HELICOPTER PROPULSION SYSTEM RELIABILITY AND ENGINE MONITORING ASSESSMENTS*

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SUMMARY

Bell Helicopter is conducting a study of helicopter propulsion system reliability problems, specific technology solutions, and engine monitoring implications. The study is approximately 50 percent complete. Engine monitoring implications thus far include consideration of reciprocating engine monitoring, realization of maintenance cost savings due to derated operation, bookkeeping of three-engine installations using two-engine cruise, monitoring of contingency rating usage and integration of drive system monitoring functions. Commercial acceptance will require "up-front" demonstration of cost effectiveness.

INTRODUCTION

Of the various helicopter subsystems, the propulsion subsystem (i.e. engines and drive train) has the greatest impact on reliability, maintainability and safety. A study by Boeing Vertol (Reference 1) of over 1500 FAA Malfunction or Defect Reports (FAA Form 9330) for the U.S. civil turbine-powered helicopter fleet shows the propulsion subsystem accounts for:

49.2% of the failures

60.1% of the unscheduled maintenance manhours

87.3% of the repair parts cost

Similarly, an in-house study by Bell Helicopter Textron (BHT) shows that the propulsion subsystem is involved in 79% of the major, and 49% of the minor, material failure related accidents in a Military light helicopter fleet.

Against this background, BHT has been awarded a contract by NASA - Ames to conduct a study of "Propulsion Systems Reliability and Integrated Engine Monitoring Technology Assessments for Civil Helicopters". The objective of the study is to increase civil helicopter productivity by improving propulsion system life, reliability and maintainability through proper focusing of future research technology programs. Study tasks and schedule are shown by Figure 1. Those tasks which are engine related such as derated engine characteristics, engine design changes, and engine cycle modifications have been subcontracted to Detroit Diesel Allison.

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PROBLEM IDENTIFICATION

The Statement of Work for this task is to "Identify the major short life, unreliable, and high maintenance engine and power transfer components and subsystems in current civil helicopters. Categories shall include both reciprocating and turbine engines, single and multiple engine configurations, single and tandem rotor vehicles, and light, medium and heavy helicopters".

This task was approached in three ways:

- Accident rate data
- Maintenance rate data
- Direct operator input

Accident Rate Approach

For this approach, the U.S. civil helicopter population was determined, using the latest available data (Reference 2), with results as shown by Table 1. This population was broken out by the various study categories as shown by Table 2. Also shown are the flight hour distributions of the various categories, as determined from Reference 3. Accident data for this population and time period, as reported by the National Transportation Safety Board was then examined. A total of 2302 helicopter accidents occurred, of which 1472 (64%) involved no material failure of the helicopter. However, of the 831 which were material failure related, 586 (70%) had an engine or drive train related cause factor. Table 3 shows a breakdown of accidents by engine type (reciprocating or turbine). Considering the 469 accidents which had a powerplant related cause factor, 354 (75.5%) involved reciprocating engine models, while the remaining 115 (24.5%) involved turbine powered models. These numbers in themselves are meaningless, however when compared to either the population percentages or the flight hour percentages shown in Table 2, it is evident that reciprocating engine powered helicopters are involved in a disproportionately large percentage of powerplant related accidents. Similar results were obtained for drive train related accidents, and for accidents due to all causes. This suggests that perhaps some of the automotive technology which is emerging for monitoring reciprocating engines might well be applied to aircraft.

Similar breakdowns of accident cause factors were made for the other study categories, i.e. single vs twin, light, medium and heavy weight, and single vs tandem rotor. These breakdowns are handicapped by the small twin, heavy, and tandem populations, and did not yield any particularly startling results.

Maintenance Rate Approach

For this approach, an analysis was made of U.S. Navy Maintenance and Material Management (3M) data for the models, systems, and characteristics noted in Table 4. In this group, the twins, heavies, and tandems are better represented than in the civil population, as shown by Table 5. Typical results are shown by Figure 2, which is for engine related problems. The parameters shown across the top are:

MFHBF - Mean Flight Hours Between Failures

MFHBMA - Mean Flight Hours Between (Unscheduled) Maintenance Actions

MMH/FH - Maintenance Man Hours per Flight Hour

MMH/MA - Maintenance Man Hours per Maintenance Action

EMT/MA - Elapsed Maintenance Time per Maintenance Action

The different categories are shown along the left. When categorized by weight, it can be seen that although failure rates are similar, the light helicopter is much easier to repair. When number of engines is considered, it is interesting to note that MMH/FH for the twins is exactly twice that of the singles. Catorizing by type of rotor system has little effect on engine Reliability and Maintainability (R&M) characteristics, as would be expected. Summaries similar to Figure 2 were also prepared for the other systems listed in Table 4.

