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Civil Helicopter Design and Operational Requirement

Kenneth T. Waters

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Langley Research Center
Hampton, Virginia 23665

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CLASSIFICATION

ABSTRACT

This report documents the design and operational requirements and other factors that have a restraining influence on expansion of the helicopter market. The needs of operators, users, pilots and the community at large are examined. The impact of future technology developments and other trends such as land use, energy shortages and civil and military helicopter requirements and development trends are discussed. Areas where research and development are needed to provide opportunities for lowering life cycle costs and removing barriers to further expansion of the industry are analyzed.

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FOREWORD

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This report was prepared by the Boeing Vertol Company for the National Aeronautics and Space Administration, Langley Research Center, under NASA Contract NAS1-13624. William Snyder was NASA technical monitor for this work. The Boeing Vertol Project Manager was Kenneth T. Waters. Wayne Weisner was the former project manager at Boeing Vertol Company and conducted a number of operator surveys, data from which are included in this report.

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SUMMARY

This study has examined design and operational requirements for civil helicopters in an attempt to identify those technology areas that need research and development to accelerate acceptance of helicopters by operators, users, pilots, passengers and the community at large. The most important issues to these groups are identified and a level of need is established for several operational categories based on opinion surveys and known restraints in the fast developing civil helicopter market. For example, civil helicopter sales increased by 18% in 1976. Differences between military and civil requirements were examined to determine where emphasis should be placed. The restraints of future developments in technology, land use, fuel shortages, impending FAA regulations, the impact of operational safety in future and commercial use of helicopters are discussed.

In general, research and development areas that offer opportunities for high payoff in the civil helicopter field are:

Safety improvements to reduce accident rates to 1/3 of the current rates and reduce fatalities and injuries with crashworthy features.

Cost reductions in acquisition costs, direct operating costs and fixed costs.

Performance improvements to increase payload to empty weight ratio, increase speed and range for specific operations.

Reduce noise both externally and internally for community and user acceptance.

Reduce vibration throughout the aircraft in all six degrees of freedom.

Develop IFR regulations for helicopter operations and lightweight low cost avionics commensurate with these regulations.

Meeting the challenge of the rapidly developing civil helicopter market in the next decade will require a dedicated and coordinated effort between operators, users, manufacturers, regulatory agencies and support organizations. Benefits to the military will result from nearly all of the R&D needed for civil helicopters.

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1.0 INTRODUCTION

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Defining requirements for civil helicopters is a very elusive task. There are 7,160 helicopters and 2,547 operators in the United States at the present time, most of which operate small numbers of helicopters. In many cases, the special handling equipment for operations such as agricultural spraying and seeding, forestry logging, seeding and spraying; and heavy construction work are designed and developed by the operators. The major driving force in this type of operation is operating cost and efficiency in a very cost competitive market. Any small performance benefit such as helicopter cruise speed must be traded with added weight and possible loss of payload. For example, operation in construction, logging and agriculture cannot take advantage of high speeds but maximum hover payload and maneuverability is critical to the operation. For this study the various types of operation are categorized such that similar operations are grouped and therefore requirements are grouped.

In the past, most helicopters have been developed to meet military requirements which are generally more stringent than FAA requirements. Civil helicopters were therefore adaptations of military vehicles, and in some cases have carried penalties of weight, performance and mismatch of cabin size to power capability. New civil uses are now creating demands that were never envisioned by military needs. The goals for reliability, maintainability and safety now emerging in military helicopters are still not good enough for civil-use helicopters in competition with fixed-wing airplanes and land transportation modes.

Small civil operators cannot afford to buy a new unproven helicopter and introduce it into a high-utilization operation where a few minutes of time lost on each cycle can eliminate profits. For example, spraying insecticide over 20 acres with a Bell 47 takes approximately 8 minutes for an overall rate of 150 acres per flight hour. Any malfunctions or incompatibilities in the helicopter, spraying equipment or ground handling can seriously reduce effectiveness. The operator gets paid for the number of acres that are sprayed and high utilization is critical to profits.

In view of the large number of opinions and varied experience among operators, it is difficult to define hard and fast rules. Therefore the design and operational requirements listed in this report must be considered general in their applicability for specific operations but nevertheless will reflect a concensus derived from operator surveys and literature research.

The method used in defining civil helicopter design and operational requirements in this report is as follows: Reference 1 presents an approach for establishing priorities for research programs that includes most of the factors and assumptions that must be considered for deciding when individual proposed programs will have a payoff. A relative value for proposed programs results from weighting and subjective analysis. In this report, the objective trees were used as a starting point but expanded down to the detail design requirement level. Admittedly, the approach used in this report is highly subjective and weighted by the author's interpretation of extensive review of the operator surveys, literature research and personal interviews with operators, insurance underwriters, safety consultants, accident investigators, reliability and maintainability experts, test pilots, life cycle cost analysts and helicopter designers.

The report includes a list of design and operational requirements that need action to include them in new designs or change existing designs or operational procedures for more efficient operations. Requirements having a major impact are discussed in detail to describe a program for meeting the requirement. Minor items are listed for consideration only.

This study then lists areas of design requirements and specification that can be changed and thereby present opportunities for reduced direct operating costs, fixed costs and increased acceptance by operators, users, pilots, passengers and the community. It is emphasized that the detail life-cycle cost aspects of civil helicopter operations are covered in another study report, Reference 5.

2.0 DESIGN AND OPERATIONAL REQUIREMENTS

2.1 Problem Definition

Civil helicopter growth is restrained by the following:

- Acquisition and operational costs
- User and operator acceptance
- Pilot acceptance
- Safety and mission reliability
- Passenger acceptance
- Community acceptance.

The overall objective is to increase civil helicopter uses and expand the market. In order to accomplish this objective it will be necessary to increase the acceptance and utility of helicopters in civil applications. This can be accomplished by increased acceptance by users, operators, pilots, passengers and the community.

Operator and pilot surveys, conducted under the direction of Dr. Ira Jacobson of the School of Engineering and Applied Science at the University of Virginia (see Reference 1), provide insight to solving the above stated problems and meeting the objectives. Table 1 is a ranking of the opinions of the respondents to the operator and pilot surveys of technological improvements which could most aid operations. This ranking provides a good illustration of the general agreement between the opinions of pilots and operators. In Reference 2, the predominance of pilot involvement as a cause of accidents was clearly evident from the statistics. It was brought out that many of these pilot error accidents may have contributory factors of poor design execution for the operations being performed and poor operational planning and management. Therefore, it can be concluded that changes in requirements that have a favorable impact on reducing pilot error type of accidents will have a high payoff in increased acceptance and reduced operating costs.

The top four (4) factors in Table 1 were all weighted approximately equal by both pilots and operators. Similarly, the lower six factors were also weighted close to each other but were approximately one-half as important as the top four. It is clear then that higher payoff will result from introducing changes to improve

- Direct operating cost and initial costs
- Aircraft performance and safety.

The factors of improved IFR capability, pilot aids and displays and cockpit environment all effect safety by reducing pilot workload and fatigue in a demanding man-machine interface environment.

TABLE 1. RANKING OF TECHNOLOGICAL IMPROVEMENTS WHICH COULD MOST AID OPERATIONS

Ref: Unpublished University of Virginia 1976 survey and Report No. UVA/528051/ESS77/102 dated May 1977

	Factor	Operator Survey Combined (163)	Operator Survey Corporate (59)	Operator Survey Commercial (61)	Operator Survey Civil Govt (43)	Pilot Survey (38)
Nearly Equal Weighting, Average 2.6	Direct Operating Costs	1	3	1	3	N/A
	Aircraft Performance	2	1	2	4	1
	Aircraft Initial Costs	3	4	2	1	N/A
	Aircraft Safety	4	2	4	2	2
Nearly Equal Weighting, Average 4.65	Passenger Acceptance	5	5	5	7	3
	Reduced Fuel Consumption	6	6	6	5	N/A
	Community Acceptance	7	7	7	6	5
	Improved IFR Capability	8	7	8	8	7
	Pilot Aids and Displays	N/A	N/A	N/A	N/A	6
	Cockpit Environment	N/A	N/A	N/A	N/A	4

Notes: N/A = Not asked to rank in questionnaire.

2.2 Operator and User Acceptance

2.2.1 Operator Costs. – Operator acceptance is highly influenced by direct operating costs (DOC's), initial costs and fixed costs. These costs in turn are reduced by increasing TBO's or going "on condition" for power plant and dynamic systems, reducing maintenance costs, lower spares costs and reduced fuel consumption, all of which are favorably influenced by design improvements, proper emphasis in design requirements and increased productivity. Similarly, fixed costs such as depreciation (based on initial value) are reduced by design simplicity, reduced parts count, use of low cost parts and components and standardization for high volume production of parts. Insurance costs are influenced by both the helicopter industry safety record and the safety record of individual helicopter models and the operator. Design features effect the safety record both from the material failure standpoint as well as handling characteristics that lead to pilot error accidents. Design and operational factors that impact the above costs are outlined in Figure 1, "Operator Acceptance".

