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COMPARATIVE LUBRICATION STUDIES OF OH-58A TAIL ROTOR DRIVE SHAFT BEARINGS

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Light Observation Helicopter (LOH) Project Managers Office
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St. Louis, Missouri

ABSTRACT

Comparative lubrication tests were run with OH-58A helicopter tail rotor drive shaft bearings. The tests were run in an outdoor environment with ambient temperatures ranging from 10° to 75° F. Dust was periodically applied to the bearings to simulate field conditions. The cause of bearing failure was associated with dust penetration. Rotor shaft failure was found to be caused by the shaft rotating in the standard rubber collar due to seizure of the bearings. Bearings with a positive rubbing seal having a MIL-G-81322 grease produced lives greater than with bearings having labyrinth seals and a mineral oil paste lubricant. An elongated collar prevented failure of the rotor shaft during bearing seizure. In a limited test, installation of tail boom shrouds over the bearings which excluded dust and water resulted in bearing lives in excess of 1800 hours or 1200 hours greater than the current 600 hours TBO, regardless of the lubricant-bearing combination used.

INTRODUCTION

The OH-58A is a U.S. Army Light Observation Helicopter (LOH) (Fig. 1). The aircraft can carry up to 5 passengers and crew combined. It has a maximum gross takeoff weight of 3000 pounds. It is powered by a 300 shaft horsepower (SHP) engine.

The hollow tail rotor shaft of the aircraft is 12 feet long 2024T3 aluminum. It has flexible couplings at each end. Its outer diameter is 1-inch with a .049-inch wall. It is supported at six stations equally spaced by 30-mm bore, extra light series deep-groove ball bearings with ribbon steel cages which are permanently sealed and lubricated with a paste type lubricant. This paste type lubricant has a mineral oil base thickened by 40% solid particles of molybdenum disulfide and polytetrafluoroethylene (PTFE). The solid particles are approximately 5 microns in size. The bearing has ABEC #1 tolerances with a radial clearance from .0006 to .0010-inch. A Buna N rubber collar (grommet) is pressed into the bore of the bearings and the bearing and collar are pressed onto the shaft (Fig. 2). To facilitate assembly, the shaft is coated with a water soluable glycerine-based medical gel.

Recently, a large number of bearing and shaft failures have occurred. Since December 1971, seven tail rotor drive shafts have broken. Worn drive shafts are being replaced at the average rate of over 50 per month on a fleet of 1200 helicopters.

Through the Lewis Directorate of the U.S. Army Air Mobility Research and Development Laboratory (AAMRDL), the Bearing and Gearing Section of the Fluid System Components Division of NASA-Lewis Research Center was requested to, (1) examine the failed bearings, (2) determine the cause of failure, and (3) make recommendations to reduce or eliminate completely shaft failure and replacement.

A preliminary inspection of some of the failed bearings indicated the following probable failure mode of the shaft system:

1. The liquid portion of the lubricant flowed out of the bearing.

2. The bearing torque increased.

3. The solids in the lubricant which remained after the liquid separated, now filled up the spaces between the balls and races and between the balls and cages and caused high bearing torque with subsequent jamming of the bearing.

4. The rubber collar then became a sleeve bearing on the aluminum shaft causing circumferential wear marks to appear.

5. When the wear became excessive, the shaft failed.

A preliminary analysis has indicated that no critical speed effects are adding to this wear problem.

In order to verify the failure mode and to obtain a solution to the problem, environmental tests were conducted at the NASA-Lewis Research Center to simulate field conditions of the OH-58A tail rotor drive assembly. The results of these tests and recommendations are reported herein.

TEST APPARATUS

Test Stand

The test apparatus consisted of three tail boom assemblies which were removed from OH-58A helicopters. All tail boom hardware aft of the main bulkhead, with the exception of the tail rotors and the pitch control rods, was retained intact for these tests. Each of the three tail boom assemblies were cantilever mounted on a 12.7 mm (1/2 inch) steel vertical plate, welded to, and braced by steel channels as shown in Figure 3. The tail rotor drive shafts and support bearing assemblies were left attached to the tail rotor gear boxes. The tail rotors were removed. The shaft bearings were mounted on the tail booms with the hangers, collars, and the brackets as specified in the maintenance manual for the OH-58A helicopter (ref. 1).

The splined coupling at the forward end of each drive shaft was used to attach the test stand drive motor assembly. This drive motor assembly (Fig. 4) consists of a two-horsepower, three-phase, squirrel-cage, AC induction motor and a V-belt pulley assembly for increasing the shaft speed to approximately 6000 rpm. At the cruising speed of the aircraft, the shaft runs at 6180 rpm. A galvanized steel cover protected the drive motor assembly from the outdoor environment.

The test stand was secured with lag bolts to a concrete pad located in a remote outdoor test site (Fig. 5) allowing continuous operation under the variety of environmental conditions experienced in the Cleveland, Ohio area. The ambient temperatures during testing varied from 10° to 75° F. Weather conditions included snow, frost, and heavy thunderstorms.

A timer control circuit was used to cycle the drive motors on and off. Timers could be adjusted to the desired cycle. Starts were timed such that 30 seconds elapsed between starts of the three motors to prevent overload of the main power supply circuit.

For the last series of tests, shrouds were fabricated of 0.0799 cm (0.031-inch) aluminum to cover the shaft and bearings.

INSTRUMENTATION

A thermocouple was provided for each of the six bearings on each of the shafts. For each bearing, an iron-constantan thermocouple was mounted in a copper slug and peened into a radial hole in the hanger in contact with the bearing outer race (Fig. 6). An ambient thermocouple was also provided to measure outside air temperatures. All thermocouple outputs were continuously recorded on a 24 point strip chart recorder located in an adjacent building.

To provide an indication of the relative torque of the test bearings during running and indicate impending bearing failure, the power input to the drive motors was measured. Power-transducers provided a zero to 100 millivolt signal proportional to the power input to the drive motors. This signal from each motor was continuously recorded on a strip chart recorder located in the test facility control room. Calibration of the power transducers was accomplished with a precision three-phase wattmeter.

TEST BEARINGS

The tail rotor drive shaft bearings are 30-mm bore, single row, sealed, deep-groove ball bearings of ABEC-1 tolerance. These bearings will be referred to in this report as dash 3 bearings. These bearings are currently prelubricated with 1.5 $\pm$0.2 grams of mineral oil paste with 40 percent MoS_2 and PTFE particles, commercially known as Alpha-Molykote 343X. Further details of the bearing dimensions and specifications are given in Table I.

