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TRANSMISSION THERMAL MAPPING (UH-1 MAIN ROTOR TRANSMISSION)

J. H. Drennan, et al

Bell Helicopter Company

Prepared for:

Army Air Mobility Research and Development Laboratory

December 1973

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EUSTIS DIRECTORATE
FORT EUSTIS, VIRGINIA 23604

This report was prepared by the Bell Helicopter Company under the terms of Contract DAAJ02-72-C-0072. It represents a step in a continuing program to obtain a self-contained helicopter transmission.

The single, most vulnerable part of a helicopter drive system in combat is the lubrication and cooling system. Interruption of the oil supply to the transmission dictates an immediate power-off descent and landing. The overall objective is to reduce or eliminate oil cooling and lubrication components situated remotely from the transmission. The immediate objective of this program was to determine the complete thermal map of all main components of an instrumented UH-1 main rotor transmission under varying torques and oil-out temperatures, keeping the speed constant. Thermal growth of the casing was also measured.

This report has been reviewed by this Directorate and is considered to be technically sound. The technical monitor for this contract was Mr. E. R. Givens, Technical Applications Division.

Task 1G162207AA7201
Contract DAAJ02-72-C-0081
USAAMRDL Technical Report 73-90
December 1973

TRANSMISSION THERMAL MAPPING
(UH-1 Main Rotor Transmission)

Final Report

BHC 299-099-652

By

J. H. Drennan
R. D. Walker

Prepared by

Bell Helicopter Company
Fort Worth, Texas

for

EUSTIS DIRECTORATE
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13. ABSTRACT

This report contains the results of a series of tests conducted to obtain thermal maps of a UH-1 main rotor transmission. The tests were conducted at several torque levels and several stabilized oil-out temperatures. Also, the thermal growth of the transmission cases at selected locations was measured and recorded. The general conclusions of this report are summarized as follows: (1) the major heat generating area was the input spiral bevel pinion and its related bearings; (2) thermal stability could not be attained at full bypass of the oil cooler at 60% torque; (3) thermal gradients indicate that the transmission output mast may be efficiently utilized as a heat sink by pressure wetting the surface.

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Thermocouples						
Thermal Plaques						
Gears						
Bearings						
Infrared Camera						
Lubricant Temperatures						
Heat Sinks						

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SUMMARY

This report contains the results of a series of tests conducted to obtain thermal maps of a UH-1 main rotor transmission. The tests were conducted at several torque levels and several stabilized oil-out temperatures. Also, the thermal growth of the transmission cases at selected locations was measured and recorded.

The general conclusions of this report are summarized as follows:

1. The major heat generating area was the input spiral bevel pinion and its related bearings.
2. Thermal stability could not be attained at full bypass of the oil cooler at 60% torque.
3. Thermal gradients indicate that the transmission output mast may be efficiently utilized as a heat sink by pressure wetting the surface.

FOREWORD

This report presents the results of an experimental bench test program conducted to determine operating temperatures of the main components and to complete a thermal map of a UH-1 main rotor transmission under various loads and outlet oil temperatures.

The program was conducted during the period July 1972 through February 1973 for the Eustis Directorate, U. S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia.

Technical direction was provided by Rouzee Givens, Project Engineer, U. S. Army Air Mobility Research and Development Laboratory (USAAMRDL).

The program was conducted under the technical direction of L. J. Hopfensperger, Project Engineer. Acknowledgement is given to J. Drennan, Engineering Technician in charge of the program's technical progress, and J. Young, who supplied data analysis support.

TABLE OF CONTENTS

APPENDIXES

LIST OF ILLUSTRATIONS

INTRODUCTION

The objective of the work performed during this program was to determine the stabilized operating temperatures of all main transmission components and their adjacent supporting structures under 60 percent, 90 percent, and 100 percent input torque loads (rotor shaft speed at 324 rpm) and oil-out controlled temperatures of 225°F±5°F, 265°F±5°F, 310°F±5°F, and 345°F±5°F.

Figure 1 is an illustration of the UH-1 helicopter drive system showing the relationship of the main transmission to the other components in the system. Figure 2 is a photograph of a UH-1 main transmission, and Figure 3 is a sectional representation of the gearbox as tested, indicating the major components.

The UH-1 transmission lubrication system consists of a pump, an oil cooler, a filter, interconnecting lines, and in some cases a differential pressure bypass valve. The pump draws oil from the transmission sump and directs this pressurized oil through an oil cooler, thence to an oil filter, and on to the inlet manifold on the transmission. A portion of this total volume of oil is then directed to the necessary bearings and gear meshes. The rest is shunted back into the transmission cavity through the pressure regulator bypass. All the oil then drains back to the oil sump cavity via gravity flow.

The transmission was installed in a UH-1 transmission bench test stand for testing. Instrumentation consisted of thermocouples imbedded in bearing housings, gear shafts at bearing locations and gear teeth, and transmission housings; temperature indicating (sensitive) colored tabs on gears and housings; and infrared photography. An unsuccessful attempt was made to transmit thermal data from rotating planet idlers by an FM transmitter imbedded in the planetary assembly.

All temperatures obtained by thermocouples were recorded on strip-charts during the actual stabilized runs and after shutdown to determine temperature redistribution and cooling rate. The tests were conducted in still air, which minimized convective heat loss.

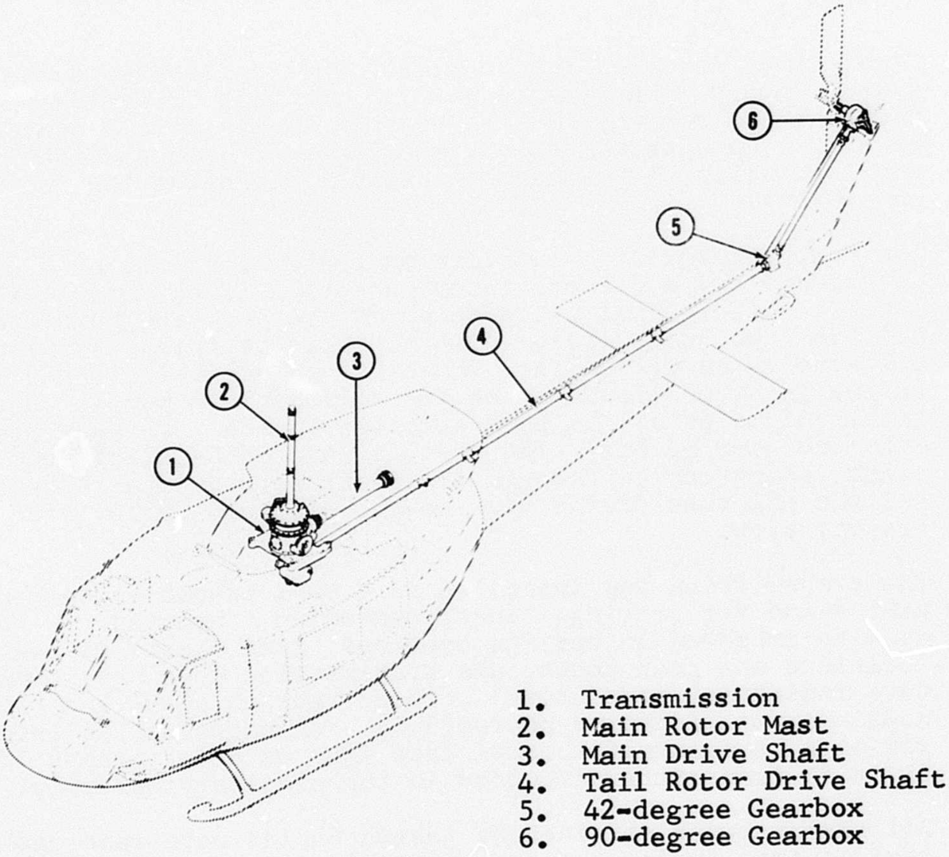


Figure 1. UH-1 Drive System, Showing the Location of the Transmission Tested.

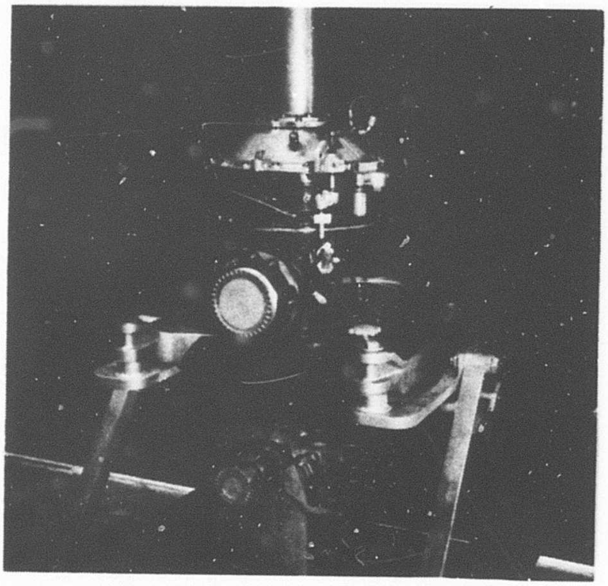


Figure 2. Standard UH-1 Transmission.

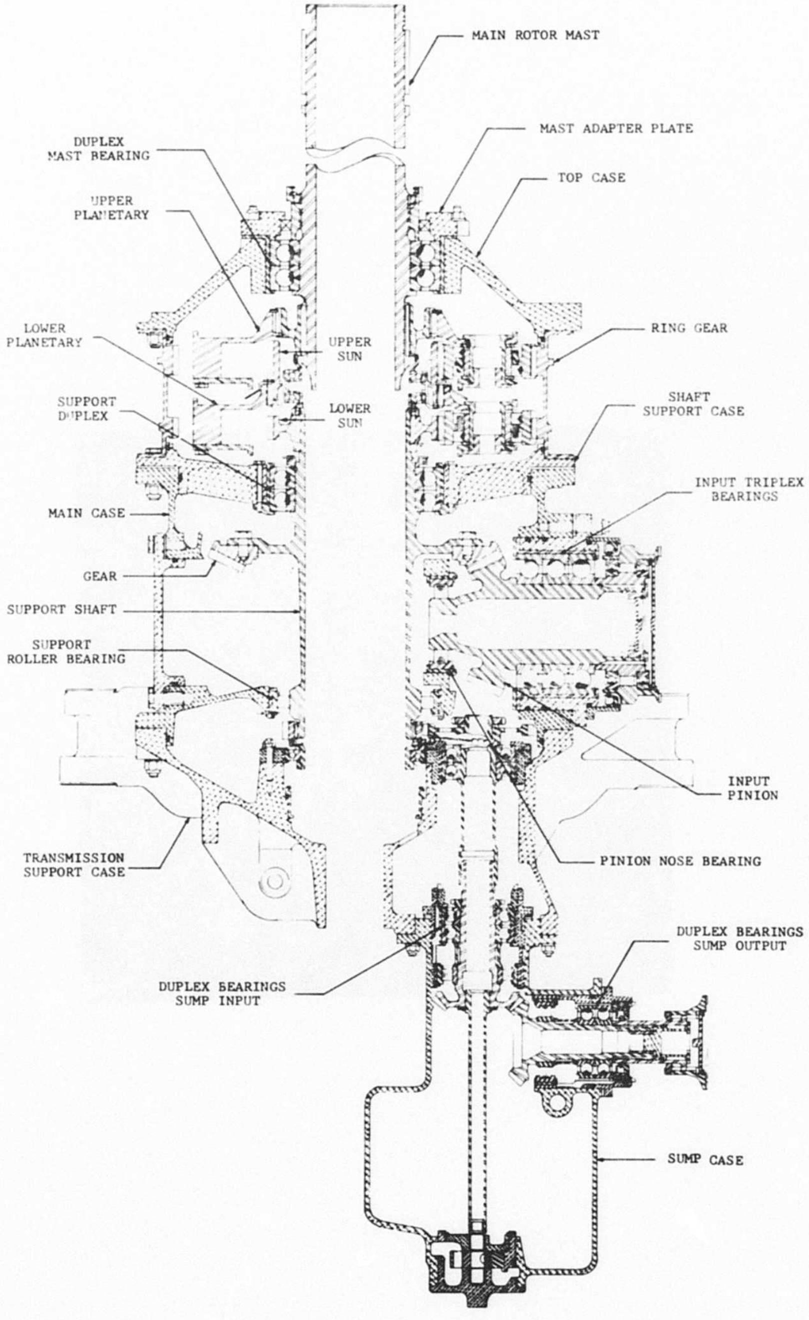


Figure 3. Transmission as Tested, Showing the Major Components.

DISCUSSION

The GFE transmission, 205-040-001-5, S/N A12-52, assigned to Contract DAAJ02-72-C-0081 was completely disassembled and inspected (upon receipt) to verify component integrity prior to testing. All components were approved for use during this test by research lab personnel. Figures 4 through 9 show pretest conditions of some components. All transmission components are not shown, since some components were replaced during the test. The reasons for these replacements will be listed later in this report under Results. Table I lists all components reworked, modified, or replaced during this test. Figures 10 and 11 show the method of installation for slip-rings and the location of thermocouples for the assemblies.

ASSEMBLY

The transmission was assembled per BHC assembly requirements where applicable. Some deviation from standard techniques was necessary due to component modification for instrumentation purposes, but this did not alter transmission performance.

LUBRICATION AND COOLING

The transmission was lubricated with Stauffer MIL-L-7808G, Lot 3248, dated May 1971. Transmission lubrication was accomplished by a sump-mounted Nelson gerotor oil pump which was gravity fed from the test transmission sump. The oil was pumped from the sump to an oil/water heat exchanger, then to the transmission oil filter and manifold. The oil temperature was automatically controlled from the operations console by a pneumatically operated proportioning valve on the heat exchanger. The heat exchanger had to be removed from the oil system in order to achieve the desired temperature during the high-temperature runs (see Test Results section).

All runs made during this test were conducted in a dead-air environment. No forced-air cooling was made to any portion of the transmission.

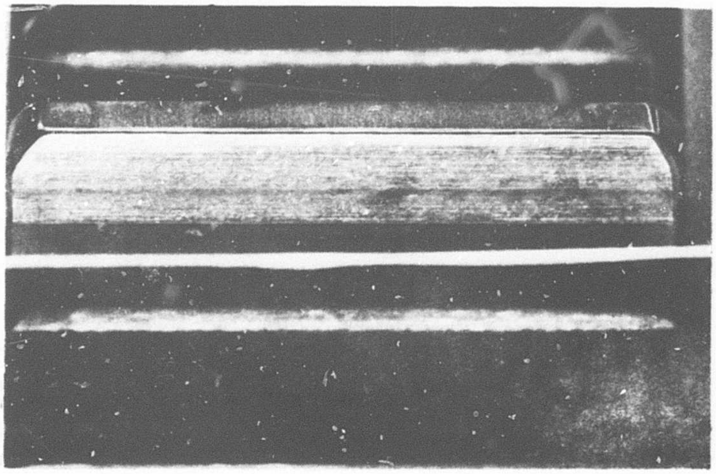


Figure 4. Pretest Upper Planet, Sun Gear Side.

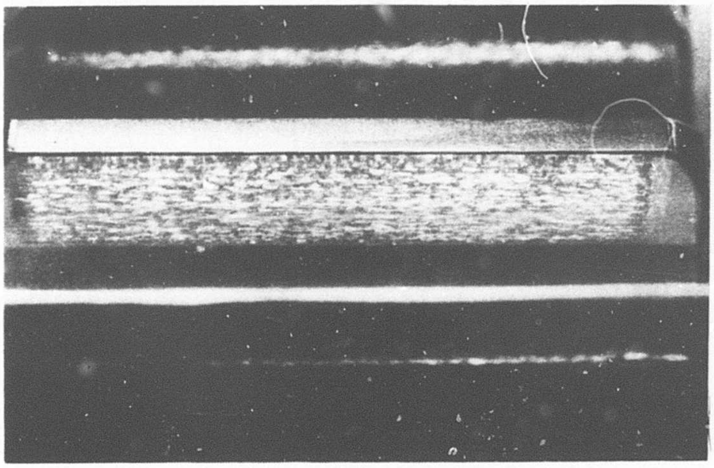


Figure 5. Pretest Upper Planet, Ring Gear Side.

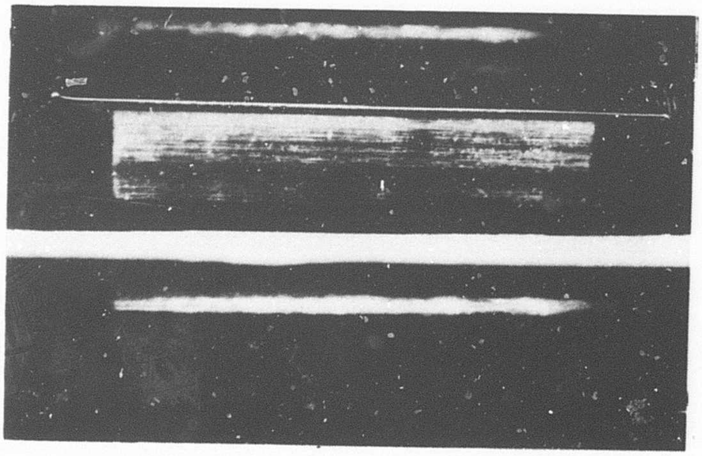


Figure 6. Pretest Lower Planet, Sun Gear Side.

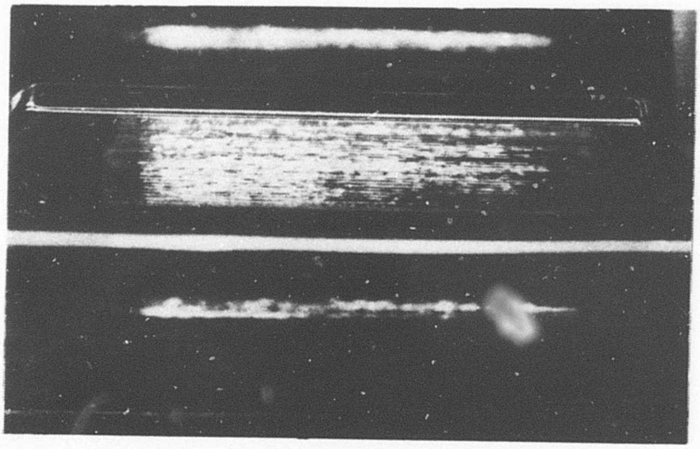


Figure 7. Pretest Lower Planet, Ring Gear Side.

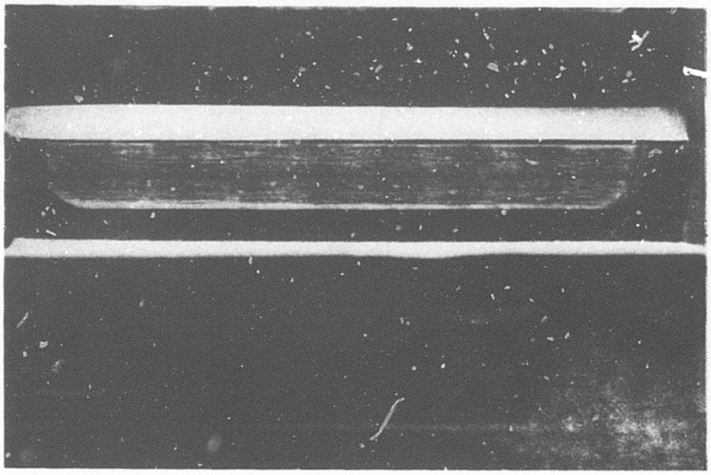


Figure 8. Pretest Upper Sun Gear.

