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ARMY HELICOPTER COST DRIVERS

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Fort Eustis, Virginia

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The objective of this investigation is to identify the major high-cost areas, referred to as "cost drivers", for Army helicopters. The helicopter life-cycle cost is divided into two major areas—acquisition and operating—for breakdown and examination. Acquisition costs, which include R&D and production, generally account for 25 percent of the life-cycle cost. The operating costs, which account for the remaining 75 percent, are examined in terms of maintenance and parts, personnel, and consumables. The helicopter is divided into major subassemblies such as rotor, transmission, and airframe, and each is examined in detail. The airframe, power plant, and avionics appear to be the major component contributors to

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acquisition costs, while the rotor, transmission, and power plant contribute most strongly to operating costs. The study recommends that in subsequent development programs, more emphasis be placed on component cost definition and component cost tracking.

PREFACE

This investigation, performed under House Task 72-18, Army Helicopter Cost Drivers, was conducted to identify the major high-cost areas, herein referred to as "cost drivers", for Army helicopters. The findings were presented to an ad hoc committee on Implementation of Cost Savings Recommendations for Aerospace Construction, established by the National Materials Advisory Board of the National Research Council. Special acknowledgement is given to Mr. C. H. Carper, who was a member of this committee, for his technical assistance and for presenting the findings of this study to the committee.

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INTRODUCTION

The investigation, performed under House Task 75-26, Army Helicopter Cost Drivers, was conducted to identify the major high-cost areas, herein referred to as "cost drivers", for Army helicopters. The findings were presented to an ad hoc committee on Implementation of Cost-Savings Recommendations for Aerospace Construction, established by the National Materials Advisory Board of the National Research Council. As a positive spin-off, the study provided a good insight into the current degree of understanding of helicopter costs, particularly at the subcomponent level. It also identified areas of research and development where additional work and emphasis are needed in order to better our knowledge of helicopter costs, to improve our capability to predict such costs, and to achieve cost reductions with future helicopter systems. Such information becomes especially significant with the increased emphasis on cost awareness, as initially set forth in DOD Directive 5000.1, Acquisition of Major Defense Systems.

It was not the intent of this investigation to examine helicopter cost contributors from an economic viewpoint by addressing variables such as production buy, escalation rates, labor rates, and profits. Rather, the major thrust was oriented toward reviewing cost contributors at an "engineering level". This involved identification of the high-cost components such as power plant, airframe, and transmission for both acquisition and operating costs, and examining each component to determine what exactly drove its costs.

APPROACH

To accomplish the objective of this study, the total helicopter life-cycle cost was divided into two distinct areas: acquisition cost and operating cost. The initially intended approach was to select three helicopter classes, such as light observation, utility, and cargo, and to identify the parameters and components that contributed to both the acquisition and operating costs. These costs were to be broken out and examined. As selected helicopters were examined, however, it became evident that complete data were not readily available within the scope of this investigation to adequately define all the elements comprising the life-cycle cost for a given helicopter. Thus, the approach evolved to gathering as much data as was available for various helicopters, examining these data for trends and patterns, and generalizing the results to the maximum extent technically practicable.

HELICOPTER LIFE-CYCLE COST

The helicopter life-cycle cost breakout presented in Table 1 shows that acquisition cost accounts for 25 percent and operating cost for 75 percent. These two major cost categories are discussed in the following paragraphs.

ACQUISITION COST

The breakout of acquisition cost into R&D and production is given in Table 1. As shown, R&D comprises approximately 15 percent of the acquisition cost. This estimate is based on the development programs for helicopters currently in the Army's inventory. In these programs, however, the helicopter systems were essentially purchased "off-the-shelf" and did not contain the current procurement requirements that strongly emphasize the "ilities", i.e., reliability, maintainability, safety, survivability, and improved fail-safe structures. With the incorporation of these requirements in recent procurement programs such as the Advanced Attack Helicopter (AAH), the Utility Tactical Transport Aircraft System (UTTAS), and the Heavy Lift Helicopter (HLH), it would be expected that the R&D cost would increase due to the additional effort required to achieve improvements in such areas. However, to incorporate the "ility" features on production vehicles would add much greater cost. Thus, in absolute terms, R&D cost will probably increase for new systems; but in terms of a percentage of acquisition cost, assuming equal production buys, the values should remain reasonably close to what they have been in the past. However, the cost of operating the new system should be significantly reduced.

The production cost, which accounts for the remaining 85 percent of the acquisition cost, is further divided into two areas: recurring, which averages 95 percent of the production cost, and nonrecurring, which averages the remaining 5 percent. Recurring cost normally includes materials, engineering and manufacturing support, and quality control; nonrecurring cost primarily includes tooling and engineering design. The ratio between R&D and production depends upon the production buy, wherein the larger the buy, the higher the percentage of production cost. To illustrate this, in a cost study performed for a lighweight observation helicopter, production cost constituted 77 percent of the acquisition cost for a production buy of 500 helicopters and 85 percent for a buy of 1,000 helicopters.

To study production cost, the helicopter was broken down into major subcomponents and a percentage of the total helicopter cost was given to each, as shown in Table 2. The airframe, which includes all fuselage primary structure, doors, windows, landing gear, etc., normally appears to be the most expensive component of the helicopter, accounting, on the average, for 25 percent of the unit flyaway cost. Avionics can vary between 10 and 20 percent, depending upon the aircraft size and the level of sophistication within the equipment. Although the percentages shown are representative values, they do change as a function of helicopter class and type.

Typical helicopter unit flyaway cost, which includes investment recurring and nonrecurring, is shown in Table 3. This cost is dependent upon several variables, including aircraft buy, production time frame, and production rate. Comparing the cost for a

TABLE 1. LIFE-CYCLE COST (LCC) BREAKOUT ESTIMATES

LCC				LCC (%)
● ACQUISITION	25			
+ R&D		15		4
+ PRODUCTION		85		21
RECURRING			(95)	
NONRECURRING			(5)	
● OPERATING	75			
+ PERSONNEL		10		8
+ CONSUMABLES		15		11
+ MAINTENANCE AND PARTS		75		56

TABLE 2. HELICOPTER TYPICAL PRODUCTION (RECURRING) COST BREAKDOWN

COST CONTRIBUTOR	TOTAL COST (%)
AIRFRAME	25
ENGINE	20
ROTOR	11
TRANSMISSION	9
	65
OTHER*	35
TOTAL	100

*AVIONICS 10-20%

TABLE 3. AIRCRAFT UNIT FLYAWAY COST

HELICOPTER	TYPE	PRODUCTION TIME FRAME	NO. AIRCRAFT PRODUCED	STANDARD PRICE ($)
AH-1G	ATTACK	1967-Pres	1101	509,833
CH-47A	CARGO TRANSPORT	1962-67	373	990,717
CH-47B	CARGO TRANSPORT	1967-68	85	1,063,448
CH-47C	CARGO TRANSPORT	1968-74	226	2,026,200
CH-54A	CARGO TRANSPORT	1964-69	66	2,134,466
CH-54B	CARGO TRNASPORT	1969-71	23	2,343,131
OH-6A	OBSERVATION	1966-70	1413	109,221
OH-13S	OBSERVATION	1963-65	285	55,640
OH-58A	OBSERVATION	1969-73	2200	104,461
UH-1B	UTILITY	1961-66	1537	244,760
UH-1C	UTILITY	1965-67	238	224,415
UH-1D	UTILITY	1963-73	1740	237,504
UH-1H	UTILITY	1963-73	4084	244,345
UH-1M	UTILITY	1965-67	820	247,758
TH-13T	BASIC INSTRUMENT TRAINER	1965-68	413	62,700
TH-55A	PRIMARY TRAINER	1965-69	792	35,590
UTTAS	UTILITY	1977-86	1107	1,105,000*
AAH	ATTACK	1980-85	472	1,923,000*
HLH	CARGO TRANSPORT	1981-89	250	8,000,000*

*PRICE BASED ON CONSTANT 1974 DOLLARS

given helicopter type shows that the cost significantly increases with time. For example, the projected cost for UTTAS (1977-86 production time frame) is more than four times the cost for the current operational utility helicopters such as the UH-1's (1961-68 production time frame). The same trend is seen in comparing the AH-1G attack helicopter cost with that projected for the AAH. Probably the most influential factors in this cost are the inflationary economic trends and the previously discussed differences in procurement requirements.

