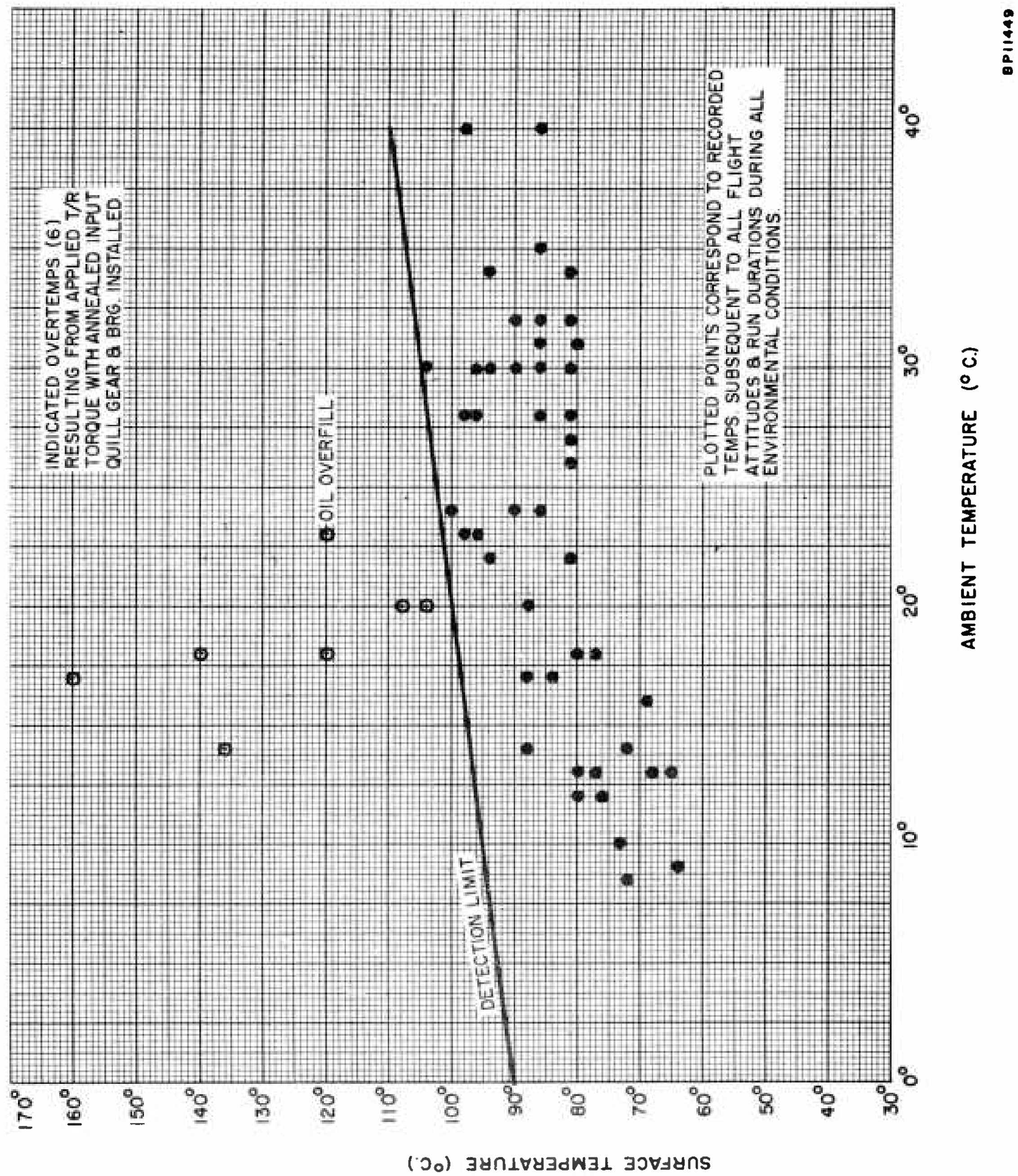


FIGURE 20. 42° GEAR BOX, SURFACE TEMPERATURE PLOT

The Operational Test sequences provided data and observations permitting the evaluation of ALARM channel capabilities. Channels not performing as well as intended or desired were either modified to provide satisfactory operation or eliminated from the system. The demonstrations of various channel capabilities during the operational tests led to refinements which were evaluated during the malfunction testing. The results of this sequence will be discussed in the Malfunction Tests section of this report.

MALFUNCTION TESTS

GENERAL

As a preliminary to the Malfunction Test sequences, the major dynamic components referenced in Table 5 were interchanged to avoid undue damage to serviceable items. These included the Main Transmission, Engine, and both Tail Rotor Drive gear boxes (42^{o} and 90^{o}). Immediately following completion of this change-over, a series of analytical data runs were performed to evaluate the differences in vibration signatures of the main transmission and engine.

Figure 21 through Figure 24 illustrate the comparisons resulting from this analysis. It is apparent in these representations that considerable variation can occur in vibrational characteristics, particularly as the component reaches its normal overhaul time, such as the two components used in the malfunction tests. This factor must be taken into consideration when specifying vibrational "GO" or "NO GO" limits as measured by the ALARM System. This can be accomplished after similar data are accumulated from a number of like components. It is conceivable that this may lead to a limit value specification which will provide an indication that the transmission or engine should be removed for overhaul, rather than at a specified time based upon the number of operating hours (TBO). However, setting the limit to this presumably higher level may result in decreased capability to detect some minor, critical, internal malfunction in the component by way of vibration sensing. A long-term evaluation will provide the answer.

One consideration realized from examination of these graphs is the possibility that the vibrational increases are due to the gradual deterioration of the components involved rather than merely a difference which has always existed between two transmissions or two engines. It is this gradual increase which will enable recording types of equipment, such as that being developed under separate contract, DA-44-177-TC-750, to predict when replacement should be made.

In the following discussions of Malfunction Test Results, all "reference" data referred to with respect to any tests involving transmission or engine vibration are basically the data shown on these four graphs labeled "XMSN (or Engine) used in Malfunction Tests". The tests will be discussed by test number as referenced in Table 4 of the "Test Procedure" section of this report.

Prior to actually commencing the malfunction test sequences on the turbine engine, an investigation of the forward engine vibration pick-up was made as a result of an analysis of previous data recorded from that channel. It was suspected that the pick-up mounting pad arrangement was creating some resonances which were masking actual vibrations. A modified pad was manufactured and the results are shown in Figure 25. This modification will alter the actual vibration levels as recorded during Operational Tests of this channel, but it is felt that the relative amplitude differences at the various flight attitudes are still valid. The modified pad was used throughout the Malfunction Tests.

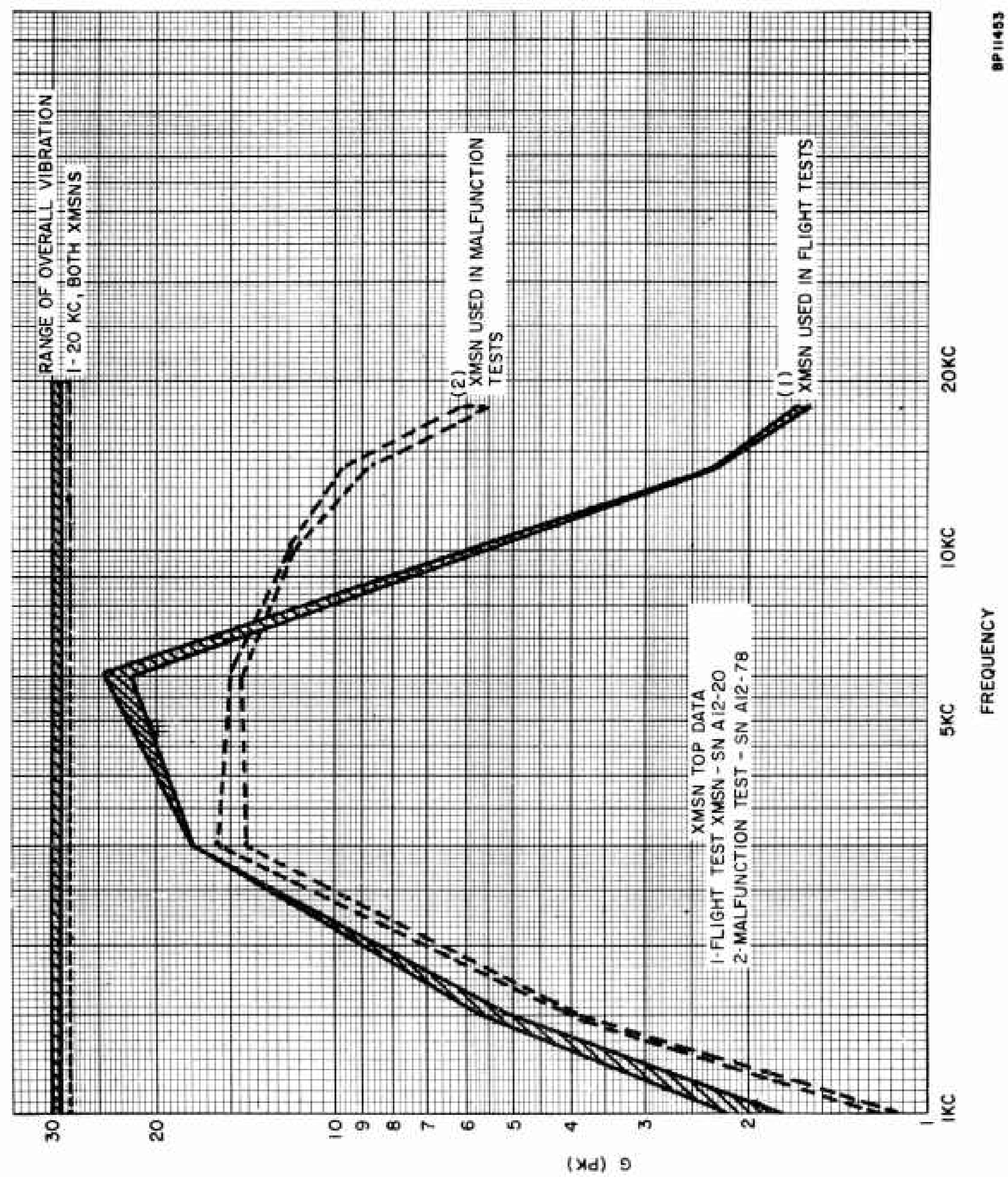


FIGURE 21. VARIATION IN NOMINAL VIBRATION CHARACTERISTICS BETWEEN INDIVIDUAL COMPONENTS

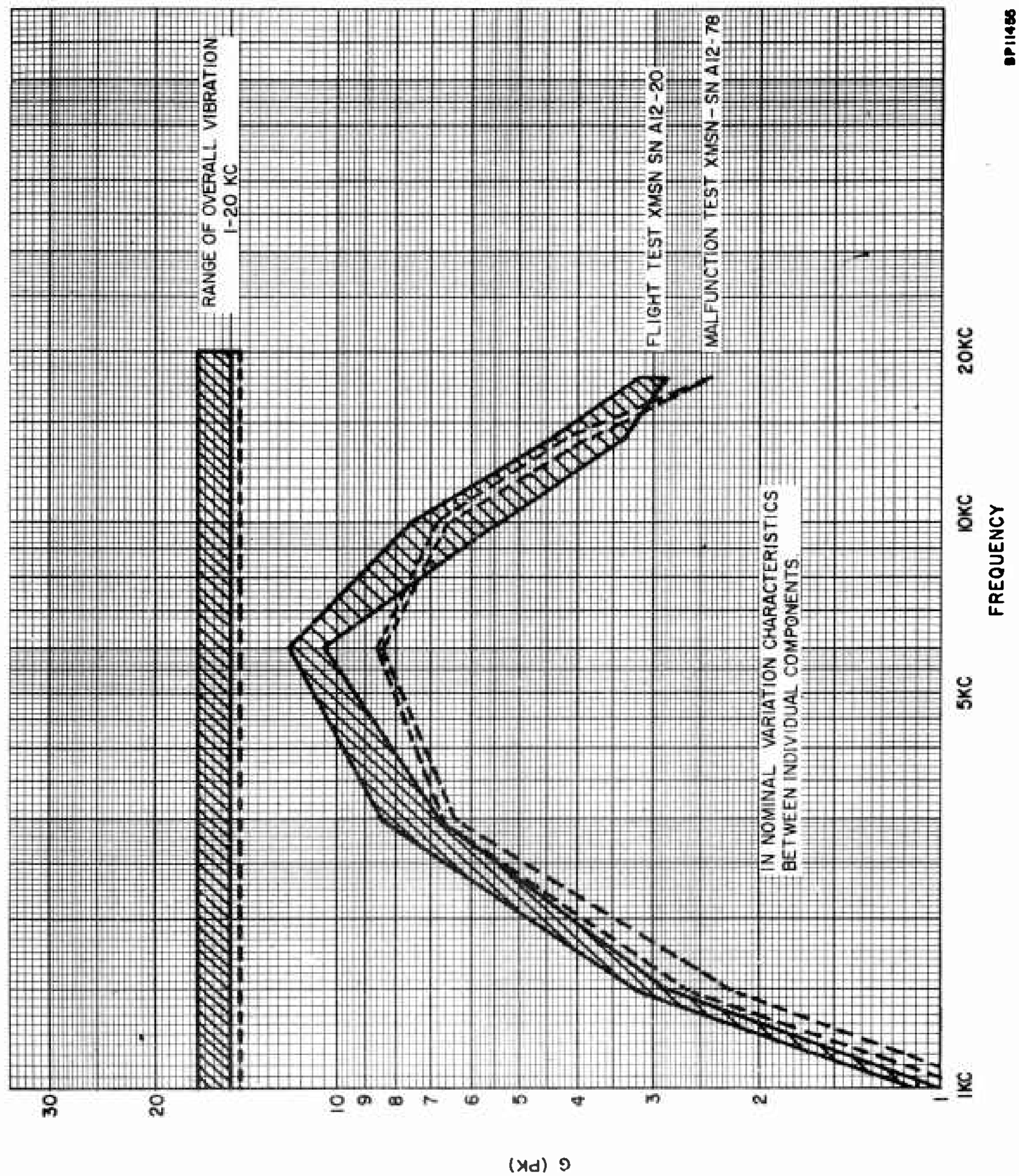


FIGURE 22. TRANSMISSION BASE VIBRATION (VARIATION)

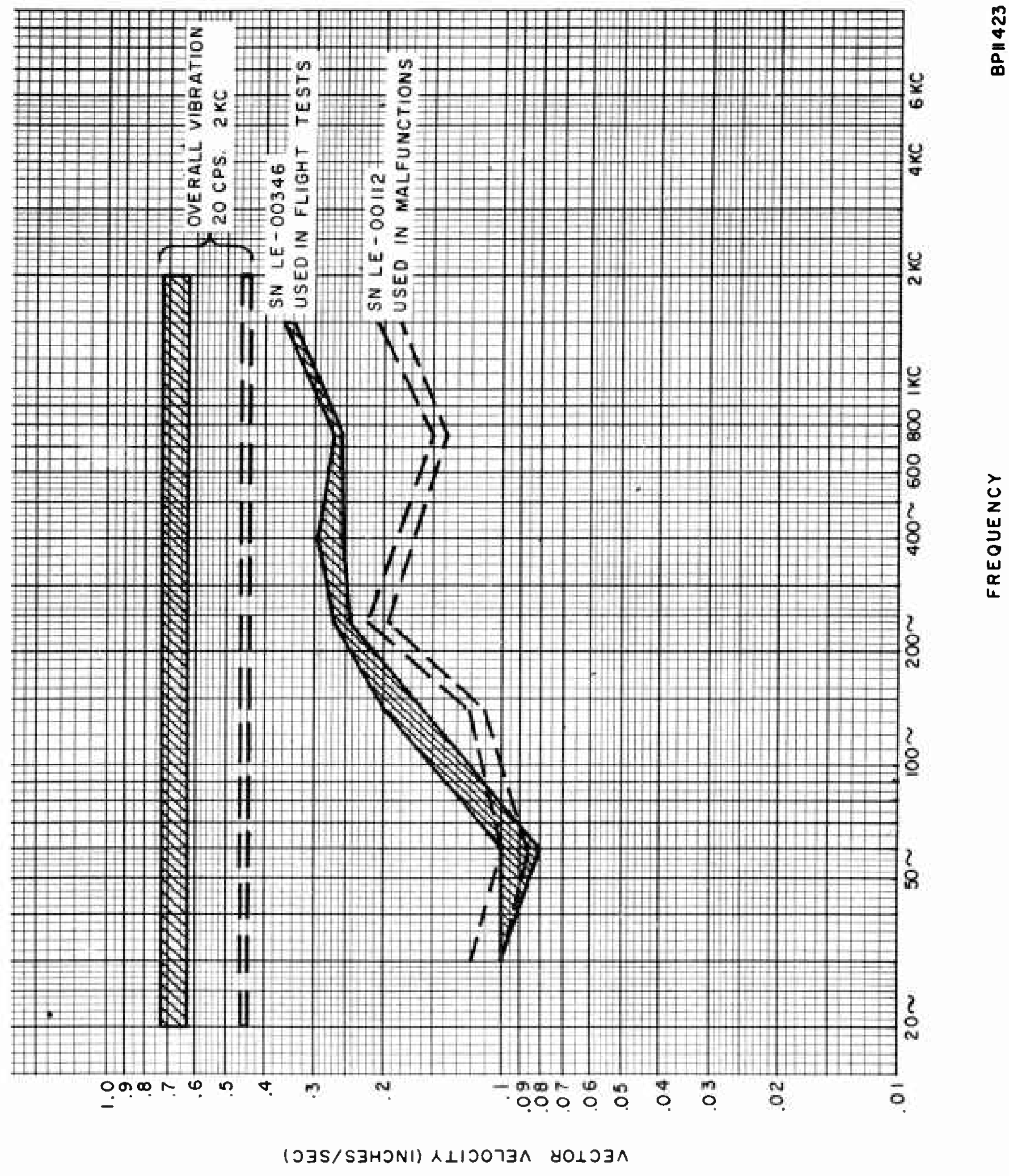


FIGURE 23. AFT ENGINE VIBRATION

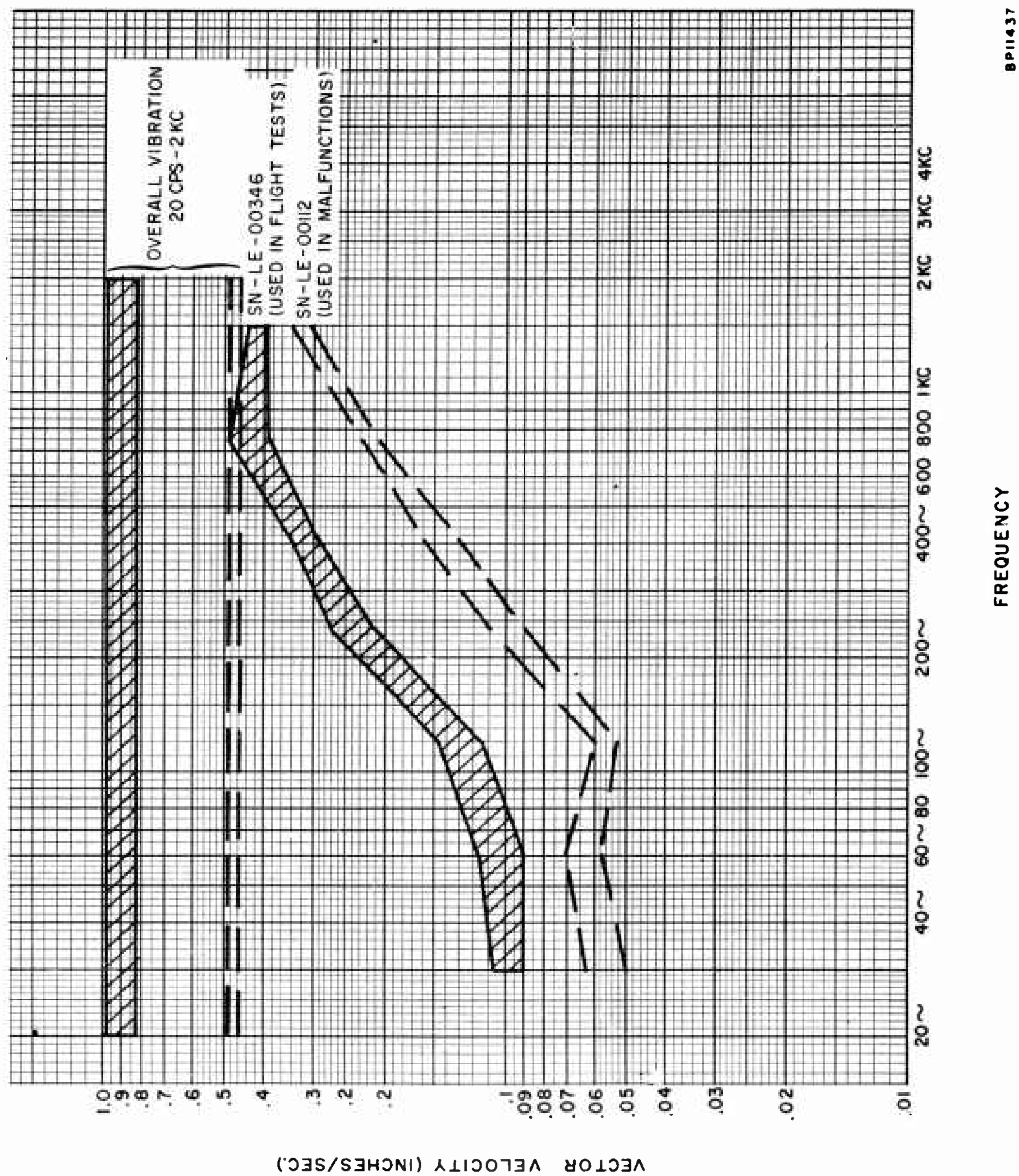


FIGURE 24. FWD ENGINE VIBRATION, ORIGINAL VS MALFUNCTION PLOT

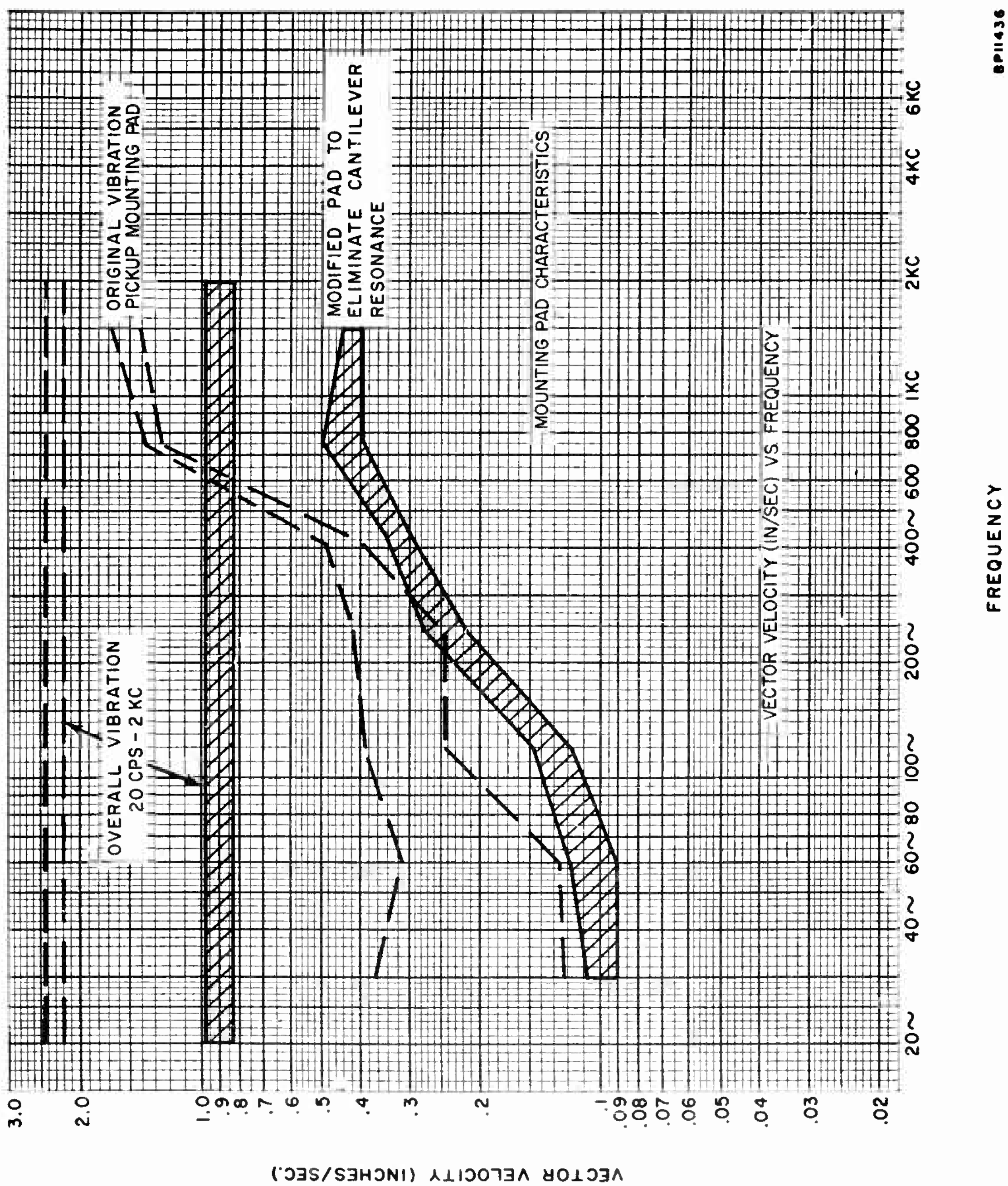


FIGURE 25. COMPARISON OF ORIGINAL AND MODIFIED FWD ENGINE PICKUP

Test #1 - Short Shaft Misalignment

This test was performed by removing aligning shims beneath the right rear engine mount as shown in Figure 26. Results were negative, with no detectable vibration increases occurring when a total of .130 inch of shimming was removed. No abnormal vibration was observed by the pilot or observers during this condition. It must be assumed that the subsequent short-shaft misalignment thus created (if any) was effectively absorbed by the shaft's couplings to the engine and transmission, preventing any abnormal vibratory motion of the engine. It should be noted that when a similar test was conducted early in the test program (involving the original engine), when only .030 inch was removed from the left rear mount, a detectable increase in vibration occurred. This condition was not evaluated further due to the risk to the then flyable aircraft. It has created some anticipation that eventually this condition can be determined as one producing abnormal engine vibration.

Test #2 - Loss of Torque, Engine V-Band Coupling Clamp

The coupling clamps on both sides of the combustion chamber were loosened to zero torque (refer to Figure 27). The vibration data were observed and recorded. No increase was detected and no abnormal operation was sensed by the pilot or observers. This particular test was performed because of some reported experiences relative to other T-53 turbine engines where the loose V-band coupling existed and excessive vibration was noted. On this configuration, a loose V-band coupling could not be considered an abnormal vibratory condition.

Test #3 - Loss of Torque, "Bishop's Hat" Mounting Bolt

This test was conducted to determine if previous reports of excessive vibration due to a loose mounting volt condition could be substantiated. Figure 28 shows the "Bishop's Hat" located in the tail pipe. Results proved negative, with no observations or recorded increases in vibration at either engine vibration pick-up.

Test #4 - Unbalanced N_2 Turbine Wheel

For this test, a series of N_2 turbine wheel rotations were performed as illustrated in Figures 29, 30 and 31. On the first removal, the turbine wheel was carefully marked for reference position on the power shaft, then rotated 90^o and reassembled. After that test run, the operation was repeated, placing the turgine wheel at 180^o from reference, and another data run conducted.

