NASA
Contractor Report 204144

Army Research Laboratory
Contractor Report ARL–CR–340

Cost Benefit Analysis of a 9–Centistoke Lubricant for Helicopter Transmissions

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August 1997

Prepared for
Lewis Research Center
Under Contract NAS2–14118

National Aeronautics and
Space Administration

NAWC
Aircraft Division
NAVAL AIR WARFARE CENTER

U.S. ARMY
RESEARCH LABORATORY

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Contract Number NAS2-14118 Mod 10

Prepared by: Sikorsky Aircraft Corporation

1.0 SUMMARY

A study was conducted to estimate the cost benefit of using a 9-cSt lubricant in helicopter transmissions in place of the DOD-L-85374 oil currently being used. The expected benefits of using this higher-viscosity lubricant include longer lives for bearings and gears and a reduced rate of internal parts corrosion.

The study was based on an analysis of direct maintenance costs for the main transmission of the SH-60B helicopter and an extrapolation of SH-60B cost benefits to other helicopters in the U.S. Navy and Marine Corps inventories. The cost savings projected from this analysis are presented in Table 1-1. Overall, the SH-60B helicopter would achieve an estimated annual savings of $709 thousand in gearbox unscheduled maintenance costs, with the savings for all U.S. Navy and Marine Corps helicopters reaching an estimated $7.5 million annually.

Table 1-1 Summary of Projected Cost Savings

Cost Category	Dollars Per Flt-Hour	Dollars Per Year	Percent
SH-60B Main Transmission	9.39	600,490	18.7
All SH-60B Gearboxes	11.08	708,500	18.7
All Navy and Marine Corps Helicopters		7,489,000	16.3

The study was conducted as follows: An analysis was performed to determine the effect of 9-cSt lubricating oil on the life of main transmission components. The analysis examined bearing life and the scoring and wear of gears in a 3400 Series SH-60B main transmission assembly. Calculated life improvement ratios range between 1.01:1 and 3.67:1 for the gear meshes, with the higher-speed meshes experiencing the greatest gains. Calculated life improvement ratios for bearings range between 1.04:1 and 4.30:1.

Field data were analyzed to quantify the unscheduled removal rate of main transmission modules and to establish the causes for removal within specific categories. Depot repair records were analyzed to develop usage factors for the gears and bearings contained in each module and to develop estimates for the fraction of corrosion-related defects by part. Unit cost data were assembled, and average repair material costs were calculated. Average material cost per unscheduled repair were calculated at $3,299 for the accessory module, $18,346 for the input module, and $47,890 for the main module.

Life factor ratios were applied to these data to project the reduction in parts usage resulting from use of the 9-cSt oil. Corrosion-related parts usage rates were projected on the basis of corrosion test data supplied by the Naval Air Warfare Center (NAWC), Aircraft Division, Trenton, NJ. Total material cost savings were projected by part. Average material cost savings per unscheduled repair were calculated at $1,924 for the accessory module, $6,023 for the input module, and $16,113 for the main module.

A composite life factor ratio was developed for each module and applied to current unscheduled removal rates to project rates of removal when 9-cSt oil is used for lubrication. Historical records were used to establish the average costs of module replacement at the fleet- and depot-levels of maintenance. An overall per-flight-hour cost savings was computed for each module type. The per-flight-hour savings were calculated at $0.79 for the accessory module, $3.01 for the input module, and $5.59 for the main module. This represents a total savings of $9.39 per flight hour or 18.7% of the $50.19 per flight hour expended on all unscheduled maintenance of the SH-60B main transmission.

The percentage cost reduction computed for the main transmission was applied to the SH-60B intermediate and tail rotor gearboxes to yield estimated per-flight-hour cost savings of $0.22 and $1.47 respectively. This represents a total savings for all SH-60B gearboxes of $11.08 per flight hour or approximately 16.3% of the $68.00 per-flight-hour cost of maintaining the entire transmission subsystem. This percentage cost reduction was then extrapolated to other helicopters in the U.S. Navy and Marine Corps inventories to obtain a rough-order-of-magnitude annual cost saving of approximately $7.5 million.

2.0 GEAR AND BEARING LIFE IMPROVEMENT ANALYSIS

A comparison was made of the EHD film thickness between a 9-cSt oil and DOD-L-85374 oil which has a viscosity of 5.5-cSt. (Both viscosity measurements are taken at 210 degrees F.) The ratio of EHD and composite surface roughness yields the specific film thickness, Λ. Figure 2-1 illustrates the relationship between component life and specific film thickness; i.e., for Λ greater than one, the life is greatly improved. The goal, therefore, was to show that the use of a 9-cSt oil will increase Λ and the lives of gears and bearings.

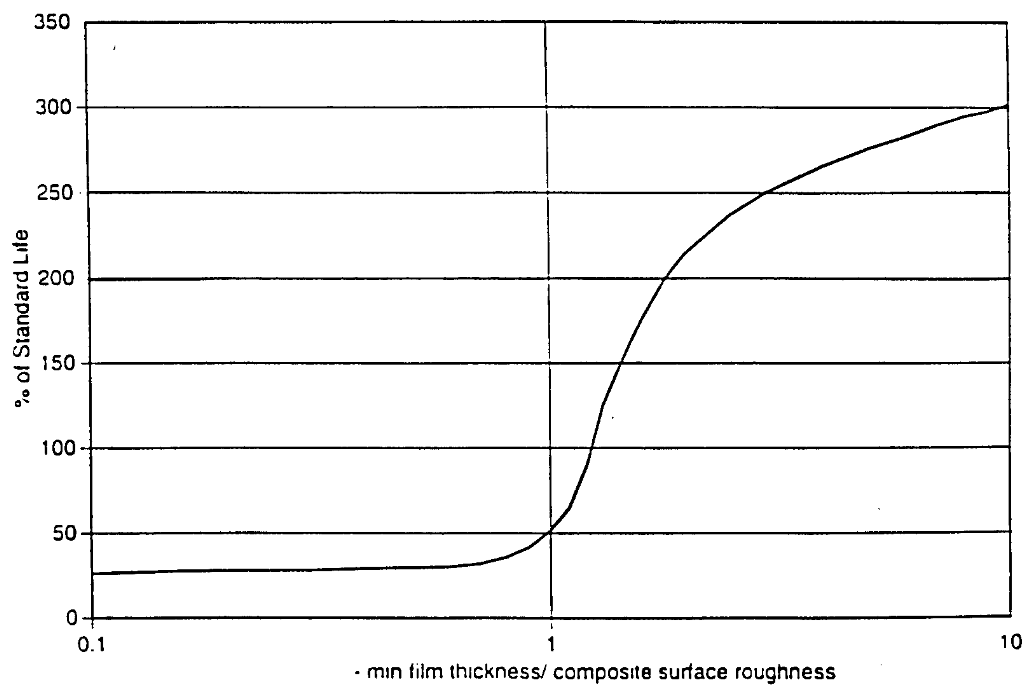

Figure 2-1. % Standard Life Versus Minimum Film Thickness/Composite Surface Roughness

2.1 Analysis of Gear Meshes

The first part of the analysis looked at each gear mesh in the main transmission. Geometric data and operating conditions were compiled and processed by a computer program to calculate the EHD film thickness for each oil. The computer program is based on the Dowson-Higgenson method as outlined in Reference 1. Application of the Dowson-Higgenson Method to the spur gears was straightforward; the bevel gears required conversion to equivalent helical gears before the analysis could be applied. This conversion involves transforming the geometric parameters (pitch diameter, cone distance, etc.) from values measured at the outer edge of the gear to mean values. For example, the conversion for outer cone distance is:

Amean = Aouter - (F/2)

where:

Amean = cone distance measured to the center of the gear

Aouter = cone distance measured to outer edge of the gear

F = face width of the gear

Amean is then used as an input for the Dowson-Higgenson calculation. Figure 2-2 shows the required bevel gear data and its conversion to equivalent helical gear data.