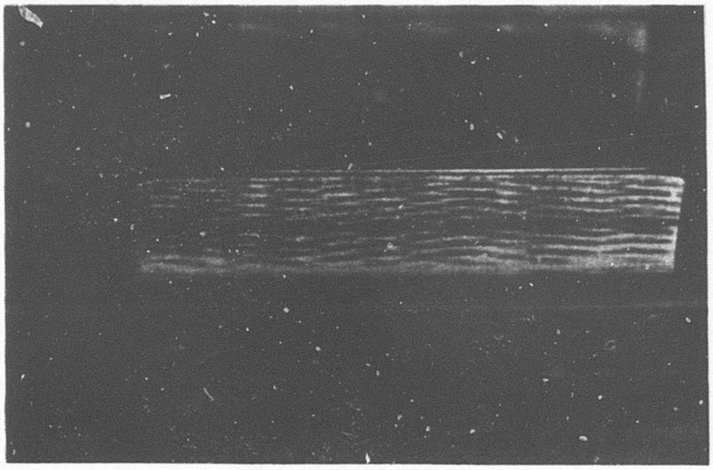
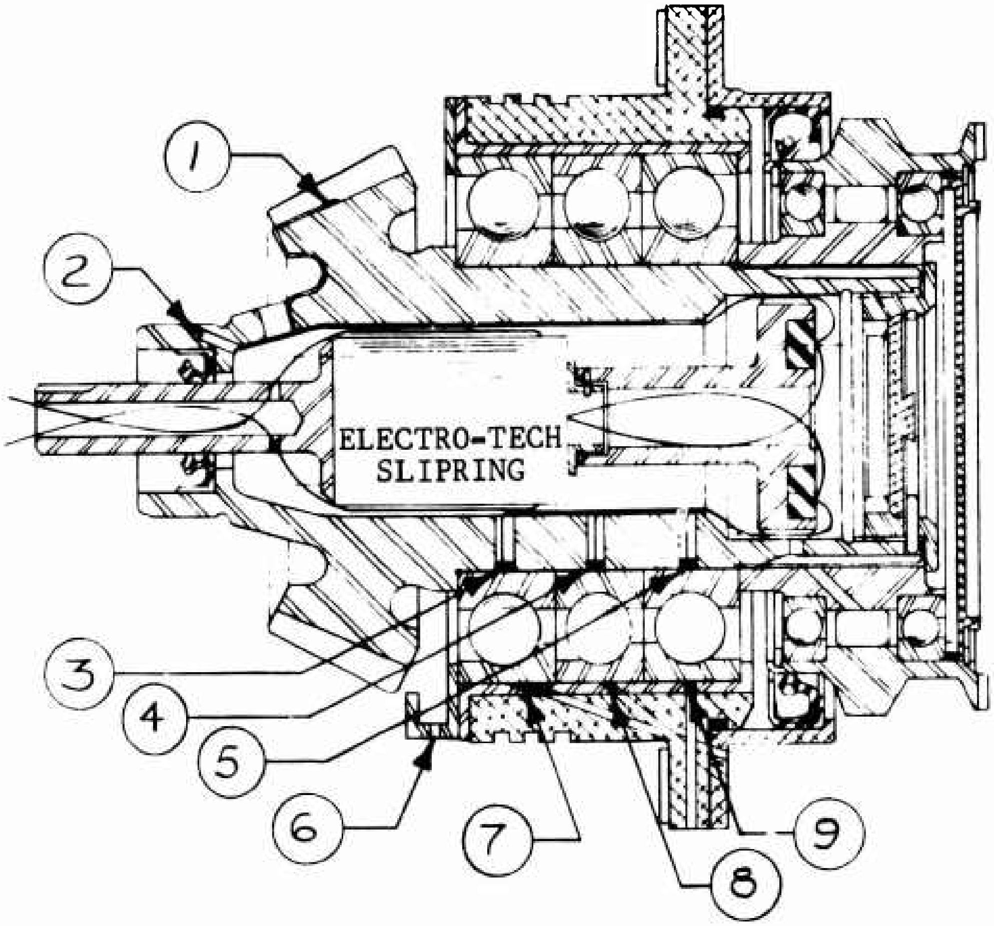


Figure 9. Pretest Lower Sun Gear.

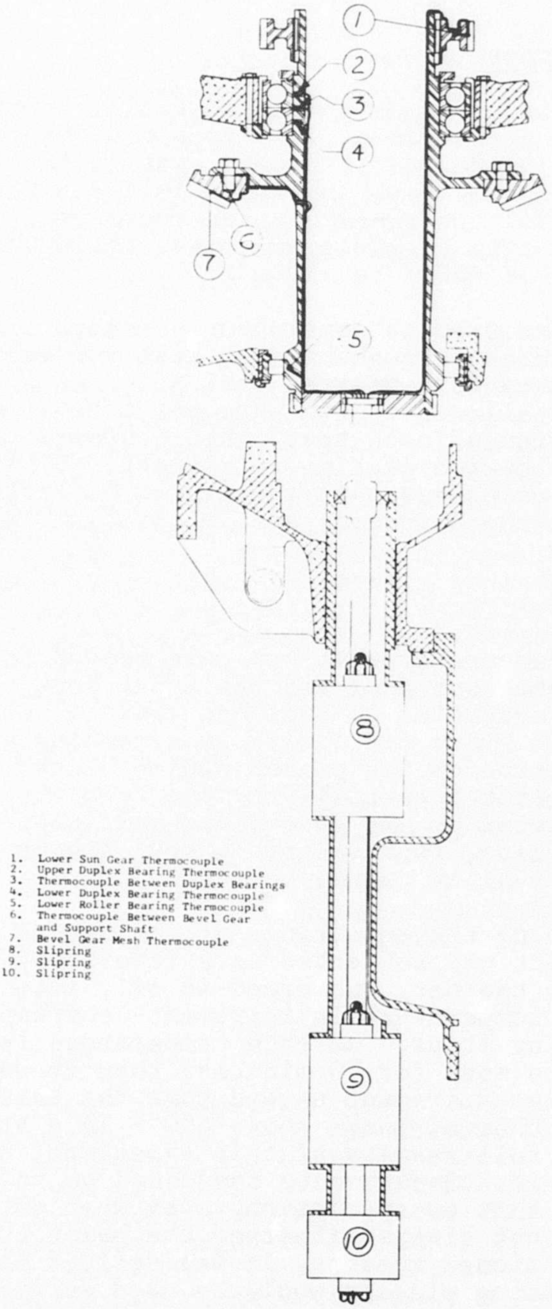
TABLE I. COMPONENTS REWORKED OR MODIFIED

Part Number	Mod/Rework Done
204-040-359-1 Top Case	Replaced with 603-040-110.
204-040-117-3 Adapter	Replaced with 603-040-108 and -109.
204-040-329 Sun Gear	Notched for T.C. - Drilled for T.C.
204-040-360 Planetary Assy	Hole drilled for routing of T.C. Notch placed in planet pin bore for T.C. routing. Drilled planet bearing race for T.C. insertion.
204-040-352 Case	Holes drilled for routing T.C. to bearings and case exterior.
204-040-324 Shaft	Drilled for T.C. implants, notched pilot diameter for routing T.C. wire.
204-040-353 Case	Modified case for slipring driver and thermocouple implants plus substituting routing to exterior of wires.
204-040-200 Pinion	Mod. to accept slipring drill for T.C. implants.
204-040-363 Quill Assy	Drilled for T.C. implants.
204-040-354 Case	Drilled for T.C. implants.
204-040-331 Ring Gear	Drilled for T.C. implants and modified for transmission antenna (subsequently not used).
204-040-365 Sump Assy	Modified input and output sleeves to accept T.C. implants for outer races.



1 Tooth Mesh Thermocouple
2 Roller Bearing Inner Race .050 Inch Below Surface
3 Inboard Triplex Bearing Inner Ring
4 Center Triplex Bearing Inner Ring
5 Outboard Triplex Bearing Inner Ring
6 Oil Out of Triplex Bearing
7 Inboard Triplex Bearing Outer Ring
8 Center Triplex Bearing Outer Ring
9 Outboard Triplex Bearing Outer Ring

Figure 10. Schematic of Input Quill, Showing the Location of Thermocouples and Slipring.



1. Lower Sun Gear Thermocouple
2. Upper Duplex Bearing Thermocouple
3. Thermocouple Between Duplex Bearings
4. Lower Duplex Bearing Thermocouple
5. Lower Roller Bearing Thermocouple
6. Thermocouple Between Bevel Gear and Support Shaft
7. Bevel Gear Mesh Thermocouple
8. Slipring
9. Slipring
10. Slipring

Figure 11. Mounting of the Bevel Gear Sliprings.

INSTRUMENTATION

Thermocouple Recorders

Temperatures were recorded on three Honeywell Electronic 16, 24-point strip-chart recorders. One recorder, designated as J1 for identification during this test, was of the type J (iron-constantan) calibration and had a full-scale range of -100° to +500°F. The two remaining recorders were designated K2 and K3 and were type K (alumel-chromel) calibration with a full-scale range of -200° to +1000°F.

These recorders were used to continuously record transmission component temperatures throughout each test run/segment. All temperature recorders were started just prior to the start of the test stand and allowed to run throughout the run/segment. Following termination of each test, the recorders continued to run for a short period of time to reflect any heat flow reversals. These recorders were calibrated prior to commencement of testing by the Standards and Calibration Laboratory of Bell Helicopter.

Thermal Plaques

Color-indicating temperature sensors were bonded to the inner surfaces of the upper sun gear and the input bevel gear shaft. A pretest program conducted to evaluate these plaques showed that there would be great difficulty in effecting a proper bond and encapsulation on the planet pinion blanks. This problem was precipitated partially by the fact that there was no expanse of material on any gear blank sufficiently void of surface irregularities, such as part number stamps and rough surface texture, to allow proper bonding.

A test bar containing the full range of indicators to be used during this contract was subjected to a laboratory test consisting of placing the bar, submerged in oil, into an oven and elevating the temperature in increments corresponding to the color-indicating steps. At each temperature level the part was allowed to soak for 30 minutes; then it was removed and examined. This experiment showed that the tabs were unreliable in the thermal range above 400°F in a static environment. The full results of this experiment are presented in Appendix I. Experiments conducted on rotating components showed that encapsulation, even when meticulously accomplished, did not always withstand the harsh environment. For these aforementioned reasons, it was decided that the temperature-indicating plaques would be used during this program as secondary indicators only.

Bond and encapsulation procedures used on the temperature-indicating plaques consisted of very carefully cleaning the surface where the indicator was to be placed. The indicator was positioned on the part and a polyimide tape, "Kapton", slightly larger than the indicator, was placed over it, mastic up. A second piece of tape larger than the first was then positioned over this, mastic down. This entire area was then coated with an adhesive, M-Bond 600, and heat cured for approximately 4 hours at 180°F. This adhesive was again applied and cured in a like manner four more times to complete the encapsulation.

Infrared Data

An AGA Thermovision (trademark) infrared-sensing camera was used during this test program to record overall external housing temperature gradients. This unit, by adjusting the sensitivity to the desired level, could provide an overall picture of the isothermal levels and would automatically step through a seven-color multiple exposure, imparting a different color relating to the specific isothermal level being photographed. This method was also a secondary type of indicator, but it provided a graphic representation of thermal gradients to be found on the external case surfaces. This eliminated the need for the many thermocouples that would otherwise have been needed to provide a complete gradient picture.

F.M. Radio Transmission

An attempt was made to obtain real-time temperature data from the upper sun gear and the lower planetary bearing inner race by utilizing an F.M. transmitter embedded in the transmission, supported in an adapter driven by the lower planetary carrier support. Due to receiving-equipment malfunction, data was not obtained during this program.

TEST STAND

Description

A main rotor transmission green run test stand was used during this program. The stand was checked for reliable performance of all equipment, and a calibration of the torque-sensing circuit was performed by the Standards and Calibration Group. All external oil plumbing for the test specimen, oil cooler, and filter was purged of its existing oil and recharged with fresh MIL-L-7808. The oil temperature controller was moved from the normal stand location to a position by the operations console to facilitate the changing of the oil-out temperature during a run. All overtemperature safety circuits were deactivated for this test.

The main rotor transmission green run test stand is a regenerative loop. This loop is powered by a 200-hp electric motor coupled to a 200-hp electromagnetic coupling. Power from this coupling is then transmitted through a speed-increasing gearbox and into the slave transmission, then from the opposite side of the slave transmission into the test transmission. The masts of the test transmission and the slave transmission are coupled by an overhead-mounted gearbox. Torque loading is applied to the test transmission and slave transmission by introducing angular displacement of the planetary ring gear (with respect to the main case) of the slave transmission with a worm gear fixture. Torque is indicated by a strain-gaged shaft in the overhead gearbox. Power is transmitted from the test transmission tail rotor output through a two-speed gearbox to a fan driven by a fluid coupling. This system is capable of dissipating either 50 or 100 hp, depending upon the driven rpm of the fan.

Stand Instrumentation and Routing

All instrumentation from the test stand was routed to an elevated console control area. This included, for this test, the thermocouple leads from the test gearbox for temperature recorders J1 and K2, which were located in the console area. Recorder K3 was located in the cell area just outside the door to the control room. All infrared monitoring and recording equipment was also located in the cell test area. Figures 12 and 13 show the mounting of the test transmission in the stand with the wiring attached.

TEST METHOD AND DESIGN OF EXPERIMENTS

Pretest Analysis

A pretest qualitative analysis was made to derive the thermal mapping test plan. The analysis consisted of reviewing results of previous testing on similar but unrelated programs, determining the capability of the test stand cooling equipment to provide required thermal stability, and determining possible heat flow paths afforded the test transmission by the test stand. An additional determination of bearing load vectors was made in order to locate imbedded thermocouples in bearing housings.

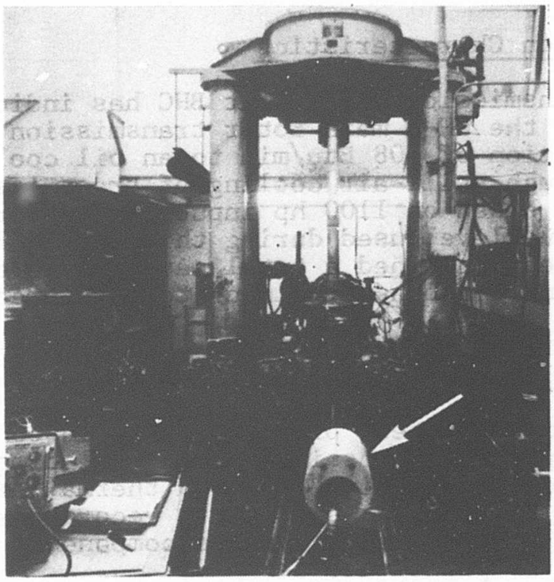


Figure 12. Transmission Mounted in Stand (Arrow Indicates Thermovision Camera).

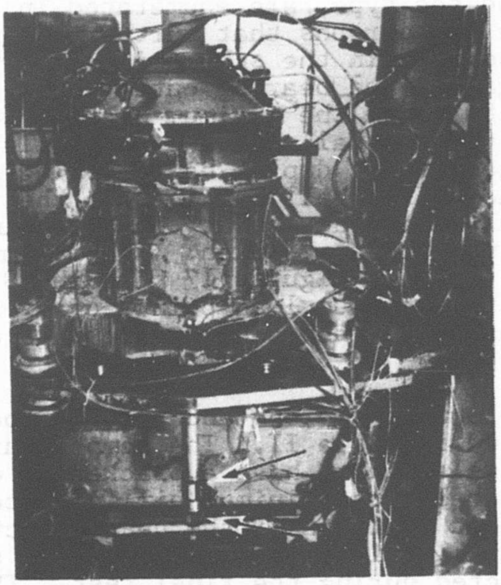


Figure 13. Close-up of Transmission in Stand (Arrows Indicate Sliprings for Bevel Gear).

Heat Rejection Characteristics

Previous transmission testing at BHC has indicated an efficiency for the UH-1 main rotor transmission of 98.42% with a heat rejection of 508 Btu/min to an oil cooler and 250 Btu/min through still-air cooling of transmission housings. This data is based on 1100 hp input, which corresponds to the 90% torque level used during this test. This transmission as tested contained a total wetted area of 12.8 ft^2. Additional information pertaining to this pretest analysis is presented in Appendix II.

THERMAL MAPPING TEST PLAN AND PROCEDURE

The thermal mapping test plan was designed to obtain as many temperature points as possible on a "real time" basis, with minimal use of "high point" bond on thermal plaques. Thermocouples were placed at positions to record the running temperatures of as many major dynamic components in the UH-1 transmission as practical.

Figure 14 is a pictorial display of the dynamic components of a UH-1 transmission, showing the location of the temperature-measuring instrumentation. The positions of this instrumentation, and the type, are enumerated in Table II. Figures 15 and 16 are photographs that further clarify some of the locations described in the schematic. Thermocouples were positioned against the bearing outer rings in the approximate area of and 180° from the maximum bearing load vectors of the input pinion triplex ball bearing and roller bearing and the input bevel gear shaft duplex ball bearing and roller bearings. For the duplex ball bearings in the tail rotor bevel gear sets, only temperatures at the approximate point of maximum load vectors were taken. The maximum load points of bearings are shown in Figures 17 through 19. Test data were derived from the maximum load points only, since no marked difference was noted when checks were made of the other positions.

The thermal plaque positions and their temperature ranges are also identified in Table II. The temperature ranges of these plaques were selected to have a bracketing effect, that is, to range just below the minimum oil inlet temperature anticipated by pretest analysis of the heat rejection modes, to a point considerably higher than the maximum oil outlet temperature expected during the final test. The pretest mathematical prediction of the maximum flash temperature rise above bulk oil inlet temperature at mesh contact was used as a guideline.

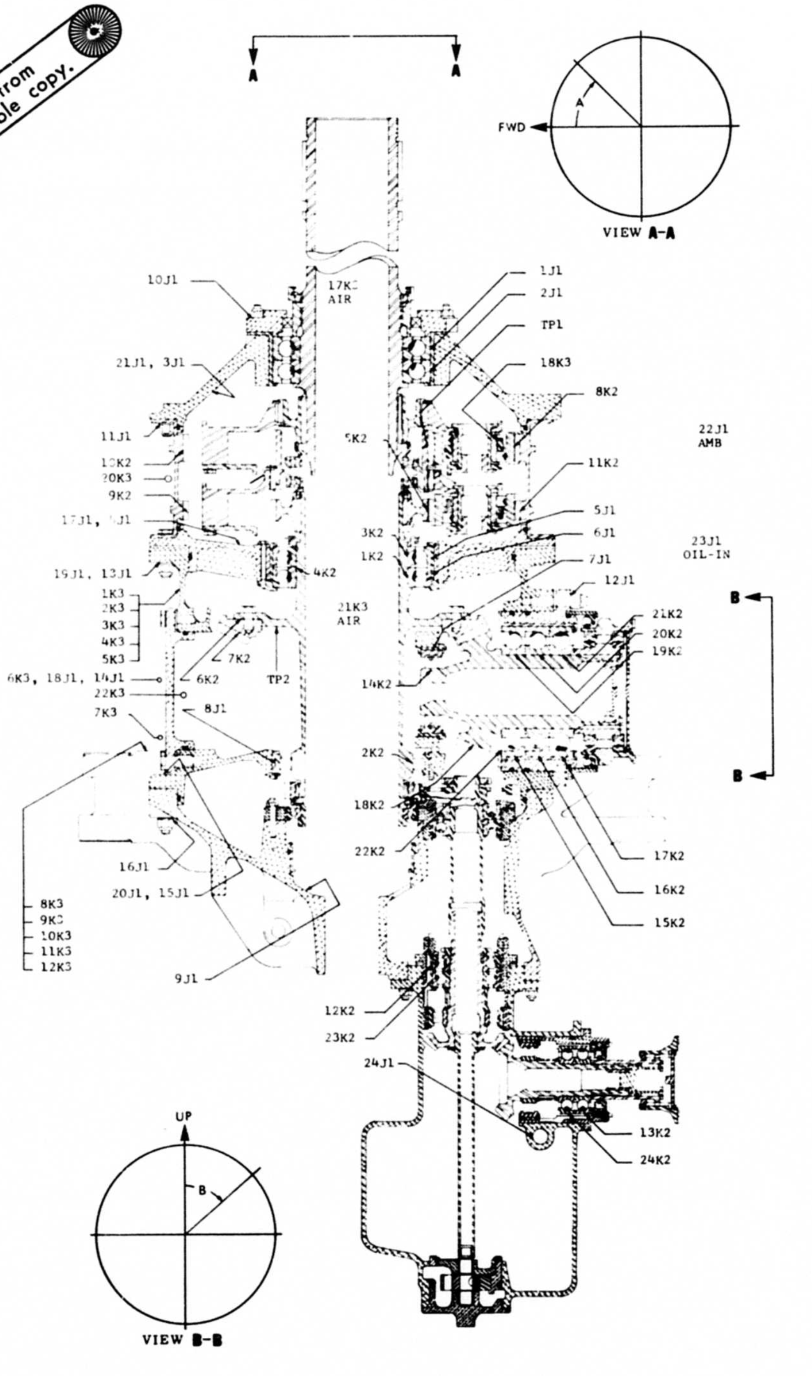


Figure 14. Section View of the UH-1 Transmission, Showing the Location of Thermocouples or Indicators.