Results of these tests are illustrated graphically in Figure 32 and Figure 33. As shown on the data plots, the most significant vibrational increases

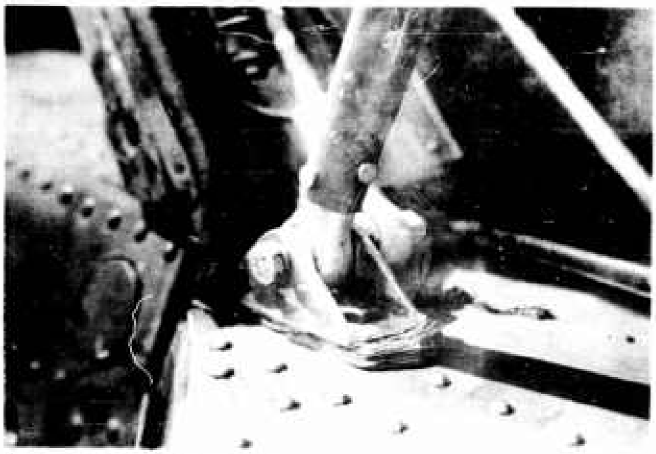


Figure 26. Right Rear Engine Mount and Shims, Short Shaft Misalignment Malfunction Test.

Figure 27. Engine V-Band Coupling Clamp (Loosened), Excessive Engine Vibration Malfunction Test.

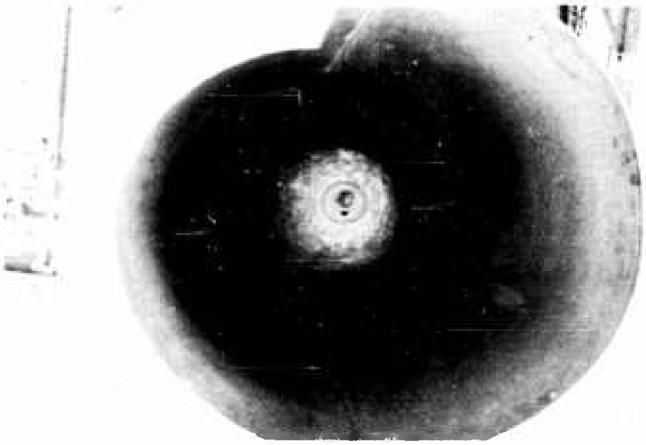


Figure 28. Engine Exhaust Opening Showing "Bishop's Hat", Excessive Engine Vibration Malfunction Test.

occurred on the Forward Engine vibration and for the 90^{o} position of the N_2 turbine wheel. This channel (Fwd Eng Vib) did indicate during the 90^{o} test as a verification of these data. From these results, it is concluded that the nature of the unbalance was most pronounced when the turbine wheel was rotated to the 90^{o} position. An engine overhaul report, to be supplied by Army depot maintenance, on this particular engine should provide information supporting the results of these tests. It is not known at this time whether the unbalance is beyond any allowable limits. The suspected reason for the greater increase in forward engine vibration than that detected at the aft engine location under these unbalance conditions was that the vibratory motion induced was transmitted by the power shafting and had a more pronounced effect on the forward support bearings due to resonances.

Test #5 - Loss of Torque, N_2 Turbine Wheel Mounting Bolt

This test was actually performed "in reverse", since it was discovered on removal of the combustion chamber for the first of the turbine wheel relocations that the bolt was already extremely loose ("finger-tight"). This meant that all previous data recorded on the engine and regarded as "reference" were the data resulting from this condition in the engine. The bolt was retorqued properly and the reference data obtained. Figure 38 shows this bolt prior to removal for pulling the turbine wheel. As illustrated in Figure 34, both forward (Part 1) and aft engine (Part 2) vibration levels were changed, but not enough to be detected. This condition was reported frequently with this particular engine configuration, and indications were that no serious trouble has ever resulted. In the few instances where an unbalance of the turbine wheel itself could make this a dangerous condition, it is assumed that either the unbalance itself or excessive play of the wheel due to this bolt being loose would result in a detectable increase in vibrational levels. Apparently, in the engine under test this condition was being approached but not sufficiently pronounced to cause any real difficulty. The engine overhaul report may provide additional information.

A data run was conducted as additional experimentation and analysis on the engine itself, during which time both the short-shaft (Xmsn) and tail rotor drive were disconnected, creating a completely unloaded engine condition. The results are shown in Figure 35. While no malfunction conclusions can be deduced from this test, it does illustrate some of the exterior influences on overall engine vibration with regard to loading conditions. This further amplifies the importance of recognizing that a considerable increase in vibrational levels will occur in moving from an aerodynamically unloaded attitude (such as ground run) to one with considerable loading such as take-offs and high climb rates.

During the test procedures, an abnormal engine condition was observed intermittently following an engine start. While operating at 6400 rpm, a faint audible hum would occur in the cargo compartment for a duration of 5 to 10 seconds and then cut off. During the audible period, the Aft Engine Vibration channel would illuminate. After considerable effort, observers were

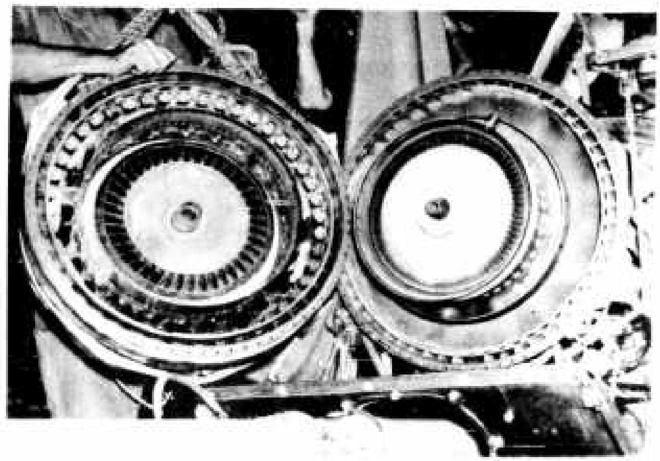


Figure 29. Combustion Chamber (N2 Turbine) Disassembly, Turbine Wheel Rotation Unbalance Test.

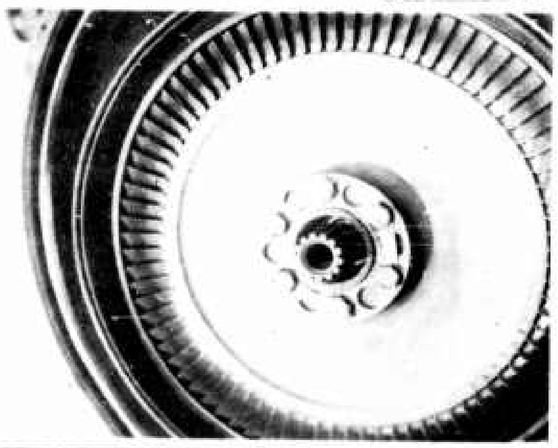


Figure 30. N2 Turbine Showing Marks Used To Determine Location For Turbine Wheel Rotation Unbalance Test.

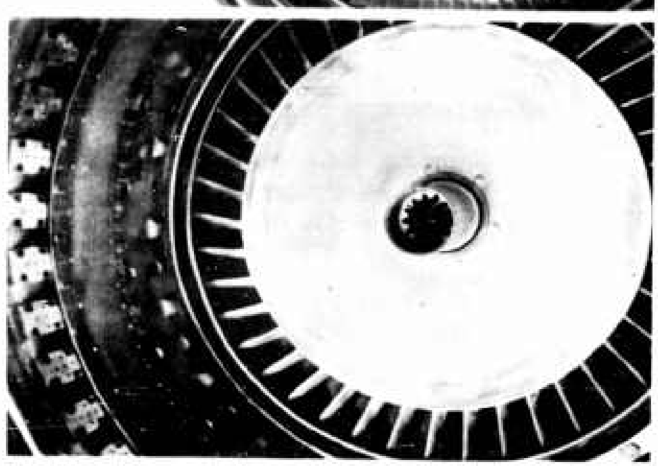


Figure 31. N1 Turbine In Preparation For The Turbine Wheel Rotation Unbalance Test.

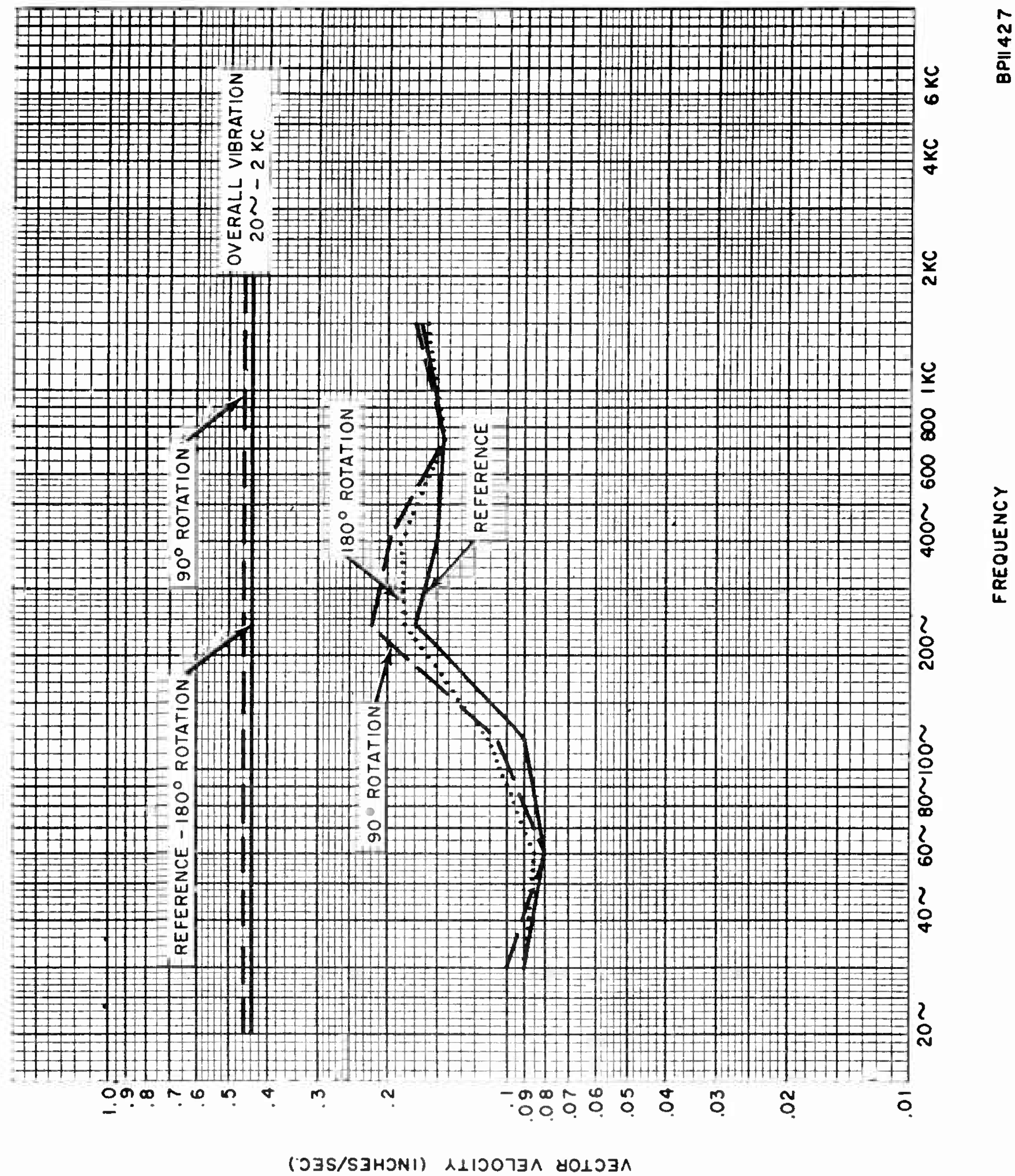


FIGURE 32. AFT ENGINE VIBRATION, VECTOR VELOCITY VS FREQUENCY, PLOT

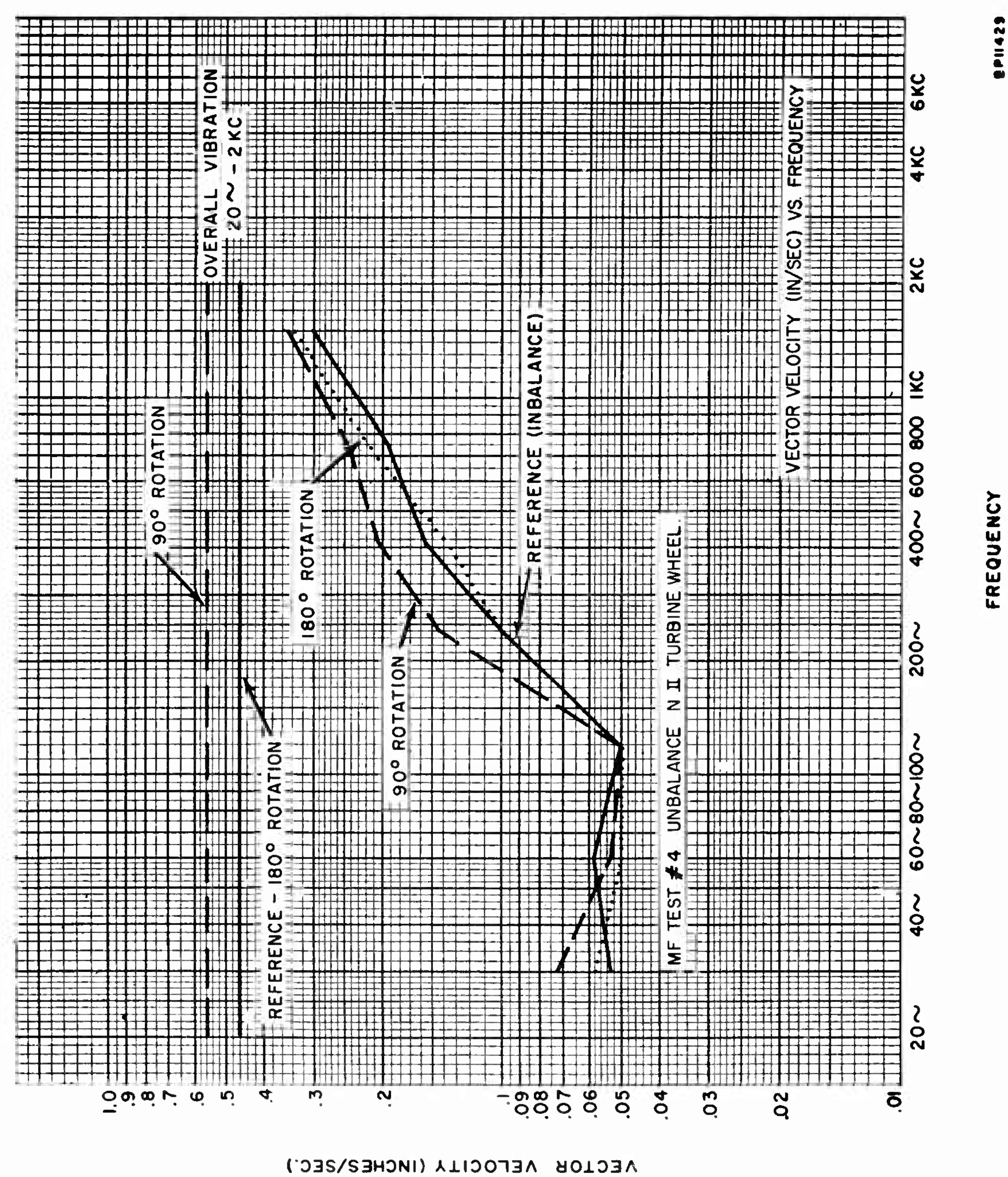


FIGURE 33. FWD ENGINE VIBRATION, VECTOR VELOCITY VS FREQUENCY, PLOT

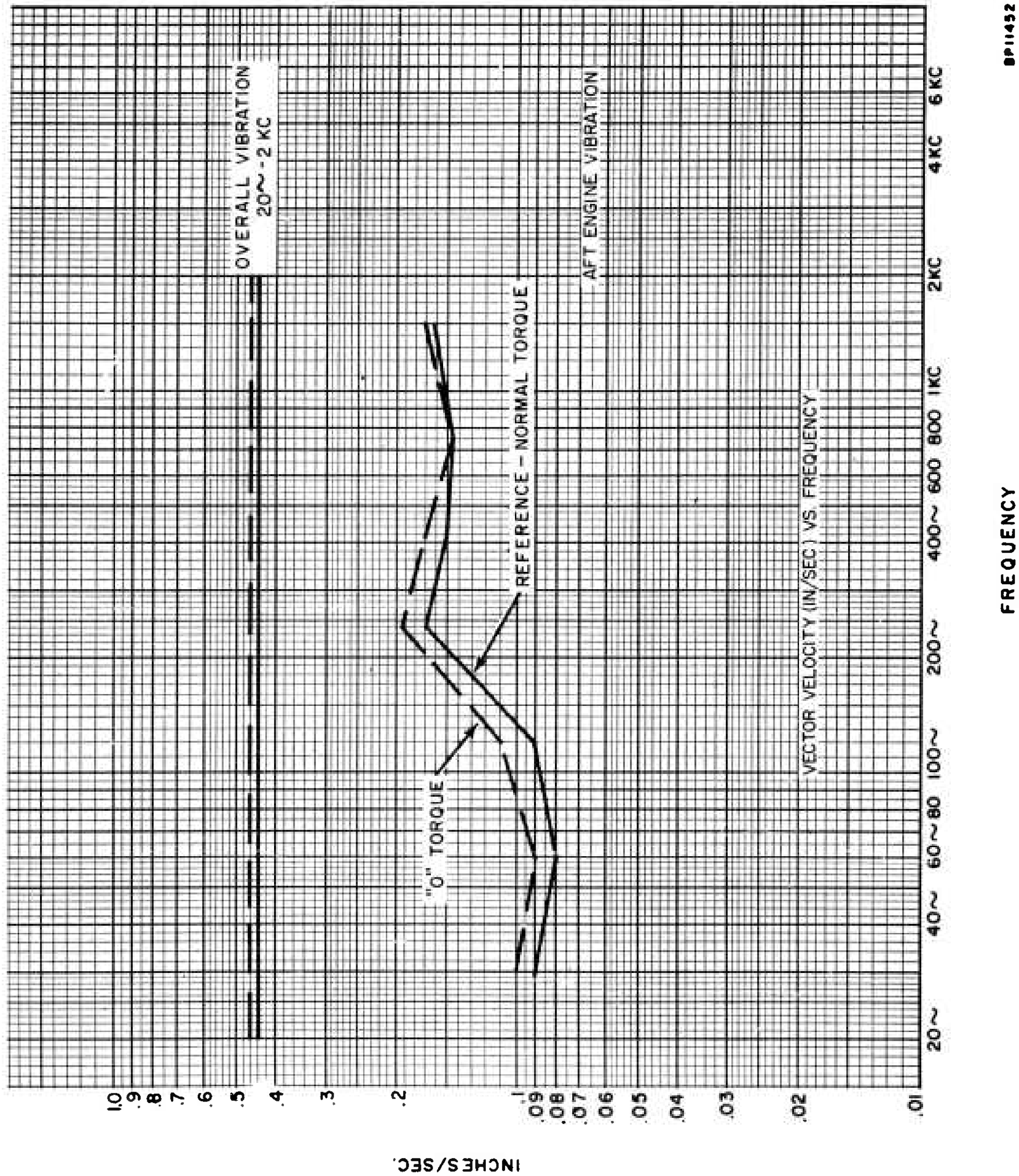


FIGURE 34. FWD ENGINE VIBRATION, VECTOR VELOCITY VS FREQUENCY, (PART 1)

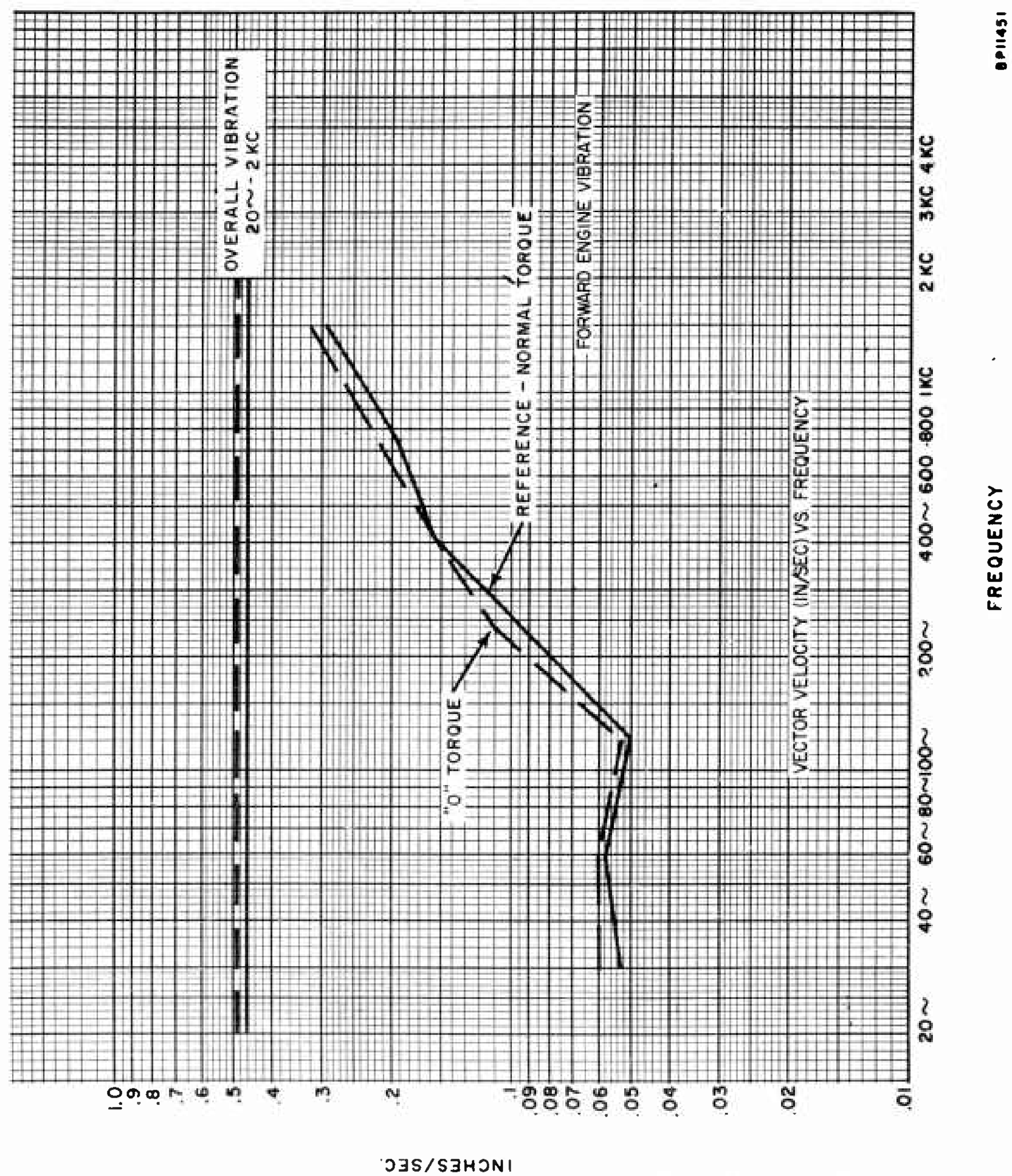


FIGURE 34. AFT ENGINE VIBRATION, VECTOR VELOCITY VS FREQUENCY, (PART 2)

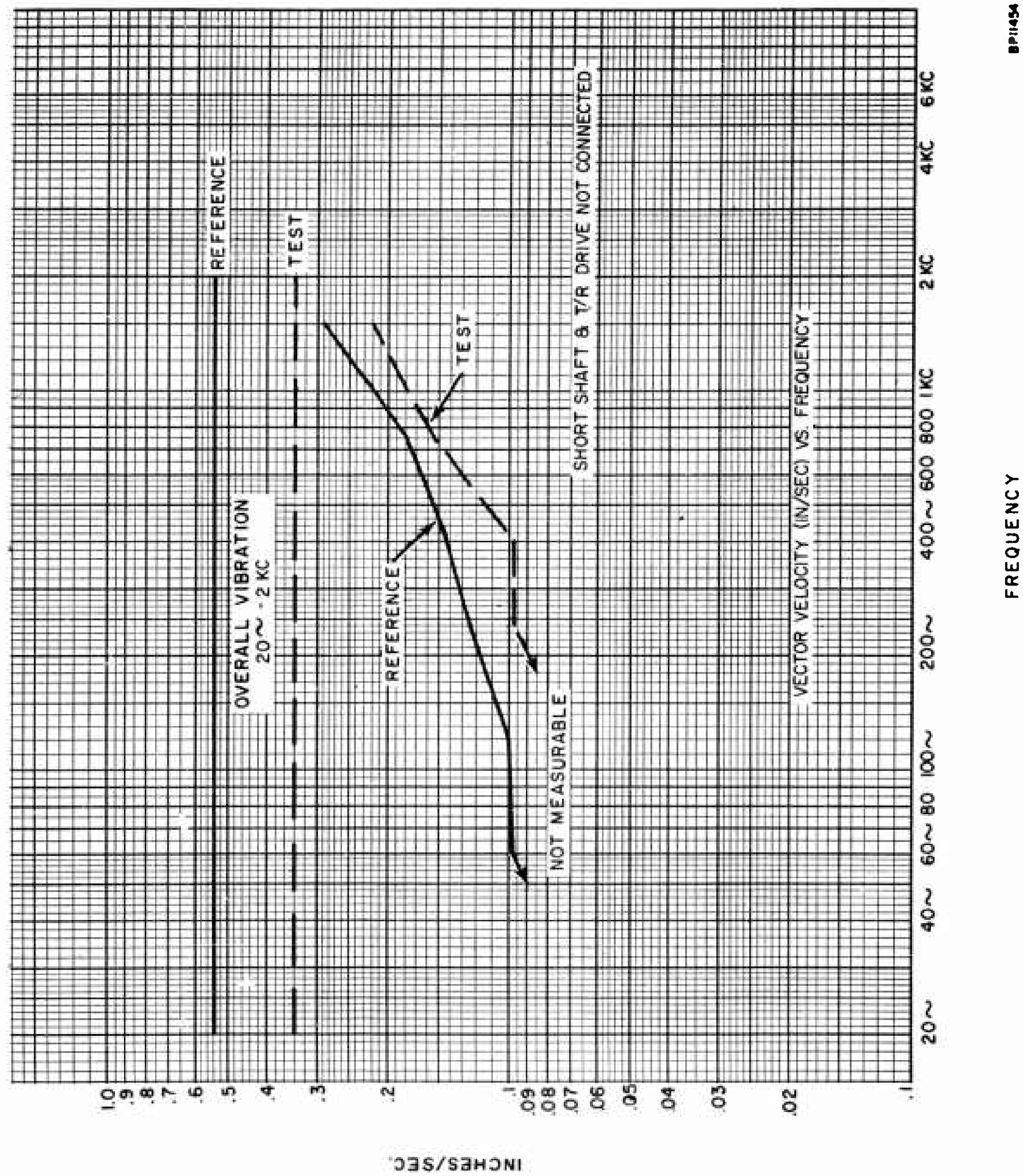


FIGURE 35. FWD ENGINE VIBRATION, VECTOR VELOCITY VS FREQUENCY, (REFERENCE AND TEST) (PART 1)