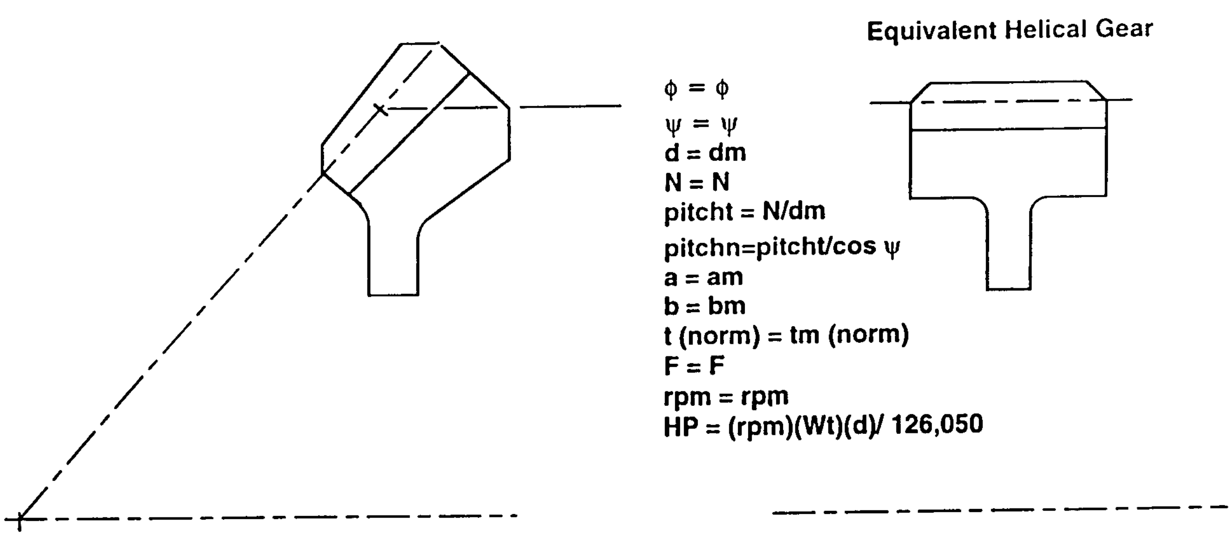

Figure 2-2. Conversion for Bevel Gear to Equivalent Helical Gear

Load values for the gear meshes are based on the maximum continuous horsepower for the H-60 helicopter obtained from Reference 2 report. The maximum continuous horsepower values are as follows:

single-engine input = 1,900

twin-engine input = 3,400

main rotor = 3,060

tail takeoff = 424

4th hydraulic = 40

An equivalent maximum continuous horsepower was developed for the individual planetary pinion/sun gear meshes and individual planetary pinion/ring gear meshes using the "equivalent fixed center system" method of analysis. The following equation yields an equivalent horsepower of 481:

$$HP_{eq} = \frac{HP}{n} \frac{(rpm_{sun} - rpm_{cage})}{rpm_{sun}}$$

where n = number of planetary pinions

Because it is known that an increase in oil viscosity causes an increase in temperature at the gear mesh, the analysis was adjusted assuming a slightly higher temperature for the 9-cSt oil. The output of the program, EHD film thickness, is used to calculate specific film thickness, Λ. A percent of standard life, or life factor, was then determined from Figure 2-1 for each oil.

2.2 Analysis of Bearings

A similar analysis was used for the bearings. Geometric data and operating conditions were input to a computer program based on the Grubin method for calculating EHD film thickness. The Grubin method is defined in Reference 3. Again, life factors for each oil were determined from Figure 2-1 and compared.

Load values for the bearings are based on prorated horsepower, and for the main rotor shaft bearings, prorated rotor head moments. Prorated horsepowers are calculated from the mission usage spectrum given in Reference 4 and the following equation:

$$HP_p = [\Sigma T_i (HP_i / HP_b)^{10/3}]^{3/10}$$

where

HP_p = prorated horsepower

HP_b = base horsepower

HP_i = horsepower at a particular point i in the load spectrum

T_i = percent time at a particular point i in the load spectrum

The prorated horsepowers at different locations in the main transmission are:

main bevel pinion = 1,200

main bevel gear = 2,400

planet pinion = 2,253

tail takeoff = 147

4th hydraulic = 25

For the main rotor shaft, the prorated head moment is 152,400 in-lbs.

2.3 Analysis Results

The results for the analysis of the gear meshes are shown in Table 2-1. Each gear mesh experiences an improvement in life with the 9-cSt oil ranging from 3.67:1 for the accessory spur gear to 1.01:1 for the oil pump spur gear. Because EHD film thickness is sensitive to RPM, the higher-speed meshes experience the greatest improvement.

The results for the analysis of the bearing lives are shown in Table 2-2. Again, every bearing exhibited an increase in life, with the highest-speed bearings experiencing the greatest improvements. The improvements ranged from 4.30:1 for the main bevel gear roller to 1.04:1 for the main rotor shaft roller bearings.

In general, the life improvement occurred more frequently and was larger for the bearings than for the gears. The difference in frequency can be explained simply by the presence of more high-speed bearings than high-speed gears. The explanation for the lower life improvement ratios for the gears is more complex. One possible cause is that higher sliding conditions increase surface heating, and higher friction coefficients result in reduced EHD film thickness, surface fatigue life, and increased wear and scoring (Reference 5). The presence of load-carrying additives in the 9-cSt lubricant would be expected to alleviate this. The advantage of the improved load-carrying capacity of the 9-cSt oil (improving scuffing/scoring modes) was not incorporated in the current study.