- REDUCE DIRECT OPERATING COSTS
  - INCREASE TBOs OR GO ON-CONDITION
  - MAINTENANCE COSTS (RELIABILITY AND DESIGN SIMPLITY)
  - REDUCE FUEL CONSUMPTION
  - LOWER SPARES COSTS AND PARTS AVAILABILITY
  - INCREASE PRODUCTIVITY
- REDUCE FIXED COSTS
  - DEPRECIATION (BASED ON INITIAL COST)
  - INSURANCE COSTS
  - MISCELLANEOUS OVERHEAD
- INCREASE VEHICLE APPLICATIONS
  - MANUFACTURER AND OPERATOR DEVELOP APPLICATIONS TOGETHER
  - INCREASE PERFORMANCE (PRODUCTIVITY) TO CAPTURE MORE OF MARKET
  - DESIGN EMPHASIS ON CONVERTIBILITY AND VERSATILITY
- LOWER INITIAL COSTS
  - DESIGN SIMPLICITY AND REDUCE PARTS COUNT
  - LOW COST PARTS AND STANDARDIZATION
- IMPROVE MISSION RELIABILITY
  - FALSE FAILURE WARNINGS (PRECAUTIONARY LANDINGS)
  - COMPONENT RELIABILITY
  - IFR CAPABILITY

Figure 1. Operator acceptance

2.2.1.1 Reference 3 has shown that 78 percent of the reliability problems of civil helicopters can be categorized into 30 problems. These problems were analyzed to determine causal factors and to recommend corrective action. Of the 30 problems that were analyzed, the following table lists their relative impact by subsystem:

TABLE 2. IMPACT OF SUBSYSTEM UNRELIABILITY ON UNSCHEDULED MAINTENANCE AND REPAIR PARTS COST

Subsystem	Relative Failure Rate (%)	Unscheduled Maintenance Manhours (%)	Repair Parts Cost (%)
Propulsion (Turbine power)+	35.3	25.1	66
Drive	13.9	35	21.3
Rotor	12.2	19.7	11.4
Airframe	19.9	10.1	1.2
Landing Gear (Floats)*	9.4	5.6	
Fuel	5	1.1	
Hydraulics	4.1	2.8	

+ Only turbine-powered helicopters were included in this study.

* An aggressive reliability improvement program has virtually eliminated floats from the problem list subsequent to the data received for this study.

In terms of unscheduled maintenance manhours and cost of repair parts, the propulsion, drive, and rotor subsystems represent over 80 percent of the reliability problem. Since these subsystems also have a major impact on mission reliability (aborts) and safety, it is clear that major emphasis should continue to be placed on improving these subsystems. Because of the significant number of problems and the unscheduled maintenance manhours involved, airframe reliability also needs improvement.

2.2.2 Increased Vehicle Application. – The manufacturer and the operator must develop applications by conducting experimental programs jointly to improve equipment and refine mission details (see Figure 1).

Helicopter manufacturers need to study fixed-wing and ground/water transportation methods to discover where pressure points are and where opportunities exist to become more competitive, for example, 1) higher block speed; 2) higher external lift capability (bulldozers and container ship loading and unloading, firefighting equipment load capability and water dispersal; and, 3) specialized loading and unloading equipment for agriculture and forestry work.

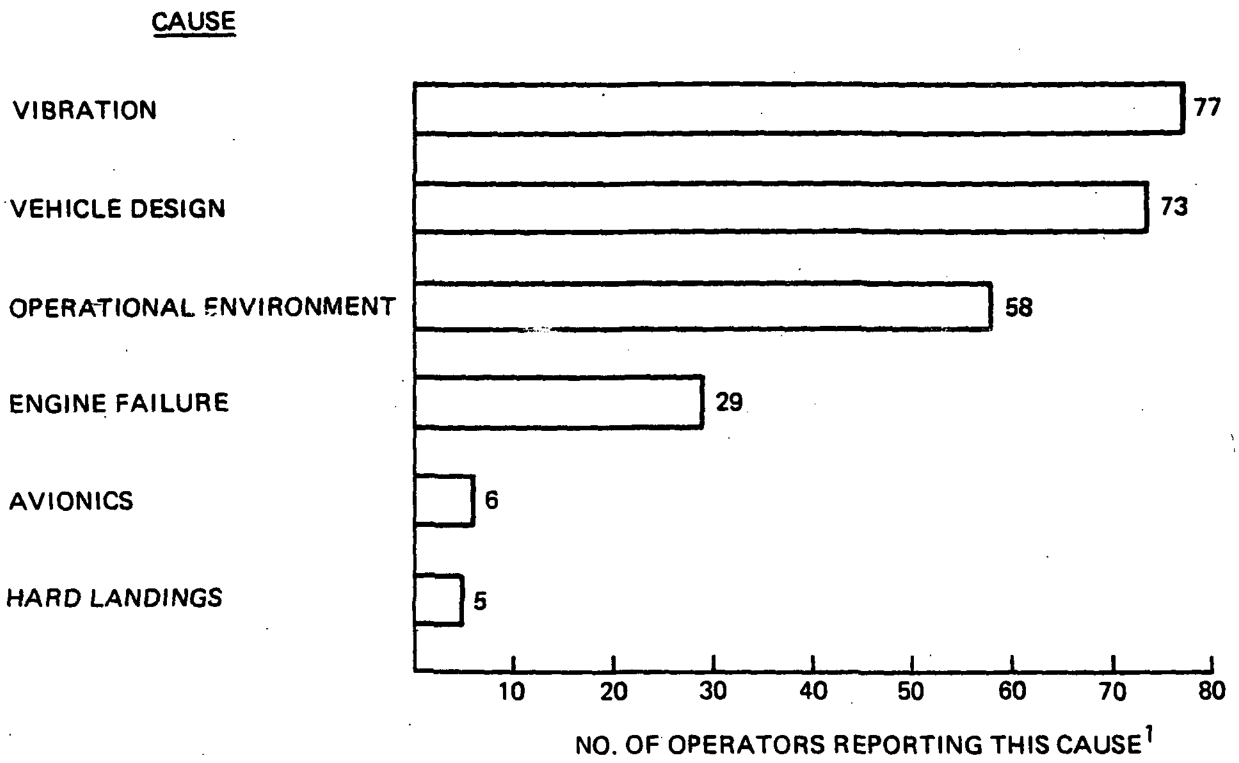
The operators would like the manufacturers to provide demonstrator or rental models for specific roles to work out bugs and provide support. Operators could install their special equipment and develop optimum techniques for a most cost effective match of the helicopter and special operational requirements.

Increased performance and productivity is required to capture more of the market. Higher speeds and greater endurance will improve block times and make helicopters more competitive with fixed-wing aircraft at greater distances. Increased speed (up to 125 knots) and tank capacity (payload) is agriculture work will increase acreage covered per flight hour. There is a need for increased external payload (using larger helicopters, CH-47 and HLH) for containership offloading and loading and lifting bulldozers in and out for firefighting and construction work. Marketing surveys need to be conducted to determine size, payload, range, endurance and special requirements to be competitive where land and sea transportation is now used. Design emphasis should be placed on convertibility and versatility. Convertibility problems should be worked out so operators can have multi-use helicopters (i.e., internal cargo, external cargo, passenger seating, ferry range tanks, hard points for mounting seed slings, spray booms, hoppers, etc.). In agricultural work, for example, new methods are being devised to use ultra-low concentration levels of insecticides and herbicides. More efficient techniques mean greater acreage for a given payload, less applicator cost and less adverse impact on the environment.

2.2.3 Mission reliability is essential in civil helicopter operations. No data has been published on civil helicopter abort rates (to the author's knowledge). Data is presented in Reference 3 on the OH-58 which is the military counterpart of one of the most widely used civil helicopters, the Bell Model 206. The magnitude and source of the problem experienced by the military are an indication of the importance of mission reliability to civil helicopter fleets. Not only are mission aborts a nuisance in lost time and revenue, but sometimes cause accidents.

The dominant source of mission abort is warning lights (50%), many of which are false or premature chip indications. A new rugged magnetic chip detector with a capability for fuzz removal has been installed on some of the newer helicopters and has (reportedly) virtually eliminated false chip indications. A significant improvement in abort rate can be expected from this development. The second major source of mission aborts is engine failures. Engine failures have the highest percentage of hazardous aborts, resulting in one-third of the major accidents, over 40% of the incidents, and 5% the precautionary landings. As discussed above, reliability of turbine engines needs substantial improvement.

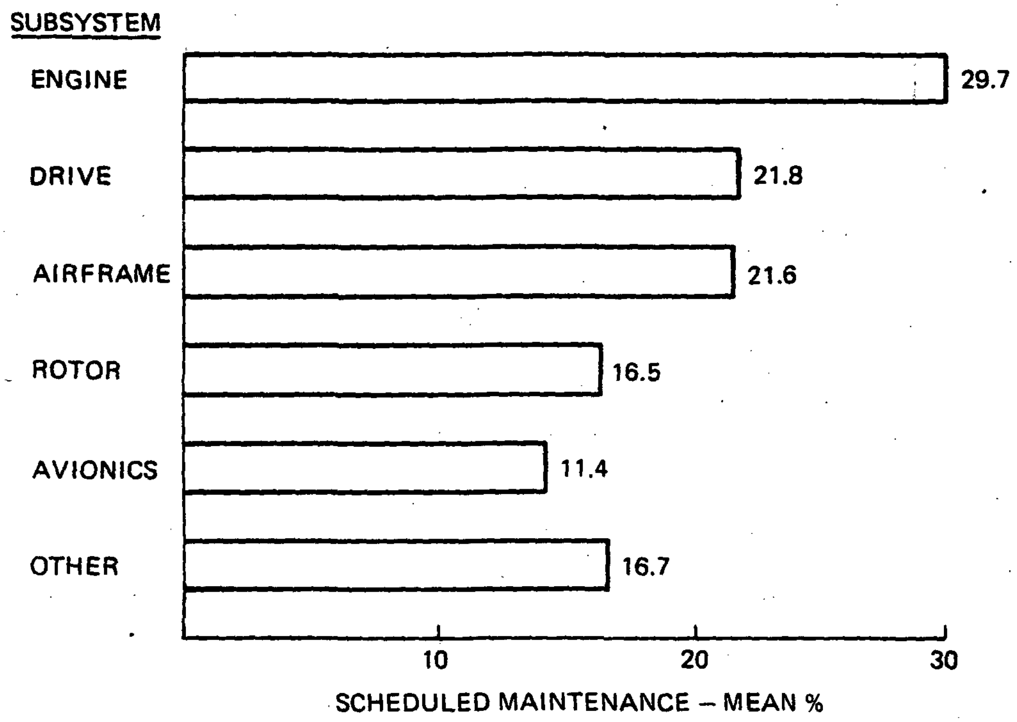
The operator survey (References 1 and 6) showed that, in the operator's opinion, unscheduled maintenance causes were as shown in Figure 2, and percentage scheduled maintenance by aircraft system as shown in Figure 3. The significance of vibration is also shown in Figure 4, which is a comparison of failure rate and maintenance manhours by subsystem with and without vibration absorbers (Reference 7).