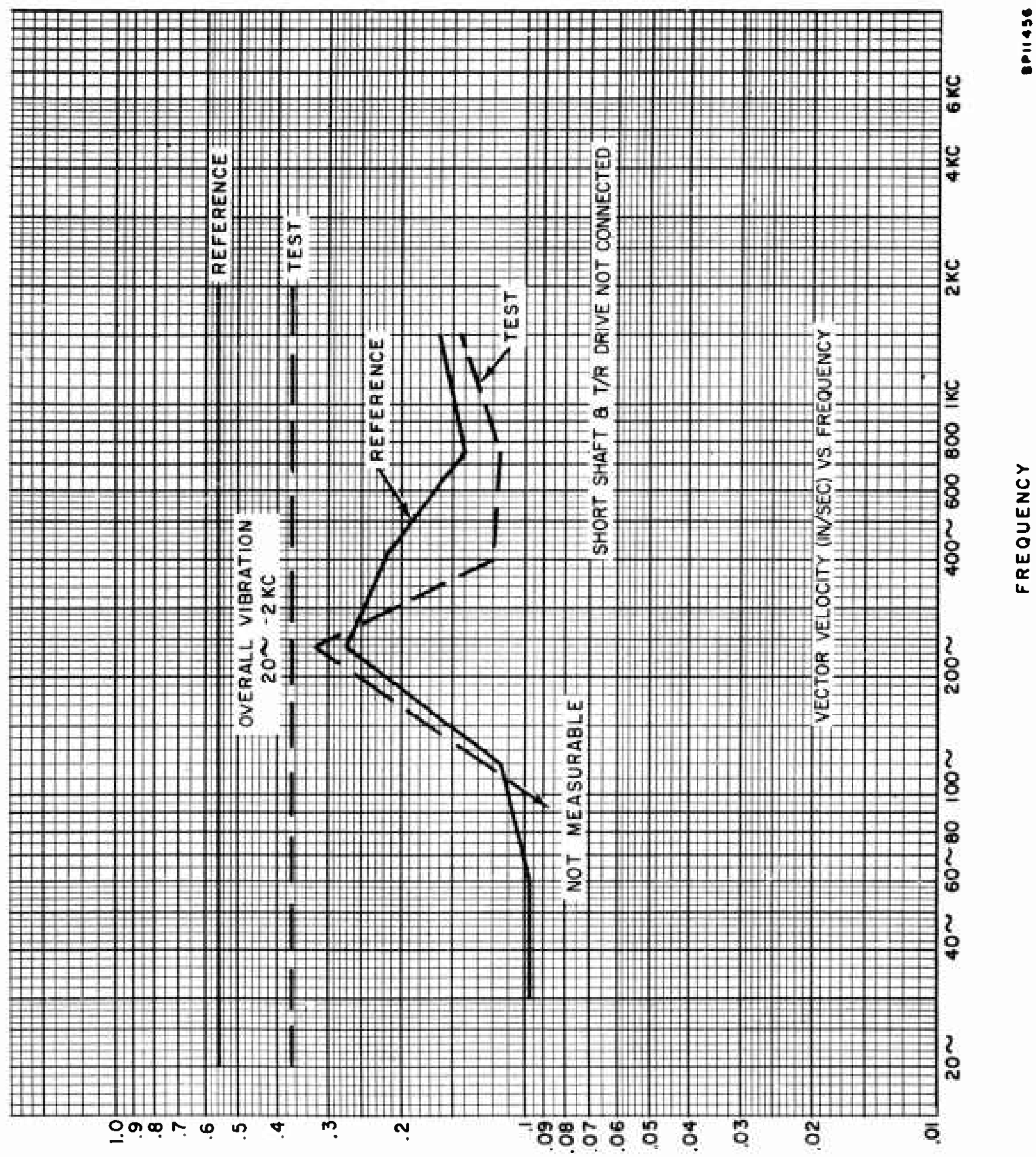


FIGURE 35. AFT ENGINE VIBRATION, VECTOR VELOCITY VS FREQUENCY, (REFERENCE AND TEST) (PART 2)

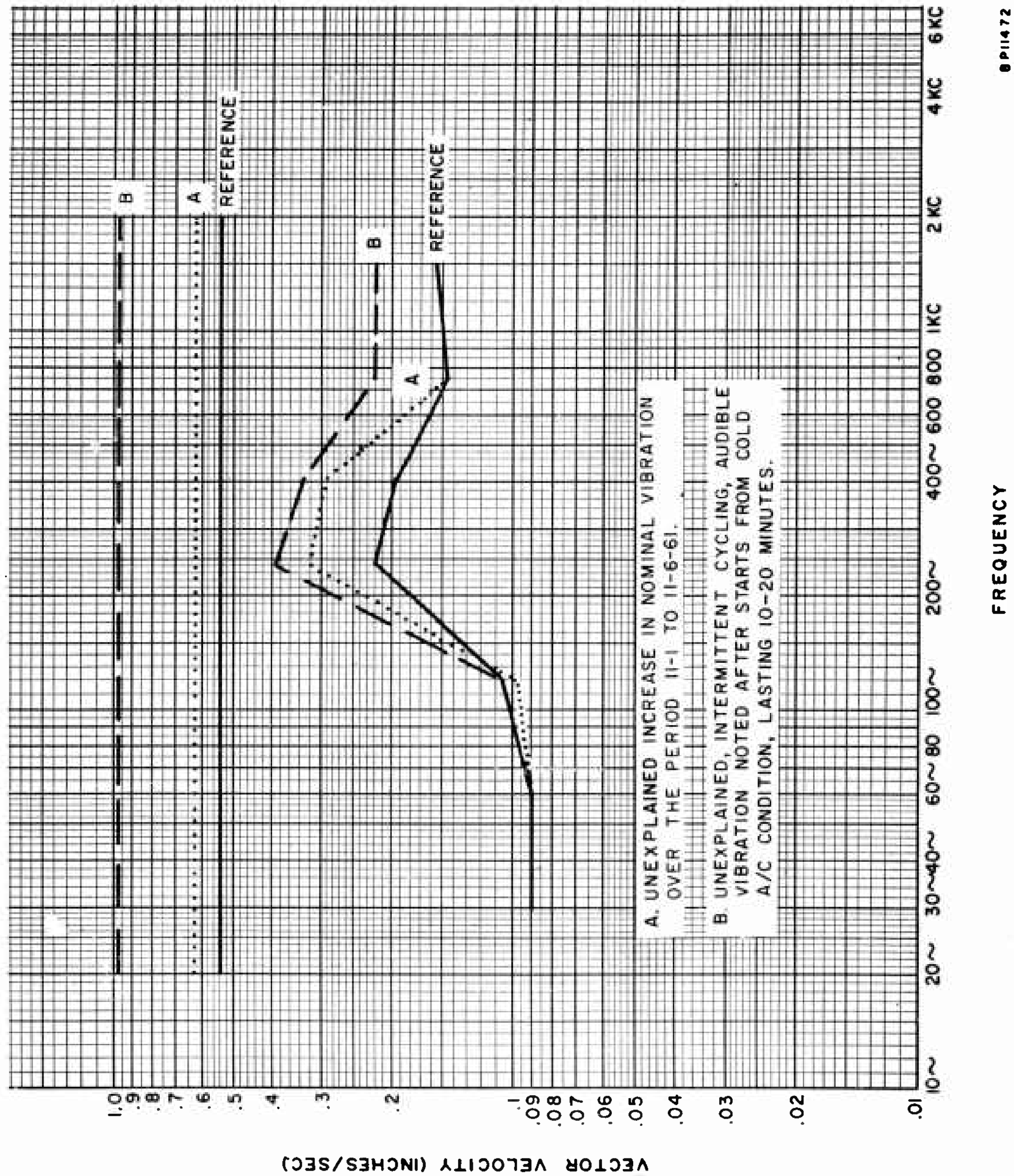


FIGURE 36. PLOT, UNEXPLAINED INCREASE IN NOMINAL VIBRATION AND INTERMITTENT CYCLING, AUDIBLE VIBRATION

able to accumulate complete data on this condition, which is presented in Figure 36. Also illustrated on this graph is another unresolved condition which occurred; specifically, an increase in the nominal or reference vibration levels just prior to the end of the test program. This also was indicated by the ALARM System. Both of these conditions (Figure 36 A and B) may be directly related, and the overhaul report should provide valuable information to resolve this phenomenon.

Test #6 - Misaligned Input Quill on 42° Gear Box

This test was devised as a means of creating either abnormal tail vibration or excessive gear box temperature by misaligning the gear box relative to its input/output shafting. Results of the test were negative; no measurable increases in vibration occurred nor did the temperature reflect any abnormal frictional forces resulting from the condition. Apparently the input and output quill flexible couplings are capable of compensating for this much misalignment. In addition, it must be realized that this test was conducted with no tail rotor torque applied; hence very little power was transmitted though the gear box. More conclusive results may be obtained if this test were to be conducted under load such as a hovering attitude.

Test #7 - Blocked Oil Collector in 42° Gear Box

This test was devised as a possible means for creating an increase in temperature. Results proved to be negative, possibly because of the unloaded condition. Visual checks and observations verified that no change resulted in the gear box. Since some residual oil remained in the output quill section, this apparently was sufficient to provide adequate lubrication in that area. An extended operation under load, with this condition present, would probably result in higher temperatures as the residual lubricant was lost.

Test #8 - Defective Bearing and/or Gear, 42° Gear Box

To perform this test, the Input Quill of the gear box was removed and disassembled down to the bevel gear with inner bearing attached. This assembly was then subjected to a heat-treat process to anneal the gear from Rockwell C 61 to Rockwell C 34 hardness. The quill was then reassembled, and the gear box reinstalled on the aircraft. Initially no change in vibration occurred. The application of full left pedal (T/R torque) caused higher surface temperatures after 15 to 20 minutes of running time. This was repeated several times, starting from a completely cooled condition, and each increase indicated on the system. Figure 20 in the Operational Test section provided a plot of the results. These indications had not occurred under similar circumstances prior to the heat-treating process. Figure 37 shows the complete results of one of these over-temperature conditions compared to a normal run under identical conditions less the annealed assembly.

In approximately 5 hours running time, tail vibration began to increase and the

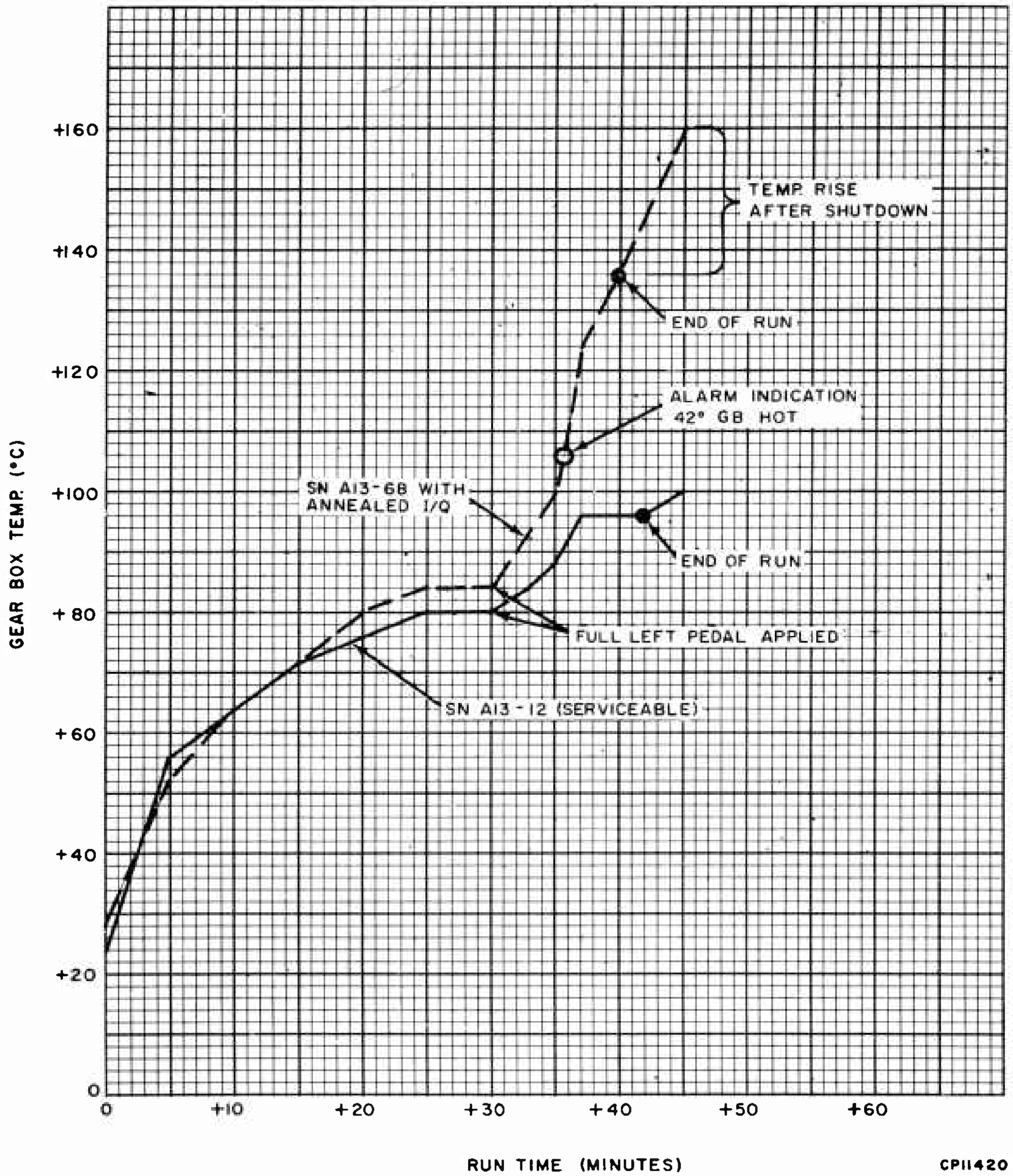


FIGURE 37. MALFUNCTION TEST #8, ANNEALED INPUT QUILL (42° 6B)

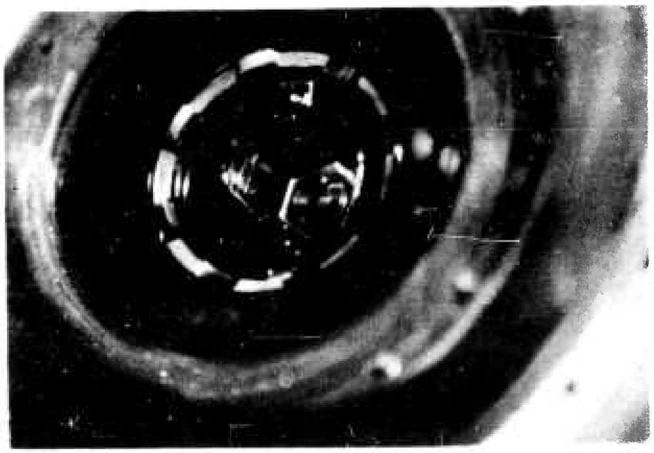


Figure 38. Power Shaft Bolt And Lock Assembly. (Loss of torque, N2 torque wheel mounting bolt, engine malfunction test).

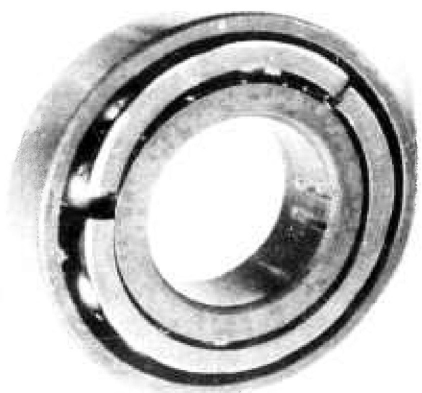


Figure 39. 42^{o} Gear Box Input Quill Bearing Retainer Failure.

Figure 40. 90^{o} Gear Box Input Quill Gear/ Bearing Prior To Annealing.

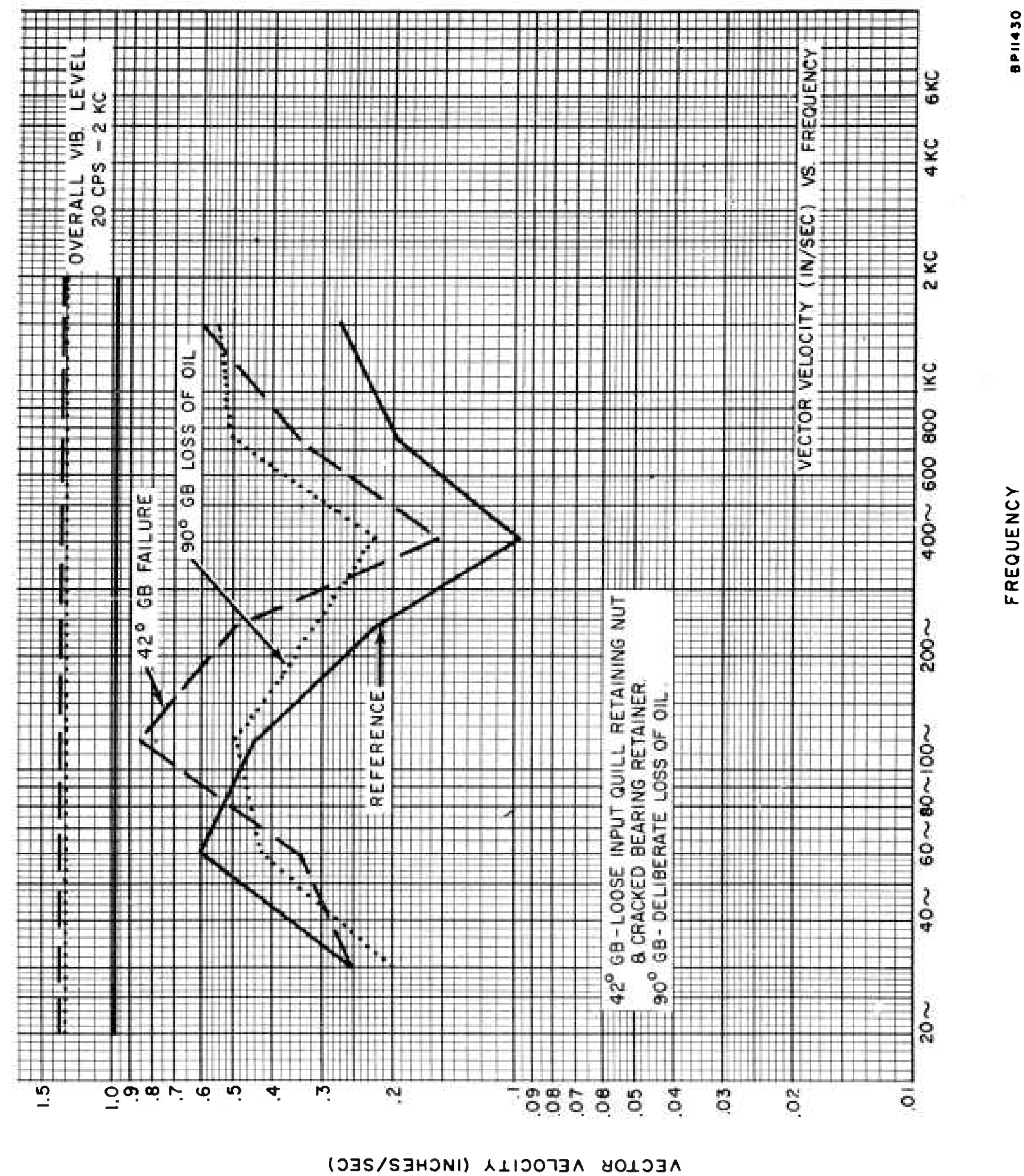


FIGURE 41. TAIL VIBRATION, INDICATED FAILURES

ALARM Tail Vibration channel indicated "NO GO". Other tests were in progress when this first occurred, resulting in about 2 more hours of running time during which recorded vibration levels continued to increase. At this time, an abnormal grinding noise was audible from the gear box, particularly on coastdown. Subsequent disassembly and inspection revealed both a loose bearing retaining nut and a failure of the inner bearing retainer, as shown in Figure 39. It is difficult to conclude when complete failure occurred. Apparently it took place after 5 hours, and the continued increases in vibration were caused by progressive deterioration of the bearings. The data associated with this test are shown in Figure 41. It is not certain whether the heat-treating process (to accelerate wear) caused this failure directly or indirectly by causing the retaining nut to become loose. Of more significance is the effect this condition had on tail vibration, particularly on increasing higher frequencies while actually decreasing levels at the lower frequencies. No indication was noted in chip detection during this sequence, probably because of its location (see discussions under Test #15).

Test #9 - Defective Bearing and/or Gear, 90° Gear Box

The 90° Gear Box Input Quill assembly was removed and disassembled to the bevel gear/bearing combination as shown in Figure 40. This assembly was annealed from a gear hardness of Rockwell C 62 to Rockwell C 34 and reinstalled. Approximately 17 total hours of running time was conducted with no change observed. The same disassembly and annealing process was repeated, lowering the gear hardness to Rockwell C 12. This time, on application of T/R torque, a temperature indication occurred as tests of the 42° Gear Box had demonstrated (see Figure 19, Part 2 plot, for data). After approximately 2 more hours, it was decided that an additional forcing condition would be made to provide accelerated gear deterioration for vibration analysis. A major portion of the lubricant was removed from the gear box and the tests continued. This resulted in a temperature and vibration indication on the system, as well as chip detection. Figure 41 shows the vibrational data, while Figure 19 may again be referenced to show the temperature result. Figure 42 shows the condition of the gear as removed after these tests. No catastrophic failure occurred, but sufficient wear occurred to justify the indications obtained on the ALARM System and certainly sufficient to replace this gear box had this condition occurred under normal operation. Figure 43 shows the 90° GB Chip Detector with the particle accumulation as it appeared on removal after this test.

Test #10 - Defective Bearing and/or Gear, Main Xmsn Input Quill

This test was performed by utilizing the Input Quill (shown in Figure 44) removed from another transmission due for overhaul (S/N A12-142). The quill was disassembled to the bevel gear/bearing set, and this portion was subjected to heat treatment to reduce hardness of the gear from Rockwell C 60 to Rockwell C 40. After reassembly and installation in the malfunction transmission (S/N A12-78), the Xmsn Base vibration indicated immediately. Data results are shown in Figure 45 and Figure 46. The Top is shown for reference only; no indication occurred on this channel although some variation is indicated.

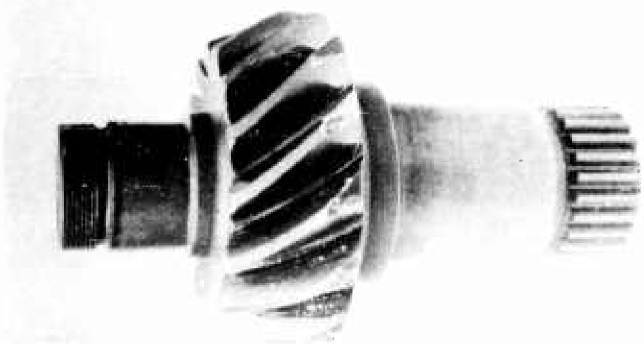


Figure 42. 90° Gear Box Input Quill (Gear after Test #9, heat treated to 1/2 hardness).

Figure 43. 90° Gear Box Magnetic Chip Detector After Test #9 (Magnetic chip detector accumulation).

Figure 44. Main Transmission Input Quill Prior To Annealing.

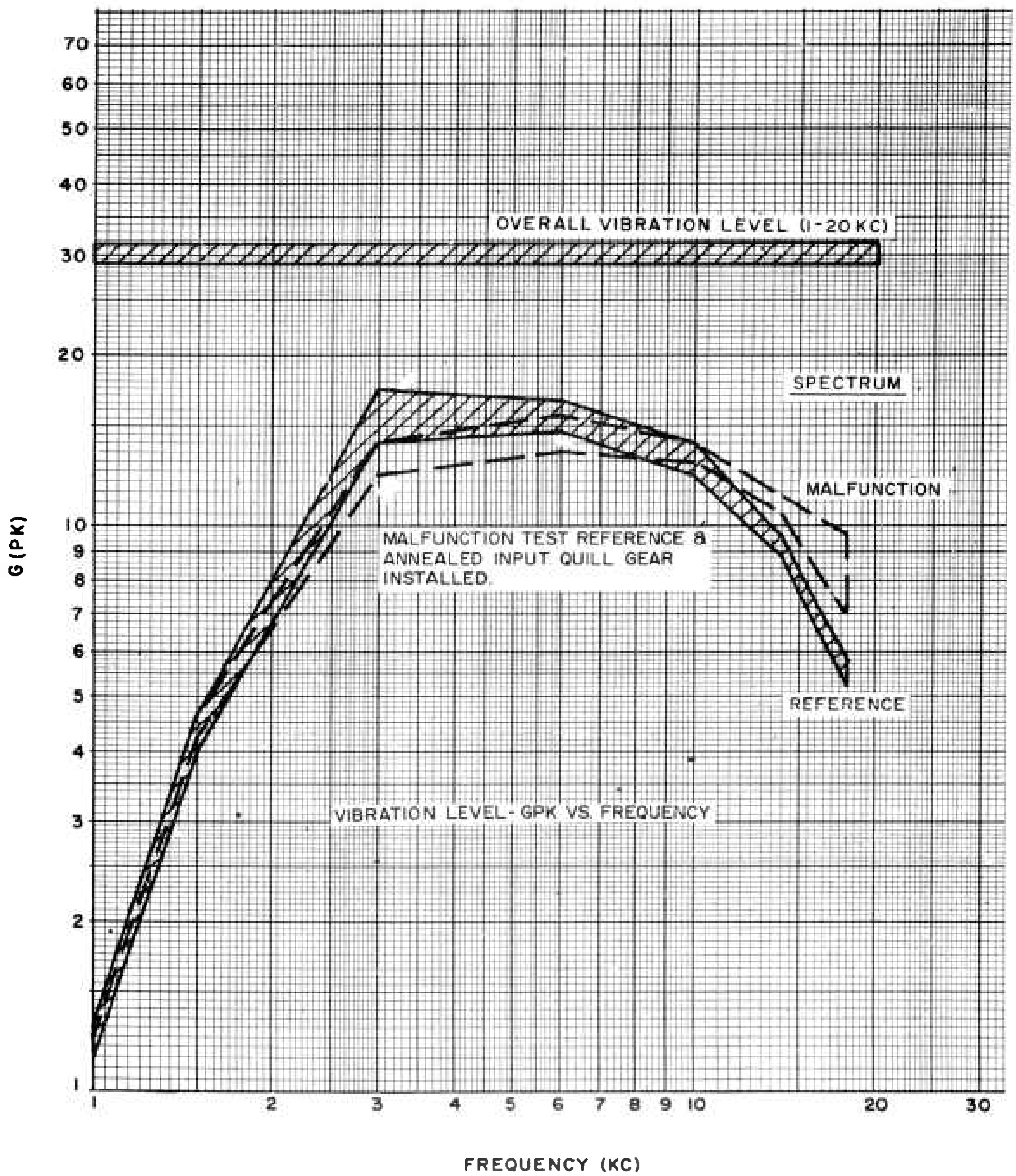


FIGURE 45. XMSN TOP VIBRATION, PLOT

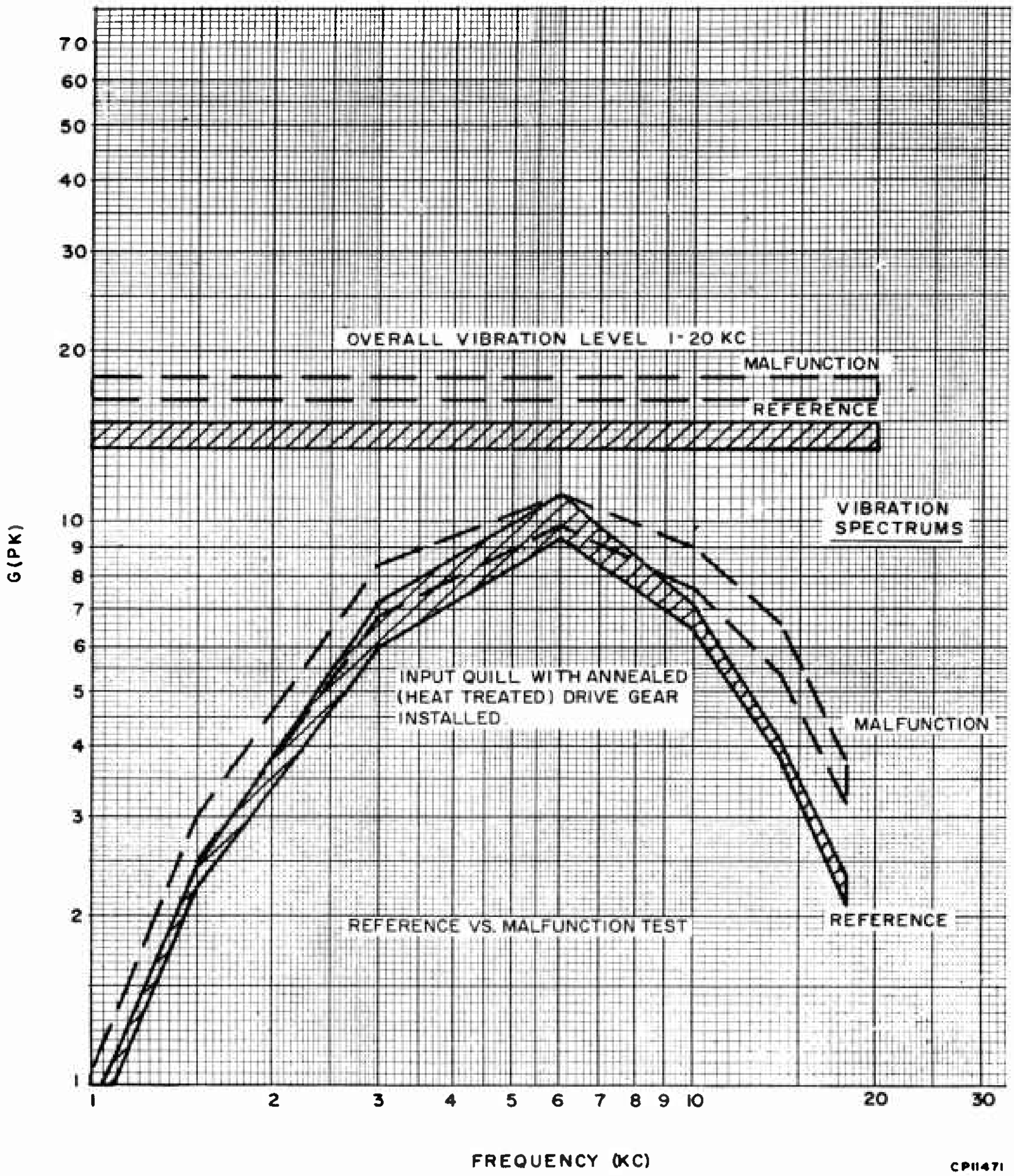


FIGURE 46. XMSN BASE VIBRATION

On subsequent removal and inspection, nothing abnormal could be observed. It was then assumed that the increased vibration was due to variations in gear patterns on this quill compared to the original. This quill was subjected to a total of 12 hours operation with no further vibrational increases attributed to any change in its condition. It was decided not to heat treat the gear any further because catastrophic failure in this area would probably have prevented any further aircraft operation. Overhaul reports (to be supplied by Army depot maintenance) on the transmission will be carefully reviewed for comments concerning this condition.