Direct Operator Input

Direct operator input to the study was obtained by visits to two large gulf coast commercial helicopter operators. The Petroleim Helicopter, Inc. heavy maintenance facility in LaFayette, Lousiana was visited on 1 October 1980. The following day, the Air Logistics facility near New Iberia, Louisiana was visited. Table 6 lists the major R&M concerns mentioned by maintenance management personnel at these facilities. It is significant that no one component, subsystem, or issue was of overriding importance. With regard to engine montoring systems, the concern is that a dedicated piece of electronic equipment, with associated wiring and connectors, will be just another maintenance burden. This feeling is based on a long history of electronic equipment problems in the gulf coast environment. There must be an obvious economic payback from the monitoring system to trade-off, against its possible liabilities.

Problem Identification Conclusion

It is concluded that there is no one overriding R&M issue, but rather a broad spectrum of areas in need of improvement.

Technology Solutions

Several technology solutions to the overall problem of improving R&M characteristics were investigated, as shown by Figure 1. These are discussed as follows, with regard to engine monitoring implications.

Engine Derating Study

The objective here was to determine the relative benefits of derating a current technology engine, vs utilizing a non-derated advanced technology engine, to improve R&M characteristics.

"Derating", in this case, means to install an "oversized" engine, while maintaining the same aircraft performance. A "baseline" situation was assumed such that the "zero derate" case consisted of a Bell Model 206B "JetRanger III" with Allison 250-C20B engine, operating on a mission which requires "takeoff" (red-line) power for takeoff and landing, and "maximum continuous" power for cruise. Allison provided data for scaling engine size, weight, cost, specific fuel consumption (SFC), and maintenance cost to twice baseline rated power. Engines derated (i.e. oversized) in 10 percent increments were parametrically installed in the aircraft. Aircraft weight, cost, and fuel consumption were allowed to increase as engine size increased. The net result is shown by Figure 3. As expected, the cost of fuel goes steadily upward, due to higher power required (because of increased gross weight), and increased SFC due to part power operation. Insurance and depreciation increase due to increasing aircraft cost caused by increased weight empty and increased engine cost. Maintenance cost decreases due to operating at reduced gas temperatures. The net effect is negligable out to about 20 percent derating. Data for an advanced technology engine, rated at baseline power, were also provided by Allison and used in the same manner. In this case, aircraft weight and power required decreased, so that this engine was in effect derated also. The net effect is a significant saving in operating cost. To put these numbers in perspective, it should be noted that the current leasing rate for this aircraft is around $350/hour.

The engine monitoring implication is that the maintenance saving shown will not be realized without a monitoring system. This is because a large percentage of the saving is due to extended Time Between Overhaul (TBO) and component retirement times, as specified by the engine manufacturer. In order to grant these extensions, the manufacturer must be assured that the engine is in fact being operated in a derated mode. A fool proof, continuous on-board monitor will be required for this assurance.

Fuel Control

Fuel control improvements are centered around the Full Authority Digital Electronic Control (FADEC). This type of control is well suited to performing engine monitoring functions.

Configuration Changes

One of the configuration changes investigated is the effect of number of engines. One-Engine-Inoperative (OEI) requirements are increasing in importance, as evidenced by the number of new twin-engined designs entering the market. One problem, of course, is that the initial cost and operating cost of a twin-engined helicopter is considerably greater than that of a comparable single-engined design. This could be aleviated somewhat by special "contingency" ratings, to be used only in OEI situations. This would increase the power available from the remaining engine if one engine were lost, thus permitting a reduction in total installed power, weight, and improved SFC since the engines would normally operate at a higher percentage of rated power. This subject is thoroughly discussed in Reference 4.

Actual usage of the contingency rating must be closely controlled. Special inspections, parts replacements, or TBO reductions may be required if the rating is used. An engine monitor will be required to record the extent of usage of the contingency rating.

Another solution is to use three engines instead of two. Since loss of an engine would reduce the power available by 33 percent instead of 50 percent, total installed power can be reduced. Also, with three engines, one engine can be shut down for long range cruise, improving the power match and reducing SFC. The engine monitoring implication is that a system would be required for bookkeeping of engine operating time and cycles. Manual bookkeeping would be inordinately complex and error prone if the two-engine-cruise mode were frequently used.