NOTES:

1. SOME GAVE MORE THAN 1 REASON.
2. MEAN UNSCHEDULED MAINTENANCE IS 20% OF TOTAL MAINTENANCE.
3. 163 RESPONDENTS TO OPERATOR SURVEY (REFERENCE 1).

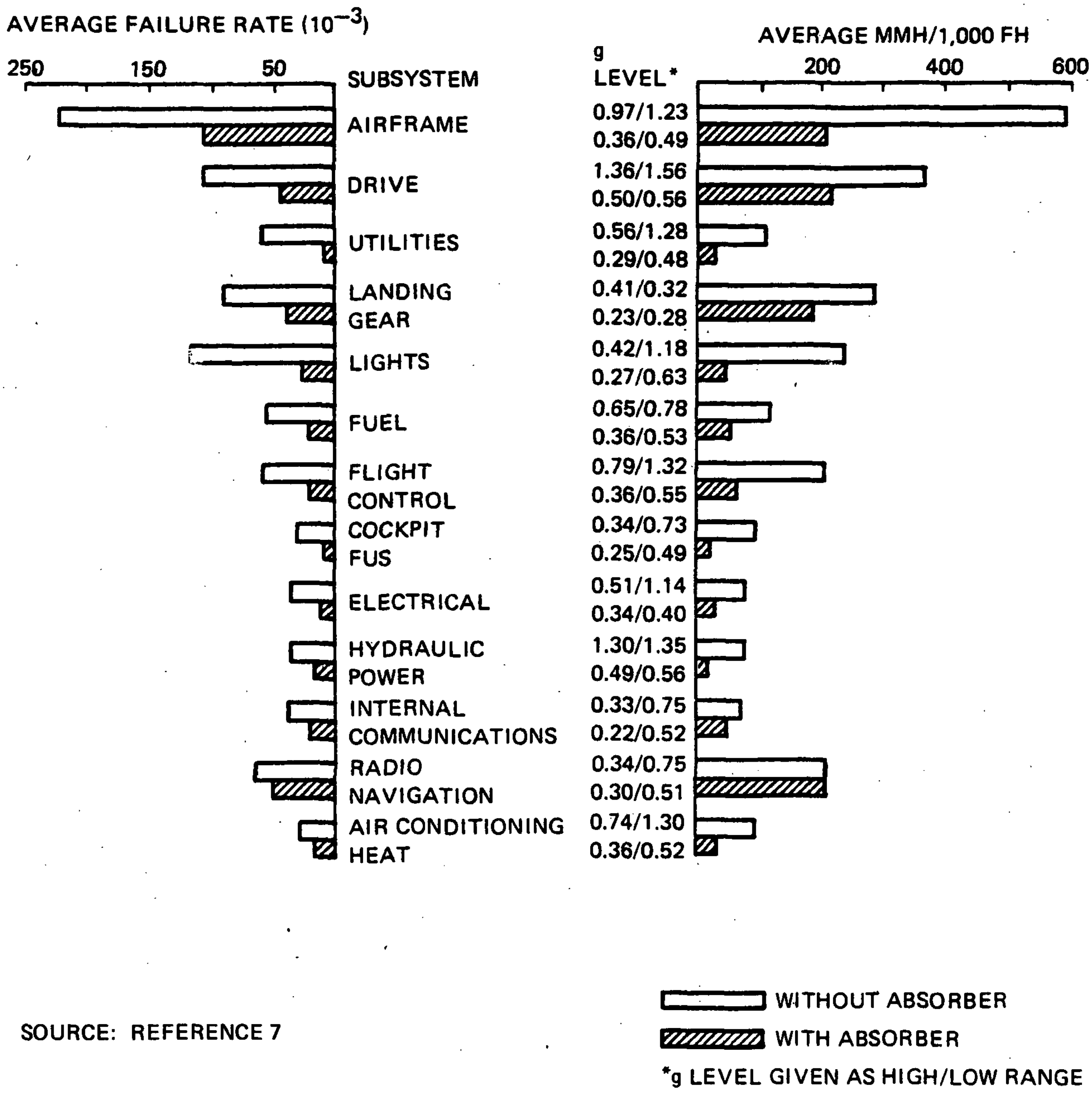
Figure 2. Causes of unscheduled maintenance



NOTES:

1. WILL NOT ADD TO 100% BECAUSE NOT ALL REPORTED EACH ITEM.
2. MEAN SCHEDULED MAINTENANCE IS 80% OF TOTAL MAINTENANCE.
3. 163 RESPONDENTS TO OPERATOR SURVEY (REFERENCE 1).

Figure 3. Mean percentage of scheduled maintenance by aircraft subsystem



SOURCE: REFERENCE 7

Figure 4. Comparison of failure rate and maintenance manhours by subsystem with and without vibration absorbers

2.3 Pilot Acceptance

Figure 5, Table I and Appendix "A" outline the factors that influence pilot acceptance.

2.3.1 Improved performance was discussed under "Operator Acceptance" in paragraph 2.2.1.

2.3.2 Improved safety is a fundamental issue with pilots. Improvements related to reduced component and system failures have been of the highest priority and have achieved substantial improvements in helicopter accident rates to date (see Reference 2). Since approximately 20% of helicopter accidents are still attributed to material failures this item should continue to hold a high priority. However, the fact that in approximately 60% of the accidents the pilot is listed as the prime causal factor, much more attention should be given to this issue than has been in the past (see Figure 6). It has been found in studies of commercial airline accident data in Great Britain (Reference 4) that "crew fallibility" is the cause in 46% of the total accidents and that "error of judgement" and "incorrect flying technique" accounted for 58% and 25% respectively of these crew fallibility accidents (Figure 7). Figure 8 shows a comparable breakdown for civil helicopter crew error accidents in the United States in 1975. (See Appendix A for a further breakdown.) In the helicopter case, 43% were judged to be "improper flying technique", 25% were "error in judgement", 19% were due to "inadequate preparation and planning", 8% were "flying into objects" and 5% were miscellaneous factors such as fatigue, diverted attention, lost or disoriented. These statistics illustrate that the helicopter has unique cockpit and human factor requirements because of low level flight, frequent takeoffs and landings and other special missions, such as logging, construction and agricultural work, which is much more hazardous and demanding of the pilot than flying airliners.

2.4 Passenger/User Acceptance

The issues involved in improving passenger acceptance are outlined in Figure 9. These involve reducing travel costs, reducing travel time, improving safety and improving comfort. The following paragraphs discuss some of the more important issues, and what the R&D needs are for civil helicopters.

2.4.1 Reduced travel costs are associated with operator's lifecycle cost including direct operating costs, fixed costs and acquisition costs covered in paragraph 2.2.1. In addition, the accessibility of public-use heliports near the travel origin and termination locations can have a significant impact on travel costs as well as travel time as discussed below.

2.4.2 Reduce Travel Time. – The need for helicopters in the air taxi and commuter role is tied directly to the speed, range and accessibility of heliports. These factors are all highly significant in capturing an increasing market for helicopters from fixed-wing and ground transportation modes.

- IMPROVE PERFORMANCE
  - MORE EFFICIENT ENGINE/LOWER FUEL CONSUMPTION
  - INCREASE SPEED
  - MORE PAYLOAD/RANGE
- IMPROVE SAFETY
  - INCREASE COMPONENT AND STRUCTURAL RELIABILITY
  - ENGINE OUT CAPABILITY AND POWER MARGIN
  - IMPROVE CRASHWORTHINESS (ENERGY ABSORBING LANDING GEAR/SEATS AND FUEL CONTAINMENT)
  - REDUCE PILOT WORKLOAD AND IMPROVE FLYING QUALITIES
  - IMPROVE MISSION PLANNING
  - IMPROVE PILOT TRAINING (MORE EXTENSIVE USE OF SIMULATORS)
  - REDUCE OBSTACLE STRIKES
  - IMPROVE DIAGNOSTICS AND SYSTEMS MONITORING
- IMPROVE COCKPIT
  - REDUCE NOISE TO IMPROVE COMMUNICATIONS AND COMFORT
  - REDUCE VIBRATION
  - IMPROVE PILOT AIDS AND DISPLAYS (MALFUNCTION WARNING)
  - IMPROVE COCKPIT ENVIRONMENT (SEAT COMFORT AND AIR CONDITIONING OR SEAT COOLING)

Figure 5. Pilot Acceptance

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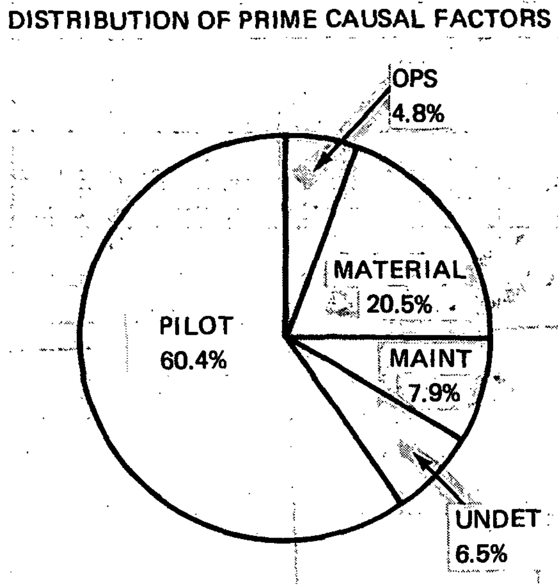
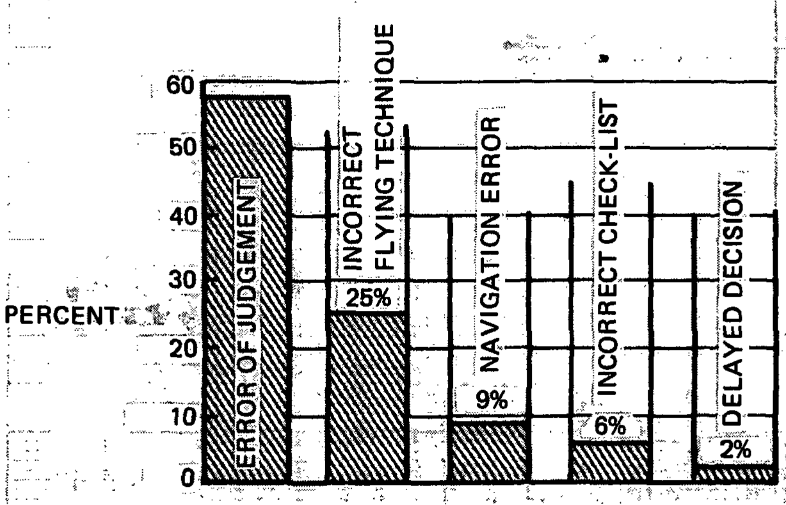
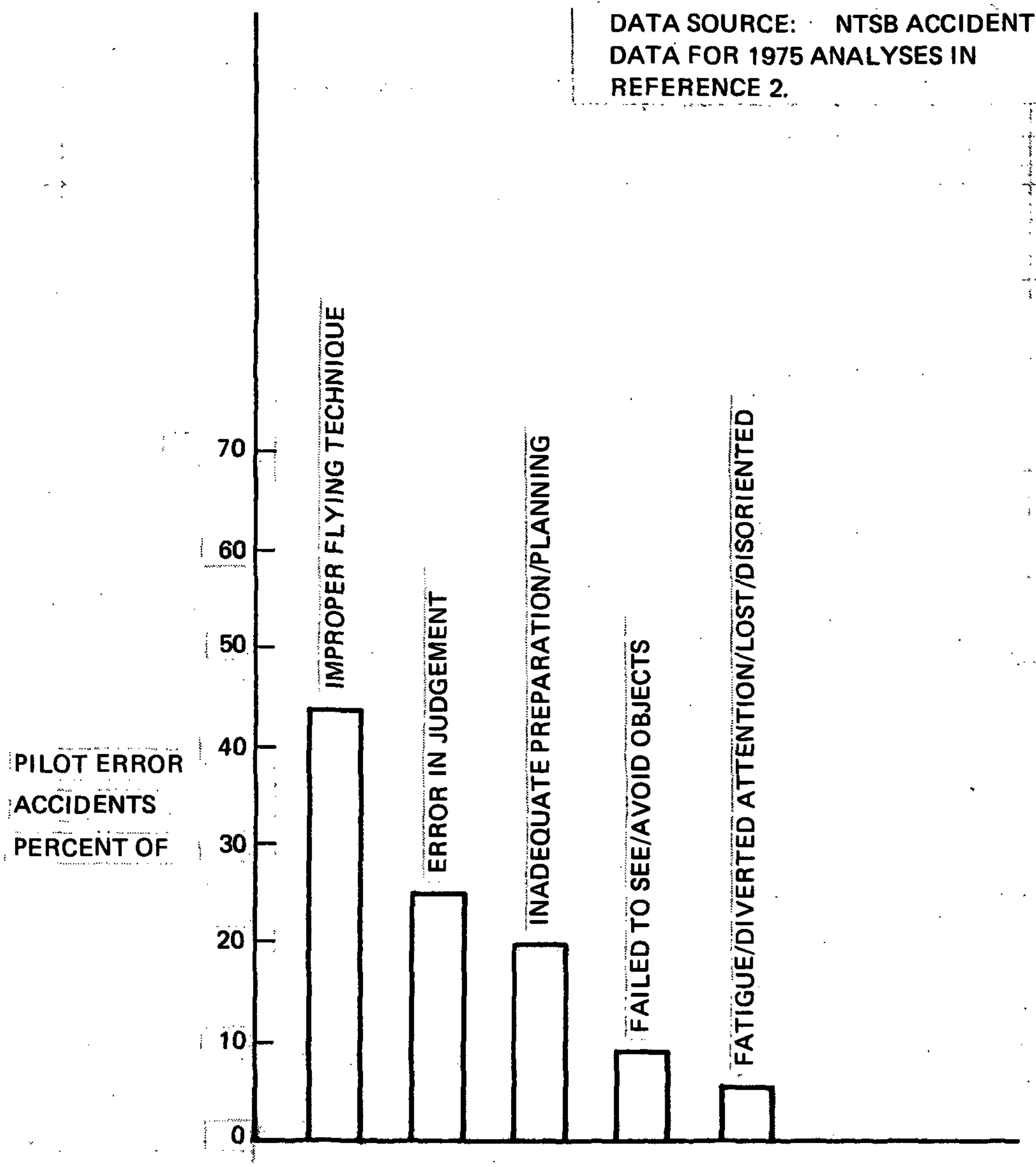


Figure 6. Civil helicopter safety data (ref 2) 1975, 293 accidents



FROM REFERENCE 4

Figure 7. Breakdown of the causes of accidents attributable to crew error for fixed-wing airliners



DATA SOURCE: NTSB ACCIDENT DATA FOR 1975 ANALYSES IN REFERENCE 2.

NOTE: MORE THAN ONE FACTOR IS LISTED FOR MOST ACCIDENTS. PERCENTAGES ARE BASED ON NUMBER OF TIMES THE FACTOR IS CITED DIVIDED BY THE TOTAL NUMBER OF FACTORS LISTED (416). SELECTION OF CATEGORIES BY BOEING VERTOL COMPANY.

Figure 8. Percent of pilot error accidents by causal factor

- REDUCE TRAVEL COSTS
  - OPERATOR LCCs
- REDUCE TRAVEL TIME
  - SPEED AND RANGE
  - PUBLIC-USE HELIPORTS CONVENIENT TO PASSENGER NEEDS
- IMPROVE SAFETY
  - MAIN AND TAIL ROTOR BLADE HAZARDS
  - CRASH SAFETY (ENERGY ABSORBING SEATS AND DELETHALIZE CABIN INTERIOR)
- IMPROVE COMFORT
  - NOISE, VIBRATION AND GUST SENSITIVITY

Figure 9. Passenger acceptance

2.4.3 Improved safety is covered under pilot acceptance paragraph (2.3.2.) Specific safety concerns of the passengers are main and tail rotor blade hazards, and crash safety which can be alleviated with energy absorbing passenger seats and eliminating hard sharp objects that cause head injuries. Lightweight sound absorbing earphones with head protection are also practical.

2.4.4 Improved comfort will require reductions in noise, vibration, and gust sensitivity and cabin air conditioning for hot humid areas. At present, the cabin interior noise is intolerable without sound absorbing earphones. Vibration in the 20- to 30-knot transition speed regime and at high speed is objectionable. Gust sensitivity is objectional in some helicopters as a function of blade aerodynamic loading, and effective hinge offset and mutual interference effects between main rotor and fuselage, main rotor and tail rotor and rotor and control surfaces.

2.5 Community Acceptance

Figure 10 outlines the major factors impacting community acceptance. The major improvements needed are increased operational safety, reduced exterior noise levels and reduced engine emissions.

2.5.1 Operational safety is covered under paragraphs 2.3.2 and 2.4.3. The significance to community acceptance is that all publicity relative to helicopter safety is negative at the present time because air accidents make news.

2.5.2 Reduced exterior noise levels are mandatory if additional heliports are to be built in populated areas and low-level (under 500-feet altitude) overflights are to be common. In order of importance are blade slap, main rotor rotational noise, tail rotor harmonics, broadband and engine noise.

2.5.3 Reducing engine emissions is largely a matter of reducing visible emissions or smoke. As engine efficiencies are improved, the visible emissions will virtually be eliminated. In fact, current turbine engines which have improved SFCs are not bad and this problem will eventually be much reduced.

2.5.4 A major impact on community acceptance is the continuing adverse publicity on subjects such as safety and noise in news media. Industry periodicals such as *Rotor and Wing* and *Aviation Week and Space Technology* are doing an excellent job of informing people within the industry on problems, solutions and discussing new uses for helicopters. HAA is credited with substantial improvements in helicopter safety. However, there is no advocacy group which is systematically showing the positive side of helicopter operations to the general public. Consideration should be given to creating an advocacy group that can inform the public on controversial subjects and emphasize the need for growth. This would be in the form of advertisements and selected new releases in appropriate news media.

- INCREASE OPERATIONAL SAFETY (SEE PILOT AND PASSENGER ACCEPTANCE)
- REDUCE EXTERIOR NOISE LEVELS (OVERFLIGHT AND GROUND OPERATIONS)
  - BLADE SLAP
  - MAIN ROTOR ROTATIONAL NOISE
  - TAIL ROTOR NOISE
  - BROADBAND NOISE
  - ENGINE NOISE
- REDUCE ENGINE EMISSIONS
  - IMPROVE SFC
  - REDUCE EXHAUST SMOKE
- CREATE HELICOPTER ADVOCACY GROUP TO INFORM PUBLIC ON:
  - SAFETY RECORD AND CONTROVERSIAL SUBJECTS
  - USEFULNESS
  - COST BENEFITS

Figure 10. Community acceptance

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3.0 IMPACT OF FUTURE OPERATIONS AND CONSTRAINTS

Future operations between 1990 and 2000 and beyond can have a substantial impact on future helicopter designs. Some of the more significant are discussed below:

3.1 Effect of Fuel Crisis

By the year 1990 fuels will amost certainly be in shorter supply and costs will be up significantly. This increase will force fuel costs to be a higher percentage of direct operating costs from the current 24% (see Figure 11). Engine technology exists to provide approximately 0.45 sfc which is a 18% reduction from the current sfc of 0.57 at cruise power. Carrying more payload instead of fuel load and tankage is an additional benefit that will result in lower costs per passenger seat mile or more work accomplished per dollar. Therefore, continuing research on turbine engine efficiencies and probably application of new fuels will be urgently needed. This will include rotor efficiency improvements, empty weight reduction and drag reduction.