Incidental to this test, an additional temperature sensor was added to the system at this time to monitor the surface temperature of the input quill. The data accumulated has since permitted selection of this point to replace the present Main Mast Bearing sensor (see Operational Test Results). No abnormal temperatures were recorded by this sensor throughout tests involving the heat-treated gear.

Test #11 - Scored Lower Mast Bearing Race

The Main Mast Assembly was removed from the aircraft and the lower mast bearing inner race (see Figure 47 for reference) was ground off to create a 0.015-inch "flat" on the surface as shown in Figure 48. The 0.015-inch dimension represents the depth of the "flat" from the true round of the race.

On reinstallation of the main mast and main rotor assembly, test runs were conducted, with the results proving negative. No Xmsn Base vibration increases were detected at any time. It is felt that the "flat" did not create any pronounced bearing impacts as had been anticipated; hence it is considered a poor malfunction test, if a malfunction at all. Here also the overhaul report may reveal additional considerations. For example, if substantial bearing deterioration has occurred, it will indicate this was a true malfunction condition and as such is not detectable by vibration as monitored in the ALARM System.

Test #12 - Blocked Lubricating Jet(s), Main Xmsn

Tests in this area involved the three main transmission lubricating jets shown in Figure 49. Initially it was planned to silver solder the small jet openings closed, but later it was decided to tape the input slots closed for complete blockage.

The first test was to create an increased oil pressure condition for relief valve (Channel 19) operation, and one blocked jet was installed. No indication occurred, and the oil pressure increased as read on the aircraft Xmsn Oil Pressure gauge. The remaining two jets were blocked and the pressure rose from 40 psi to nearly 70 psi. No indication on the Pressure Relief Valve channel occurred. To check proper operation, a regular (unmodified) relief valve was installed and the tests repeated. Pressure increased a total of 8 psi, thus proving that the

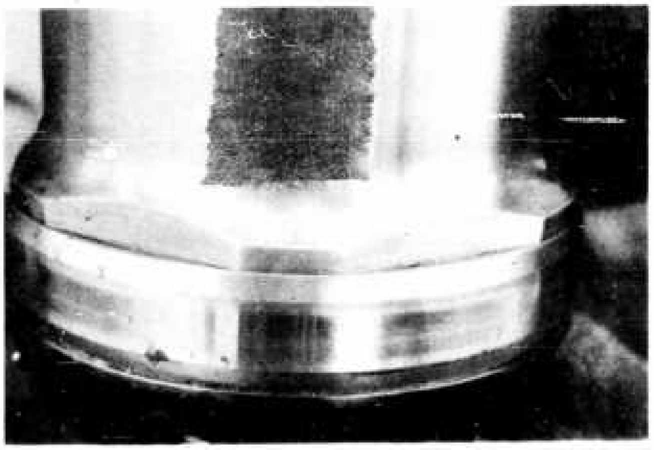


Figure 47. Lower Mast Bearing Race Before Malfunction Test, Main Transmission.

Figure 48. Lower Mast Bearing Race, With 0.015 Inch Flat.

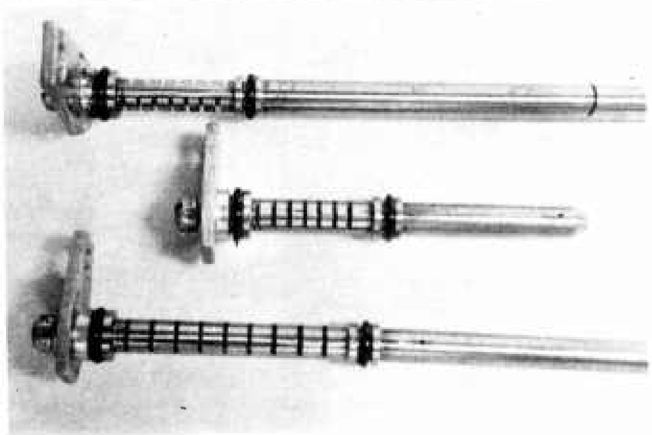


Figure 49. Main Transmission Lubricating Jets.

Figure 50. Transmission Pressure Relief Valve.

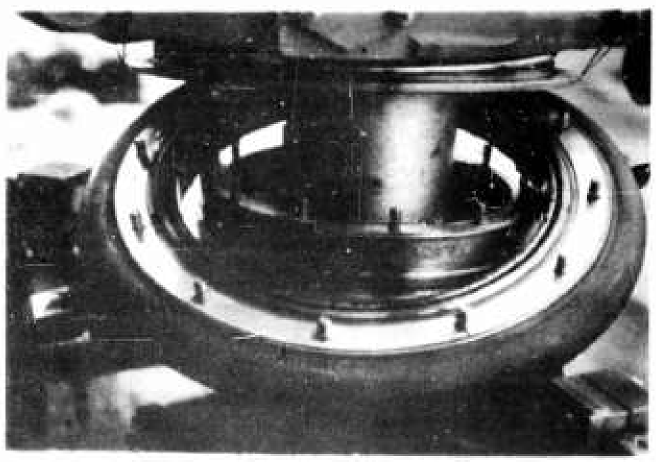


Figure 51. Swashplate Bearing Removed.

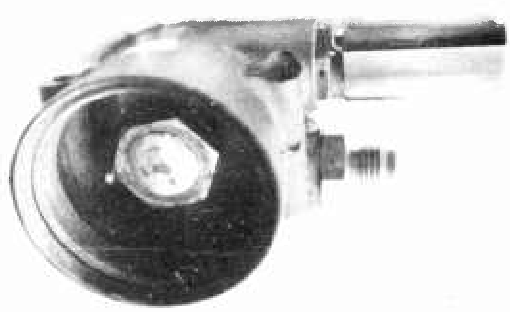


Figure 52. Fuel Filter With Blocking Plug Installed For 100% Fuel Bypass Test

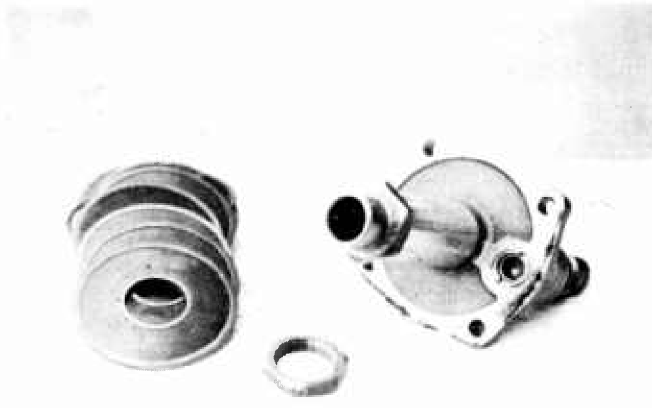


Figure 53. Transmission Oil Filter With Blocking Element Installed.

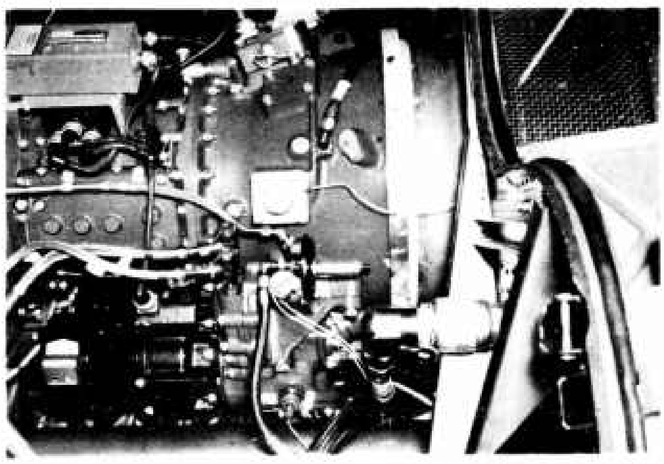


Figure 54. Engine View Showing Blocked Oil Filter Installed.

Figure 55. 90° Gear Box Chip Detector Prior To Installation.

modified relief valve used by the ALARM System was not operating. On disassembly of the valve it was discovered that the valve extension was binding, as evidenced in Figure 50. Despite attempts to repair and modify this valve, it was never successful in providing normal regulation of the transmission oil pressure. This failure prevented any positive results in this test. However, the operation of the normal valve provided evidence that considerable valve motion can occur as a result of blocked jets. Because of this, a complete redesign of the modified valve is felt to be desirable. This redesign will modify the regulating motion of the valve to provide more travel for a given pressure differential, thus increasing the possibility of detecting one blocked jet.

Test #13 - Lack of Lubricant, Swashplate Bearing

Figure 51 shows the swashplate bearing assembly disassembled to permit removal of some of the lubricant. Removal of lubricant was accomplished as thoroughly as possible without complete disassembly of the outer ring by pressure flushing the bearing with a solution of penalene.

Results of this test to create higher frictional temperatures as sensed on the inner ring surface were negative. Despite a number of attempts to remove all of the lubricant, enough residual remained in the bearing to lubricate it adequately. All temperature observations made during these tests are included in plots shown in Figure 17 (Operational Test Results section).

Test #14 - Blocked Oil and Fuel Filters

As a specific test in this area (even though considerable difficulty was being experienced with filter switches as discussed in Operational Tests), it was decided to block each filter completely to observe behavior of the oil and fuel pressures involved. Figures 52, 53, and 54 show the blocking means employed for the fuel, transmission oil, and engine oil filters respectively.

At the time this particular test was conducted, the transmission and engine oil filter switches were still functioning properly and provided proper "NO GO" indication immediately. The fuel filter switch was defective and no valid indication occurred. Of equal importance was the observation that with 100% blockage of the filters, both the transmission oil and fuel pressures as indicated on the aircraft gauges did not change more than 1 or 2 psi from the reference pressures (filters clear). The engine oil pressure decreased 20 psi but it remained within the "green" area of the gauge. Thus it is established that blocked filters are not detectable by abnormal pressures in the associated systems, verifying the feasibility of these channels designed to indicate when the filters should be removed and cleaned.

As indicated previously, the main problem in this area has been the reliability of the modified filter assemblies. This has been resolved by redesign efforts on all three units. Final operationsl tests will be conducted on reinstallation of the system in the test-bed aircraft.

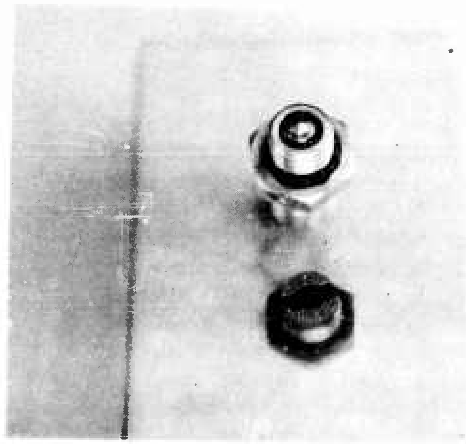


Figure 56. 42° Gear Box Chip Magnetic Detector And Magnetic Plug.

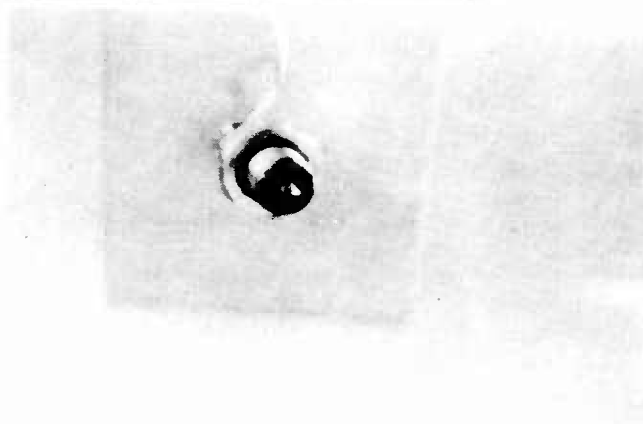


Figure 57. 90° Gear Box Chip Detector After Addition Of 500 Milligram Particles.

Figure 58. Sludge Accumulation, 90° Gear Box Chip Detector.

Test #15 - Ferrous Particles in 42° and 90° Gear Box

In order to evaluate the effectiveness of the chip detectors applied to the two tail rotor drive gear boxes, a series of tests was conducted in which ferrous particles consisting of fine metallic filings were introduced in measured increments into each gear box. Figure 55 and Figure 56 show the completely cleaned 90° and 42° detectors respectively prior to these tests, with Figure 56 also including the 42° Gear Box original magnetic plug for later reference.

In the first series, 500 milligrams of filings were introduced into the 90° Gear Box and indication occurred immediately. Figure 57 shows the detector as removed following this test. The dark sludge apparent on the detector partially obscures the metal particles. This sludge is attributed to partial breakdown of the oil due to the elevated temperatures created during Test #9 described previously. The detector in this case appears to be located at an optimum position in the gear box and quickly accumulates most of the ferrous material in the oil as desired. The magnetic chip detector has provided indication of the sludge condition as seen in Figure 58, which indicates oil deterioration. This is a desirable indication, prompting oil replacement or, if necessary, further investigation of the gear box itself for impending failure.

In direct contrast to the results obtained on the 90° Gear Box, the addition of almost 2.5 grams of filings in the 42° Gear Box failed to provide indication. As shown in Figure 59, the detector accumulated practically no particles. The test was repeated using the original magnetic plug and it too failed to accumulate any appreciable amount, as shown in Figure 59. This was considered to be entirely due to the location of the plug within the gear box, and further investigation indicated the plug should be relocated, if possible, to the lowest point in the main reservoir area rather than out along the input quill section of the housing as at present.

A modification was performed as shown in Figure 60 (plug opening appears just below the control cable in the center of the housing). With this new location, the gear box was drained and refilled but even then almost immediately on the first run-up a detector "NO GO" indication occurred and the left detector shown in Figure 61 illustrates the accumulation. This accumulation was the residue from the previous tests which apparently had remained in the housing after it had been drained. Practically all ferrous particles were accumulated by the relocated detector. Comparing this with Figure 59, the increased effectivity of the detector to particles is amply demonstrated.

Test #16 - Unbalanced Tail Rotor Blade

Previous discussions of tail vibration sensing (Operational Tests) had indicated some experimentation to determine an optimum sensor location. As indicated then, this was finally selected as directly on the 90° Gear Box. This location was used for all tests described here.

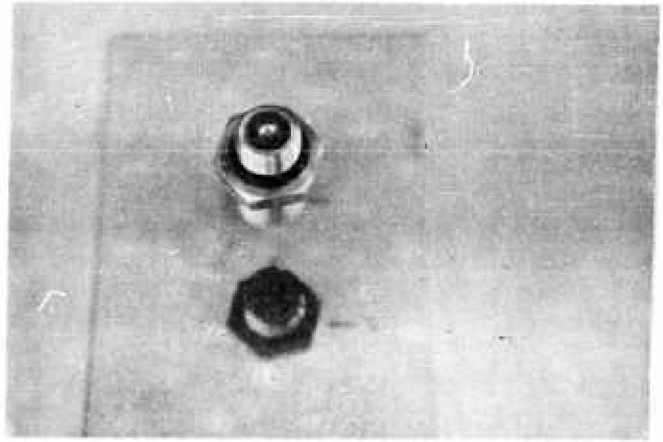


Figure 59. 42^{O} Gear Box Chip Detector After Addition Of 2.5 Grams Of Particles.

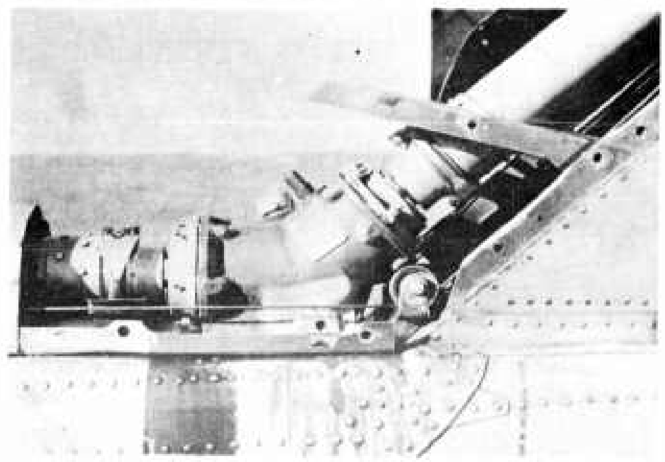


Figure 60. 42^{O} Gear Box Showing Relocated Chip Detector Provision.

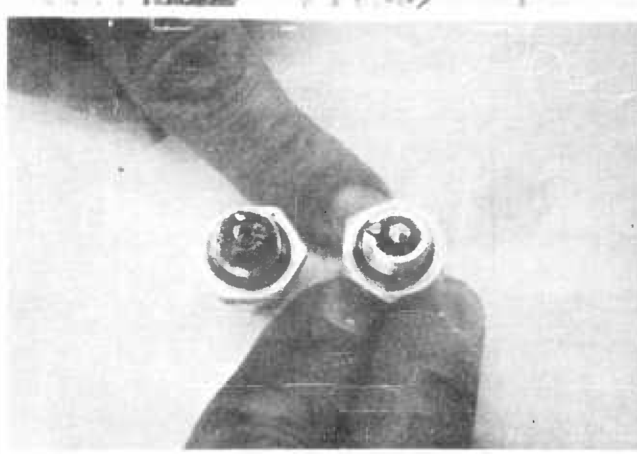


Figure 61. Relocated 42^{O} Gear Box And Transmission Chip Detector Accumulations.

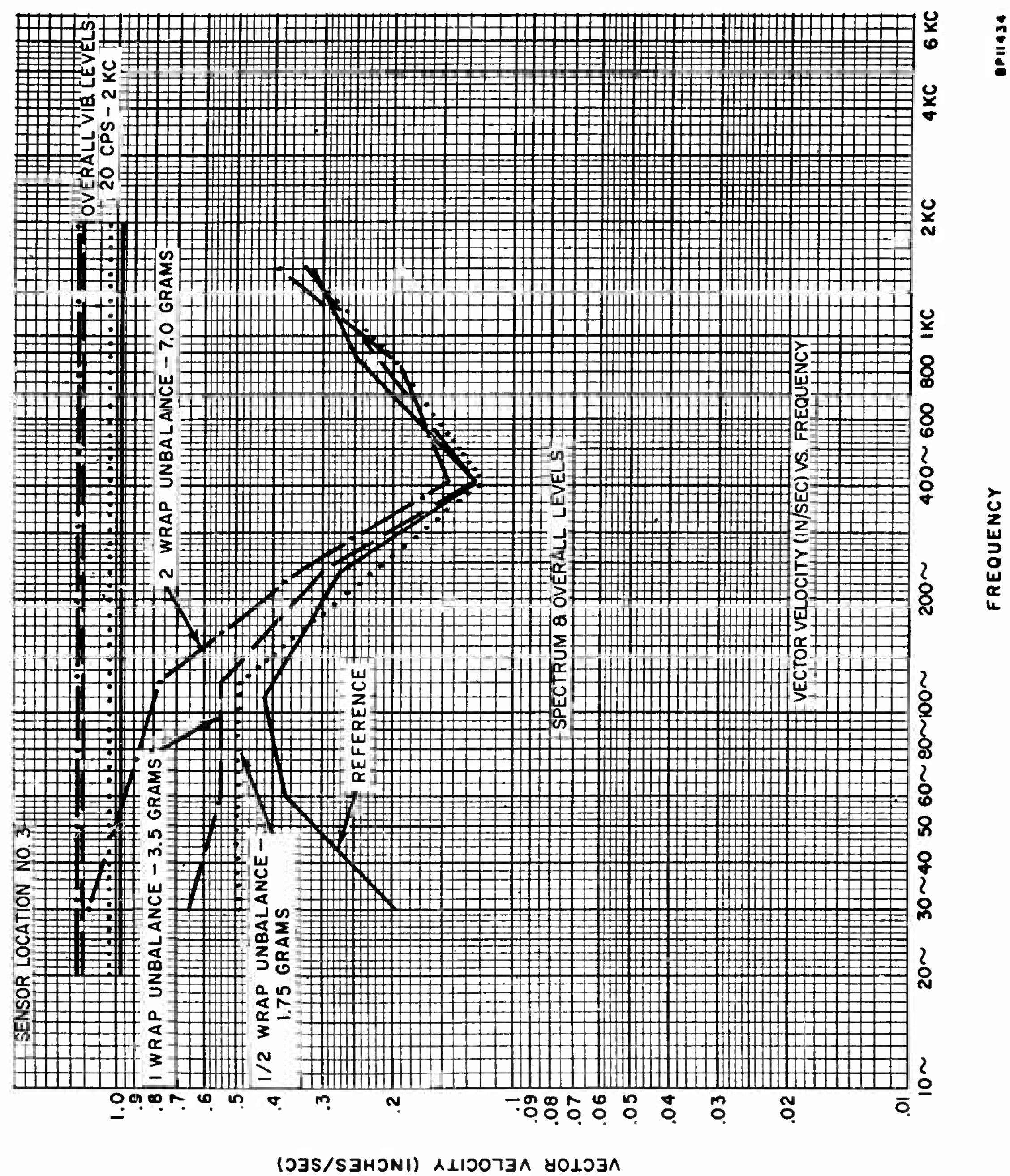


FIGURE 62. TAIL VIBRATION T/R UNBALANCE TESTS

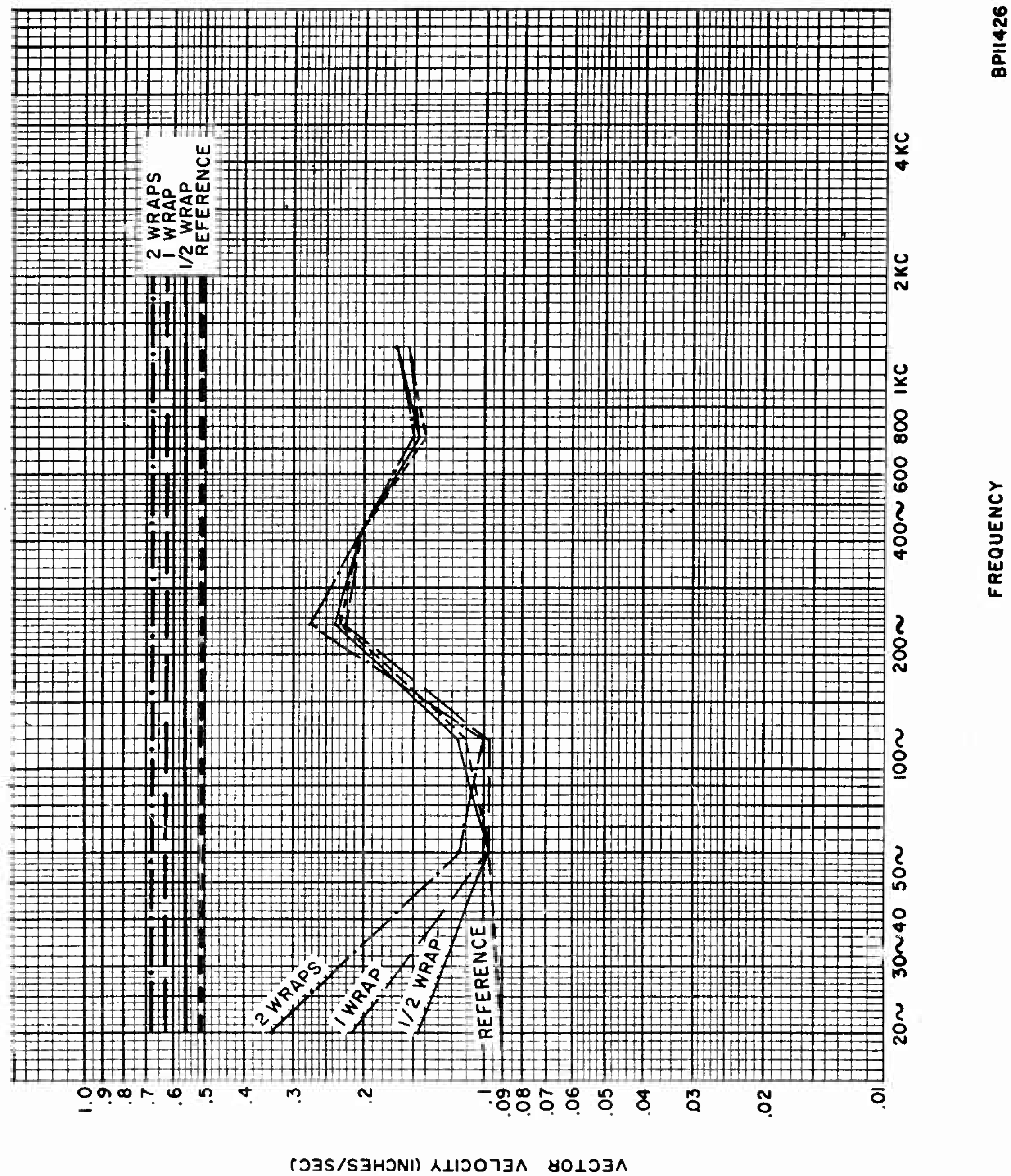


FIGURE 63. AFT ENGINE VIBRATION EFFECT OF T/R UNBALANCE

Test conditions consisted of placing successive wraps of 2-inch masking tape about 4 inches from one blade tip and evaluating the resultant vibrational effect. These results are shown in Figure 62 in comparison with reference or balanced condition. "NO GO" indications were obtained for both 1 and 2 wraps. The pilot began to notice high-frequency vibrations in the pedals with two wraps, which support the main objective of the channel, that of being capable of sensing tail vibrations better than the present method of "feel". The channel also detected the 1/2 wrap condition (1.75 grams), but this would have to be considered a marginal sensitivity setting which may cause erroneous indications if set this close to the normal vibration level.