TABLE II. THERMOCOUPLE LOCATION INDEX

Thermocouple No.	Location/Nomenclature	∡A	∡B
1J1[a]	Mast Bearing Duplex (Upper)	270°	
2J1[a]	Mast Bearing Duplex (Lower)	300°	
3J1[b]	Top Case (Inner Surface)	190°	
4J1[b]	Support Case, Bevel Gear (Upper Surface)	190°	
5J1[a]	Bevel Gear Shaft Upper Bearing (Outer Ring)	270°	
6J1[a]	Bevel Gear Shaft Lower Bearing (Outer Ring)	270°	
7J1[a]	Input Pinion Roller Bearing		30°
8J1[a]	Bevel Gear Shaft Roller Bearing (Outer Ring)	120°	
9J1[b]	Support Case, Main Transmission (Floor)	0°	
10J1[c]	Mast Adapter Plate	185°	
11J1[c]	Ring Gear Case Upper Flange	180°	
12J1[c]	Input Pinion Quill Sleeve	190°	270°
13J1[c]	Main Case Upper Flange	280°	
14J1[c]	Main Case Accessory Port Cover	275°	
15J1[c]	Main Case Lower Flange	280°	
16J1[c]	Support Case, Main Transmission	350°	
17J1[b]	Support Case, Bevel Gear (Upper Surface)	10°	

TABLE II - Continued

Thermocouple No.	Location/Nomenclature	∡A	∡B
18J1[c]	Main Case Accessory Port Cover	10°	
19J1[c]	Main Case Upper Flange	80°	
20J1[c]	Main Case Lower Flange	80°	
21J1[b]	Top Case (Inner Surface)	10°	
22J1[d]	Test Cell Ambient Air (12 inches from main case)	270°	
23J1[d]	Oil-In Temperature Probe	120°	
24J1[d]	Oil-Out Temperature Probe	270°	
1K2[a]	Bevel Gear Shaft Lower Duplex Bearing (Inner Ring)		
2K2[e]	Bevel Gear Shaft Roller Bearing (Inner Ring)		
3K2[a]	Bevel Gear Shaft Upper Bearing (Inner Ring)		
4K2[e]	Bevel Gear Shaft Between Duplex Bearing (Shaft)		
5K2[b]	Lower Sun Gear (Root)		
6K2[a]	Between Bevel Gear and Support Shaft Parting Surface		
7K2[f]	Bevel Gear Tooth (Root)		
8K2[e]	Ring Gear, Upper Mesh (Tooth Implant)	45°	
9K2[e]	Ring Gear, Lower Mesh (Tooth Implant)	45°	

TABLE II - Continued

Thermocouple No.	Location/Nomenclature	∡A	∡B
10K2[f]	Ring Gear, Upper Mesh (Tooth Root)	40°	
11K2[f]	Ring Gear, Lower Mesh (Tooth Root)	40°	
12K2[a]	Tail Rotor Drive Input Duplex, Upper Bearing (Outer Ring)	280°	
13K2[a]	Tail Rotor Drive Output Duplex, Outboard Bearing (Outer Ring)		50°
14K2[e]	Input Pinion Nose Bearing (Inner Ring)		
15K2[a]	Input Pinion Inboard Triplex Bearing (Outer Ring)		250°
16K2[a]	Input Pinion Center Triplex Bearing (Outer Ring)		80°
17K2[a]	Input Pinion Outboard Triplex Bearing (Outer Ring)		85°
18K2[f]	Input Pinion Tooth (Root)		
19K2[a]	Input Pinion Inboard Triplex Bearing (Inner Ring)		
20K2[a]	Input Pinion Center Triplex Bearing (Inner Ring)		
21K2[a]	Input Pinion Outboard Triplex Bearing (Inner Ring)		
22K2[d]	Triplex Bearing, Oil-Out		
23K2[a]	Tail Rotor Drive Input Duplex Lower Bearing (Outer Ring)	280°	

TABLE II - Continued

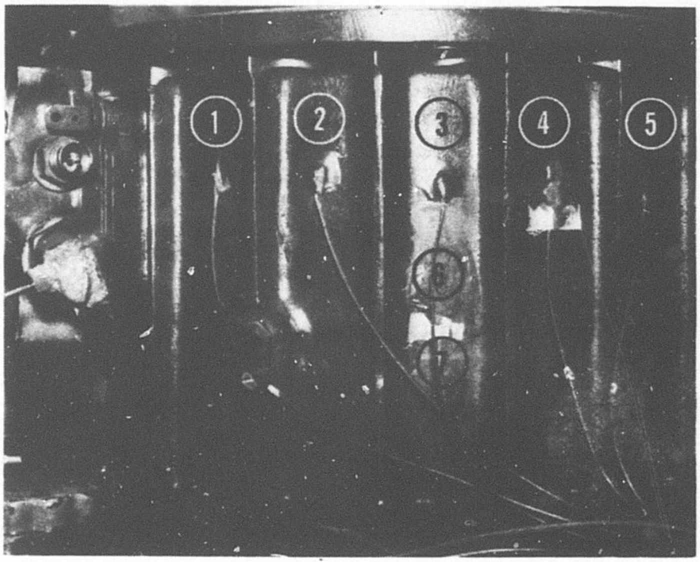
Thermocouple No.	Location/Nomenclature	∡A	∡B
24K2[a]	Tail Rotor Drive Output Duplex Inboard Bearing (Outer Ring)		
1K3[f]	Main Case, Upper 1/3 Section	105° (Fig. 15)	
2K3[f]	Main Case, Upper 1/3 Section	95° (Fig. 15)	
3K3[f]	Main Case, Upper 1/3 Section	85° (Fig. 15)	
4K3[f]	Main Case, Upper 1/3 Section	75° (Fig. 15)	
5K3[f]	Main Case, Upper 1/3 Section	65° (Fig. 15)	
6K3[f]	Main Case, Center Section	85° (Fig. 15)	
7K3[f]	Main Case, Lower 1/3 Section	85° (Fig. 15)	
8K3[f]	Support Case, Main Transmission	85° (Fig. 16)	
9K3[f]	Support Case, Main Transmission	85° (Fig. 16)	
10K3[f]	Support Case, Main Transmission	85° (Fig. 16)	
11K3[f]	Support Case, Main Transmission	95° (Fig. 16)	
12K3[f]	Support Case, Main Transmission	100° (Fig. 16)	
13K3	(No Probe)		

TABLE II - Continued

Thermocouple No.	Location/Nomenclature	∡A	∡B
14K3	(No Probe)		
15K3	(No Probe)		
16K3	(No Probe)		
17K3[d]	Air Inside of Output Mast		
18K3[e]	Upper Planetary Bearing (Inner Ring)		
19K3	(No Probe)		
20K3[d]	Oil-In Jet (Ring Gear)	10°	
21K3[d]	Air Inside Support Shaft, Bevel Gear		
22K3[d]	Air/Oil Inside Main Case	10°	
23K3	(No Probe)		
24K3	(No Probe)		
Thermal Plaques			
TP1[g]	Upper Sun Gear		
TP2[g]	Bevel Gear Support Shaft		
a	Between gear shaft and gear, gear shaft and bearing inner ring, or sleeve and bearing outer ring		
b	Imbedded in case or gear exposed to air or oil		
c	Behind bolt head		

TABLE II - Continued

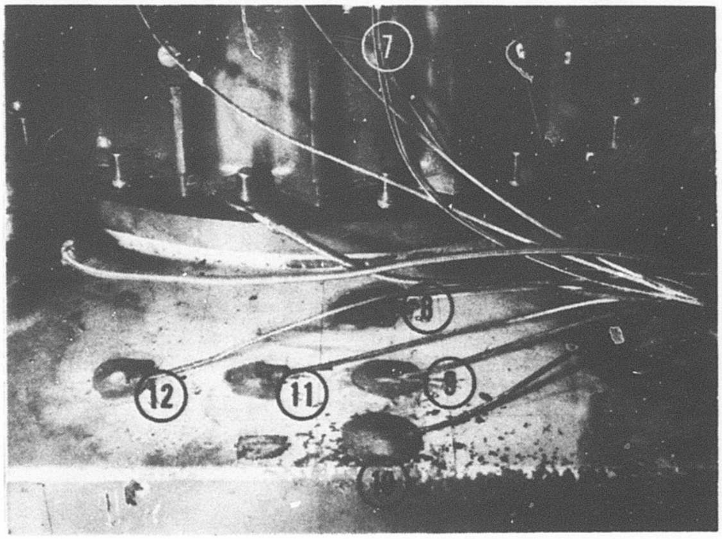
d	Introduced into center of oil flow or suspended in air
e	Subsurface in bearing journal or bearing race just below case
f	Bonded to surface to measure temp of case or gear tooth
g	Thermoplaque bonded to surface and encapsulated



Numbers Indicate:

1	Thermocouple	1K3
2	Thermocouple	2K3
3	Thermocouple	3K3
4	Thermocouple	4K3
5	Thermocouple	5K3
6	Thermocouple	6K3
7	Thermocouple	7K3

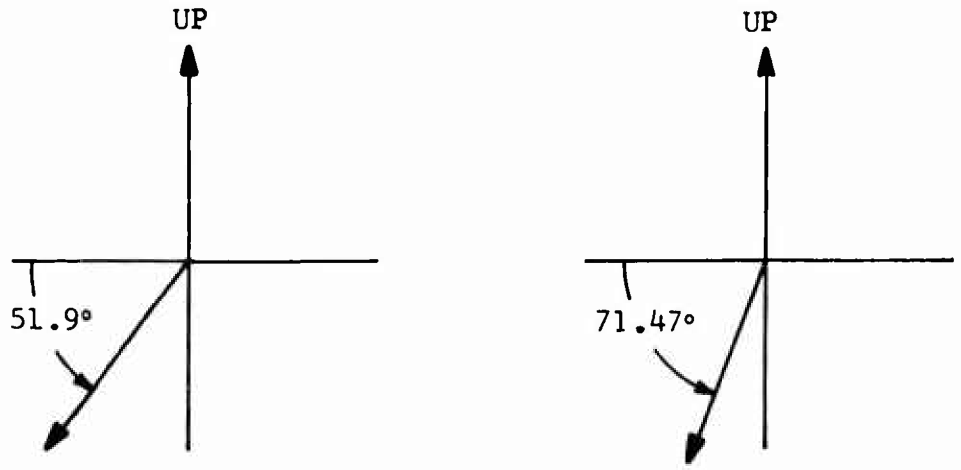
Figure 15. **Thermocouple Locations on Main Case.**



Numbers Indicate:

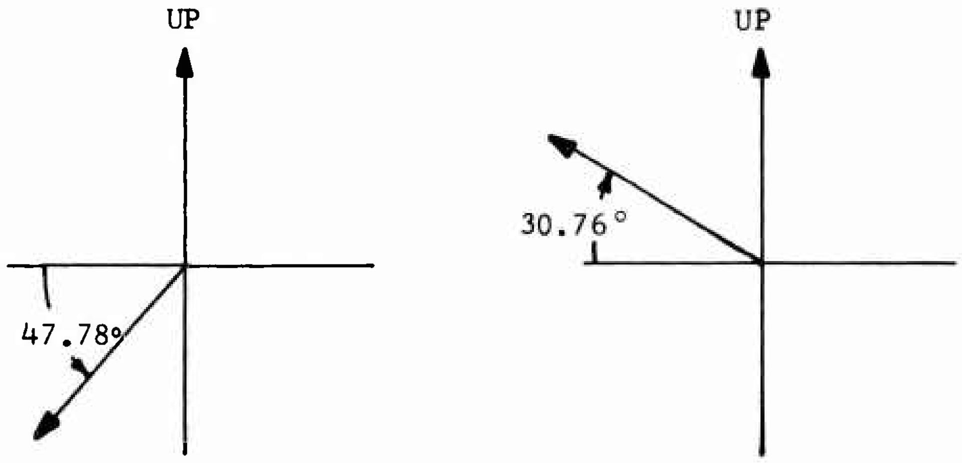
7	Thermocouple	7K3
8	Thermocouple	8K3
9	Thermocouple	9K3
10	Thermocouple	10K3
11	Thermocouple	11K3
12	Thermocouple	12K3

Figure 16. **Thermocouple Locations on Support Case.**



MAIN INPUT PINION
INBOARD BEARING

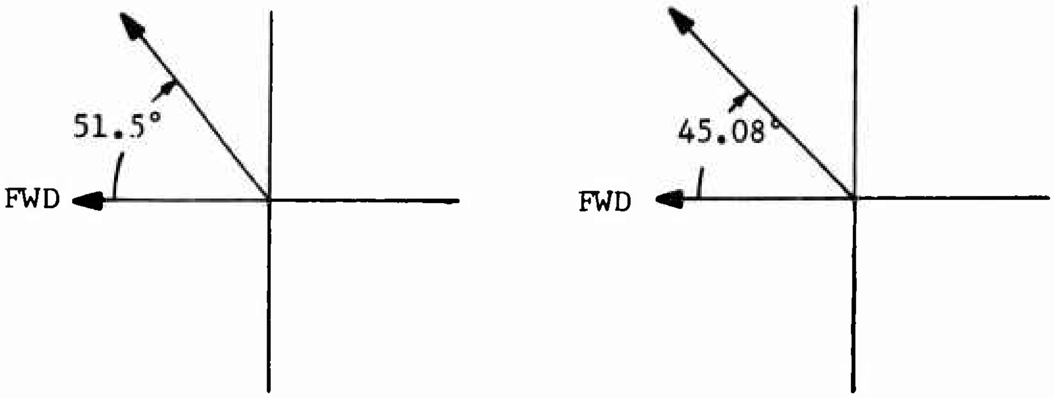
MAIN INPUT PINION
CENTER BEARING



MAIN INPUT PINION
OUTBOARD BEARING

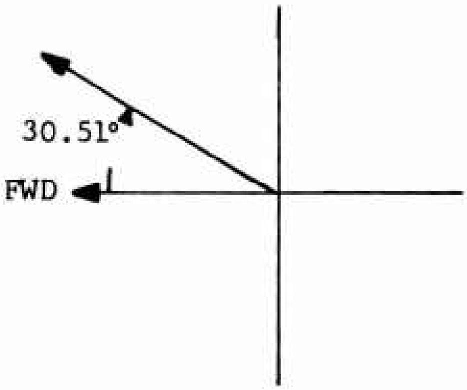
MAIN INPUT PINION
ROLLER BEARING

Figure 17. Bearing Load Vectors, Main Input Pinion.



MAIN INPUT GEAR
UPPER DUPLEX BEARING

MAIN INPUT GEAR
LOWER DUPLEX BEARING

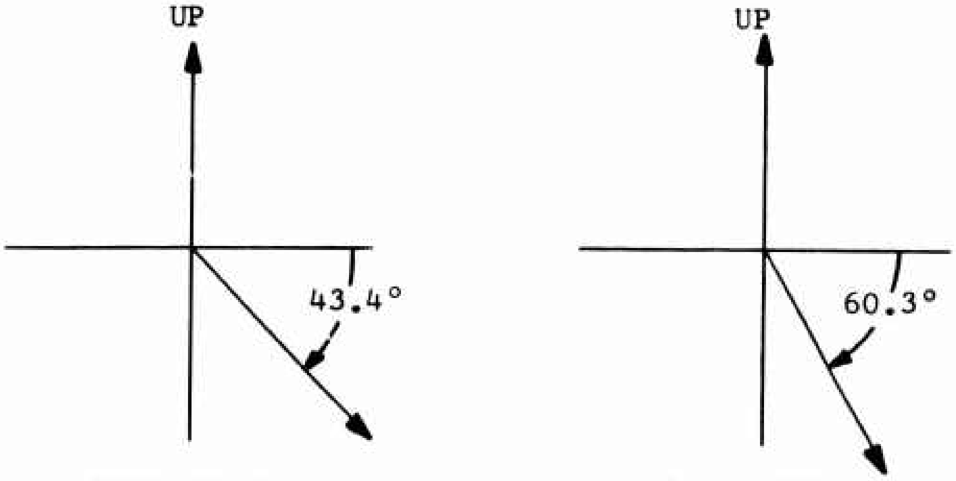


MAIN INPUT GEAR
ROLLER BEARING

Figure 18. Bearing Load Vectors, Main Input Gear.

SUMP INPUT
UPPER DUPLEX

SUMP INPUT
LOWER DUPLEX



SUMP OUTPUT
INBOARD DUPLEX

SUMP OUTPUT
OUTBOARD DUPLEX

Figure 19. Sump Bearing Load Vectors.

Five sliprings were utilized to implement real-time monitoring of the rotating members of the transmission. Accurate and rapid test results were obtained and recorded by their use. Also, this data would require no interpretation of temperature data error due to "soak-back" effects following termination of a test run.

Since this study was conducted, at least in part, in a stabilized oil temperature condition and in view of the anticipation of a "soak-back" effect, it was therefore anticipated that static temperatures, i.e., those made after test termination, would not be indicative of operating temperatures. Many components, after test termination, are subjected to variables that may have either raised or lowered actual component temperatures during these transitional conditions. In enumerating some of these variables, attention should be given to the following: (1) oil inlet temperatures following termination of the load segment, (2) oil flow rate at gear meshes and bearing contact areas, and (3) contact forces and sliding actions at the varying dynamic conditions during coast-down. These conditions are all interrelated; and when they become different (as during shutdown), then actual, at load, operational temperatures become an unknown unless real-time recordings were obtained during the previous conditions.

It was also determined that thermal plaques had several other limitations which precluded their use as a prime indicator for data acquisition. First, the environment in which they were to be used is extremely hostile. Even meticulous handling and application techniques could not insure that data obtained from a run would be totally reliable. Secondly, the temperature would be approximate and could conceivably be in error by as much as 9° to 19°, depending upon the temperature range of the plaque being used. At the location under observation, accurate gradients across some items would be nonexistent.

Slipring data therefore was deemed to be the better method to be followed. Temperatures recorded by this means were verified by routing a known nonrotating temperature through the slipring and correlating the reading obtained from this rotating readout with the static reading.

GROWTH

The thermal mapping test also provided for the measurement of the thermal growth of the transmission cases. Table III identifies the diametral and axial points measured after each run. During measurement of the cases, thermocouple readings were also recorded. Figure 20 is a schematic showing the points at which the dimensional growths were measured.