Another set of bearings was tested that will hereinafter be referred to as dash 5 bearings. These bearings are identical to the dash 3 bearings except for the improved positive contact seals on the dash 5 bearings (Fig. 7). In these tests, the dash 5 bearings were prelubricated either with the mineral oil paste or with a grease conforming to MIL-G-81322 specifications.

There are significant differences between the mineral oil paste and the MIL-G-81322 grease. A "grease" lubricant is usually composed of a base liquid and some thickeners such as a lithium or sodium soap complex. If the thickener is viewed under high magnification, it appears as a fibrous mass similar to steel wool. Attractive electrical forces called Van Der Waal's bonds tend to retain the liquid base in the thickener (ref. 2).

In the mineral oil paste lubricant, however, the mineral oil is thickened by adding 40% by volume of 5 micron size particles of PTFE and molybdenum disulfide. In this mixture, no electrical forces of attraction exist and the liquid may easily migrate from the solids, thus leaving a semi-dry sludge in the bearing.

The tail-rotor shaft/bearing assemblies were set up for three series of tests as shown in Table II. This table gives the bearing and lubricant type for each assembly. On the third test assembly of Test Series II, elongated collars (grommets) of the type shown in figure 8, were used to mount the bearings on the shaft.

PROCEDURE

The bearings to be tested were mounted in hangers and subsequently on the drive shafts in compliance with the procedure in the maintenance manual (ref. 1). A commercial water soluble glycerine-based medical lubricating jelly was used to lubricate the shaft while sliding the bearings and collars into position on the shaft. The shaft and bearing assembly was then mounted on the tail boom in compliance with the manual (ref. 1). Upon completion of all assemblies, each test stand was run for a few minutes to assure that no undesireable vibrations were present and to allow for calibration and adjustment of the power transducers.

After the three test assemblies were transported to the outdoor test site and tied down, the test cycle was begun. Test Series I was run prior to the incorporation of the automatic start-stop timer circuit. For this test series, manual shutdowns were effected twice daily with a shutdown period of 30 minutes. For Test Series II and III the timer circuit was installed and set for a 60 minute "on" period and a 15 minute "off" period. Starting of the second and third test stands was delayed 30 seconds and 60 seconds, respectively, after the start of the first test assembly. This cycle was repeated continuously around the clock for each test assembly until failure of one of the test shaft bearings.

To simulate the dusty and dirty environment that these tail rotor drive shaft bearings experience in field operations, fine air-cleaner test dust (Table III) was periodically applied to both sides of each bearing with a rubber bulb syringe. This procedure was repeated two or three times in a 24 hour period to all three of the test shafts.

To simulate the periodic washing of the helicopter with water and detergent that occurs during routine US Army operations, a garden type, hand-pump sprayer was used. Each bearing was sprayed on both sides with a water-detergent solution. Bearings on each of the three shafts were washed by this procedure daily when ambient temperatures were above freezing.

For Test Series III, where the shrouds were used to cover the shafts and bearings, the dusting and washing procedures were not employed.

RESULTS AND DISCUSSION

Test Series I - Two tail boom assemblies were initially tested. The first of these assemblies contained the dash 3 bearings with the mineral oil paste lubricant having the nonrubbing labyrinth-type seal. The bearings were attached to the shaft by means of the standard rubber collar. The second assembly contained the dash 5 bearings with the improved rubbing-type positive seal and the mineral oil paste lubricant. These bearings were also mounted on the standard collar. In this way, a direct comparison could be made between the dash 3 bearings with the labyrinth seals and the dash 5 bearings with the positive-contact seals (see Fig. 7). These tests were run for 165 hours with only 3 planned shutdowns and were subsequently shut down twice each 24 hour period until failure occurred.

Thirty-four hours after test start-up, air cleaner test dust was applied with a rubber syringe to simulate takeoff and landing environments of the helicopter. Eighteen and twenty-four quarter-ounce bursts of dust were applied to the dash 3 and dash 5 bearings, respectively. The dash 3 bearings with the labyrinth seal ran for

283 hours, and the dash 5 bearings with the positive rubbing seal ran for 310 hours. While this test would tend to indicate that the positive rubbing seal in the dash 5 bearing was superior in this application to the labyrinth seal in the dash 3 bearing, the ten percent increase in life was not considered statistically significant and was far short of the required 600 hour time between overhaul (TBO).

There was extensive wear of both types of seals due to the inclusion of the dust and the resultant loss of lubricant. Typical failures of the bearings and shafts are shown in figures 9 and 10. The failure mode for both shafts together with the bearings thereon was identical to those experienced in the field. There was wear of the bearing seal accompanied by loss of lubricant. The loss of lubricant together with dust inclusion caused the bearing to seize. Seizure may also be accompanied by fracture of the bearing cage (retainer). Upon seizure, the friction force between the collar and the inner race (which is greater than the friction force between the collar and the shaft) causes the shaft to rotate within the collar. The sliding action together with abrasive particles which lodge between the collar and the shaft causes the shaft to wear. This wear can subsequently lead to shaft failure.

Temperatures in these tests were generally erratic. They ranged from 10° to 50° F above ambient. It was concluded that with either type seal, temperature was not indicative of impending failure. Erratic torque spikes were found to signal the early stages of bearing failure. During these torque excursions, the shaft would turn within the collar causing wear. For field applications, "match marks" between the collar and shaft should be standard operating practice. The failure of these "match marks" to line-up after helicopter operation would indicate the probability of shaft wear which could lead to failure.

No correlation was found between bearing noise levels and failure. The highest noise levels were reached at start-up or with dust ingestion with less than 50 hours running time on the bearings. However, torque levels were relatively constant, indicating no adverse affect on the bearing. These bearings ran for approximately 100 hours past the first detection of increased noise level. This observation would indicate that premature replacement and down time in the field has been occurring based upon a noise criterion for failure without considering whether the shaft rotated in the collar.

Test Series II - The second test series was run to compare the mineral-oil paste type lubricant with the MIL-G-81322 grease and also to compare the standard collar with the alternate elongated collar. Three tail boom assemblies were utilized in this test series. On the first test assembly, the dash 3 bearings with the labyrinth seal and the mineral oil paste were installed. On the second and third test assemblies, dash 5 bearings with the positive rubbing seal and the MIL-G-81322 grease were installed. The bearings on the third test assembly were mounted on the shaft with the alternate elongated collar. This constitutes the only difference between the second and third assemblies in this test series. This test series was run with the timer circuit set for 60 minutes "on" period and a 15 minute "off" period.