Continued difficulty with wind gusts causing "NO GO" indications on this channel at various times forced another modification to channel response time. It is now delayed 10 seconds, and further observations will verify whether this is sufficient to eliminate environmental transients such as wind.

During these tests it was noticed that the Aft Engine Vibration Channel was indicating "NO GO" with tail rotor unbalances. An analysis of this effect was made, and is shown on Figure 63. The vibration of the tail section under these conditions was being propogated through the structure and influencing the engine area. All were predominantly tail rotor 1/rev influence below 100 cps as shown in the graph. Modification has been made to the Aft Engine Vibration Channel, restricting its frequency response to above 100 cycles to eliminate this undesirable interaction.

Test #17 - Unbalanced Main Rotor Blade

Following the final modification to the Low-Frequency Mast Vibration Channel sensor, which resulted in its being located in the nose compartment (see Operational Test discussion) a series of unbalance tests very similar to those conducted on the tail rotor were performed involving the main rotor. Figure 66 shows the application of one wrap of 2-inch tape near the tip of the blade.

Results of these tests are shown in Part 1 of Figure 64. With the application of the 1/2 wrap of tape on one main rotor blade, positive channel indication occurred. The aircraft operator was unaware of any increased vibration with 1/2 wrap but began to notice the effect of 1 wrap. This again satisfies the objective of detection before it can be felt physically.

Test #18 - Main Rotor Out of Track

Figure 64, Part 2 illustrates the results of deliberate introduction of main rotor out-of-track conditions as created by the indicated adjustment of one pitch change link (PCL). With one flat adjustment, essentially the same effect is created as by 1/2 wrap of tape for unbalance; (Test #17) a "NO GO" condition was indicated by Channel 26 (Low-Frequency Vibration) but no increase in cockpit vibration was noted. More than one flat out of adjustment causes noticeable vibrations in the cockpit area.

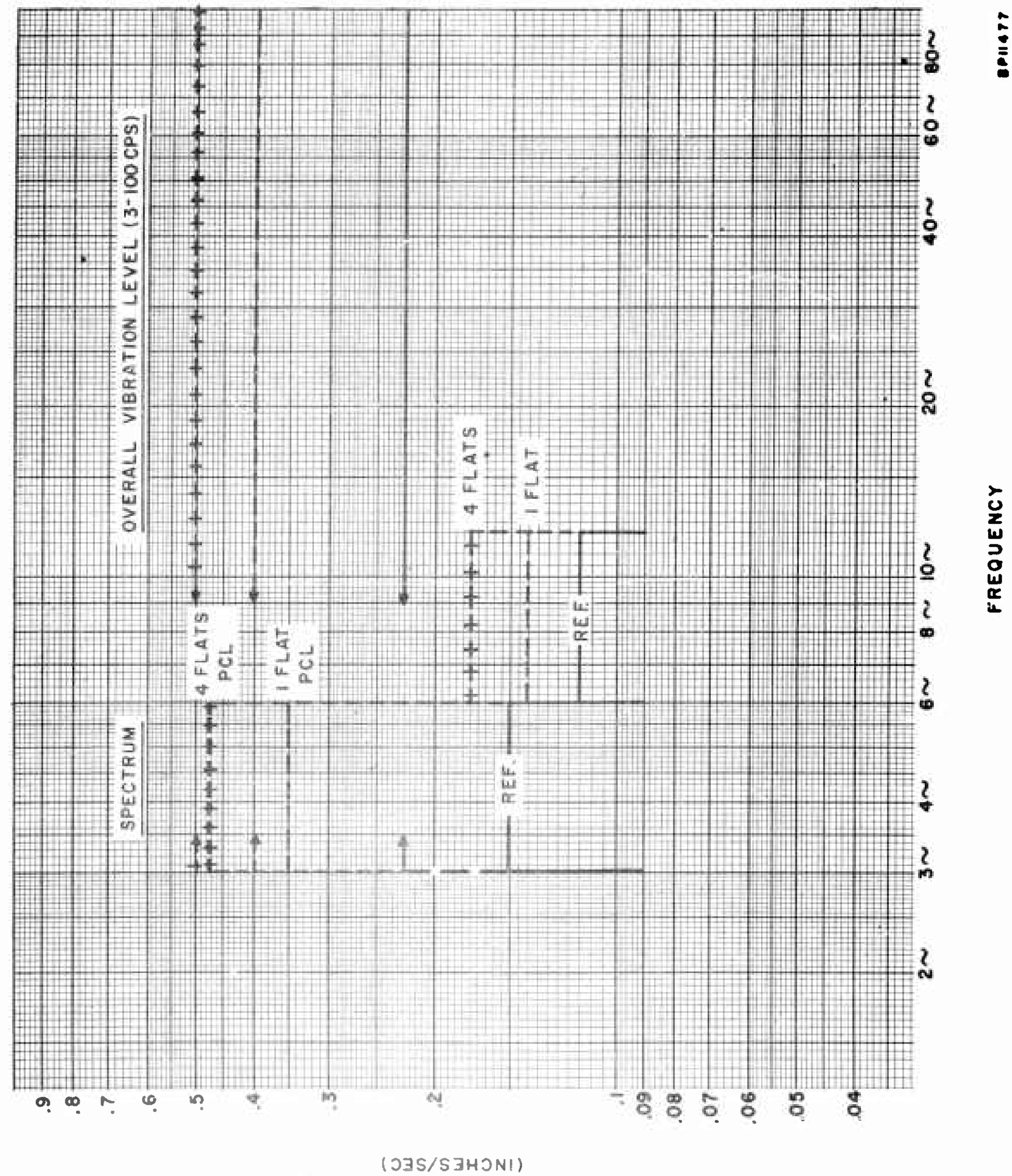


FIGURE 64. LOW FREQUENCY MAST VIBRATION, MAIN ROTOR UNBALANCE (PART 1)

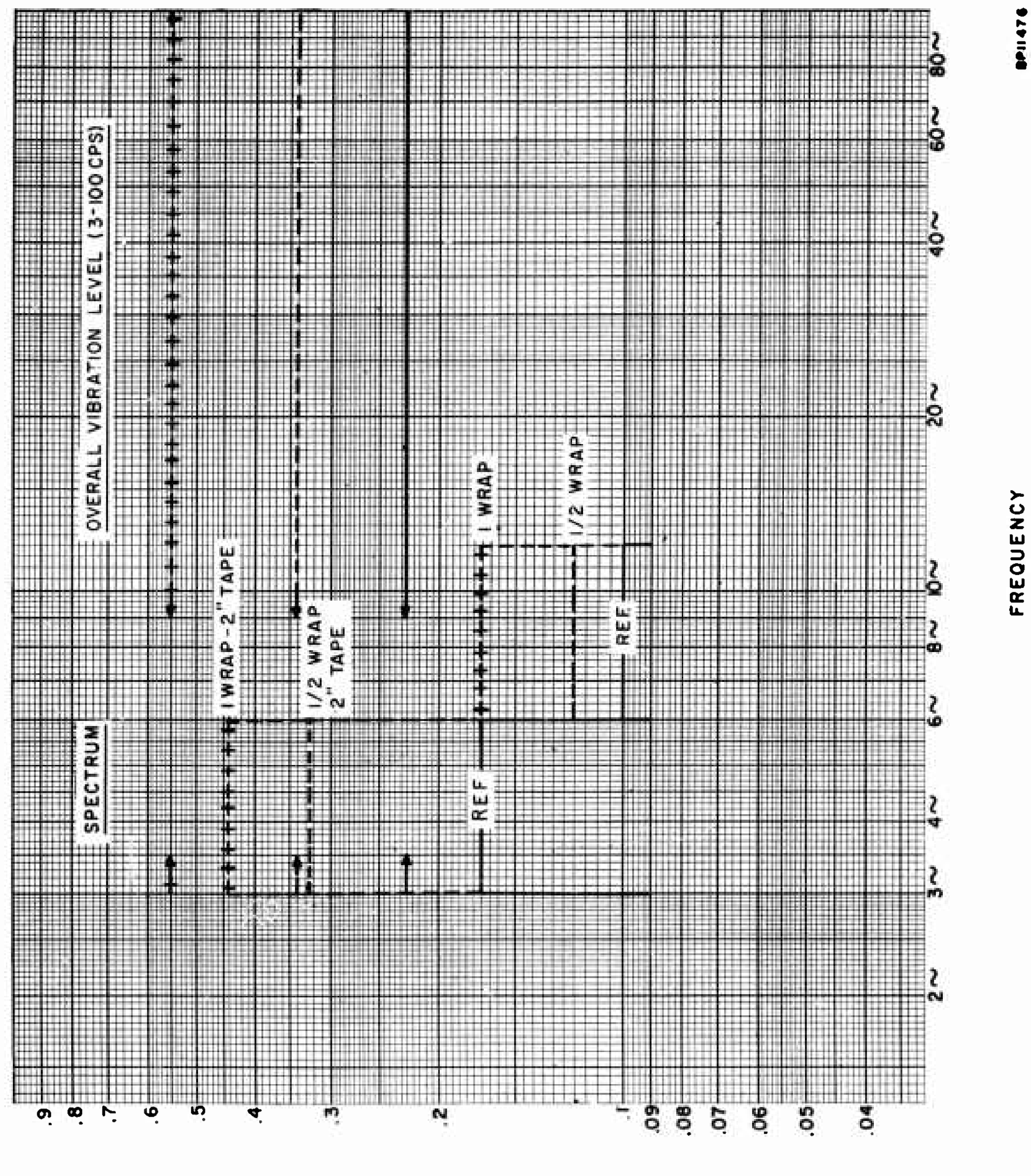


FIGURE 64. LOW FREQUENCY MAST VIBRATION, MAIN ROTOR OUT OF TRACK (PART 2)

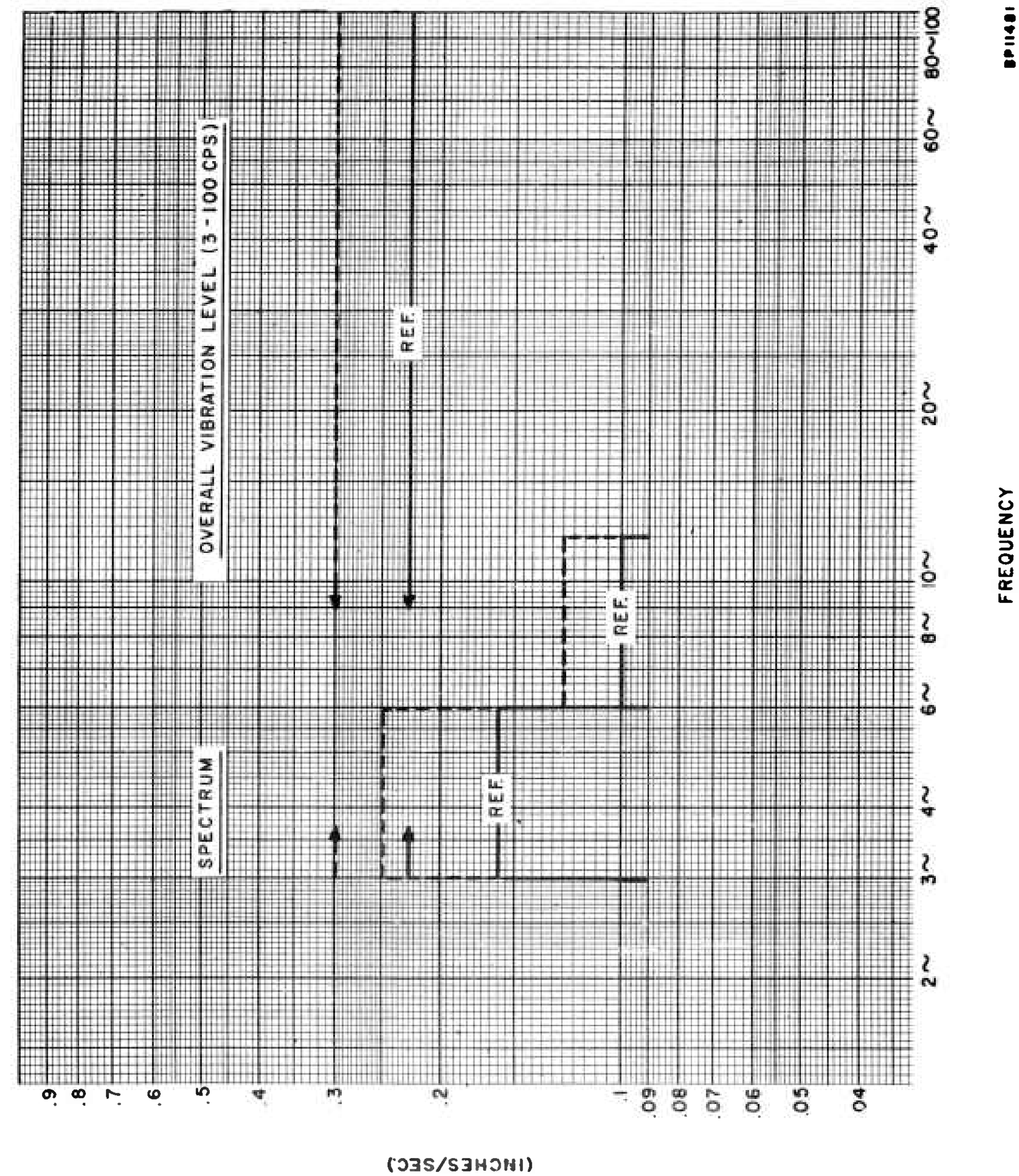


FIGURE 65. LOW FREQUENCY MAST VIBRATION, UNCENTERED CYCLIC CONTROL (PART 1)

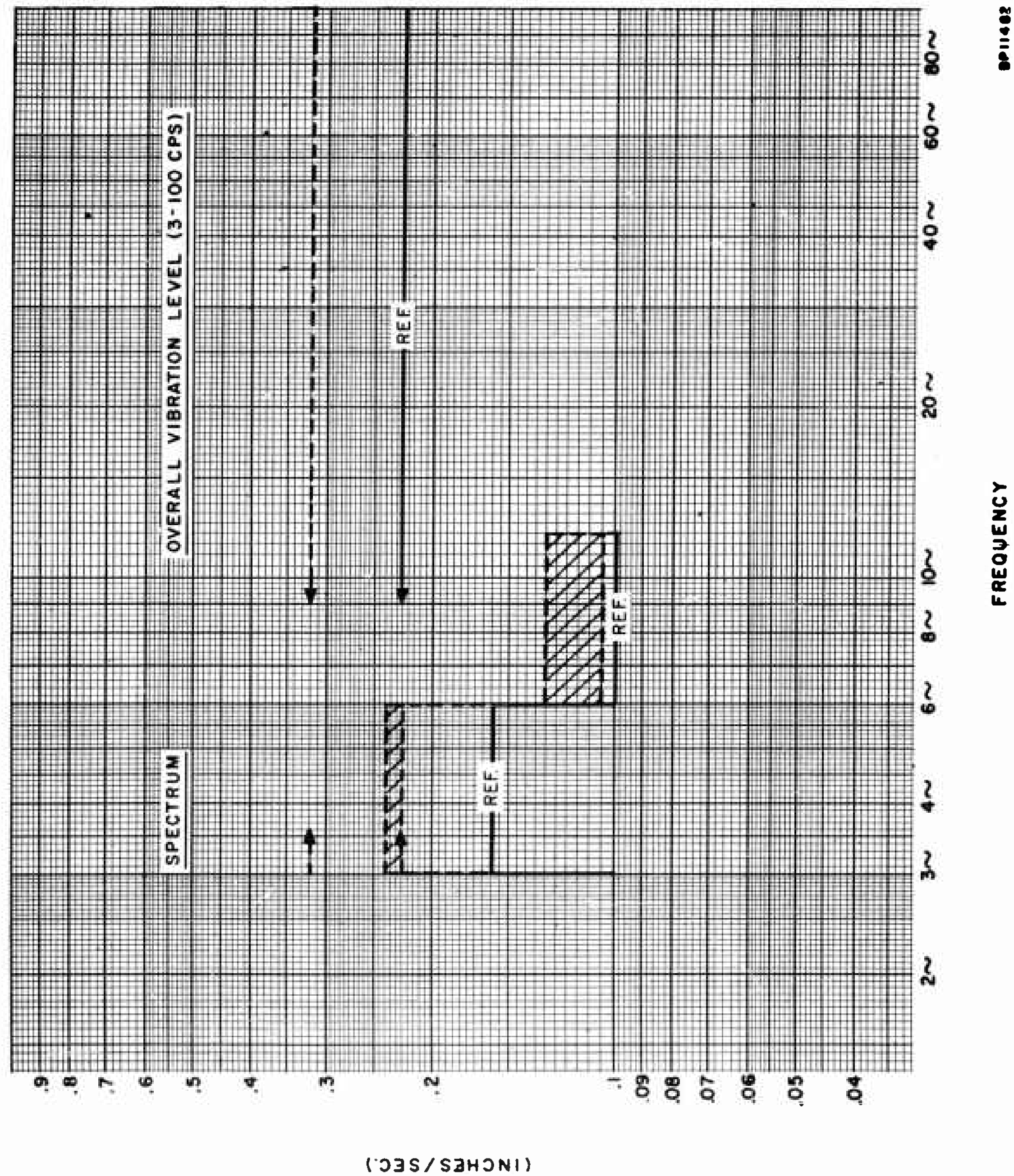


FIGURE 65. LOW FREQUENCY MAST VIBRATION, BLADE SET OVER-TIGHT TIEDOWN (PART 2)

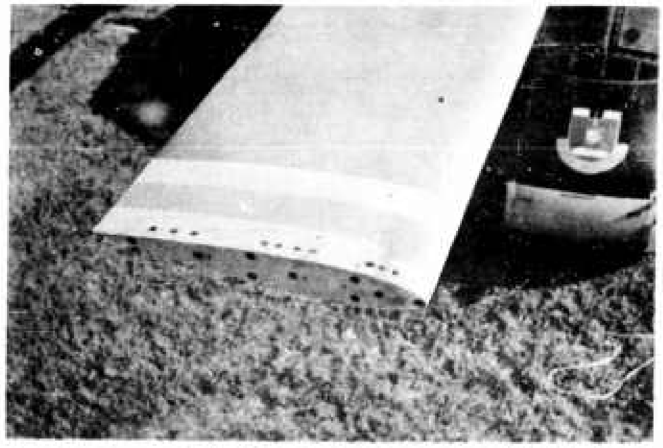


Figure 66. Main Rotor Blade With One Wrap Of Tape Added.

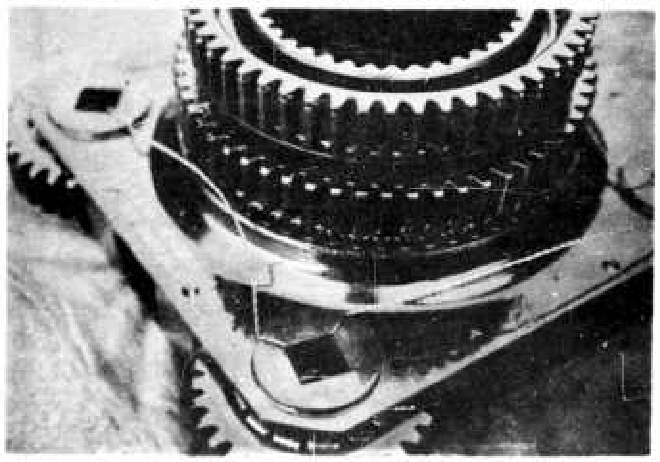


Figure 67. Upper Planetary Bearing Retainer Failure.

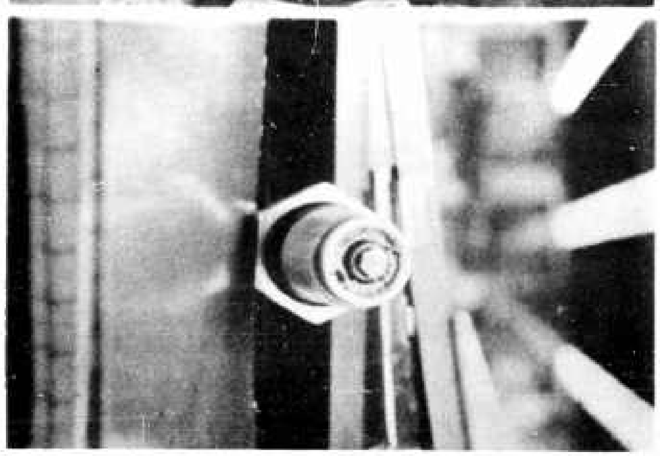


Figure 68. Main Transmission Chip Detector After Addition Of 1 Gram Of Particles.

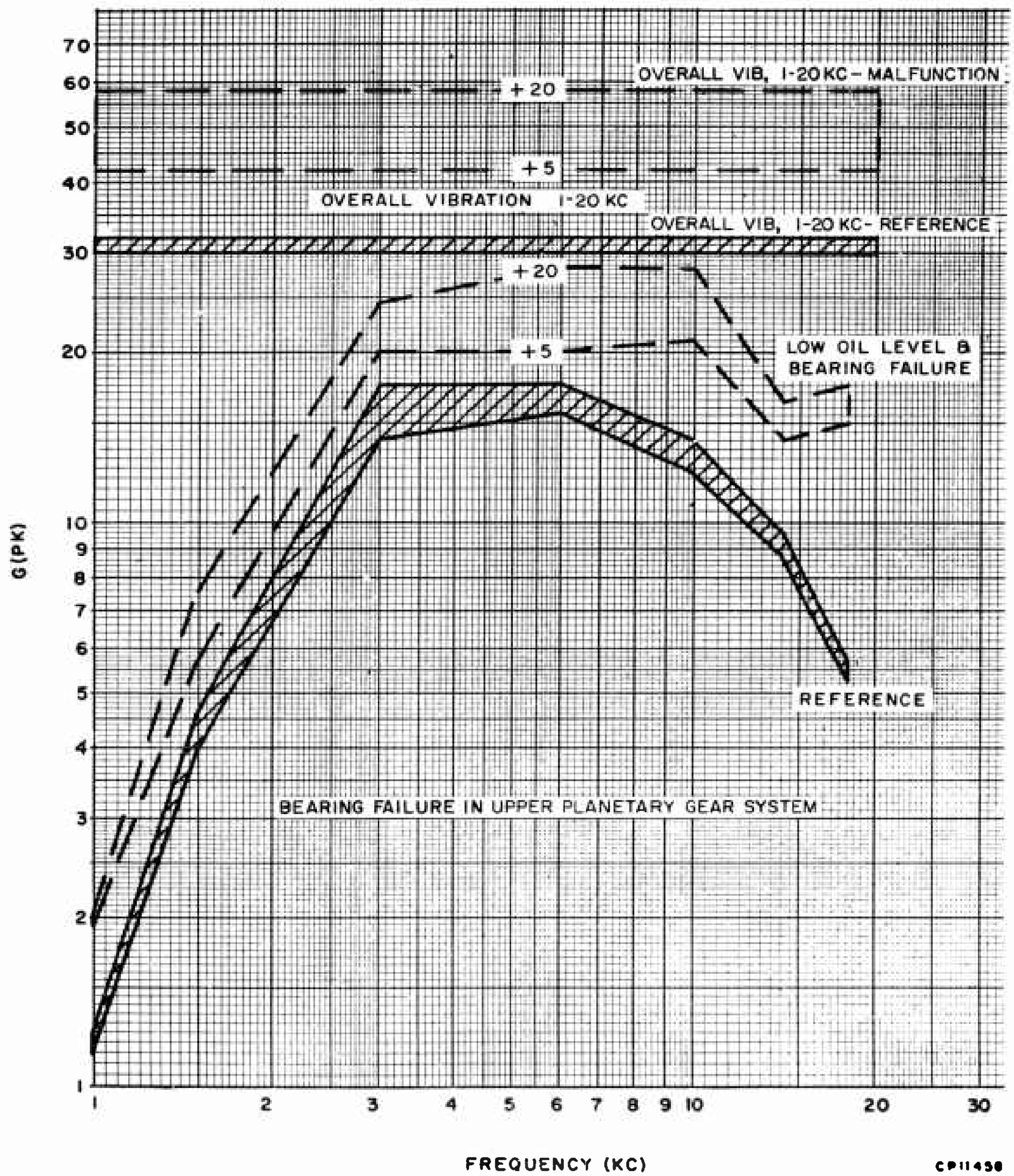


FIGURE 69. XMSN TOP VIBRATION

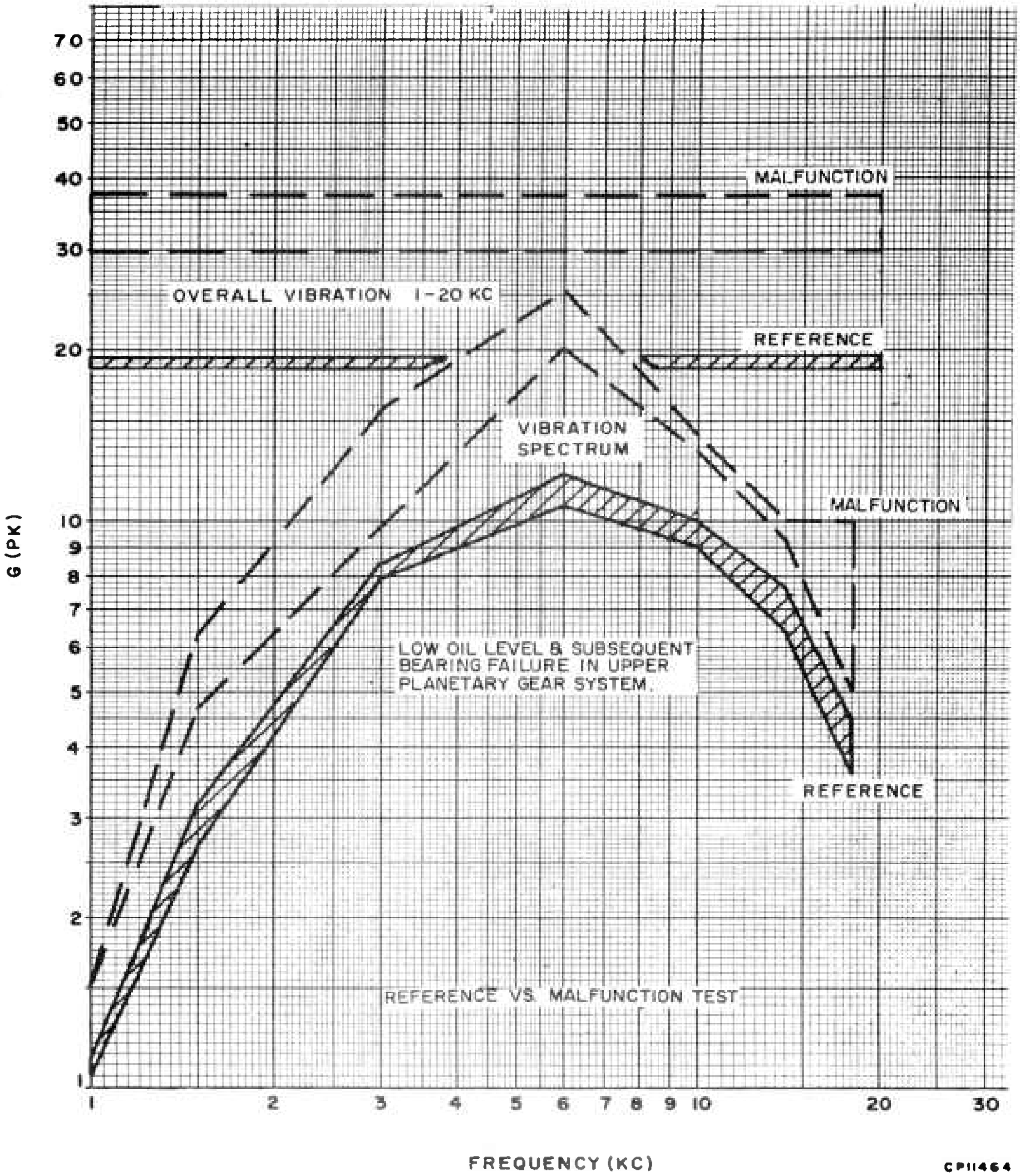


FIGURE 70. XMSN BASE VIBRATION

Additional observations made on the channel included those presented in Figure 65. Part 1 shows the effect of an uncentered cyclic control during 6400 rpm ground run operation, indicated as "NO GO" on the channel. This is not an abnormal condition in the main rotor, but does show an improper reference condition which should be recognized and corrected by centering the control before using this channel as the indication of an unbalance or out-of-track condition. Figure 65, Part 2, plots the results from an over-tight main rotor tie-down over a 2-day period which caused a "set" condition in the blade and subsequent 1/rev vibrations which were detected by the channel. A brief period of ground-run operation cleared this condition and the channel indicated "GO".