Airframe

Basic helicopter airframe structure on the average accounts for one-fourth of the helicopter production cost. The most widely used construction for the helicopter airframe is skin/stringer, with bonded honeycomb receiving limited application. Aluminum is the most common material used for the airframe; steel and titanium are used to a lesser degree. Composite material application to the airframe of production helicopters has been very limited to date, with the majority being in secondary structures. In the past 2 years, however, this application has received considerable emphasis, and composites will most likely be used more extensively in the upcoming generation of helicopters. On the average, material cost comprises approximately 11 percent of the total airframe cost and includes raw materials and subcontracting. Often when a contractor reports material cost, it includes not only raw material cost but also purchased parts cost and subcontracted cost such as for parts manufactured by an outside vendor. In an extreme case, the material cost could include outside purchase and manufacture of all components to the point that only final assembly would be required at the contractor's facility. At the other extreme, the majority of components and parts would be fabricated at the contractor's facility, so most of the material cost would be for raw materials. Hence, care should be taken in the interpretation of material cost data. The remaining 89 percent of the airframe cost is for manufacturing. The major activities comprising manufacturing cost are fabrication, which is approximately 30 percent, and assembly and installation, which accounts for the remaining 70 percent.

Some of the factors reported in References 1 through 3 that most significantly affect airframe cost include: number of parts, fastener and rivet count, rivet technique (hand versus automatic), component manufacturing techniques, and number of manufacturing operations.

Historically, component weight has been used as a yardstick for determining component cost. However, a linear regression analysis[1] has shown that for subassemblies in a given

[1] L.J. Marchinski, *Design Studies To Reduce Airframe Costs by Quantifying Design Factors That Drive Cost*, Boeing Vertol Company, Naval Air Development Center Contract N62269-73-C-0312, October 1973.

[2] L.J. Marchinski, *Design to Cost at Work for Helicopter Systems*, presented at the 30th Annual National Forum of the American Helicopter Society, Washington, D.C., May 1974.

[3] Minutes From *HLH ATC/Prototype Program 11th Quarterly Review With Program Management*, presented at Boeing Vertol Company, Philadelphia, Pennsylvania, 30 May 1974.

airframe, parts count correlates more closely with manufacturing man-hours than does weight. Figures 1 and 2 demonstrate this point. Automatic riveting offers a 75 to 80 percent cost reduction over hand riveting. The proper use of low-cost manufacturing techniques such as chem-milling, precision forging, and numerical control machining can also reduce component cost. For these techniques to be effective, however, they must be considered during component design, and they require close coordination between the designer and the manufacturer. In Reference 1, 15 percent of the major assemblies for the cockpit, cabin, stub wings, and aft fuselage of the CH-46F were redesigned to determine the cost reduction that could be achieved through a reduction in the number of parts, a reduction of hand labor/manufacturing operations, and the use of suitable lower cost manufacturing techniques. For the assemblies examined, 29.2 to 85.8 percent reduction in manufacturing man-hours was reported; the higher percentages were in secondary structures such as doors and fairings, and the lower percentages were in primary structures such as frames and stringers. Based on these figures, the predicted total man-hour cost reduction for the entire airframe structure is approximately 44 percent.

Landing gear cost varies significantly in the percentage of aircraft flyaway cost, depending on the gear configuration, complexity, and design requirements. Typically, gear cost in terms of percentage of aircraft unit flyaway cost varies from as low as 1 percent for the UH-1H, which is a skid configuration, to as high as 4 percent for the wheeled gear on the CH-47. Recent requirements in crashworthiness design and kneeling capability for aircraft transportability have added to gear complexity and cost. Generally, the bulk of gear manufacturing for wheel-type gears is subcontracted by the airframe manufacturer. The manufacturer contributes, on the average, less than 10 percent to the total gear cost, and this is in assembly and installation. Brakes, wheels, tires, etc., are normally Government-furnished equipment.

Rotor System

In past years rotor blades have been all-metal construction, with the most typical constituent materials being steel and aluminum. About 10 years ago, composite materials began to see limited use in blades for helicopters such as the CH-46 and CH-47; in the latest generation of helicopters–UTTAS, AAH, and HLH–they are being used much ich more extensively. Typical rotor blade cost for both metal and composite material construction is shown in Table 4. It is emphasized that this cost has not been normalized to a common production time frame, production rate, and quantity; it should in no way be used to compare the ability of different contractors to economically manufacture a rotor blade.

Typical construction for metal blades is shown in Figure 3. For these blades, it appears that the major cost driver is the number of operations required in fabricating and assembling the blade and its many detailed parts. Operations common to the manufacture of metal rotor blades include: (1) fabrication of major subassemblies, such as forming or extruding the spar and machining the aft fairing core; (2) surface cleaning and preparation for adhesive bonding of major subassemblies/components; (3) final assembly, which encompasses bonding of subassemblies such as the spar, aft fairing, and tip fittings; and (4) extensive quality control inspection throughout the entire manufacturing cycle.

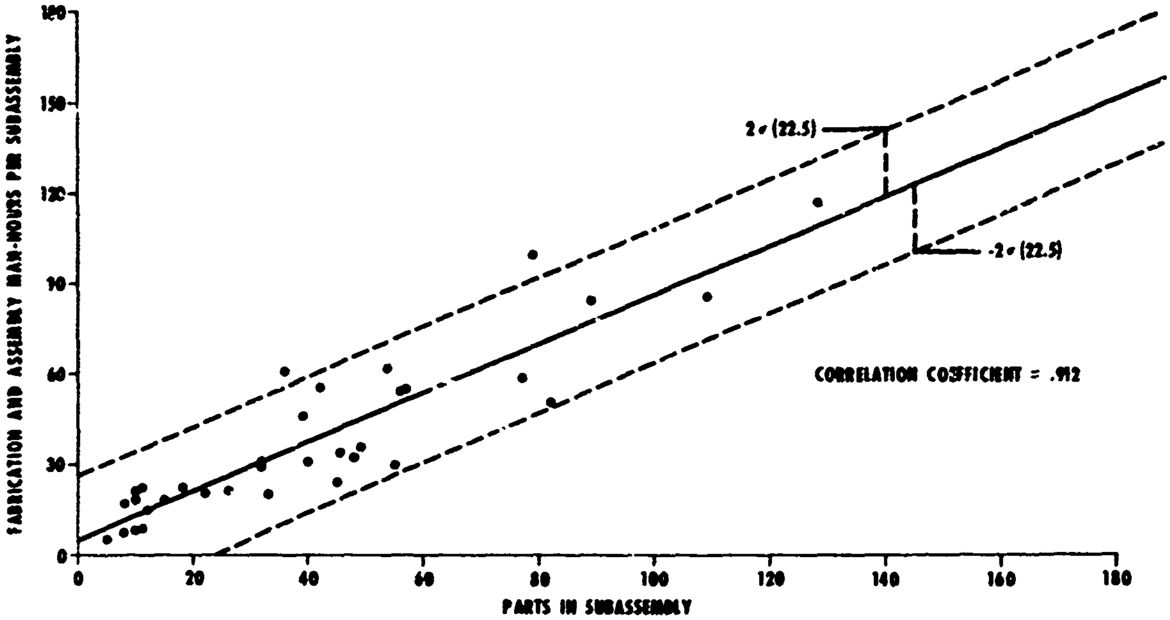

Figure 1. Man-hours per subassembly vs parts count in subassembly.

