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16. Abstract

The feasibility of an emergency aspirator once-through lubrication system has been demonstrated as a viable survivability concept for Army helicopter mainshaft engine bearings for periods as long as 30 minutes. It has also been shown in an experimental study using a 46-mm bore bearing test machine that an oil-air mist once-through system with auxiliary air cooling is an effective primary lubrication system at speeds up to 2.5×10^6 DN for extended operating periods of at least 50 hours.

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INTRODUCTION AND BACKGROUND

New Army specifications for advanced technology engines require that "The engine oil system will adequately lubricate the engine for not less than 0.1 hour (6 min) of operation at 75 percent maximum continuous power after a 12.7 mm projectile hit into the oil cooler, oil tank, or external oil line." This new requirement is obviously much more severe than the previous requirement of a 30 to 60 second oil interruption test conducted during engine qualifying tests. One potential solution for meeting the new requirement is found in the use of an oil-air mist back-up lubrication system.

The work done to date on oil-air mist back-up systems has been confined to gearbox transmissions where initial bearing temperatures are cool compared to engine bearing temperatures and DN values (product of bearing bore in mm and shaft speed in rpm) have rarely exceeded 1 million.

Gas turbine mainshaft bearings operate at DN values to 2.2×10^6 and under these high speed conditions bearing thermal imbalance (precipitates bearing failure) must be controlled by proper lubrication and cooling. Therefore, a practical solution of maintaining adequate internal running clearance under loss of the conventional oil jet lubrication must provide enough oil and cooling capacity to forestall bearing thermal imbalance for at least 6 minutes.

The degree to which an oil-air mist can provide adequate thermal stability to the engine sump bearing system is unknown. However, data are available which confirms that bearing failure due to thermal imbalance can be arrested for a finite period of time if traces of liquid lubricant are present. Based on this knowledge it is felt that an emergency lubrication system using oil-air mist may be a practical, immediate approach toward providing bearing life extension under combat damage (loss of circulating oil conditions). Also, in order to provide adequate time for an aircraft with an inoperative primary lubrication system to reach safe territory and make a successful landing, a goal of this program segment is for a 30 minute emergency system operation rather than the 6 minute specification period.

Mist lubrication is not only of interest as a back-up emergency system but also has an advantage as a possible primary lubrication system for high speed bearings. Oil churning, with its consequent viscous drag is nearly absent in mist-lubricated bearings. The resulting reductions in bearing power loss and in heat generation can be a very real advantage at high bearing speeds.

The objectives of this program are therefore: (1) to evaluate by a series of full-scale test rig studies the practicability of using an emergency built-in oil-air mist lubrication system to provide up to 30 minutes of back-up system operation following loss of the primary system which is conventionally an oil jet recirculating system; (2) to demonstrate the suitability of a once-through primary mist lubrication system with four different type military engine oils at operating conditions significant for advanced components; and (3) to provide a conceptual design of mist lubrication with emergency provisions for a typical small military engine bearing.

The effort reported herein was performed under NASA Contract NAS3-17343 at SKF Industries, Inc. The work extends the efforts started in prior NASA Contracts NAS3-9400 and NAS3-13207 (as reported in refs. 1 to 4) and complements the work being performed in a concurrent study with a 125-mm bearing rig and entitled "Microfog Lubrication for Bearings." (Summary of this work is given in the attached Appendix I.) The earlier basic work was to explore wettability and other factors to increase the feasibility of using high temperature liquid lubricants in a once-through mist lubrication system; optimization measurements of mist cooling and other dynamic effects; and development of a novel mist reclassifier nozzle.

TEST RIG AND BEARINGS

Oil-Air Mist System for Primary Lubrication

A high-speed, high temperature bearing test machine was modified for use with a once-through, mist lubrication and air cooled system and was used for all testing in this work. The rig was fitted with a special drive turbine to provide a variable speed range from 0 to 65 000 rpm. Figure 1 shows a cross-sectional view of the test rig and figure 2 shows the two separate mist and cooling air manifolds as well as the nozzle configurations. Oil mist is generated outside the rig and enters the mist manifold through a 0.75-inch i.d. tube and flows around the manifold in two circumferential paths to feed eight equally spaced reclassifying nozzles. Nozzle orifices are designed to provide a maximum mist velocity of 1000 ft/sec which will impinge on the bearing inner-race chamfer and between the inner-race land and cage bore. Cooling air to the bearing is supplied through eight nozzles spaced between the mist nozzles.

Oil-Air Mist System for Emergency Lubrication

An aspirator was installed in the lower section of the test rig, as shown in figure 1, to provide emergency lubrication during the lubrication interruption studies. The aspirator nozzle was directed at the gap between the test bearing inner ring and the cage. It receives air from a line passing through the rig housing which draws its oil supply, by suction, from the residual oil in the bottom of the oil manifold ring.

To make the results of this study as directly applicable as possible to future Army helicopter turbine engine bearings, the 46-mm bore diameter high-speed mainshaft thrust bearing from an advanced Army helicopter engine was used in all tests. Modifications were made to the bearings to provide pumping of the mist oil through the bearings and thereby improve lubricant distribution in the bearing.

RESULTS

Significant results to date in the program include the following:

1. The feasibility of an emergency aspirator lubrication system has been demonstrated as a viable survivability concept for helicopter mainshaft engine bearings for periods as long as 30 minutes after interruption of the recirculating oil supply. Test bearings were found to fail within 30 seconds without this system but by using a built-in aspirator misting device with only a 0.61 cubic inch natural oil reservoir, bearing operation was extended to 2.5 minutes. The emergency system worked successfully for a total duration of 30 minutes by refilling the reservoir (bottom of bearing cavity) every 2.5 minutes. Duration of the emergency mist lubrication was limited only by the size of the reserve oil reservoir, at least within the 30 minute time boundary. A type II ester oil (MIL-L-23699) was used at an inlet temperature of 330° F, a bearing speed of 38 000 rpm (1.75×10^{6} DN) and temperature of 455° F, and an aspirator air flow rate of 0.84 SCFM.