Transmission System Improvements

Transmission and drive system monitoring could be incorporated into the engine monitoring system. One low-cost candidate function would be to record actuations of the various "chip detectors". These are magnetic devices in the lubrication system which collect magnetic debris from the oil. Collection of sufficient debris completes an electrical circuit and turns on a cockpit light. Detectors are now available which will self-clear normal wear particles. Frequent self-clearing, however, may indicate an incipient problem. Therefore, an indication of the frequency of clearing operations, whether automatic or pilot initiated, would provide useful diagnostic information. More sophisticated monitoring techniques based on vibration signal analysis are also available and could be incorporated into the monitoring system.

ENGINE MONITORING CONCLUSIONS

Engine monitoring implications of the study which have evolved thus far are summarized as follows:

Reciprocating Engine Monitoring

All aircraft engine monitoring programs of which we are aware are directed at turbine engines. However, most civil helicopters are powered by reciprocating engines. Although this percentage of the population is decreasing, it is estimated by the FAA that "recips' will still represent 40 percent of the population in 1992. Accident statistics indicate that reciprocating engines could benefit from a monitoring system. Automotive technology in this area is rapidly emerging, and should be considered for adaption to the general aviation fleet.

Extended TBO and Retirement Lives

In establishing TBO's and retirement schedules, engine manufacturers must assume "worst case" operation, since actual engine usage is unknown. Scheduled maintenance based on actual usage would be feasible if such usage were recorded by the monitoring system.

Engine Record Bookkeeping

Accurate logging of engine starts, run time, time above certain power levels, and engine cycles is a valuable monitoring function, even for a single-engine aircraft. This function becomes more useful as the number of engines increases, and is a practical necessity if engine run times are unequal, i.e. OEI cruise.

Contingency Rating Usage

If a "contingency" or "emergency" power rating is available for infrequent, short-term use, actual usage of this rating must be closely controlled. By recording such usage, the engine monitor can trigger any required maintenance actions.

Transmission and Drive System Monitoring

If the engine monitor is to be used in a helicopter, integration of transmission and drive system monitoring functions should be considered. Candidate functions are chip detector actuations, chip detector clearing operations, bearing temperatures, and vibration signal analysis.

Cost Effectiveness

Commercial operators are concerned that an engine monitor might cost more than it saves. The monitoring system must be tied to an extended or "on-condition" maintenance schedule so that cost effectiveness will be evident "up-front", not as a hopeful result.

REFERENCES

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3. General Aviation Activity and Avionics Study, U.S. Department of Transportation, Federal Aviation Administration, Office of Management Systems.

4. Sample, R.D.: Emergency-Power Benefits to Multi-Engine Helicopters. Journal of the American Helicopter Society, July 1977, pg. 27.

U. S. CIVIL HELICOPTER POPULATION

CY 1978

MANUFACTURER	NO. OF MODELS		NO. REGISTERED
AEROSPATIALE	7		239
AGUSTA	1		12
BELL	7		3209
BRANTLY	2		153
ENSTROM	2		369
HILLER	2		85
HUGHES	2		1728
KAMAN	1		19
MBB	1		61
SIKORSKY	11		383
VERTOL	2		23
		TOTAL	6281
MISC			173
		TOTAL	6454

TABLE 1

HELICOPTER POPULATION SETS

CHARACTERISTIC	MODELS (NUMBER)	REGISTERED (NUMBER)	PERCENT POPULATION 1978	FLT. HOURS 1970-1978
RECIP	14	3779	60.2	46.4
TURBINE	24	2502	39.8	53.6
SINGLE ENGINE	27	5979	95.2	95.4
TWIN ENGINE	11	302	4.8	4.6
LIGHT	21	5549	88.3	91.0
MEDIUM	11	627	10.0	8.5
HEAVY	6	105	1.7	0.5
SINGLE ROTOR	35	6239	99.3	99.9
TANDEM ROTOR	3	42	0.7	0.1