TABLE 2-1. GEAR MESH LIFE FACTOR CALCULATIONS

MESH LOCATION	RPM pinion/gear		OIL TYPE	TEMPERATURE	EHD	COMPOSITE ROUGHNESS	LAMDA	LIFE FACTOR	IMPROVEMENT LIFE FACTOR RATIO
ACCESSORY DRIVE			9 cSt	250 DEG F	21.328	28.28	0.754	0.325	1.16
	11806/5748		DOD-L-85374	240 DEG F	13.286	28.28	0.47	0.28	
ACCESSORY SPUR			9 cSt	250 DEG F	41.442	28.28	1.465	1.56	3.67
	12050/7335		DOD-L-85374	240 DEG F	25.815	28.28	0.913	0.425	
HYDRAULIC PUMP			9 cSt	215 DEG F	15.819	28.28	0.559	0.3	1.11
	4115/1207		DOD-L-85374	210 DEG F	9.456	28.28	0.334	0.27	
INPUT BEVEL			9 cSt	250 DEG F	24.306	28.28	0.859	0.39	1.34
	20900/5748		DOD-L-85374	240 DEG F	15.141	28.28	0.535	0.29	
MAIN MODULE BEVEL			9 cSt	215 DEG F	13.555	28.28	0.479	0.28	1.04
	5748/1207		DOD-L-85374	210 DEG F	8.103	28.28	0.286	0.268	
OIL PUMP SPUR			9 cSt	180 DEG F	5.672	28.28	0.201	0.265	1.01
	3330/263		DOD-L-85374	180 DEG F	3.016	28.28	0.107	0.262	
RING/PLANETARY			9 cSt	180 DEG F	19.654	28.28	0.695	0.315	1.16
	709/258		DOD-L-85374	180 DEG F	10.451	28.28	0.369	0.272	
SUN/PLANETARY			9 cSt	180 DEG F	11.476	28.28	0.406	0.275	1.03
	948/708		DOD-L-85374	180 DEG F	6.102	28.28	0.216	0.266	
TAIL TAKEOFF			9 cSt	215 DEG F	13.145	28.28	0.465	0.28	1.05
	4115/1207		DOD-L-85374	210 DEG F	7.858	28.28	0.278	0.267	

TABLE 2-2. BEARING LIFE FACTOR CALCULATIONS (1 OF 3)

BEARING NUMBER	TYPE	RPM	OIL TYPE	TEMPERATURE	EHD	COMPOSITE ROUGHNESS	LAMDA	LIFE FACTOR	IMPROVEMENT LIFE FACTOR RATIO
70951-08362			9 cSt	250 DEG F	28.32	8.9	3.17	2.53	1.23
HIGH SPEED INPUT	BALL	20900	DOD-L-85374	240 DEG F	16.68	8.9	1.87	2.05	
70952-08164			9 cSt	250 DEG F	33.09	8.9	3.70	2.61	1.17
HIGH SPEED INPUT	ROLLER	20900	DOD-L-85374	240 DEG F	19.50	8.9	2.18	2.24	
70952-08555			9 cSt	250 DEG F	20.31	8.9	2.27	2.29	1.71
INPUT GEAR	ROLLER	5748	DOD-L-85374	240 DEG F	11.97	8.9	1.34	1.34	
SB1074			9 cSt	250 DEG F	12.20	8.9	1.36	1.39	3.86
FREEWHEEL UNIT	BALL	5748	DOD-L-85374	240 DEG F	7.19	8.9	0.80	0.36	
SB1137			9 cSt	250 DEG F	9.02	8.9	1.01	0.52	1.79
FREEWHEEL UNIT	BALL	5748	DOD-L-85374	240 DEG F	5.32	8.9	0.59	0.29	
SB1139 (1/2)			9 cSt	250 DEG F	12.19	8.9	1.36	1.39	3.86
LOAD CASE 1	THRUST	11805	DOD-L-85374	240 DEG F	7.18	8.9	0.80	0.36	
GENERATOR DRIVE	BALL								
SB1139 (1/2)			9 cSt	250 DEG F	13.31	8.9	1.49	1.61	4.03
LOAD CASE 2		11805	DOD-L-85374	240 DEG F	7.84	8.9	0.88	0.40	
GENERATOR DRIVE	BALL								
SB2165			9 cSt	250 DEG F	27.71	8.9	3.10	2.52	1.25
HIGH SPEED INPUT	ROLLER	20900	DOD-L-85374	240 DEG F	16.33	8.9	1.83	2.02	
SB2205			9 cSt	215 DEG F	15.24	8.9	1.70	1.89	4.02
MAIN BEVEL PINION	ROLLER	5748	DOD-L-85374	210 DEG F	8.56	8.9	0.96	0.47	
SB2307			9 cSt	180 DEG F	10.80	11.7	0.93	0.44	1.57
PLANETARY PINION	ROLLER	707	DOD-L-85374	180 DEG F	5.36	11.7	0.46	0.28	
SB2560			9 cSt	215 DEG F	11.60	8.9	1.30	1.24	3.76
MAIN BEVEL GEAR	ROLLER	1207	DOD-L-85374	210 DEG F	6.52	8.9	0.73	0.33	
SB2562			9 cSt	215 DEG F	3.17	8.9	0.35	0.28	1.04
MAIN ROTOR SHAFT	ROLLER	263	DOD-L-85374	210 DEG F	1.78	8.9	0.20	0.27	

TABLE 2-2. BEARING LIFE FACTOR CALCULATIONS (2 OF 3)

SB3165			9 cSt	250 DEG F	11.22	11.3	0.99	0.50	1.72
LOAD CASE 1	HIGH	7186	DOD-L-85374	240 DEG F	6.61	11.3	0.58	0.29	
HYDRAULIC PUMP	ROLLER								
SB3165			9 cSt	250 DEG F	12.39	11.3	1.10	0.64	2.06
LOAD CASE 2	LOW	7186	DOD-L-85374	240 DEG F	7.30	11.3	0.65	0.31	
HYDRAULIC PUMP	ROLLER								
SB3217			9 cSt	215 DEG F	10.06	11.3	0.89	0.41	1.41
LOAD CASE 1		4116	DOD-L-85374	210 DEG F	5.65	11.3	0.50	0.29	
TAIL TAKEOFF	ROLLER								
SB3217			9 cSt	215 DEG F	11.50	11.3	1.02	0.53	1.83
LOAD CASE 2		4116	DOD-L-85374	210 DEG F	6.46	11.3	0.57	0.29	
4TH HYDRAULIC DRV	ROLLER								
SB3220			9 cSt	215 DEG F	10.91	11.3	0.96	0.47	1.62
TAIL TAKEOFF	ROLLER	4116	DOD-L-85374	210 DEG F	6.13	11.3	0.54	0.29	
SB3265			9 cSt	215 DEG F	12.09	11.3	1.07	0.61	2.03
4TH HYDRAULIC DRV	ROLLER	4116	DOD-L-85374	210 DEG F	6.79	11.3	0.60	0.30	
SB3313			9 cSt	215 DEG F	20.52	11.3	1.81	2.01	3.72
MAIN BEVEL PINION	ROLLER	5748	DOD-L-85374	210 DEG F	11.53	11.3	1.02	0.54	
SB3354			9 cSt	250 DEG F	13.82	11.3	1.22	0.99	3.00
LOAD CASE 1	THRUST	5748	DOD-L-85374	240 DEG F	8.15	11.3	0.72	0.33	
INPUT GEAR	ROLLER								
SB3354			9 cSt	250 DEG F	13.82	11.3	1.22	0.99	3.00
LOAD CASE 2		5748	DOD-L-85374	240 DEG F	8.15	11.3	0.72	0.33	
INPUT GEAR	ROLLER								
SB3409			9 cSt	180 DEG F	5.18	11.3	0.46	0.28	1.04
MAIN ROTOR SHAFT	ROLLER	263	DOD-L-85374	180 DEG F	2.57	11.3	0.23	0.27	
SB3504			9 cSt	180 DEG F	4.00	11.3	0.35	0.28	1.04
MAIN ROTOR SHAFT	ROLLER	263	DOD-L-85374	180 DEG F	1.98	11.3	0.18	0.27	