Bearing outer-race temperatures were recorded throughout these tests. The power input to the drive motors was also continuously recorded. Quarter-ounce bursts of aircleaner test dust were applied to each bearing on all three test assemblies one to two times a day until failure of one or more of the bearings on each assembly occurred. Additionally, the bearings were washed with water and detergent three times during the test series to simulate the periodic washing of the operational helicopters.

The bearing temperatures recorded throughout this test series were erratic and varied considerably from bearing to bearing with no apparent trend. These results were similar to those of Test Series I. After about 140 hours, at least two bearings on the first test assembly with the dash 3 bearing became very noisy. Concurrently, there were indications of increased torque on the drive motor power recorder. Also, at about this time, the first indication of impending distress on one dash 5 bearing on the third test assembly was apparent in the form of some noise and drive motor power spikes following a dust application.

At 149 hours, a dash 3 bearing on the first test assembly seized causing the shaft to rotate in the rubber collar. The shaft damage resembled those of Test Series I and the previously mentioned field failures. The disassembled bearing revealed a dried, dust impregnated lubricant and fractured cage similar to those failures in Test Series I (Fig. 11).

After continued operation of the second and third test assemblies, with subsequent dust applications and a second washing, several bearings on the third test assembly became noisy (intermittent squealing).

At 196 hours of operation, following a dust application, one bearing on the third test assembly began smoking. This failure was accompanied by harsh vibrations but no loud noises or squealing. It was apparent that the bearing had seized and began to rotate within the hanger rather than on the shaft as was typical of previous failures. The hanger became very hot and subsequently broke (Figs. 12 and 13). The temperature of this bearing at failure exceeded 400° F (off scale).

There was also indication that the inner race of the bearing had rotated on the elongated collar. The elongated collar did <u>not</u>, however, rotate on the shaft as indicated by the alignment of the match marks. The higher friction forces between the elongated collar and the shaft prevented rotation at the collar-shaft interface and <u>no damage to the shaft occurred</u>. This was perhaps the most significant failure of all the tests. A failure such as this in field operation is less severe than previous failures in which total shaft failure can occur. It is conceivable that this shaft and collar could be reused. In addition, this assembly with the elongated collar would provide a more fail safe operation with less concern for catastrophic tail rotor drive shaft failure.

The second test assembly continued on test, when at approximately 250 hours and after a dust application, noise began to emanate from the dash 5 bearings. At 286 hours, two bearings on this shaft had seized and the collars had rotated wearing smooth rings around the shaft (Fig. 14).

Examination of the dash 5 bearings from the second and third test assemblies indicated that gross wear of the positive contact rubbing seals occurred due to the inclusion of the dust. This wear allowed the dust to penetrate the bearings and allowed leakage of the MIL-G-81322 grease to the point where the bearings became dry and subsequently seized. In these tests the bearings with the MIL-G-81322 grease produced lives on the order of 30 to 100 percent greater than those with the mineral oil paste. The bearing failures with both lubricants were similar. It was concluded that these failures were more a function of the exposure to the dust environment, causing wear of the seals, than any other single factor.

Test Series III - Based upon Test Series II, where it was concluded that all the bearing failures were more a function of the total exposure to environmental dust than to any other single factor, a third test series was planned. Three additional shaft assemblies were tested. A simple tail boom shroud was designed and installed on the OH-58A tail boom assemblies (Fig. 15). The shroud protected the bearings against the dirt and water from the outdoor environment. All the bearings in this test were mounted on the standard collars. The six bearings on the first shaft were the dash 3 type with the mineral oil paste lubricant. On the second shaft assembly, the dash 3 bearings with the mineral oil paste lubricant were alternated with the dash 5 bearings with the MIL-G-81322 grease. On the third shaft, six dash 5 bearings with MIL-G-81322 grease were installed. This test series was run exactly as Test Series II including the same on-off cycle except that there were no dust applications nor periodic washings of the assemblies with water and detergent. These shafts were run in excess of 1800 hours without failure before being shut down. (The recommended time-between-overhaul is 600 hours).

From this test series, it can be concluded that if the bearings are kept clean and dry, they will complete the full time-between-overhaul without replacement or failure regardless of which lubricant or bearing design is used. Furthermore, in accordance with Test Series II, if the elongated collars were installed and a bearing failure did occur, the drive shaft would be protected and replacement of the shaft would not be necessary.

SUMMARY

Comparative lubrication tests were run with OH-58A helicopter tail rotor drive shaft bearings. The tests were run in an outdoor environment with ambient temperatures ranging from 10° to 75° F. Weather conditions included snow, frost, and heavy thunderstorms. Test bearings were deep-groove ball bearings having either a labyrinth seal or a positive rubbing seal. The bearings were lubricated with a mineral oil paste lubricant or a MIL-G-81322 grease. The bearings were supported on the test shaft by means of a rubber collar of either a standard or elongated type. Fine, air-cleaner test dust was periodically applied to the bearings in some of the tests to simulate field conditions. Additionally, the test assemblies were periodically washed with detergent and water. A series of tests were also conducted wherein the test bearings were covered by a tail boom shroud which prevented exposure to dust and water. The following results were obtained:

1. The cause of bearing failure and subsequent seizure was associated with dust penetration of the bearings due to wear of the bearing seals because of the dust and loss of the base oil from the lubricant in the bearing.

2. Rotor shaft failure was found to be caused by the shaft rotating in the standard

rubber collar due to seizure of the bearings.

3. The bearings with the positive rubbing seals with the mineral oil paste lubricant produced a bearing life 10 percent greater than those bearings having the same lubricant but with the labyrinth seals when exposed to dust. The difference in life was not considered significant.

4. Bearings with the positive rubbing seals and the MIL-G-81322 grease produced lives 30 to 100 percent greater than the bearings with the labyrinth seals and the mineral oil paste when exposed to dust. While this increase was considered significant, the improvement was not sufficient to achieve a desired 600 hour TBO.