TABLE 2

ACCIDENT CAUSE FACTORS BY ENGINE TYPE

TYPE	ACCIDENTS %	POPULATION %	FLT. HOURS %	% ACCIDENTS / % POPULATION	% ACCIDENTS / % FLT. HOURS
		POWERPLANT RELATED			
RECIP	75.5	60.2	46.4	1.25	1.63
TURBINE	24.5	39.8	53.6	0.62	0.46
		DRIVETRAIN RELATED			
RECIP	76.1	60.2	46.4	1.26	1.64
TURBINE	23.9	39.8	53.6	0.60	0.45
		ALL CAUSES			
RECIP	75.9	60.2	46.4	1.26	1.64
TURBINE	24.1	39.8	53.6	0.60	0.45

TABLE 3

3M DATA ANALYSIS

TIME PERIOD: 1 YEAR 4/79 - 3/80
FLIGHT HOURS: 15000 - 27000

MODELS	SYSTEMS	CHARACTERISTICS
TH-57	ENGINE	MFHBF
UH-1E	MAIN DRIVE SHAFT	MFHBMA
UH-1N	MAIN TRANSMISSION	MMH/FH
SH-2F	TAIL ROTOR DRIVE SHAFT	MMH/MA
SH-3H	HANGER ASSEMBLY	EMT/MA
CH-53D	INTERMEDIATE GEARBOX	
CH-46D	TAIL ROTOR GEARBOX	

TABLE 4

3M HELICOPTER CHARACTERISTICS

MFGR	MODEL	NO. ENGINES	WT. CLASS	ROTOR SYSTEM	CIVIL EQUIV.	FLT. HOURS
BELL	TH-57	1	L	S	206	18079
BELL	UH-1E	1	M	S	205	14990
BELL	UH-1N	2	M	S	212	27536
KAMAN	SH-2F	2	M	S	NONE	16921
SIKORSKY	SH-3H	2	H	S	S-61	25440
SIKORSKY	CH-53D	2	H	S	NONE	15505
VERTOL	CH-46D	2	H	T	107	16890

TABLE 5

OPERATOR CONCERNS

- ELECTRONIC FUEL CONTROLS
- ENGINE MONITORING SYSTEMS
- ENGINE ACCELERATION DEVICES
- DRIVE SHAFT COUPLINGS
- OIL LEAKS
- ENGINE POWER CHECK PROCEDURES
- CORROSION
- REPAIRABILITY
- MODULAR INTERCHANGEABILITY
- TWIN ENGINES
- DERATING
- MILITARY TECHNOLOGY TRANSFER
- INSPECTION REQUIREMENTS