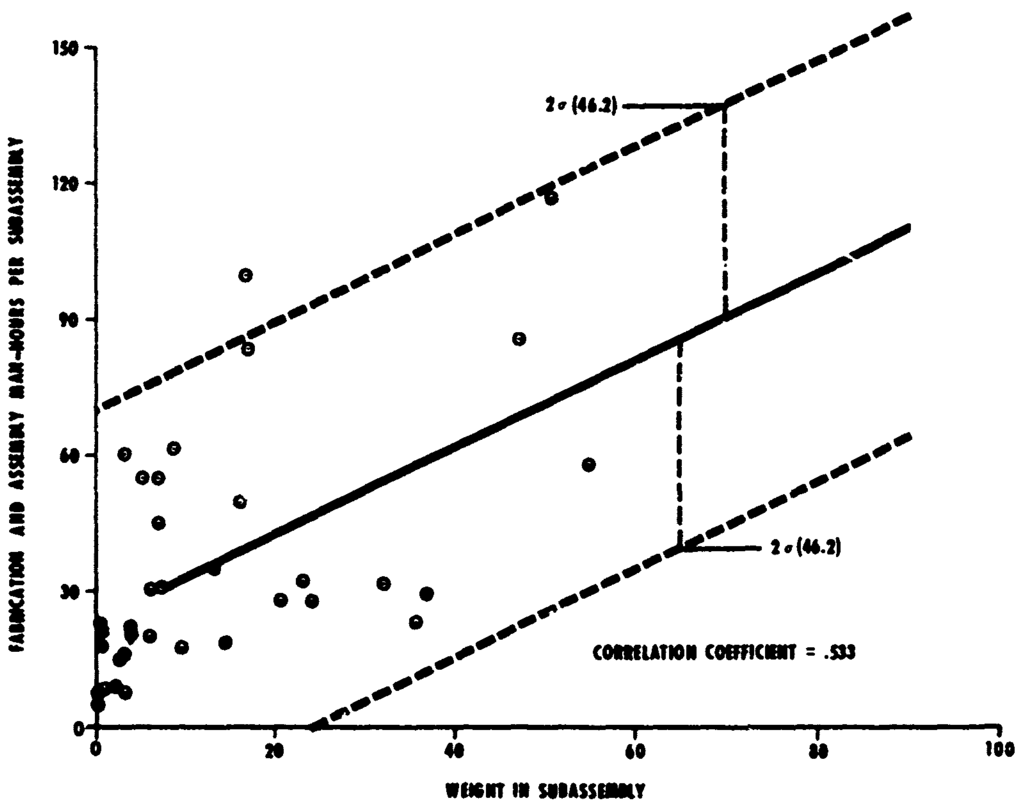

Figure 2. Man-hours per subassembly vs weight in subassembly.

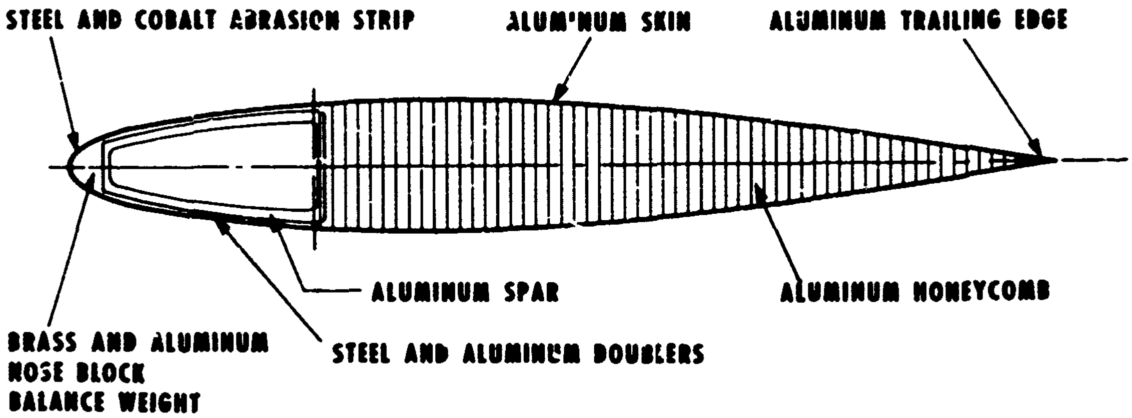

Figure 3. UH-1H rotor blade cross section.

TABLE 4. ROTOR BLADE COST (RECURRING)

BLADE	CONSTRUCTION	WEIGHT (LB)	PRICE ($)
OH-6A	ALUMINUM	26	3,000
UH-1H	ALUMINUM	200	3,400
AH-1G	ALUMINUM	229	3,800
AH-1G (MOD)	ALUMINUM	229	4,400
CH-47	STEEL AND ALUMINUM	300	20,150
CH-46	STEEL AND ALUMINUM	155	24,000
CH-53	ALUMINUM	363	20,500
CH-54	ALUMINUM	354	20,000
HLH	FIBERGLASS/TITANIUM	780	42,900*

*PROJECTED COST BASED ON CONSTANT 1972 DOLLARS

Although intuitive judgment suggests a correlation between the number of steps/operations and parts count, no data has been published relating these parameters.

Metal blade cost can be significantly affected by the airfoil shape, since asymmetrical airfoil blades require more extensive, complex tooling than those with symmetrical airfoil shapes. Because of the necessity to maintain close airfoil shapes and the large number of bonded joints within a blade, close tolerance in construction is essential. This close-tolerance requirement increases blade cost.

Normally, the breakout of blade material cost and labor cost is close to 50-50. Material cost is such a high percentage because major subassembly operations such as forming the spar and machining the aft fairing are subcontracted to outside vendors (outside vendor operations are included under material cost), and several subcomponents such as tip fittings, root end bushings, retention bolts, and deicing blankets are purchased by the prime contractor in prefabricated form.

As with metal blades, the prime drivers for composite blade cost are the number of operations and the handling of detailed parts. Typical composite blade sections are shown in Figures 4 and 5. The fabrication sequence for the HLH composite rotor blade is shown in Figure 6.[4] Also common to the metal blades, the composite blade material cost is about equal to the labor cost. A material and labor breakout for the HLH blade is shown in Figure 7.

The basic cost for constituent materials, such as graphite, fiberglass, and Kevlar 49, for composite blades is considerably more than that for metal blades. However, composite blades have the potential for significantly reducing the required number of operations and fabrication steps because composites are amenable to automated layup techniques, such as filament winding, and to combining curing and bonding operations into a single-step operation (i.e., cure the spar, aft fairing, trailing edge, and tip fittings in one step). Also, composite blades do not require the extensive surface preparation and cleaning that metal blades require, and complex airfoil shapes and twist distributions are obtained at virtually no increase in cost.

Significant to rotor blade cost are the features of: blade deicing, which normally includes a deicing blanket around the blade nose periphery; a failure detection system such as the pressurized spar Blade Inspection Method (BIM) on the CH-53; and, in the case of all composite blades, a lightning protection system. Figure 7 shows that the deicing on the HLH blade accounts for 8 percent of the blade cost. For smaller, less expensive blades this percentage will be considerably higher because the blanket cost and its installation are basically independent of blade size. The Integral Spar Inspection System (ISIS) accounts for about 4 percent of the HLH blade cost. The titanium nose cap serves basically as the lightning protection system, so there is no differentiable cost on the HLH blade for this feature.

[4] *HLH Rotor Blade Manufacturing Technology Development Report*, D301-10280-1, Boeing Vertol Company, Philadelphia, Pennsylvania, 1974.