5. The elongated collar prevented failure of the rotor shaft during bearing seizure whereby the bearing inner race rotated on the collar and the outer race rotated in the bearing hanger. Both the collar and the shaft could be reused after test

6. The installation of shrouds over the bearings resulted in lives in excess of 1800 hours or 1200 hours greater than a 600 hour TBO, regardless of the lubricant-bearing combination used.

RECOMMENDATIONS

The civilian version of the OH-58A helicopter is called the JetRanger. The JetRanger tail boom has a lightweight shroud which covers the tail rotor drive assembly, which is 10 1/2 inches shorter than that of the OH-58A. It is recommended that this shroud be lengthened and adapted to the OH-58A. The shroud would keep the majority of the dust particles from penetrating the bearings. It is estimated that the shroud together with its fasteners would weigh less than 5 pounds.

It is further recommended that the dash 5 bearings with a positive rubbing type seal and a MIL-G-81322 lubricant replace the currently used dash 3 bearings with the mineral oil paste lubricant. In addition, the elongated collars should be used to replace the standard collars in current applications. The elongated collars will add an extra margin of safety and minimize, if not eliminate, shaft replacement.

ACKNOWLEDGEMENT

The authors would like to acknowledge the cooperation and help extended to them during this project by all of the personnel of the AVSCOM LOH Project Managers Office, St. Louis, Missouri, and in particular to Messrs. Marcus A. Bayliss and Richard Thomas. We would also like to acknowledge the technical assistance and cooperation of LTC Gilbert J. Weden of the Army Air Mobility Research & Development Laboratory, Lewis Directorate, Cleveland, Ohio.

REFERENCES

1. Anon. "Organizational Maintenance Manual, ARMY MODEL OH-58A HELICOPTER" TM 55-1520-228-20, October 1970.

2. LUBRICATION AND LUBRICANTS, Ed. Braithwaite, G.R., pp. 197-268, ELSEVIER PUB. CO., 1967.

TABLE I

Test bearing specifications

Bore size	30 mm
Outside diameter	55 mm (spherical diameter)
Width	13 mm
Number of balls	11
Ball diameter	7.1438 mm (0.28125 in.)
Ball grade (AFBMA)	25
Race curvature: inner	52 percent
outer	54 percent
Internal Radial Clearance	0.015 to 0.025 mm
	(0.0006 to 0.0010 inch)
Retainer	two-piece, spot-welded, pressed steel

TABLE II Test Configurations

Test Series	Test Stand	Bearing		Lubricant	
		Dash 3	Dash 5	Mineral Oil Paste	MIL-G-81322
I	1[a]	-	-	-	-
	2	X		X	
	3		X	X	
II	1	X		X	
	2		X		X
	3[b]		X		X
III	1	X		X	
	2[c]	X	X	X	X
	3		X		X

a. Test Stand 1 not used in Test Series I

b. Alternate grommet, see Figure 8

c. Three dash 3 bearings with mineral oil paste alternated with three dash 5 bearings with MIL-G-81322

TABLE III

Test Dust Particle Size and Distribution

0 to 5 microns	39 ± 2%
5 to 10 "	18 ± 3%
10 to 20 "	16 ± 3%
20 to 40 "	18 ± 3%
40 to 80 "	9 ± 3%

TABLE IV

OH-58A FAILURE SUMMARY

	Series I		Series II		
Hours to Failure	283	310	149	196	286
Bearing Type	DASH 3	DASH 5	DASH 3	DASH 5	DASH 5
Grommet Type	STD	STD	STD	ELONG	STD
Lubricant Type	ALPHA	ALPHA	ALPHA	81322	81322
No. of Seized Bearings	2	1	1	1	2
No. of Wear Rings on Shaft	2	1	1	0	2
Applications of Dust	18	24	9	14	19
Washings	1	1	2	3	3
Start-Up/Shut-Downs	16	23	149	196	286

TABLE IV

OH-58A FAILURE SUMMARY

	Series III		
Hours to Failure	>1800	>1800	>1800
Bearing Type	DASH 3	DASH 3, DASH 5	DASH 5
Grommet Type	STD	STD	STD
Lubricant Type	ALPHA	ALPHA, 81322	81322
No. of Seized Bearings	0	0	0
No. of Wear Rings on Shaft	0	0	0
Applications of Dust	0	0	0
Washings	0	0	0
Start-Up/Shut-Downs	>1800	>1800	>1800

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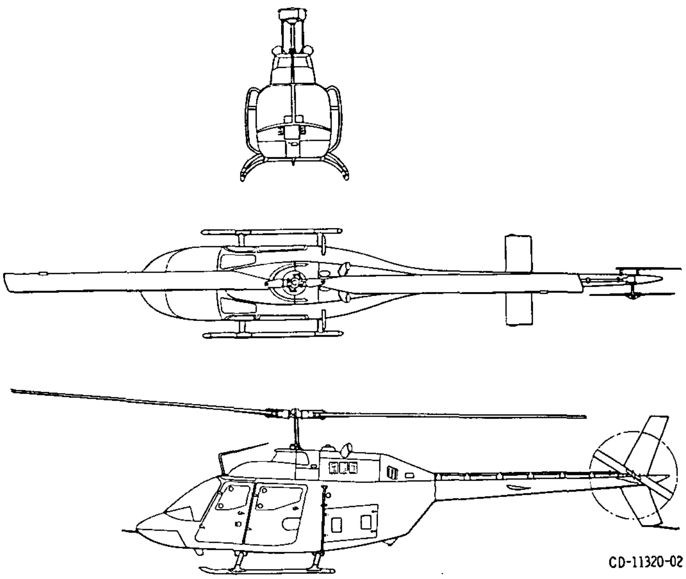

Figure 1. - OH-58A helicopter.

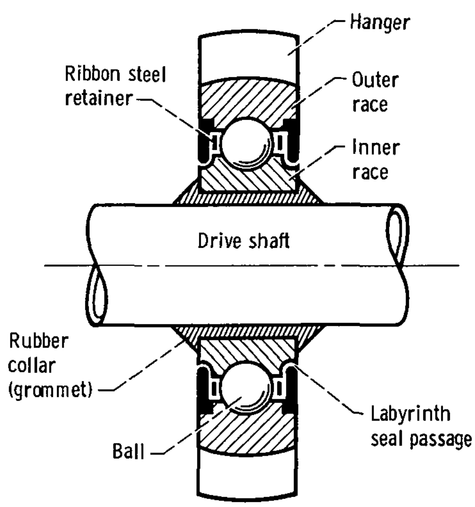

Figure 2(a). - Cross section of bearing mount on OH58A drive shaft (dash 3 bearing).