The results of Tests #17 and #18 demonstrate the desired criterion established for Channel 26. With this capability the channel provides indication of increasing unbalances and out-of-track conditions in the main rotor system and may be utilized effectively to balance and/or track the system (by trial and error) through observation of the "GO/NO GO" indication this channel provides.

Test #19 - Excessively Low Oil, Main Xmsn

Previous tests involving the Main Transmission provided very little information on abnormal gear and/or bearing noises within that component. As a last test to create an abnormal condition within the transmission, nearly all of the oil was removed and a data run commenced. All vibration levels (Top and Base) increased considerably and were indicated as "NO GO" on both channels as expected, due to the increase of high-frequency impact noises within the component (See Figure 69 and Figure 70). As this data were being recorded, it was very difficult for observers to discern any appreciable increase in the sound normally associated with the transmission. After 25 minutes of run time, a definite abnormal noise was heard and shut-down accomplished immediately. Investigation revealed a failure of one of the upper planetary bearing retainers (see Figure 67) which was attributed to both extended runs with blocked jets (see Test #12) and this test.

While this test was not considered a realistic operational condition (excessively low oil), it did serve to permit an evaluation of operator sensitivity to the noise frequencies created in this area. It was difficult to detect this condition by sound alone, and less pronounced conditions would undoubtedly go unnoticed, but positive detection by the ALARM vibration monitors is shown.

Test #20 - Loss of Oil, 90° Gear Box

(This test included as part of Test #9 - Defective Bearing and/or Gear, 90° Box.)

Test #21 - Tail Rotor Out-of-Track

This test of tail vibration detection capabilities was performed by successive adjustment of one tail rotor pitch change link to create out-of-track conditions. Results were completely negative. Even with misadjustment out to the limit (causing a visual out-of-track condition), no increase in tail vibration was recorded nor was any indication observed on Channel 25. It must be concluded that,

Figure 71. Relocated Main Transmission Chip Detector.

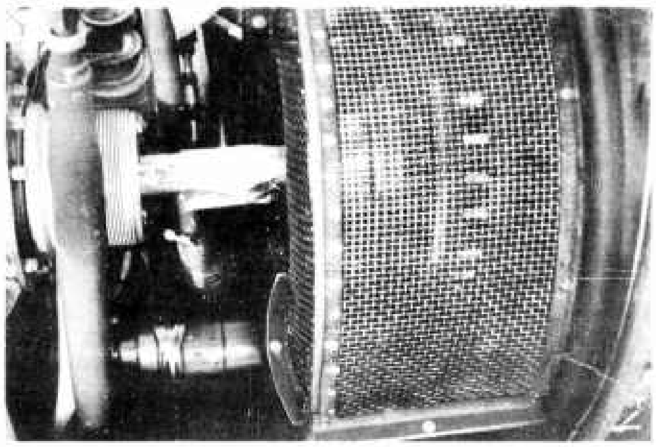


Figure 72. Method Of Providing Short Shaft Unbalance.

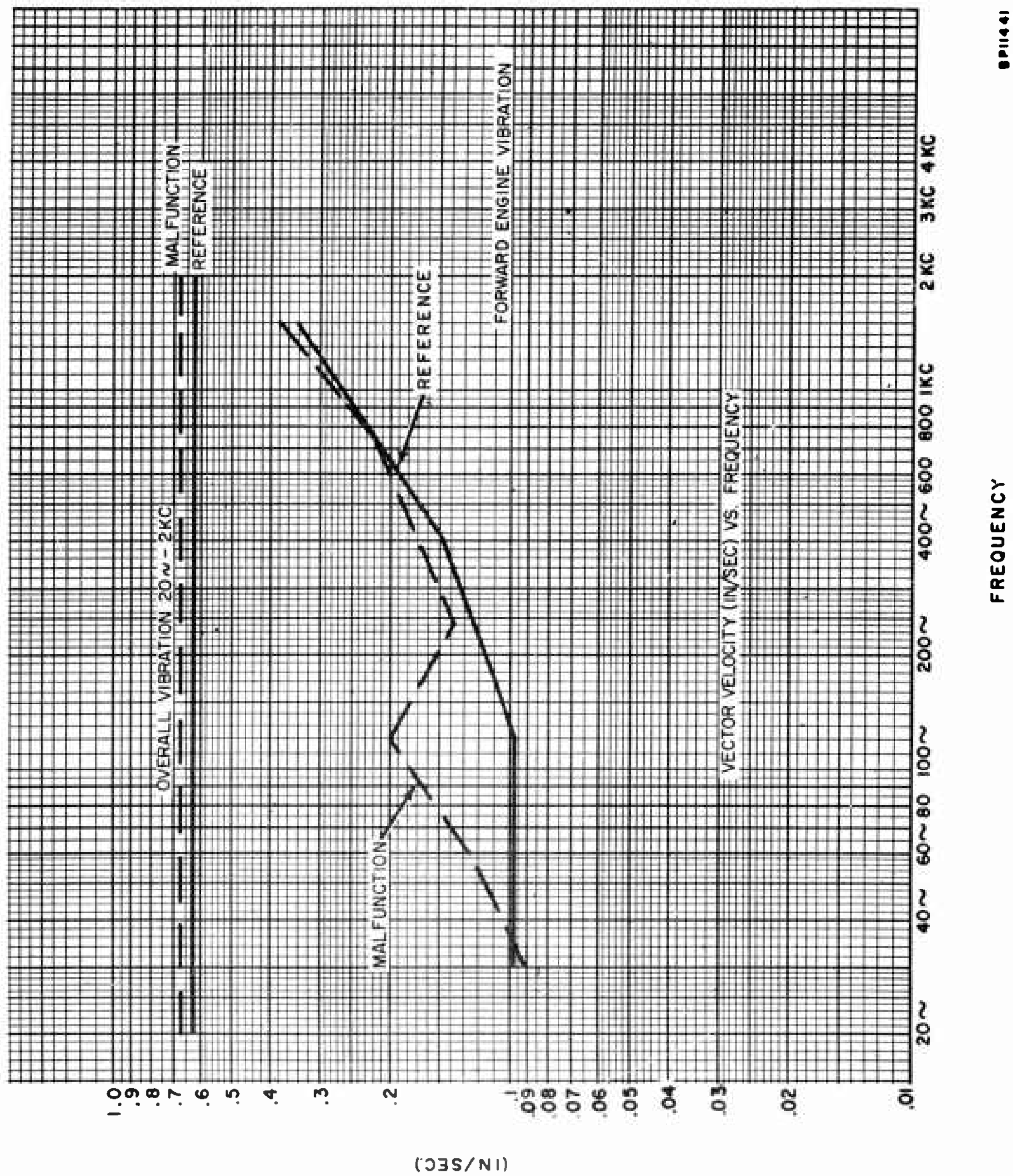


FIGURE 73. MALFUNCTION TEST FWD ENGINE VIBRATION (PART 1)

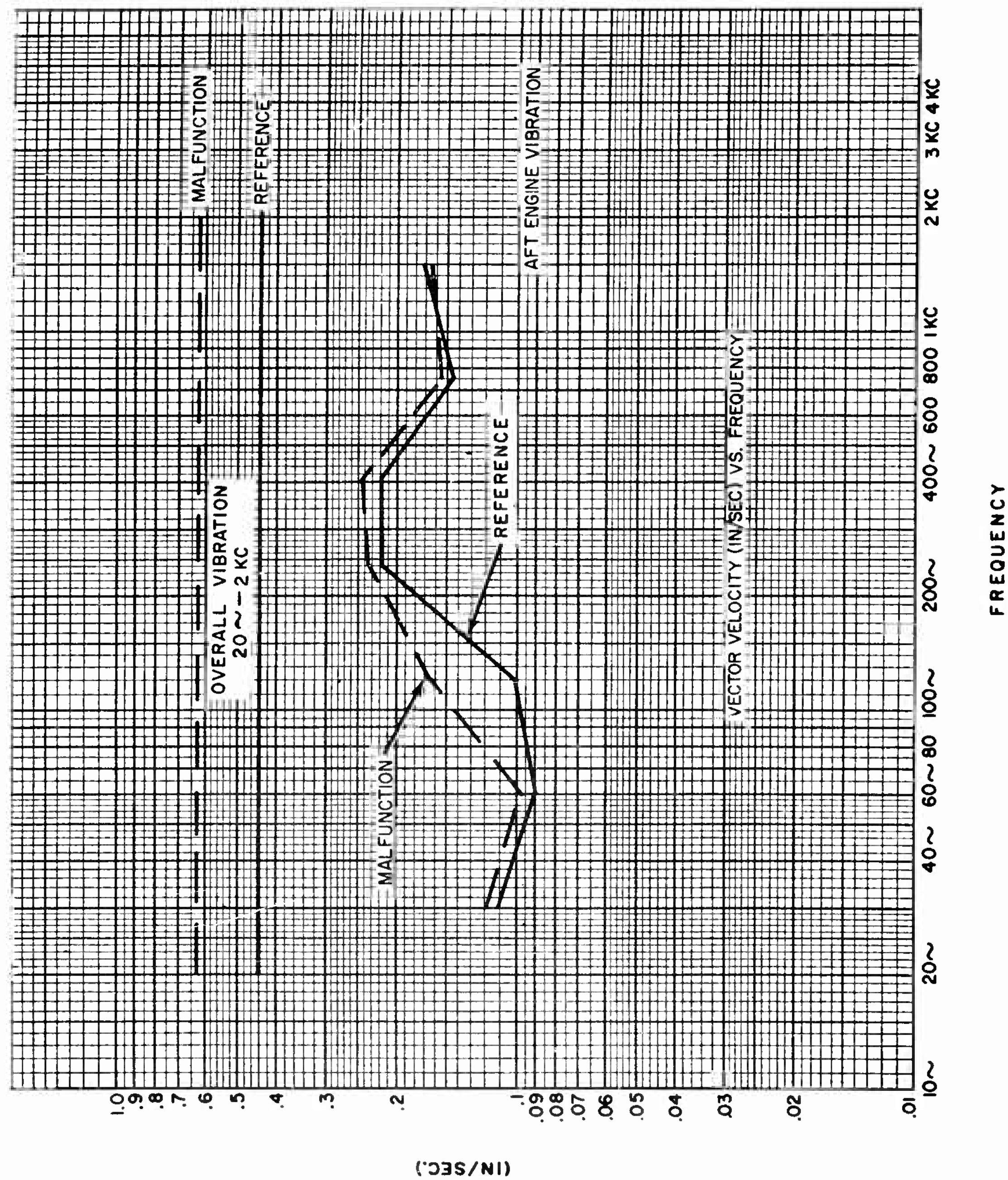


FIGURE 73. MALFUNCTION TEST AFT ENGINE VIBRATION (PART 2)

with no pitch applied, this condition is not detectable by the ALARM System as a dynamic (ground run) malfunction. It is believed this condition would definitely be detected in flight, but no verification of this was possible during the malfunction tests.

Test #22 - Ferrous Particles in Main Xmsn

Throughout all tests involving malfunctions placed in the Main Transmission, no indication occurred on the Main Transmission Chip Detector. On inspection of the detector, never did there appear more than a very slight accumulation of fine, normal-wear particles. Very few particles were picked up and no indication noted after the addition of 1 gram of particles into the oil and nearly 4 hours of A/C operation. Figure 68 shows the detector following this test.

Since it was known that ferrous particles were definitely present in the transmission at these times, the failure of the detector to accumulate them was attributed to the location utilized. The fact that the center of the detector is located 1 inch above the bottom of the sump (which is the location of the present magnetic plug) apparently permits all of these particles to settle on the bottom, with very few coming near enough to the detector magnet to be attracted and detected.

Investigation was begun to relocate the detector, similar to that performed on the 42^{o} Gear Box (see Test #15). In order to avoid a structural modification of the Xmsn Sump Case, it was decided to place the detector in the drain opening. This placed the sensor flush with the sump bottom just beneath the pump intake screen (see Figure 71). It was also decided to utilize a smaller detector with a 0.060-inch gap in place of the previous detector which had a gap width of 0.100 inch. The detector from the 42^{o} Gear Box was adapted to fit into sump drain opening.

Following this modification the transmission was filled with clean oil. A test run was commenced without adding particles, since it was felt there would be some ferrous particles remaining in the transmission from previous tests. A chip indication occurred immediately on Channel 11, and subsequent inspection revealed the condition seen in Figure 61 (detector on the right side). The two detectors (42^{O} GB and Xmsn) are shown together in this photograph because both relocation tests had been conducted concurrently.

The results of this test verified suspicions that the original magnetic plug location is not an optimum one. Automatic chip detection becomes feasible in this area if the sensor is located properly.

Test #23 - Engine Oil Leakage

(See discussion, Engine Oil Flow (Channel 29) in Functional Test Results Section).

Test #24 - Short Shaft Unbalance

Attempts to create a short shaft unbalance by such normally encountered difficulties as improper lubrication at the shaft couplings proved unsuccessful. Any unbalance thus induced appears insignificant since no change could be detected in either engine or transmission vibration characteristics.

In order to examine where and how shaft-created vibrations might occur, a 20-gram metal weight was attached to the shaft by aluminum tape as shown in Figure 72. During the test run which followed, the Aft Engine Channel indicated "NO GO" consistently and the Fwd Engine Channel intermittently. Figure 73, Part 1 and Part 2, presents the data recorded for this condition.

It will be recalled from previous discussions (see Test #16) that the Aft Engine Channel response had been limited to above 100 cps due to effects of tail vibrations. This, fortunately, still permits the type of vibration created by short shaft unbalance to be accepted, since the fundamental frequency is about 106 cps. Figure 73 shows the largest increase at 120 cps because the reading taken was through the filter set to accept the range of 60-120 cps.

TEST RESULTS

GENERAL

Certain elements of the test results may be clarified by a discussion of the methods employed to evolve certain conclusions which were, of necessity, established for the vibration and filter bypass channels.

Vibration Channel

At the beginning of the ALARM program, it was presumed sufficient data was available for determination of operating limits in the monitored vibration areas. The research and study phase of the ALARM program determined that such information did not exist. This was reported in TREC Technical Report 60-49, pages 33 and 34. The test results provided in this report (TRECOM Technical Report 63-10) therefore contain no prescribed operating limits. The detection level was designated as an indicated limit, but must not be construed to be an established operating limit. Further substantiating data must be accumulated before any recommended operating limits can be determined.

The present prescribed aircraft inspection procedure has no basis for comparison with electronic vibration inspection. The present inspection procedure is primarily a visual inspection and the adherence to the inspection requirements will vary with personnel. Such factors as individual interpretation of requirements, education and experience will vary the results of a particular inspection.

Filter Bypass Channel

The filter bypass circuit will indicate on the ALARM display panel when the filter is 100% blocked. The decision was made early in the study phase as reported in the August 1960 progress report (TREC Tech Report 60-48) to provide an indication when the filter allowed a 50% flow bypass. The design of the filter indicating mechanism is presently inadequate to provide this indication. A redesign of the bypass valve to provide a linear and greater travel of the valve could provide a greater degree of accuracy in the indication of the valve opening.

Determination of Detection Levels

The Interlock/Continuity channels of the ALARM have no discrimination as to the detection level. The circuit is either "GO" or "NO GO", with no circuit adjustment provided. Adjustment is provided for switch movement, liquid level variation and filter and transmission bypass. These adjustments are physical placements however, rather than a discriminatory circuit adjustment for the sensor output signal.

At the beginning of the ALARM program, it was felt that sufficient data would be available to determine the operating limits of vibration, temperature, etc., of aircraft. The study and research program revealed that fundamental data required to determine specific limits did not exist. In the vibration area, voluminous vibration data were available, but the information was useless, in that it concerned reduction of vibration, rather than determination of the cause and effect.

The ALARM test program was the beginning, then, of a determination of the "Signature" of the various components under known physical conditions. The conditions under which data were taken were those classed as normal and malfunction. The normal condition was the condition in which the aircraft was considered as being in compliance with the inspections as provided in the applicable operating and maintenance manual. The malfunction condition was the condition of the aircraft when a known malfunction was introduced into a component of the aircraft.

The sensor outputs, under both normal and malfunction conditions, were plotted on appropriate curves. These curves then become a "Signature" or description of the sensor output. The sensor output, theoretically, is a direct relation to the component condition. The curve then becomes an indication of the component condition. In the test program, the results supported this theory in most cases, but in some cases, a known malfunction did not cause a change in the signature. The lack of supporting data may have been due to several reasons. One, the sensor may not have been ideally located. Two, the band or spectrum monitored may have been too great; and, three, the component may not exhibit the characteristics as envisioned.

Vibration

The vibration test results indicated that the normal and malfunction signatures would have variations that would overlap. The normal signature may have peaks that would go into the malfunction area and the malfunction signature may dip into the normal area. The overlap has been primarily in the high and low frequency bands, such as that shown in Figure 41.

In the vibration area, momentary peaks in normal operation were great enough and the duration long enough to cause the ALARM System to indicate a "NO GO" condition. To eliminate this problem, a 10-second delay was added to the circuit. This delay requires the signal to be consistent for 10-seconds before the "NO GO" indication is displayed.

Determination of detection levels in the cases of large and distinct changes between normal and malfunction operation become simply an adjustment to a detection level between the normal and malfunction range. This condition is shown in Figure 69. The detection level in this case would be set at approximately 35 g, over-all. At a particular frequency of 5 KC, a simulated input g level would be approximately 18.0 g. At 10KC the simulated input level would drop to approximately 15.2 g.

In the instances where an indefinite vibration level between normal and malfunction operation was found the detection level was set just above the normal operating range. An example of this condition is shown on Figure 45. The detection level over-all would be set at approximately 32g. Again at 5 KC the detection level would be approximately 15.2g and at 10 KC would be approximately 13.0g.

It should be noted here that even though the top transmission sensor output was not easily distinguishable between normal and malfunction operation, the base transmission sensor output was much more discriminate, as shown on Figure 46. Here the normal operation level was at an over-all peak of approximately 15g. The malfunction operation appeared as a minimum of 18g over-all. The differential in this case is large enough to give a valid "GO/NO-GO" indication.

Temperature

Determination of detection levels for the temperature channels was based on the normal operating temperatures under all ground and flight conditions. Test data accumulated are illustrated on Figures 17, 18, 19, 20, and 37, and show the normal and malfunction operating conditions. The normal operation temperature increased with increased ambient temperature. The slope was determined by a 2°C increase in ambient temperature resulting in a 1°C increase in operating temperature. This gives a straight line relationship between ambient and operating temperature. This relationship was built into the temperature circuitry to compensate for ambient temperature changes. Detection level was arbitrarily set at a level just above the maximum average normal operating temperature.

As shown by the data, some normal operation temperatures may exceed the detection level. The normal operating conditions that would exceed the detection level are conditions which place the aircraft under severe operating conditions for extended time periods. It was felt under these circumstances the normal condition was no longer normal and continuation of the condition could lead to eventual component failure.

Oil Flow

Only a limited amount of sensor output information was recorded for this channel. For this reason, no numerical detection limit is given. The detection level was determined by the following procedure: The oil flow was assumed as normal at 6400 engine rpm with no visible oil leaks. The oil flow channel was adjusted until the "NO GO" condition by the circuit was illuminated. The circuit was then adjusted until the "NO GO" condition was removed. A controlled leak was then introduced into the system. The leak rate was increased until a "NO GO" condition was indicated.

The leak flow rate was then measured. This procedure was repeated until the minimum leak rate with consistent "NO GO" indications was achieved.

ANALYSIS OF SIGNIFICANT RESULTS

PRE-ANALYSIS

The Phase II Test Program, Project ALARM, has substantially supported the recommendations and determinations reported at the conclusion of Phase I. Further substantiation of system design philosophy is also indicated as referenced in TREC Technical Report 60-49.

An analysis of significant test results recorded during the test program for Phase II supports the following conclusions:

1. Verification of interlocks as a means of inspection.
2. Verification of liquid level detectors as a means of inspection.
3. Verification of engine oil flow monitor at 6400 rpm as a means of inspection.
4. Verification of filter bypass monitor to determine a clogged filter.
5. Verification of the thermal ribbon technique as a means to detect temperature rise in a component.
6. Verification of the battery test circuit to determine battery condition before engine shutdown.
7. Verification of the electric chip detectors as a means of detecting the presence of ferrous material in the lubricating system.
8. Verification of the engine overspeed indicator to be capable of determining when an overspeed condition has existed.
9. Verification of the vibration changes that occur between a serviceable component and a malfunctioning component.

ANALYSIS

Verification of Interlocks As a Means of Inspection

Verification of the interlocks of the ALARM System have shown the feasibility of this concept as a means of inspection. In the cases where interlocks were eliminated, the problem involved was in the mounting of the sensor itself rather than the concept. Designs of the sensor should be considered in the initial design phase of the aircraft rather than after the aircraft has been developed.

Verification of Liquid Level Detectors As a Means of Inspection

The liquid level detectors have verified their ability to detect both an overfill and a low level warning. In only one instance was a false warning given and this was a "GO" condition when the gear case was actually drained. This was attributed to the location of the level detectors. The present sight gauges were used for the installation of the liquid level detectors. The 90° Gear Box location is such that a residual of oil remains in the bottom of the recess for the sight glass. The 90° liquid level detector requires that an adjustment be made to insure that the lower detector is not allowed to remain in this residual. The over-all effect on this channel is to reduce the range of the level between overfill and low level.

It should be emphasized that modifications to the aircraft were kept to a minimum. More ideal locations and methods to mount and monitor could have been utilized, had extensive modifications been permitted.

The only problem involved in these channels again point out the desirability of designing the sensors into the components at the aircraft design stage.

Verification of Engine Oil Flow Monitor at 6400 RPM As a Means of Inspection

The engine oil flow monitor was verified in that the ability of the circuit was capable of detecting a leak rate of one pint per minute. Expansion of the flowmeter concept was studied but the circuitry involved was deemed too complex for the time and economic factors involved in this program.

Verification of Filter Bypass Monitor to Determine a Clogged Filter

The filter bypass concept as evolved for the ALARM System breadboard was not tested to determine the position of the bypass valve when an indication was given. The only test performed was a complete blockage of the filter.

The filter bypass valve mechanism is an internal valve of the filter assembly and the mechanism is difficult to monitor during operation. The bypass fluid is mixed with filtered fluid in a common cavity at the output. Measurement of the fluid bypassed becomes an impossibility during operation.

Verification of the valve actuation and indication can be done by disassembly of the filter and physical actuation of the valve performed. This is not under operating conditions, but is considered to be a reasonable check on the valve actuation position.

The filter bypass concept as it has developed in the ALARM System is not ideal. The original concept was to detect the movement of the bypass valve at a 50% opening. This concept has been completed. A more recent discussion has determined a more desirable concept would be to indicate just as the valve opens. This would indicate when contaminated fluid is being mixed with the filtered fluid. The change in concepts involves only the setting of the internal switch of the filter. No problems or complications are foreseen in making a change of this type.

Verification of the Thermal Ribbon Technique As a Means to Detect Temperature Rise in a Component

Verification of temperature monitors to determine the condition of an aircraft dynamic component is not complete, but evidence that temperature indication

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Verification of the valve actuation and indication can be done by disassembly of the filter and physical actuation of the valve performed. This is not under operating conditions, but is considered to be a reasonable check on the valve actuation position.

The filter bypass concept as it has developed in the ALARM System is not ideal. The original concept was to detect the movement of the bypass valve at a 50% opening. This concept has been completed. A more recent discussion has determined a more desirable concept would be to indicate just as the valve opens. This would indicate when contaminated fluid is being mixed with the filtered fluid. The change in concepts involves only the setting of the internal switch of the filter. No problems or complications are foreseen in making a change of this type.

Verification of the Thermal Ribbon Technique As a Means to Detect Temperature Rise in a Component

Verification of temperature monitors to determine the condition of an aircraft dynamic component is not complete, but evidence that temperature indication logical condition to induce vibration just as the main rotor out-of-track condition was. Results of the test indicate this was not true. No significant change in the vibration signature was noted. It is felt this condition may be detectable during in-flight conditions but this could not be determined, since no in-flight malfunctions were permitted. The scored main mast bearing did not show significant changes and again the validity of the test is questionable.

POST ANALYSIS

The present inspection procedure requires visual and audible inspection of the aircraft in the "first" and "second" echelon inspection. In a few isolated instances, minor inspection tools are used. Normally, the inspection tools are used in "third", "fourth", and "fifth" echelons. Determination of component serviceability then is limited to human judgement. The human element becomes a variable that can be controlled only to the degree that the education, experience, etc., can be developed in a particular individual. The ability of man to absorb and retain information will vary with each individual. The inspection procedure then becomes a variation with each individual.

Recent advances in the electronic industry have provided a great step forward in relieving man of the responsibility of making repetitive decisions. Where physical limits can be defined and repeated reliably, a decision can be made electronically based on these limits and the history of the conditions. This has been the approach used in the ALARM concept. The ALARM System has shown that it is feasible to translate physical conditions of a particular component into electrical signals which can be made to indicate the limit imposed upon it. The problem which is still to be solved lies in the determination of specific limits.

Additional test programs with the experimentation of sensor ranges, sensitivity, location and signal conditioning will be a step forward in the direction of solving the major problem of determining the specific limits of a serviceable component.

The placement of a sensor and the frequency band coverage and number of sensors may be altered to give a closer look at a particular frequency. The ALARM sensor placements and ranges were estimated as to the best possible coverage with the conditions as known and limited to determine feasibility.

Determination of monitor points and how they should be accomplished for the ALARM test program was based on the research and study phase of the ALARM program (TREC Technical Report 60-49). Considerations included, but were not limited to, trouble areas, sensor installation, modification of the aircraft, and economic factors.

Significant results may be further expanded by a research program concerning the location and type of sensor to be utilized. ALARM restrictions precluded ideal sensors and locations. Use of sensors that have been designed specifically for a particular application may give more consistent and reliable data.

Example: Built in temperature sensor for bearings. Vibration pick-up sensor designed as a portion of the original component rather than mounted by a bracket.

The results have determined the concept of an automatic electrical inspection system is feasible regardless of having worked with less than ideal conditions.

The ALARM System, as evolved, was designed as a study and breadboard feasibility concept. Further testing and evaluation must be done to establish limits for operation.

ALARM SYSTEM MONITOR CHANGES

The breadboard ALARM System was approved for construction with the monitor points outlined in TREC Technical Report 60-49, dated September 1960.

Changes from the format as proposed to the ALARM System breadboard, as delivered, include the following:

1. Rotor mast bearing temperature - this channel is now designated as the transmission input quill bearing temperature.

2. Engine excess oil flow - the location of this channel sensor was changed from the output side of the filter to the input of the oil reservoir. This change allowed monitoring of the total flow of the system rather than a partial flow.

3. Interlock channels that did not prove feasible in application included crew doors, cargo doors, suspension cable, air vents, and the antenna cover. These interlocks were eliminated from the ALARM breadboard.

4. The magnetic chip detection channels were changed from the static mode check to dynamic and in-flight mode.

5. The tail vibration sensor location was changed from the mid point on the tail pylon to a direct mounting on the 90° Gear Box housing.