TABLE III. LOCATIONS FOR MEASUREMENTS OF THERMAL GROWTH

Dimensions/ Measurements	Component
D_1 (Dia)	Top Case
D_2 (Dia)	Ring Gear Above Upper Stiffener
D_3 (Dia)	Ring Gear Upper Stiffener
D_4 (Dia)	Ring Gear Between Stiffener
D_5 (Dia)	Ring Gear Lower Stiffener
D_6 (Dia)	Ring Gear Below Lower Stiffener
D_7 (Dia)	204-040-352 Case
D_8 (Dia)	204-040-353 Case Flange Upper
D_9 (Dia)	Input Quill Sleeve
D_{10} (Dia)	204-040-353 Case at Input Bore
A_1 (Dim)	Ring Gear Between Flanges
A_2 (Dim)	-353 Case Between Flanges

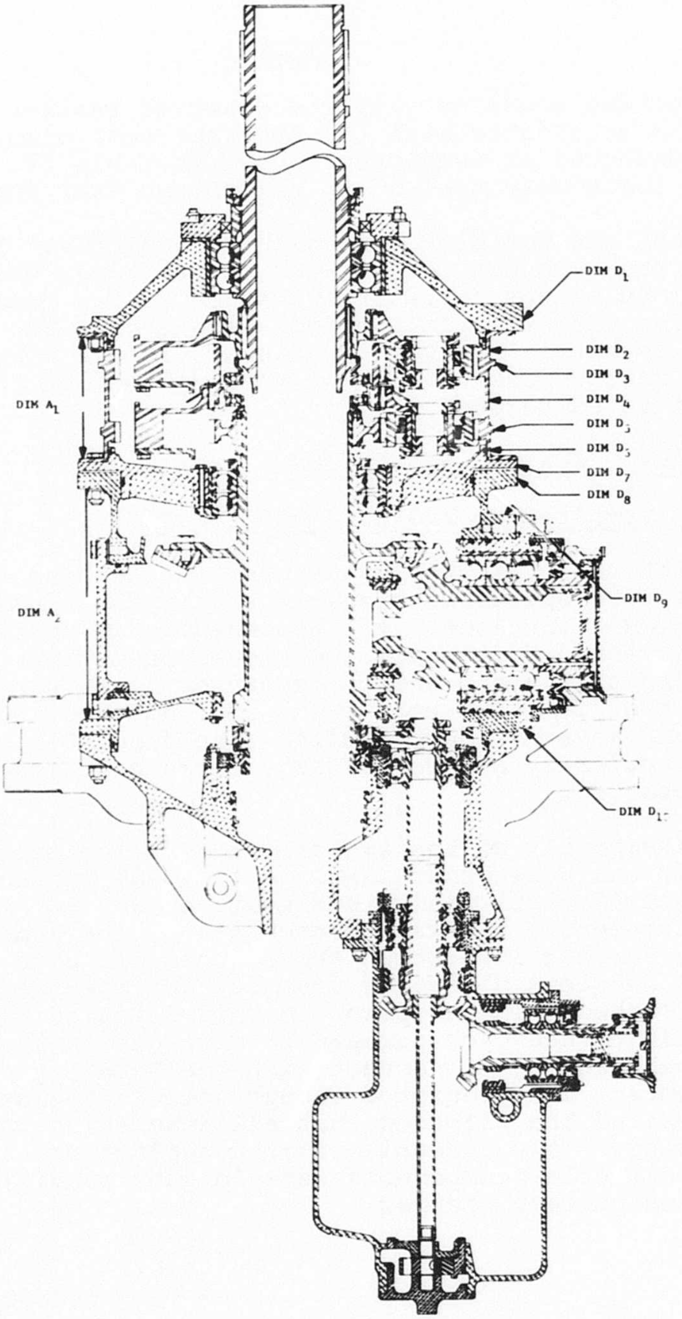


Figure 20. Locations for Measurements of Thermal Growth.

RESULTS

This section contains only the observed results of each test run. In accordance with the contract test plan, all tests were conducted at conditions shown in Table IV. No lift or thrust loads were applied to the output mast for this test.

Each test run was broken into three segments. The constant during each run was the oil-out temperature, which was to be maintained at the target temperature ±5°F. Exceptions to this plan are given in the following text. The variable during each test was the input power level. These power levels were representative of input powers of 60%, 90%, and 100% of rated torque.

EQUIPMENT CHECK AND INSPECTION

Oil-Out Temperature 230°±5°F and 260°±5°F

An operational test was conducted to determine if all thermocouples were operating properly and if the thermal plaques would remain in place. All components did operate properly, and test stand components functioned properly. This test was conducted at the oil-out temperatures to be experienced during the first two test runs, 230° and 260°±5°F. During this run, several thermocouples were found to be indicating reverse polarity and were easily corrected. No other problems were observed.

Upon disassembly of the transmission following the operational test, it was noted that light scoring was present on the main input spiral bevel pinion and gear set due to an incorrect shim placement. Figures 21 and 22 show the condition of both gears. Further inspection showed that all bond on thermal plaques had been dislodged from the surfaces to which it had been attached. The slipring installed inside the shaft of the input pinion had been damaged as a result of the stationary outer ring coming in contact with the rotating driving member. This contact had generated enough heat in the area where the wires exited the slipring that all insulation was melted from the wiring. This necessitated the replacement of the slipring. All other components were in good condition with no indicated pattern change.

TABLE IV. LOAD AND SPEED SCHEDULE

Step No.	Input	Mast Output		Tail Rotor Drive	
	RPM	Torque (In.-Lb)	Approx HP	Torque (In.-Lb)	Approx HP
1	6600	135,180	693	775	50.0
2	6600	192,514	1002	1400	100.2
3	6600	207,806	1065	1400	100.2

Figure 21. Condition of Main Input Pinion at End of Run 2B, Operational Check.

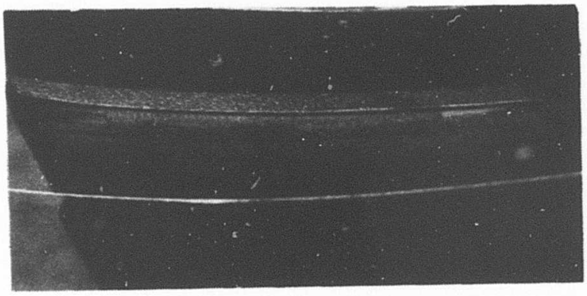


Figure 22. Condition of Main Input Gear at End of Run 2B, Operational Check.

TEST 1 - THERMAL DATA AND INSPECTION

Oil-Out Temperature 230°±5°F

Following the previous functional test run and after the replacement of the distressed gears, the first test run was conducted at 230°F stabilized oil-out temperature. The bevel gear set was visually inspected between each segment of this run to verify pattern placement and condition of the bevel gear. No discrepancies were noted at any point during the test run. Figures 23, 24, and 25 are the thermal maps obtained during the test. No indication of any problem was found after the test run was completed.

TEST 2 - THERMAL DATA AND INSPECTION

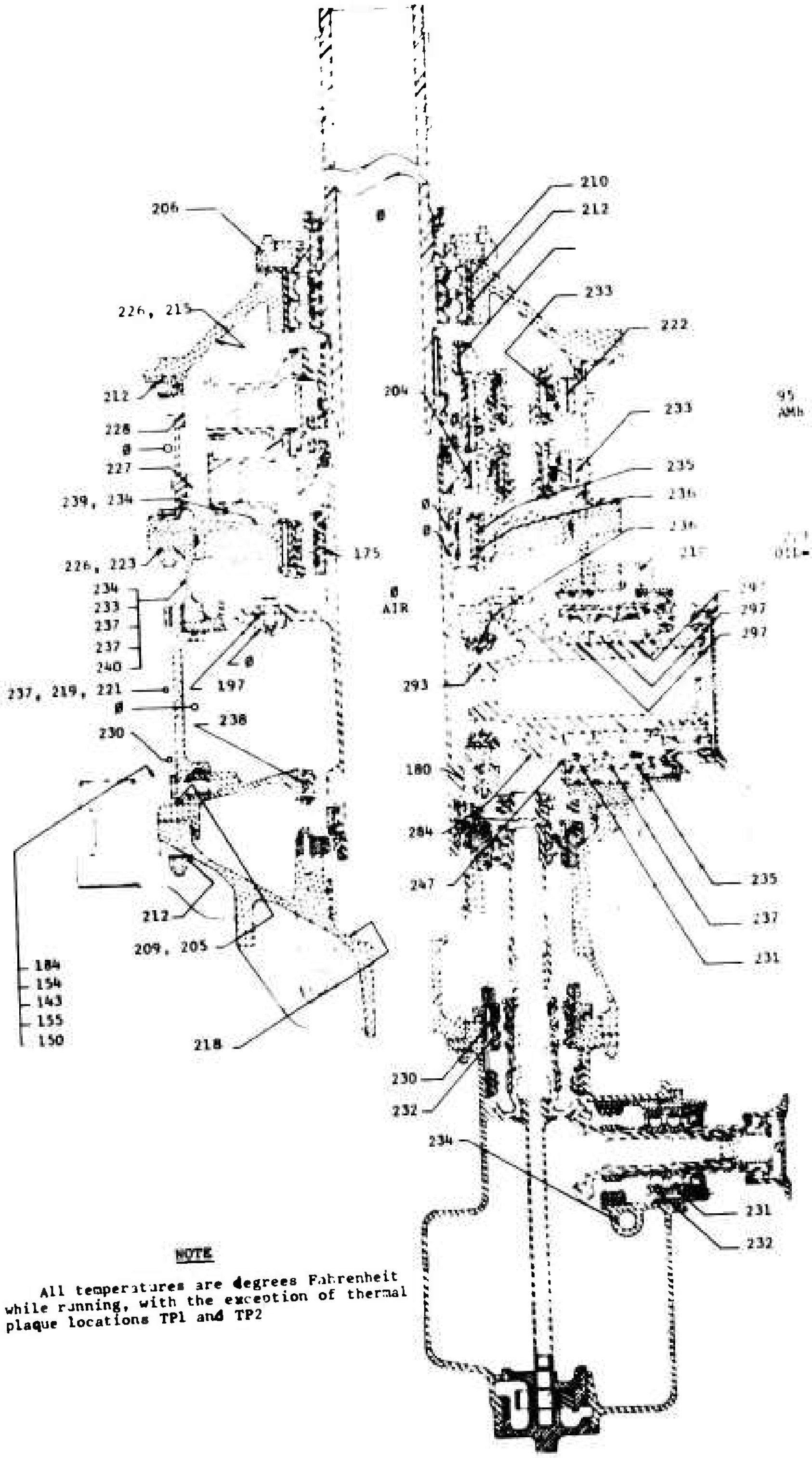
Oil-Out Temperature 260°±5°F

After successful completion of the previous run and verification of component integrity, the second test run was conducted without any halt for inspection of the gear train. During this test run a slight amount of oil vapor emitted from the test transmission. Figures 26, 27, and 28 depict the thermal maps derived from this test run. Following the run, the transmission was removed from the stand and disassembled for inspection of all components and to record the data obtained from the thermal plaques on the upper sun gear (Figure 29). All components appeared to be in good mechanical condition with no change in pattern from the beginning of the test.

TEST 3 - THERMAL DATA AND INSPECTION

Oil-Out Temperature 300°±5°F

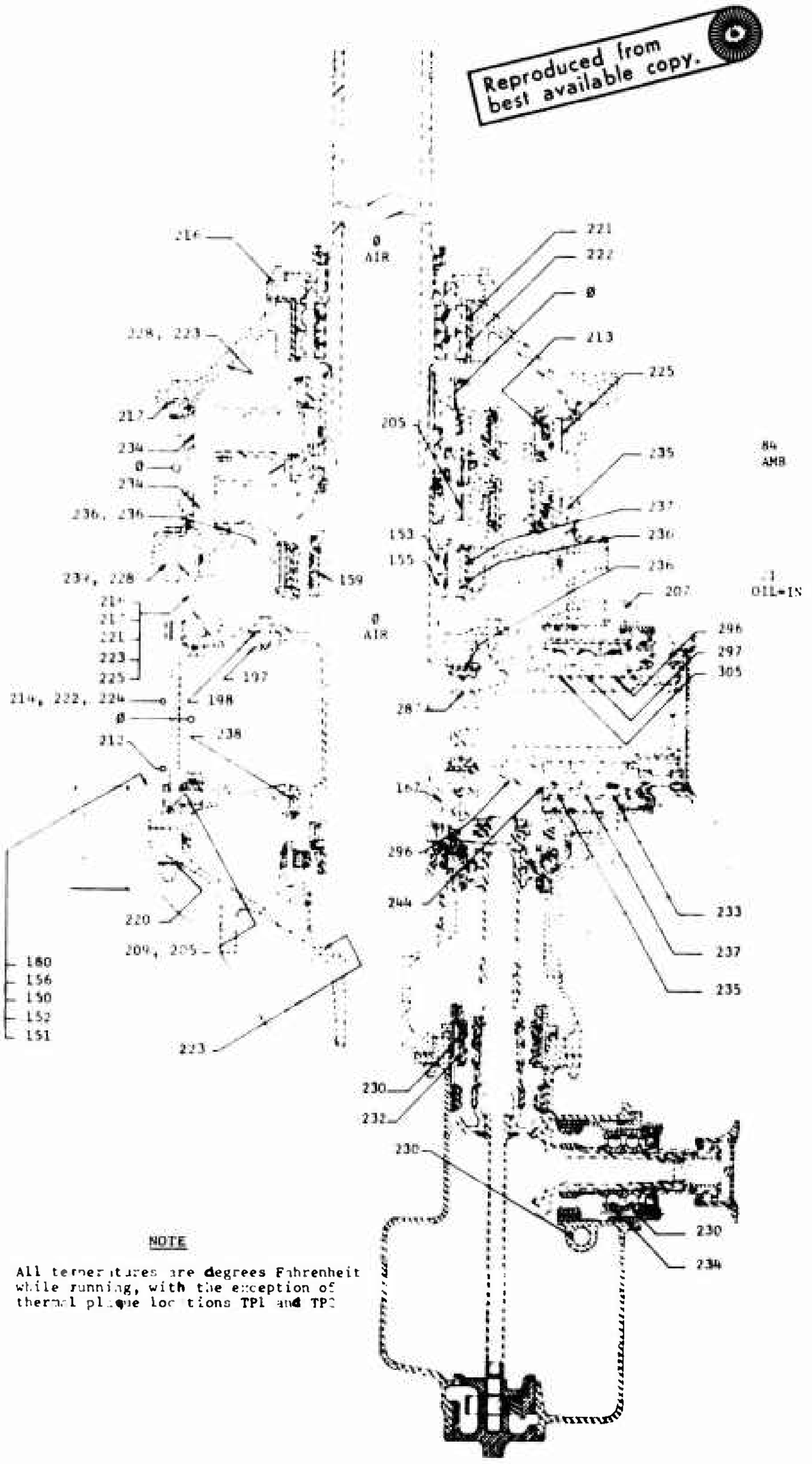
Step one of run three was conducted at 693 hp as scheduled in the test plan. No apparent indication was seen after this first segment that would necessitate disassembly of the transmission. The torque level was raised to the second segment to obtain data points for the thermal map of that condition. Shortly after this level was reached, a total loss of torque was experienced. At the time of this loss, several thermocouple channels in the input pinion experienced a sharp temperature rise and then became inactive. Inspection of the test gearbox revealed extensive damage to the detail parts inside. The input spiral bevel pinion had sustained a fatigue failure through a small hole which had been drilled through the root of a tooth to facilitate a thermocouple implant. Replacement of the main input spiral bevel



NOTE

All temperatures are degrees Fahrenheit while running, with the exception of thermal plaque locations TP1 and TP2

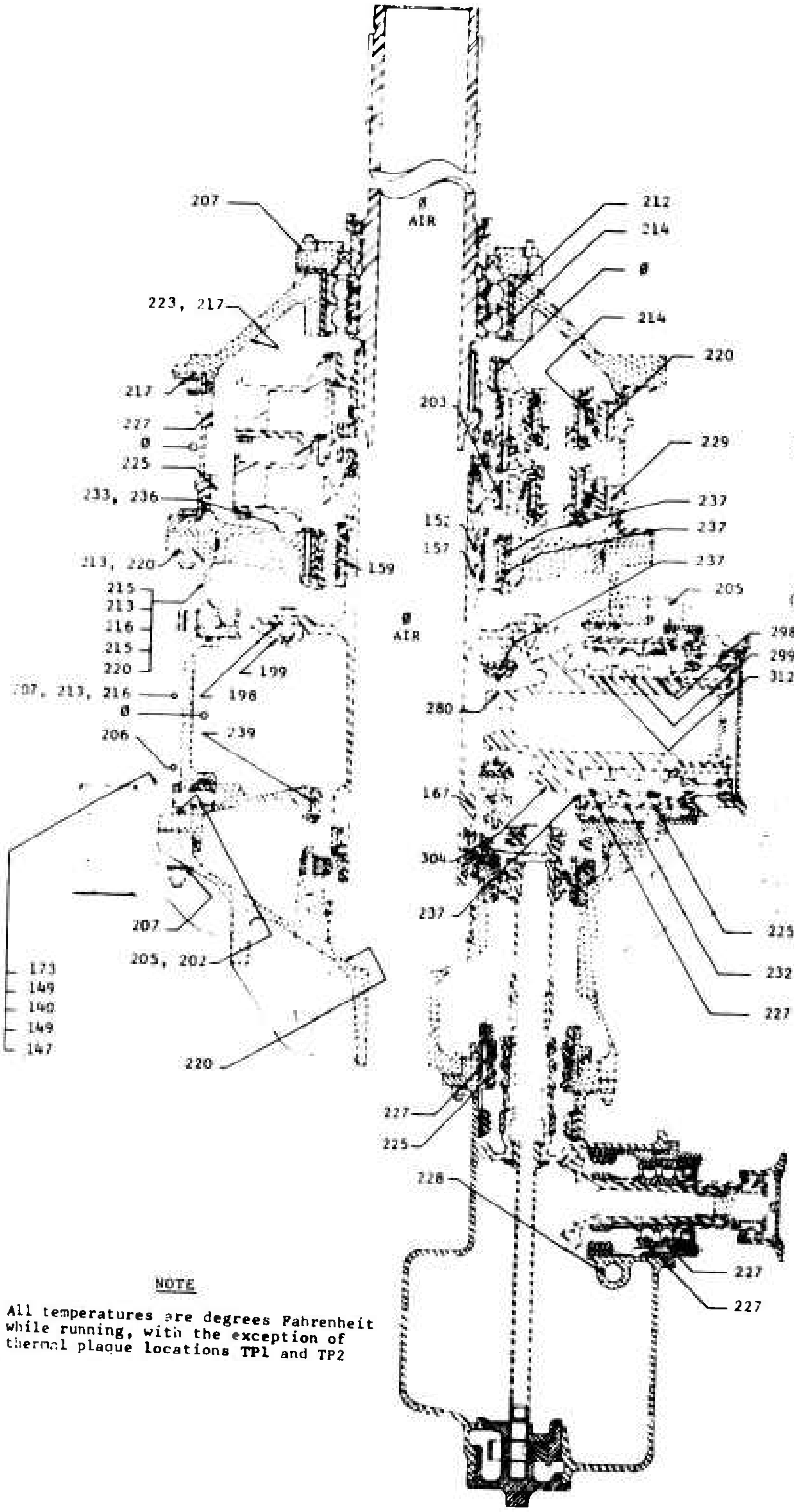
Figure 23. Thermal Map, 60% Torque, 230°±5°F Oil Out.