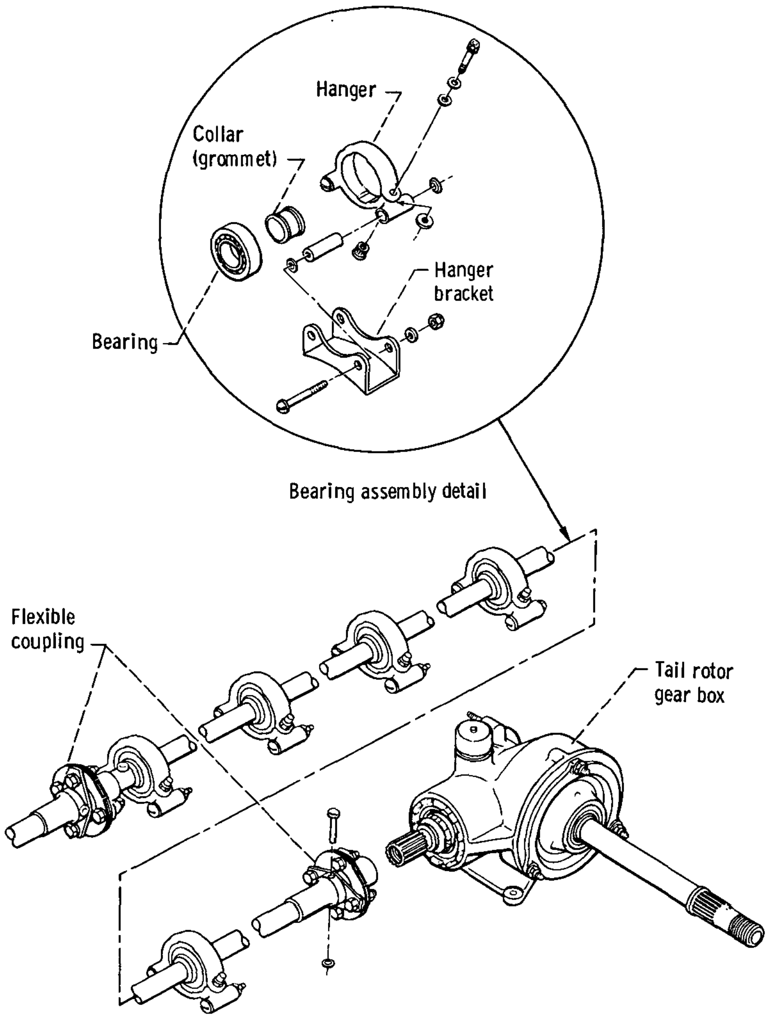

Figure 2(b). - Tail rotor drive shaft assembly details.

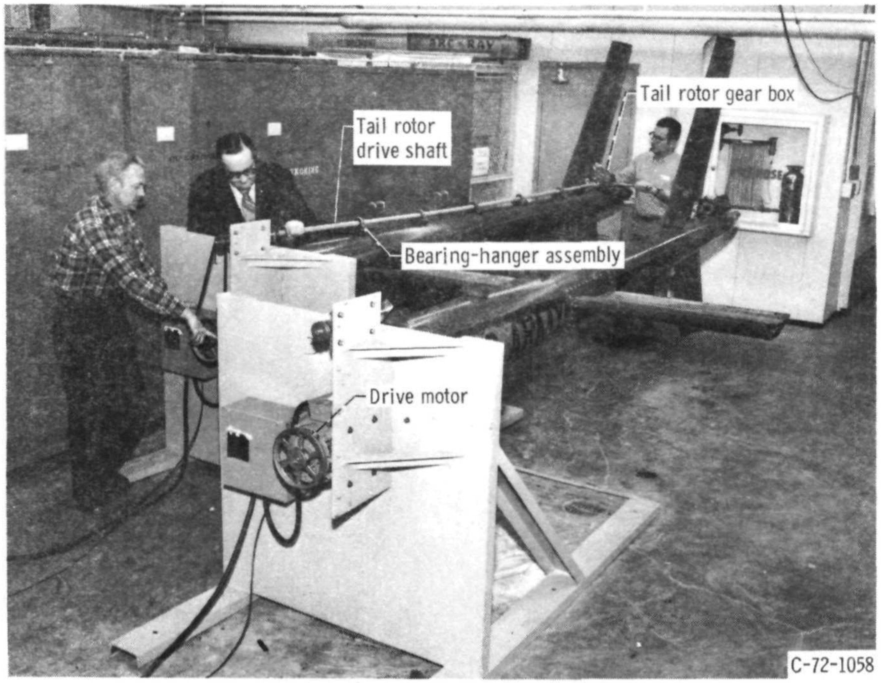

Figure 3. - OH 58A Tail rotor test assembly.

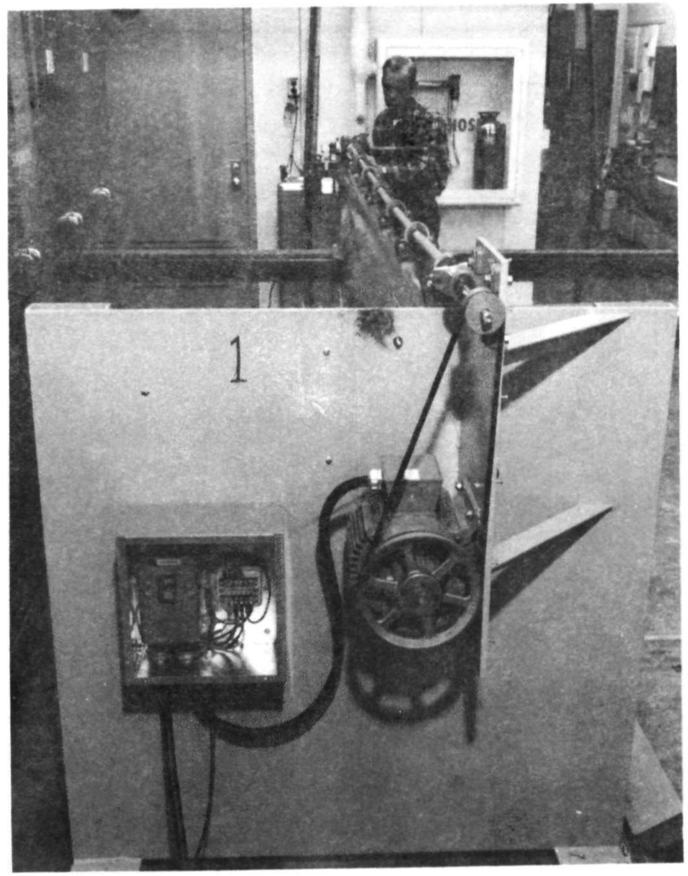

Figure 4. - Drive motor assembly.