3.2 Effect of Noise Restriction

The FAA is currently drafting a regulation which will limit the noise which future helicopters will be permitted to make and still certify. Although the rule is also required to be "Economically Reasonable and Technically Practicable" (ERTP) it is likely that the limits will be at a level such that many current helicopters would have difficulty meeting them. The trend to decentralization and industrial parks in suburban areas has created both a demand for helicopter air taxi travel to and from these facilities and also complaints from neighbors about the noise. Therefore, a critical need exists for a dramatic reduction from the main rotor blade impulsive noise and tail rotor noise nuisance. Both turbine engine and reciprocating engine noise then may become predominant and treatment of these noise sources may become necessary. Figure 12 shows the relative importance of noise levels from these sources.

3.3 Heliport Development/Land Use

As land values continue to increase and land use becomes more restricted, it will become economically impractical to provide air travel for outlying industrial parks with new fixed-wing airfields. Therefore, helicopter air taxi service demands will increase with an increasing need for public-use heliports. These heliports will be strategically located to service major airports and for limited range intracity and intercity trips of up to approximately 400 miles. The major problem will be community and local government acceptance of helicopters which are considered in some areas to be a nuisance.

3.4 Impact of Military Developments

It appears likely that the military will continue to develop helicopters to meet future warfare needs. However, these needs will problably differ substantially from the major needs and requirements in the civil market. The military emphasis on survivability in a nap-of-the-earth, all-weather, day and night, hostile environment will generate technology of limited use for

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NEED

- LOWER CRUISE POWER SPECIFIC FUEL CONSUMPTION
- HIGHER POWER AVAILABLE – ONE-ENGINE-INOPERATIVE

BACKGROUND

- THE FUEL SYSTEM IS A SIGNIFICANT PERCENTAGE OF A HELICOPTER'S WEIGHT DISTRIBUTION.

TYPICAL HELICOPTER WEIGHT DISTRIBUTION

EMPTY WEIGHT = 54%
PAYLOAD = 20%
FUEL = 25%
FUEL TANK = 1%
100%

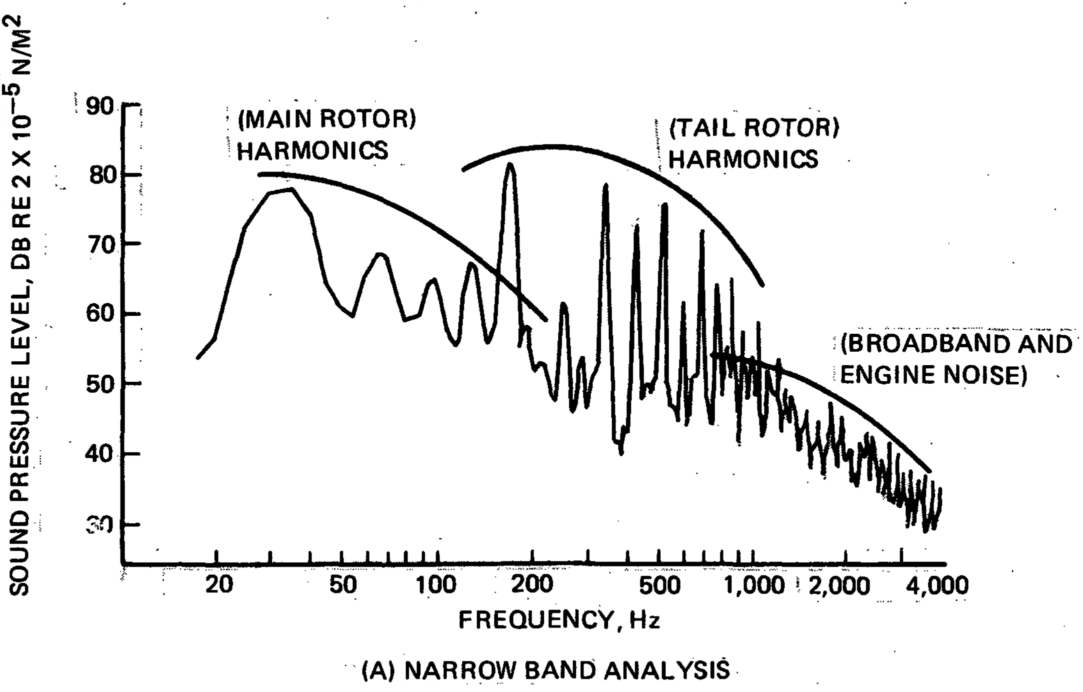
- FUEL IS A MAJOR OPERATING COST ITEM.

TYPICAL HELICOPTER DOC DISTRIBUTION

FUEL AT 65¢/GAL = 24%
A/C MAINTENANCE = 10%
DYNAMIC COMP O.H. = 25%
ENGINE O.H. = 20%
LIFE COMP = 5%
ENGINE SPARES = 7%
AIRFRAME SPARES = 7%
MISCELLANEOUS = 2%
100%

- MAXIMUM CONTINGENCY POWER IS TYPICALLY ONLY 10% HIGHER THAN TAKEOFF POWER.

Figure 11. Improved engine performance



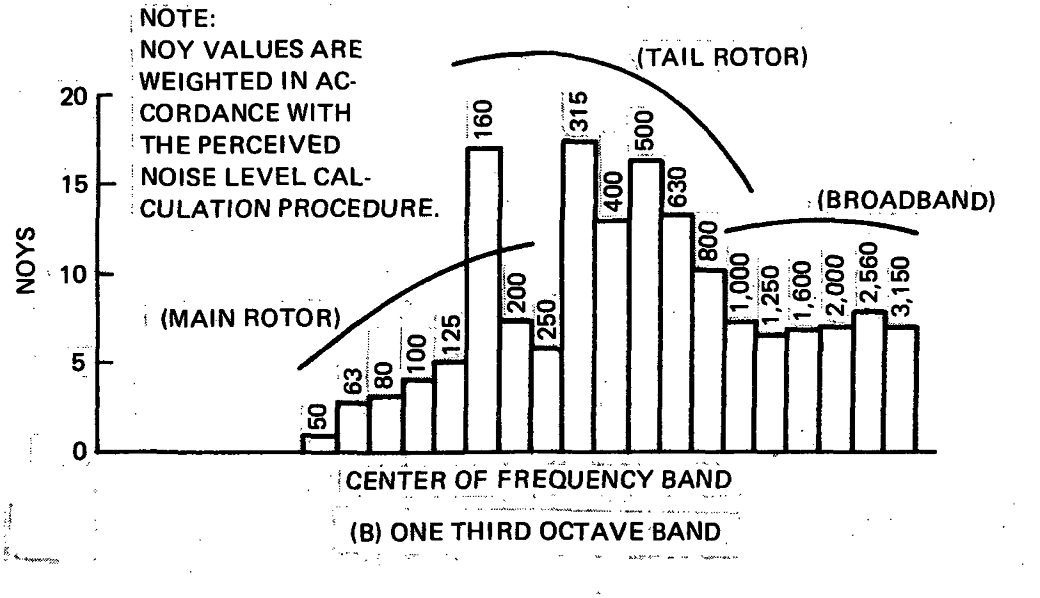


Figure 12. External noise spectrum – BO-105 helicopter in forward flight

civil applications. Civil operators are preoccupied with productivity and cost effectiveness in an extremely competitive marketplace where efficient and reliable turbine engines and dynamic system components are necessary. Future civil-use helicopters will be designed to meet civil operator needs with major improvements in safety and ride comfort and a substantial reduction in external noise. These helicopters must also be much easier to fly safely for long periods of time. Military developments for reduced pilot workload in a NOE environment will be useful in civil helicopters except that the military avionics will probably be much more sophisticated and expensive than those required for civil use. Perhaps a greater challenge will be to develop low-cost, low-weight but very versatile avionics for civil uses.

3.5 Requirements for Human Reliability Demonstration

In the more recent military procurement of helicopters there has been increasing emphasis on component reliability, mission reliability and maintainability. In future, it is becoming clear that the one remaining part of the system that is unpredictable involves human factors which includes both pilots and mechanics. Defect tolerance and redundancy has, to some extent, reduced the adverse effects of maintenance errors, but this area still needs a substantial improvement. Many civil helicopter accidents are caused by poor quality control in engine and dynamic system component overhaul, with resulting inflight failure.

The remaining area that still needs the most attention is the pilot error accident. Approximately 60 percent of all civil helicopter accidents in 1975 were attributed to pilot error. Of these accidents, approximately 43% are caused by poor flying techniques, 25% by errors in judgement, 19% by inadequate preparation and planning, 8% from failure to see/avoid objects and 5% from fatigue, inattention, lost or disoriented. (See Appendix A and Figure 8.) It appears the man-machine interface needs a major effort if a substantial reduction in accidents is to be achieved.

Future requirements will be developed for a human reliability demonstration in new helicopters to insure that pilots are capable of safe operation of the aircraft under prolonged high stresses and mental concentration. Quiet, comfortable cockpits with controls and displays that promote improved communication, reduce pilot fatigue and provide simple cues that reduce errors in judgement are needed. The first step in achieving the goal of substantial reduction in pilot errors is to closely study a large number of accidents and contrive difficult situations in simulators. Some typical helicopter high stress/workload situations are: 1) power off autorotation simulating sudden engine failure; 2) high gross weight, marginal power takeoff and landing approaches in gusty wind conditions; 3) precision hovering at 150 feet to 300 feet above ground level as in construction of power line towers or placing equipment on roof tops; 4) making high-bank turns at the ends of fields near trees and other obstacles as in agricultural work.

3.6 Foreign Developments

Pressure from foreign helicopter manufacturers is still intense and has forced U.S. manufacturers to introduce new designs such as the Bell 222 and the Sikorsky S-76 in order to meet customer demands. At the present time there is little activity in the civil helicopter market to come out with new helicopters with gross weights over 10,000 pounds. This market is being filled with modifications of proven helicopters such as the Boeing Vertol 107 and the -237. These helicopters will be useful for the next 15 to 20 years but after that, much more efficient turbine engines and lightweight airframes should be available for new models. These new large models will be designed with emphasis on productivity for heavy construction, firefighting, 200 nautical mile offshore oil exploration, logging and forestry work. Heavy lift capability is needed for extremely large loads in construction, containership loading and unloading, etc.