TABLE 2-2. BEARING LIFE FACTOR CALCULATIONS (3 OF 3)

SB3612			9 cSt	215 DEG F	10.44		7.1	1.48	1.59	4.30
LOAD CASE 1	HIGH	1207	DOD-L-85374	210 DEG F	5.86		7.1	0.83	0.37	
MAIN BEVEL GEAR	ROLLER									
SB3612			9 cSt	215 DEG F	14.50		7.1	2.05	2.18	2.91
LOAD CASE 2	LOW	1207	DOD-L-85374	210 DEG F	8.14		7.1	1.15	0.75	
MAIN BEVEL GEAR	ROLLER									

2.4 Other Issues

2.4.1 Corrosion

The 9-cSt oil developed for test by the Navy contains a package of corrosion-prevention additives whereas DOD-L-87354 oil does not. Corrosion testing conducted at the Naval Air Warfare Center (NAWC), Aircraft Division, Trenton, NJ showed a minimum of 50% better corrosion protection for the 9-cSt oil with additives than for the DOD-L-87354 oil without additives. In the analysis of life improvement, a reduction of 50% was assumed in rejection rate for internal components subject to corrosion. The corrosion-protection improvement does not affect MTBUR (mean time between unscheduled removal) but reduces the cost of depot repair since fewer internal components are reworked or scrapped for corrosion. (See cost benefit analysis.)

2.4.2 Filter/ Pump Pressure Regulator

Since the viscosity of the 9-cSt oil is higher than current state-of-the-art oils in use in helicopters, the filter will experience a larger pressure drop when the advanced oil is used. This can have the effect of reducing the oil pressure into the oil cooler and eventually into the gearbox. Most lubrication pumps will have the capacity to overcome this by regulating the oil bypass valve to make the pump oil-out pressure higher and therefore keep the oil pressure into the gearbox the same. If pressure is the same, flow will be reduced since losses are higher. The regulator can be further adjusted to increase pressure and maintain the same flow if desired. The exact amount can be determined by test. The overall effect will be small.

2.4.3 Gearbox Breather Vents

Oil viscosity should have no effect on air flow through the gearbox breather vents.

2.4.4 Flow Rates, Oil Jet Hole Sizes

The 9-cSt oil will cause a reduction of system pressure and a reduction of flow in the gearbox. If the pressure regulator is adjusted as indicated in the discussion above, flow can be maintained for a small pressure increase, or pressure can be maintained for a small flow decrease. For oil jets and lines, the flow is generally turbulent. In turbulent flow, oil viscosity has only a small effect. Therefore, losses through oil lines and jets will not be affected appreciably.

2.4.5 Oil Cooler, Blower, Ducting

The existing system will experience a higher pressure loss with a 9-cSt oil than it does with DOD-L-87354 oil. If the pressure regulator is adjusted to maintain pressure, or pressure is increased to maintain flow, the oil cooling rate should be slightly higher, since temperature should be slightly higher for the same operating conditions. Since oil-in temperature is slightly higher, ΔT from ambient to oil-in temperature is slightly higher, and oil cooling rate should be slightly greater in terms of BTU per minute. Overall, the cooler oil-out temperature will be about the same and the effect will be negligible.

2.4.6 Operating Temperature

The increased oil viscosity creates higher pressure which in turn increases temperature. This is more evident in high-speed areas of the transmission than in low-speed areas of the transmission. The 9-cSt oil was tested by the Navy in an H-60 main transmission, and temperature at various locations was measured and compared to the operating temperature for the same operating conditions using DOD-L-87354 oil. It was determined that at the high-speed input section of the gearbox, at the input modules, the oil temperature was approximately 10 degrees F hotter with 9-cSt oil than with DOD-L-87354 oil.

The input pinion of the input module rotates at 20,000 rpm, with the output gear rotating at 5,768 rpm. At the main bevel mesh area, the pinion rotates at 5,768 rpm, with the gear rotating at 1,206 rpm. In this area of the gearbox, it was found by testing that the temperature was approximately 5 degrees F higher than with the baseline oil. In the low-speed planetary area of the gearbox, the temperature was about the same with each oil. The test temperature data was used in the comparative analysis by increasing the temperature of the main bevel mesh and tail takeoff meshes by 5 degrees F and by increasing the temperatures in the input module by 10 degrees F. The temperature effect was included in the analysis as a slight decrease in viscosity in the affected areas.

2.4.7 Sensors

Pressure and temperature indicators are used within the transmission system. Since the sensors are designed to read the oil pressure and temperature, changes in viscosity will have no effect on the accuracy within the engineering ranges used.

2.4.8 Cockpit Pilot Indicators, VIDS

The pressure and temperature sensors send electrical signals to the cockpit indicators. Since the sensors are unaffected, the indicators will also be unaffected.

2.4.9 Gearbox Seal Compatibility

The chemistry of the 9-cSt oil is compatible with all currently used seals, and no affect on seal life or performance would therefore be anticipated.

2.4.10 Operating Limitations

Since viscosity is increased in the 9-cSt oil compared to the DOD-L-87354 oil, cold weather operation may be affected. Generally MIL-L-7808 oil is used in cold climates when the temperature averages below a specified minimum. For the 9-cSt oil, the temperature at which the MIL-L-7808 oil is used may have to be higher to account for the viscosity difference. It is estimated that the point at which low-temperature oil (MIL-L-7808) would have to be used would be higher by approximately 25 degrees F for the 9-cSt oil versus the DOD-L-87354 oil.

2.4.11 Manuals

References to the transmission lubricant in operating and maintenance manuals would need to be updated.

3.0 COST BENEFIT ANALYSIS

A cost benefit analysis was conducted to project the cost saving that would accrue from the use of 9-cSt oil in helicopter transmissions. The study was based on the application of life improvement factors to parts usage rates experienced with the SH-60B helicopter main transmission. The results were then extrapolated to other gearboxes used in the SH-60B helicopter and to the transmission subsystems of other Navy and Marine Corps helicopters.

3.1 Analysis of Transmission Unscheduled Removal Data

Modules of the SH-60B main transmission are maintained under an on-condition maintenance policy. Except for scheduled retirement of the main rotor shaft at 4,400 hours, main transmission modules are removed from the aircraft for unscheduled causes only. Unlike transmission components of other fleet aircraft, the H-60 main transmission modules receive no scheduled overhaul. The impact of a scheduled overhaul policy is discussed in para. 3.5.3.