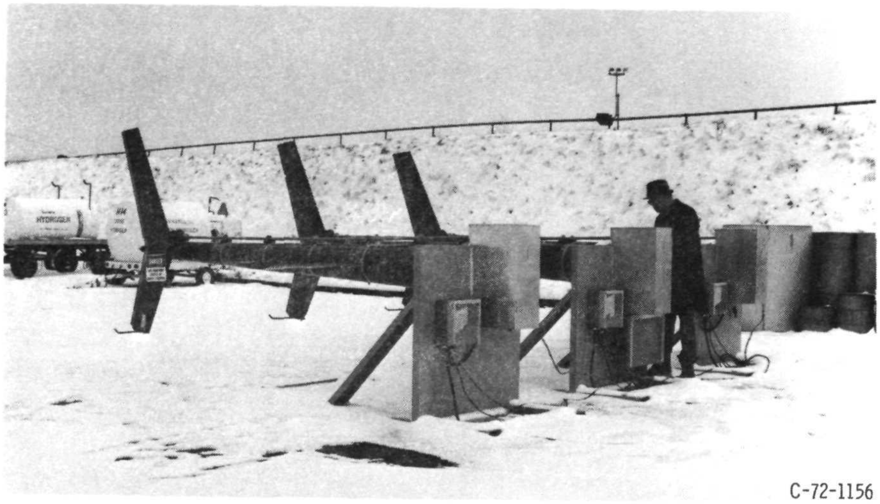

Figure 5. - Outdoor test site with 3 assemblies in place.

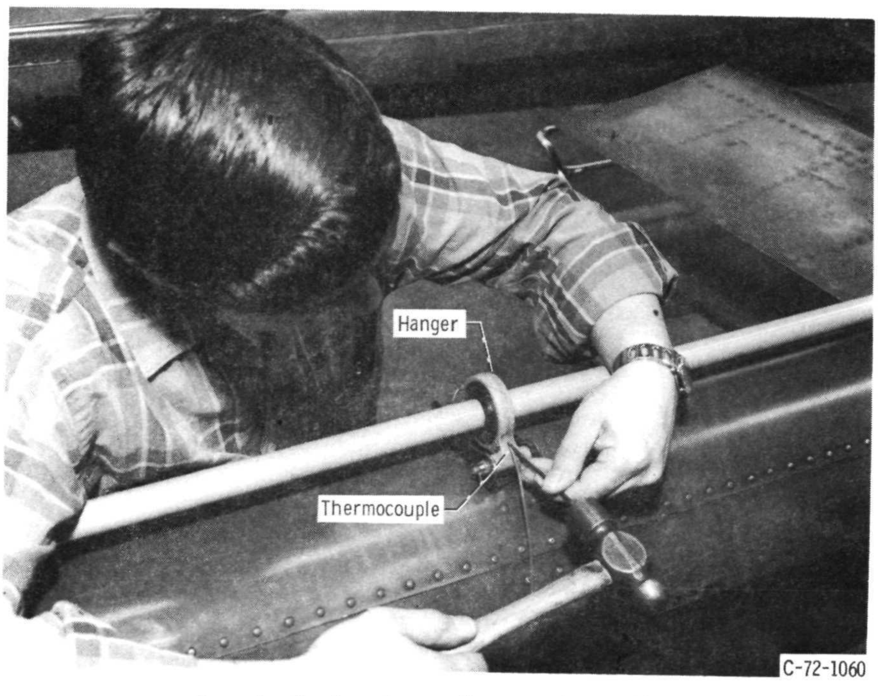

Figure 6. - Bearing outer-race thermocouple assembly.

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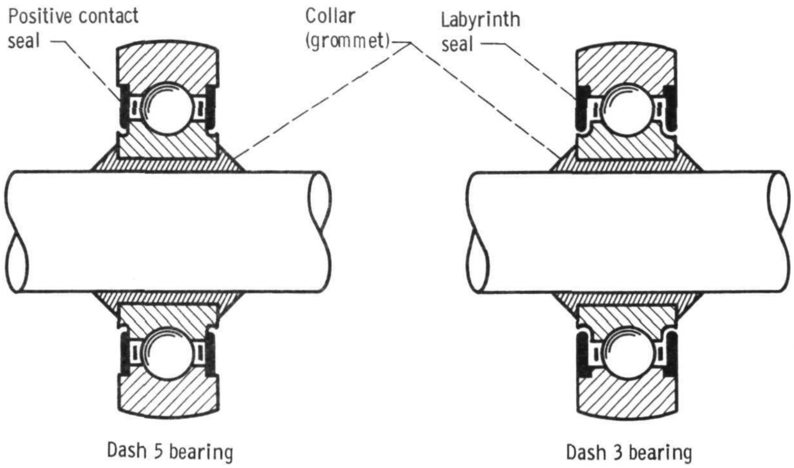

Figure 7. - Cross section of dash 3 and dash 5 bearings.

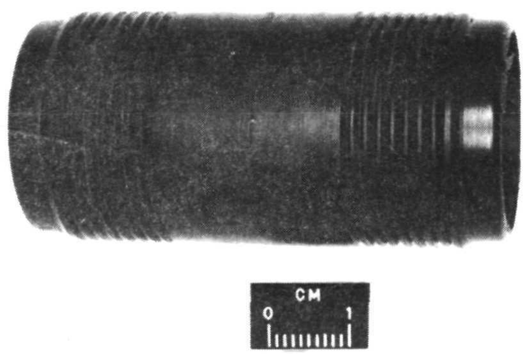

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Figure 8. - Elongated rubber collar.