3.7 Durability, Defect Tolerance and Fail Safety

The trend to defect tolerant dynamic subsystems for the complete helicopter is unmistakable. Progress toward that goal shows small steps being made in the 1960s and giant steps being made in the 1970s. One can project further and foresee that helicopter components to be designed in the 1980s will be 100% defect tolerant. Specifications will probably require this feature, but if they do not, it is so attractive to manufacturers and users and practical to accomplish that it will occur. Thus, by 1990, we believe that all new helicopters introduced into service will be 100% defect tolerant. Reference 14 and Figure 13.

3.8 Commercial Air Travel

Commercial air travel by helicopter is very limited at present because of high operating costs, bad publicity on accidents and relatively low productivity compared to fixed-wing airliners at distances of over 100 nautical miles (Reference 8). It is predicted that trial runs with 44-passenger Boeing Model 237 helicopters may be made in the United Kingdom in the 1980s but this would require government subsidy in the initial stages.

The success of commercial air travel ventures will depend on the availability of modern aircraft and new capital investors; on innovative operators; on growth in fixed-wing transport which results in airport congestion; on community leadership which implements planning for VTOL utilization and; on the availability of flexible IFR regulations and flexible route structures.

The principle requirements that impact a cost-effective commercial operation are:

1. proven safety record for the helicopter model,
2. two to three times the reliability of present helicopters,
3. one-tenth the current abort rate,
4. greatly reduced turbine engine fuel consumption, highly reliable and reduced acquisition costs,
5. crash safety improvements of energy absorbing landing gear and seats and fuel containment,
6. 100% defect tolerance,

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7. low internal and external noise,
8. low vibration and gust sensitivity (ride quality),
9. cruise speed of 200 knots at 200 nautical mile range,
10. instruments and equipment for IFR flight and inadvertent flight in moderate icing.

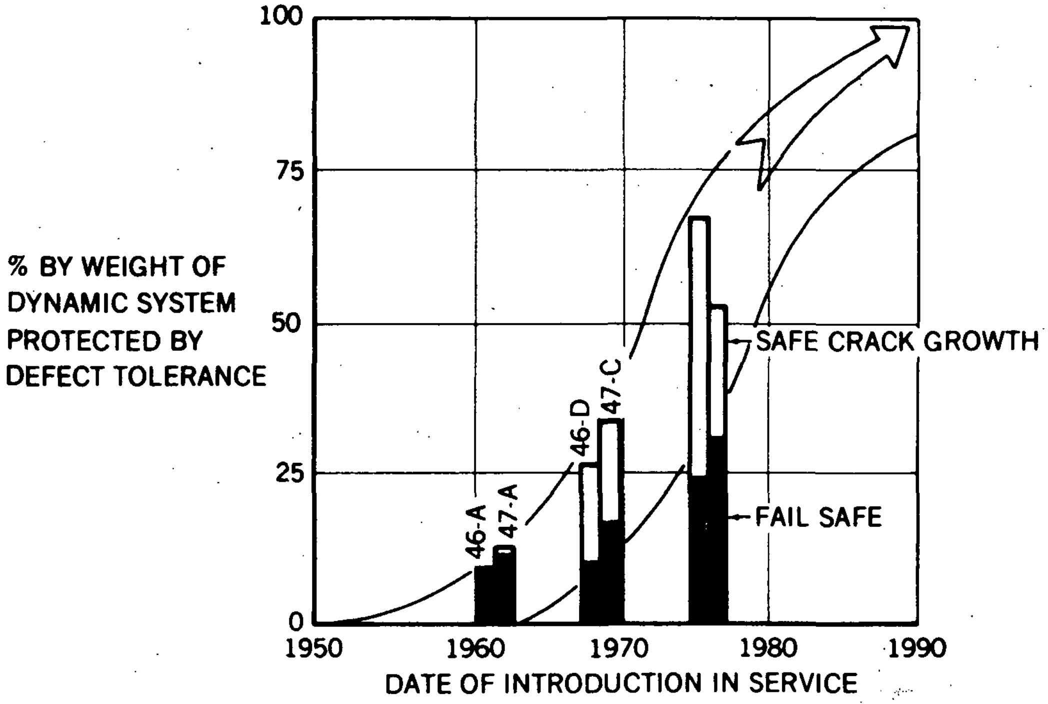

Figure 13. Trend toward 100% defect tolerance

4.0 MAJOR DIFFERENCES BETWEEN MILITARY AND CIVIL DESIGN AND TECHNOLOGY REQUIREMENTS

In this section, major differences between military and civil requirements are examined to define factors that effect cost and operations efficiencies. Relating to the unique requirements of civil helicopters, research and development needs are identified. In general, military designs are for extreme conditions because they fly in a hostile environment day and night in all types of weather. In Vietnam, for example, the helicopter operated at high altitudes and temperatures from unprepared sites and was found to be marginal because of engine power reductions under high hot conditions. This was aggravated by engine power degradation from compressor blade erosion and sand filter devices had to be fitted causing still more power loss. Thus, new U.S. Army helicopters such as the UTTAS are sized with substantial power margins which make for a poor match of cabin seating capacity for the available power if used in low-altitude offshore oil air taxi roles, for example. See references 9, 10, 11 and 12.

Table 3 is a listing of differences between military and civil requirements, some of which result in inefficiencies when military aircraft are adapted for civil use. The effect of these differences on civil helicopters is identified. Table 4 is a listing of these differences in terms of the impact on the civil helicopter market and identification of benefits that will result from research and development in these key technology areas.

Examples of differences between military and civil operations that require different emphasis are discussed below:

- Operational speed for military operations in NOE are not comparable to the higher speeds of 200 knots that are needed to introduce operational efficiencies in civil offshore operations. Further, in air taxi, commuter and corporate/executive transportation competition with fixed wings, high speed and increased range are critical to capturing more of the market. All-weather capability including inadvertent encounters with moderate icing is required if this market is to reach its full potential. New federal regulations must be written to take advantage of unique helicopter capabilities and low-cost, low-weight avionics are required which probably would not be adequate for the military NOE operation which require more sophisticated avionics.

- Reliability, maintainability, defect tolerance and quality control are more critical to civil operations than the military. This statement can be justified by the major emphasis on direct operating costs which can make or break a civil operator whereas the military operates on a TO&E. The costs of insurance and related costs of lost time due to lack of readiness, flight aborts and accidents are examples of the critical need for durable, easily serviceable, safe civil helicopters.

- Improved ride quality with low noise and vibration and reduced gust sensitivity is especially needed in civil helicopters with considerably less need in military operations.

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TABLE 3. MILITARY/CIVIL UNIQUE ROTORCRAFT REQUIREMENTS

Requirement	Military Emphasis	Civil Emphasis	Impact on Civil Helicopters
Regulatory	MIL specs	Federal air regulations (certification)	1. FAA regulations are less severe and result in more payload than military (structural, demo and crashworthiness). 2. Category "A" is more severe than military
Operational Speed	Improved low altitude, NOE speed capability	Increased cruise speed capability at altitude	Offshore oil support. Increase productivity for air taxi and corp/exec transport.
Payload	Increased lbs/hp. Cabin sized for high/hot operation	Increased lbs/hp	Passenger seats/power match is critical.
Range	Increased mission radius and endurance. Increased ferry range with auxiliary tanks.	Increased range capability at cruise airspeeds	Low cost per passenger seat mile. Is strong competitive factor with fixed wings. Need more efficient turbine engines (low sfc)
IMC Capability (IFR)	NOE (all-weather) with sophisticated avionics	High density and remote area capability with low cost, simplified avionics	FAA certification to fixed wing standards imposes unnecessary severe design requirements with consequent high costs and weight. A low weight/cost system with reduced capability is needed
Maneuverability and "g" Loads	Increased capability for NOE	Current maneuverability sufficient for most missions	1. Logging has high frequency of surge loads (high power/high g.w.) 2. Tail rotor control becomes marginal at high altitude/windy conditions.
Quietness (External)	Reduced detectability	Reduced noise footprint	FAA regulation change will impose severe economic penalties
Ride Quality	Reduced vibration for crew fatigue	Reduced internal noise and vibration for pilots and passenger acceptance	Especially air air taxi and corporate/exec transport.
Reliability	Mission completion (fail operational redundancy)	Low maintenance cost (no failures)	Has significant impact on DOCs: On-condition removal. On-condition removal of engines & dynamic components.
Maintainability	Field replaceable (large fleet – ample spares)	Field repairable (small fleet – limited spares)	Has significant impact on DOCs. Must stress design simplicity in future. Easy access to components.
Cost Effectiveness	Low acquisition costs (large fleet – small hrs/yr)	Low operating costs (small fleet – large hrs/yr). Includes depreciation.	1. Low cost per seat mile to compete with fixed wings and ground transportation. 2. To be cost competitive with conventional operations in constructional utility field.