NOTE

All temperatures are degrees Fahrenheit while running, with the exception of thermal plaque locations TP1 and TP2

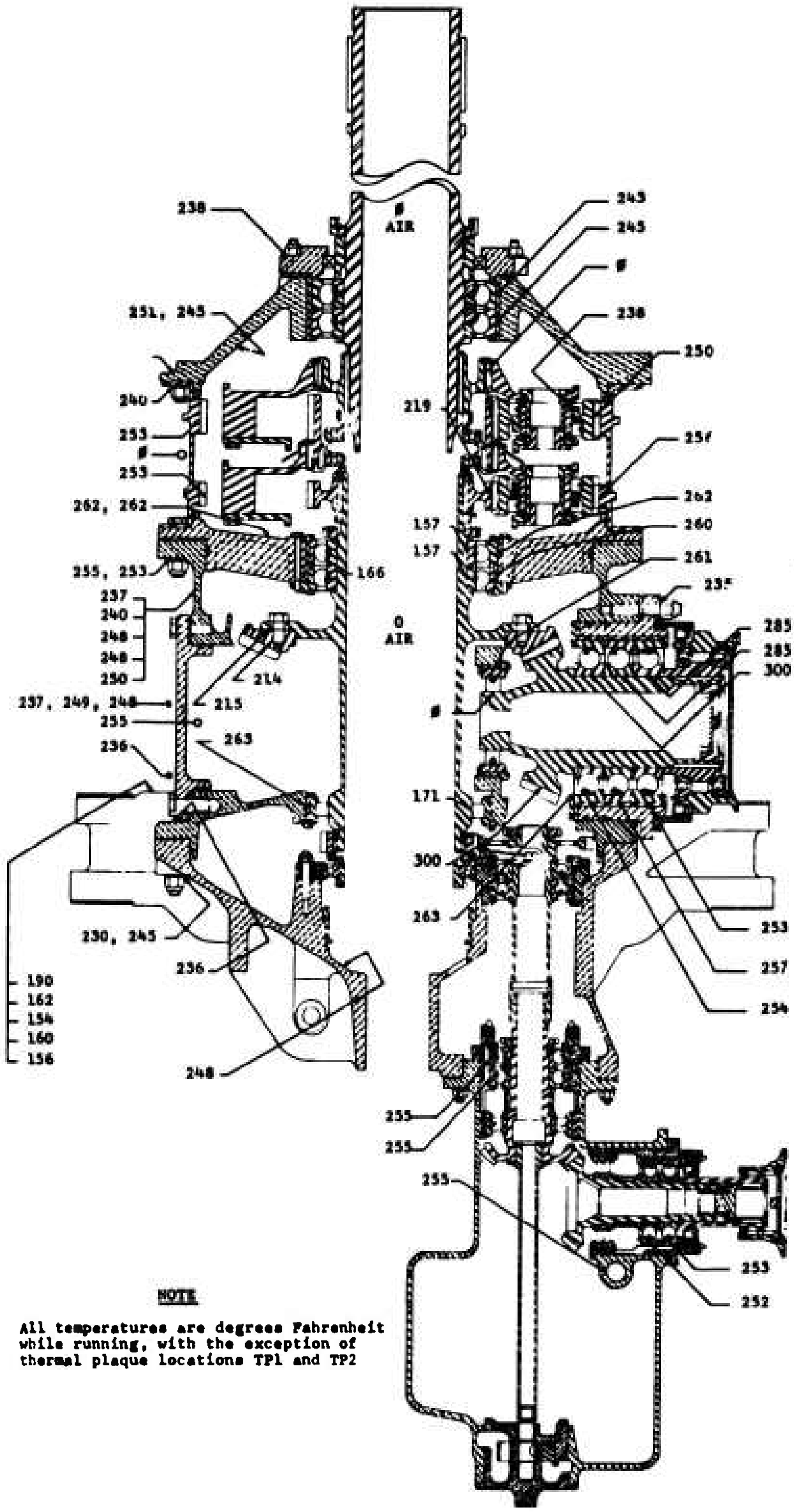
Figure 24. Thermal Map, 90% Torque, 230°±5 °F Oil Out.



NOTE

All temperatures are degrees Fahrenheit while running, with the exception of thermal plaque locations TP1 and TP2

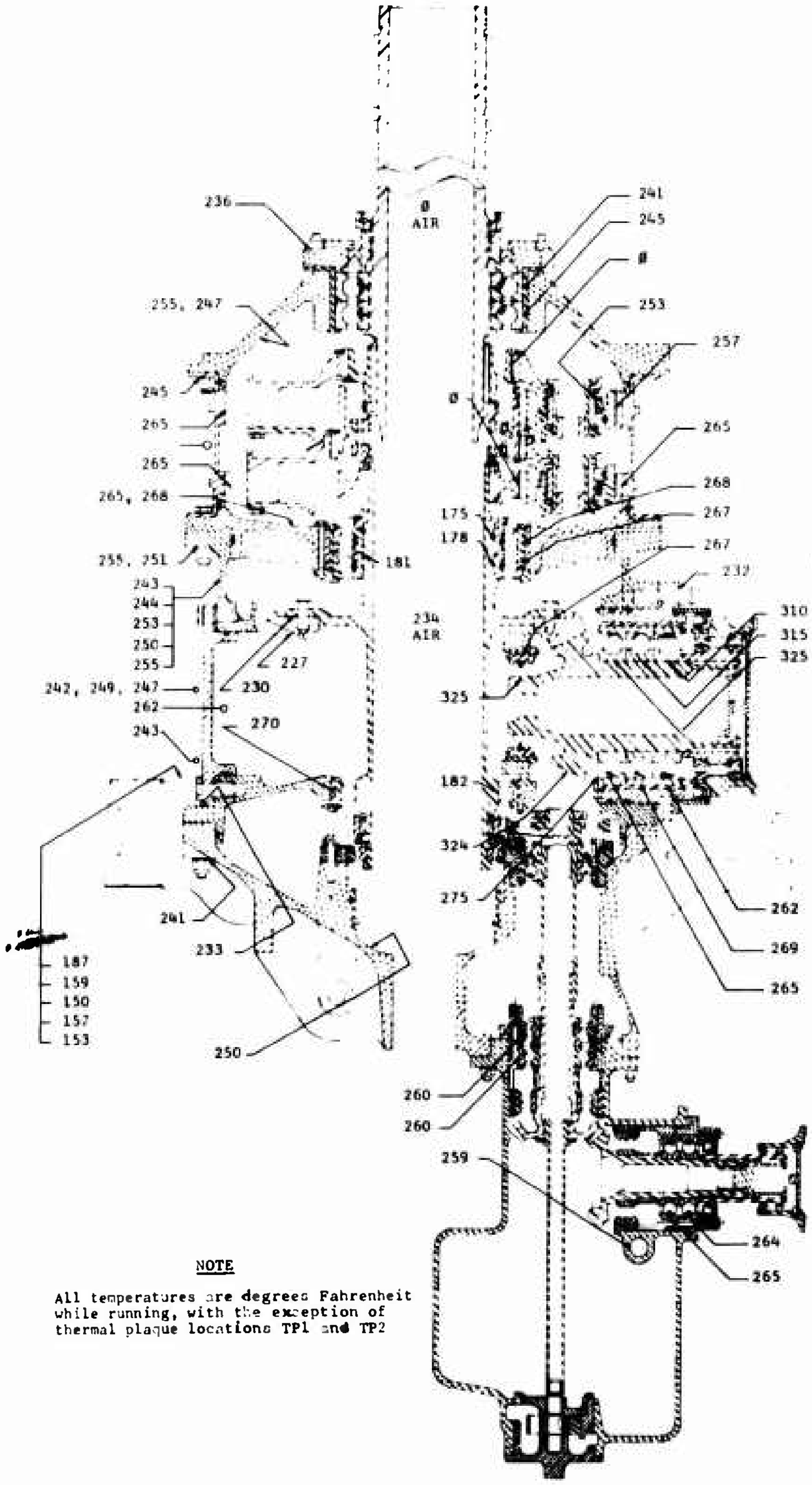
Figure 25. Thermal Map, 100% Torque, 230°±5°F Oil Out.



NOTE

All temperatures are degrees Fahrenheit while running, with the exception of thermal plaque locations TP1 and TP2

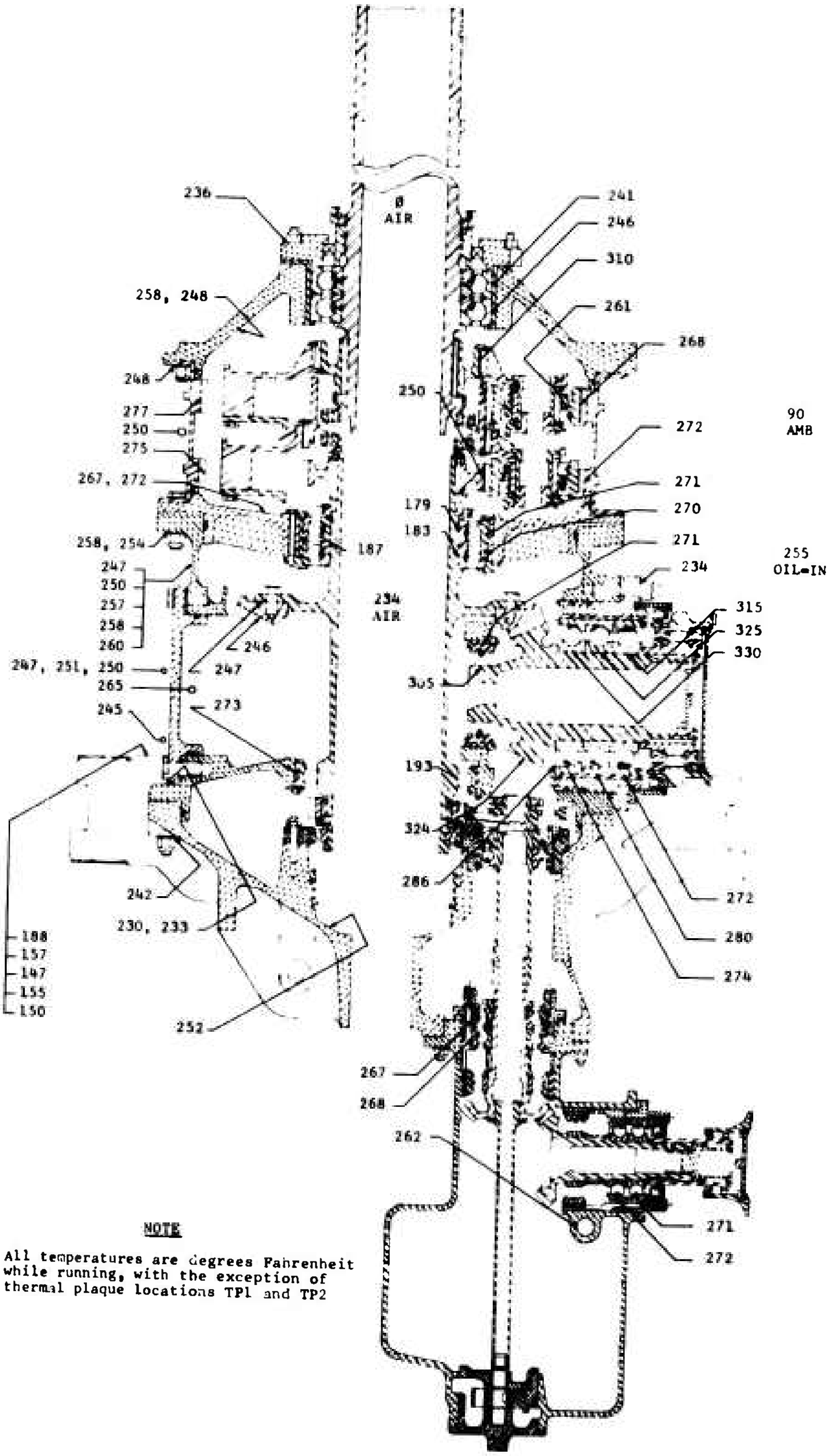
Figure 26. Thermal Map, 60% Torque, 260°±5°F Oil Out.



NOTE

All temperatures are degrees Fahrenheit while running, with the exception of thermal plaque locations TP1 and TP2

Figure 27. Thermal Map, 90% Torque, 260°±5°F Oil Out.



NOTE

All temperatures are degrees Fahrenheit while running, with the exception of thermal plaque locations TP1 and TP2

Figure 28. Thermal Map, 100% Torque, 260°±5°F Oil Out.

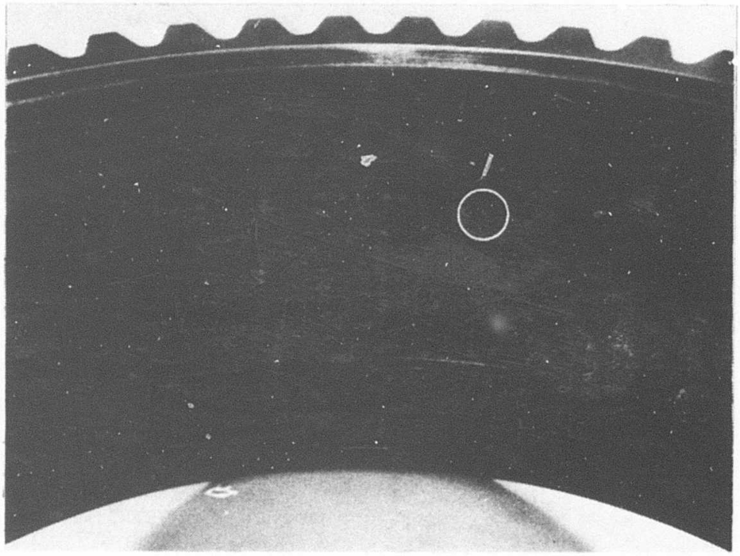


Figure 29. Thermal Plaques on the Upper Sun Gear, 60% Torque, 260°±5°F Oil Out. Circle Indicates Maximum Exposure of 310°F.

set, the spiral bevel gear shaft, and the sump drive spur gear set was required. An inspection of all gears and bearings remaining gave no indication of debris damage above the spiral bevel set, although some damage in the form of light scoring was noted to the sump bevel set. Photographic documentation of all components was made. Figures 30 and 31 show the damaged gears. Figures 32 through 37 exhibit the condition of the remaining gears, and Figure 38 shows the condition of the upper sun gear thermal plaques at this point. Figure 39 shows the plaques on the gear shaft.

It was noted that no apparent change had occurred in the condition of any of the remaining gears. The gear shaft was not visibly damaged, but inspection indicated that the bevel gear flange had approximately six-thousandths inch runout and was replaced. A new spiral bevel gear set was obtained for continuation of the test. This set was modified for the insertion of thermocouple probes, as the previous set had been, with the exception that the implant holes in the gear teeth roots were eliminated and the mesh thermocouples were bonded directly to the root area. All remaining transmission components were cleaned with solvent to remove any undetected debris and were reassembled for continuation of testing. The program was resumed at the beginning of the second segment of Run 3. The pattern and condition of the main input spiral bevel set were examined following each segment of test Run 3. At the beginning of the second segment, it was noticed that due to a malfunction in the test stand heat exchanger water valve, the target test temperature of 300°F oil-out would not be obtained. No replacement valve was available, and due to the rapidly approaching completion date, it was decided to continue testing in a totally bypassed condition. Although the total heat soak effect would not be obtained, it was felt that the data obtained would be representative of the gradients observed during the prior test segments. During the final two test segments, observation showed that moderate to severe vaporization of the oil was occurring in the gearbox, as a dense vapor filled the entire cell area. The oil seal at the main shaft also began to leak slightly, before the end of segment two. This leak manifested itself in the form of a few drops per minute. By the end of the third segment, these few drops had progressed to a steady rate of approximately 120 drops per minute. Due to this leakage, approximately one quart of oil had to be added to the transmission following each inspection shutdown during this test run. The oil that remained in the system was still clear and showed no signs of chemical breakdown. Figures 40, 41, and 42 are the thermal maps obtained during this test. The final gear inspection showed good pattern placement and condition.

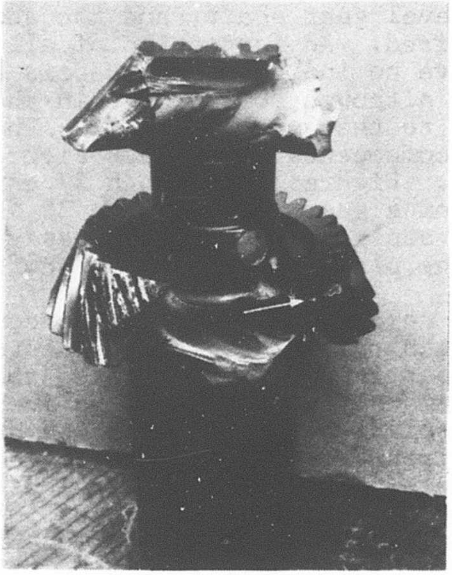


Figure 30. Damaged Pinion After Failure at 90% Torque, 330°±5°F Oil Out (Arrow Indicates Fatigue Origin in Hole Drilled for Thermocouple).

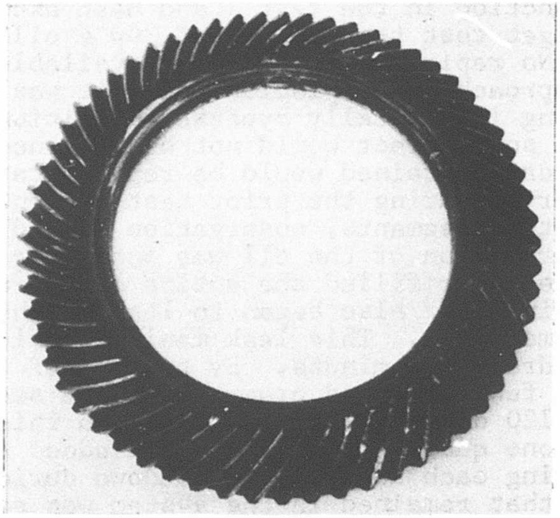


Figure 31. Damaged Gear.

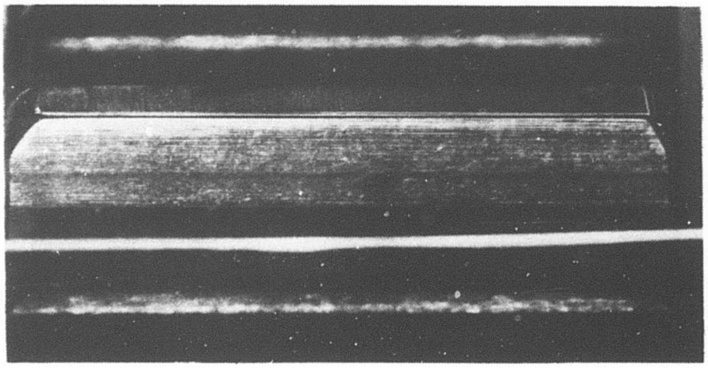


Figure 32. Upper Planetary Gear Following Input Pinion Failure at 90% Torque, 300°±5°F Sun Gear Side.

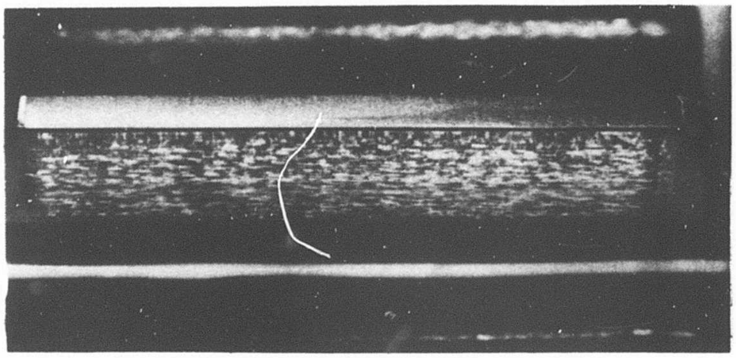


Figure 33. Upper Planetary Gear Following Input Pinion Failure at 90% Torque, 300°±5°F Ring Gear Side.

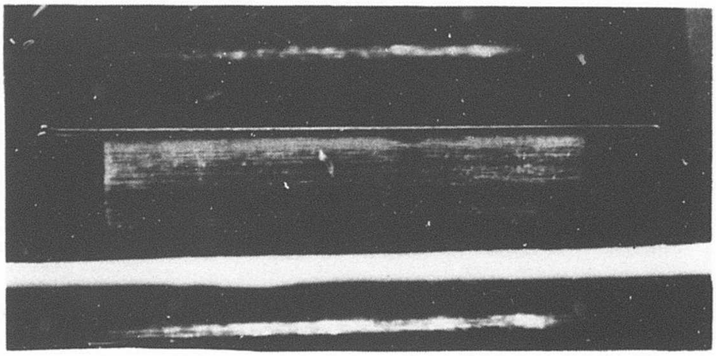


Figure 34. Lower Planetary Gear Following Input Pinion Failure at 90% Torque, 300°±5°F Sun Gear Side.

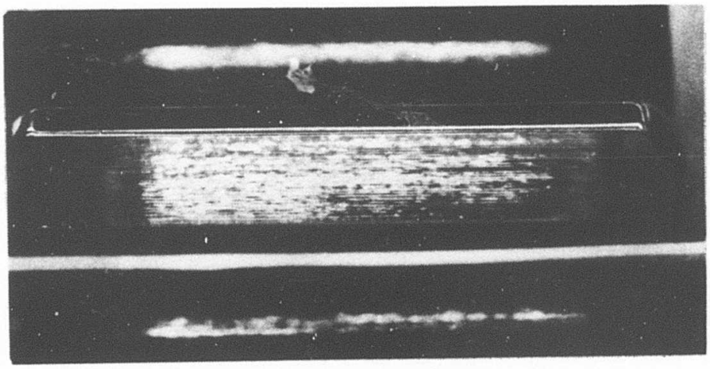


Figure 35. Lower Planetary Gear Following Input Pinion Failure at 90% Torque, 300°±5°F Ring Gear Side.