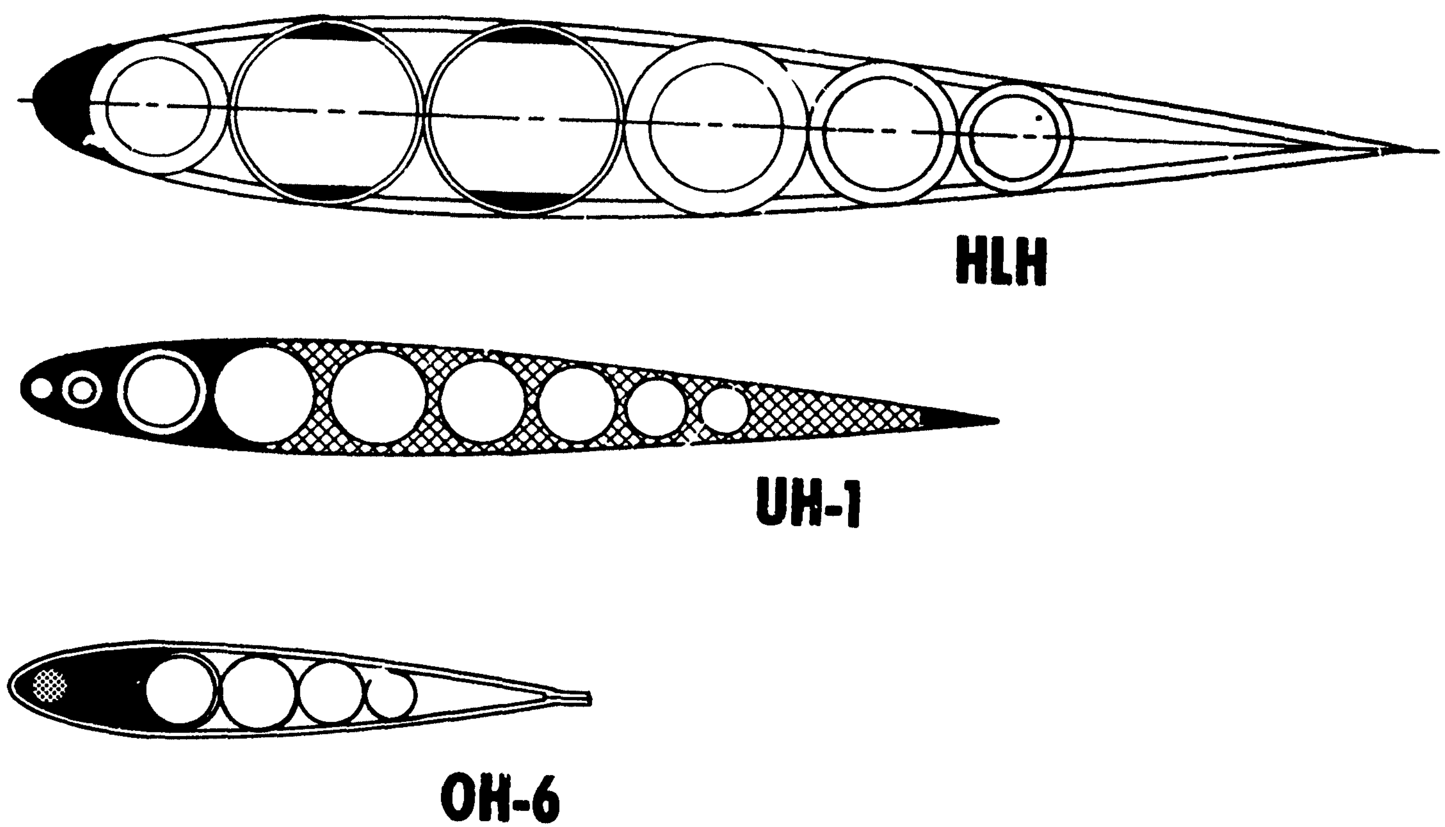

Figure 4. Multitubular spar rotor blade concept, prior R&D.

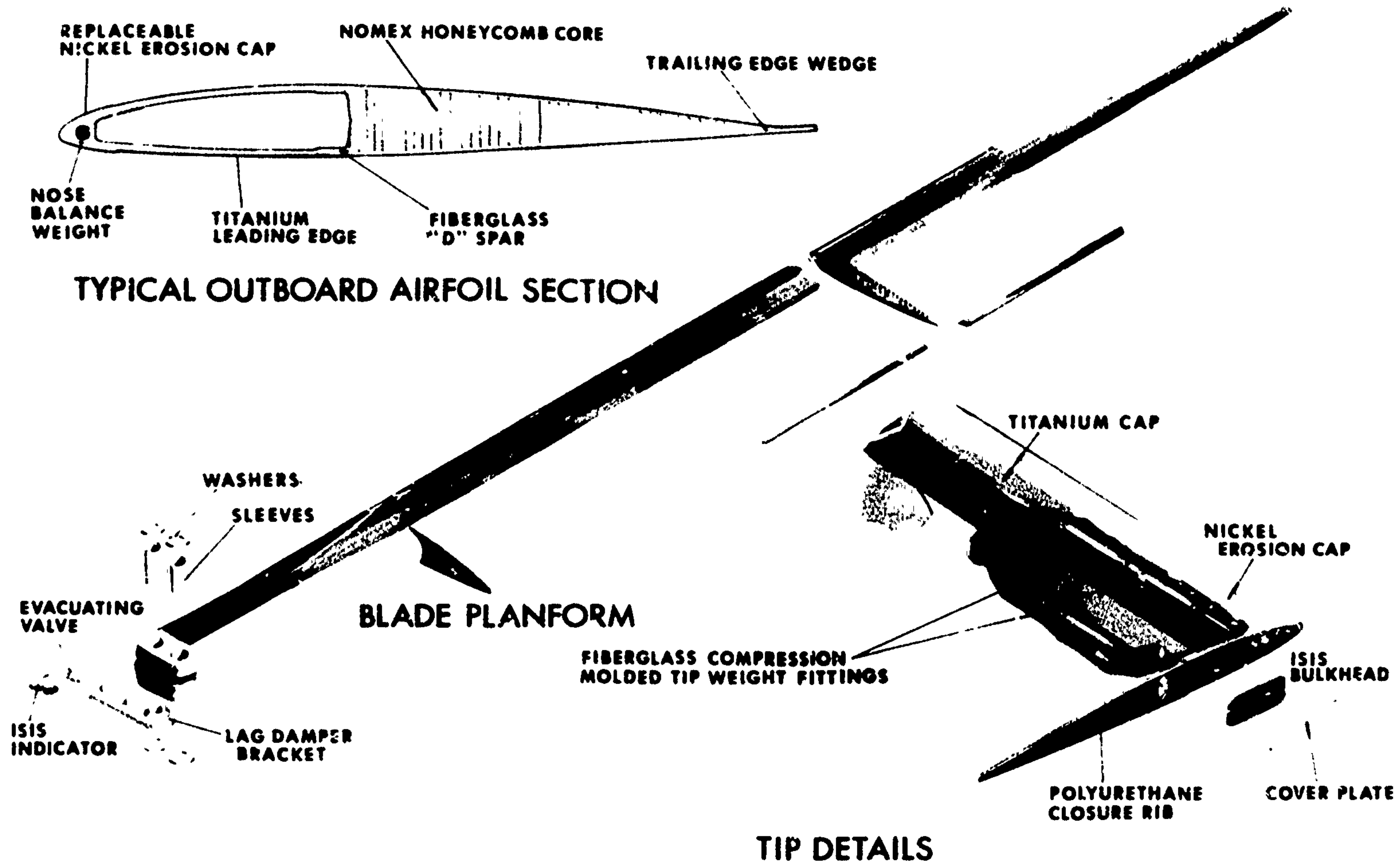

Figure 5. HLH rotor blade.

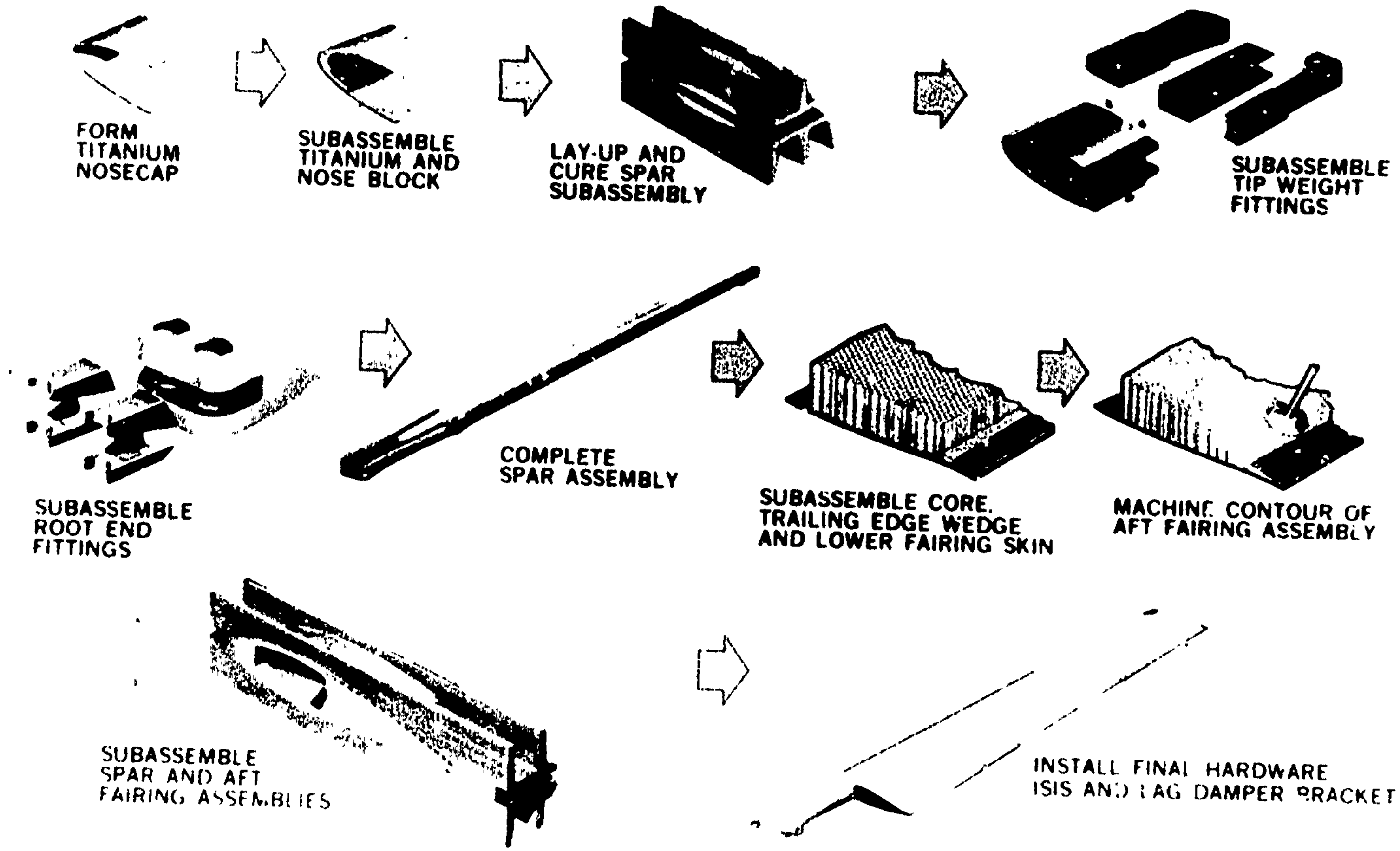

Figure 6. HLH rotor blade fabrication sequence.

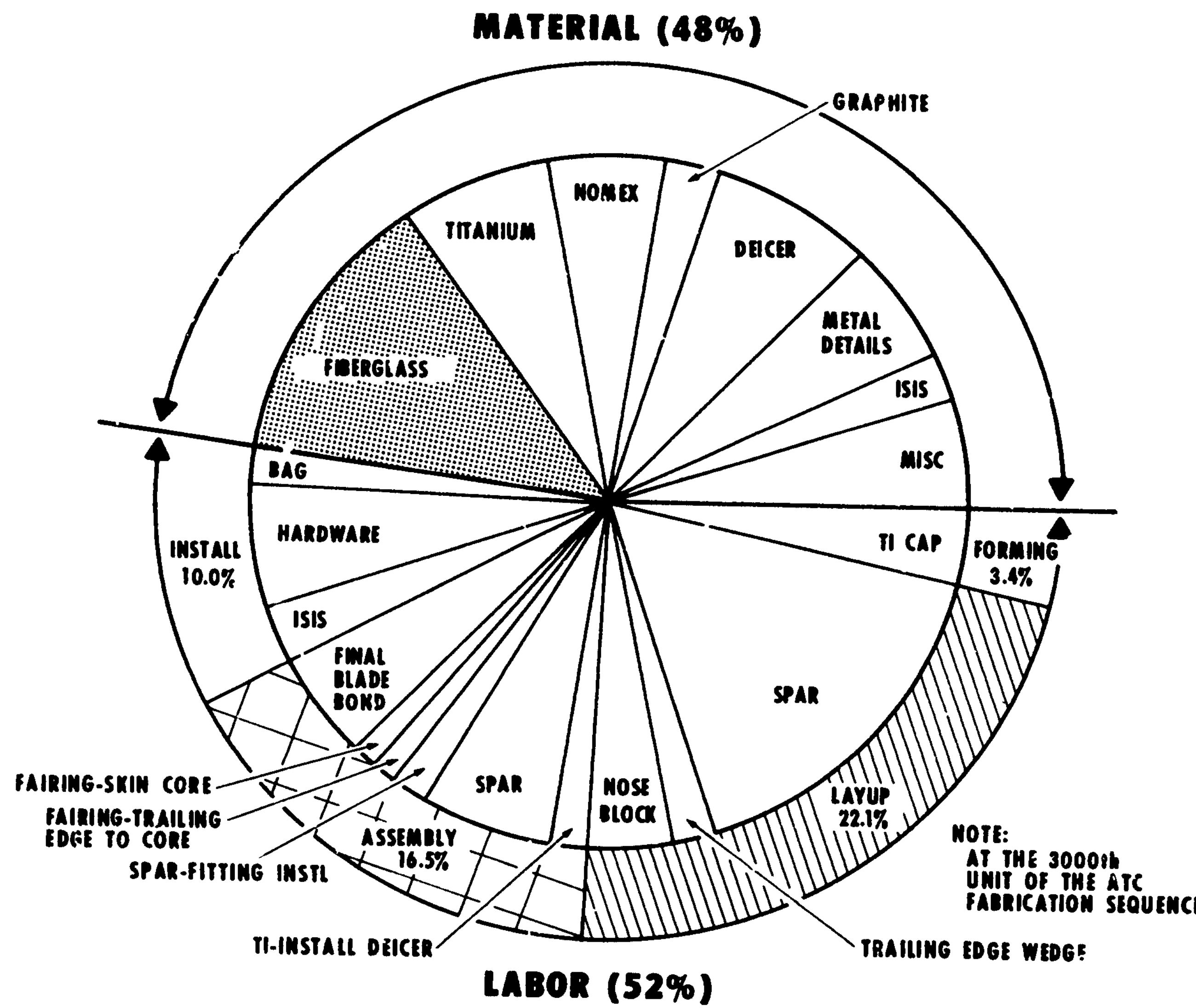

Figure 7. Incremental material and labor breakdown, HLH rotor blade.

For the rotor hub, which is the second major component of the rotor system, there appears to be a direct correlation between its cost and its number of parts. In this case, use of designs (such as an elastomeric bearing hub) or concepts (such as a rigid rotor) that significantly reduce parts count should result in lower hub cost.

Power Plant

The production cost breakdown for a typical current helicopter turbine engine shows that the high-cost components are the compressor, turbine, and accessories, as shown in Figure 8, which was taken from Reference 5. The data are based on cost data solicited from the major gas turbine engine manufacturers. Compressor cost is strongly influenced by compressor type, such as centrifugal, axial-centrifugal, and axial, and its number of stages; the cost does not appear to be a function of engine horsepower. As with the compressor, the turbine cost is a function of its number of stages. Normally, the turbine cost increases with increasing engine horsepower. The fuel control is the major cost contributor among the accessories, accounting for as much as 65 percent of accessory cost. The next most significant contributors include fuel and lube pumps and associated filters.

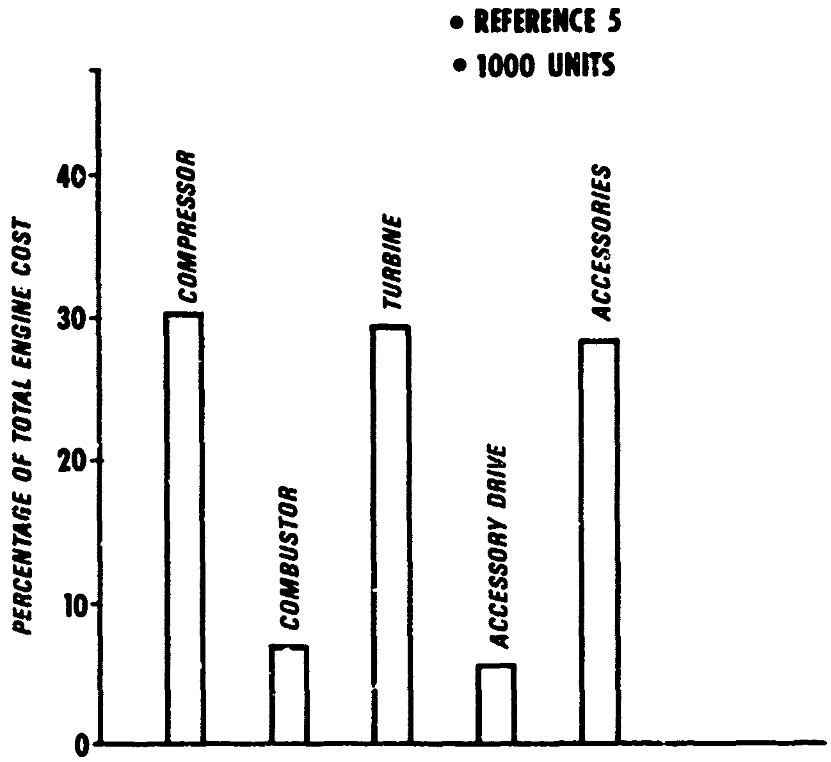

Figure 8. Average component cost in percentage of total engine cost

[5] David B. Cale, *Turbine Engine and Turbine Engine Component Cost*, USAAVLABS Technical Report 68-59, U.S. Army Aviation Materiel Laboratories, Fort Eustis, Virginia, July 1968, AD 838413L.

On the average, the material cost for turbine engines is four times the labor cost, reflecting considerable outside production of components such as compressors, fuel control, and turbine blades. However, this ratio varies significantly among manufacturers, from as high as 14:1 to as low as 2:1. Overhead cost, when separated from material and labor cost, is very significant, accounting for an average of 29 percent of the engine production cost.

Based on a recent engine cost reduction study,[6] a 10-percent reduction in engine acquisition cost will be achievable during the 1980 time frame through the application of currently available advanced technology components such as reduced stage compressors and turbines. A 25-percent reduction in engine acquisition cost for the 1985 time frame is considered to be achievable through continued advanced component development, coupled with the use of advanced materials such as composites and ceramics, and further development of low-cost fabrication techniques.

Transmission

The material and labor breakouts for transmission cost, which on the average account for 9 percent of the aircraft production cost, are 13 and 87 percent respectively. The material cost is for the actual constituent materials comprising the transmission. The major activities making up the labor cost are fabrication, which is 97 percent of this cost, and assembly, which is 3 percent. Generally, the majority of the helicopter airframe manufacturers subcontract fabrication of major subcomponents such as castings, gears, and bearings to outside vendors.

Relating helicopter transmission cost to weight and output shaft torque was attempted in Reference 7; however, no close correlation was achieved. The author attributed this to the fact that the cost data for different transmissions was supplied in a variety of ways since there is no standard method of accounting used by the helicopter manufacturers. Also, the data failed to consider factors such as number of units produced and workload at the time of purchase.

Some of the variables identified in Reference 2 require further study to assess their impact on transmission cost:

- Number of parts
- Tolerances
- Special processes
- Number of machining operations
- Specifications

[6]T.D. Balliett, *Reduced Cost Concepts for Gas Turbine Engines*, USAAMRDL Technical Report (to be published), Eustis Directorate U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia.

[7]J.D. Conboy, *State of the Art Review of Helicopter Transmission, Turboprop Gearboxes, and Lubrication Thereof*, Aeronautical Engine Laboratory, NAEC-AEL-1849, U.S. Naval Air Engineering Center, February 1967.

Weight
Horsepower
Reduction factor
Inspection requirements

OPERATING COST

For the purpose of this study, helicopter operating cost was broken out into three areas. These areas and their typical contribution to operating cost are shown in Table 5. Direct support maintenance is comprised of two major areas: field labor, which accounts for approximately 70 percent, and parts (both overhauled and new), which accounts for the remaining 30 percent. Depot labor is included in the cost of overhauled parts. Consumables include fuel, oil, and lubricants, which, for this study, were based on November 1974 prices. Personnel cost includes salary and training for the flight crews. Since direct support maintenance is the most significant contributor to helicopter operating cost, focus was placed on this area for the study.

TABLE 5. HELICOPTER OPERATIONAL COST

COST CONTRIBUTOR	OPERATIONAL COST (%)
DIRECT SUPPORT MAINTENANCE	75
CONSUMABLES	15
PERSONNEL	10

Typical direct support maintenance cost in dollars per flight hour, for Army helicopters ranging from a small observation type with a design gross weight of 5,000 pounds to a heavy lift transport type with a design gross weight of 122,500 pounds, is shown in Table 6. There appears to be a direct relationship between the dollar per flight hour maintenance cost and the helicopter design gross weight. Although dollars per flight hour is a widely used method of representing helicopter maintenance cost, caution should be taken when using it since it depends highly on the aircraft use, which varies not only between different aircraft systems but also within a particular system depending on its mission deployment.

TABLE 6. COMPARATIVE HELICOPTER DIRECT SUPPORT MAINTENANCE COST ESTIMATES

AIRCRAFT	DOLLARS PER FLIGHT HOUR	DESIGN GROSS WEIGHT (LB)
CH-54	1120	38,000
CH-47	1002	33,000
AH-1G	250	9,500
UH-1	260	9,500
OH-58	155	3,000
HLH*	3000-4000	122,500

*ADVANCED DEVELOPMENT STATUS

The direct support maintenance cost breakout by components for the CH-47 cargo helicopter is presented in Table 7. As can be seen, the major contributors are the rotor system, the power plant, and the transmission. These cost areas account for over two-thirds of the direct support maintenance cost and are typically the three high-cost areas for other helicopters, although the relative ranking of the three may change from system to system. As an example, for the UH-1 helicopter the power plant is the highest cost maintenance component, with the rotor system ranking second and the transmission third. Also, the table shows that inspections, which include daily and periodic, account for almost 10 percent of the total field and depot maintenance cost. Although the direct support maintenance cost for the airframe (excluding depot maintenance) is less than 5 percent of the total, over 50 percent of this maintenance cost is directly related to fasteners (rivets and screws) and secondary structures (fairings, panels, doors, windows, and work platforms). The three major cost-contributing components are discussed in subsequent paragraphs.

TABLE 7. CH-47 FIELD AND DEPOT MAINTENANCE COST ESTIMATES[8]

AIRCRAFT GROUP	COST (%)	DOLLARS PER FLIGHT HOUR
ROTOR	28.8	288.82
POWER PLANTS	27.4	274.98
TRANSMISSION	11.5	114.96
AIRFRAME*	4.7	47.11
AUXILIARY POWER UNIT	4.7	46.64
FLIGHT CONTROL	3.1	31.10
HYDRAULIC	2.2	22.47
INSPECTIONS	9.4	93.92
OTHER	8.2	81.81
TOTAL	100.0	1,001.81

*DOES NOT INCLUDE DEPOT MAINTENANCE

[8] *Executive Summary Report, CH-47 Assessment and Comparative Fleet Evaluation,* USAAVSCOM Technical Report 74-46, Systems Performance Assessment Division, U.S. Army Aviation Systems Command, St. Louis, Missouri, November 1973.

Rotor System

Typically, the rotor blades account for 80 percent of the total rotor system direct support maintenance cost; the hub accounts for the remaining 20 percent. High maintenance cost within the rotor hub is related to seal problems resulting in fluid and lubricant leakage. A major thrust to resolve this high maintenance area has been to improve seal techniques and to use new components such as elastomeric and dry lubricant bearings that eliminate sealing requirements.

Typically, the major cost contributor for the rotor blade is externally induced damage caused by foreign objects such as sand, rocks, and trees (Table 8). Material deterioration (cracking), combat damage, and overstressing during severe maneuvers and hard landings account in equal proportions for nearly 30 percent of maintenance cost. Because of the large number of adhesively bonded areas inherent to the metal rotor blades, coupled with the frequent difficulty in achieving a good bond in these areas at manufacture, debonding is a contributor to maintenance cost. Other cost contributors include corrosion, blade imbalance (excessive vibration), and removal of blades for time change. The rotor blades currently in the Army's inventory are not highly repairable; statistics show that about one-half of all the blades removed are subsequently scrapped. Because of the severe external environment and poor blade repairability characteristics, only 2 to 5 percent of all rotor blades on Army helicopters reach their retirement life.

TABLE 8. ROTOR BLADE DIRECT SUPPORT MAINTENANCE COST CONTRIBUTORS[9]

CONTRIBUTOR	COST (%)
FOREIGN OBJECT DAMAGE	44
CRACKING	9
COMBAT DAMAGE	9
OVERSTRESS/STRIKES	9
DEBONDING	6
OTHER	23
TOTAL	100

[9] Royace H. Prather, *Army Helicopter Rotor Blade Failure and Maintenance Experience*, presented at the Army Helicopter Reliability and Maintainability Symposium, Williamsburg, Virginia, November 1973.

It is believed that composite materials offer a great potential for reducing rotor blade maintenance cost. Because of the inherently better damage-tolerance characteristics of composites over metals, and their significantly improved repairability, increased use of composites in the damage-susceptible blade areas, such as the skins and spar, can as much as halve blade maintenance cost.

Power Plant

The major contributors to power plant direct support maintenance cost are listed in Table 9. As can be seen, power plant maintenance cost is not significantly driven by one particular item but, rather, by an accumulation of many small items. Some 25 items make up the "other" contributor, and each is less than 4 percent. This makes improvement programs difficult, since there is no one strong contributing area that can be addressed. However, some of the anticipated changes to the power plant to lower acquisition cost, such as advanced technology components having fewer stages and made of advanced materials, should inherently improve maintenance characteristics (fewer parts, less complex tooling, etc.) and hence lower operating cost. As shown, the most significant cause for engine

TABLE 9. POWER PLANT DIRECT SUPPORT MAINTENANCE COST CONTRIBUTORS[10]

CONTRIBUTOR	COST (%)
FOREIGN OBJECT DAMAGE	11
IMPROPER MAINTENANCE	8
CARBON SEAL LEAKAGE	6
EROSION	5
FUEL CONTROL	4
OPERATOR INDUCED DAMAGE	4
COMPRESSOR BLADE/DISC FATIGUE	4
OTHER	58
TOTAL	100

[10] G.J. Rummel and H.J.M. Smith, *Investigation and Analysis of Reliability and Maintainability Problems Associated With Army Aircraft Engines*, USAAMRDL Technical Report 73-28, Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, August 1973, AD 772950.

maintenance is foreign object damage, which includes ingestion of sand, rocks, nuts, bolts, and tools. It is also significant to note that almost 10 percent of all power plant maintenance cost is associated with improper maintenance, which includes engine removal due to maintenance errors and improper diagnosis. It should be further noted that these two highest contributors (totaling approximately one-fifth) to the power plant maintenance cost have little to do with the engine design per se. In fact, about 60 percent of all engine maintenance cost is nonengine caused.

Transmission

Today, about 60 percent of the maintenance cost on the transmission is for scheduled overhauls. Because of this, efforts are currently under way to establish rational criteria for on-condition maintenance. This involves operating without the need for mandatory scheduled removals and overhauls of helicopter transmissions and engines. Extending or eliminating the time between overhauls (TBO) on a rational basis can result in significant maintenance cost savings, with minimum, if any, expenditure for hardware modification.

The causes for unscheduled removals of the transmission for maintenance are listed in Table 10. The single biggest contributor is removal/replacement of worn and deteriorated bearings, the need for which is primarily caused by overloads/stresses on the bearings due to excessive case deflections, as opposed to inadequate lubrication. This also holds true for the high removal/replacement rates for the gears. Hence, the two most significant contributors to unscheduled transmission maintenance are engineering design type problems.

TABLE 10. TRANSMISSION DIRECT SUPPORT MAINTENANCE COST CONTRIBUTORS [11]

CONTRIBUTOR	COST (%)
BEARINGS	45
GEARS	23
RETENTION AND MOUNTING HARDWARE	15
NONROTATING STRUCTURE	5
OTHER	12
TOTAL	100

[11] *Major Item System Study (MISS) UH-1H Transmission Assembly, Period Covered by Jan 1, 1964 Thru June 30, 1970,* Systems Engineering Directorate, U.S. Army Aviation Systems Command, St. Louis, Missouri.

An effective means of reducing the Army's helicopter operating cost in these areas is to improve the system reliability and maintainability through increased effort in the development phase of a helicopter program. This approach has been strongly emphasized in the UTTAS development program, where extensive testing is being conducted to achieve required reliability levels prior to fielding the aircraft, and increased emphasis is being placed on maintainability through design use which permits ease of inspection/accessibility, disassembly, and straightforward repair techniques. Although the initial cost will be higher, it is believed that this approach will result in reduced operating cost for the UTTAS fleet and an overall lower life-cycle cost than would be achieved through improving the reliability and maintainability through Engineering Change Proposals (ECP's).

COST STUDY LIMITATIONS

It became evident from this brief study that data on acquisition and operating costs for Army helicopters are, at best, spotty and inaccurate. For acquisition cost, there are two major deficiencies. First, the cost for a given helicopter system is not available in enough detail for an in-depth analysis to define, understand, and quantify the cost drivers. For helicopters currently in the Army's inventory, the cost for major components such as airframe, rotor, and transmission was generally not readily available from the manufacturer. This situation has resulted primarily from inadequate emphasis, by both the Government and the contractor, on cost tracking and awareness in past programs. With design-to-cost as an integral part of the latest major Army helicopter programs, such as UTTAS and AAH, more in-depth tracking of component fabrication cost and component cost drivers should be achieved. Second, there is definitely a lack of a common baseline for production cost because cost accounting techniques vary among manufacturers. For example, a material cost to one manufacturer may not be accounted for as a material cost to another manufacturer.

For operating cost, the data also appear to be inconsistent and conflicting. Once again, this is primarily due to the absence of a common baseline and uniform ground rules for cost accounting. As an example, one source of information may consider overhauled parts in determining the maintenance cost and a second source may not.

To date, the information on the life-cycle cost of Army helicopters is very limited, and the Army's ability to predict life-cycle cost contains considerable room for improvement. In light of the deficiencies in helicopter cost understanding discussed above, this is not surprising. Only with increased cost awareness and emphasis on improving cost tracking techniques will life-cycle data and prediction capability improve to a truly useful level.

COMPOSITE MATERIAL APPLICATION CONSIDERATIONS

In recent years investigations have been made into the application of composite materials as primary structure in the helicopter, considering such components as main and tail rotor blades, airframe, tail rotor drive shafting, and flight controls. The materials most commonly considered have been fiberglass, boron, graphite, and Kevlar 49, all in an epoxy matrix. The data base for the acquisition cost of helicopter composite structures is limited because only a few items have been manufactured and many production manufacturing methods for composite structures are still being developed. Based on the data that are available, however, it appears that composite materials do offer the potential for reduced component acquisition cost over conventional metallic designs. Figure 9 shows that the current cost per pound for composites is generally much higher than that for metals; although the trend for 1978 is for decreasing composite cost and increasing metal cost, composite cost will still remain higher. The area that enables composite structures to be competitive in acquisition cost is the fabrication of the component. The fact that composite structures are highly amenable to automated fabrication techniques such as filament winding and automatic tape layup, coupled with the potential for significant reductions in parts count, which reduces assembly time and essentially eliminates rivets, will allow an overall cheaper fabrication process than that obtainable with metals. Composites are more amenable to adhesive bonding and combined operations. Also, scrap material (material cut away in making the final component) for metals runs on the average of 35 percent for metallic aircraft components and 10 percent for composites.

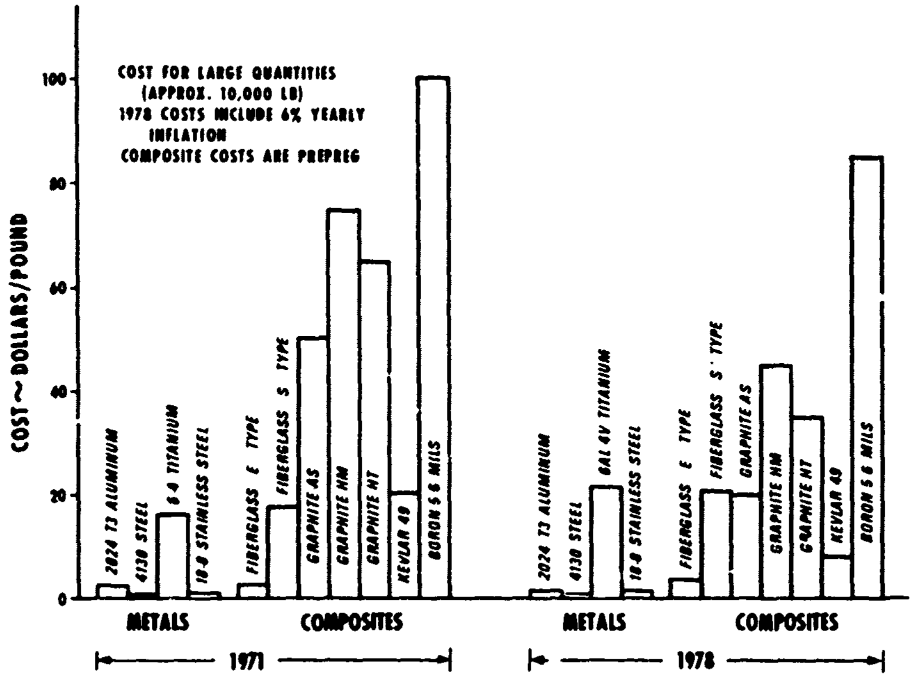

Figure 9. Material cost.