6. The low frequency sensor and location were changed. The transmission top accelerometer is used only for high-frequency pickup on the transmission. A velocity-type pickup was mounted in the forward aircraft frame for low-frequency monitoring.

7. An engine overspeed indication with lock-in circuitry was provided additionally. The circuit is capable of being reset by a pushbutton.

8. The ambient temperature sensor location was changed from the "hell-hole" to the oil cooler drive shaft housing.

H-23 TEST PROGRAM

PURPOSE

The purpose of this Test Program was to obtain data on transmission, tail, and low-frequency fuselage vibration levels and temperature levels of wobble plate, main drive clutch, Cardan joint, tail rotor drive shaft hanger bearings and tail rotor gear box.

No malfunction tests were permitted but wherever possible, increases in temperature and vibration levels were induced to observe the detection capability of the installed ALARM System.

A brief flight test for observation of system operation in flight was performed at the conclusion of the aircraft availability period.

PROCEDURES

The ALARM System was installed in approximately four working days without difficulty. No modifications of the aircraft structure were required. The wiring necessitated that several access covers be removed for proper routing.

The procedure for all ground tests was as follows:

1. The aircraft engine was run up to 3100 rpm (maximum normal ground run setting) for observation of channel indications.

2. A check was made on channel calibrations by minor readjustment to determine that detection level was just above normal vibration or that temperature amplitude was being monitored by the sensors.

3. Vibration levels by octave bands analysis was recorded.

4. Ambient and surface temperatures as instrumented on the aircraft were recorded.

5. When induced increases in any parameter were attempted, observation of the channel under test was made for a "NO GO" indication.

Test equipment utilized included the following:

1. ULF Variable Band Pass Filter (Krohn-Hite 330-M)
2. Infrasonic Voltmeter (Ballantine 316)
3. Impedance Bridge (Electro-Instruments 250-DA)

All vibration and temperature measurements were taken directly from the vibration pickup and thermal ribbons. The vibration measurements were recorded by amplitude in the frequency range of the sensor, and the temperature measurements were recorded by the resistance value of the thermal ribbons.

During the flight test portion, an observer accompanied the pilot during the brief flight, and vibration and temperature indications were noted. Readjustments were required to determine in-flight setting since no automatic level switching was provided in this particular ALARM System. Recalibration of the system at the conclusion of the flight was indicative of in-flight "NO GO" settings. This was not considered as final as only one flight was made due to aircraft availability.

CONCLUSIONS

No valid conclusions are made from the test program as the program was concluded due to aircraft unavailability before sufficient data could be recorded.

DISCUSSION OF TESTS PERFORMED

Transmission Vibration: Since no malfunction tests were permitted, the normal operating vibration pattern was determined to be at approximately 10 KC. The apparent detection level was approximately 25 g's at 10 KC.

Low Frequency Vibration: Flight tests indicated ability to detect 1/rev vibration when increases occurred. Detection level for this particular aircraft was approximately 0.25 in/sec.

Tail Vibration: T/R unbalance detected with three wraps of tape. Detection level approximately 1.2 in/sec.

Wobble Plate Temperature: Normal temperature setting for a "NO GO" condition established at 45°C at an ambient of 25°C. Since no malfunction was permitted, the 45°C setting was arbitrary.

Main Drive Clutch Temperature: Normal temperature setting for a "NO GO" condition established as 70°C at an ambient temperature of 25°C. Overheat condition induced by the "splitting needle" technique.

Cardan Joint Temperature: Normal temperature setting for "NO GO" condition established as 35°C for an ambient temperature of 25°C. An overheat condition was induced by wrapping the joint with asbestos.

Tail Shaft Bearing Temperature: Measurements indicated the "NO GO" temperature to be 40°C at an ambient of 25°C. An overheat condition was indicated on the midshaft bearing but due to time limitations it was not possible to determine the cause. It was suspected that dirty or over-lubrication of the bearing caused this indication.

Tail Rotor Gear Box Temperature: Normal temperature setting for a "NO GO" condition was established as 35°C at an ambient of 25°C. Overheat condition induced by wrapping gear box in asbestos. A considerable time lag was evident with this method and an indication of a "NO GO" condition after the aircraft was shut down was noted.

The results of these tests were inconclusive in that the tests were concluded before sufficient data could be recorded. The data that was recorded is indicative, however, that the ALARM System as installed on the H-23 aircraft has the ability to indicate a potentially dangerous condition of a component. No attempt has been made to compare the results of these tests with the HU-1 test results due to insufficient data.

RECOMMENDATION

It is recommended that further research be conducted to accumulate test data on aircraft conditions, perform malfunction tests, and further evaluate the ALARM System.

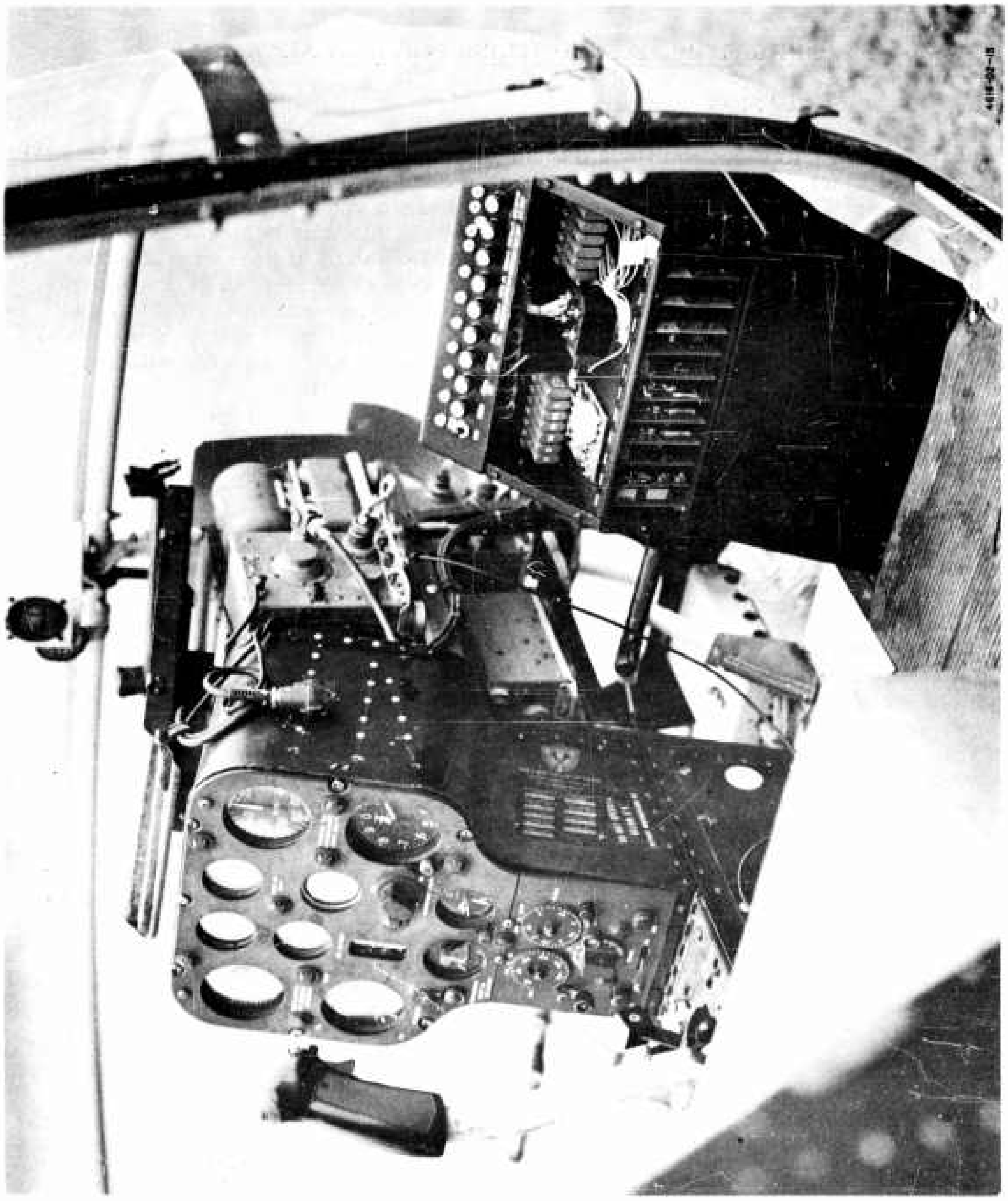


FIGURE 74. TEST ALARM SYSTEM INSTALLED IN H-23 AIRCRAFT

OPERATOR'S INSTRUCTIONS FOR H-23 ALARM

GENERAL DESCRIPTION

The ALARM System for the H-23 has an 11 channel capacity as follows: One tail vibration channel, one transmission vibration channel, one low frequency mast vibration channel, seven temperature channels and a spare transmission vibration channel complete except for the sensor. The complete unit is powered by the ship's +27.5V system and requires a current of less than 0.6 amps. The unit contains its own zener regulated supplies to provide +12V and +4.5V for internal use. The system is completely contained in one package minus the cables and sensors which are located throughout the ship. The ALARM System is physically mounted in the right side of the cabin in front of the passengers seat with the base of the unit mounted to the forward most part of the floor.

From top to bottom the unit consists of (1) indicator and control section, (2) relay and cable section, (3) printed circuit cards and power supply section. (See Figure 75)

INDICATOR AND CONTROL SECTION

The equipment is turned on and off by means of a toggle switch located on the right hand side of the unit. This switch controls the hot side of the ship's 27.5V into the unit. The fault light indicators are also located on this section and directly above the indicators are the test jacks associated with the respective channels. The test jacks allow the sensor signals to be monitored as desired. There are three test jacks associated with the Tail Shaft BRG Hot Indicator, and an overheat condition on any one of the three bearings will cause the indicator to illuminate. The AMB TEMP test jack located directly above the test button is connected to the ambient temperature thermal ribbon which is the reference element for all the temperature channels.

All the indicators are connected such that a failure causes the indicator to illuminate so that if all monitored points are functioning properly, all indicators will be extinguished.

The remaining switch located on the Indicator and Control panel is the Test button. This switch controls the self-check relays and when the button is pressed, all indicators must illuminate, thus indicating that all channels are functioning properly.

RELAY AND CABLE SECTION

The center section contains 14 relays and the external jacks required for system connection. The relays are, as far as practical, located physically above the associated printed circuit board and below the associated indicator (See Figure 76).

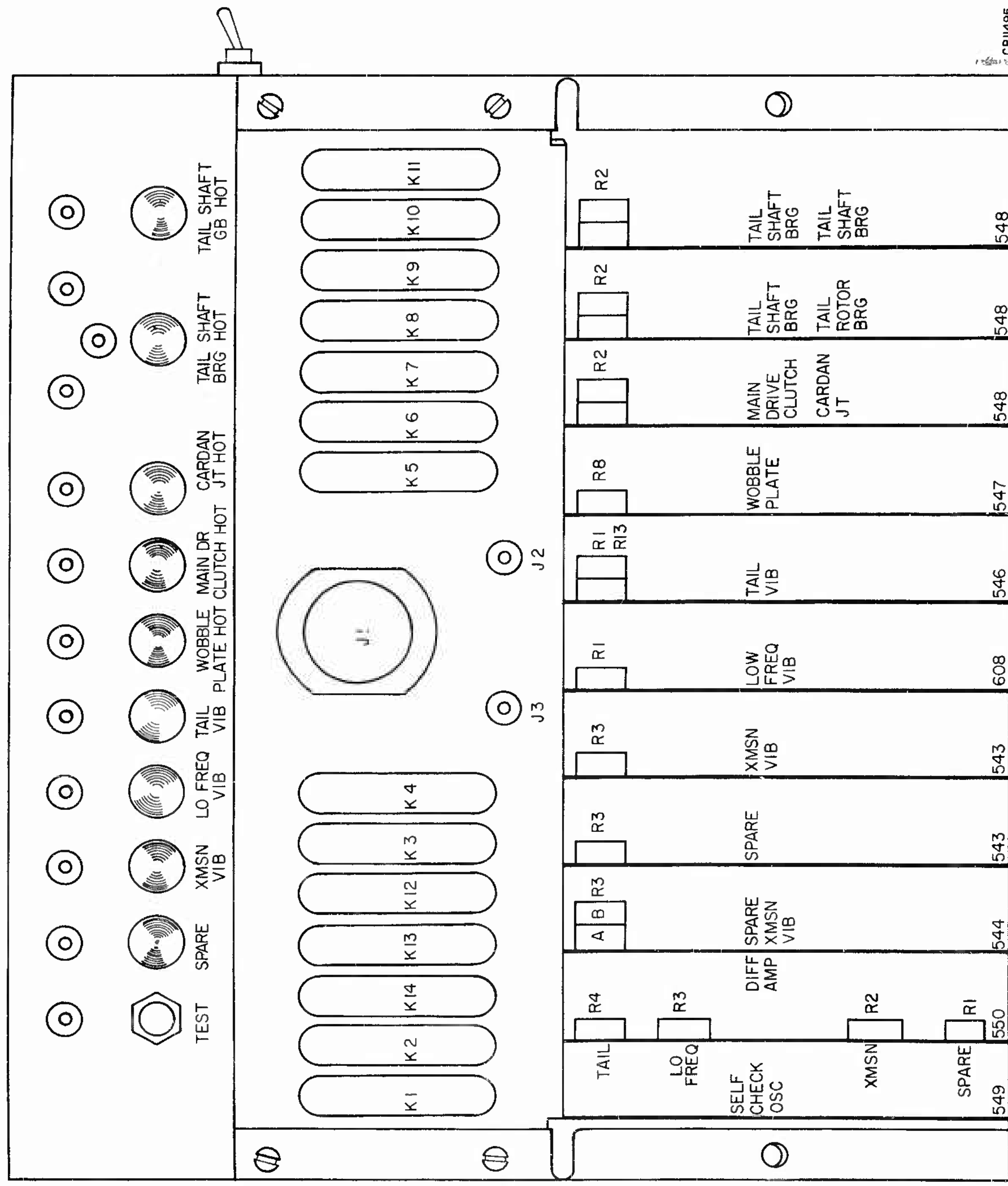


FIGURE 75. FRONT VIEW, H-23 ALARM, COVER REMOVED

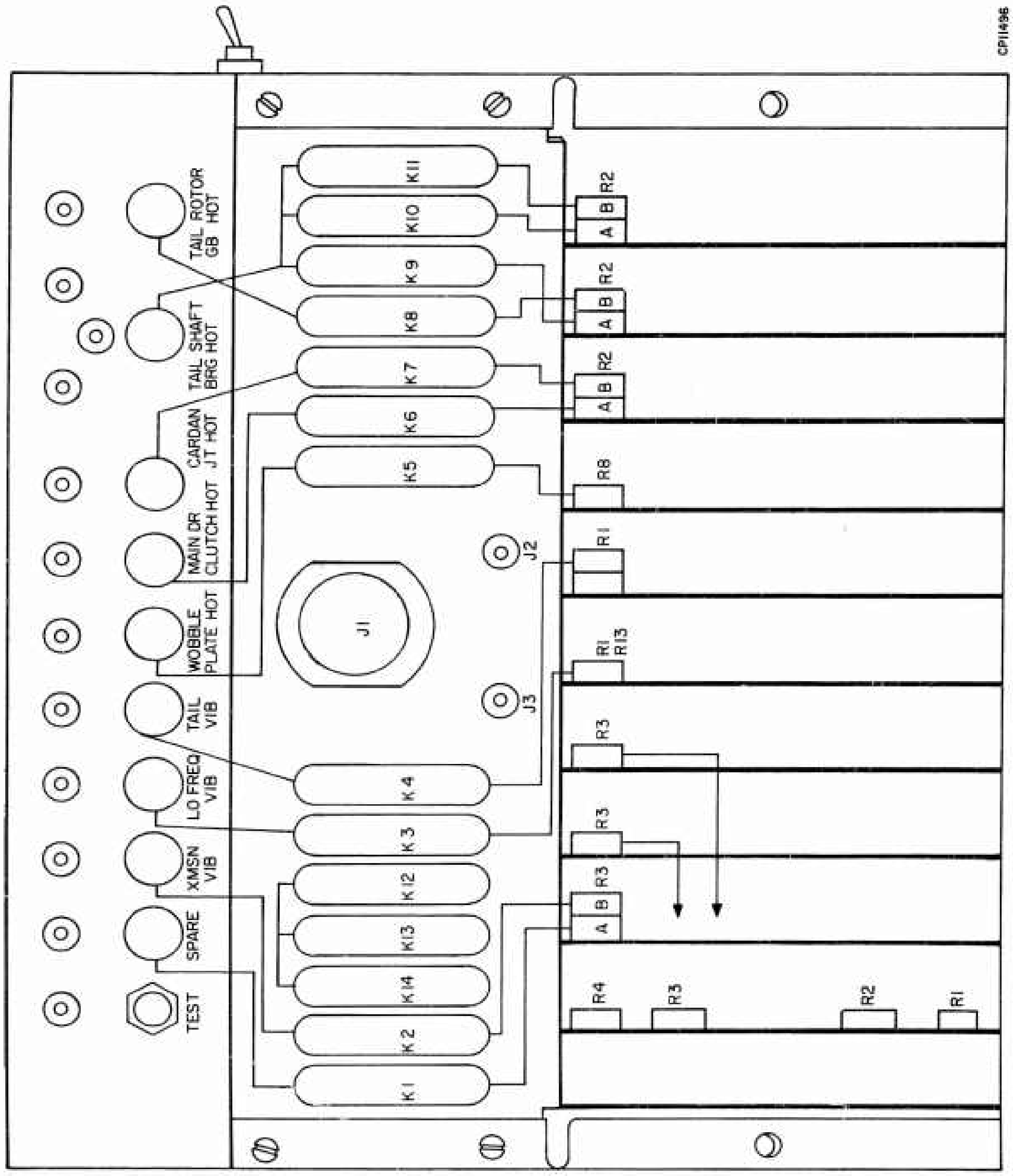


FIGURE 76. H-23 ALARM, RELATIONSHIP OF INDICATORS, RELAYS AND POTENTIOMETERS

The external cable connectors are located at the back of the unit. Three cable connectors are used, two coaxial connectors and one pigmy type quick disconnect. The coaxial connector J2 is the input to the spare channel and J3 is the input to the transmission vibration channel. Primary power and the remaining sensor input signals are fed through the 31 pin connector J1.

PRINTED CIRCUIT CARDS AND POWER SUPPLY SECTION

The bottom section of the unit contains 11 plug-in printed circuit cards and one non-pluggable board which contains the power supply section and miscellaneous components. The printed circuit connectors used with the boards have a key such that a board cannot be inserted in an upside down manner. However, care must be taken to insure that the proper board is inserted into the proper position. From left to right facing the front of the unit, the boards are:

Function	Monitor Point	I.D. No.
1. Self-Check Oscillator		549
2. Attenuator		550
3. Differential Amp. & Relay Driver		544
4. Transmission Vibration	Spare	543
5. Transmission Vibration	Transmission	543
6. Low Freq. Mast Vibration	Transmission	608
7. Tail Vibration	Tail	546
8. Temp. Sensing & Ambient Gen.	Wobble Plate, Amb. Temp.	547
9. Temperature (2)	Main Drive Clutch, Cardan Joint.	548
10. Temperature (2)	Tail Shaft Bearing, Tail Rotor Gear Box	548
11. Temperature (2)	Tail Shaft Bearing, Tail Shaft Bearing	

The boards have the identification number etched into the printed circuit side. In general the board types progress from left to right in the same manner as the indicator lamps are stenciled. The overall schematic diagram follows the same pattern which is intended to serve as an aid in troubleshooting and familiarization.

Figure 76 shows the relationship between indicators, relays and potentiometers. Identification of potentiometers is provided by Figure 75, and it will be noticed that in the case where two potentiometers are mounted atop one another, the one next to the board is always designated as "A". Reference appropriate schematic diagram. The single exception is board 546 where R1 and R13 designations are used.

Components R1, R2, R3, CR1, CR2, and CR3 are located on the fixed mounting board at the extreme right side of the unit. The wiring harness to this board is long enough to permit the removal of the board without removing any wires.

The approximate total weight of the system is 14 pounds, with the main unit and mounting base weighing 11 pounds. The cable between the main unit and the rear access plate weighs 1.4 pounds and the sensor cable weighs approximately 1.4 pounds. The tail vibration pickup and bracket weigh 0.37 pounds.

ADJUSTMENT

Due to the small size of the potentiometers used, it will be necessary to use a small screwdriver, such as a jeweler's type, to make the following adjustments:

Both the spare vibration channel and the transmission vibration channel were set up by the following method. The detection level was set at 4.0V by adjusting R3A and R3B on board number 544 such that the bases of Q2A and Q2B were at +4.0V. The sensitivity was set for 5g at 10 KC by adjusting R3 (boards number 543) such that the indicator illuminates with an input at J2 or J3 of 0.65 Vpp at 10 KC.

The tail vibration channel detection level was set by adjusting R13 on board 546 such that the base of Q4 was +3.5V. Sensitivity was set for 2 in/sec. by adjusting R1 such that the indicator illuminates with an input of 108.5 MVpp at 100 cps at J1-P.

All of the temperature channels except the main drive clutch have been set to indicate at a temperature of 80^{o}C when the ambient is 40^{o}C. The clutch channel has been set to indicate at 130^{o}C. There is only one control for each channel. At an ambient temperature of 25^{o}C, the maximum range of adjustment is approximately 100^{o}C on all temperature channels.

The low frequency vibration channel was set for 0.5g at 20 cycles by adjusting R1 on board 608 such that the indicator illuminates with an input of 0.056 Vpp at J3.

To set up the potentiometers R1 through R4 on the attenuator board (550) the following procedure is used. Press the test button and while holding it down, adjust R4 counter clockwise such that the tail vib indicator goes out; then turn it clockwise until the light just comes on. Repeat this process for R3-low frequency Vib., R2-XMSN Vib. and R1-spare.

DATE	TEST CONDITIONS	DATA RECORDED IN IN/SEC								ALL	ALARM IND.	NOTES AND COMMENTS
		20-40	40-80	80-160	160-320	320-500	500-1KC	1-2KC				
8/28	3100 RPM											
8/29	3100 RPM									1.35 to 1.45		SEEMED TO BE MORE LOW FREQUENCY VIBRATION FELT IN CABIN THAN ON 8/28.
8/30	3100 RPM									1.25		FILTER NOT GROUNDED.
9/5	3100 RPM									1.15		
9/6	3100 RPM	0.17	0.275	0.305	0.36	0.445	0.17	0.65		0.70		FIRST TIME GROUNDED FILTER USED.
9/7	3100 RPM	0.25	0.405	0.50	0.165	0.28	0.36			0.775		
9/7	3100 RPM	0.31	0.46	0.625	0.18	0.31	0.505			1.10	TAIL VIBRATION LIGHT CAME ON 3 MIN. AFTER START OF RUN, THEN FLICKERED.	3/4 INCH MASKING TAPE ON MAIN ROTOR BLADE.
9/8	3100 RPM	0.31	0.36	0.49	0.17	0.26	0.41			1.03	TAIL VIBRATION LIGHT CAME ON AND OFF (FLICKERED).	0.012 LBS TAPE ON MAIN ROTOR BLADE (3 WRAPS).
9/8	3100 RPM	0.46	0.44	0.625	0.18	0.26	0.37			1.23	TAIL VIBRATION LIGHT INDICATED STEADILY.	3 WRAPS OF TAPE ON TAIL ROTOR BLADE. WEIGHT OF THE 3 WRAPS 0.004 LB.
9/19	3100 RPM									1.4		REF. RUN AFTER REPAIRS WERE COMPLETED ON ENGINE COOLING FAN.

DP11504

FIGURE 77. TAIL VIBRATION TEST DATA

DATE	A/C COND.	P/U POS.	TEST CONDITIONS	DATA RECORDED IN G'S								ALL	ALARM IND.	NOTES & COMMENTS
				500-1KC	1KC-2KC	2-4KC	4-8KC	8-12KC	12-16KC	16-20KC				
8/28														
8/30												80.9		
9/5			3100 RPM									84.7		
9/6			3100 RPM	13.1	48.1	40.5	32.7	21.5	15.4	9.22		84.7		NO TAPE ON EITHER BLADE
9/7			3100 RPM	18.5	69.3	46.2	35.05	23.2	16.1	9.2		97.4		NO TAPE REF. RUN
9/7			3100 RPM	14.25	55.7	67.4	40.5	30.0	19.25	10.75		86.7	TAIL VIBRATION LIGHT CAME ON 3 MIN. AFTER START OF RUN THEN FLICKERED.	3/4" MASKING TAPE ON MAIN ROTOR BLADE
9/8			3100 RPM											NO NOTICEABLE CHANGE
9/8			3100 RPM	12.3	56.5	43.3	31.6	26.2	18.5	9.24		84.7	TAIL VIBRATION LIGHT FLICKERED OFF AND ON.	3 WRAPS OF TAPE ON MAIN ROTOR BLADE AND 1 WRAP ON TAIL
9/11			3100 RPM REF. RUN	16.0	63.5	48.2	40.5	24.6	17.7	10.0		86.6		
9/19			REF. RUN AFTER ENGINE COOLING FAN REPAIRS.									96.2		

DP11507

FIG. 78 XMSM VIBRATION CHANNEL TEST DATA

DATE	A/C COND.	P/U POS.	TEST CONDITIONS	DATA RECORDED IN IN/SEC.								ALL	ALARM IND.	NOTES & COMMENTS
				3-6	6-12	12-24	24-50	50-100						
8/30		ON ALARM IND. UNIT	3100 RPM REF. RUN									0.8		SPLITTING NEEDLES TO HEAT UP CLUTCH
9/5		"	3100 RPM SPLITTING NEEDLES									2.4		THIS RUN WAS PRIMARILY FOR CHECKING HEAT SENSORS.
9/6		"	3100 RPM	0.3	0.36	0.14	0.28	0.40				6.4		
9/7		"	3100 RPM REF. RUN	0.17	0.14	0.12						0.16		
9/7		"	3100 RPM 2 WRAPS 3/4" MASKING TAPE ON MAIN ROTOR	0.14	0.16	0.17						0.25		WEIGHT OF TAPE 0.012 LBS.
9/8		"	3100 RPM 3 WRAPS TAPE ON MAIN ROTOR	0.11	0.19	0.15						0.22		
9/8		"	3100 RPM 1 WRAP TAPE ON TAIL ROTOR BLADE.			0.11						0.15		
9/11		"	3100 RPM REF. RUN		0.13	0.14						0.20		WEIGHT OF TAPE 0.056 LBS.
9/11		"	3100 RPM 6 WRAPS 2" MASKING TAPE ON MAIN ROTOR		0.18	0.14						0.20		
9/12			3100 RPM REF. RUN		0.13	0.12						0.19		
9/12			3100 RPM 6 WRAPS OF TAPE ON MAIN ROTOR		3 WRAPS 0.12 0.17	0.14						0.18		
9/19		ON ALARM IND. UNIT	3100 RPM									0.51		THIS RUN MADE AFTER ENGINE COOLING FAN REPAIRS

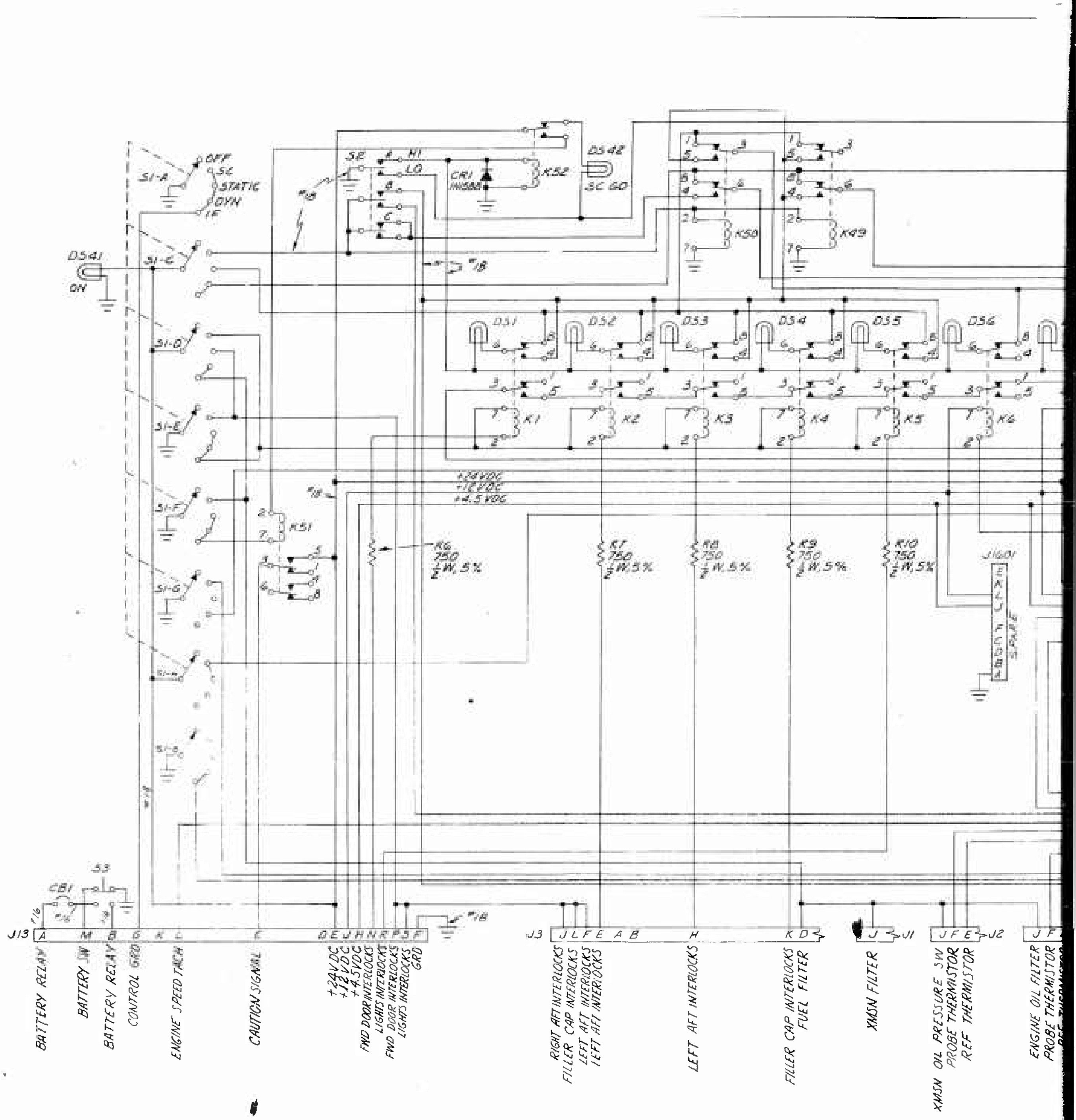
DP11506

FIGURE 79. LOW FREQ. VIBRATIONS TEST DATA

				AMB. TEMP.		WOBBLE PLATE		MAIN DR. CLUTCH		CARDAN JOINT		FWD SHAFT		MID SHAFT		AFT SHAFT		TAIL ROTOR G.B.		NOTES AND COMMENTS
DATE	O.A.T.	TEST CONDITIONS	RUN TIME	BEFORE RUN	AFTER RUN	COLD	@ RT	COLD	@ RT	COLD	@ RT	COLD	@ RT	COLD	@ RT	COLD	@ RT	COLD	@ RT	
8/31	20°C	3100 RPM	20 MIN							22.1°	27.5°	22.1°	26°	22°	25.1°	21°	25.8°	21°	34°	
9/1	34°C	NO RUN		30°		32°		28°		39°		41°		36°		39°		39.5°		
9/5	26°	3100 RPM	23 MIN	26°	29.4°	27.3°	49.5°	24.3°	68.8°	28.2°	34.3°	31.8°	32.2°	29.6°	40.5°	30.5°	31.5°	31°	33.2°	MAIN DR. CLUTCH LIGHT CAME ON DUE TO HEATING UP OF CLUTCH BY SPLITTING THE RPM NEEDLES.
8:10 AM 9/6	26°	EVERYTHING NORMAL 3100 RPM REF. RUN	25 MIN	24	28.2	24.8	39	22.8	68.5	27.0	34.5	31	36.2	29.4	37.5	29.8	35.6	31	36	
8:45 AM 9/6	26°	3100 RPM - TAIL ROTOR G.B. AND FWD. SHAFT WRAPPED IN ASBESTOS	20 MIN			SEE NOTES AT RIGHT	67°C						37.6						36	WOBBLE PL READING IS FOR 10 MIN AFTER SHUTDOWN. MAIN DR CLUTCH LT WAS LIT THROUGHOUT ENTIRE RUN. TAIL ROTOR G. B. LT CAME ON, AND THEN THE TEMP RESPONSE WAS RESET: IT THEN RELIT IG A TEMP RISE.
8:10 AM 9/7	24°	3100 RPM REF. RUN	40 MIN	23.3	31.2	23.8	44	23.6	72.5	24.1	30.8	24.6	27.4	24.0	38.0	24.3	28.1	24.5	29.8	
10:35 AM 9/7	25°	3100 RPM - TAIL ROTOR G.B. AND FWD. SHAFT WRAPPED IN ASBESTOS	25 MIN		30.5		41.5		73		31.1		29		51.5		28	(A TEMP. RISE OF 1° WAS RECORDED 10 MIN. AFTER RUN) 29° - 30°		T/R GEAR BOX TEMP. IND. LIT APPROX. 10 MIN. AFTER START OF RUN, AND REMAINED ON UNTIL APPROX. 10 MIN. AFTER SHUTDOWN. TAPE ON BLADES
9/8	22°	3100 RPM	35 MIN	22.4	31	22	45	21.8	71.5	22.5	30.6	22.5	27	22.1	38.8	23	26.8	22.8	28.4	3 WRAPS TAPE ON MAIN BLADES
9/8	27°	CARDAN JT & FWD SHAFT WRAPPED IN ASBESTOS 3100 RPM			31.5		45.2		73		36.5		32		41.1		29		30	FWD SHAFT TEMP IND LAMP LIT. HOWEVER, THE CARDAN JT LAMP DID NOT IND, AS THERE WAS NOT SUFFICIENT OVERHEATING.
8:35 AM 9/11	24°	3100 RPM REF. RUN	25 MIN	22.3		22.5		21		23.3	34	25		24		24.5		25		
9:30 AM 9/11	31°	CARDAN JT WRAPPED IN ABESTOS 3100 RPM	30 MIN		32		37		68		39		36		37.5		34		34.1	CARDAN JT. LIGHT INDICATED OVERHEATING AT 38°.
8:15 AM 9/12	22°	3100 RPM	30 MIN	23		23		22		22.8		24.4		24.0		24.5		24.6		
9:30 AM 9/12	26°	3100 RPM	35 MIN		34.4		48.5		70		38		32		42.5		31.5		33	
9/13	30°	3100 RPM	3 MIN	33.1		33.1		33.3		38		40		39.0		36		37		ENGINE COOLING FAN SHAFT WAS TWISTED OFF DURING ENGINE RUN UP.
9/19	18°	3100 RPM REF. RUN	35 MIN	18	25.4	17.8	37	17.6	63.5	18.5	25.3	19	22	18	37	18.7	23	18.6	25	REF. RUN AFTER REPAIRS WERE MADE TO ENGINE COOLING FAN.
9/20	18°	IN FLIGHT					26.5		57		27								32.5	THESE READINGS WERE SET DURING FLIGHT TESTS.

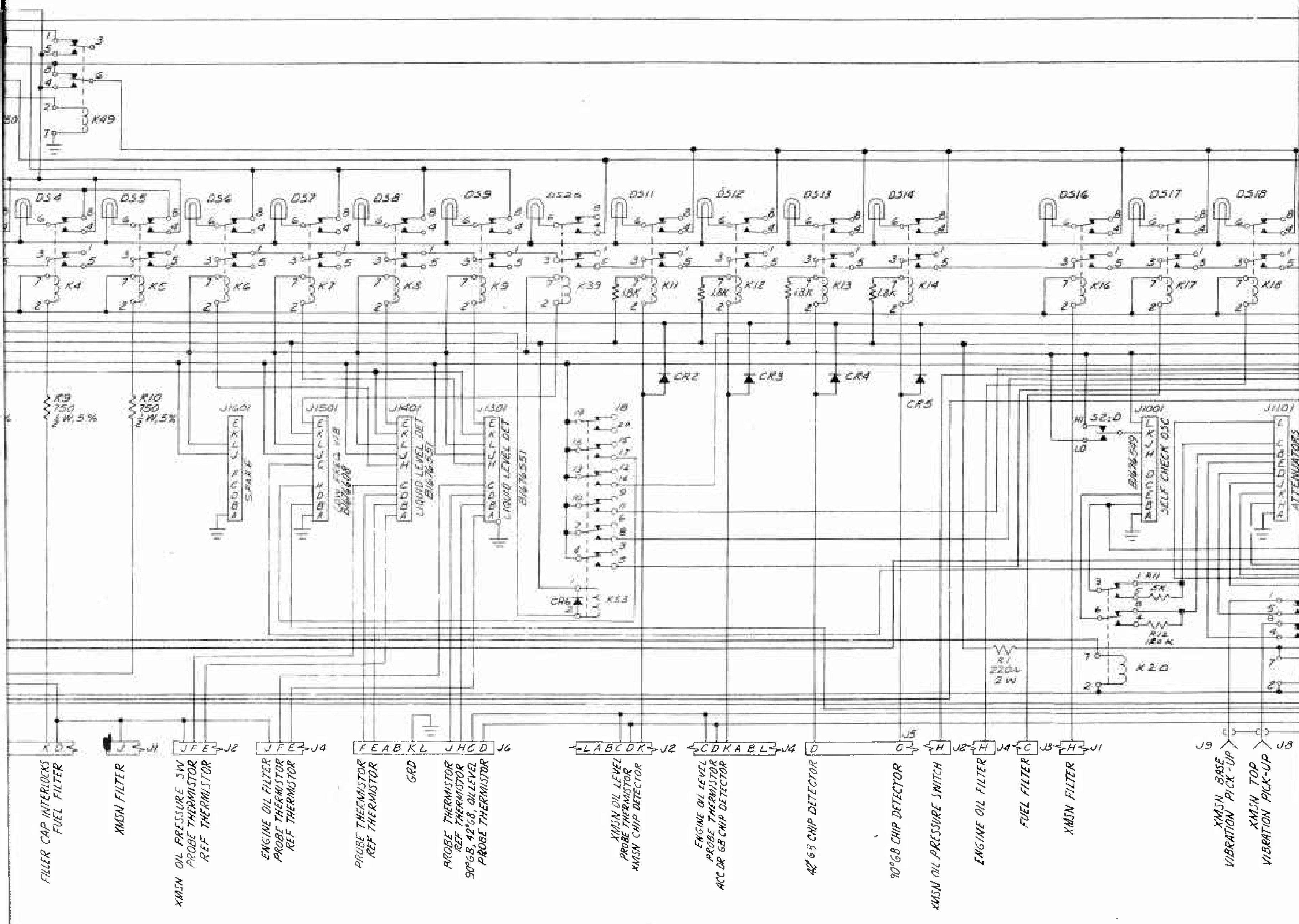
DP11509

FIGURE 80. TEMPERATURE TEST DATA H-23 ALARM SENSORS (ALL READINGS ARE IN DEGREES CENTIGRADE)



S1-A
OFF
SC
STATIC
DYN
IF
S1-C
S1-D
S1-E
S1-F
S1-G
S1-H
S1-B
DS41
ON
S2
HI
LO
CR1
1N588
K52
DS42
SC GO
K50
K49
DS1
DS2
DS3
DS4
DS5
DS6
K1
K2
K3
K4
K5
K6
K51
+24VDC
+12VDC
+4.5VDC
R6
750
½W, 5%
R7
750
½W, 5%
R8
750
½W, 5%
R9
750
½W, 5%
R10
750
½W, 5%
J1601
SPARE
CB1
S3
#18
#16
J13
A M B G K L C D E J H N R P S F
J3
J L F E A B H K D
J1
J F E
J2
BATTERY RELAY
BATTERY SW
BATTERY RELAY
CONTROL GRD
ENGINE SPEED TACH
CAUTION SIGNAL
+24VDC
+12VDC
+4.5VDC
FWD DOOR INTERLOCKS
LIGHTS INTERLOCKS
FWD DOOR INTERLOCKS
LIGHTS INTERLOCKS
GRD
RIGHT AFT INTERLOCKS
FILLER CAP INTERLOCKS
LEFT AFT INTERLOCKS
LEFT AFT INTERLOCKS
LEFT AFT INTERLOCKS
FILLER CAP INTERLOCKS
FUEL FILTER
XMSN FILTER
XMSN OIL PRESSURE SW
PROBE THERMISTOR
REF THERMISTOR
ENGINE OIL FILTER
PROBE THERMISTOR

1


K49
DS4
DS5
DS6
DS7
DS8
DS9
DS26
DS11
DS12
DS13
DS14
DS16
DS17
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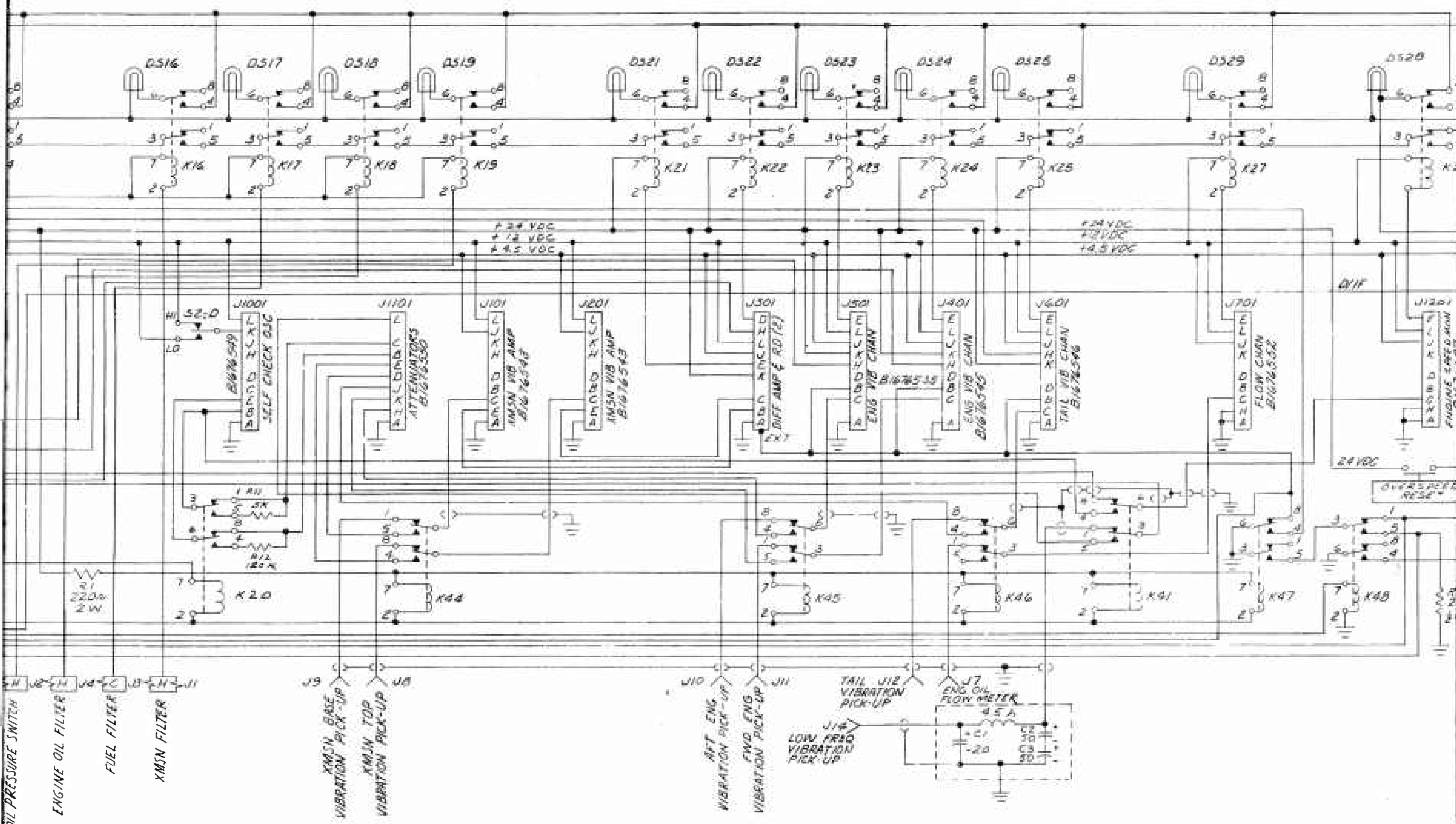
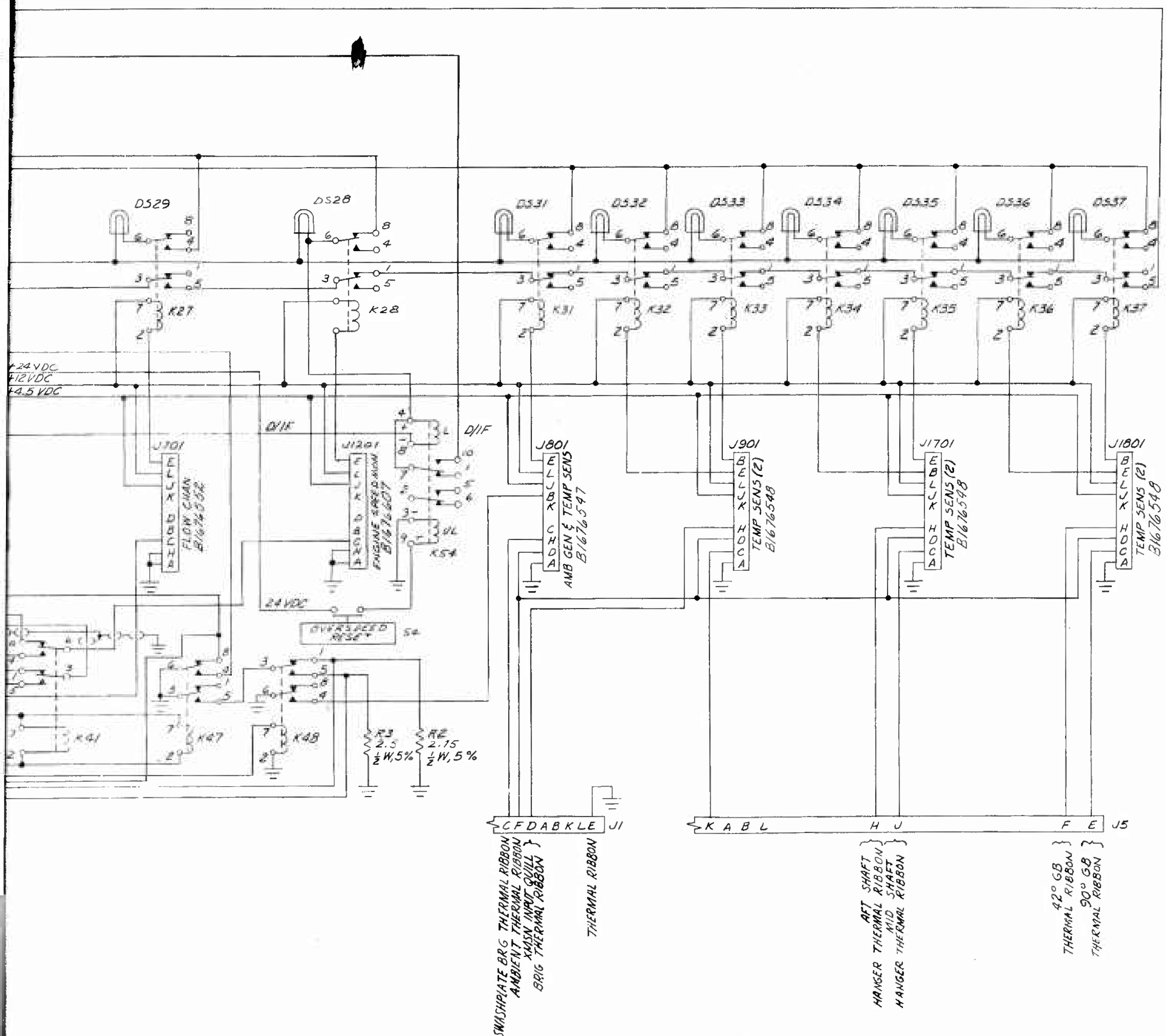
K4
K5
K6
K7
K8
K9
K33
K11
K12
K13
K14
K16
K17
K18
CR2
CR3
CR4
CR5
R9 750 ½W, 5%
R10 750 ½W, 5%
J1601 SPARE
J1501 LOW PRESS 1/8 B1676008
J1401 LIQUID LEVEL DET B1676551
J1301 LIQUID LEVEL DET B1676551
CR6
K53
S2,D
HI
LO
J1001 B1676419 SELF CHECK OSC
J1101 ATTENUATORS
R11 5K
R12 120K
R1 220Ω 2W
K20
J1
J2
J4
J6
J5
J3
J9
J8
FILLER CAP INTERLOCKS FUEL FILTER
XMSN FILTER
XMSN OIL PRESSURE SW PROBE THERMISTOR REF THERMISTOR
ENGINE OIL FILTER PROBE THERMISTOR REF THERMISTOR
PROBE THERMISTOR REF THERMISTOR
GRD
PROBE THERMISTOR REF THERMISTOR 90°GB, 42°GB, OIL LEVEL PROBE THERMISTOR
XMSN OIL LEVEL PROBE THERMISTOR XMSN CHIP DETECTOR
ENGINE OIL LEVEL PROBE THERMISTOR ACC DR GB CHIP DETECTOR
42°GB CHIP DETECTOR
90°GB CHIP DETECTOR
XMSN OIL PRESSURE SWITCH
ENGINE OIL FILTER
FUEL FILTER
XMSN FILTER
XMSN BASE VIBRATION PICK-UP
XMSN TOP VIBRATION PICK-UP

2

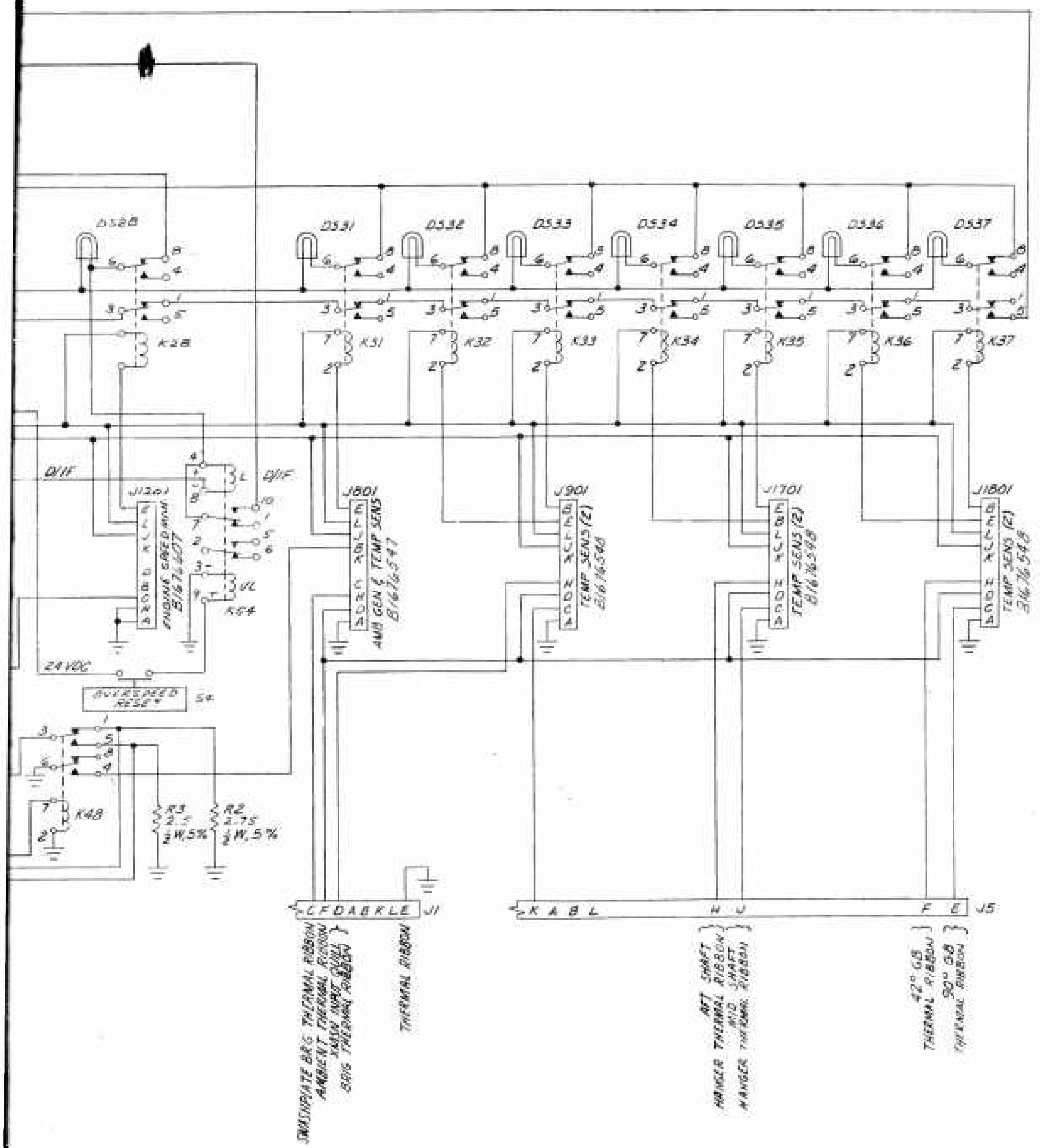

DS16
DS17
DS18
DS19
DS21
DS22
DS23
DS24
DS25
DS29
DS28
K16
K17
K18
K19
K21
K22
K23
K24
K25
K27
+24 VDC
+12 VDC
+4.5 VDC
DIFF
J1001
J1101
J101
J201
J301
J501
J401
J601
J701
J1201
SELF CHECK OSC
ATTENUATORS
XMSN VIB AMP
DIFF AMP & RO(2)
ENG VIB CHAN
TAIL VIB CHAN
FLOW CHAN
HI
LO
S2-D
EXT
24 VDC
OVERSPEED RESET
R11
R12
120 K
R1
220Ω
2W
K20
K44
K45
K46
K41
K47
K48
J1
J2
J3
J4
J8
J9
J10
J11
TAIL J12
VIBRATION PICK-UP
J7
ENG OIL FLOW METER
J14
LOW FREQ VIBRATION PICK-UP
XMSN OIL PRESSURE SWITCH
ENGINE OIL FILTER
FUEL FILTER
XMSN FILTER
XMSN BASE VIBRATION PICK-UP
XMSN TOP VIBRATION PICK-UP
AFT ENG VIBRATION PICK-UP
FWD ENG VIBRATION PICK-UP

3



NOTES
1. UNLESS OTHERWISE SPECIFIED
ALL RESISTORS ARE IN OH
ALL CAPACITORS ARE IN M
2. ALL WIRE #22 EXCEPT WHERE

FIGURE 81. SCHEMATIC DIAGRAM, CONTROL DISPLAY, ALARM SYSTE
FOR THE JHU-1



NOTES:
1. UNLESS OTHERWISE SPECIFIED
ALL RESISTORS ARE IN OHMS
ALL CAPACITORS ARE IN MICROFARADS
2. ALL WIRE #22 EXCEPT WHERE SPECIFIED

5

FIGURE 81. SCHEMATIC DIAGRAM, CONTROL DISPLAY, ALARM SYSTEM, FOR THE JHU-1

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The system has been breadboarded and has proved feasible and practical for aircraft implementation. The equipment is undergoing flight test.

The ALARM system has proved readily adaptable to most types of light aircraft.

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