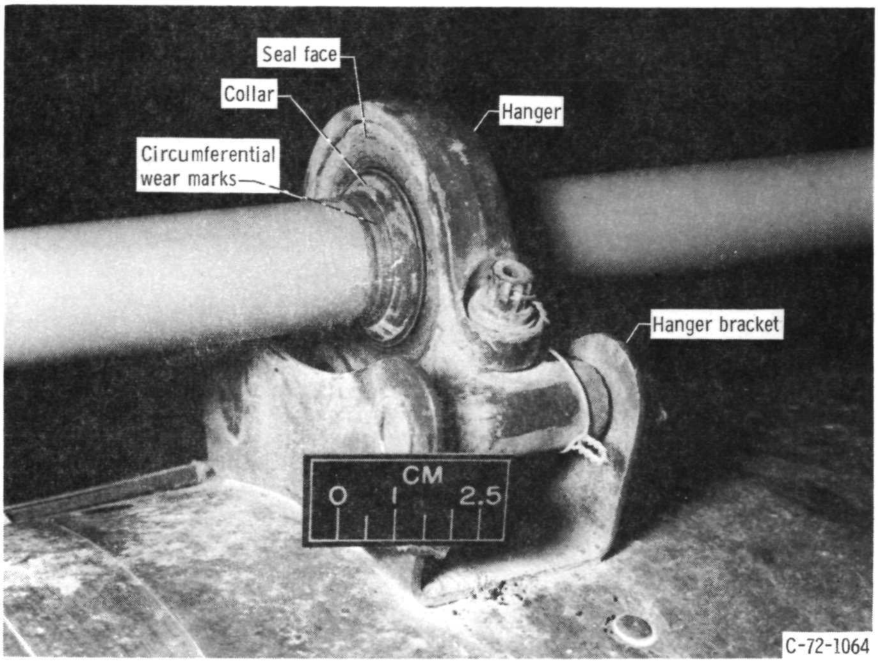

Figure 9. - Close-up of failed bearing immediately after testing.

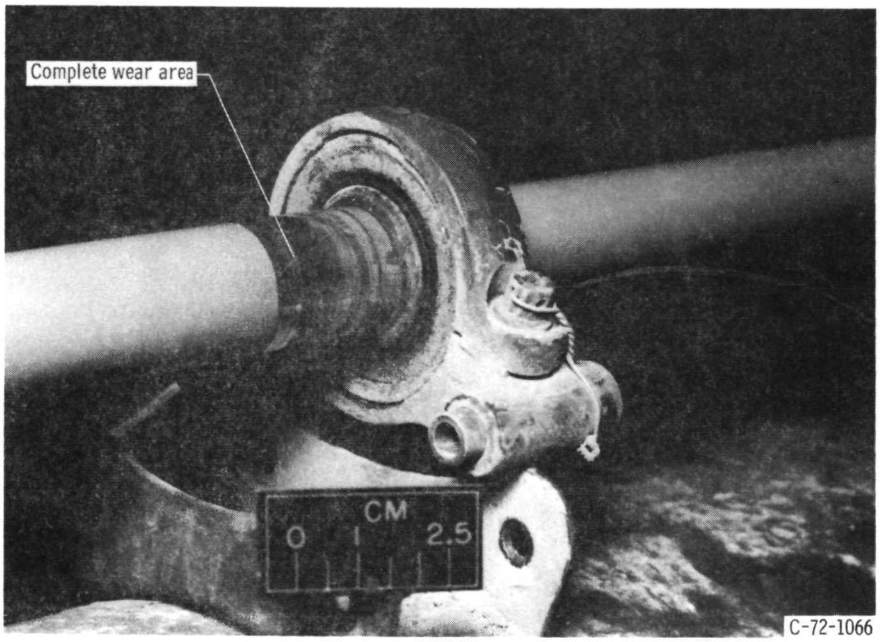

Figure 10. - Close-up of failed bearing showing wear area on shaft.

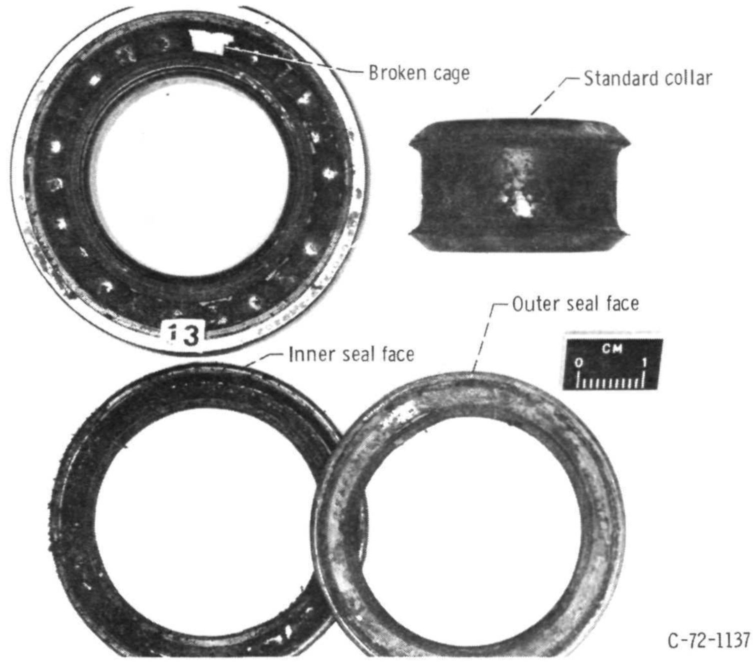

Figure 11. - Failed bearing showing dust impregnation and broken retainer (cage).

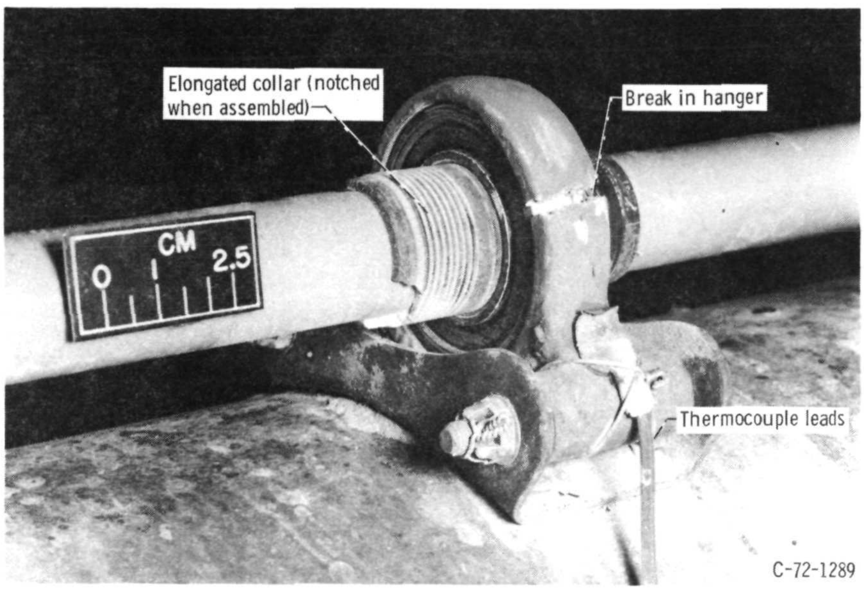

Figure 12. - Failed bearing with broken hanger immediately after testing.