TABLE 3 – Continued

Requirement	Military Emphasis	Civil Emphasis	Impact on Civil Helicopters
Crash Safety	Energy absorbing structure, landing gear and seats. Fuel containment	Very little at present	Civil needs improved crash safety features but less than military (product liability issue). Will reduce payload and increase acquisition cost.
Emergency Power	High power margins and contingency power in some cases	One engine inoperative (OEI) capability (twins)	Would prevent accidents if contingency power of 125–150% of T.O. power could be made available. OEI power is marginal today in most aircraft.
Obstacle Strike Capability (Wires and Solid)	Wire cutters, deflectors, detectors and windshield reinforcement. Main rotor blade cut 8" hardwood tree, and sustain tip weight loss, tail rotor blade cut 1" hardwood dowel. Tail rotor retention with blade loss.	Very little at present	Need to develop wire avoidance methods through human factors studies and provide cable cutters, deflectors and windshield structure reinforcement. Need to improve damage tolerance of main and tail rotor blades and airframe through use of composites.
Ground Personnel Hazards	Main rotor height set by air transport limitations. Protective features and marking of tail rotor.	Raise main rotor for more head and obstacle clearance. Protective features on tail rotor and marking.	Operators want more head clearance. Raised skids are used for slope landings and brush clearance. High tail rotors or "fan in fin" are desirable.
Water Landing	Water landing rotors turning or flotation until passengers escape if shut down (Sea State 3)	Fixed floats or pop-out floats for over water operation	Most helicopters use emergency pop-out floats for over water operations. Some fixed floats are used. Need durability and reliability improvements.
Hi/Low Temperature	−65°F to +125°F	100°F minimum −40°F to +120°F is adequate	Not significant since most civil helicopters are certified for −40°F to +120F now.
Wind Gusts Ops	Navy 45 knots shipboard rotor brake and blade flap restrainers	40 knots steady gusting to 60 knots rotor brake for emergency start up and shutdown only	Offshore oil exploration and some operations in mountainous terrain may be a problem with single rotor helicopters.
High Altitude	20,000 feet	T.O. and landing 10,000 enroute 15,000	Not significant reduction in weight or cost.
Engine Inlets and Windshield. Anti-icing and Blade Deicing	0°F	−22°F is adequate for most operations. Helicopters are now restricted from icing operation. (Inadvertent only)	With increased emphasis on IFR flight there is an increasing need for deliberate operations in icing flight.
Corrosion Control	Navy has major emphasis on corrosion control	Offshore oil exploration have a major corrosion problem	Increased use of composites is desirable in the airframe.

TABLE 3 – Continued

Requirement	Military Emphasis	Civil Emphasis	Impact on Civil Helicopters
Defect Tolerance in Dynamic System Components	Trend towards 100% defect tolerance. Combination of fail safe and safe crack growth.	Same	Fail safe is dual load paths. Safe crack growth through incipient failure detection. Approximately 20% of accidents caused by defects. Objective is no undetected catastrophic failures.
Durability	Trend toward more durable airframes	Same	Composite airframe would be significantly better.

TABLE 4. CIVIL HELICOPTER KEY TECHNOLOGY AREAS/IMPROVEMENTS

1. Composite Structures
   - crash safety improvements can be built in
   - reduce weight
   - reduce cost
   - improve damage tolerance
   - improve corrosion resistance
   - field repairable
   - reduce airframe drag

2. Vibration Reduction
   - reduce vibration generated failures
   - reduce pilot fatigue
   - increase pilot and passenger comfort and acceptance

3. Noise Reduction
   - a. External
     - increase community acceptance
     - increase ground personnel acceptance
   - b. Internal
     - develop lightweight/low-cost noise treatment
     - increase pilot and passenger acceptance (reduce fatigue)
     - improve communications

4. Transmission and Drive
   - increase power to weight ratio
   - 3,000 hour MTBR (solve gear and bearing spalling problems)
   - increase defect tolerance to 100%
   - improve diagnostics/troubleshooting
   - go on condition
   - reduce noise generation
   - no undetected catastrophic failures

5. Rotor Aerodynamic Environment
   - increase cruise speeds to 200 knots
   - reduce rotor induced vibration
   - lower gust response

TABLE 4 – Continued

6. Flight Systems
   a. Flight Controls
      - improve flight control system to reduce pilot workload
      - improve handling qualities for autorotative capability in high wind gusts at high loads at high and low altitude
      - fly-by-wire
      - lightweight/low cost

7. Power Plant System
   - lower SFCs (0.45 at cruise power)
   - lower costs ($40/SHP objective)
   - 5,000-hour MTBR reliability
   - improve diagnostics
   - 2-1/2 minute contingency power 125 to 150% of T.O. power

8. Rotor Blades, Hubs, Upper Controls and Tail Rotor
   - main blade damage tolerance – cut 8-inch diameter hardwood tree
   - tail rotor blade damage tolerance – cut 1-inch diameter hardwood dowel
   - main blade sustain tip weight loss not catastrophic
   - low maintenance (eliminate bearings)
   - 100% defect tolerance – no undetected catastrophic failures

9. Human Factors (Man-Machine Interface)
   - advanced systems monitoring/cockpit computer
   - pilot seat comfort reduce fatigue
   - reduce reflections and glare
   - avoid rotor flicker critical frequencies
   - reduce noise and vibration
   - improve communication/navigation systems
   - improve pilot training and proficiency methods (simulators)
   - reduce pilot workload (flight controls and multifunction displays)
   - air conditioning or seat cushion cooling
   - improve cockpit arrangement and visibility

10. Crash Safety
    - energy absorbing landing gear and seats
    - fuel containment
    - composite structure
    - delethalize cockpit and passenger space
    - provide lightweight intercom/headgear/helmets

TABLE 4 – Continued

11. Configuration Design
    - use low cost components
    - standardization
    - design simplicity
    - maintenance and inspection accessibility
    - protect personnel from tail rotor and main rotor hazards
    - build in crash safety and energy absorbing features
    - emphasize field repairability of engines, dynamic components, avionics, etc.
    - install wire cutters, deflectors and structurally reinforce windshields in agricultural aircraft for wire protection

- Crashworthiness in military helicopters is a reality today that is given little emphasis in civil helicopters. Civil emphasis should be to use available technology from the military but develop requirements for civil helicopters that vary with the type of operation and take into account the hazards involved. Because the military emphasis is on combat survivability and there is a higher probability of crashes in combat, the crashworthiness is probably more stringent than is needed for civil air taxi, for example. Furthermore, as goals for substantially reduced accident rates are achieved the pressure for crashworthiness is relieved.

- Operational conditions such as high, gusty winds, needs for flotation on overwater operations, mountainous terrain operation, high out-of-ground-effect hover in logging and construction work, requirements for contingency power and more efficient turbine engines, the effect of external noise on the community, and the fact that civil helicopters are continuously loaded up to maximum gross weight whereas the military only operate at gross weight on occasion, are all differences between civil and military requirements that result in needs for research and development. Benefits to the military helicopter programs will result from nearly all of the research and development that is needed for civil helicopters.

5.0 CIVIL HELICOPTER RESEARCH AREAS FOR HIGHEST PAYOFF OR EMPHASIS

As a result of studying the design and operational requirements in Section 2.0, the impact of future operations in Section 3.0 and the major differences between military and civil helicopter requirements in Section 4.0, a listing of key technology areas was generated. The matrix shown in Figure 14 illustrates the interaction between key technology areas and civil helicopter market restraints as discussed in Section 2.0.

In Figure 15 a level of need is developed, based on a review of prior work and current thinking of the industry, FAA, NTSB, HAA and the users. The needed technology response is indicated by a 1 to 3 rating where 1 is the greatest need and 3 the least in terms of a requirement for specific operations or market segments. The level of need illustrated in Figure 15 cannot be considered to be a priority ranking because the effect of life cycle cost and future market trends are not presented. For example, if future market growth trends could be predicted and a market dollar value were assigned them the relative importance of individual technology improvements (and their cost benefits) could be evaluated. Reference 5 deals with the life-cycle-cost effect of technology improvements on civil helicopters. Comparing the needs on a market dollar value would provide a means for establishing realistic priorities for those technologies which effect only one or two groups; for example, the value of high-speed rotor development which impacts the corporate/executive transport, air taxi and offshore exploration markets. Another example is the result of safety improvements on an already safe operation such as construction and industrial use helicopters where further improvements would not appear to offer significant payoff. The response here, of course, is to never relax on safety issues and showing a good record on paper is never enough. Every air accident is given front page attention in news media in far greater proportion than automobile accidents, for example, which are commonplace. The technology areas in Figure 15 are discussed below as follows:

- Safety issues in aircraft can never be compromised. Increasing attention to product liability will force continuing efforts in helicopter safety to achieve reductions of accident rates to 1/3 of the current 16/100,000 flying hours in the next decade. Some form of improved crash safety similar to that achieved by the military but to less stringent standards is also required but this area needs definition.

- Powerplant unreliability is a major safety and operational cost shortcoming. The objective should be 5,000 mean engine hours between removals and overhaul; a high degree of field repairability; specific fuel consumption (SFC) of 0.45; reliable engine diagnostic systems; acquisition costs of $40/SHP and emergency ratings of at least 125% of takeoff power for 30 seconds (150% of takeoff power for 2-1/2 minutes is desired).

- Drive and Rotor System unreliability is a major safety and operational cost shortcoming. The objective should be 3,000 hours MTBR for transmissions and 5,000 hours for hubs; 100% defect tolerance for fail safety; a high degree of field repairability; bearingless main and tail rotor hubs; light weight transmission assemblies with redundant lubrication systems;

MARKET RESTRAINTS	COMPOSITE STRUCTURES	VIBRATION REDUCTION	NOISE	TRANSMISSION & DRIVE SYSTEM	ROTOR AERODYNAMIC ENVIRONMENT	FLIGHT SYSTEMS	POWER PLANT SYSTEMS	ROTOR HUB, BLADES & UPPER CONTROLS & TAIL ROTOR	MAN-MACHINE INTERFACE COCKPIT AIDS, DISPLAY & COMFORT	ENERGY ABSORBING LANDING GEAR & SEATS & FUEL CONTAINMENT
(1) COST OF OWNERSHIP										
ACQUISITION	X			X			X	X		
OPERATIONS										
RELIABILITY	X	X		X		X	X	X	X	
MAINTAINABILITY	X	X		X			X	X	X	
FUEL CONSUMPTION					X		X			
ALL-WEATHER OPERATIONS						X	X	X	X	
CRASH SURVIVABILITY								X	X	X
(2) COMMUNITY/USER ACCEPTANCE										
SAFETY	X			X		X	X	X	X	
NOISE										
EXTERNAL			X		X		X	X	X	
INTERNAL	X		X	X						
RIDE QUALITIES										
VIBRATION	X	X		X	X	X			X	
GUST RESPONSE					X	X			X	
(3) IMPROVED PERFORMANCE										
PAYLOAD										
WEIGHT EMPTY REDUCTION	X	X		X		X	X	X		
IMPROVED ROTOR EFFICIENCY					X					
REDUCED FUEL CONSUMPTION					X		X			
SPEED										
REDUCED DRAG					X					
IMPROVED ROTOR CAPABILITY					X	X				