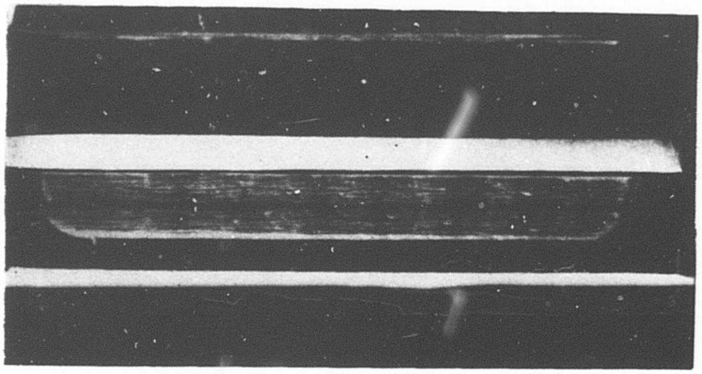


Figure 36. Upper Sun Gear Following Input Pinion Failure at 90% Torque, 300°±5°F Oil Out.

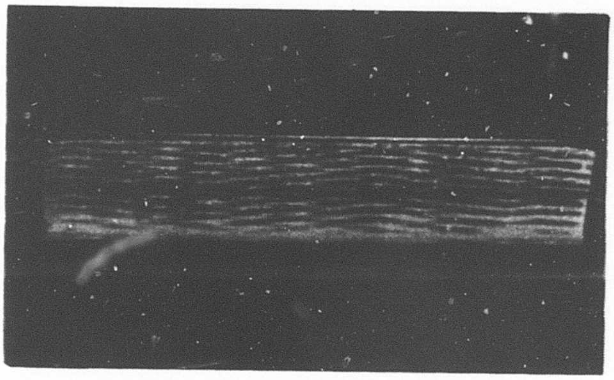


Figure 37. Lower Sun Gear Following Input Pinion Failure at 90% Torque, 300°±5°F Oil Out.

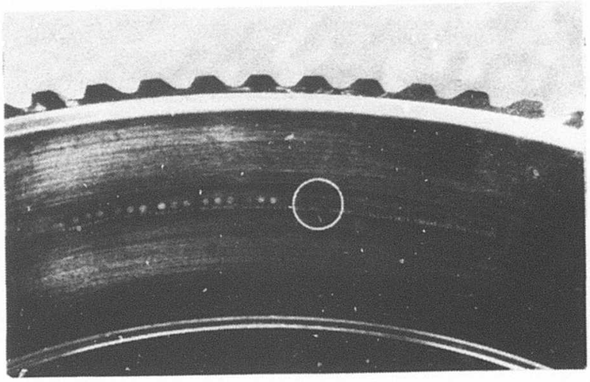


Figure 38. Thermal Plaques Following 60% Torque Run at 300°F Sump Oil. Circled Plaque Shows Maximum Exposure of 340°.

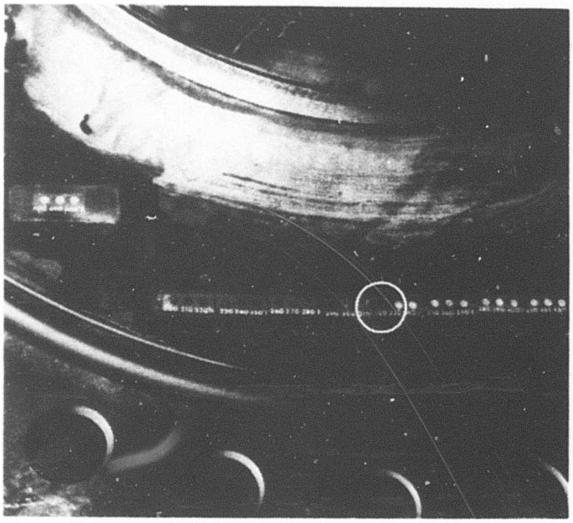
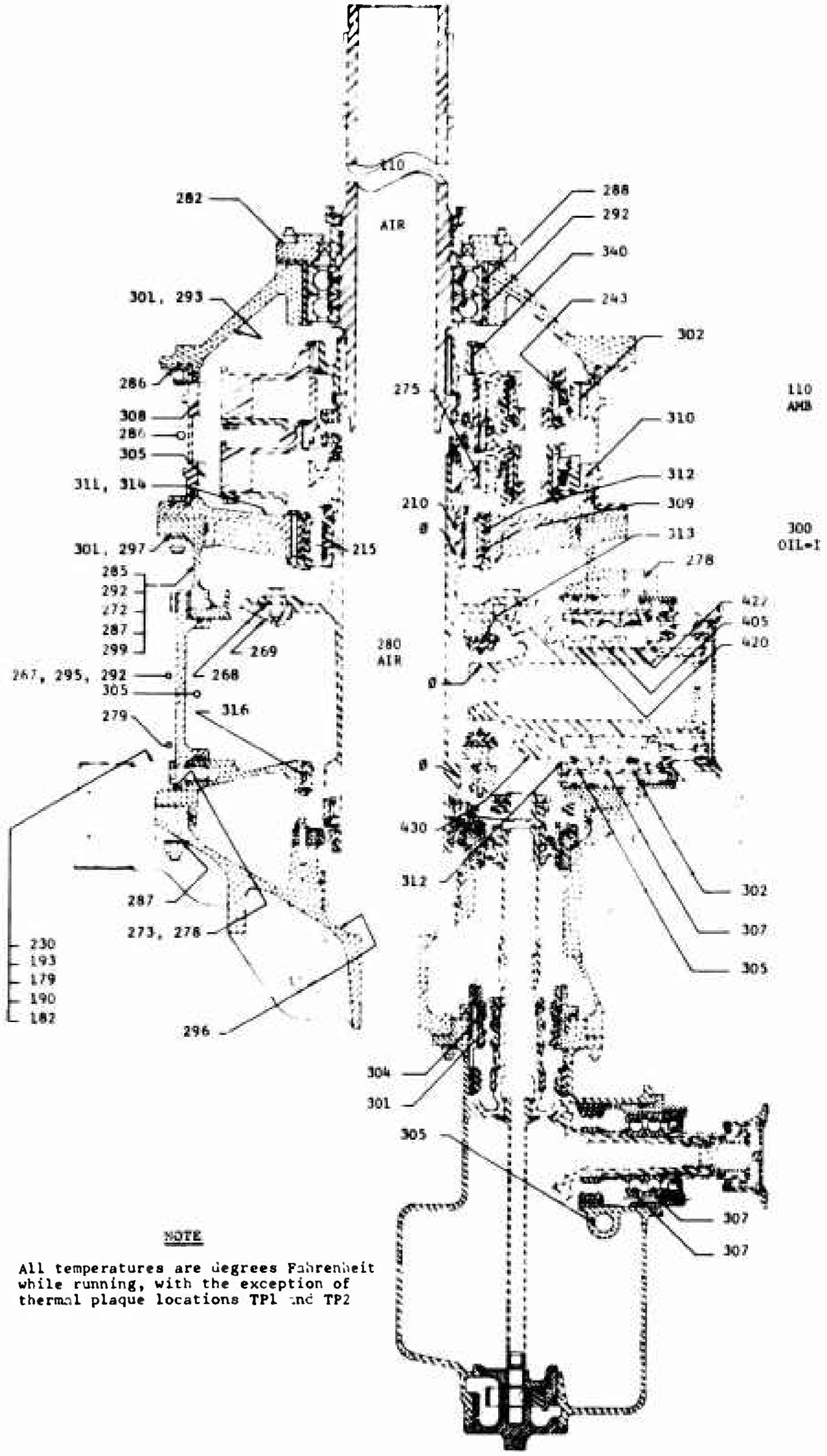


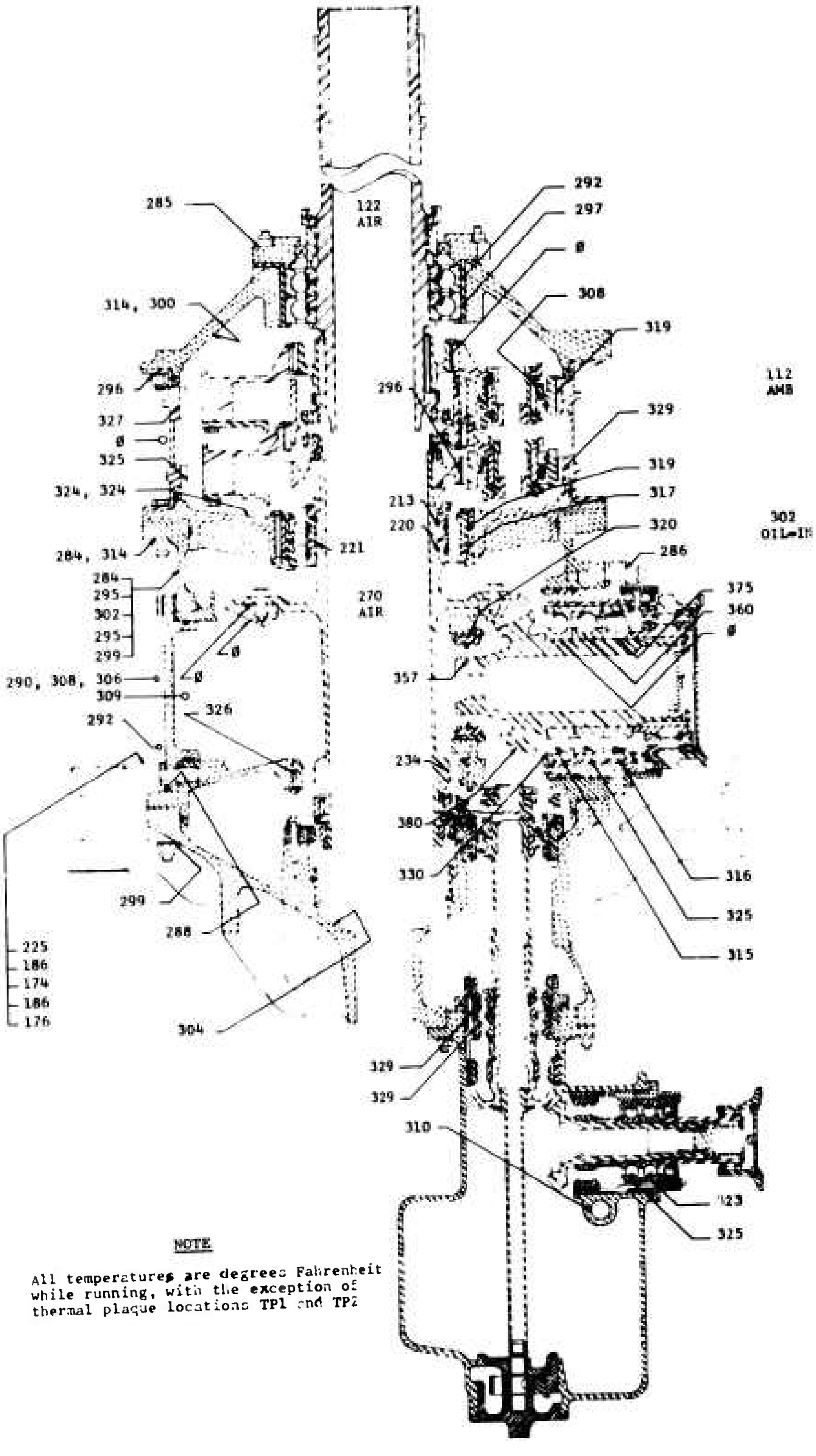
Figure 39. Thermal Plaques on the Bevel Gear Support Shaft Following the Input Bevel Gear Failure, 300°±5°F Oil Out. Circle Indicates Maximum Exposure of 320°.



NOTE

All temperatures are degrees Fahrenheit while running, with the exception of thermal plaque locations TP1 and TP2

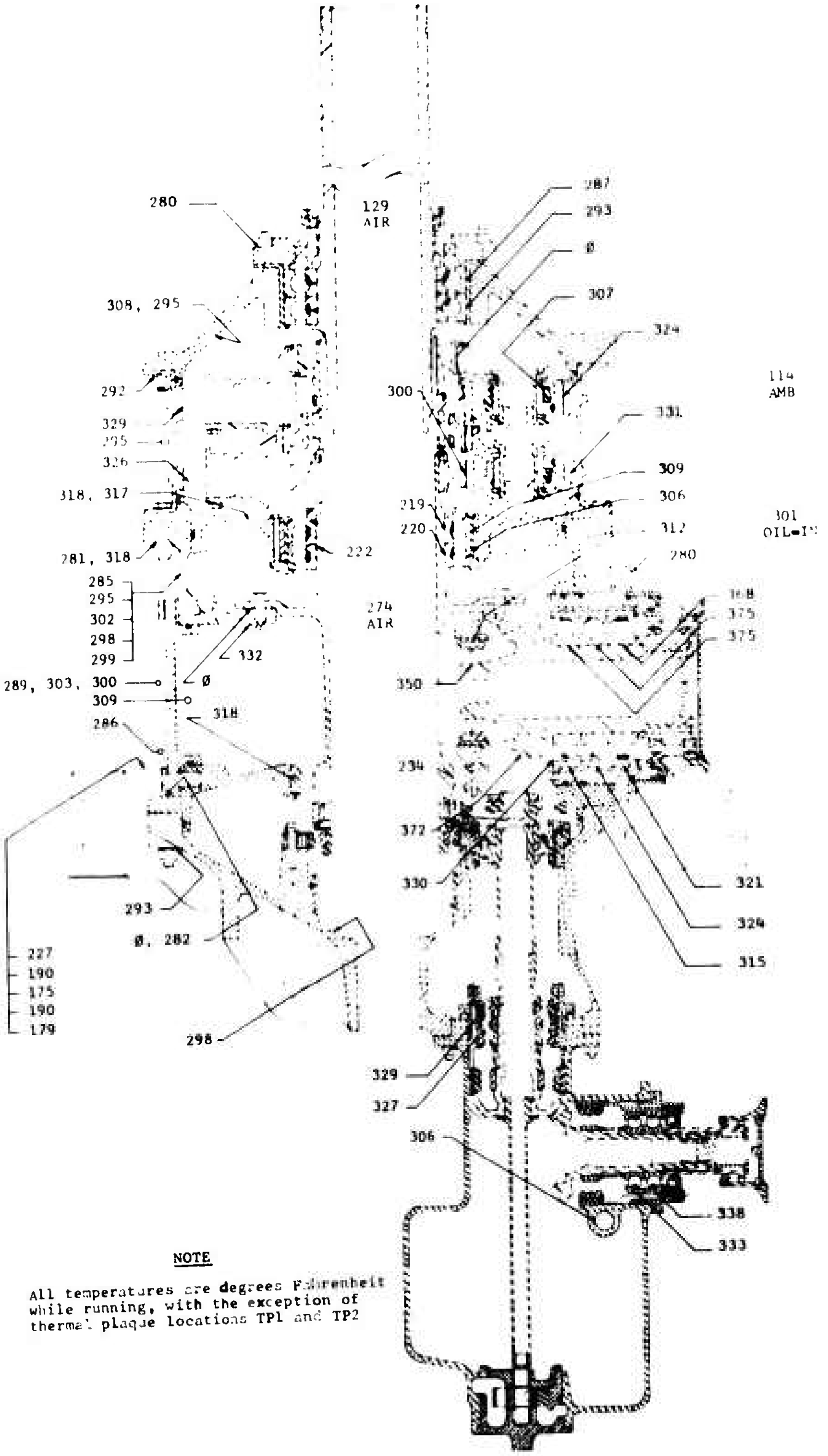
Figure 40. Thermal Map 60% Torque, 300°±5°F Oil Out.



NOTE

All temperatures are degrees Fahrenheit while running, with the exception of thermal plaque locations TP1 and TP2

Figure 41. Thermal Map 90% Torque, 300°±5°F Oil Out.



NOTE

All temperatures are degrees Fahrenheit while running, with the exception of thermal plaque locations TP1 and TP2

Figure 42. Thermal Map 100% Torque, 300°±5°F Oil Out.

The data indicated for the triplex bearing inner ring and pinion tooth temperatures in Figure 40 reflect the temperatures recorded just prior to the bevel pinion failure, and they therefore seem extrodinarily high in relation to the rest of the figures of this set.

TEST 4 - THERMAL DATA AND INSPECTION, 345°F OIL-OUT

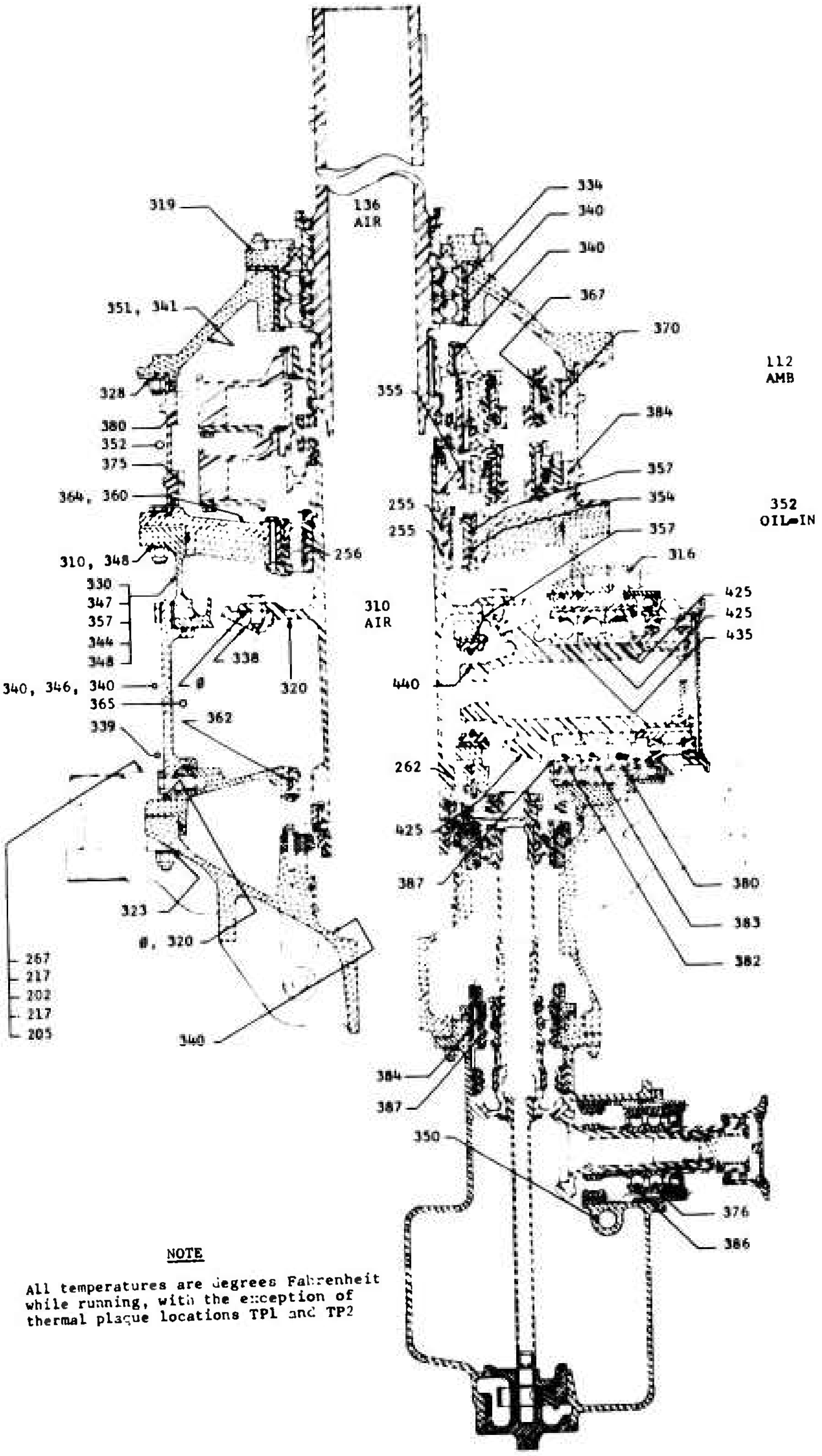
Test 4 was continued in the same manner as Test 3, with an inspection of the input bevel gear following each segment of the run. Throughout this test run, for all segments, the gear pattern and its placement remained good; no degradation of the observed gear was apparent. The oil leak at the main input pinion steadily increased during each segment until at termination of the final run segment a stream of oil approximately .06 inch in diameter was steadily being ejected from around the seal area. Again it must be stated that the oil temperatures recorded on the thermal maps made during this run (Figures 43, 44, and 45) are not at a true stabilized condition, but were actually rising when the test segment was terminated at the target temperature. This condition was due to the previously explained situation. Figure 46 represents the upper sun gear thermal plaques, and Figure 47 shows the input bevel gear support shaft thermal plaques following this run. Figures 48 through 57 are documentary photographs of all components at the termination of testing.

THERMAL GROWTH DATA

Thermal growth data was taken at predetermined points on the test transmission after each of the test runs. Each time growth data was recorded, the temperatures of the measured components were recorded for use in determining this growth. The derived results of these measurements appear in the section of this report entitled "Data Reduction and Evaluation." Table V gives the growth data obtained during a representative run.

INFRARED CAMERA DATA

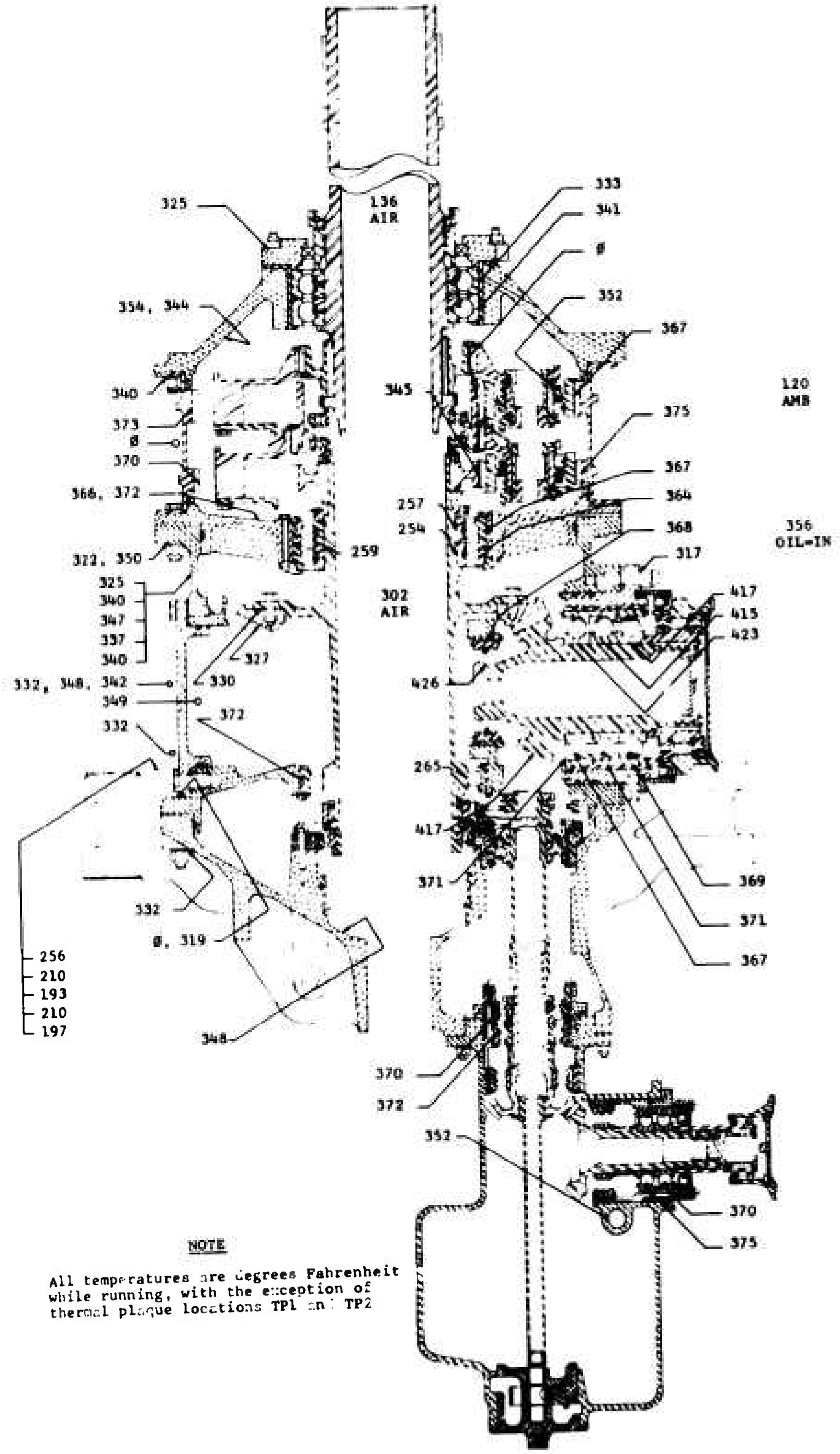
Infrared photography was used as a means of recording the upper section temperature gradients. These gradients were recorded periodically throughout the test program and provided an excellent overall view of the transmission thermal gradient and heat flow. The data obtained by the equipment was recorded as C scan (continuous oscillating sweep similar to television raster) and was photographed with a camera attached to a rotating, seven-color wheel which provided a means of representing seven isothermal levels, each in a different color. Figure 58 depicts some photographs obtained



NOTE

All temperatures are degrees Fahrenheit while running, with the exception of thermal plaque locations TP1 and TP2

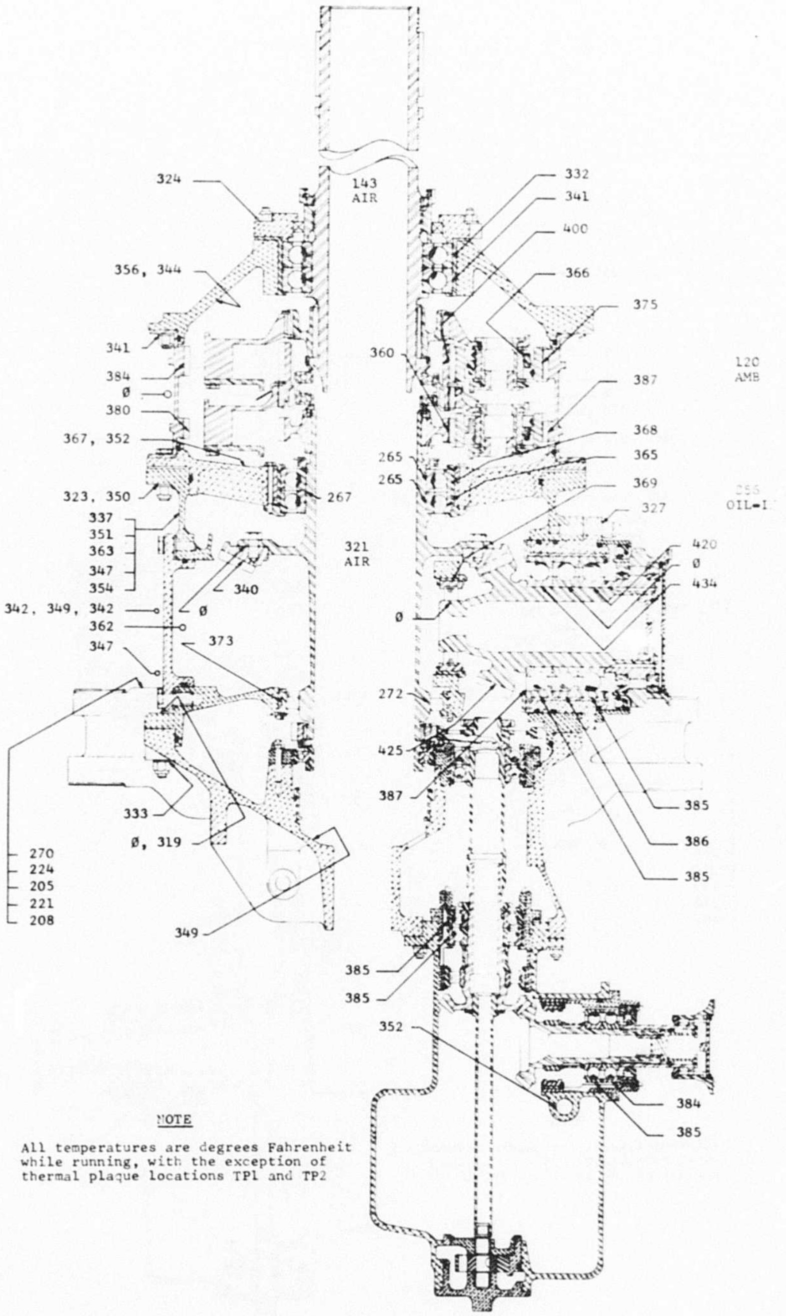
Figure 43. Thermal Map 60% Torque, 345°±5°F Oil Out.



NOTE

All temperatures are degrees Fahrenheit while running, with the exception of thermal plaque locations TP1 and TP2

Figure 44. Thermal Map 90% Torque, 345°±5°F Oil Out.



NOTE

All temperatures are degrees Fahrenheit while running, with the exception of thermal plaque locations TP1 and TP2

Figure 45. Thermal Map 100% Torque, 345°±5°F Oil Out.

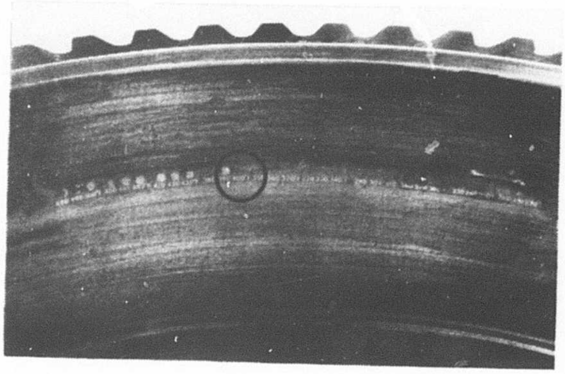


Figure 46. Upper Sun Gear Thermal Plaques Following 345°±5°F Oil Out. Circle Indicates Last Dot Turned Is 400°F; 390°F Dot Did Not Turn.

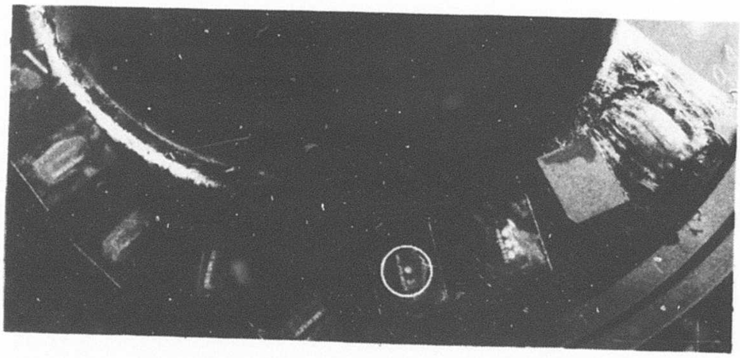


Figure 47. Bevel Gear Support Shaft Following 345°±5°F Oil Out. Circle Indicates Last Dod Fully Turned Is 380°F, With 400°F Dot Partially Exposed; 390°F Dot Not Exposed.

Figure 48. Input Bevel Gear Following Final Test Run at 345°±5°F Oil-Out Temperature.

Figure 49. Input Bevel Pinion Following Final Test Run at 345°±5°F Oil-Out Temperature.

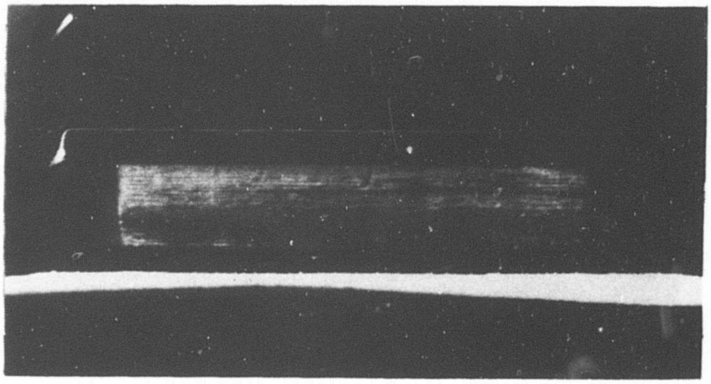


Figure 50. Lower Planetary Pinion Sun Gear Side Following 345°±5°F Oil-Out Temperature.

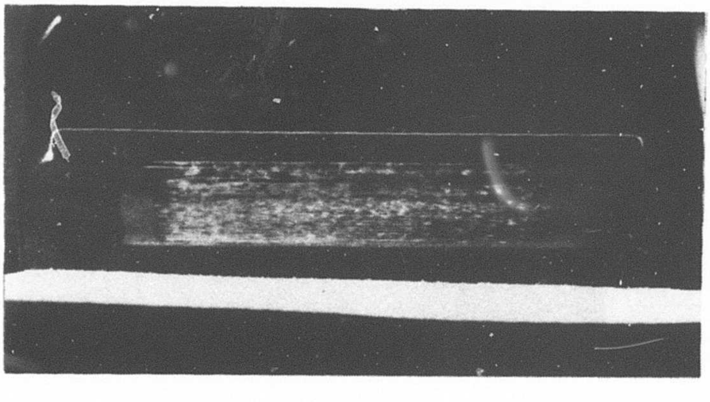


Figure 51. Lower Planetary Pinion Ring Gear Side Following 345°±5°F Oil-Out Temperature.

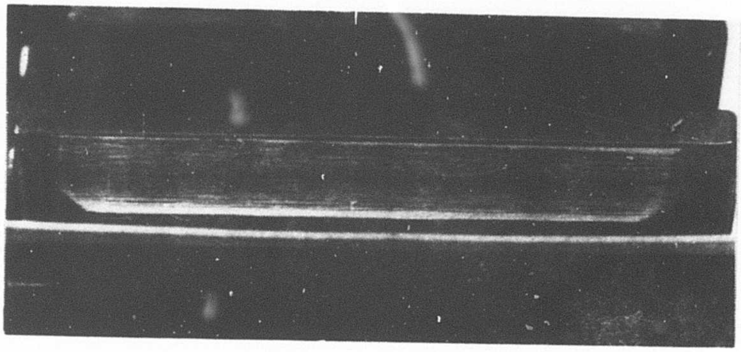


Figure 52. Upper Sun Gear Following 345°±5°F Oil-Out Temperature.

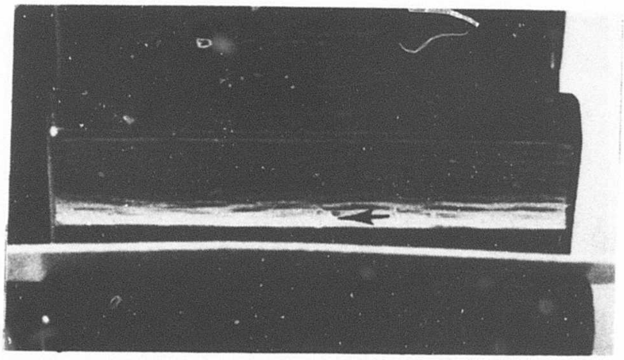


Figure 53. Lower Sun Gear Following 345°±5°F Oil-Out Temperature. Arrow Indicates Debris Damage of Unknown Origin.

Figure 54. Sump Output Gear After 345°±5°F Oil-Out Temperature.

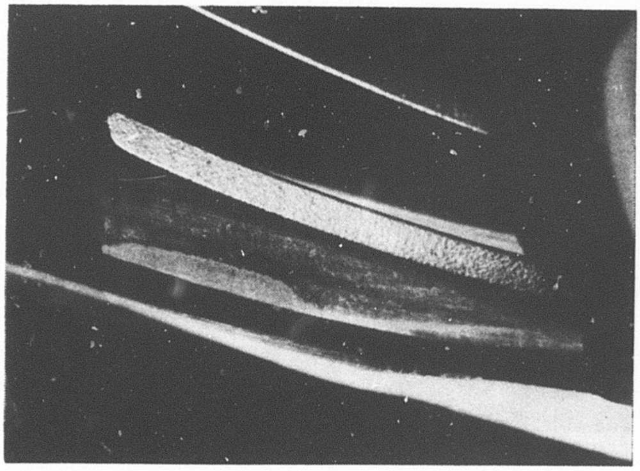


Figure 55. Sump Input Pinion After 345°±5°F Oil-Out Temperature.

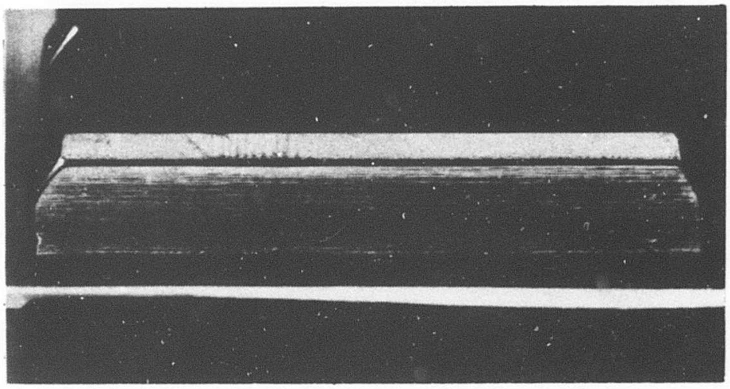


Figure 56. Upper Planetary Pinion Sun Gear Side Following 345°±5°F Oil-Out Temperature.

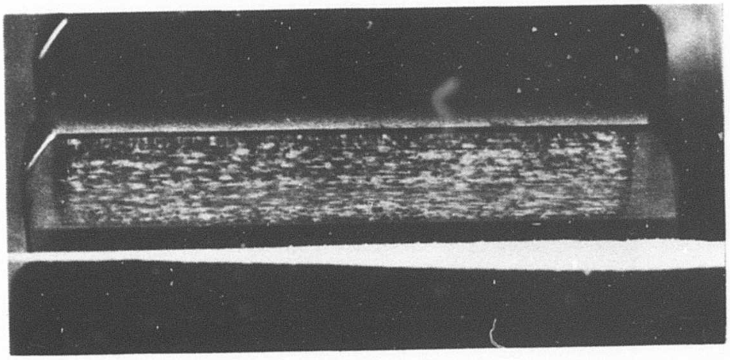
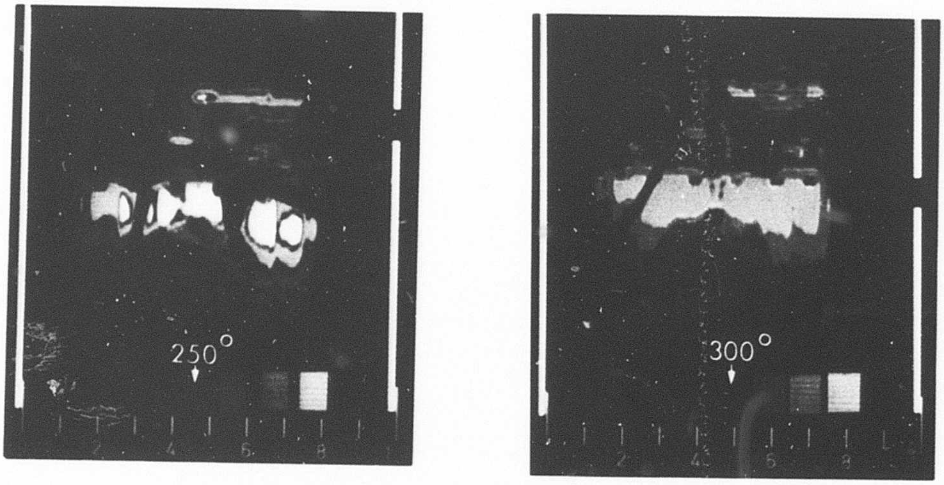


Figure 57. Upper Planetary Pinion Ring Gear Side Following 345°±5°F Oil-Out Temperature.