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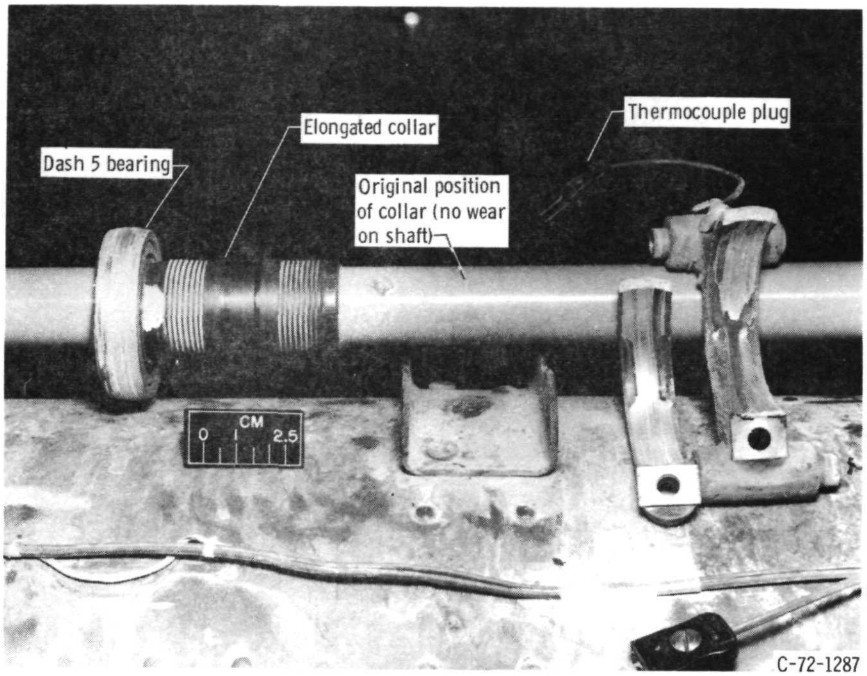

Figure 13. - Disassembled hanger and bearing-collar assembly. Collar has been moved and no wear is seen on shaft.

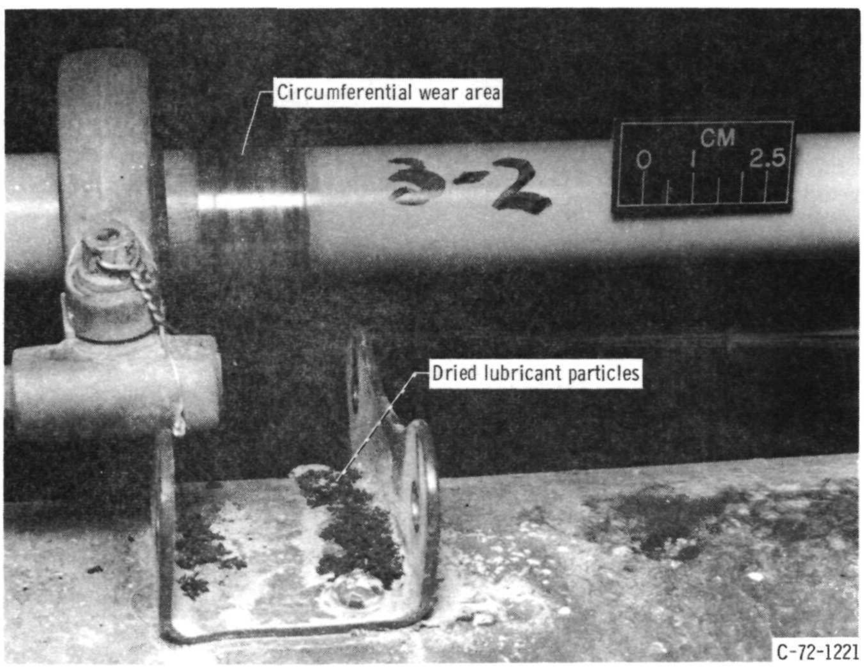

Figure 14. - Failed bearing showing wear on shaft and accumulation of dried lubricant particles on hanger bracket.

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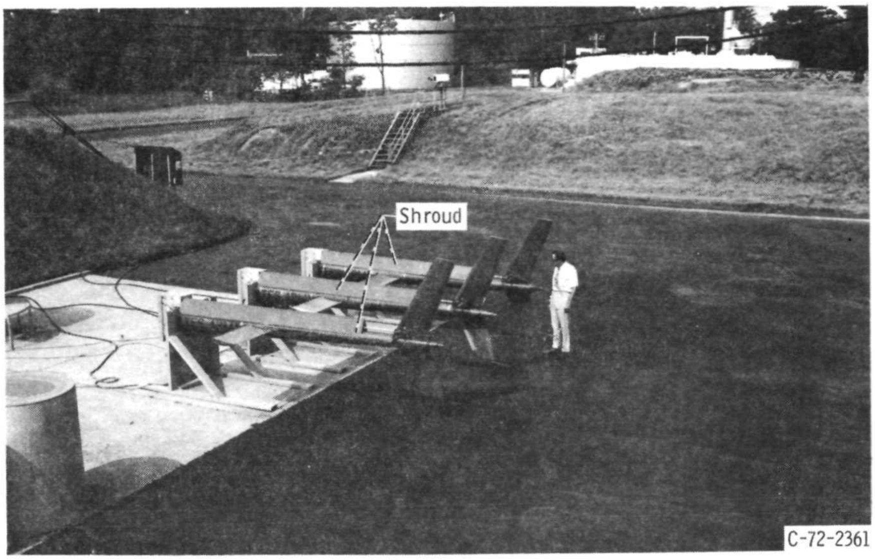

Figure 15. - OH 58A Test assemblies showing NASA-designed shrouds.