Figure 14. Technology – market primary relationships

LEVEL OF NEED – 1 MOST, 3 LEAST

TECHNOLOGY/SHORTCOMING	SMALL PUBLIC USE/ CIVIL GOVT POLICE FIRE ETC	SMALL AGRICULTURAL	SMALL/MEDIUM CORP/EXEC AIR TAXI	SMALL/MED/LARGE OFFSHORE OIL EXPLORATION	MEDIUM/LARGE CONSTRUCTION FORESTRY	HEAVY LIFT CONSTRUCTION CONTAINER SHIP
1. SAFETY (AIR/CRASH/OPERATIONS)	1	1	1	1	1	1
2. POWERPLANT RELIABILITY AND	1	1	1	1	1	1
3. DRIVE & ROTOR SYSTEM RELIABILITY AND EFFICIENCY	1	1	1	1	1	1
4. FLIGHT SYSTEMS						
– PILOT/COCKPIT/CONTROLS	1	1	1	1	1	1
– HANDLING QUALITIES	2	1	2	1	1	1
5. NOISE						
– EXTERNAL	1	3	1	2	2	1
– INTERNAL	2	2	1	1	2	2
6. VIBRATION/GUST SENSITIVITY	2	2	1	1	1	1
7. ROTOR AERODYNAMICS						
– HIGH SPEED	2	3	2	2	3	3
– HIGH PAYLOAD	2	1	1	1	1	1
8. COMPOSITE AIRFRAME	3	3	1	1	2	1
9. IMC OPERATION (IFR)	3	3	2	1	3	3

Figure 15. Technology – market level of need matrix

an order of magnitude improvement in bearing and gear (spalling) life and reliable diagnostic systems. Damage tolerant composite main and tail rotor blades to reduce damage from accidental contact with trees, brush and stones are required, with 5,000 hours mean time between removals.

- Flight System unreliability is principally a function of so-called pilot error accidents. Since the pilot is the most critical part of the flight system and accounts for approximately 60% of civil helicopter accidents, it is recommended that a detailed study of a large number of accidents be conducted and contrived difficult situations be evaluated on a simulator. The objective would be to define design, operational and training shortcomings that are creating situations where pilot errors will occur.

  Handling qualities need improvement in many operations. The objective is to improve precision maneuvering and ease the pilot's workload in flying the helicopter in takeoff, NOE, landing, IFR situations and for precision hovering in construction and heavy-lift operations.

- Noise is a major problem in helicopters. External noise from main and tail rotors and engines are restraining development of public-use heliports and restricting helicopters from being used most economically in populated areas. Internal noise makes communication difficult (creating unsafe conditions), is fatiguing and reduces passenger acceptance. The objective is to reduce cockpit and cabin noise to fixed-wing levels so that business can be conducted enroute.

- Vibration and gust sensitivity are restraining helicopter passenger acceptance. Vibration is a major cause of component failures and is fatiguing and annoying to passengers and pilots. The objective is to reduce vibration levels to ± 0.10 g's throughout the occupied areas and in equipment compartments in all six degrees of freedom.

  The gust sensitivity objective is to set criteria for acceptable limits and develop methods for predicting mutual interference effects between main rotor/tail rotor/fuselage.

- Rotor aerodynamics at high speeds are a restriction in the corporate/executive transport and air taxi market in competition with fixed-wing aircraft. The objective is to develop a 200-knot cruise speed helicopter. This speed is also desirable in the offshore oil exploration market. Since payload is also critical in most cases it cannot be compromised for speed, and hover efficiency must be maintained. In agriculture, construction, forestry and heavy-lift operations payload is paramount and speed is not an issue.

- Composite airframes and secondary structure offer lighter weight, lower cost, corrosion resistance, lower maintenance cost, damage tolerance and structural integrity. The objective is to conduct trade studies, cost benefit analyses and bench testing of composite materials to determine the most cost effective use of composites for civil helicopters.

- Instrument and Meteorological Conditions (IMC) flying under instrument flight regulations is gaining acceptance for commercial operations such as corporate/executive transport, air taxi and offshore oil exploration. The major restraint is the weight and cost of avionic equipment to qualify under FAA fixed-wing regulations. The objectives are: (1) develop FAA regulations that are commensurate with helicopter operating techniques and capabilities, and (2) to develop lightweight, low-cost equipment to give operators an opportunity to compete in the marketplace with fixed-wing counterparts.

6.0 CONCLUDING REMARKS

Figure 15 summarizes the areas where research and development is needed to meet design and operational requirements for civil helicopters. These technology/shortcoming areas were selected as offering the highest payoff in terms of impact on marketing restraints, breaking into new markets and offering opportunities for increasing helicopter sales in competition with other transportation modes. This selection includes consideration of the effect of future developments and constraints as well as trends in helicopter technology in critical areas. A large number of individual detail development programs will be needed also, but in most cases they will fall under the umbrella of the general categories that are listed below.

Safety

- Reduce accidents to 1/3 of current rate by 1985 by improving subsystem reliability and reducing pilot error accidents.
- Reduce fatalities and injuries by introduction of crashworthiness features.

Cost

- Reduce acquisition cost by reducing parts count, design simplification, commonality and low-cost parts and components.
- Reduce operating costs with more efficient engines, reduced maintenance through durability and serviceability, reduced spares costs and improved quality control of original equipment and spares.

Performance

- Improve payload to empty weight ratio by lightweight design techniques and materials applications.
- Increase speed for some operations with advanced rotor aerodynamics.

Noise

- Reduce main rotor, tail rotor and engine external noise.
- Reduce internal noise in occupied areas.

Vibration

- Reduce vibration throughout the aircraft in all six degrees of freedom.

Instrument Meteorological Conditions (IMC)

- Define new FAA regulations for helicopter all-weather flight including moderate icing.
- Develop lightweight/low-cost avionics to meet the new FAA regulations above.

Meeting the challenges of the rapidly developing civil helicopter market in the next decade will require a dedicated effort between operators, users, manufacturers, regulatory agencies and support organizations. A major problem in civil helicopters is the uncoordinated efforts between these organizations. This can best be illustrated by a comparison with military helicopter users who spend millions of dollars defining and monitoring operational and service test requirements which are admitted to be inadequate in many cases. A similar effort in the civil field does not exist. That is why the AHS and HAA operators' panels are gaining popularity and is the beginning of a useful voice in the industry.

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CIVIL HELICOPTER PILOT SURVEY (38 PILOTS)

Ref: Unpublished University of Virginia 1976 Survey and
Report No. UVA/528051/ESS77/102 dated May 1977

Research Emphasis Ratings (1 Little Emphasis; 7 Major Emphasis)

	Mean
● Passenger Acceptance	
– Costs more competitive with other systems	6.2
– Reduce noise	5.8
– Increase system safety	5.8
– Reduce vibration	5.5
● Community Acceptance	
– Improve safety of operation	5.7
– Reduce external noise	4.2
– Reduce pollution	2.0
● Safety Considerations	
– Increased component reliability	6.4
– Increased structural reliability	5.5
– Engine-out capability	5.2
– Improved crashworthiness	5.0
– Reduced pilot workload	3.9
– Improved air traffic control system	3.7
– Increased visibility	2.8
● Performance Considerations	
– More efficient powerplant	5.7
– Reduced fuel consumption	5.3
– Increased speed	5.1
– More payload	5.1
– Greater range	4.9
– Higher ceiling	3.2
– Greater rate of climb	3.1
– Increased maneuverability	2.6
● Cockpit Equipment	
– Improved communications through reduced noise levels	5.55
– Increased comfort by decreasing noise annoyance	5.50

	Mean
– Reduced vibration	5.47
– Improved seat comfort	4.4
● Pilots Cockpit Aids and Displays	
– Improved malfunction rating system	4.7
– Cockpit design standardization	4.1
– Improved avionics	4.1
– Improved cockpit layout	3.9
– RNAV capability	3.4
– Weather radar	2.6

PILOT CAUSAL FACTORS IN ACCIDENTS WITH GENERAL AVIATION HELICOPTERS IN 1975

		Percent of 416 Factors Cited
● Incorrect Flying Techniques		
– Failed to maintain adequate rotor rpm	61	
– Improper operation of flight controls	45	
– Mismanagement of fuel	21	
– Simulated conditions	10	
– Inadequate supervision of flight	10	
– Improper compensation for wind conditions	7	
– Improper level off	7	
– Improper operation of powerplant and powerplant controls	7	
– Poorly planned approach	5	
– Failed to attain/maintain flying speed	2	
– Failed to maintain directional control	2	
Subtotal	177	43%
● Error in Judgement		
– Misjudged speed and altitude	46	
– Misjudged altitude/clearance	22	
– Selected unsuitable terrain	9	
– Attempted operation beyond experience/ability level	9	
– Exercised poor judgement	5	
– Operation with known deficiencies in equipment	4	
– Continued VFR flight in adverse weather conditions	3	
– Initiated flight in adverse weather conditions	3	
– Misjudged speed, altitude or clearance	2	
– Delayed initiating go-ahead	1	
– Delayed action in obtaining takeoff	1	
Subtotal	105	25%
● Inadequate Preparation and Planning		
– Inadequate preflight preparation/planning	43	
– Lack of familiarity with the aircraft	13	
– Improper inflight decision/planning	11	
– Failed to follow approved procedures/directives	10	
Subtotal	77	19%

		Percent of 416 Factors Cited
• Visibility or Diverted Attention		
– Failed to see/avoid objects or obstructions	36	
Subtotal	36	8%
• Pilot Fatigue, Diverted Attention or Lost/Disoriented		
– Diverted attention from operation of the aircraft	12	
– Pilot fatigue	6	
– Lost/disoriented	2	
– Spatial disorientation	1	
Subtotal	21	5%
TOTAL	416	100%