The Navy 3M System which is used to document aircraft maintenance in the field employs a code system to describe the reason for component repair or replacement. The codes represent generic fault modes, and the system provides no narrative description of the physical condition observed and/or fault symptoms recorded. The data allow the cause for component repair or replacement to be determined only within general classifications.

Since H-60 main transmission modules are not disassembled in the field, when the fault is internal, the technicians performing the repair can only record what is seen, sensed or recorded by the aircraft instrumentation, and only then to the extent allowed by the 3M code system. Occasionally, technicians in the field will use the code system improperly and record a cause for repair or replacement that doesn't relate to the type of component. For purposes of this study, removals of main transmission modules were grouped into the following categories:

Leaking

External Causes

- Corrosion/Pitting
- Induced/Secondary Damage

Internal Causes

- Internal Fault
- Probable Internal Fault

Leaking and external faults such as corrosion, pitting and impact damage are detected visually by the maintainer and are not subject to misinterpretation or erroneous classification. Internal fault refers to conditions such as gearbox overtemp and chip indications which are detected by the aircraft sensors and instrumentation. They are also nonambiguous insofar as the maintainer is concerned, although the sensor indications cover a range of gearbox faults and fault severity which the maintainer in the field usually cannot investigate.

Probable internal fault encompasses those conditions observed and recorded by the maintainer which are likely associated with faults inherent to the gearbox. Abnormal noise and vibration fall into this category. Conditions such as "broken" and "out of specification" are vague and may relate to an internal fault or to some type of induced damage. For purposes of the analysis, these conditions were grouped under the category of probable internal fault. Main transmission removal rates are tabulated by category in Table 3-1.

Table 3-1. SH-60B Main Transmission Unscheduled Removal Rates
Three Years Ending June 1996; 193,120 Flight Hours

	Rate Per 10,000 Flight Hours*		
Cause for Removal	Input Module	Access. Module	Main Module
Leaking	.14	.28	.51
External Causes			
Corrosion/Pitting	2.24	1.59	1.62
Induced/Secondary Damage	.54	.35	0
Sub-Total	2.78	1.94	1.62
Internal Causes			
Internal Wear/Failure	.82	.56	.51
Probable Internal Wear/Failure	.75	.28	.20
Sub-Total	1.57	.84	.71
Total Unscheduled Removals	4.50	3.05	2.85

Source: Navy 3M Data

* Ship set rate.

Because the SH-60B operates in a salt-water environment, external corrosion is the leading cause of unscheduled gearbox replacements, representing more than 60% of all removals. Removals for internal faults are less than 30% of the total. The mean time between unscheduled removal (MTBUR) for internal faults is as follows:

	MTBUR*
Accessory Module	11,900
Input Module	6,370
Main Module	14,100

Aircraft hours; ship set rate; internal faults only.

3.2 Analysis of Depot Repair Data

Some of the H-60 main transmission modules removed from aircraft in service are sent to the Sikorsky Aircraft Overhaul and Repair Facility for repair. The remainder are repaired at military depots.

Sikorsky maintains a database of parts rework and replacement activity at O&R. Originally the database was maintained by data collectors on site who extracted data from paper forms and records. It is now in the process of being converted into a fully automated system which relies on data entered electronically by the personnel performing component teardown and evaluation. The database contains coded descriptions of parts discrepancies, including the type of fault, its location and origin, and the disposition of the part (rework or scrap). It also provides for supplemental narrative descriptions of part condition and disposition.

The O&R parts discrepancies database was designed as a sample data collection system. Over the years it has captured the majority but not 100% of parts rework and replacement activity at O&R. It is used to assess trends in parts reliability and to investigate design and maintenance problems, but it cannot be relied upon to provide a completely accurate measure of part failure rates.

Another system at Sikorsky O&R tracks parts usage for procurement purposes using a metric called the overhaul usage factor. This factor reflects the average anticipated usage of a part based on prior history, expressed as a percentage of the parts per end-item assembly. For example, a main module bearing with a quantity of two per module and an overhaul usage factor of 0.25 would be expected to consume an average of one bearing every other unscheduled repair. While providing no information on the causes for parts replacement, the overhaul usage factor is believed to represent a reasonably accurate estimate of parts usage.

3.3 Parts Usage and Repair Material Cost Projections

Table 3-2 lists the gears and bearings that make up each of the three modules of the SH-60B main transmission assembly. The quantity of each part per assembly (QPA) is shown, together with the overhaul usage factor reflecting the average fraction of that part replaced during depot maintenance.

3.3.1 Corrosion-Related Parts Usage

Also listed for each part is the corrosion factor, or fraction of discrepant parts rejected for corrosion and pitting. This factor was derived by examining parts discrepancy records for a sample of each module type. Because sampling may cause distortions in a statistic such as this, it was decided to develop a relative ranking based on the sample data:

	Factor
Negligible	0.0
Low	.05
Moderate	.20
High	.35

For each bearing and gear, this factor represents the average fraction of discrepant parts that will be rejected because of corrosion and pitting. In combination with the overhaul usage factor and the quantity per assembly, it yields an estimate of the average number of parts that will be rejected for corrosion at each depot-level induction of the module.

3.3.2 Unit Costs and Average Material Costs

Listed in Table 3-2 are the unit costs (cost to the customer) for each part. Costs vary with procurement quantities. They also increase over time due to inflation. The costs listed in Table 3-2 represent recent procurement but may not represent the cost of parts procured in the past and being replaced at O&R today or the cost of parts that might be procured in the future.

The average cost per repair shown in Table 3-2 is a product of the quantity per assembly, the overhaul usage factor, and the unit cost.

TABLE 3-2. PARTS USAGE AND REPLACEMENT COST PROJECTIONS (Page 1 of 2)