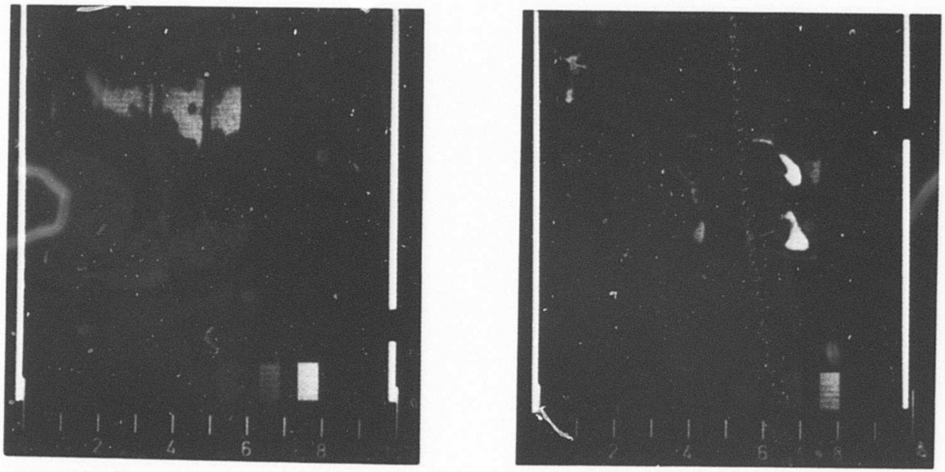
TABLE V. DIMENSIONAL GROWTH EVALUATION

	Matl.	Low Temp (inches) L_C	T_C	High Temp (inches) L_H	T_H	$T = T_H - T_C$	$\frac{\Delta L}{L_C}$/ $T \times 10^6$	Coefficient of Expansion $K \times 10^6$
Dia D_1	Mag	17.284	80°	17.328	300°	220	11.6	15.1
Dia D_2	Steel	15.566	80°	15.581	300°	220	4.3	6.5
Dia D_3	Steel	15.367	80°	15.375	300°	220	2.4	6.5
Dia D_4	Steel	15.090	80°	15.110	300°	220	6.0	6.5
Dia D_5	Steel	15.090	80°	15.116	300°	220	7.8	6.5
Dia D_6	Steel	15.001	80°	15.020	300°	220	5.7	6.5
Dia D_7	Mag	17.116	80°	17.164	285°	205	13.6	15.1
Dia D_8	Mag	17.188	80°	17.254	285°	205	18.7	15.1
Dia D_9	Mag	8.659	80°	8.682	285°	205	12.9	15.1
Dia D_{10}	Alum	8.634	80°	8.656	285°	205	12.4	13.1
Dim A_1	Steel	4.725	80°	4.724	300°	220	- 0.9	6.5
Dim A_2	Mag	8.910	80°	8.936	285°/ 250°	265	11.0	15.1



260° Oil Out
Each Color 10°F

300° Oil Out
Each Color 20°F



300°F Oil Out

Colors as Follows:

Red	175°F
Green	140°F
Purple	280°F
Light Blue	300°F

300°F Oil Out

View of Sump Showing Gradients Not Used for **Quantitative Data**

Figure 58. Infrared Photographs.

at various stages during the test program, and they are representative of the bulk of all photographs obtained, in that the gradients themselves remained in about the same relationship, for the portion of the transmission shown, at any given oil-out temperature.

DATA REDUCTION AND EVALUATION

The purpose of this section is to evaluate the data gathered and to reduce it into a reasonably short, yet complete, analysis of the major components of the UH-1 transmission and the part that each contributes to the heat generation in the gearbox during operation. In addition, the heat rejection of the cases and components and the thermal growth of the transmission will be discussed.

The predominate area of heat generation, as noted from the test data, upholds the pretest assumption that the location of greatest heat generation would be in the area of the high-speed input bevel pinion. Throughout the program, the inboard input triplex bearing inner ring manifested itself as the item generating the greatest quantity of heat. The other two bearings of this set were very close to this temperature. The pinion mesh temperature followed the inboard input bearing inner ring as the second largest heat source, with the pinion roller bearing being very close as third highest source of heat generation.

Both planetary stages comprise the next most critical area. From the thermal maps in the preceding section of this report, thermal data appears only periodically for the upper sun gear but consistently for the lower sun gear. The reason is noted on each map: some locations contain thermal plaques while the preponderance of locations are recorded in real time from the thermocouples. These plaques were observed only at periodic teardown inspections.

Post-run temperature as indicated by the thermal plaques inside the upper sun gear showed an apparent higher level than the lower sun gear. However, the lower sun gear was instrumented with thermocouples, and, as shown in Figure 57, the real-time monitoring afforded by the sliprings before and after shutdown definitely showed that thermal soak-back existed. The temperature redistribution at shutdown resulted in an immediate cooling trend for the lower sun gear followed by a gradual increase. The increasing temperature is evidence of the soak-back phenomenon. An actual peak soak-back temperature was not obtained due to abbreviated post-run monitoring. Soak-back was not observed until the actual runs were completed and data reduction commenced. The inference

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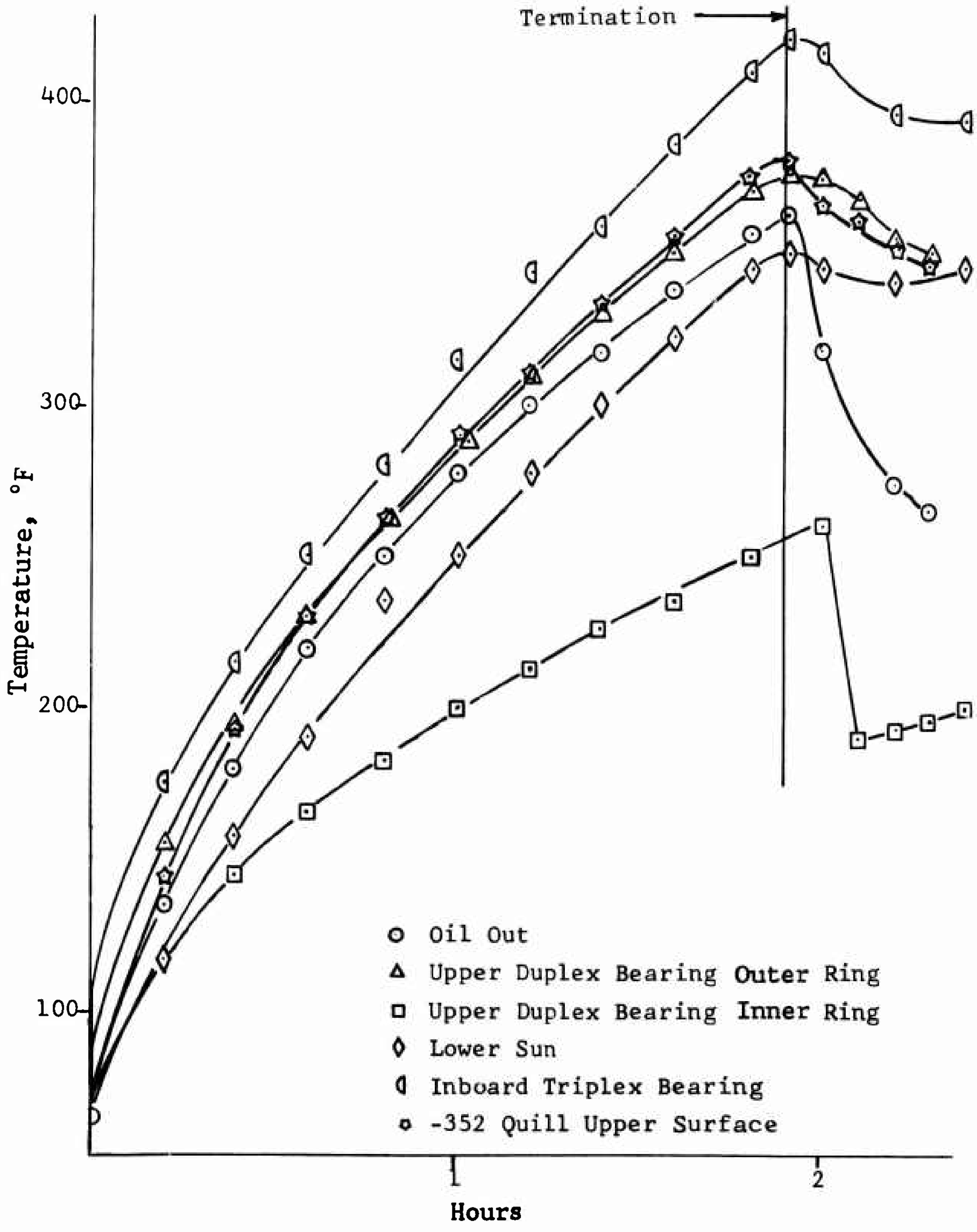


Figure 59. Graph Depicting Thermal Soak-Back Phenomenon.

made from these observations is that actual stabilized running temperatures could have been lower than indicated by the thermal plaques, since the thermal plaques only provide peak temperature data and are independent of time.

The duplex and roller bearings on the input gear shaft exhibited apparent atypical heat-generating characteristics in that the outer rings were hotter than the inner rings. However, considering the speed range, load intensity, and location of the gear shaft, the resulting temperature distribution is credible. The gear shaft is located on the mast centerline and is the innermost rotating member. The oil flow distribution is such that very little jetted oil and virtually no cascading oil impinge on the gear shaft; hence, heat influx to the gear shaft from the hot oil is not exhibited. Inner ring temperature levels are therefore a function of bearings and gear mesh frictional input, while the outer rings have the additional referred heat from the housings which in turn are heated by the adjacent planetaries and cascading oil at the outer periphery. Finally, the cooling effect of the center transmission void space as influenced by the main rotor mast provides an overall increasing temperature field from transmission centerline to the outer diameters.

SUMP BEARINGS AND GEARS

Analysis of data derived from the thermocouple implants in the sump section of the transmission tested is confounded by the fact that it becomes almost impossible to differentiate between heat generated by this section's elements and that imparted to these components by the oil from the upper sections that supply the lubrication. From the preponderance of the data gathered during the test, it is reasoned that the heat generated by these elements is insignificant in comparison to that generated in the upper sections, and therefore reflect lubricant temperature. The scoring present on the sump gears is, in all likelihood, due to debris damage from the main input pinion failure during the second segment of the 300°F run and not a result of the heat, as the scoring was present following this failure and did not progress during later test runs.

External case temperatures reflect the areas of high heat as being those in close conjunction with the areas earlier mentioned as being the major heat generators. As seen in the infrared photographs, these areas are localized hot spots or bands where the oil from these heat generators is being centrifuged against the walls of the case. These hot spots cool fairly rapidly, losing an average of approximately 30 degrees across the height of the main case. The support case upper surface exhibits a very low temperature relative to the surrounding and attached structures. This may be observed both on the thermal maps and in the infrared photographs. This low relative temperature is attributed to the fact that this case has very little real wetted area, and its heat arises only by conduction or radiation from the support case undersurface along which oil drains back into the sump cavity and by conduction from the attached main case.

Of all the areas of the transmission measured for thermal effects, the area shown to be the coolest is one of the areas most exposed to the atmosphere: the mast. Thermal data taken throughout the program indicates that the mast temperature is, from a few inches above the mast bearings to the top of the mast, almost the same as the surrounding air. Little or no heat transfer occurs between transmission and main rotor mast.

THERMAL GROWTH

Thermal growth data generated during this program indicates that there is general conformity with the published data for the expansion rates of materials. Table V shows that exact conformity with these rates is not exhibited at any of the discrete points selected for measurement.

In measurements taken on the transmission main case, a very well defined thermal gradient exists, which makes measurements across the total height or width erroneous for determining thermal expansion coefficients. Measurements taken on and around the ring gear case appear inaccurate, especially the growth measured between flanges, which indicates a negative growth. However, the section view presented enumerating the locations of the measurements shows that the ring gear is used to pilot the two mating cases: the top case and the bevel gear support case. Both of these cases are magnesium, whereas the ring gear is steel. This situation then may be used to explain the negative growth presented in the Results section. Since the expansion rate of magnesium is more than twice that of steel, a forcing effect is exerted at both flanges of the ring gear, causing them to be deflected toward each other. This causes all measurements taken on this part to reflect this action.

CONCLUSIONS

1. As anticipated in pretest analysis, the major heat-generating area was the input spiral bevel pinion and its supporting bearings.

2. The thermal preload that exists on the input pinion triplex bearing inner rings compounds the operating stresses.

3. The upper and lower planetary assemblies apparently generate the same amount of heat. The upper planetary operates at high load and low speed, while the lower planetary operates at lower load and higher speed.

4. Temperature characteristics exhibited during full oil cooler bypass indicate that thermal stability is not attainable at powers at or above 60% in still air.

5. Relative temperature and increasing temperature gradients from the transmission centerline outward to the housing walls reveal the possibility of utilizing the main rotor mast as an effective oil cooling unit. This could be implemented by pressure jetting the hot oil up the inside of the mast and allowing gravity return along the inside wall.

RECOMMENDATIONS

Further studies and tests should be made to:

1. Determine the effectiveness of the main rotor mast as an oil cooler.
2. Determine with the existing UH-1 transmission if temperature stability could be attained without an oil cooler at power above 60% in still air, making a parallel determination with forced-air cooling.
3. Investigate the cost effectiveness and adequacy of finning the transmission housings.
4. Determine if the temperature characteristics of sump bearings (outer rings hotter than inner rings) are caused by hot oil cascading from the input bevel gear area and planetary area.
5. Modify the input pinion triplex bearing to eliminate axial preload, and repeat mapping test for the input bevel gear area.

APPENDIX I

THERMAL PLAQUES

The temperature indicators are accurate from 200°F to 400°F if the part is allowed to soak at temperature for approximately 30 minutes. Any less soak time than this will result in a partial change of the actual temperature indicator.

Above 400°F the results were not predictable, in that some spots would go early and some would go late. For instance, the 490°F spot changed at approximately 420°F, the 480°F spot was one-half changed at 470°F, and at 525°F the 550°F spot changed.

Actual Results

Furnace Temp.	Results
220°F	210 and 220 changed - 30 min soak
230°F	230 changed - 30 min soak
240°F	240 changed - 30 min soak
250°F	250 one-half changed - 15 min soak
260°F	260 changed - 30 min soak
280°F	270 and 280 changed - 30 min soak
300°F	290 and 300 changed - 30 min soak
325°F	320 changed; 330 did not - 30 min soak
340°F	330 and 340 changed - 30 min soak
350°F	350°F changed - 30 min soak
360°F	360 one-half changed - 10 min soak
380°F	370 and 380 changed - 30 min soak
410°F	390 and 400 changed - 15 min soak
420°F	410, 430, and 490 changed - 30 min soak

Furnace Temp	Results
450°F	450 and 465 changed - 30 min soak
470°F	480 one-half changed - 20 min soak
500°F	
525°F	525 and 550 changed - 30 min soak

APPENDIX II

TRANSMISSION EFFICIENCY AND HEAT REJECTION ANALYSIS

Efficiency Analysis

The efficiency of the UH-1 transmission is 98.4%. This was first determined by test and later verified analytically. The results of the analytical analysis based on 1100 hp input is shown below.

Item	HP Loss
Upper Planetary Gears	5.06
Lower Planetary Gears	3.04
Planet Bearing Cages	.12
Spiral Bevel Gears	4.56
Input Triplex Bearing	2.203
Gear Shaft Duplex Bearing	.634
Total Windage	2.274
Total HP Loss	17.891

$$\text{Efficiency} = \frac{1100\ \text{HP} - 17.891\ \text{HP}}{1100\ \text{HP}} \times 100 = 98.4\%$$

The above analysis predicts the primary heat generators to be the planetaries, the bevel gears, and the triplex and duplex bearings. Thus, those components should be monitored with thermocouples or thermal plaques during the test.

Heat Rejection Analysis

As previously stated in "Heat Rejection Characterisitcs" on page 16, the UH-1 transmission transfers 508 Btu/min to the oil cooler and 250 Btu/min to the still test cell air while transmitting 1100 hp. The mode of heat transfer from the case to the surrounding still air is convection and radiation acting in parallel. By calculating the wetted area of the UH-1 transmission, measuring the average skin temperatures of that wetted area, measuring the ambient temperature, and calculating the horsepower loss to the oil cooler, an overall heat transfer coefficient of .00135 Btu/(min-in.^{2} - °F) was calculated as follows:

$$Q_o + Q_a = \text{Total power loss} = 758\ \text{Btu/min}$$

$$Q_a = UA\,\Delta T = 250\ \text{Btu/min}$$

where Q_o = Heat transfer to the oil cooler, Btu/min

Q_a = Heat transfer to the still air, Btu/min

U = Overall heat transfer coefficient, Btu/(min-in.^{2} - °F)

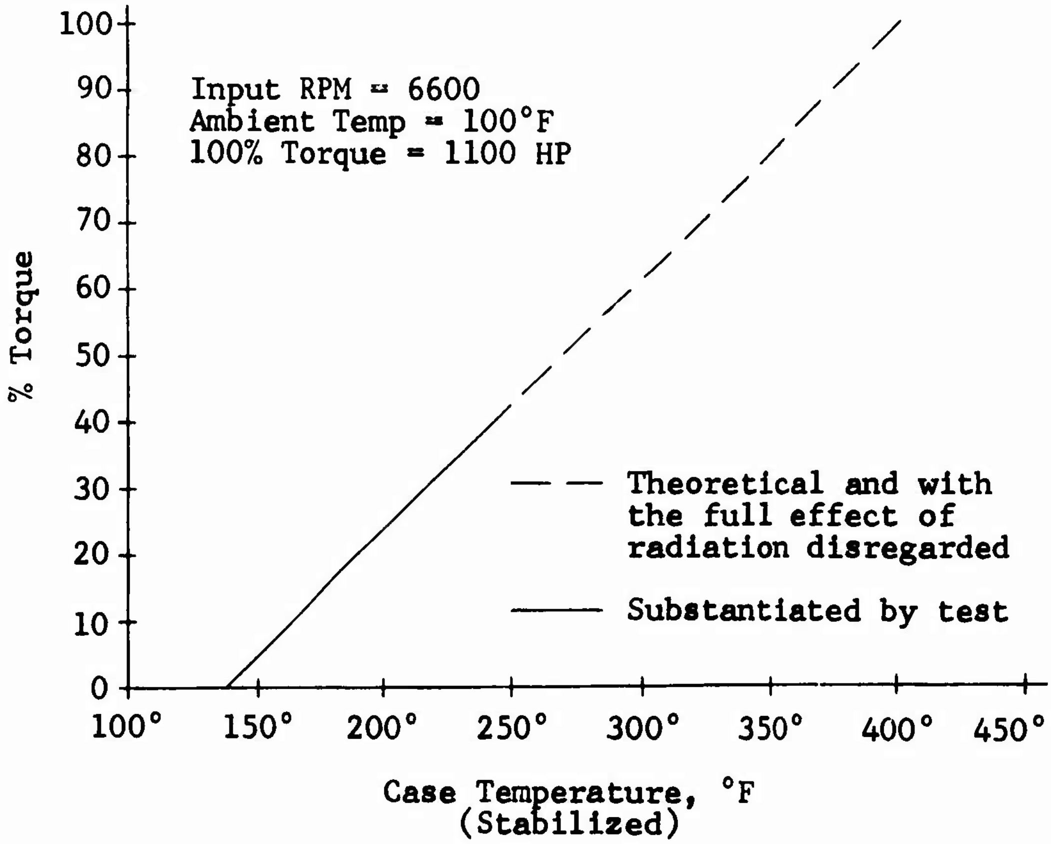
A = Wetted area of cases, in.^{2}

ΔT = Difference between case and ambient temperature, °F

$$250 \text{ Btu/min} = U(1856 \text{ in.}^2)\ 101°\text{F}$$

$$U = .00135 \text{ Btu/(min-in.}^2 - °\text{F)}$$

If the oil cooler is to be completely bypassed, then 758 Btu/min must be transferred through and away from the case walls. Using the overall heat transfer coefficient of .00135, a curve showing the stabilized case temperature as a function of torque with no horsepower loss to the oil cooler can be drawn and is shown below.



The above curve neglects the full effect of heat transfer by radiation. Thus, the theoretical portion of the curve should only be considered as representing the minimum predicted case temperatures.