2. It was also shown that a microfog or mist once-through lubrication system with auxiliary air cooling can be an effective primary lubrication system for gas turbine engine bearings.

   (a) In a series of short-term, step speed tests, with four different military specification lubricants (three esters and a polyphenyl ether) it was demonstrated that a mist oil-flow rate of about 30 in^3/hr with a total cooling air flow rate of 15 to 20 SCFM was satisfactory for operating the test bearings at speeds up to 65 000 rpm with a thrust load to give maximum bearing Hertz stress of 200 000 psi. As shown in the plotted data in figure 3, bearing heat generation was less than one-half of that originally estimated for a mist system and only one-third to one-fourth of that obtained with a standard recirculating oil system. Table I shows data from these test runs at the maximum speed obtainable for stabilized operating conditions. Similar data for 125-mm bearing runs is also given there for comparison.

(b) As given in the data of table II, similar mist oil and cooling air flow rates were shown to provide satisfactory lubrication and cooling over an extended operating period of 50 hours at 55 000 rpm (2.5×10^6 DN) under the same load conditions. Again similar extended run data are presented for the larger bearing work.

3. Additional short-term, step-speed once-through mist tests indicated the feasibility of operating under high-speed conditions with oil-flow rates as low as 3.1 cubic inch/hour and in another test where the total cooling air flow rate was reduced to 10 SCFM when supplied at 180° to 200° F. This amount of air represents only about 0.1 percent of the total compressor mass air flow for an advanced helicopter engine. An interesting comparison is that a typical lightweight refrigeration unit for cabin cooling in a helicopter will use about 2.5 percent of the compressor air flow for normal operation.

4. It was also shown that a simplified drip/mist system (oil atomized by dropping directly into the cooling air flow path) was effective and permitted operation up to DN values of 3×10^6 with air and oil flow rates similar to prior mist step-speed tests.

5. Bearing failures encountered during long duration mist lubrication evaluation tests resulted from excessive wear at the interface between the cage rail and outer-ring land on the outboard side (the side downstream of the mist and cooling air nozzles) of the bearing. Current work on this project is concerned with improving bearing cage designs to eliminate or lessen cage-land wear and thereby prevent such bearing failures.

REFERENCES

1. Shim, J.; and Leonardi, S. J.: Microfog Lubricant Application System for Advanced Turbine Engine Components. Task I: Theory, Equipment, And Experimental Approaches to Principal Variables. (Mobil Oil Corp.; NAS3-9400) NASA CR-72291, 1967.

2. Shim, J.; and Leonardi, S. J.: Microfog Lubricant Application Systems for Advanced Turbine Engine Components: Determination of the Velocities, Particle Size Distributions, and Wettabilities of Microfog Streams of Various Lubricants. (Mobil Research and Development Corp.; NAS3-9400) NASA CR-72489, 1968.

3. Shim, J.; and Leonardi, S. J.: Microfog Lubricant Application System for Advanced Turbine Engine Components, Phase 2, Tasks 1 and 2: Wettabilities of Microfog Streams of Various Lubricants and Optimization of Microfog Lubrication. (Mobil Research and Development Corp.; NAS3-13207) NASA CR-72743, 1970.

4. Shim, J.; and Leonardi, S. J.: Microfog Lubricant Application System for Advanced Turbine Engine Components, Phase 2, Tasks 3, 4, and 5: Wettability and Heat Transfer of Microfog Jets Impinging on a Heated Rotating Disc, and Evaluation of Reclassifying Nozzles and a Vortex Mist Generator. (Mobil Research and Development Corp.; NAS3-13207) NASA CR-120843, 1971.

TABLE I. - SUMMARY OF DATA FOR OIL-AIR ONCE-THROUGH BEARING LUBRICATION STEP-SPEED TEST RUNS FOR 125-mm AND 46-mm BEARINGS

(DATA AT MAXIMUM SPEED OBTAINABLE FOR STABILIZED OPERATING CONDITIONS)

Test fluid	125-mm bearing tests (see Appendix I)								46-mm bearing tests							
	Low viscosity synthetic paraffinic-hydrocarbon (S. H.) (6.12 cs @ 210° F)		S. H. + 5% weight paraffinic resin (7.26 cs @ 210° F)		Advanced type II ester (MIL-L-23699) (5.14 cs @ 210° F)		High viscosity synthetic paraffinic-hydrocarbon (39.6 cs @ 210° F)		Advanced ester (MIL-L-23699) (5.2 cs @ 210° F)		Ester (MIL-L-7808) (3.5 cs @ 210° F)		Ester (MIL-L-7808) NATO-0-148 (3.3 cs @ 210° F)		5P4E polyphenyl ether (13.1 cs @ 210° F)	
	Flow	Temperature, °F	Flow	Temperature, °F	Flow	Temperature, °F	Flow	Temperature, °F	Flow	Temperature, °F	Flow	Temperature, °F	Flow	Temperature, °F	Flow	Temperature, °F
Mist oil, in^3/hr	53	235	50	215	42	220	50	210	31	190	36	200	30	205	27	200
lb/min	0.0245	---	0.0234	---	0.0235	---	0.0240	---	0.0177	---	0.0195	---	0.0191	---	0.0185	---
Mist air, SCFM (Btu/hr removed)	14.5 (3500)	173	13.2 (3060)	170	13	156	12.7	162	9.66 (1804)	180	13.6 (1587)	210	15.0 (2754)	205	15.0 (3078)	215
Through bearing cool air in, SCFM	51 (23 000)	150	31 (9700)	160	27.6	240	32.8	215	5.64 (1110)	160	5.6 (983)	137	5.71 (1409)	110	5.6 (1344)	140
Through bearing cool air out, SCFM	------	375	------	365	------	360	------	385	------	330	------	290	------	322	------	350
Bearing housing cool air in, SCFM	16 (4700)	110	11.1 (3500)	90	13.9	85	14	80	------	---	------	---	------	---	------	---
Bearing housing cool air out, SCFM	------	390	------	380	------	360	------	410	------	---	------	---	------	---	------	---
Total air, SCFM	81.5	---	55.3	---	54.5	---	59.5	---	15.3	---	19.2	---	20.7	---	20.6	---
Bearing O.R. temperature, °F	------	500	------	490	------	440	------	495	------	430	------	345	------	390	------	425
Bearing heat generated, Btu/hr	26 090		13 200		10 600		14 480		2 586		2 174		3 253		3 447	
Speed, rpm	21 400		21 200		20 000		18 000		60 000		51 000		65 700		50 000	
DN·10^6	2.68		2.65		2.5		2.25		2.76		2.35		3.02		2.3	
Bearing load, lb	3280		3280		3280		3280		400		400		400		400	