Part Number	Component/Part		QPA	Usage Factor	Corr. Factor	Unit Cost	Avg. Cost/ Repair	Life Factor Ratio	Pred. Cost (Corr.)	Pred. Cost (Other)	Delta Cost/ Repair
70351-08080-043	Accessory Gearbox										
70351-08072-101	Drive Pinion (37-76 Mesh)		1	0.1	0.2	6247	625	1.16	62	431	131
70351-08088-102	Spur, Hyd. Pump (56-92 Mesh)		1	0.1	0	3300	330	3.67	0	90	240
70351-08093-101	Spur, Gen. Drive (56-92 Mesh)		1	0.1	0	5894	589	3.67	0	161	429
SB1139-101	Brg. Set, Gen. Drive	Ball	1	0.7	0	1531	1072	3.95	0	271	800
SB3165-101	Cone, Brg., Hydraulic Pump	Roller	2	0.65	0.05	396	515	1.89	13	259	243
SB3165-201	Cup, Brg., Hydraulic Pump	Roller	2	0.65	0.1	130	168	1.89	8	80	80
							3299	2.15	84	1292	1924
70351-08001-043	Input Module										
70351-08001-046	Input Module										
70351-08060-103	Acc. Drive (37-76 Mesh)		1	0.25	0.2	5131	1283	1.16	128	885	270
70351-08205-101	Pinion, Input Bevel (22-80 Mesh)		1	0.6	0.05	6758	4055	1.34	101	2875	1079
70351-08221-101	Output Bevel (22-80 Mesh)		1	0.2	0.05	13620	2724	1.34	68	1931	725
70951-08362-041	Brg. Assy., High-Speed Input	Ball	1	0.7	0.3	1963	1374	1.23	206	782	386
70952-08164-041	Brg. Assy., High-Speed Input	Roller	1	0.65	0.3	1608	1045	1.17	157	625	263
70952-08555-042	Brg. Assy., Input Gear	Roller	1	0.9	0.3	3257	2931	1.71	440	1200	1292
SB1074-101	Brg., Freewheel Unit	Ball	1	0.8	0	826	660	3.86	0	171	489
SB1137-101	Brg. Set, Freewheel Unit	Ball	1	0.95	0	1087	1033	1.79	0	577	456
SB2165-101	Brg., High-Speed Input	Roller	1	0.8	0.2	1788	1430	1.25	143	915	372
SB2613-101	Roller, Freewheel Unit	Roller	14	0.9	0	60	756	1.00	0	756	0
SB3354-101	Cone, Bearing	Roller	2	0.75	0.05	528	792	3.00	20	251	521
SB3354-201	Cup, Bearing	Roller	2	0.6	0.1	218	262	3.00	13	79	170
							18346	1.21	1276	11047	6023

TABLE 3-2. PARTS USAGE AND REPLACEMENT COST PROJECTIONS (Page 2 of 2)

Part Number	Component/Part		QPA	Usage Factor	Corr. Factor	Unit Cost	Avg. Cost/ Repair	Life Factor Ratio	Pred. Cost (Corr.)	Pred. Cost (Other)	Delta Cost/ Repair
70351-38100-047	Main Module										
70351-08176-101	Gear, Oil Pump Dr. (12-152 Mesh)		1	0.15	0	6602	990	1.01	0	981	10
70351-38104-102	Input Pinion (21-100 Mesh)		2	0.45	0.1	5861	5275	1.04	264	4565	446
70351-38114-101	Main Bevel (21-100 Mesh)		1	0.3	0	15720	4716	1.04	0	4535	181
70351-38151-101	Pinion, Tail Takeoff (22-75 Mesh)		1	0.25	0.3	7236	1809	1.05	271	1206	332
70351-38167-101	Bevel, Tail /Hyd. Pump (22-75 Mesh)		1	0.1	0.3	9259	926	1.08	139	600	187
70351-38172-101	Sun Gear (62-83 Mesh)		1	0.05	0.2	7622	381	1.03	38	296	47
70351-38177-101	Ring Gear (83-228 Mesh)		1	0.15	0.3	19265	2890	1.16	433	1744	712
SB2205-101	Brg., Main Bevel Pinion	Roller	2	0.7	0.1	2378	3330	4.02	166	745	2418
SB2307-501	Brg. and Gear, Planetary	Roller	5	0.45	0.3	8640	19440	1.57	2916	8668	7856
SB2560-101	Brg., Main Bevel Gear	Roller	1	0.8	0.3	2738	2191	3.76	329	408	1454
SB2562-101	Brg., Main Rotor Shaft	Roller	1			3838	0	1.04	0	0	0
SB3217-101	Cone, Bearing	Roller	2	0.3	0	386	232	1.62	0	143	89
SB3217-201	Cup, Bearing	Roller	2	0.4	0.1	180	144	1.62	7	80	57
SB3220-101	Cone, Brg., Tail Takeoff	Roller	1	0.3	0	307	92	1.62	0	57	35
SB3220-201	Cup, Brg., Tail Takeoff	Roller	1	0.3	0	187	56	1.62	0	35	21
SB3265-101	Cone, Brg., 4th Hyd. Drive	Roller	1	0.3		348	104	2.03	0	51	53
SB3265-201	Cup, Brg., 4th Hyd. Drive	Roller	1	0.4		206	83	2.03	0	41	42
SB3313-102	Cone, Bearing	Roller	2	0.4	0	876	701	3.72	0	188	512
SB3313-202	Cup, Bearing	Roller	2	0.2	0	478	191	3.72	0	51	140
SB3409-101	Cone, Brg., MR Shaft	Roller	1	0.55	0.3	2976	1637	1.04	246	1102	290
SB3409-201	Cup, Brg., MR Shaft	Roller	1	0.3	0.3	1519	456	1.04	68	307	81
SB3504-102	Cone, Brg., MR Shaft	Roller	1	0.45	0.1	1087	489	1.04	24	423	41
SB3504-202	Cup, Brg., MR Shaft	Roller	1	0.25	0.2	341	85	1.04	9	66	11
SB3612-102	Brg., Main Bevel Gear	Roller	2	0.4	0.3	2090	1672	3.61	251	324	1097
							47890	1.71	5162	26615	16113

3.3.3 Life Factor Ratios

The life factor ratios (LFR) listed in Table 3-2 were developed from the method described earlier in the report. For some parts, life factor ratios were developed for two different load conditions. Because it is not possible to ascertain from the data, the specific location and application of a part when there is more than one application per module, for purposes of the cost analysis, a numerical average of the two life factor ratios was used.

3.3.4 Corrosion-Inhibiting Benefit Factor

Limited testing has been conducted on the corrosion-inhibiting properties of the 9-cSt oil. Correspondence from the NAWC Aircraft Division, Trenton (Reference 6) reports that in corrosion testing of 52100 steel balls, pass ratios of from 50% to 75% have been experienced. This compares with an expected pass ratio of zero % for the current DOD-L-85734 oil which has no corrosion-inhibiting additives. NAWC recommended that the more conservative 50% value be used, i.e., an expected reduction of 50% in the corrosion rate of steel parts used in the H-60 main transmission modules.

3.3.5 Repair Material Cost Projections

Use of the 9-cSt oil will reduce the cost of repair by extending the life of gears and bearings and reducing the rate of internal corrosion. Table 3-2 shows the predicted average cost of repair material if modules are operated with the 9-cSt oil. Costs are computed as follows:

Corrosion-Related Parts Usage

Unit Cost x QPA x Usage Factor x Corrosion Factor x 0.5

Wear- and Failure-Related Parts Usage

Unit Cost x QPA x Usage Factor x (1 - Corrosion Factor)/ Life Factor Ratio

Also shown is the average cost saving per repair. This is the cost saving in repair material that would be anticipated based on current part usage rates and the projected life-enhancing and corrosion-inhibiting properties of the 9-cSt oil. The projected saving is the difference between the current average cost and the predicted cost.

3.4 Effect on Transmission Unscheduled Removal Rates

Table 3-2 reflects the reduced parts usage and reduced material costs that would be expected if the modules were repaired at the same frequency they are currently being repaired. However, to the extent that bearing and gear wear contributes to module malfunctions and failure indications in service, these service-life improvements will also reduce the frequency of unscheduled removals.