TABLE 6

PROGRAM TASKS AND SCHEDULE

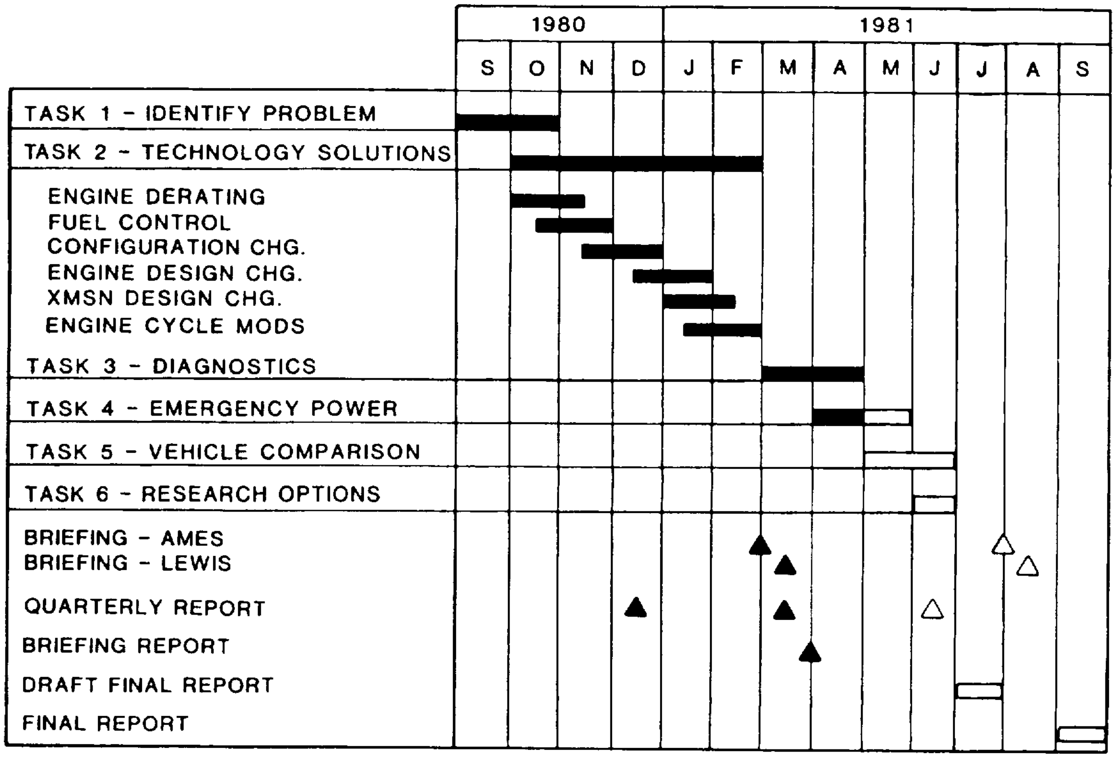

FIGURE 1

3M SUMMARY - ENGINES

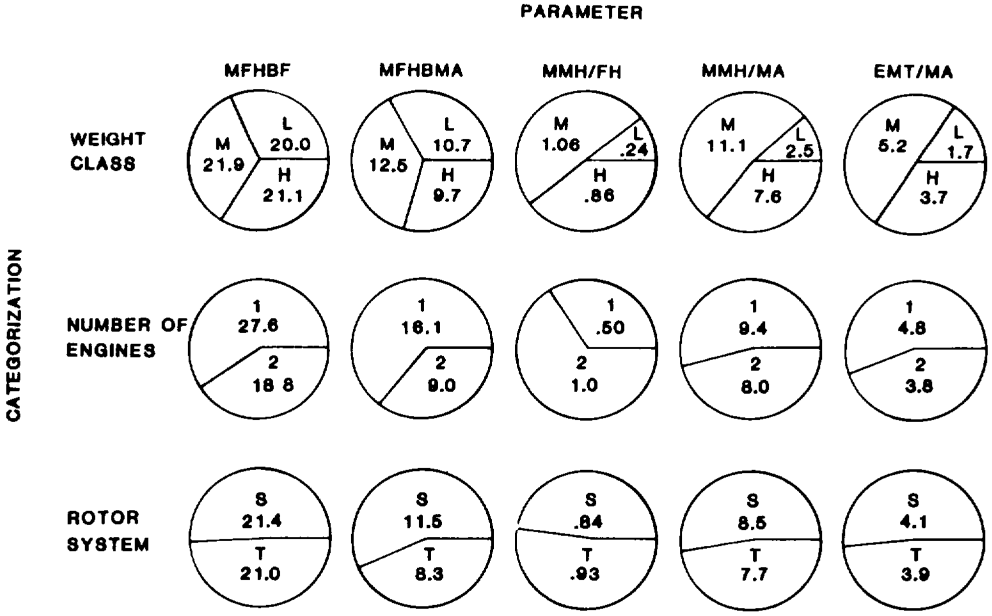

FIGURE 2

DERATING STUDY RESULTS

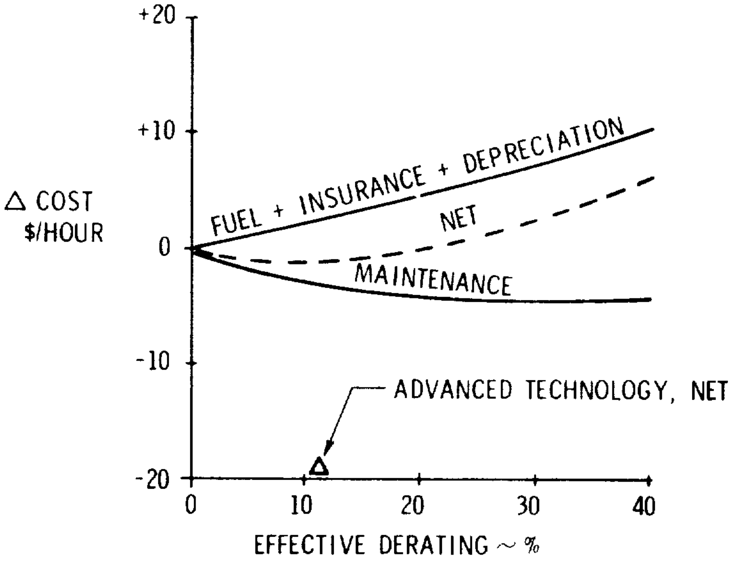

FIGURE 3