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TIEDOWN AND BENCH TESTING OF GREASE-LUBRICATED HELICOPTER TAIL AND INTERMEDIATE GEARBOXES

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EUSTIS DIRECTORATE POSITION STATEMENT

This effort is relevant to the Army's program to increase helicopter survivability, reliability, maintainability, and safety.

This report has been reviewed by this directorate, and the conclusions submitted by the contractor are considered to be valid.

The technical monitor for this effort was Mr. George T. Singley III of the Structures Technical Area, Technology Applications Division.

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Experimental results are presented for modified, grease-lubricated H-3 intermediate and tail gearboxes operated on a regenerative test facility and an actual H-3 tiedown aircraft.

The H-3 intermediate and tail gearboxes were suitably modified for operation with grease lubrication and utilized a lubricant conforming to specification MIL-G-83363 (USAF). A 10-hour bench test was conducted followed by a 50-hour tiedown test on an NSH-3A aircraft. The gearboxes operated satis-

factorily, with no required maintenance throughout the test. Upon disassembly, the gear teeth of the tail gearbox were found to be slightly scored. Further bench testing was conducted to investigate the scoring phenomenon. In this testing, initial scoring was induced at a power level of 250 hp and progressed at 300 hp.

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BACKGROUND AND INTRODUCTION

The use of a grease lubricant in place of the oils presently used for the lubrication of helicopter intermediate and tail gearboxes offers potential reductions in vulnerability and maintenance. In the area of vulnerability, helicopters operating in combat zones are susceptible to ground fire which can puncture gearboxes, with resulting lubricant loss. The use of a nonflowing grease lubricant would significantly reduce this danger to power train system integrity. Maintenance could be reduced by eliminating the necessity for daily lubricant level inspections. The maintenance platforms and attendant ground support equipment associated with these inspections and necessary lubricant refills would also be eliminated. In addition, lubricant loss due to seal leakage would be sharply reduced due to the higher apparent viscosity of the grease lubricant.

In previous work, testing has been conducted with 17 different candidate grease lubricants for use in helicopter gearbox applications. Of these greases, two were initially chosen for consideration for use in intermediate and tail gearboxes. After preliminary gearbox testing, further development was concentrated on one of the lubricants based on its superior gear surface protection as well as retention on drive system contact surfaces. This lubricant, now designated by military specification MIL-G-83363 (USAF), has undergone exhaustive testing in the intermediate and tail gearboxes of the H-3 helicopter. This testing is documented in an Air Force Materials Laboratory technical report designated AFML-68-338, Part II.

Under USAF Contract No. F33615-68-C-1389, 440 hours of testing was conducted on grease-lubricated H-3 intermediate and tail gearboxes at power levels up to 400 hp. In all of this testing, all significant gearbox temperatures were stabilized at levels well below the critical temperatures for either bearing or gear material breakdown or grease degradation. Another research and development effort was conducted independently by Sikorsky Aircraft to establish the long-term performance of grease-lubricated helicopter gearboxes. The intermediate and tail gearboxes of an H-3 helicopter were subjected to a 2000-hour endurance test at power levels up to 400 hp, and a prorated power substantially above the H-3 mission prorated power. All gearbox components were in satisfactory condition following test. The task remaining was to evaluate the performance of these gearboxes on an actual H-3 aircraft.

The opportunity for such an evaluation was afforded by the existence of an H-3 aircraft program designed to test and evaluate an advanced roller gear main transmission as well as two experimental YT58-GE-16 turboshaft engines. This program, performed under USAAMRDL Contract DAAJ02-69-C-0042, utilized a suitably modified H-3 aircraft designated NSH-3A Bu. No. 152105. For the purposes of the program reported herein, the standard oil-lubricated intermediate and tail gearboxes were replaced with gearboxes utilizing the MIL-G-83363 grease lubricant. No further aircraft modifications were necessary to accommodate these test gearboxes.

Both the test intermediate and tail gearboxes were subjected to a 10-hour bench test prior to installation on the tiedown aircraft. This test demonstrated satisfactory operation of the grease-lubricated gearboxes at power levels in excess of their normal design power. For the tiedown test, the gearboxes were installed on the roller gear tiedown aircraft, and 50 hours of tiedown testing was conducted at test conditions compatible with the test requirements for the roller gear main transmission.

Some gear scoring was encountered during the course of the tiedown testing. Additional bench testing of the H-3 intermediate and tail gearboxes was therefore conducted to evaluate the nature and impact of this gear tooth surface distress. Initial gear tooth scoring was encountered in the tail gearbox following testing at a power level of 250 hp. Operation at 300 hp resulted in increased scoring. Additional testing at 100 hp resulted in no change in gear tooth condition. The early onset of gear tooth scoring in the grease-lubricated H-3 tail gearbox is at variance with all previous testing and is, as yet, unexplained. However, due to the excellent results experienced in previous testing, the scoring experienced in this test is not considered to be detrimental to the concept of grease-lubricated gearbox operation.

In transmission systems in which vulnerability to ground fire is a significant factor, the use of a grease lubricant offers a definite advantage. Accordingly, Sikorsky Aircraft has incorporated grease-lubricated intermediate and tail gearboxes into its prototype Utility Tactical Transport Aircraft System (UTTAS) for the U. S. Army.

In addition, a program is now under way to investigate the feasibility of grease lubrication for medium-power main transmissions. Under Contract F33615-72-C-2031, jointly sponsored by the U. S. Air Force Materials Laboratory and the U. S. Army Air Mobility Research and Development Laboratory, an H-3 main transmission will be modified for use with grease lubrication and operated in a regenerative test facility.

TIEDOWN TEST EQUIPMENT

TEST HELICOPTER

The ground test vehicle for the tiedown test program was a modified SH-3A helicopter designated NSH-3A Bu. No. 152105. It is designed primarily for antisubmarine warfare missions and is capable of carrier-based operation. The basic SH-3A aircraft has a gross weight of 19,000 lb and is powered by two T58-GE-8 engines, each developing a 30-minute power rating of 1250 hp.

The roller gear main transmission utilized in the tiedown test was specifically designed to support the requirements of the advanced YT58-GE-16 engines. The grease-lubricated intermediate and tail gearboxes complement this combination by providing increased survivability and maintainability. The significant NSH-3A aircraft parameters are summarized in Table 1.

TABLE 1. TEST AIRCRAFT PARAMETERS

Helicopter Designation:	NSH-3A
Aircraft Bureau No.:	152105
Number of Engines:	2
Engine Type:	YT58-GE-16
Main Rotor Speed:	203 rpm
Main Rotor Blades	
Type:	Constant Cord NACA 0012
Radius:	31 ft
Number:	5
Tail Rotor Speed:	1243 rpm
Tail Rotor Blades	
Type:	Constant Cord NACA 0012
Radius:	5 ft 2 in.
Number:	5

TEST GEARBOXES

The test gearboxes consisted of standard H-3 intermediate and tail gearboxes suitably modified for grease lubrication. The gear-end bearings of each gearbox were provided with noncontacting bearing shields to retain sufficient lubricant in the bearing cavities while permitting any excess grease to be purged from the bearing areas. In addition, the intermediate gearbox was equipped with a baffle in the gearbox sump to assist in ducting the grease into the gear mesh. The ball bearing on the output of the tail gearbox utilized an integral shield to retain the grease lubricant. Bayonet-type thermocouples were provided at each bearing location for continuous temperature monitoring. In addition, vibration detection devices consisting of three accelerometers, two mounted on the tail gearbox and one on the intermediate gearbox, were installed.

Cross-sectional views of the modified intermediate and tail gearboxes are shown in Figure 1. The significant gearbox design parameters are given in Table 2.

TABLE 2. TEST GEARBOX DESIGN PARAMETERS

Parameter	Intermediate Gearbox	Tail Gearbox
Input Speed (rpm)	3030	3030
Output Speed (rpm)	3030	1243
Ratio	1:1	2.4375:1
Number of Teeth, Input	29	16
Number of Teeth, Output	29	39
Pitch Diameter, Input	6.5	3.95
Pitch Diameter, Output	6.5	9.626

In addition to the internal modifications made to the test gearboxes, the input and output seals had their garter springs removed from the sealing lip in order to reduce the lip pressure. This is fairly common practice in seals intended for grease applications and results in reduced seal wear.

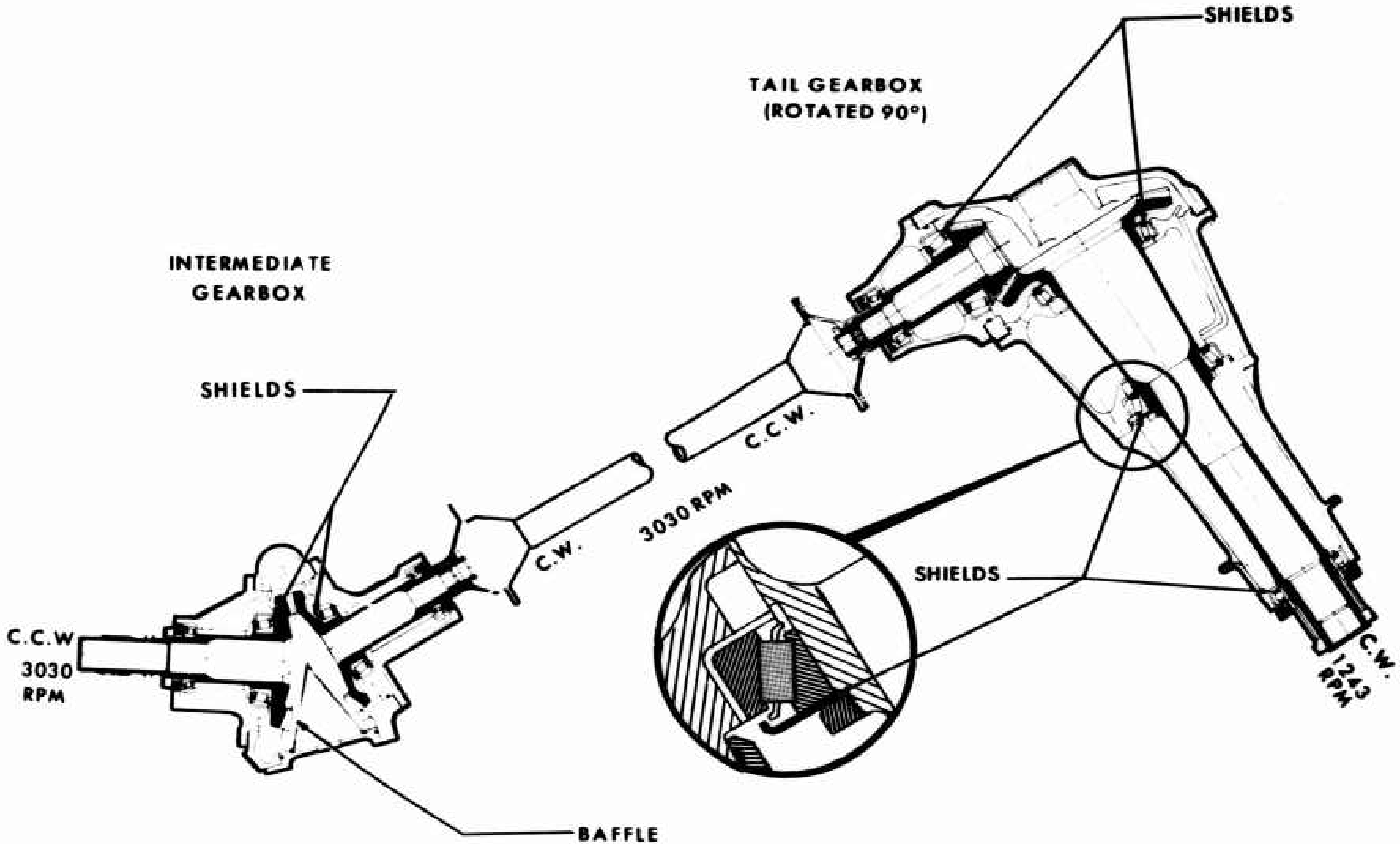


Figure 1. Cross-Sectional Views of Modified H-3 Intermediate and Tail Gearboxes.

BENCH TEST

In order to insure safe aircraft operation, the experimental grease-lubricated gearboxes were subjected to a bench test prior to their installation on the tiedown aircraft. The gearboxes were installed in the regenerative test facility, and a normal production acceptance test for H-3 intermediate and tail gearboxes was run. The normal production acceptance test consists of the following spectrum:

Time (hr)	Input Speed (rpm)	Power (hp)
0.5	1695	50
0.5	3390	200

Following the completion of this 1-hour test, the grease-lubricated gearboxes were run at the spectrum shown in Table 3 for 10 hours.

TABLE 3. BENCH TEST POWER SPECTRUM

Time (hr)	Input Speed (rpm)	Power (hp)
8.5	3390	100
1.0	3390	250
0.25	3390	400
0.25	3390	0

During the bench testing, all gearbox bearing temperatures were continuously monitored. The test gearboxes are shown in the bench test facility in Figure 2. Following the successful completion of the bench test, both gearboxes were installed on NSH-3A aircraft 152105.

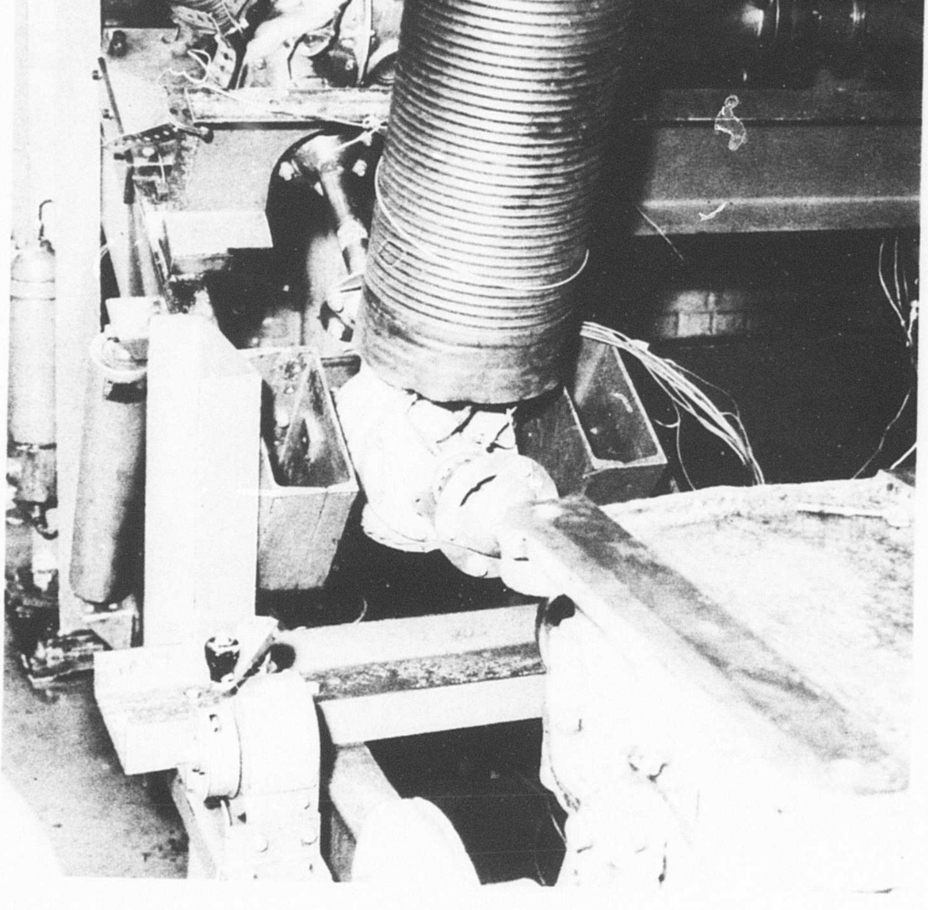


Figure 2. Modified H-3 Intermediate and Tail Gearboxes in Regenerative Bench Test Facility.

AIRCRAFT TIEDOWN TEST

The NSH-3A test aircraft was installed on the tiedown test pad and ballasted to a maximum gross weight of 19,100 pounds. The helicopter was restrained to the tiedown pad by means of cables, and the tail wheel was attached to a hydraulic accumulator. Instrumentation and communications systems were connected to, and monitored in, the control room.

INITIAL TESTS

Initial testing was conducted in order to check out drive train vibrational parameters. Installation of the main rotor blades was omitted in order to reduce rotor system inertia in the event that vibration levels necessitated a rapid stop of the drive system. The tail rotor blades were installed, but were operated at flat pitch since no reaction of main rotor torque was necessary.

The Number 1 engine was started and a normal rotor engagement was made. The drive system was run up to 100 percent speed, and vibration measurements were taken. In addition, all instrumentation was checked out, and a complete set of data was recorded at the 100 percent speed condition. A normal shutdown was then accomplished and the aircraft was inspected.

Overspeed testing was conducted in order to verify resonance-free operation of all shafting up to the autorotative redline speed of 117 percent. After stabilization at 100 percent speed, the drive system was slowly accelerated to the normal engine redline speed of 112.5 percent. The rotor system was then quickly accelerated to 117 percent and back to 112.5 percent, and vibration measurements were recorded. The data was examined to determine whether any resonances or excessive increases in vibration levels were present. Following this vibration survey, the main rotor blades were installed preparatory to testing of the drive system under power.

FIRST POWER RUNS

After installation of the main rotor blades, a 5-hour break-in test was conducted at the power spectrum shown in Table 4. All gearbox temperatures were continuously monitored, and data was recorded at the beginning and end of each power condition.

TABLE 4. 5-HOUR BREAK-IN POWER SPECTRUM

Time (hr)	Tail Rotor Power (hp)
1	Flat Pitch
1	100
1	250
1.5	350
0.5	375

ENDURANCE TEST

The 50-hour endurance test was conducted on the tiedown aircraft in five 10-hour cycles as shown in Table 5. The power spectrum is generally in accordance with specification MIL-T-8679. The takeoff, military, and normal ratings are based on the performance ratings of the experimental YT58-GE-16 engines at standard day, sea-level static conditions.

During the testing, the tail rotor directional controls were cycled to their extreme positions 15 times per hour in the normal rated power portion of the spectrum. In other portions of the test, the controls were held in either cruise or vertical ascent positions, depending on the power condition being run. The NSH-3A aircraft is shown in Figure 3 on the tiedown pad with the grease-lubricated intermediate and tail gearboxes as well as the roller gear main transmission installed.

TABLE 5. ENDURANCE TEST, 10-HOUR CYCLE

Test Condition (Per MIL-T-8679)	Time (hr)	Rotor Speed (%)	Tail Rotor Torque (%)	Note
Takeoff	1	100/Idle	63/Idle	1
Military	1	100	63/36	2
Normal Rating	3	100	63	3
90% Normal Rating	1	100	57	4
80% Normal Rating	1	100	50	4
60% Normal Rating	1	91	40	4
Overspeed	1	110	58	4
Single Engine	1	100	31	5

Notes:

1. "Takeoff" is a 1-hour period of alternate runs of 5 minutes at takeoff power and 5 minutes with both engines at ground idle after applying and releasing the rotor brake during the first minute of the idle run.
2. The "military power" test condition is a 1-hour period with the controls positioned for "vertical ascent: at military power for the first 30 minutes and with the controls held in "cruise position" at 60% normal rating for the remaining 30 minutes.
3. The "normal rating" test condition covers a 3-hour period. Fifteen times each hour the main rotor cyclic control and the directional controls are positioned and held for 10 seconds each at forward, aft, left, and right. Control deflections do not exceed those encountered in normal flight.
4. Continuous operations with controls held in "cruise" position.
5. Single-engine operation - 30 minutes each engine per 10-hour cycle.

Figure 3. NSH-3A Aircraft on Tiedown Pad.

DATA ACQUISITION

The following test data was recorded during the tiedown test for the grease-lubricated intermediate and tail gearboxes. All temperatures were continuously monitored by means of a strip chart recorder in the tiedown facility control room. Vibration measurements were taken periodically using both a direct-writing oscillograph and a frequency spectrum analyzer.

TEMPERATURES

The following gearbox bearing temperatures were continuously monitored by thermocouples attached to the bearing outer race:

Intermediate Gearbox

Input Outer Bearing
Input Inner Bearing
Output Inner Bearing
Output Outer Bearing

Tail Gearbox

Input Outer Bearing
Input Inner Bearing
Output Inner Bearing
Output Middle Bearing
Output Outer Bearing

VIBRATION OUTPUTS

The following gearbox vibration sources were periodically monitored:

Intermediate Gearbox

Input Housing

Tail Gearbox

Input Housing - Horizontal
Output Housing - Vertical

The tiedown facility control room operating and data monitoring consoles are shown in Figures 4 and 5.

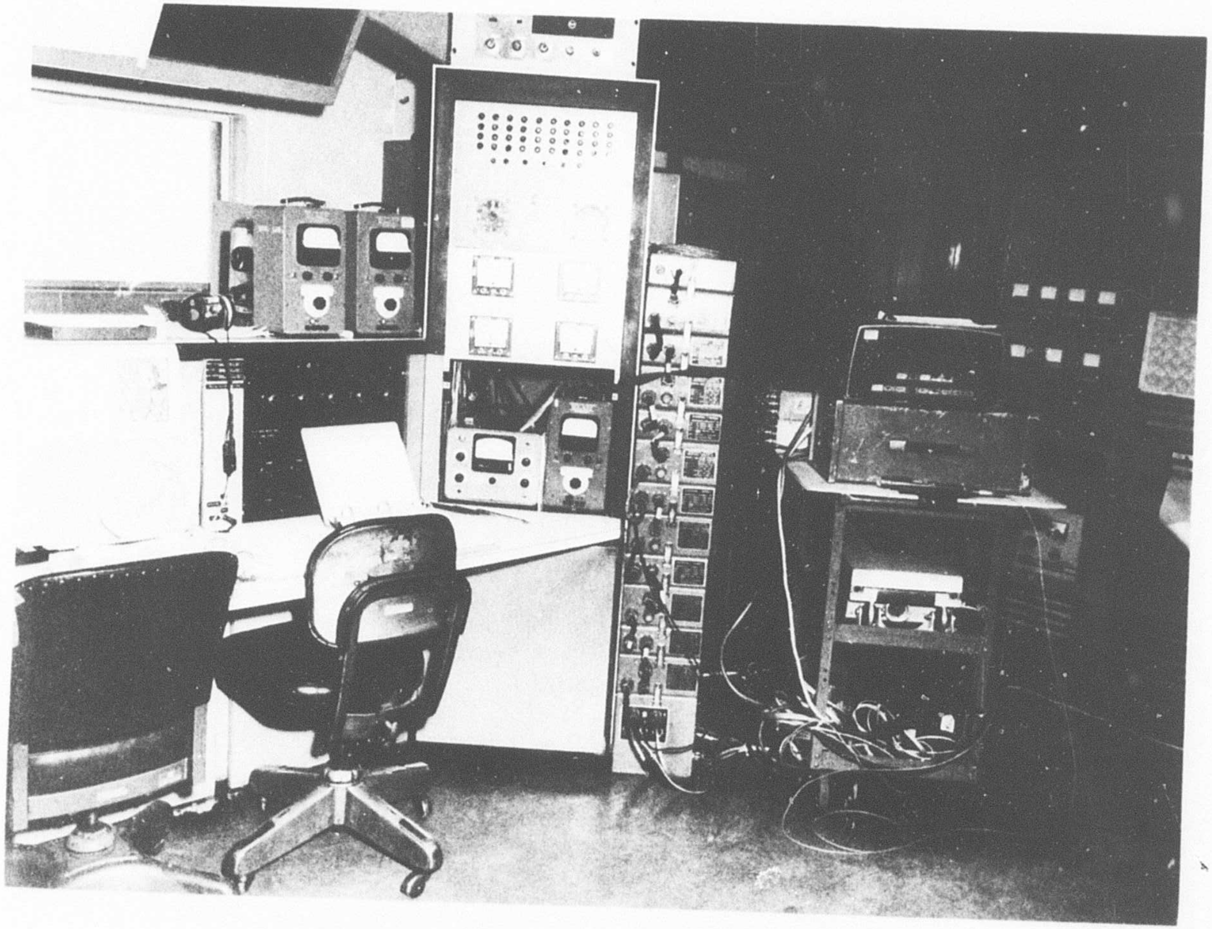


Figure 4. Tiedown Aircraft Control Room - Test Engineer's Console.

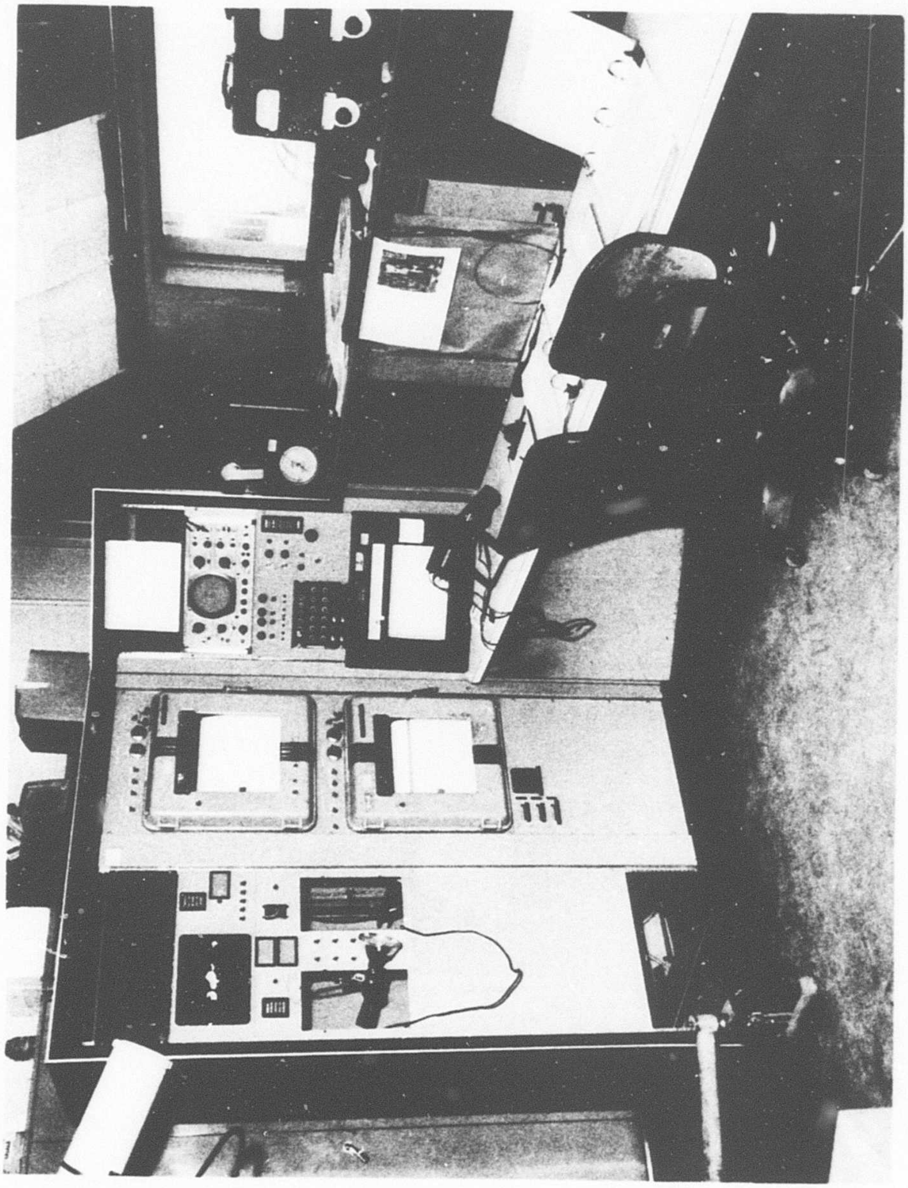


Figure 5. Tiedown Aircraft Control Room - Technician's Console.

BENCH AND TIEDOWN TEST RESULTS

Preparatory to tiedown testing, the grease-lubricated intermediate and tail gearboxes were subjected to a bench test consisting of a standard 1-hour acceptance test plus an additional 10 hours of operation. The bench test was conducted in the intermediate and tail gearbox regenerative test facility at the following power spectrum:

Power (hp)	Input Speed (%)	Input Speed (rpm)	Time (hr)
50	50	1695	0.5
200	100	3390	0.5
100	100	3390	8.5
250	100	3390	1.0
400	100	3390	0.25
0	100	3390	0.25

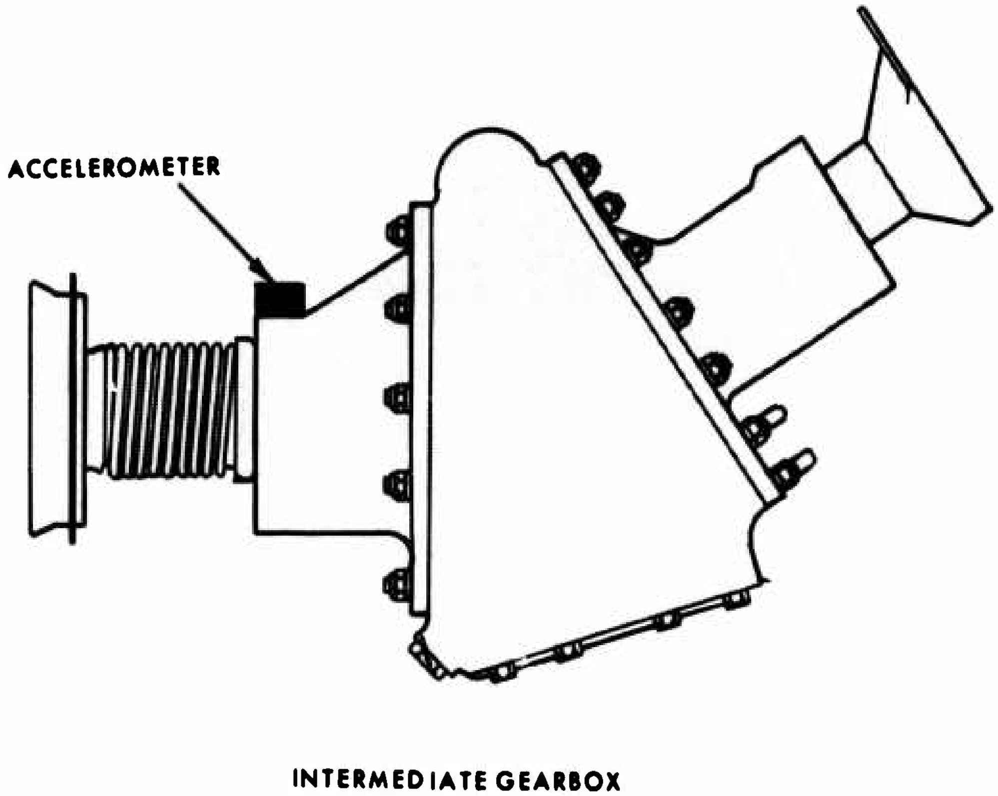
All gearbox bearing temperatures were continuously monitored throughout the test. The maximum allowable temperature at any bearing location was 120°C. This limit was established on the basis of the results of previous bench testing. Since the quantitative effect of the auxiliary cooling used in the bench test, but not in the tiedown test, were unknown, the normal temperature limitation for oil-lubricated gearboxes, 145°C, was chosen for the grease-lubricated gearboxes used in the tiedown test. In all but the 400-hp portion of the testing, all bearing temperatures were essentially stabilized at levels well below the 120°C limit. The bearing temperatures had not stabilized at the end of the short 400-hp test run, but were again below 120°C. The bearing temperatures at the lower power conditions are termed "essentially stabilized", since it appears to be a characteristic of grease-lubricated gearboxes that true temperature stabilization is never achieved. An irregular deviation in bearing temperature of approximately ±5°C is a normal occurrence with grease-lubricated gearboxes operating under steady-state conditions of load, speed, and ambient temperature. Oil-lubricated gearboxes operated under steady-state conditions will stabilize and remain stabilized. The maximum temperature reached during the bench testing was 97°C and occurred at the tail gearbox input inner bearing during the 400-hp portion of the test. This temperature was well below the acceptable (120°C) limit of the test. Typical stabilized bearing temperatures of the tail and intermediate gearboxes recorded during the 10-hour test are shown in Table 6. It can be seen that at each power condition, the hottest-running bearing is the input inner bearing of the tail gearbox. This is consistent with the results of all previous testing of grease-lubricated S-61 tail and intermediate gearboxes.

TABLE 6. TYPICAL STABILIZED BEARING TEMPERATURES		
	Bearing Temperature (°C)	
	@100hp	@250hp
Intermediate Gearbox		
Input Outer	74	75
Input Inner	73	71
Output Inner	58	56
Output Outer	72	63
Tail Gearbox		
Input Outer	71	68
Input Inner	81	88
Output Inner	56	81
Output Middle	32	38
Output Outer	43	46

Following the successful completion of the bench test, the grease-lubricated intermediate and tail gearboxes were installed on NSH-3A aircraft 152105. Also installed on this aircraft were an advanced roller gear drive main transmission and two experimental YT58-GE-16 engines. Instrumentation for the intermediate and tail gearboxes consisted of thermocouples on the outer race of all bearings, as previously used for the bench test, and a total of three vibration sensors. Vibration was measured on the tail gearbox by means of two accelerometers, one of which was mounted on the input housing and the other mounted on the output housing. One accelerometer was mounted on the input housing of the intermediate gearbox. The locations of these transducers are shown in Figure 6. The thermocouple outputs were continuously monitored throughout the test by means of a strip chart recorder. The accelerometer outputs were normally read on a direct-write oscillograph, and such readings were taken several times during the testing to determine any changes in the vibration signature. The vibration outputs also were recorded using a frequency spectrum analyzer during the course of tiedown testing.

The test conditions originally planned for the 50-hour tiedown test are presented in Table 7.

It was necessary to reduce certain of the higher power levels due to the influence of two factors. First, through most of the testing, the experimental YT58-GE-16 engines were not able to produce rated power due to hot-day performance degradation and the absence of any power margin. Second, the tail rotor torque necessary to effectively balance a given main rotor torque was apparently lower than that originally calculated. This may be at least partially due to yaw-restraining effects introduced



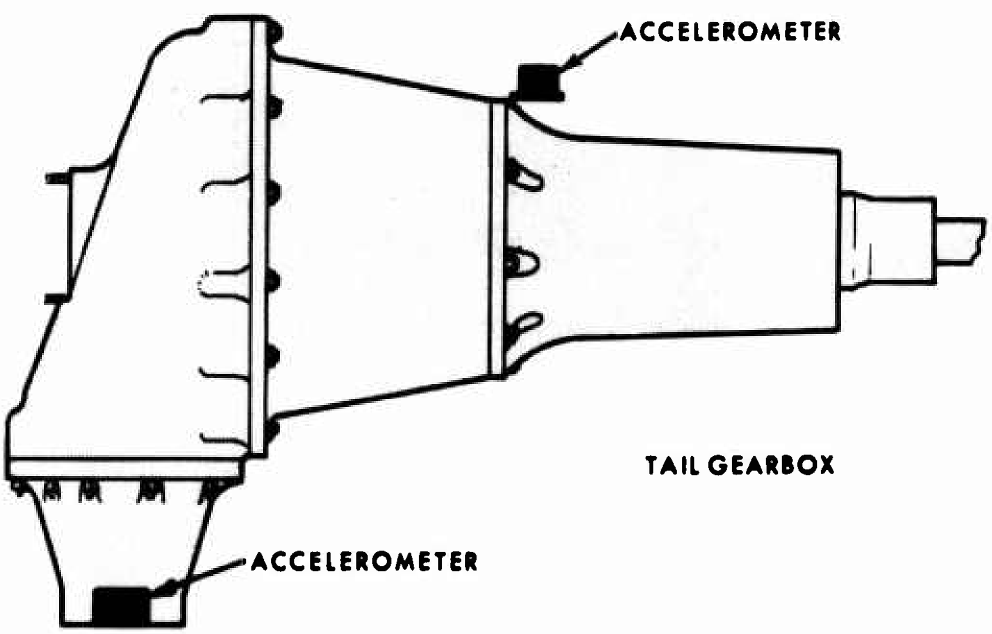


Figure 6. Test Gearbox Vibration Transducer Locations.

TABLE 7. PLANNED TEST CONDITION POWER LEVELS

Tail Rotor Torque (%)	Tail Rotor Power (hp)	Drivetrain Speed (%)	Time (hr)	Comments
100	565	100	0.5	Maximum
62	350	100	1.5	
44	250	100	1.0	
18	100	100	1.0	
7	40	100	1.0	
63	357	100	2.5	Endurance Limit
5	10	40	2.5	Ground Idle
63	357	100	2.0	Endurance Limit
36	204	100	2.5	
63	357	100	15.0	Endurance Limit
5.	322	100	4.0	
50	282	100	3.5	
40	204	91	4.0	Underspeed
57	357	110	4.0	Overspeed
32	175	100	2.5	
32	175	100	2.5	

by the main tiedown cables. The tail rotor power conditions under which the tiedown aircraft was actually operated are presented in Table 8. A total of 57.6 hours of operation was conducted as compared to the projected total test duration of 50 hours. At all power conditions, the gearbox bearing temperatures stabilized at levels well below the 145°C limit. The highest recorded temperature was 113°C and was experienced at the input inner bearing of the tail gearbox. The power spectrum actually experienced during the course of the tiedown test is presented in Table 9. This spectrum represents a substantial increase in mission prorated power over that of the standard H-3 helicopter. The gear tooth Hertz stress acceleration factor is estimated to be 6.37.

Following the tiedown test, the intermediate and tail gearboxes were completely disassembled. The inspection of the intermediate gearbox showed excellent condition of both gears and bearings. The tail gearbox exhibited similar results with one exception. Moderate scoring had been experienced on the tail gearbox spiral bevel gears. This scoring, while not typical of H-3 tail gearbox performance in production, is attributed to the high power levels, relative to prorated design, experienced during tiedown testing. The intermediate and tail gearbox components following tiedown testing are shown in Figures 7 through 12. The scoring evident on the tail gearbox gear teeth, while not typical in H-3 tail gearboxes, is similar in appearance to scoring which has been experienced on spiral bevel gears of other gearboxes such as the H-53 nose gearbox and the H-3 and H-54 main transmissions. As far as can be determined, scoring of this nature has in no case resulted in gear tooth fracture.

RECORDED TEMPERATURES

The monitored bearing temperatures for the various powers experienced during the course of tiedown testing are presented in Table 10. Each temperature is corrected for a 15°C standard day. None of the bearing temperatures exceeded the imposed limit of 145°C, and the highest recorded reading during the test was 113°C, on the input inner bearing of the tail gearbox. Each bearing temperature was observed to vary as much as ±5°C with time, a characteristic of grease-lubricated gearbox operation which has been noted in previous tests.

VIBRATION READINGS

A survey of the intermediate and tail gearbox vibration levels is presented in Table 11. The vibration levels at each location varied considerably during the course of the test. Since no significant amount of data on the vibration levels of intermediate and tail gearboxes had been accumulated in previous testing, no meaningful conclusions can be drawn from the recorded test data. However, it is believed that vibration monitoring should be seriously considered as a failure detection method in lieu of the presently used chip detectors. Both the intermediate and tail gearbox vibration outputs were subjected to a frequency spectrum analysis. This was conducted on the intermediate gearbox at 3 hours and 42 hours of test time and on the tail gearbox at 34 hours and 37 hours.

TABLE 8. ACTUAL TEST CONDITION POWER LEVELS

Tail Rotor Torque (%)	Tail Rotor Power (hp)	Drive Train Speed (%)	Time (hr)	Comments
55-60	311-339	100	0.5	
55-62	311-350	100	1.6	
36-48	203-271	100	1.3	
17-18	96-102	100	1.7	
7	40	100	4.8	Flat Pitch
45-65	254-367	100	2.5	
5	10	40	2.5	
51-60	288-339	100	2.1	
35-41	198-232	100	2.7	
47-60	266-339	100	14.9	
49-58	277-328	100	3.9	
47-62	266-350	100	3.5	
35-41	180-218	91-100	4.0	Underspeed
38-55	232-342	108-110	4.0	Overspeed
28-32	159-181	100	2.6	
27-31	153-175	100	2.7	
5	10	40	2.3	Ground Idle

TABLE 9. ACTUAL POWER SPECTRUM

Tail Rotor Torque (%)	Tail Rotor Power (hp)	Drive Train Speed (%)	Time (hr)	Test Condition
60	339	100	0.2	Dual Engine
52-60	294-339	100	1.2	Dual Engine
45-65	254-367	100	4.9	Dual Engine
50-60	283-339	100	8.6	Dual Engine
51-57	289-322	100	10.6	Dual Engine
47-62	266-351	100	3.7	Dual Engine
36-48	204-272	100	1.6	Dual Engine
35-37	198-209	100	2.2	Dual Engine
30	170	100	0.2	Dual Engine
17-18	96-104	100	1.5	Dual Engine
7	40	100	4.8	Dual Engine, Flat Pitch
5	10	40	4.8	Dual Engine, Ground Idle
38-55	232-342	108-110	4.0	Dual Engine, Overspeed
35-41	180-218	91- 94	4.0	Dual Engine, Underspeed
28-32	159-181	100	2.6	Single Engine, No. 1
27-31	153-175	100	2.7	Single Engine, No. 2

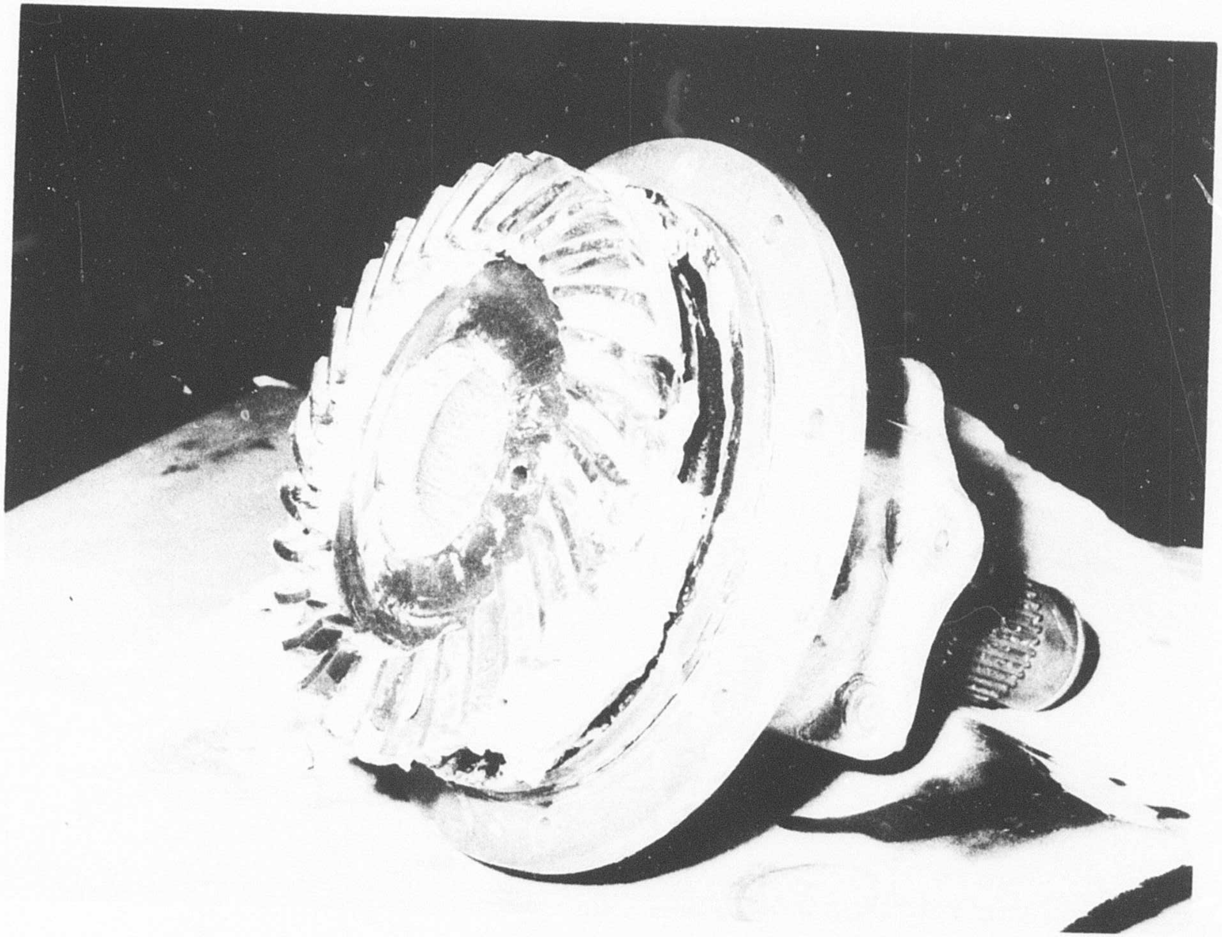


Figure 7. Intermediate Gearbox Input Section Following Tiedown Testing.

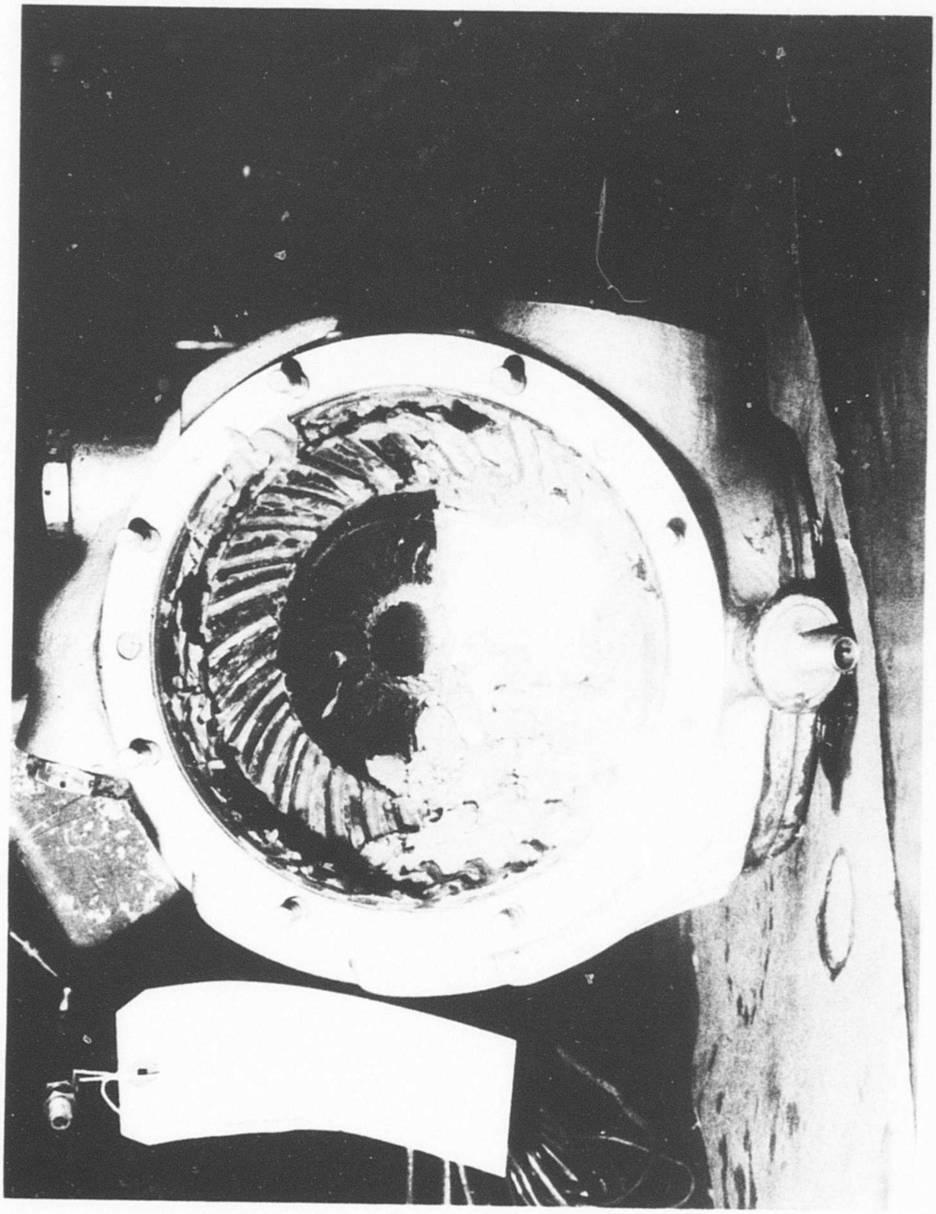


Figure 8. H-3 Intermediate Gearbox Following Tiedown Testing.

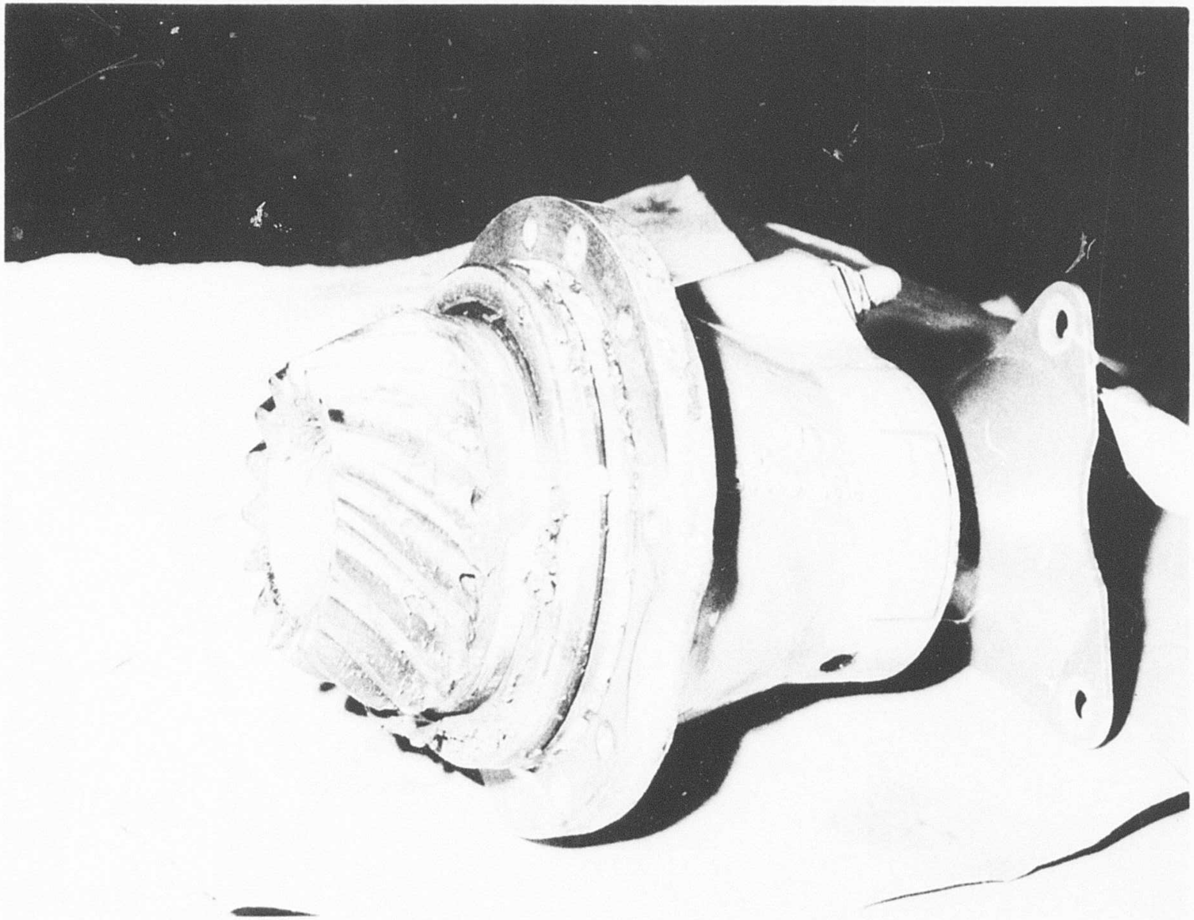


Figure 9. Tail Gearbox Input Section Following Tiedown Testing.

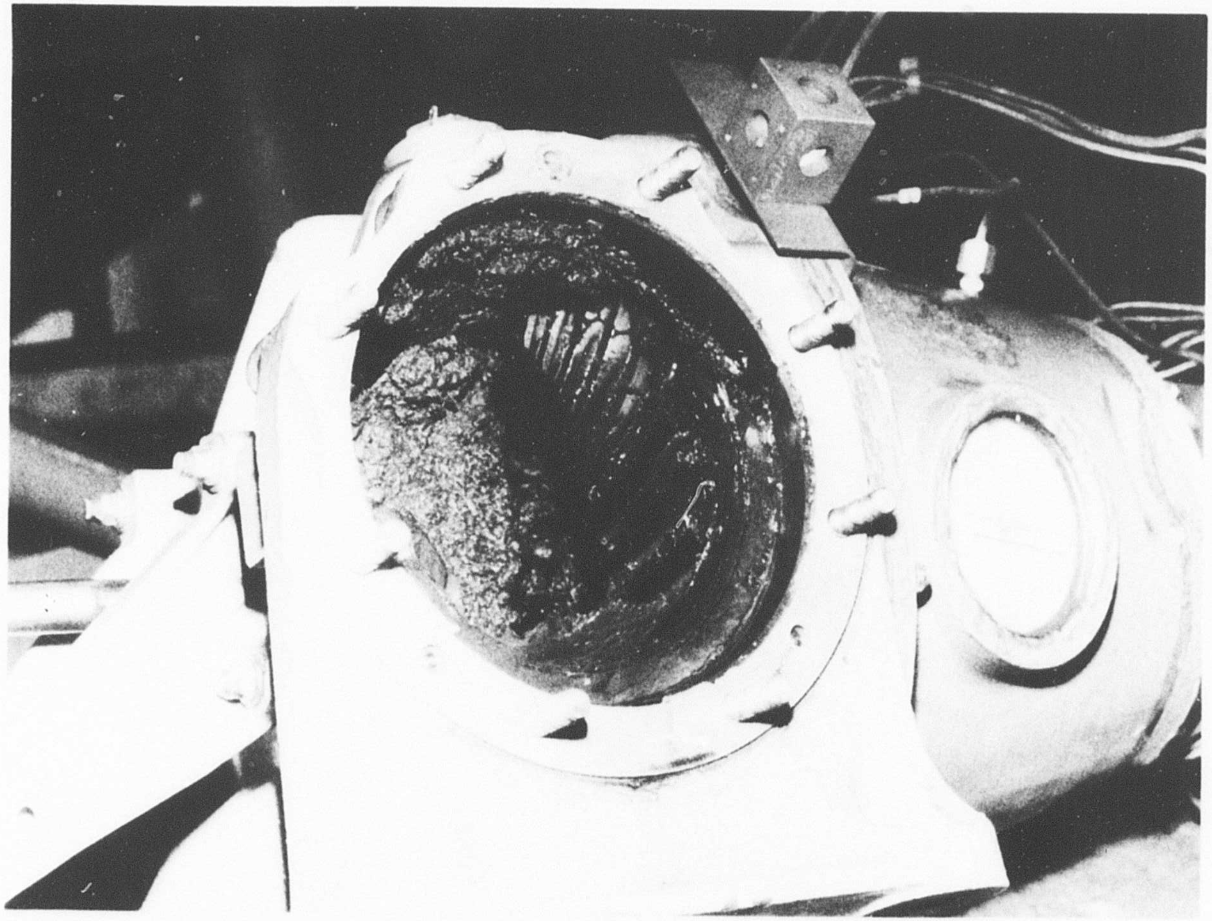


Figure 10. H-3 Tail Gearbox Following Tiedown Testing.

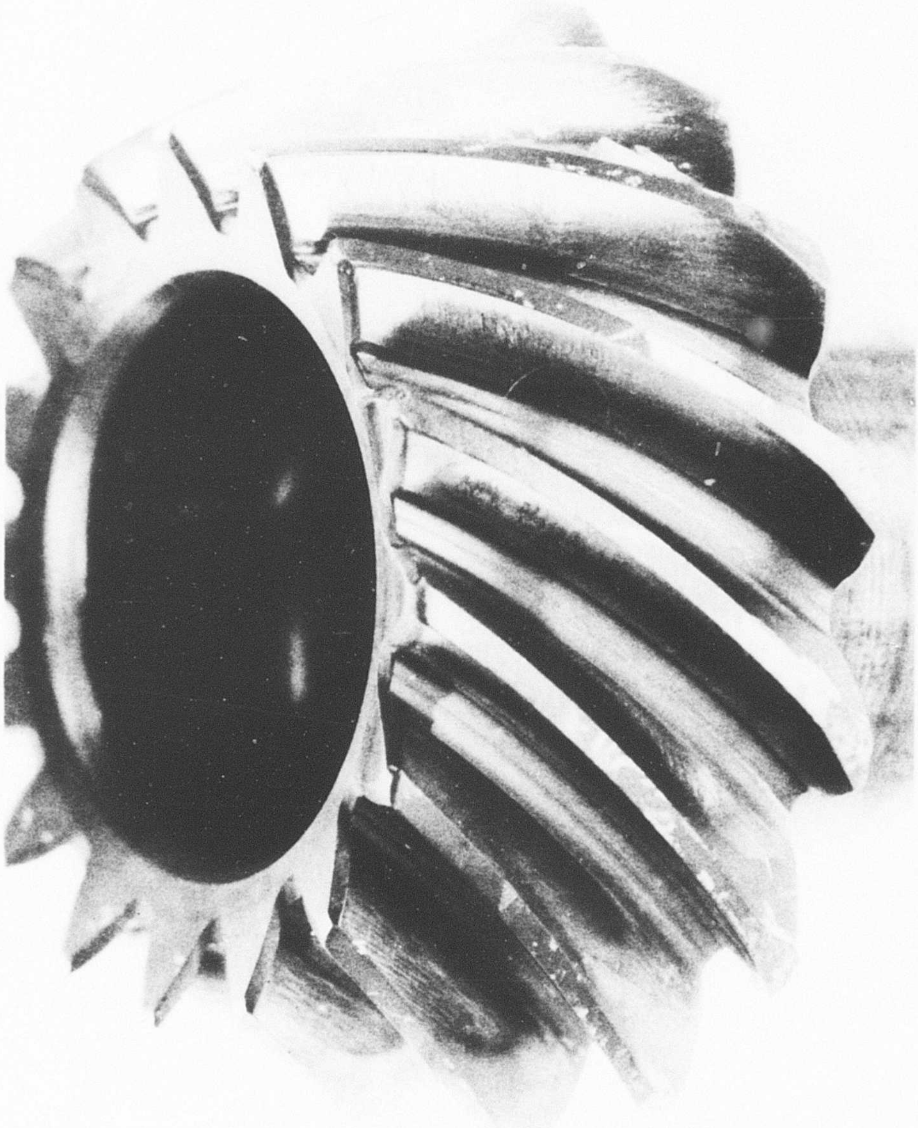


Figure 11. Tail Gearbox Input Gear Following Tiedown Test - After Cleaning.

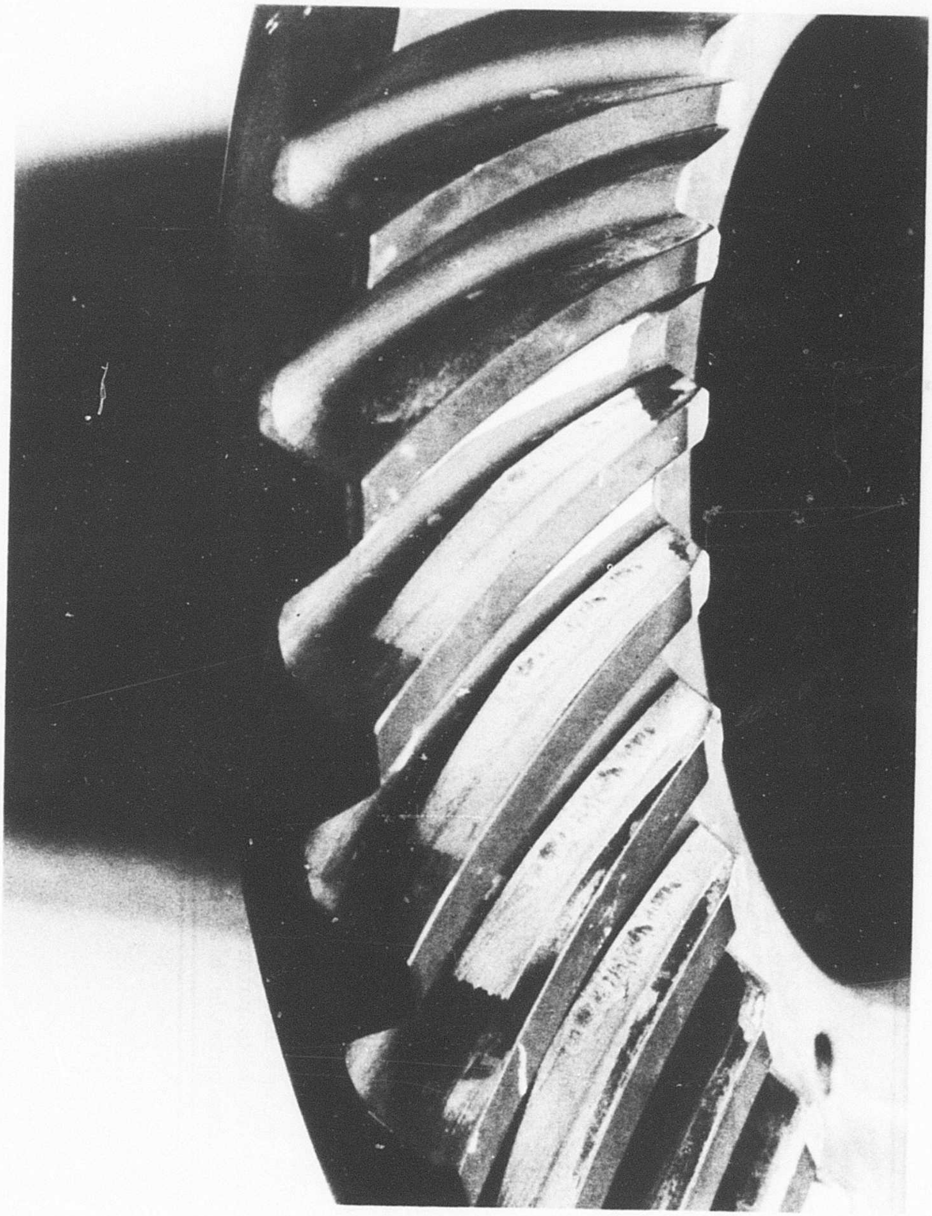


Figure 12. Tail Gearbox Output Gear Following Tiedown Test - After Cleaning.

TABLE 10. INTERMEDIATE AND TAIL GEARBOX BEARING TEMPERATURES

Bearing	Test Condition				
	60% NRP* (180-218 hp)	80% NRP* (266-355 hp)	100% NRP* (266-339 hp)	Over-Speed (232-342 hp)	Maximum Recorded
Tail Gearbox					
Input Outer	60	63	74	86	100
Input Inner	80	82	87	96	113
Output Outer	18	20	25	20	40
Output Middle	26	30	56	42	76
Output Inner	62	66	79	76	109
Intermediate Gearbox					
Input Outer	40	46	46	54	78
Input Inner	38	50	51	63	85
Output Outer	21	26	54	48	75
Output Inner	31	38	49	44	85

NOTES:
1. Table entries are temperatures in ^{o}C.
2. All values except "maximum recorded" are corrected to a 15^{o}C standard day.
3. Redline temperature, 145^{o}C.
4. Maximum outside air temperature, 33^{o}C.

*Normal Rated Power

TABLE 11. INTERMEDIATE AND TAIL GEARBOX VIBRATION SURVEY

Vibration Parameter	Intermediate Gearbox Input	Tail Gearbox Input	Tail Gearbox Output
Maximum Level (g)	2.5-3.0	1.0-4.5	0.8-2.0
Frequency (cps)	550	300	600
Maximum Level (g)	2.5	1.0	0.7
Frequency (cps)	54	20	22

NOTE:
When the measured vibration signal is composed of more than one frequency component, the amplitude and frequency of each component are listed.

Plots of the frequency spectra are shown in Figures 13 through 16. It is seen that a change in both the amplitude and nature of the vibration occurred during the course of the test. This change was also noted on oscillograph traces as a change in waveform. The general vibration levels showed an increase for the intermediate gearbox with test time. This could indicate a possible component deterioration if vibration monitoring were to be used as an indication of component condition. However, no detectable deterioration of the intermediate gearbox occurred. Based on these observations and the general lack of a vibration data base for these gearboxes, it is apparent that a considerable amount of work needs to be performed before vibration monitoring can be considered a viable solution to grease-lubricated gearbox failure detection.

GEARBOX INSPECTION

As previously noted, aside from the scoring experienced in the tail gearbox, no significant deterioration of the gearbox components could be detected. The grease in the tail gearbox showed a slight darkening in color, but the consistency of the grease was apparently unchanged. No comparable color change was seen in the intermediate gearbox grease. An investigation by the U. S. Air Force Materials Laboratory has determined that the darkening in color of the grease is largely the result of exposure to heat and mechanical working. The color change of the grease is not considered to indicate any degradation of its lubrication characteristics. As opposed to the slight scoring found on the tail gear-

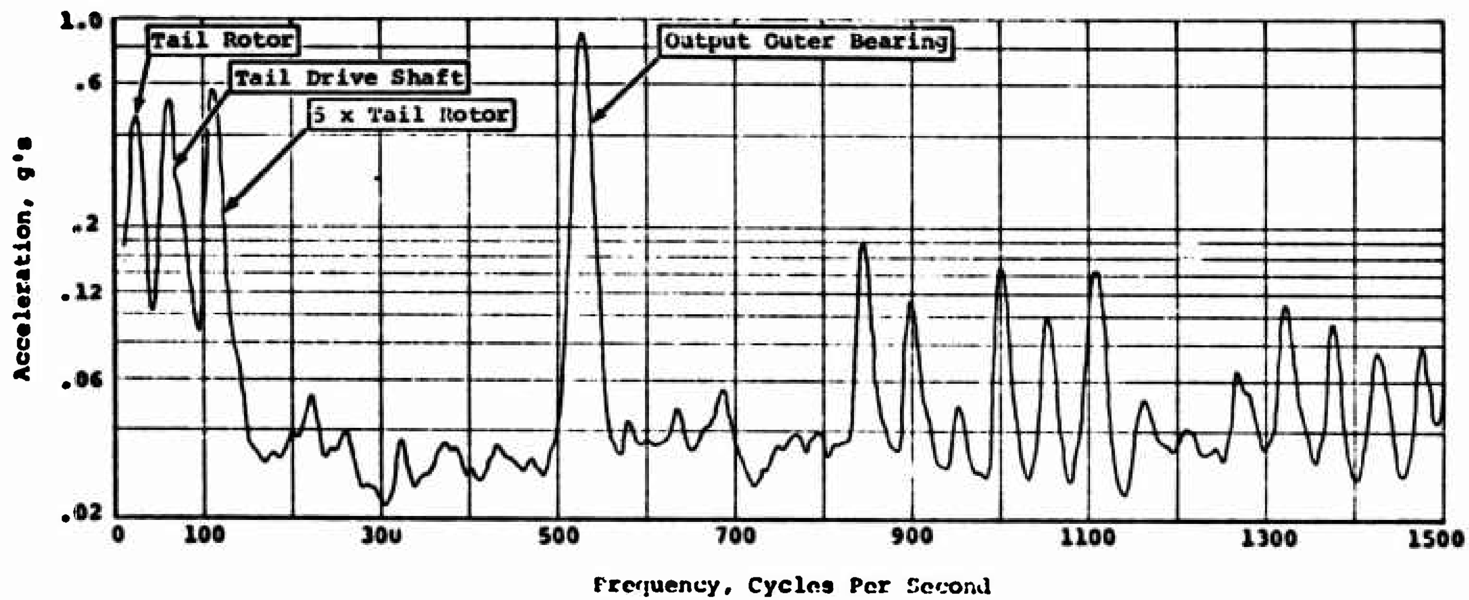


Figure 13. Intermediate Gearbox Vibration Spectrum After 3 Hours of Tiedown Testing.

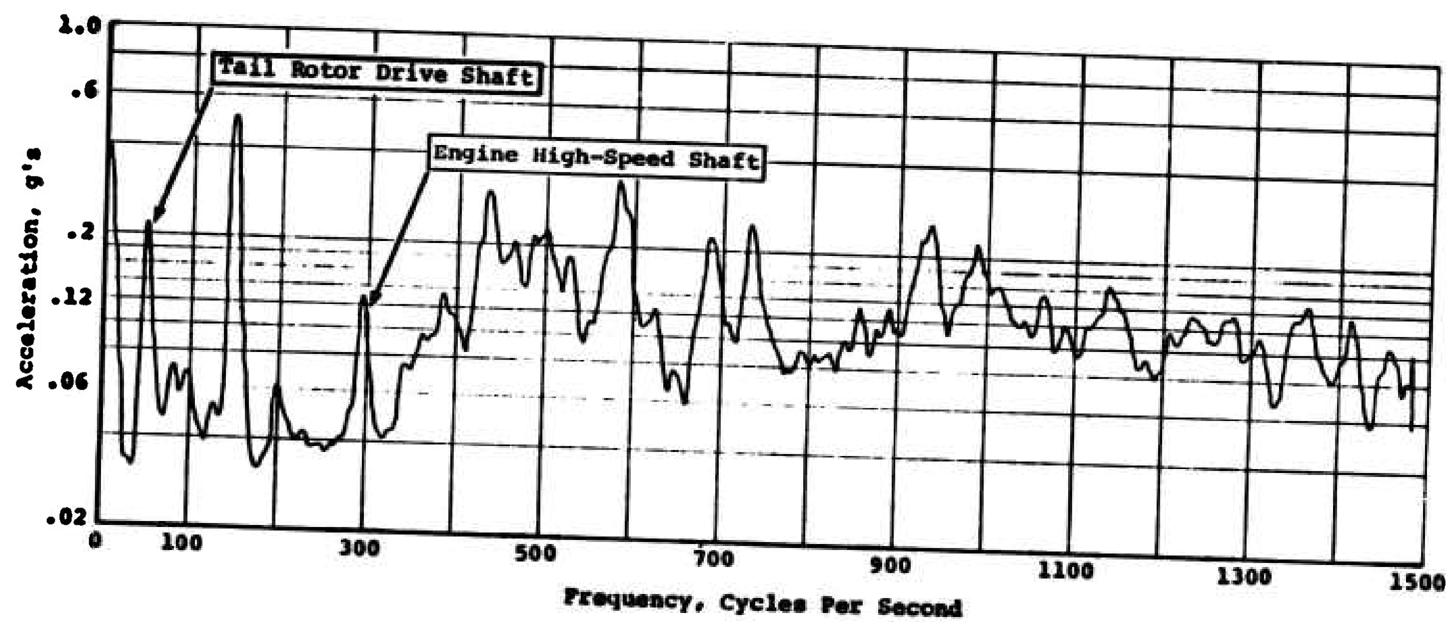


Figure 14. Intermediate Gearbox Vibration Spectrum After 42 Hours of Tiedown Testing.

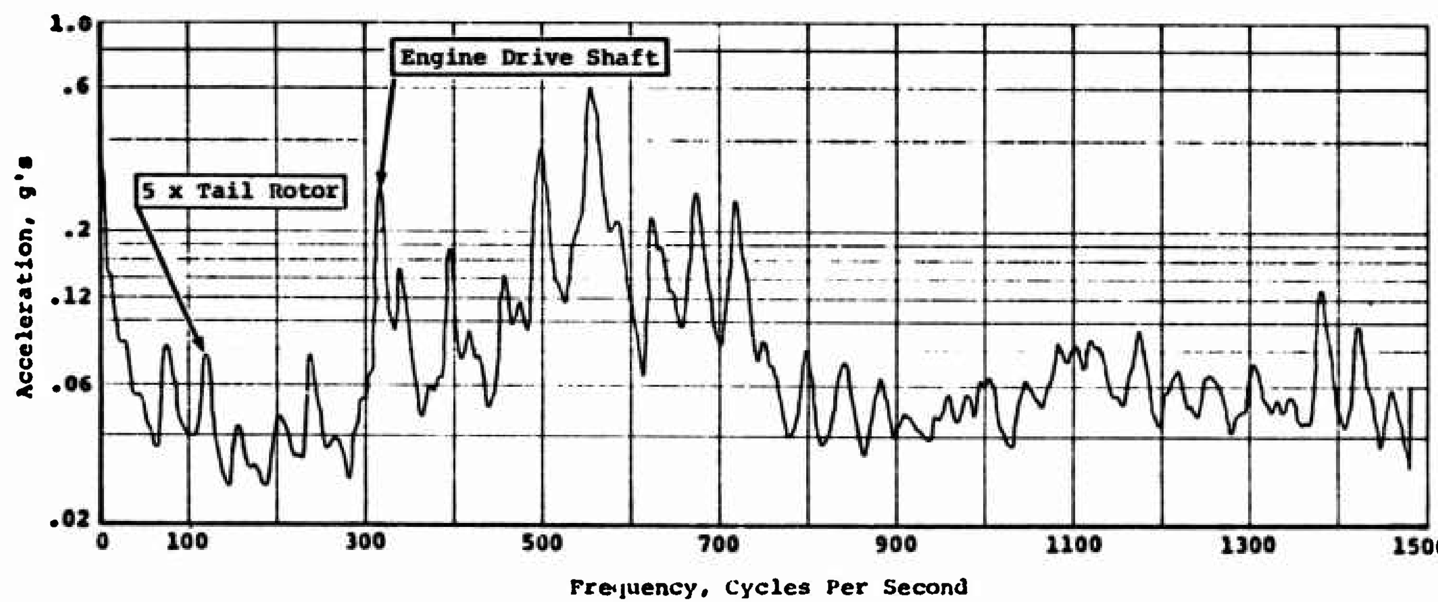


Figure 15. Tail Gearbox Input Vibration Spectrum After 34 Hours of Tiedown Testing.

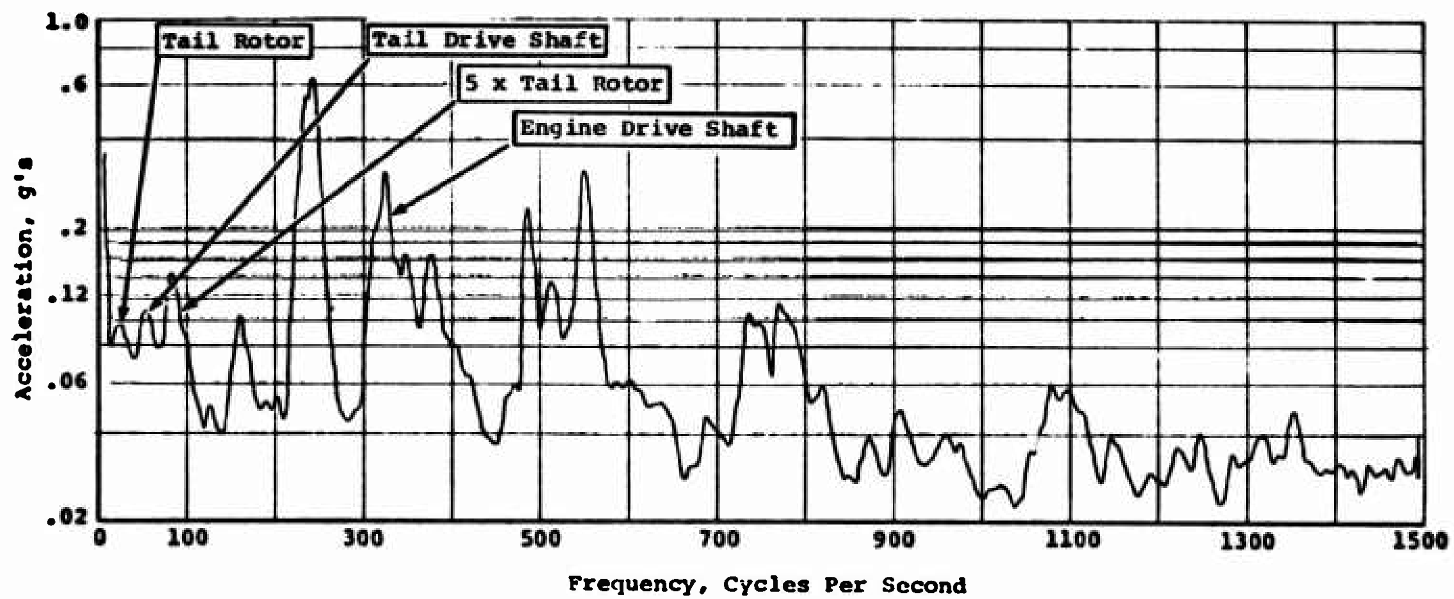


Figure 16. Tail Gearbox Output Vibration Spectrum
After 37 Hours of Tiedown Testing.

box gear teeth, the gear teeth of the intermediate gearbox had a smooth, highly polished appearance with no evidence of surface distress.

In order to determine whether the scoring of the tail gearbox gear teeth could have been seriously detrimental to aircraft operation, both the input and output gear shafts were magnetic particle inspected following the visual inspection. The magnetic inspection revealed no indication of the formation of any cracks.

The pitch control roller bearing in the tail gearbox showed some lubricant stains, but no surface distress was detected. Finally, the seals in both gearboxes were examined and were seen to be in excellent condition with no detectable wear or elastomer deterioration.

GEAR SCORING TESTS

Following the completion of the tiedown testing, a decision was made to investigate the gear scoring phenomenon which had been experienced in the tail gearbox. The tail gearbox bevel gears were both reground to remove all traces of scoring. Subsequent to the regrind, inspection revealed that the output bevel gear teeth had suffered slight metallurgical damage during the grinding procedure. This gear was therefore scrapped and replaced with a new gear. The tail and intermediate gearboxes used in the tiedown testing were reassembled with a fresh quantity of MIL-G-83363 grease lubricant. No replacement of parts was necessary for the intermediate gearbox. The tail gearbox had the new output gear as well as two new bearing shields to replace shields which had been damaged during disassembly.

The intermediate and tail gearboxes were then installed in the regenerative bench test facility. Step-load testing was conducted at the following power levels and test times:

Power (hp)	Test Time (hr)
200	4
200	20
250	4
250	20
300	4
100	4

After the initial 4-hour run at 200 hp, the tail gearbox was disassembled and inspected. The gear teeth were found to have a smooth, highly polished appearance with no evidence of scoring. The gearbox was then reassembled and an additional 20 hours of testing was conducted at the 200-hp power level. Inspection following this test run showed no change in the appearance of the gear teeth. Operation at the 250-hp level was then begun. After 4 hours of operation, the gear teeth showed evidence of very slight initial scoring. An additional 20 hours of testing was conducted at 250 hp. After this 20-hour run, the gear teeth showed a scoring condition which, while still considered to be slight, was noticeably more severe than that evidenced after the 4-hour run. The condition of the gear teeth following the 20-hour test is shown in Figure 17. It should be noted that the scoring at this point was evenly distributed across the gear tooth contact pattern. The power level was then increased to 300 hp, and the test gearboxes were operated for 4 hours at this condition. This was followed by a disassembly inspection that revealed that the gear tooth scoring had progressed in severity. The condition of the gear teeth is shown in Figure 18. It can be seen that the overall scoring was somewhat heavier than it was prior to the 250-hp test run. In addition, a narrow band of more severe scoring was present in the center of each gear tooth face. This is typical of scoring resulting from heavy loads since the pattern of the spiral bevel gear teeth was developed for maximum contact stresses in the center of the tooth face. All of the scoring experienced on the tail gearbox gear teeth occurred during the recess action of the gear teeth. This is apparent since the scoring is present only in the addendum of the pinion and the dedendum of the driven gear. This may be at least partially due to the fact that the sliding velocity in recess action is significantly greater than that in approach for this gear set. The sliding velocity at the final point of contact is 1403 ft/min as compared to 775 ft/min at the initial point of contact. The higher sliding velocity would tend to generate greater instantaneous temperature increases in the recess portions of the gear mesh and hence would have a greater adverse effect on the lubricant film.

Following the testing through the 300-hp power level, a decision was made to run at a lower power to determine whether this would have any healing effect on the gear tooth surfaces. The tail gearbox was reassembled and operated at 100 hp for 4 hours. Inspection at the end of this test run showed no detectable change in the condition of the gear teeth. The previously experienced scoring was still present, and no noticeable healing had taken place. The input pinion gear teeth are shown following the low-power run in Figure 19.

At the conclusion of all the scoring tests, the intermediate gearbox was disassembled and inspected. The gear teeth showed slight evidence of initial scoring in the central portion of the tooth. This was the first time in all of the testing performed to date that scoring had appeared in the grease-lubricated H-3 intermediate gearbox and is at this point unexplained. The grease in the intermediate gearbox had a smooth consistency with a slight darkening and showed no evidence of physical degradation. The gearbox input and output sections are shown in Figures 20 and 21.

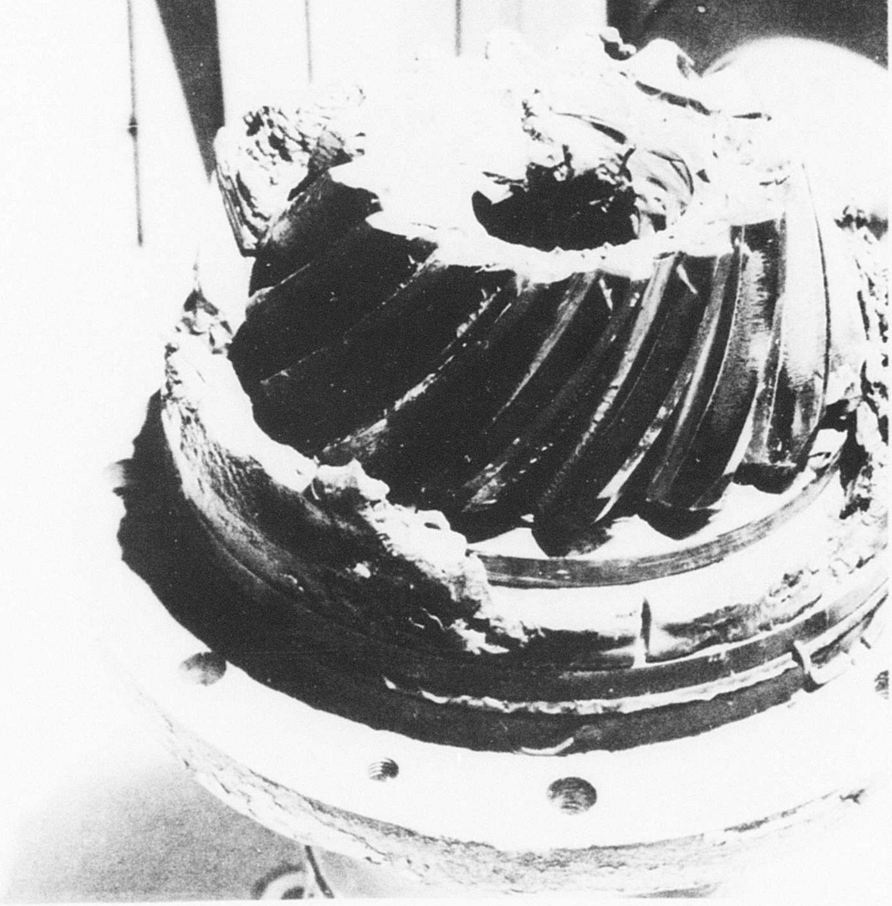


Figure 17. Tail Gearbox Input Gear After 24 Hours of Operation at 250 hp.

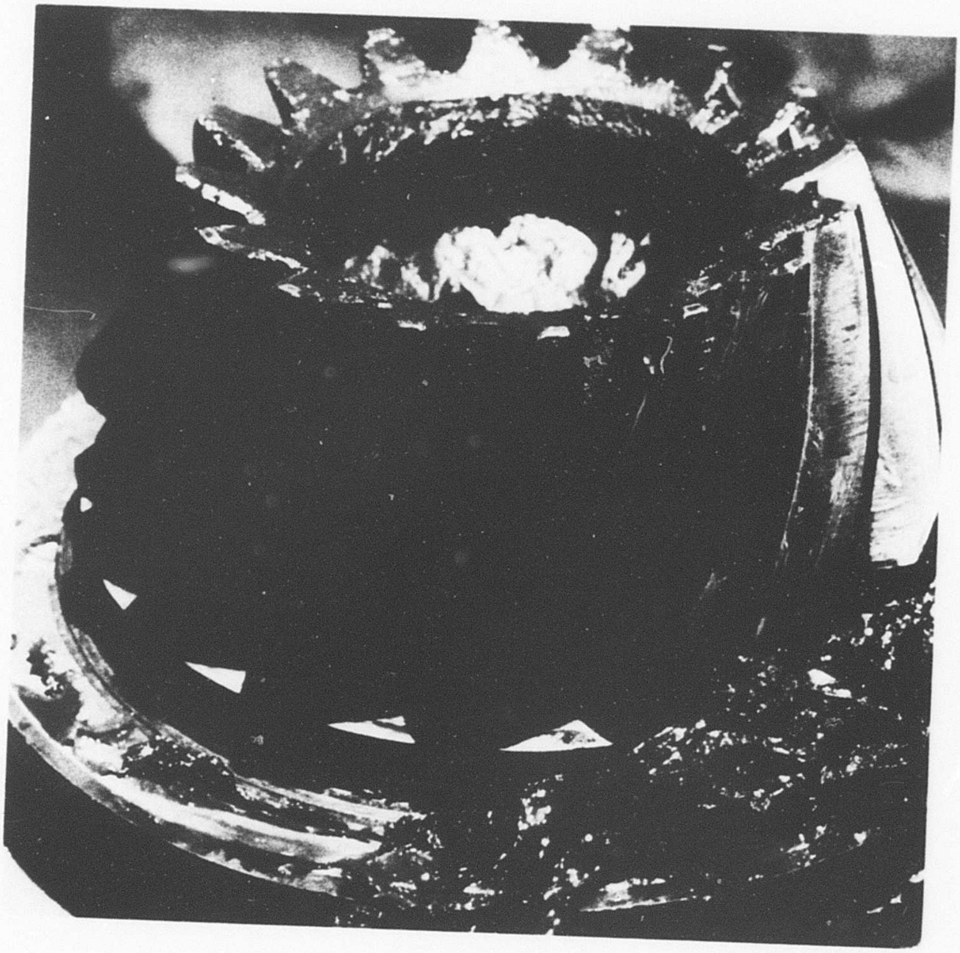


Figure 18. Tail Gearbox Input Gear After 4 Hours
of Operation at 300 hp.