As with acquisition cost, there is very little data available to indicate how the operating cost for composite helicopter structures will compare with that of existing metal design. Based on a limited data base established through R&D programs on composite repairability, damage tolerance, failure characteristics, and in-service experience, operating cost should be reduced with composite structures due primarily to improvements in the following areas.

Reliability and Maintainability: Increased reliability results primarily from a reduction in parts count, a reduction in the number of mechanical fasteners, improved damage tolerance of the materials, increased component fatigue life, and reduced corrosion tendencies. The high degree of repairability for composites, as already demonstrated in the repairable rotor blade program for the UH-1, shows that maintenance characteristics for composite blades are superior to those of metal. Composite structures tend to be much more field repairable in that it is possible to repair larger defects in the field; also, repair kits and operations are simpler.

Safety and Survivability: Composite materials are relatively notch insensitive and offer the potential for significantly improved ballistic and foreign object damage tolerance. These improvements are achieved through the judicious selection of damage-tolerant materials such as fiberglass and PRD-49 and the application of unique construction concepts such as geodesic and mixed material designs that are viable only with composite materials.

Improved Aircraft Performance: Composite structures can be structurally and geometrically tailored to complex shapes, thus yielding improved aerodynamic performance and increased structural life of the rotor system.

FINDINGS

ACQUISITION COST

1. Production cost constitutes approximately one-fifth of the total life-cycle cost.

2. Very limited data are available for breaking out production cost of helicopters according to major components.

3. Airframe, engine, and avionics normally are the major helicopter production cost drivers.

4. Approximately 90 percent of the airframe production cost is for labor. Factors that affect airframe cost include parts count, fastener and rivet count, riveting techniques, component manufacturing techniques, and number of manufacturing operations.

5. The high-cost components for the power plant are the compressor, turbine, and accessories, each accounting for close to 30 percent.

OPERATING COST

1. On the average, operating cost runs three to four times the combined development and acquisition cost for the system. The single highest contributor to a helicopter's life-cycle cost is the direct support maintenance cost, which accounts for approximately 60 percent.

2. The rotor system, power plant, and transmission are the major maintenance cost drivers.

3. Improvements are needed in the repairablility of rotor blades. Approximately one-half of all rotor blades removed are scrapped, and only 2 to 5 percent of all blades go to their retirement life.

4. Over 50 percent of all airframe maintenance is related to fastener/secondary structures.

5. Power-plant maintenance cost is not driven by one major contributor but rather by an accumulation of more than 30 small items. The most common cause for engine maintenance is foreign object damage (11 percent of the total).

6. Approximately 60 percent of transmission maintenance cost is for scheduled overhauls. Bearings and gears are the major contributors to unscheduled maintenance cost.

RECOMMENDATIONS

As a result of this study, it is recommended that:

1. In subsequent programs encompassing R&D advanced development through engineering development, more emphasis be placed on component cost definition and component cost tracking, and universal cost tracking outline charts be developed for cost analysis and tracking activities to ensure commonality of data among contractors. These charts should be developed for the major helicopter subcomponents such as airframe, engine, transmission, rotor system, avionics, and subsystems, and should include certain minimum variables to be measured and employed in all programs.

2. Helicopter cost contributors be accurately defined at the component/subsystem levels. This data should be assembled by the Government, presented as Cost Estimating Relations (CER's), industrial engineering data, or a combination of both, and disseminated to industry.

3. Cost awareness and design-to-cost be emphasized in the design phase of component/subsystem development. As has been emphasized in numerous publications dealing with design-to-cost, the designer should be provided cost contributing data and associated cost target values.

4. The use of low-cost manufacturing techniques such as automatic riveting, precision (no-draft) forging, numerical control machining, and chem-milling be increased.

5. Maximum use be made of designs having fewer parts and fastener counts, components be designed to minimize the number of handling and machining operations, and materials be judiciously selected and standarization used where possible

6. Communication and coordination between the engineering (designer) and manufacturing groups be increased.

7. A design cost guide be developed for major helicopter components/subsystems, with both metal and composite materials being considered.

8. For helicopter operating cost reductions, helicopter system reliability be increased through increased efforts in the program development phase, and system maintainability be improved through the use of designs that permit ease of inspection, accessibility, disassembly, and straightforward repair procedures.

9. From statistical analysis of in-service data, a rational basis be established for extending, to the maximum extend possible, scheduled overhaul periods (especially for the power plant and transmission) without compromising the flight safety of the aircraft.

10. Because composite materials have been previously demonstrated to be cost effective in certain applications, and since numerous production manufacturing techniques for composites are under development, the use of these materials be considered for reduced cost of both primary and secondary structural components.

REFERENCES

1. Marchinski, L. J., *Design Studies To Reduce Airframe Costs by Quantifying Design Factors That Drive Cost*, Boeing Vertol Company, Naval Air Development Center Contract N62269-73-C-0312, October 1973.

2. Marchinski, L. J., *Design to Cost at Work for Helicopter Systems*, presented at the 30th Annual National Forum of the American Helicopter Society, Washington, D. C., May 1974.

3. Minutes From *HLH ATC/Prototype Program 11th Quarterly Review With Program Management*, presented at Boeing Vertol Company, Philadelphia, Pennsylvania, 30 May 1974.

4. *HLH Rotor Blade Manufacturing Technology Development Report*, D301-10280-1, Boeing Vertol Company, Philadelphia, Pennsylvania, 1974.

5. Cale, David B., *Turbine Engine and Turbine Engine Component Cost*, USAAVLABS Technical Report 68-59, U. S. Army Aviation Materiel Laboratories, Fort Eustis, Virginia, July 1968, AD 838413L.

6. Balliett, T. D., *Reduced Cost Concepts for Gas Turbine Engines*, USAAMRDL Technical Report (to be published), Eustis Directorate, U. S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia.

7. Conboy, J. D., *State of the Art Review of Helicopter Transmission, Turboprop Gearboxes, and Lubrication Thereof*, Aeronautical Engine Laboratory, NAEC-AEL-1849, U. S. Naval Air Engineering Center, February 1967.

8. *Executive Summary Report, CH-47 Assessment and Comparative Fleet Evaluations*, USAAVSCOM Technical Report 74-46, Systems Performance Assessment Division, U. S. Army Aviation Systems Command, St. Louis, Missouri, November 1974.

9. Prather, Royace H., *Army Helicopter Rotor Blade Failure and Maintenance Experience*, presented at the Army Helicopter Reliability and Maintainability Symposium, Williamsburg, Virginia, November 1973.

10. Rummel, K. G., and Smith, H. J. M., *Investigation and Analysis of Reliability and Maintainability Problems Associated With Army Aircraft Engines*, USAAMRDL Technical Report 73-28, Eustis Directorate, U. S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, August 1973, AD 772950.

11. *Major Item System Study (MISS) UH-1H Transmission Assembly, Period Covered by January 1, 1964 through 30 June 1970*, Systems Engineering Directorate, U. S. Army Aviation Systems Command, St. Louis, Missouri.

12. Dougherty, J. J., III, and Blewitt, S. J., *Analysis of Criteria for On-Condition Maintenance for Helicopter Transmissions*, USAAMRDL Technical Report 73-58, Eustis Directorate, U. S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, September 1973, AD 773024.