bilized operating conditions).

TABLE II. - EXTENDED MIST LUBRICATION BEARING TEST RUNS

Bearing size, mm/load lb	Test fluid	Speed, rpm/DN	Hours run @ speed	Bearing O. R. temper-ature, °F	Mist oil, in.^{3}/hr/qt./hr	Total cooling air, SCFM/°F	Bearing heat rejection, Btu/hr	Reason for stopping test and bearing condition
46-mm/400	Advanced type II ester (MIL-L-23699)	55 K/2.5×10^6	50.8	400	38/0.66	20.5/200	1 809	End of planned time. Generally good condition. Rails slightly polished.
125-mm/3280	Synthetic paraffinic-hydrocarbon plus 5% weight paraffinic resin	20 K/2.5×10^6	35.5	500	54/0.94	51.0/150	13 508	Test bearings failed in both runs. Rings and balls smeared. Excess wear at cage-rail/O. R. land interface on outboard side (downstream of nozzles).
		20 K/2.5×10^6	29.2	420	45/0.78	38.9/150	7 376	

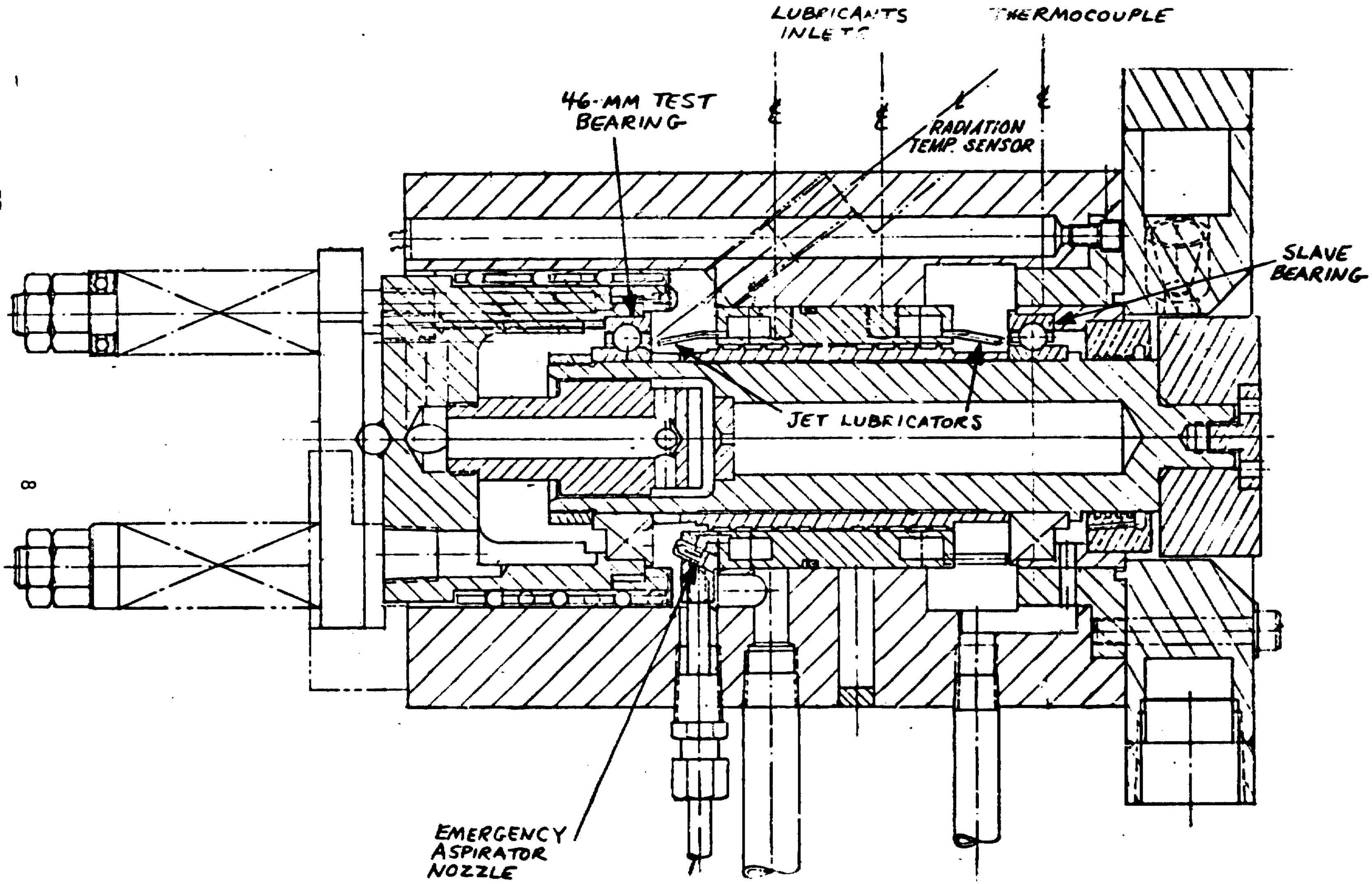


FIGURE 1 - TEST RIG WITH EMERGENCY ASPIRATOR
PRIOR TO MIST SYSTEM MODIFICATION.

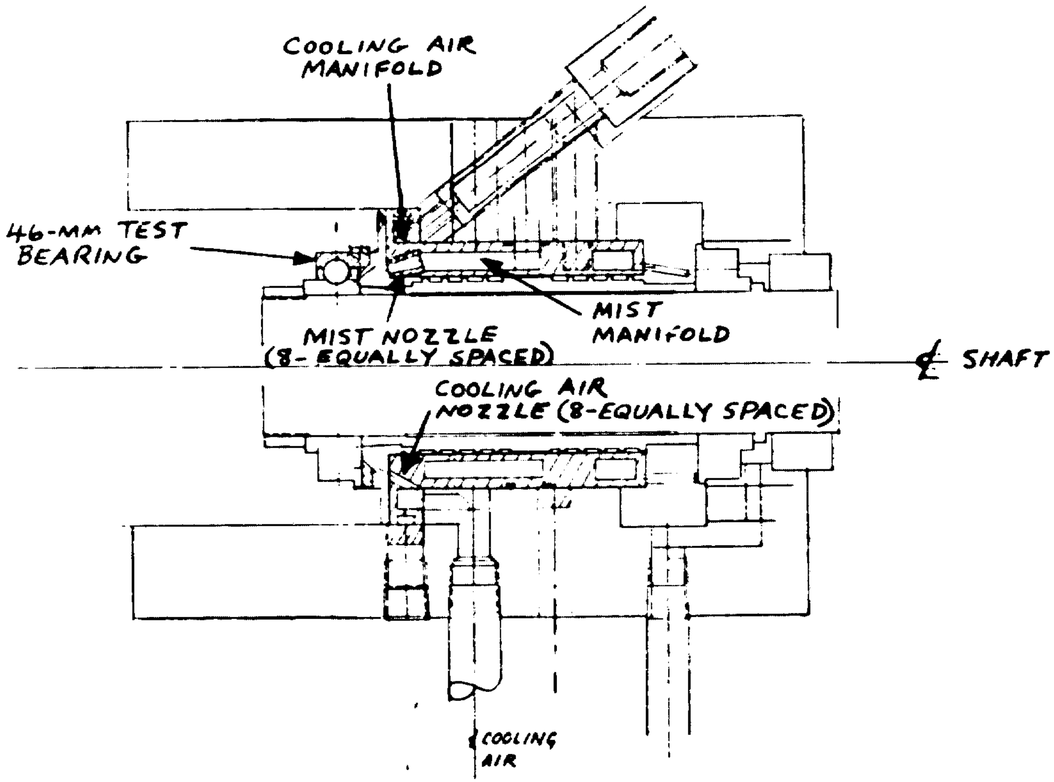


FIGURE 2 - MIST AND COOLING AIR MANIFOLDS AND NOZZLE CONFIGURATION FOR TEST RIG.

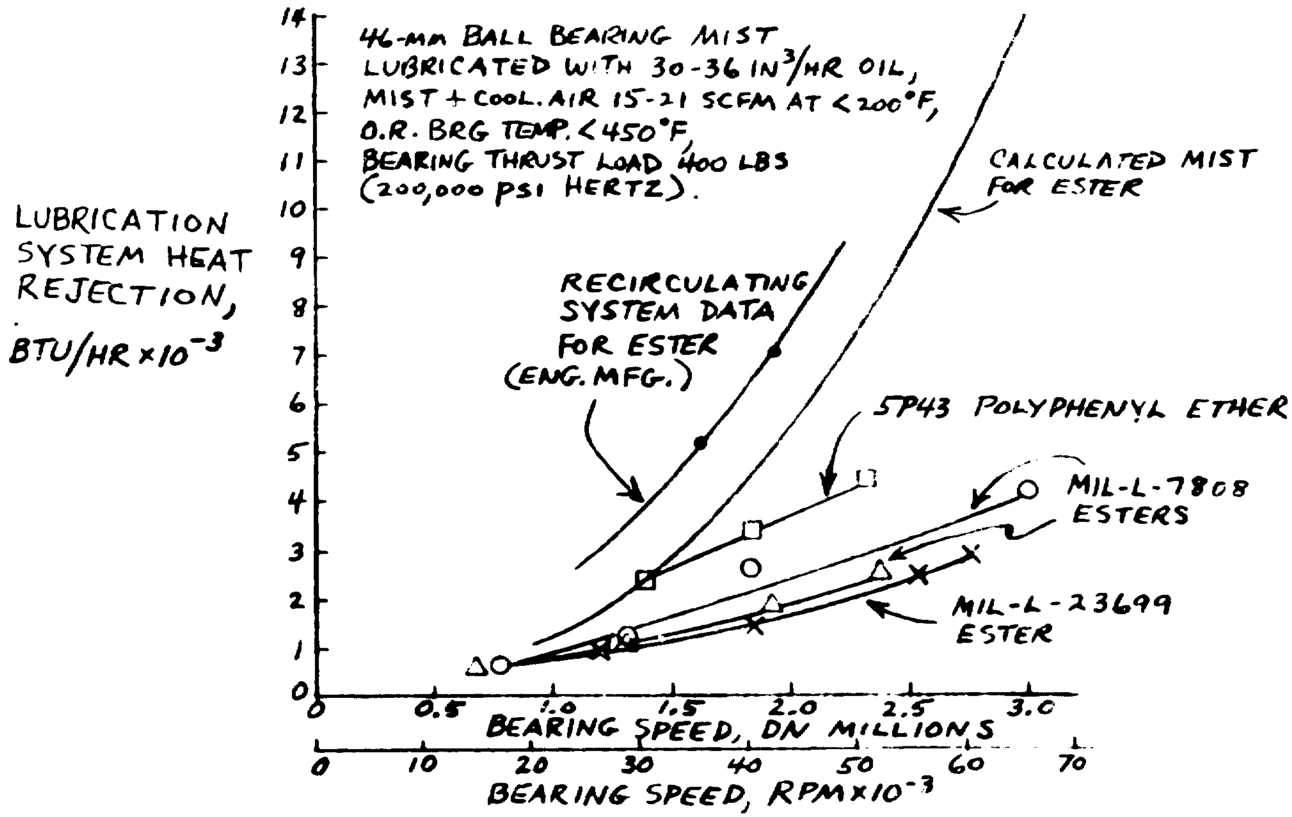


FIGURE 3.- LUBRICATION SYSTEM HEAT REJECTION

APPENDIX I

"MICROFOG LUBRICATION FOR AIRCRAFT ENGINE BEARINGS (125 MM BORE)" SUMMARIZED FROM FINAL REPORT NASA CR-134977 (CONTRACT NAS3-16826)

INTRODUCTION

Advanced aircraft system performance has been limited by the finite heat sink capacity of the lubricating oil coolers and the operating speed and temperature limitations of the engine bearings. The fuel is used as a heat sink in advanced aircraft designs to absorb heat rejected to the oil circulating through the bearing compartments. Since cooling of the crew and passenger compartments and other high priority aircraft equipment such as electronics takes preference over the bearings for this limited fuel heat sink capacity, increased system performance depends critically on minimizing heat rejection from the bearing compartments. Insulation of these compartments is effective in keeping engine combustion heat and hot air convection from heating the oil significantly, so that the major source of heat rejection to the oil is the frictional heat generation in the bearings. In addition, developments in blading materials and turbine cooling have modified advanced engine designs to the point where the bearings must operate at much higher speeds and temperatures than current practice to obtain optimum performance.

A test rig was designed and built (fig. AI-1) for testing aircraft gas turbine mainshaft thrust bearings at high temperatures and speeds using microfog or oil-mist lubrication. Oil-mist lubrication reduces bearing frictional heat significantly by eliminating circulating oil churning at high speeds, and at the same time it allows higher bearing operating temperatures since the lubricant can be discarded after use and thermal degradation is thus of no concern. Oil-mist systems have reduced weight and complexity compared to circulating systems, since large capacity supply and scavenge pumps and heat exchangers are absent. In addition, they are less vulnerable to ballistic damage or accidental leaks and plugging of jets since large area pressurized oil tanks and circulating oil supply lines are not needed.

Early studies and evaluation testing of mist lubrication of aircraft turbine bearings reported in NASA report CR-54662 showed a definite potential. However, these studies were basically conducted with bearings and lubricant supply components which were designed for recirculating systems. In particular the bearing and oil-mist supply configuration was not optimized for supplying mist and cooling air to the bearing areas where the lubricant is required for most effective utilization. Thus, initial attempts to operate large mainshaft size angular-contact ball thrust bearings with mist lubrication under advanced turbine powerplant speeds, loads, and temperatures were unsuccessful with most candidate lubricants and only partially successful with one test oil at 1.75×10^6 DN.

Bearing failures occurred by a thermal imbalance mode apparently related to the inability of the available oil-mist systems to supply a constant, stable oil film to the load carrying elastohydrodynamic (EHD) contacts in the bearing and at the same time provide sufficient heat transfer response by the cooling gas or mist to prevent self-aggravating bearing temperature excursions. Basic oil-mist studies therefore were conducted under Contracts NAS3-9400 and NAS3-13207 to determine oil-mist particle size distributions, optimum mistor designs, mist reclassifier operation and wetting efficiencies, and gas flow over the surface, heat transfer coefficients through wetted films, and a variety of related basic phenomena underlying oil-mist lubrication technology.

Based on these results, further studies were initiated in the subject contract which included the modification of the aircraft engine mainshaft bearing test rig to incorporate a more effective mist and cooling air delivery and application system. Mist oil is transmitted through special nozzles with screens to increase oil particle size. The mist impinges on chamfered bearing surfaces designed to promote oil-film recirculation within the bearing and wetting out of the mist on the rotating elements. The through bearing cooling air is supplied through nozzles arranged concentrically with the mist nozzles, thus picking up any drops of oil forming on the mist nozzles. Cooling air is also applied around the bearing housing to increase cooling of the outer ring which carries very heavy centrifugal loads at high speeds.

RESULTS OF EXPERIMENTAL PROGRAM

Significant results obtained from this study are:

(1) Engine bearings have operated successfully for over 30 hours under high load (250 ksi maximum Hz stress) at high speeds of 2.5×10^6 to 3×10^6 DN with oil-mist lubrication producing measured heat generation rates one-fourth that of comparable bearings with conventional circulating oil-jet lubrication. Previous estimates of the reduction in bearing heat generation rate for oil-mist lubrication did not exceed about one-third that for oil-jet lubrication. Figures AI-2 to AI-4 give results of this testing.

(2) Air cooling (passing of air through and around a bearing) is an effective method of removing bearing generated heat even at speeds up to 3×10^6 DN.

(3) Shaft cooling air (air passing through the shaft to aid in cooling the inner ring) is not necessary. There is evidence that housing cooling air (air passing around the bearing housing) may not be necessary either. This would simplify the system to passing cooling air directly through the bearing only, along with the mist.

(4) Approximately 40 percent of the oil leaving the mist generator is plated out on a stationary test bearing. With a rotating bearing an even higher percentage is assumed to be plated out due to collision of the rotating elements with the mist particles passing through the bearing.

(5) Step-speed tests performed with four different candidate oils previously established to have the best potential for mist lubrication indicated that differences do exist in the bearing operating characteristics (heat generation rates) when different oils are used. The most effective oil evaluated to date appears to be a synthetic paraffinic oil plus 5 percent by weight of a heavy paraffinic resin.

(6) Initial testing showed that a mist-oil flow rate of approximately 50 in^3/hr and a total cooling air and mist air flow rate of approximately 50 SCFM was sufficient to lubricate and cool the bearing when operating at DN values in the range of 2.6×10^6. More recent testing has indicated that the oil flow rate can be reduced to 13.5 in^3/hr (less than a half pint per hr) and cooling air flow rate to approximately 40 SCFM while operating at 2.5×10^6 DN.

(7) A simplified system of inserting mist and cooling air into the bearing from one side only has proved to be more effective than applying the air from both sides.

(8) Occasional thermal imbalance bearing failures have occurred which indicate that localized heated areas within the bearing due to skidding or slippage between the elements may not be immediately corrected by the mist and cooling air flow patterns evaluated. (Thermal imbalance failures also occur with recirculating oil lubricated bearings.)

(9) The oil flow rates which testing has shown to be sufficient are appreciably lower than those established to be necessary based on the assumption that the ball track is wiped dry each time a ball passes and must be replenished by new oil. Apparently the oil supplied is reused many times before dissipated or thrown from the bearing.

(10) No major modifications to the bearing design are necessary to obtain adequate lubrication from the mist. The bearings tested incorporated a large chamfer at the intersection of the inner ring land and face to maximize plating out of the oil (which is directed at the chamfer) and a slightly tapered bore on the cage to improve circulation and utilization of the oil.

(11) No appreciable build-up of varnish or oil decomposition products has resulted in any of the tests performed even at bearing outer ring temperatures of 500° F.

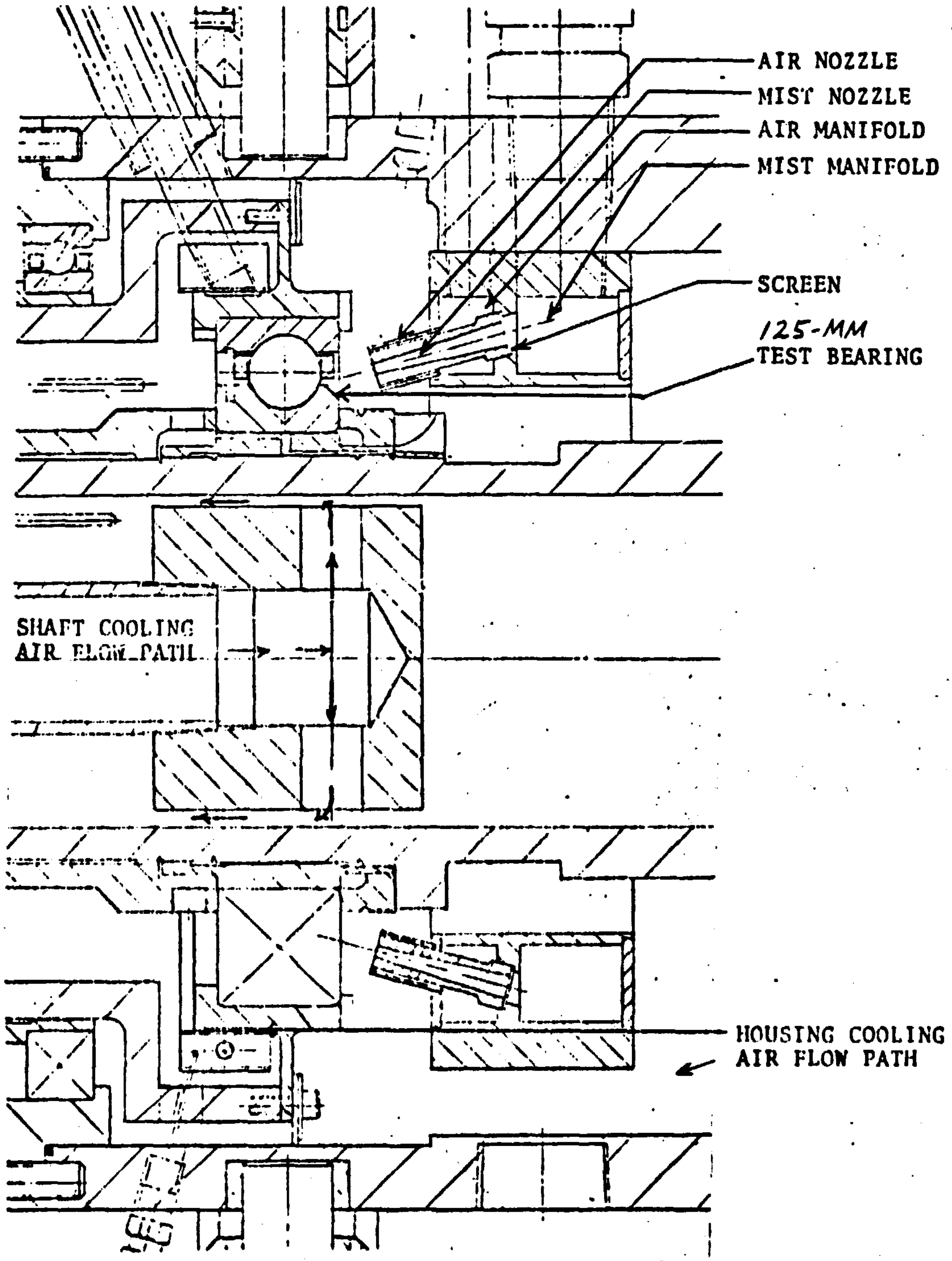
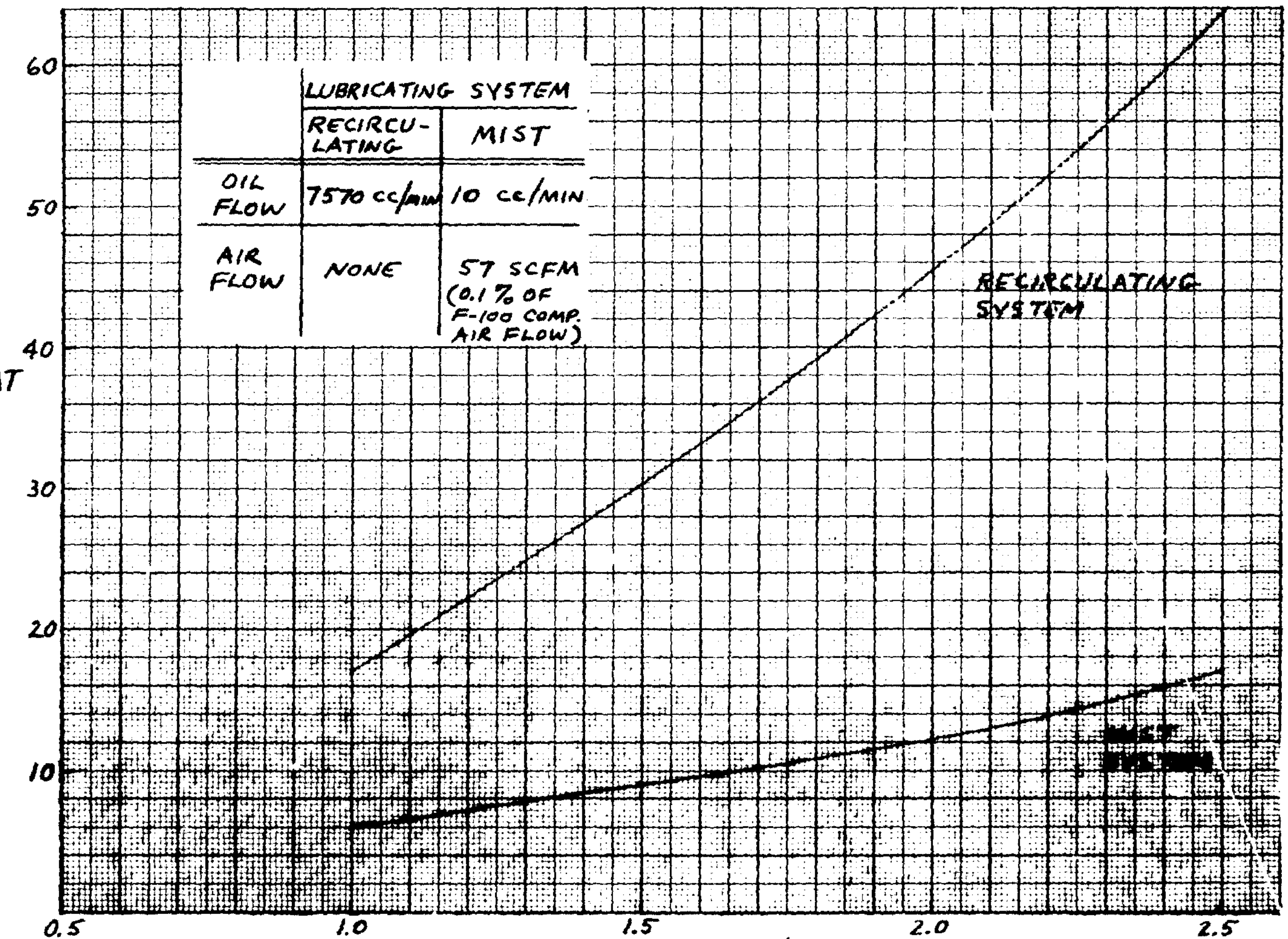