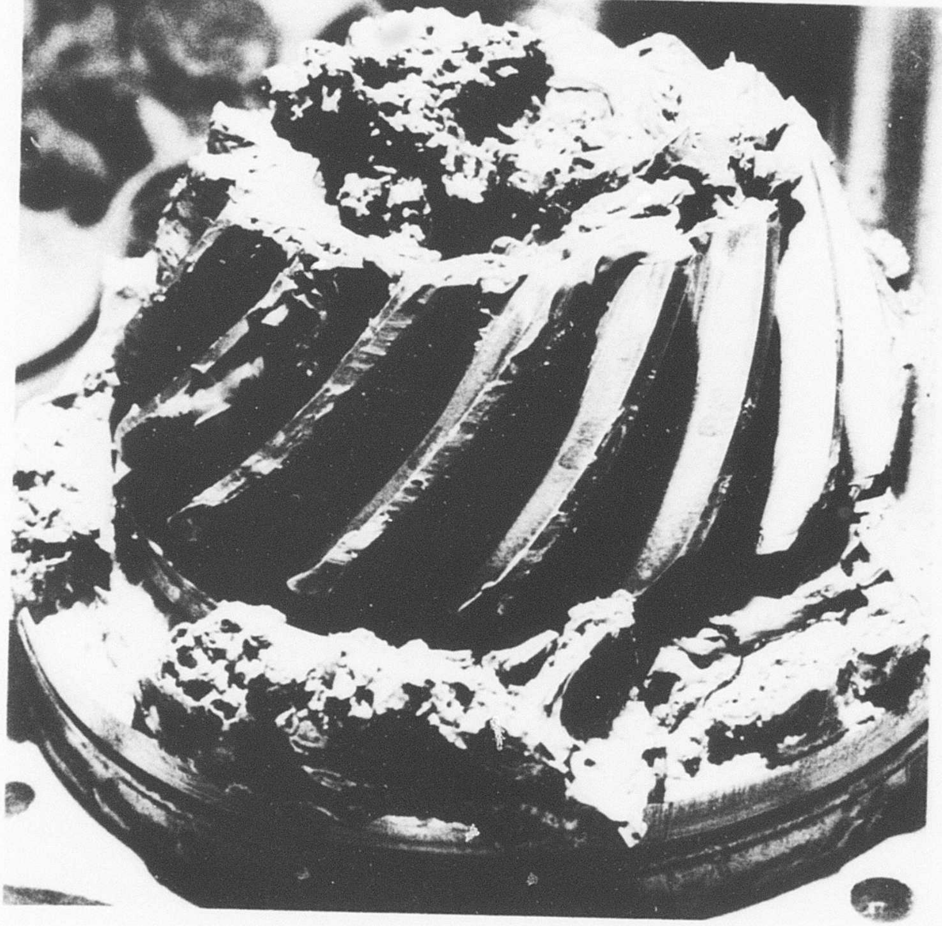


Figure 19. Tail Gearbox Input Gear After 4 Hours of Operation at 100 hps.

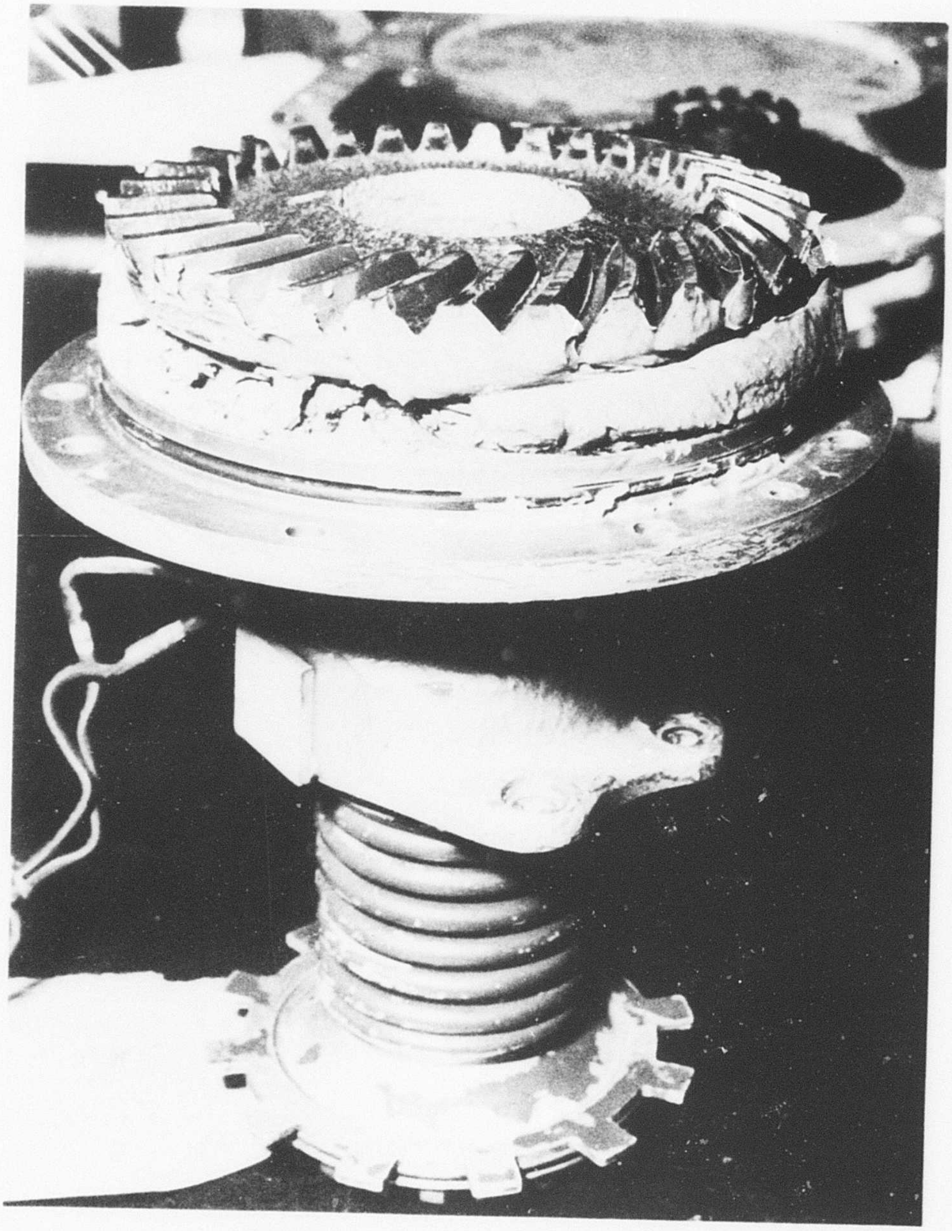


Figure 20. Intermediate Gearbox Input
Gear Following Scoring Tests

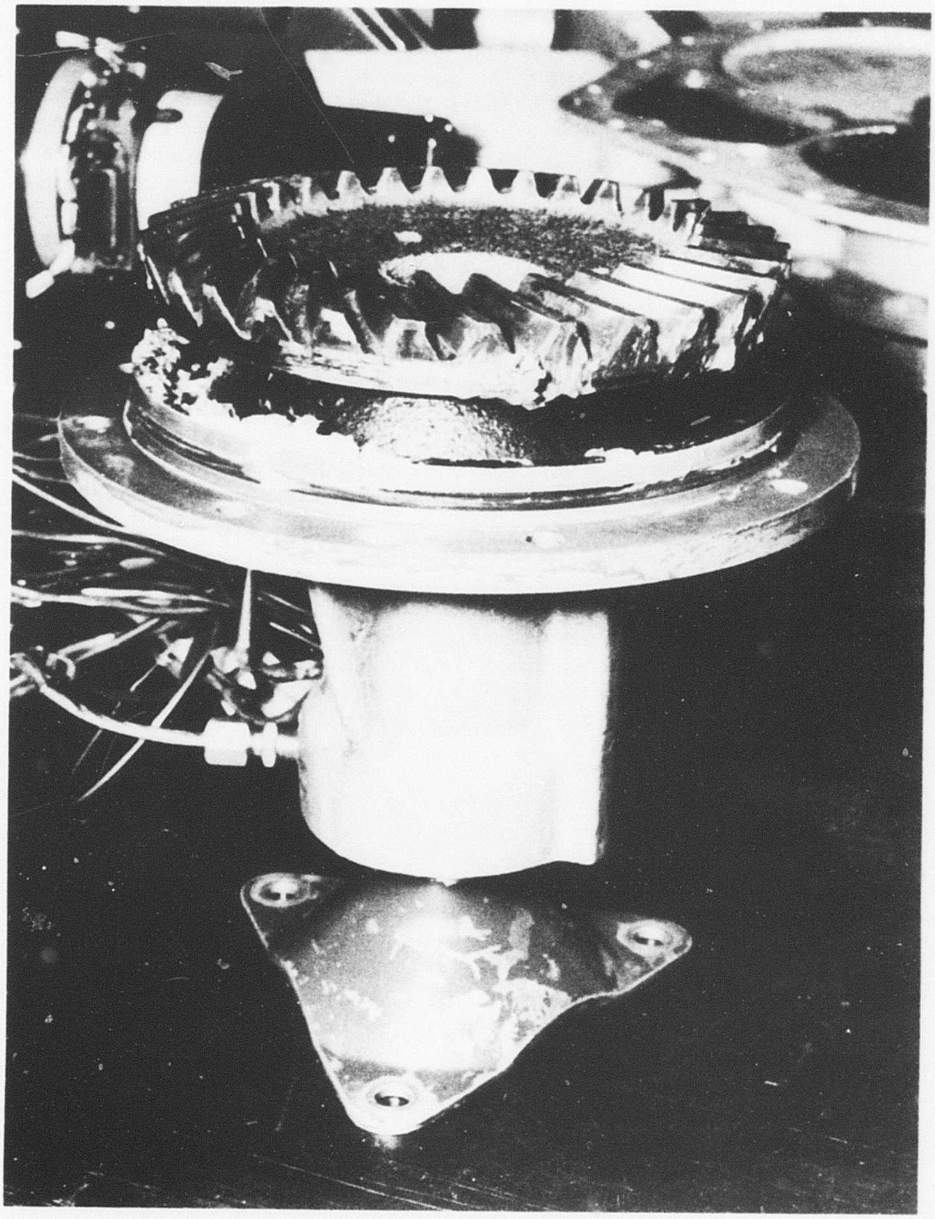


Figure 21. Intermediate Gearbox Output Gear
Following Scoring Tests

CONCLUSIONS AND RECOMMENDATIONS

This program was conducted to demonstrate the capability and performance of H-3 helicopter intermediate and tail gearboxes operating with grease lubrication. Both bench tests and tiedown aircraft tests were conducted. Finally, additional bench testing was conducted in order to further investigate the gear scoring phenomenon encountered during tiedown testing.

The results of the initial bench testing demonstrate that the grease-lubricated H-3 (S-61) intermediate and tail gearboxes are capable of satisfactory operation at power levels up to 400 hp. The 50-hour tiedown test demonstrated for the first time satisfactory grease-lubricated gearbox operation on an actual aircraft. Both the intermediate and tail gearboxes operated with no malfunctions at power levels significantly higher than those normally encountered in an H-3 aircraft mission. No lubricant leakage was experienced, nor was any scheduled or unscheduled maintenance required throughout the test. All gearbox operating temperatures remained below the limit of 145°C, which is the normal limit for these gearboxes operating with the standard oil lubrication system.

The scoring experienced on the tail gearbox gear teeth is not typical of field experience with the H-3 tail gearbox. It is attributable, at least in part, to the high power spectrum experienced during the tiedown testing. In addition, the nonflowing grease lubricant may not remove heat from the gear mesh areas as efficiently as an oil, thus resulting in higher instantaneous gear tooth face temperatures. The scoring experienced was no more severe than has been seen in certain other helicopter gearbox spiral bevel gear applications. In no case has scoring of this nature resulted in gear tooth fracture. The onset of scoring at 250 hp in the scoring bench tests may be a result of operation at a constant power level rather than the cycled power conditions normally encountered in aircraft flight operations. In an actual H-3 aircraft mission, a power level of 250 hp would be experienced for only a few minutes at a time, rather than the 4-hour test time used for the scoring tests. It is believed that such an extended period of constant power operation can contribute substantially to the gear tooth surface breakdown, although it is not possible to verify this contention with the data presently available.

It is concluded that the H-3 intermediate and tail gearboxes would benefit significantly in the areas of survivability and maintainability through the utilization of grease lubrication. It is therefore recommended that grease lubrication be strongly considered for future helicopter gearboxes having size and power levels similar to, or smaller than, those of the H-3. In view of the aforementioned advantages, Sikorsky Aircraft has utilized grease-lubricated intermediate and tail gearboxes in its prototype YUH-60A (UTTAS) helicopter.

It is further recommended that additional evaluations be conducted in the area of gear tooth scoring. Determinations should be made of the factors affecting the onset of scoring, with particular emphasis on the relative effects of constant power levels and cycled power levels. Finally, it is recommended that vibration monitoring be seriously pursued as a failure detection method for grease-lubricated gearboxes.