The database reflects the rate at which gears and bearings are found discrepant and are reworked or repaired at O&R. It does not reflect the rate at which each of these parts has contributed to unscheduled removals of the modules in service. (A number of parts are typically reworked or replaced in the course of a repair, but ordinarily only one of them was the cause of removal.) Investigations are sometimes conducted to identify the root cause of module removals and returns to O&R, but such findings are not available for all of the modules covered by the data. Because the database represents only a sample of module returns, even 100% determination of root cause might not provide an accurate measure of each part's historical contribution to the unscheduled removal rate.

Lacking definitive data on the causes of module removals in service, the most reasonable assumption from the standpoint of this analysis is that each part contributes to unscheduled removals in proportion to the rate at which it is found discrepant at O&R. This would apply to internal modes other than corrosion, which in itself is not a cause for module removal.

The total line for each module in Table 3-2 shows the weighted-average life factor ratio for non-corrosion-related modes based on the average parts usage. In Table 3-3 these weighted-average LFRs are applied to the current MTBUR for internal faults to predict the MTBUR with modules operating with the 9-cSt oil.

Table 3-3. Current and Projected MTBURs (Flight Hours)

	Current MTBUR	Projected MTBUR
Accessory Module	3,280	3,855
Input Module	2,220	2,360
Main Module	3,510	3,920

Although the weighted-average LFRs range between 1.2 and 2.2 for the three modules, the effect on the overall MTBUR is considerably less, because the life improvements affect removals for internal causes only and the majority of the removals are for corrosion and leakage.

3.5 Projected Direct Maintenance Cost Savings

3.5.1 Current Average Repair Costs

Part of the cost incurred when main transmission modules are removed from the aircraft for malfunction or failure is the labor to replace the module at the Organizational level of maintenance and the labor to repair the module at depot. Material usage at depot makes up the remainder of the unscheduled removal costs. Table 3-4 presents average labor costs by module type.

The average cost of replacing a module at the Organizational level is derived from the average man-hours reported via the 3M System. Labor is priced at $20 per man-hour. The average man hours expended on replacement of a module include, in addition to the removal and installation tasks, the man hours consumed in troubleshooting and fault isolation, and the man hours consumed in post-replacement test and checkout.

Table 3-4. Current Average Costs Per Unscheduled Removal (Dollars)

Transmission Module	O-Level Labor	D-Level Labor	D-Level Material	Total
Accessory Module	275	4,200	3,665	8,140
Input Module	470	10,900	24,625	35,995
Main Module	2,285	31,100	77,200	110,585

The average cost of depot-level labor is somewhat variable. It depends on the scope of the repairs, the number of units repaired under a given contract, and when and by whom the repairs were performed. It also depends on the cost accounting method. Labor costs may not be fully burdened under some reporting systems, for example. As a result, it is possible to find significantly different repair costs reported in the historical records.

One source of repair cost data is the NALDA (Navy Aviation Logistics Data Analysis) System. Costs are reported for repair at Navy depots and repair at contractor facilities. A review of the costs contained in this database indicate that module repair costs range from about 20% to 30% of the module replacement cost. There is no way of telling the time-frame represented by the NALDA cost data or the specific costs included. It was decided therefore to use relatively current contractor data.

Internal records at Sikorsky were the alternate source of repair cost data. These records reflect repair costs for the subset of main transmission modules repaired at Sikorsky O&R. A review of these records produced the current average depot labor costs and depot material costs shown in Table 3-4.

3.5.2 Cost Projections

Cost projections are summarized in Table 3-5. The labor cost saving is derived by applying the difference in unscheduled MTBUR from Table 3-3 to the average Organizational- and depot-level repair costs from Table 3-4. The material cost saving is derived from the delta material cost per repair from Table 3-2. The per-flight-hour value is based on the current module removal rates.

Table 3-5. Cost Projections

Module	Labor Saving ($/FH)	Material Saving ($/FH)	Total Saving ($/FH)	Cur. Avg. Cost ($/FH)	Saving (%)
Accessory Module	.20	0.59	.79	2.48	31.9
Input Module	.30	2.71	3.01	16.21	18.6
Main Module	1.00	4.59	5.59	31.50	17.7
Total	1.50	7.89	9.39	50.19	18.7

The current average cost of unscheduled maintenance of the main transmission is $50.19. This was derived by dividing the average cost factors from Table 3-4 by the MTBUR values from Table 3-3. The total projected cost saving for the main transmission is $9.39 per flight hour. This represents approximately 18.7% of the total per-flight-hour direct maintenance cost associated with main transmission unscheduled removals and repairs. At an average annual aircraft utilization of 63,950 flight hours, the $9.39 per flight hour savings translates into an annual savings of $600,490.

Table 3-6 gives the estimated total direct maintenance costs for the other two gearboxes of the SH-60B helicopter. The Organizational-level labor cost and Depot-level labor and material cost were derived from Navy and contractor data sources as described for the main transmission modules above. Applying the same percentage cost reduction to these other two gearboxes yields an additional cost saving of $1.69 per flight hour.

Table 3-6. Intermediate and Tail Rotor Gearbox Projections

Gearbox	MTBUR	O-Lev Labor Cost ($)	D-Lev Repair Cost ($)	Total Cost ($)	Total Cost ($/FH)	Proj. Sav. ($/FH)
Intermediate	12,500	155	14,100	14,255	1.15	0.22
Tail Rotor	2,975	785	22,600	23,385	7.85	1.47

The Navy's VAMOSC (Visibility and Management of Operating and Support Cost) system reports a total direct maintenance cost of $68.00 per flight hour for the SH-60B transmission and drives subsystem (Table 3-7). This includes the gearbox maintenance costs from Tables 3-5 and 3-6 which total $59.19 per flight hour. The balance of the $68.00 per flight hour involves other subsystem components such and the rotor brake, oil cooling system and the drive shafts and couplings. It also involves other types of maintenance such as removal of gearboxes for cannibalization, scheduled maintenance or modification, and all on-aircraft repairs such as corrosion rework and replacement of consumable hardware.

Use of the 9-cSt oil affects only that part of direct maintenance cost associated with the unscheduled removal and repair of gearboxes for gear- and bearing-related internal faults. From Tables 3-5 and 3-6, the projected cost savings is $11.08 per flight hour. This represents approximately 16.3 % of the $68.00 per flight hour cost of maintaining the entire drives and transmissions subsystem. At an average annual aircraft utilization of 63,950 flight hours, the $11.08 per flight hour savings translates into an annual cost savings of $708,500.

3.5.3 Cost Benefits for Gearboxes Subject to Scheduled Overhaul

Gearboxes of the SH-60B helicopter are maintained under an on-condition maintenance policy. Except for scheduled retirement of the main rotor shaft at 4,400 hours, they receive no scheduled overhaul. As discussed elsewhere in this report, the expected cost benefits of using 9-cSt oil in on-condition gearboxes include a lower rate of unscheduled removal in service and a reduced rate of parts consumption at depot. The relative benefits may be less for gearboxes being maintained under a scheduled overhaul policy, however.