FIGURE AI-1. - OIL-MIST LUBRICATION TEST RIG

125-MM BALL BEARING; O.R. BRG. TEMP. 400°F (RECIRC.)
AND 500°F (MIST); THRUST LOAD 3,280 LBS (200,000 PSI HERTZ);
SYN. PAR. OIL.



BEARING HEAT GENERATION, BTU/HR × 10^{-3}

BEARING SPEED, DN × 10^{-6}

FIGURE AI-2.- COMPARISON OF BEARING HEAT GENERATION RATES

125-MM BALL BEARING; O.R. BRG. TEMP. 410°F (RECIR. SYSTEM) AND 495°F (MIST SYSTEM); BRG. THRUST LOAD 3,280 LBS (200,000 psi HERTZ); MIST + COOLING AIR 60 SCFM AT < 200°F; SYN. PAR. OIL

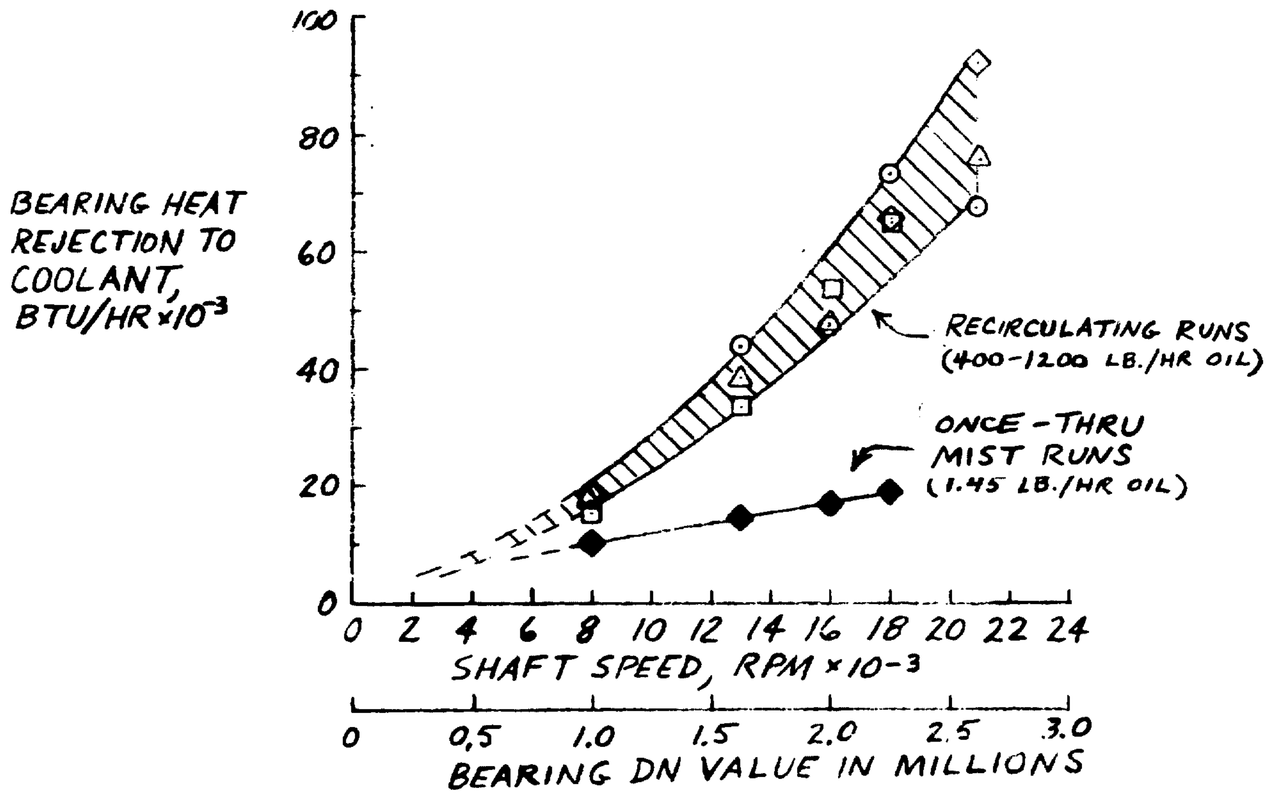


FIGURE AI-3. – BEARING HEAT REJECTION TO COOLANT

125-MM BALL BEARING; O.R. BRG. TEMP. 410°–440°F; 200,000 PSI HERTZ THRUST LOAD; MIST + COOLING AIR 56 SCFM; SYN. PAR. OIL + 5% WT RESIN

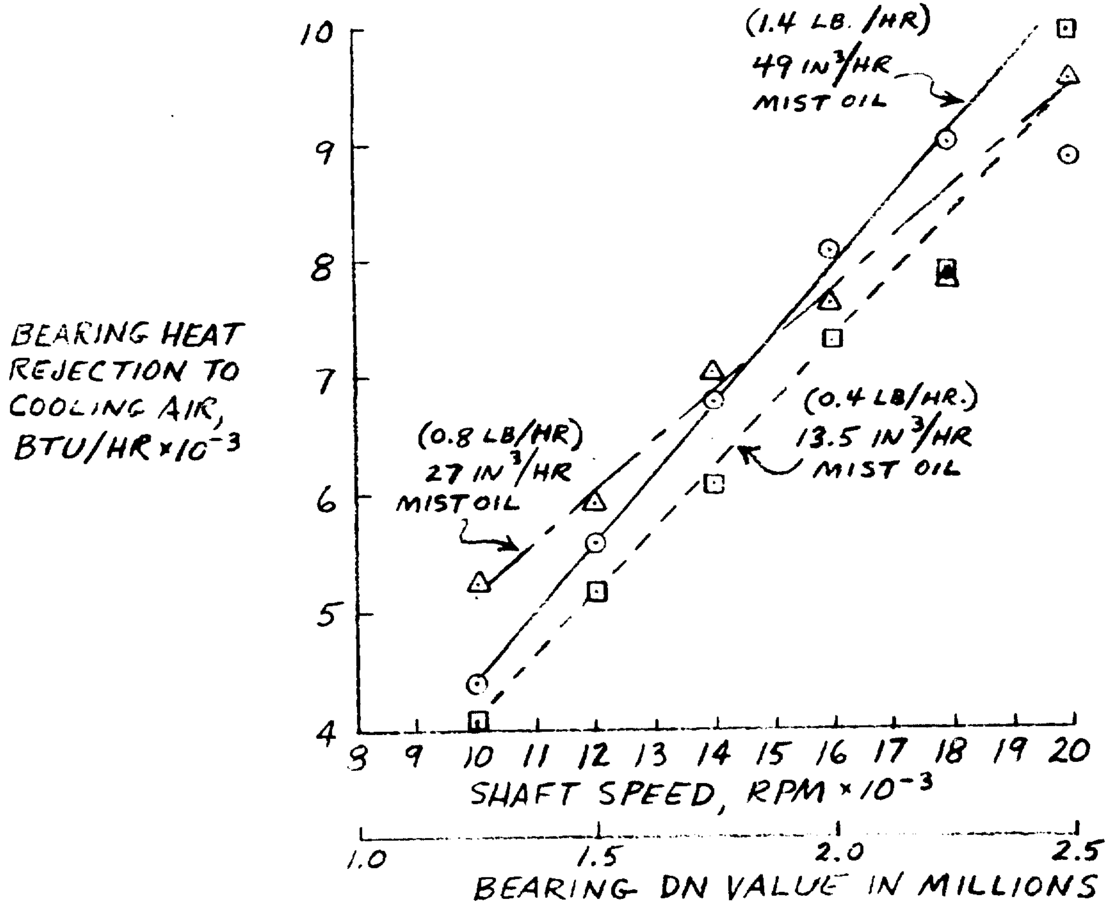


FIGURE AI-4.– BEARING HEAT REJECTION FOR THREE MIST OIL FLOWS