The use of 9-cSt oil primarily benefits normal wear modes such as bearing spalling and gear scuffing and scoring. Scheduled overhaul intervals are usually not dictated by these modes, however, but by gearbox-specific conditions such as fretting of a joint, housing exterior corrosion or fatigue damage in a part. In most cases, the use of 9-cSt oil will not have a mitigating effect on these conditions so as to allow an increase in (or elimination of) the gearbox overhaul interval.

Gearboxes subject to scheduled overhaul are removed for both scheduled and unscheduled reasons. In most cases, scheduled removals dominate, and only a small percentage are removed for premature failure. Because the unscheduled removals all occur prior to the overhaul interval, they tend to occur early in the life of the component (the time since new or overhaul) and are often the result of flaws in the manufacturing or overhaul processes rather than the consequence of advanced wear of internal parts. If the use of 9-cSt oil does not lengthen the scheduled removal interval and makes only a minor improvement in the rate of unscheduled removal, the costs associated with gearbox removals in service will not be reduced to the extent predicted for the on-condition maintenance case.

Besides the cost benefit of lowering the gearbox removal rate, the use of 9-cSt oil also reduces parts usage at depot. Again, the benefit may be less for the scheduled overhaul case than for the on-condition maintenance case. Under a scheduled overhaul policy, the gearbox is completely disassembled for inspection of parts, and parts tend to be replaced on a preemptive basis when wear or damage is at an early stage. Because fewer parts are allowed to reach advanced stages of wear, the life-enhancing properties of 9-cSt oil will have a smaller impact on parts usage and consequently yield a smaller reduction in cost. Generally, a scheduled overhaul program is significantly more costly than an on-condition maintenance program, and for the reasons cited, it is anticipated that conversion to 9-cSt oil will have a proportionately smaller overall cost benefit when the gearbox is subject to scheduled overhaul.

3.6 Extrapolation to Other Fleet Aircraft.

Table 3-7 shows the per-flight-hour cost of maintaining the transmission and drives subsystems of other Navy and Marine Corps helicopters. Included are all aircraft which have a significant presence in the inventories and a significant number of hours flown on an annual basis. Costs were obtained from the Navy's VAMOSC (Visibility and Management of Operating and Support Cost) system. A 10% adjustment was made for missing data.

Table 3-7. Fleet-Wide R.O.M. Cost Savings Projection

Aircraft Model	Avg. Number Aircraft	Drives System Cost ($/FH)*	Average Annual Flt-Hrs	Average Annual Cost ($000)	R.O.M Annual Saving ($000)
AH-1W	147	164	30,775	5,047	823
HH-1N	36	77	8,960	690	112
UH-1N	111	117	24,790	2,900	473
SH-2G	17	272	3,240	881	144
UH-3H	41	75	9,145	685	112
SH-3H	67	103	15,510	1,598	260
CH-46D	32	150	8,655	1,298	212
HH-46D	46	150	11,890	1,784	291
CH-46E	241	153	65,824	10,071	1,642
CH-53D	57	184	11,650	2,144	350
RH-53D	18	332	2,270	754	123
CH-53E	143	301	32,385	9,748	1,589
MH-53E	45	286	7,350	2,102	343
SH-60B	166	68	63,950	4,350	709
SH-60F	77	51	30,915	1,577	257
HH-60H	25	37	8,150	302	49
Total				45,931	7,489

* Source: U.S. Navy VAMOSC system; fiscal years 1994-1995; fiscal year 1996 dollars.

The average annual cost is the product of the annual flight hours and the per-flight-hour direct maintenance cost. A rough-order-of-magnitude (ROM) cost saving is projected for each model by applying the same 16.3% cost saving computed for the SH-60B.

This must be regarded as a gross estimate for several reasons. First, and most obvious, is the number and complexity of the gearboxes on other model helicopters and the fraction of total subsystem direct maintenance cost that the gearboxes represent. Second, the gearboxes on many other helicopter models are subject to scheduled overhaul, and as discussed above, this may a limiting effect on the life-enhancing benefits of converting to 9-cSt oil. Third is the relative reliability of gearboxes on other model helicopters and the principal causes for unscheduled gearbox replacement, both of which can affect the benefits of using the 9-cSt oil.

In the case of the SH-60B, which formed the basis for this study, shipboard deployment and long hours flying low over the water leads to a relatively high rate of gearbox replacement for external corrosion, replacements which are unrelated to the lubricating oil used. Other models, especially those in the Marine Corps inventory, may have a much lower incidence of corrosion-related gearbox replacements and this could significantly alter the cost distribution.

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (*Leave blank*)

2. REPORT DATE
August 1997

3. REPORT TYPE AND DATES COVERED
Final Contractor Report

4. TITLE AND SUBTITLE
Cost Benefits Analysis of a 9–Centistoke Lubricant for Helicopter Transmissions

5. FUNDING NUMBERS
WU–581–30–13
1L162211A47A

6. AUTHOR(S)
Thomas A. Cook and Michelle A. Consolini

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Sikorsky Aircraft Corporation
6900 Main Street
Stratford, Connecticut 06601–1381

8. PERFORMING ORGANIZATION REPORT NUMBER
E–10892

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Research Laboratory
Cleveland, Ohio 44135–3191
and
NASA Lewis Research Center
Cleveland, Ohio 44135–3191

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
NASA CR–204144
ARL–CR–340

11. SUPPLEMENTARY NOTES
This report prepared for and managed by Lewis Research Center as a Task of Ames Contract NAS2–14118. Project Manager, David G. Lewicki, Structures and Acoustics Division, NASA Lewis Research Center, organization code 5950, (216) 433–3970. Work funded by Naval Air Warfare Center, Patuxent River, Maryland 20670–5304.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified - Unlimited
Subject Category 37

This publication is available from the NASA Center for AeroSpace Information, (301) 621–0390.

12b. DISTRIBUTION CODE

13. ABSTRACT ***(Maximum 200 words)***

A study was conducted to estimate the cost benefit of using a 9–cSt lubricant in helicopter transmissions in place of the DOD–L–85374 oil currently being used. The study was based on an analysis of direct maintenance costs for the main transmission of the U.S. Navy SH–60B helicopter and an extrapolation of SH–60B cost benefits to other helicopters in the U.S. Navy and Marine Corps inventories. For the study, an analysis was performed to determine the effect of 9–cSt lubricating oil on the life of main transmission components. Field data were also analyzed to quantify the unscheduled removal rate of main transmission modules and to establish the causes for removals within specific categories. Life factor ratios were applied to these data to project the reduction in parts usage along with cost savings resulting from use of a 9–cSt oil. Overall, the SH–60B helicopter would achieve an estimated annual savings of $709 thousand in gearbox unscheduled maintenance costs, with the savings for all U.S. Navy and Marine Corps helicopters reaching an estimated $7.5 million annually.

14. SUBJECT TERMS
Lubrication; Transmissions (machine elements); Gears; Bearings; Helicopters; Cost analysis

15. NUMBER OF PAGES
27

16. PRICE CODE
A03

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified		