A NEW ROTORCRAFT DESIGN FRAMEWORK BASED ON RELIABILITY AND COST

A Thesis
Presented to
The Academic Faculty

by

Robert Scott

In Partial Fulfillment
of the Requirements for the Degree
Doctor of Philosophy in the
School of Aerospace Engineering

Georgia Institute of Technology
August 2016

A NEW ROTORCRAFT DESIGN FRAMEWORK BASED ON RELIABILITY AND COST

Approved by:

Dr. Daniel P. Schrage, Advisor School of Aerospace Engineering *Georgia Institute of Technology*	Dr. Dimitri Mavris School of Aerospace Engineering *Georgia Institute of Technology*
Dr. Lakshmi N. Sankar School of Aerospace Engineering *Georgia Institute of Technology*	Dr. Lance N. Fiondella School of Electrical and Computer Engineering *University of Massachusetts - Dartmouth*
Dr. Apinut Sirirojvisuth School of Aerospace Engineering *Georgia Institute of Technology*	

Date Approved: July 13, 2016

TABLE OF CONTENTS

CHAPTER

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

A_o	Operational availability
APUC	Average procurement unit cost
BY	Base year
C_{LCC}	Total life-cycle cost
$C_{RDTE,RAM}$	Development cost related to RAM improvement
C_{OS}	Life-cycle operation and support cost
C_{proc}	Life-cycle procurement cost
c_{proc}	Unit procurement cost
CER	Cost estimating relationship
d	Annual discount rate
D	Design & assessment vehicle characteristics array
DGW	Design gross weight, (lb)
DL	Disk loading, (lb/ft^2)
DMC, c_{maint}	Direct maintenance cost ($/FH)
DOC, c_{OS}	Direct operating cost ($/FH)
f_{H-S}	Harris-Scully size factor
FM	Figure of Merit
FY	Fiscal Year
H	Design & assessment technology parameters array
i	Annual inflation rate
k	Reliability correction factor
L/D_e	Lift to equivalent drag ratio
$LCC/LCC_{baseline}$	Life-cycle cost ratio

LCF	Learning curve factor
MMH/FH	Maintenance man-hours per flight hour
MTBMA	Mean time between maintenance actions (flt. hrs.)
MTOW	Maximum takeoff weight (lb)
$N_{a/c}$, n	Number of production aircraft
$N_{acq\ yrs}$	Number of acquisition years in production
N_{eng}	Number of production engines
N_{FH}	Life-cycle flight hours
$N_{LC\ yrs}$	Fleet life-cycle years
N_{maint}	Number of maintainers per aircraft
NDARC	NASA Design and Analysis of Rotorcraft Code
OEC	Overall evaluation criterion
OPR	Operational rate ratio
O&S	Operating and Support
PI	Productivity Index
Pr_{avg}	Average pressure ratio per turboshaft compressor stage
R	Design & assessment requirements array
RAM	Reliability, Availability, and Maintainability
ROI	Return on investment
SHP_{inst}	Installed horsepower
SP	Specific power (hp / $\mathrm{lb_m}$)
T	Thrust (lb)
TBO	Time between overhaul (flt. hrs.)
VTOL	Vertical takeoff and landing
WE	Weight Empty, (lb)

W_{fuel}	Fuel weight (lb)
W_{pay}	Payload weight (lb)
Yr_{BE}	Break-even year
κ_{FADEC}	FADEC complexity factor
κ_{Mar}	Marinization complexity factor
α	Response surface coefficient
λ	Response surface ratio parameter
ρ	Air density (slug/ft^3)
χ	Technology Factor

SUMMARY

A new approach to the conceptual design of rotorcraft is presented which incorporates cost and reliability assessment methods to address the cost premium historically associated with vertical flight. The methodology provides a new analytical capability that is general enough to operate as a tool for the conceptual design stage, but also specific enough to estimate the life-cycle effect of any RAM-related design technology which can be quantified in terms of weight, power, and reliability improvement.

Helicopters provide essential services in civil and military applications due to their multirole capability and operational flexibility, but the combination of the disparate performance conditions of vertical and cruising flight presents a major compromise of aerodynamic and structural efficiency. In reviewing the historical trends of helicopter design and performance, it is apparent that the same compromise of design conditions which results in rotorcraft performance challenges also affects reliability and cost through vibration and fatigue among many possible factors. Although many technological approaches and design features have been proposed and researched as means of mitigating the rotorcraft affordability deficit, the assessment of their effects on the design, performance, and life-cycle cost of the aircraft has previously been limited by the nature of parametric cost models. Since they are based on statistical regressions of prevailing design trends in a fleet not representative of the new technology in question, manual adjustment is required to account for the new effects.

To address this analytical shortcoming, a multidisciplinary conceptual design framework is created which combines aspects of multiple cost and reliability models – some newly developed and some surveyed from literature. The key feature distinguishing the framework from contemporary design and assessment methods is its ability to use reliability as a design input in addition to the flight conditions and missions used as sizing points for the aircraft. The methodology is first tested against a reference example of reliability-focused technology insertion into an existing rotorcraft platform. Once the approach is validated, the framework is applied to an example problem consisting of a technology portfolio of technology and advanced rotorcraft configurations and a set conditions representative of capabilities desired in near-future joint service, multirole rotorcraft. The framework sizes the different rotorcraft configurations for both a baseline set of assumptions and a tradespace sweep of reliability investment to search for an optimum design point corresponding to the level of technology insertion which results in the either the lowest overall life-cycle cost or the highest value depending on the assumptions used for the aircraft life-cycle scenario.

The study concludes by discussing the results of the reliability tradespace investigation and their implications for future rotorcraft development and procurement programs. An overview of further applications related to business case analysis, probabilistic methods, and risk assessment is also provided to show how the tool could be used in the future to inform actual acquisition programs.

CHAPTER 1

INTRODUCTION

Rotorcraft are challenged from the perspective of reliability and cost relative to other forms of aviation. Although rotorcraft possess a unique set of capabilities including vertical takeoff, hover, and safe and maneuverable low speed flight, these qualities come at the expense of higher total ownership costs and higher rates of down time due to maintenance. In nearly every possible operating condition, and according to nearly every metric of cost effectiveness and reliability, rotorcraft fall far short of fixed wing aircraft. This discrepancy in life-cycle costs between rotorcraft and other forms of transportation must be mitigated if vertical flight is to realize its full potential. Reduced costs could lead to a more expansive and effective use of rotorcraft in the roles for which they are already utilized, and would also encourage expansion of VTOL flight into new mission roles. In this study, the reduction of cost to a level which facilitates new acquisition and added operational capabilities is referred to as affordability.

An inherent hypothesis of many integrated design methodologies is that the operational interests receiving the earliest attention in the design of an aircraft will tend to be most fulfilled by the machine which is ultimately built and flown. Many alternative rotorcraft configurations have been conceptualized around the priority of improving overall effectiveness by increasing the cruise efficiency beyond that of the conventional single main rotor helicopter without sacrificing hover and low speed capability. These concepts almost invariably add complexity to the aircraft, and the few examples which have been successfully brought to at least a low level of production and fielding have exhibited lower reliability and higher operating costs.

Although reliability is often a stated design requirement, little has been done to quantify the performance and cost impact to a conceptual aircraft if reliability is actually used as a design constraint. The limited operational history of non-conventional rotorcraft configurations has proven that concepts which trade reliability for performance rarely experience broad acceptance in the VTOL aviation community. With renewed interest in alternative configurations which promise to increase overall mission capability and value, there is increasing need for a preliminary design framework capable of weighing the reliability implications which accompany increased complexity versus reliability investment.

An aircraft sizing and concept evaluation methodology is proposed to highlight the competing effects of performance and complexity. To accomplish this, a new objective technology assessment **i**ntegrating price, performance, and design is proposed. The framework features a new parametric model of helicopter mission reliability which is used to develop an availability expression with an assumption of current maintainability technology. The maintenance model is integrated into a full life-cycle cost model and coupled to a rotorcraft sizing tool such that both cost and availability outputs can be iterated upon within the design framework until a user-specified set of overall evaluation criteria or benefit to cost ratios are satisfied. The principle outcomes envisioned for this effort include a quantification of the effects on aircraft size using availability as design constraint, and a methodology for the evaluation of rotorcraft technology in terms of performance, cost (total ownership, RDTE, procurement, and/or O&S), availability, or overall system effectiveness. Additionally, the application of the quantifying relationships is applied to a rotorcraft life-cycle analysis case in order to demonstrate the impact of the new analytical to consideration of rotorcraft programs *in the year 2000*.

Rotorcraft Performance Challenges

The motivation for a cost and reliability-based design methodology arises from a well-documented challenge to building and operating aircraft with vertical lift capability. Rotorcraft have demanded a steep life-cycle cost premium in exchange for VTOL capability throughout the history of aviation. Comparing the current list prices of light to medium helicopters against light to medium fixed wing aircraft shown as shown in Figure

1-1 suggests that this premium is roughly between 100 and 200 percent above the cost of comparable fixed wing aircraft at today's level of design technology.

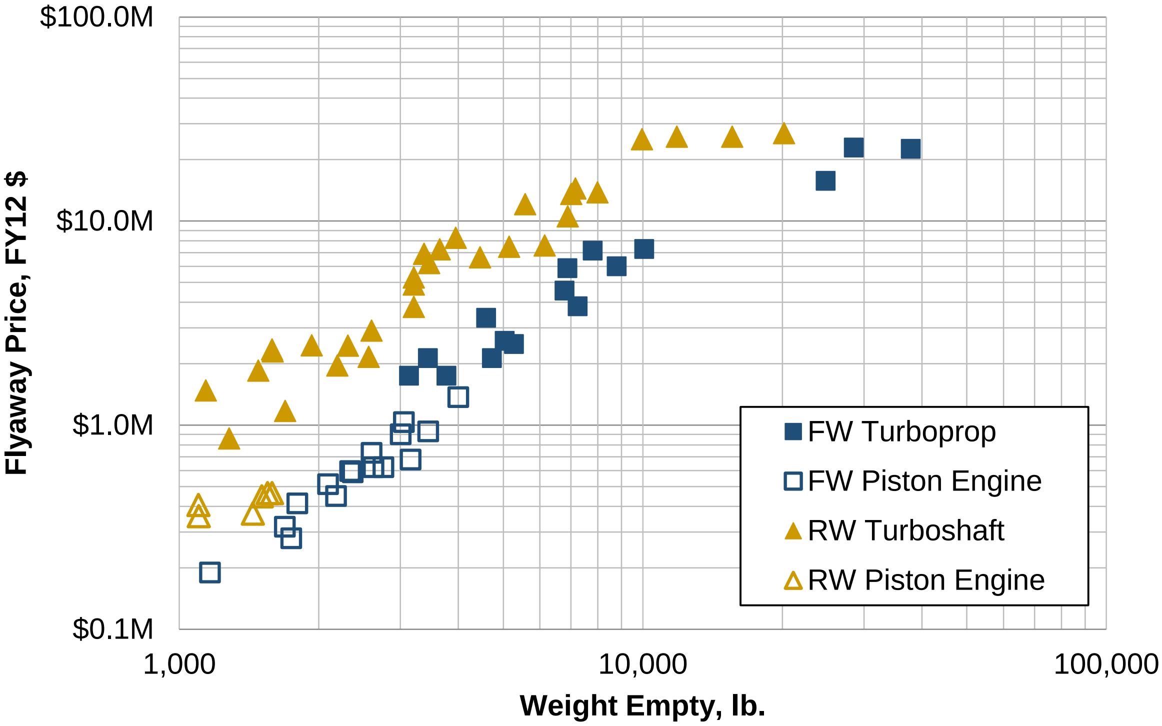


Figure 1-1. Comparison of current list prices in fixed wing (FW) and rotary wing (RW) piston and turboshaft powered aircraft.

Due to the nature of VTOL flight, a new analytical capability specifically designed to investigate rotorcraft cost challenges will likely require practical and theoretical bases spanning multiple rotorcraft disciplines. Accordingly, the study begins with a review of the historical works which have documented rotorcraft cost trends and proposed affordability solutions which can quantified into a conceptual design framework. The starting point of this research is thus a restatement of the frequently examined problem:

Research Question 1: What drives rotorcraft total ownership cost?

The aggregate knowledge of almost 90 years of helicopter aeromechanical analysis has established a thorough physics-based explanation of why the design of an efficient vertical takeoff and landing aircraft presents a tremendous engineering challenge. By contrast, the linkage of aeromechanical challenges to the concepts of affordability, and specifically the effect of aircraft reliability on affordability in rotorcraft is a relatively immature course of analysis. The primary goal of this project is to rectify this deficiency in analytical capability. In order to do so, the new rotorcraft design methodology must include physical and empirical models relating reliability, availability, and maintainability (RAM) to aircraft design and performance in the same way such characteristics are related design requirements in a traditional design procedure. The accompanying objective of the project is to apply the RAM-augmented process to a topical design problem and observe the life-cycle cost implications of designing a highly reliable rotorcraft beginning at the conceptual stage with an aim to improve to cost effectiveness of the rotorcraft.

The challenge to producing a cost effective rotorcraft begins with the uniquely stressing design conditions which define VTOL flight. A conceptual aircraft design may be thought of as a solution to a set of equations representing airframe weight, fuel, power, and geometry. The independent variables in the equations represent the required performance conditions, referred to sizing conditions. For rotorcraft, the distinguishing condition is vertical flight. When considering basic hover performance, a helicopter designer is primarily concerned with three interrelated variables: disc loading, power loading, and figure of merit. From momentum theory (Ref. 1-1), the equation relating these quantities can be derived as:

$$\mathrm{FM} = \frac{\mathrm{T}}{\mathrm{P}}\sqrt{\frac{\mathrm{DL}}{2\rho}} \qquad (1-1)$$

Eqn. 1-1 formalizes the inherent rotorcraft performance challenge. Even for an ideal figure of merit, the hovering rotor requires a large amount of power. As long as vertical flight capability is included as a sizing condition, the aircraft will represent a compromise between two extremely different constraints. Plotting power loading (T/P) from Eqn. 1-1 as a function of disc loading (DL) in Figure 1-2 shows this compromise is manifest as high installed power. Plotting lines of constant figure of merit in Figure 1-2, the best design strategy for reducing the installed power required seems to be a reduction in disc loading.

This approach is effective only up to practical limit though because it increases the operational footprint of the aircraft and results in bigger and heavier rotor systems which will also perform less efficiently in forward flight due the parasite drag of the larger hub and the profile drag of the additional blade area.

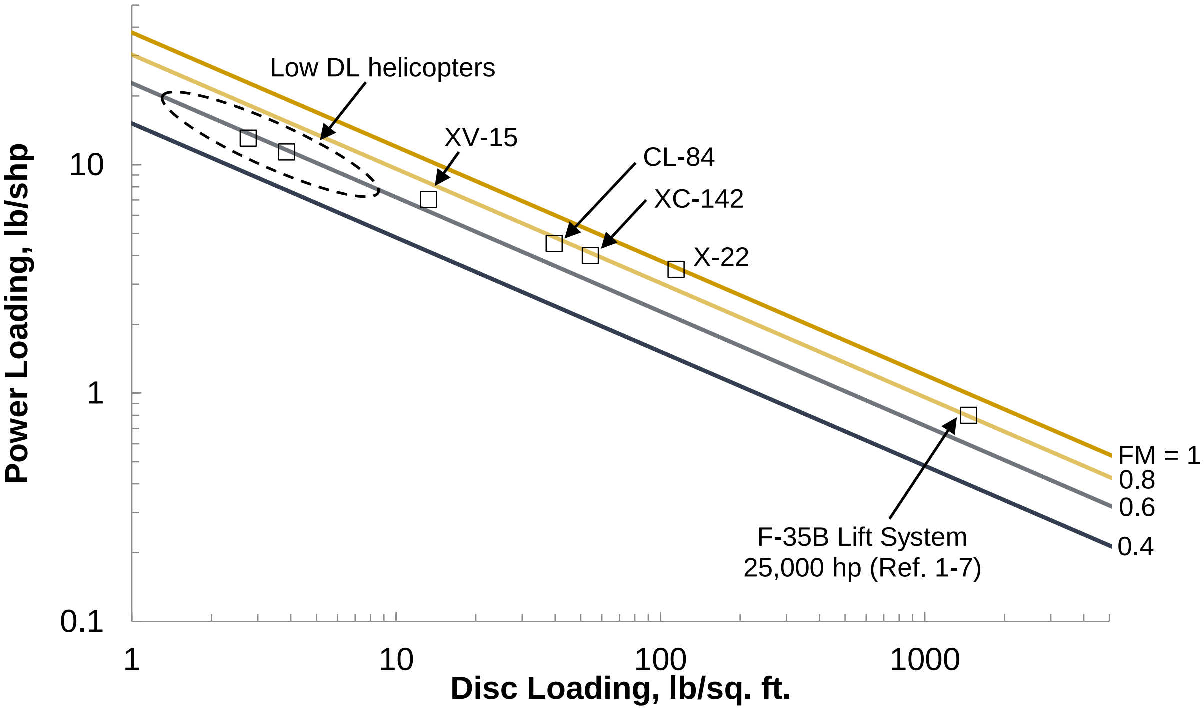


Figure 1-2. VTOL power loading trends, sea level standard conditions. (Ref. 1-17, *Jane's All the World's Aircraft*, multiple years, unless otherwise noted.)

Figure 1-3 illustrates the design consequence of hovering capability. Conventional low disc loading helicopters have historically exhibited a design trend of 50-100% more installed power than propeller-driven aircraft of similar airframe weight. The practical implications of this trend are that rotorcraft designs can be expected to require more powerful, costlier engines and drive systems; and they may also be expected to consume more fuel than fixed wing aircraft to perform a mission of similar range. Since the fitted trendline of rotorcraft power loading in Figure 1-3 is also steeper than that of fixed wing power loading, it is also reasonable to expect the marginal cost of aircraft growth to be costlier in rotorcraft than in other flight vehicles.

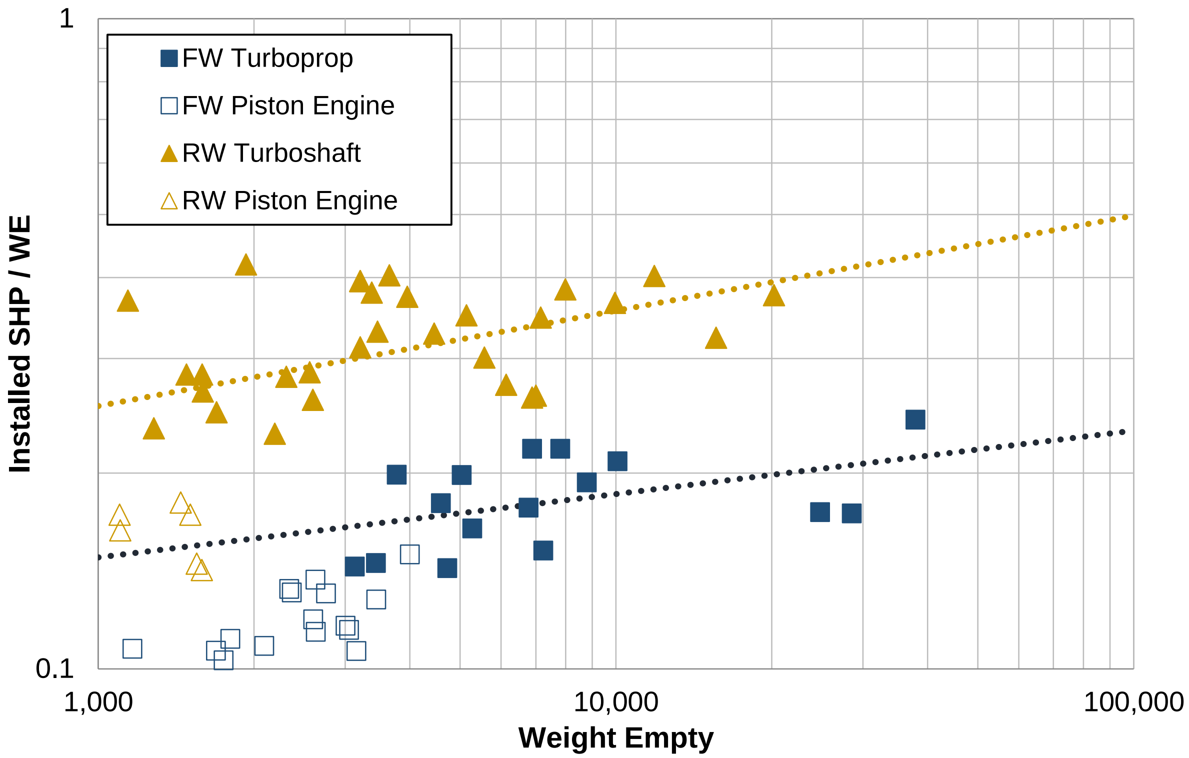


Figure 1-3. Comparison of installed power trends in current production listed rotary wing (RW) and fixed wing (FW) aircraft. (Ref. 1-6)

The rotorcraft performance problem is further compounded by the poor efficiency of the lifting rotor in edgewise flight. Noting the efficiency disparity as early as 1926 in one of his seminal theoretical treatments of the lifting rotor (Ref. 1) Glauert states:

> The maximum lift-drag ratio of the rotating wings is poor compared with that of ordinary fixed wings: its ordinary value is approximately 6, and it is unlikely to exceed 8 in any practical sense.

Figure 1-4 corroborates Glauert's assertion, even in modern aircraft. While turboprop airplanes have reached a level of efficiency appearing to meet and possibly even exceed Von Karman's well established speed-efficiency boundary hypothesis from Ref. 1-10, rotorcraft lag far behind in top speed and lift to drag. Plotting the lift to drag of only the rotor for a representative helicopter as is done for the UH-60A, the compromise inherent to the combination of lifting and thrusting mechanisms in one system becomes obvious. Considering only the rotor itself, without the parasite drag of the rest of the aircraft, the cruise efficiency is less than that of turboprops. Advanced configurations, represented in Figure 1-4 by the XH-59A compound and XV-15 tiltrotor offer the potential to partially bridge the rotorcraft efficiency gap. For nearly as long as helicopters have flown, designers have attempted to escape the limits of conventional helicopter performance trends by combining the best aspects of helicopters and conventional takeoff aircraft in alternative rotorcraft configurations such as these. In some cases, these advanced configurations such as the XV-15 and XH-59A have successfully demonstrated improvements in cruise efficiency – taking significant steps toward the equivalent lift to drag ratio of modern fixed wing turboprop aircraft – while still retaining the characteristic VTOL hover and low speed attributes.

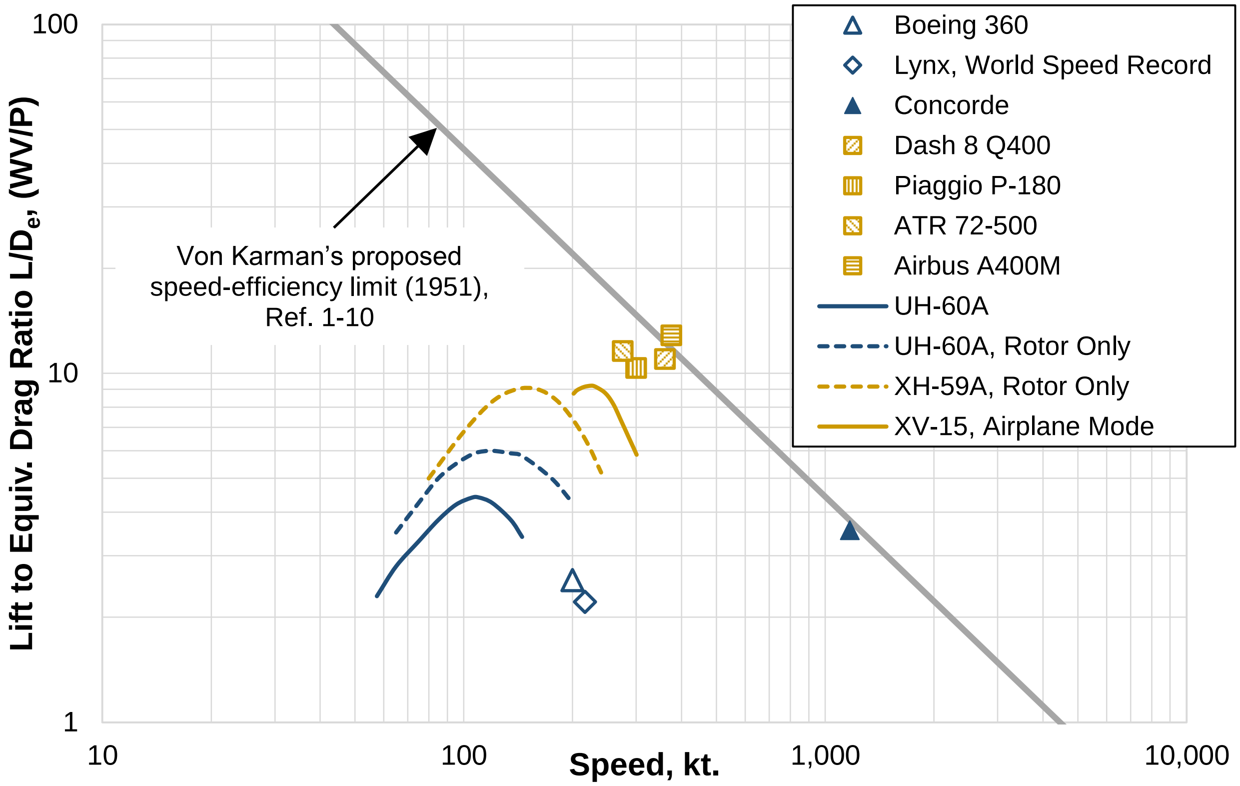


Figure 1-4. Comparison of fixed wing and rotary wing aircraft lift to equivalent drag ratio. (Ref. 1-9, 1-11, 1-12, 1-13, 1-17)

Unfortunately, the cruise efficiency improvement displayed by tiltrotors and compounds relative to the conventional helicopters plotted in Figure 1-4 still lags behind that of modern fixed wing turboprop aircraft and carries with it yet another cost premium.

The increase in complexity, weight, and cost introduced by these configurations as they are presently realized has the potential to offset any gains in performance efficiency and cost effectiveness. At their current level of design maturity these configurations present their own unique set of tradeoffs which will be examined in greater detail in this study.

A historical context is necessary to consider rotorcraft performance and cost from the perspective of how much improvement could be reasonably expected without paradigm-shifting technological advances. Extrapolation of the historical aerodynamic performance trends in Figures 1-5 and 1-6 (Ref. 1-3) shows that production helicopters have experienced limited improvement in both hover and cruise efficiency over the past 20 years. Figure 1-7 shows that rotorcraft structural efficiency has similarly experienced a leveling off of improvement over time up to the present data.

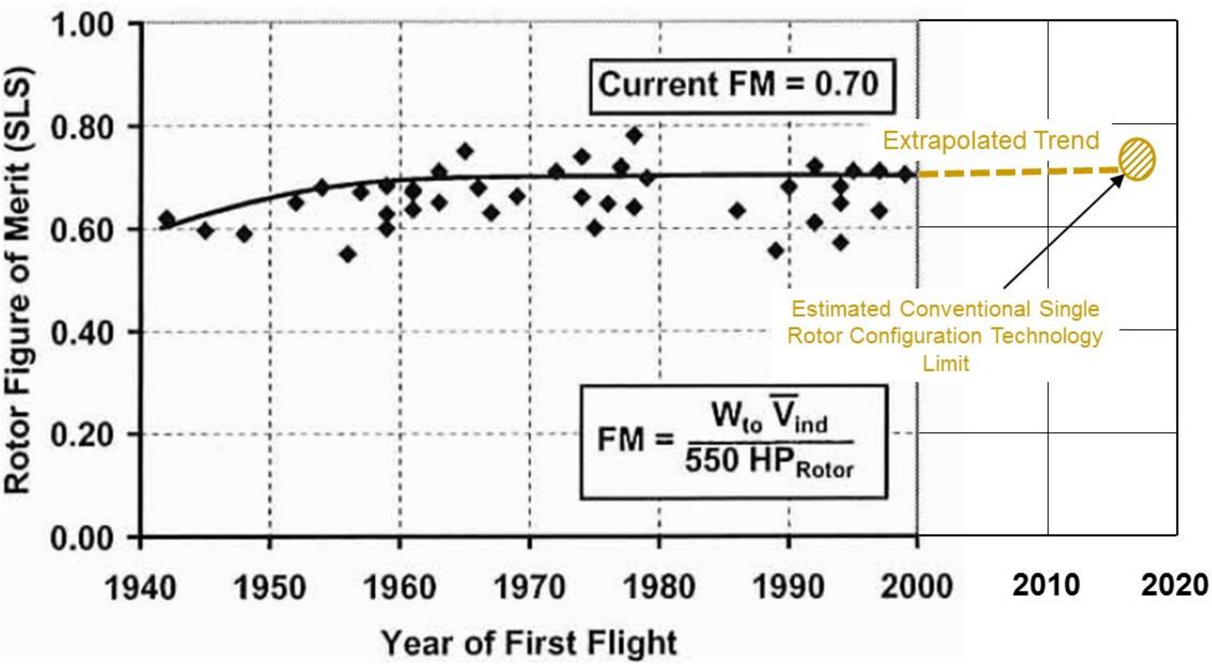


Figure 1-5. Historical trend in helicopter hover figure of merit. (Ref. 1-3)

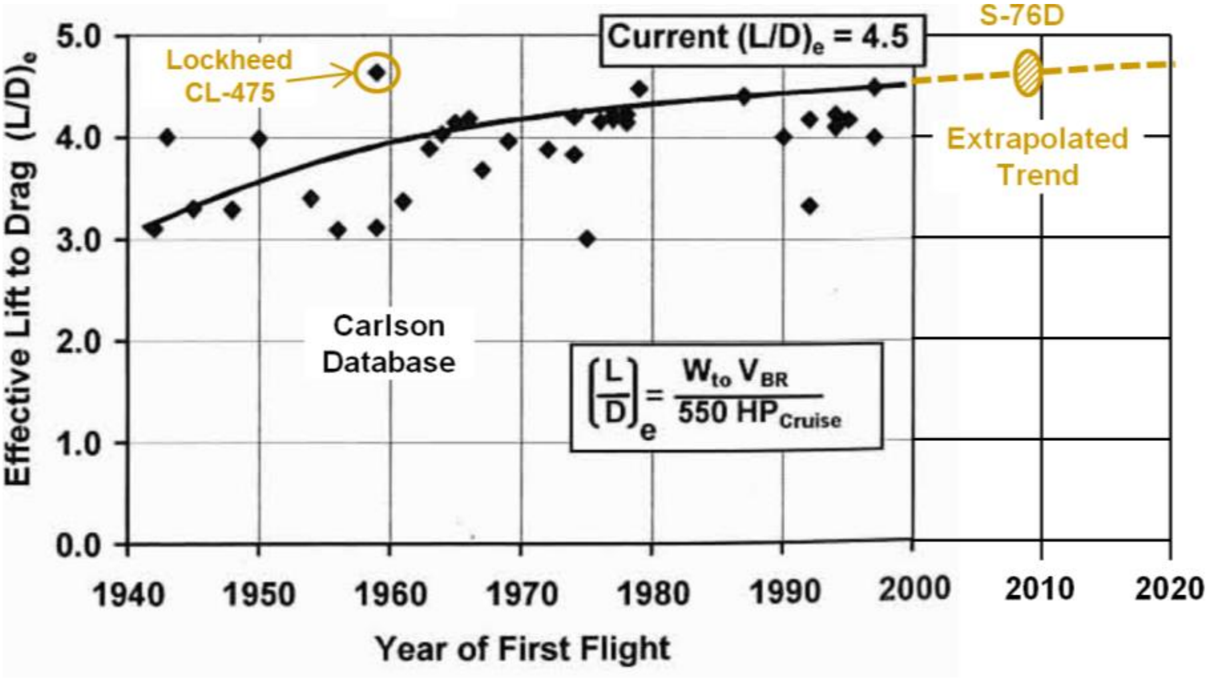


Figure 1-6. Historical trend in helicopter lift to equivalent drag ratio. (Ref. 1-3)

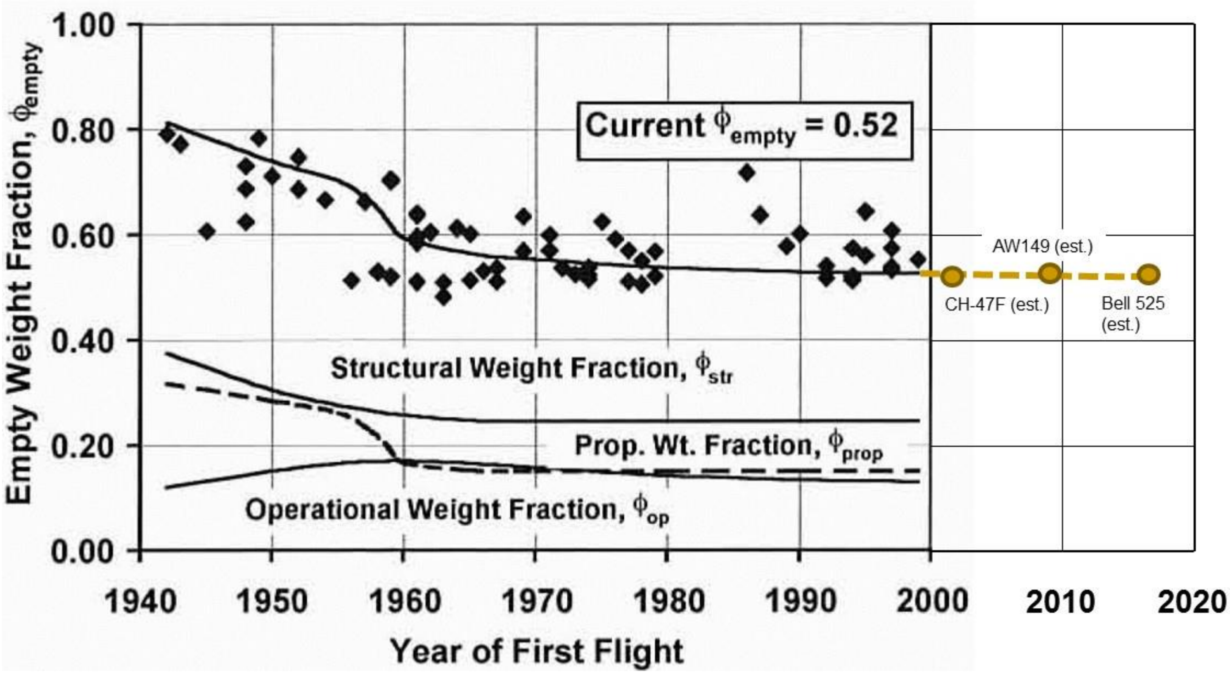


Figure 1-7. Historical trend in helicopter empty weight fraction. (Ref. 1-3)

From a cost perspective, the trends shown thus far suggest that rotorcraft will cost more to operate because their low efficiency causes greater fuel burn; and they will also cost more to buy and maintain due to their disproportionately high airframe weight, high installed power, and greater complexity. At the same time, the slowing rate of performance improvement in the historical trends indicates that conventional rotorcraft performance may already be reaching technological maturity. If this is true, attempting to improve rotorcraft affordability by improving performance and efficiency may not be a cost effective strategy in the near term. The current pace of progress yields small gains in efficiency at best, while the research investment needed to achieve the improvement would likely be large and spread over an extended period of development time.

The historical examinations of rotorcraft cost listed in Table 1-1 demonstrate that this dilemma has persisted across several decades in spite of having been identified in scientific terms by Glauert in the 1920's and operationally (in terms of cost impact) by Schnebly and Carlson as early as 1950's (Ref 1-18). The common conclusion reached by all of the commentaries listed in Table 1-1 is that direct mitigation of life-cycle cost is necessary in addition to the indirect approach of improving rotorcraft efficiency. Since each of the studies also note that the most prominent manifestation of the rotorcraft affordability challenge occurs during the operational phase of the aircraft life-cycle, the direct approaches to cost mitigation which they consider each center around improvements to rotorcraft reliability and maintainability.

Table 1-1. Historical obstacles to rotorcraft affordability

Reference	Schnebly, Carlson (*1954*), Ref. 1-18	Olson (*1993*), Ref. 1-19	Harris (*2012*), Ref. 1-20
Cost Driving Mechanisms Identified	Low L/D Low Cruise Speed **High Maintenance Cost** High Acquisition	High Acquisition Cost High insurance rate **High maintenance cost** Low utilization Limited service life Limited operations	High Fuel Cost **High Maintenance Cost**

Rotorcraft Reliability and Maintainability Challenges

Thus far, in reviewing rotorcraft performance trends it is apparent that the difficulties in engineering a flying machine with capabilities to operate in two distinct flight regimes causes rotorcraft to require more power, yet still cruise slower and less efficiently. The implications of these facts to life-cycle cost are higher acquisition costs due to power and weight and higher operating costs due to fuel burn. Although ongoing efforts devoted to improving rotorcraft efficiency may ultimately yield further affordability improvement, such approaches fundamentally emphasize performance with affordability as a consequence, rather than affordability itself. As noted in Table 1-1, multiple studies at different points in VTOL aviation history have each concluded that rotorcraft require special engineering attention devoted to the improvement of reliability and maintainability. Historical experience also notes that the life-cycle considerations receiving early, and preferably concurrent development focus are the attributes most likely to be successfully implemented in the platform which is ultimately brought to fruition (Ref. 1-5). Acknowledging the noted rotorcraft efficiency disadvantages and their resulting impact to life-cycle cost, the survey turns to a more direct examination of the actual components of life-cycle cost to determine if there may be other factors – specifically factors related to reliability – which may differentiate rotorcraft from fixed wing aircraft.

Figure 1-8 illustrates the role of maintenance as an obstacle to rotorcraft affordability. Plotting the cumulative cost of scheduled maintenance actions of several different types of aircraft as a function of their life-cycle flight hours shows that rotorcraft not only have a higher frequency of scheduled maintenance, but also that the cost of each periodic inspection and repair far exceeds that of fixed wing aircraft.

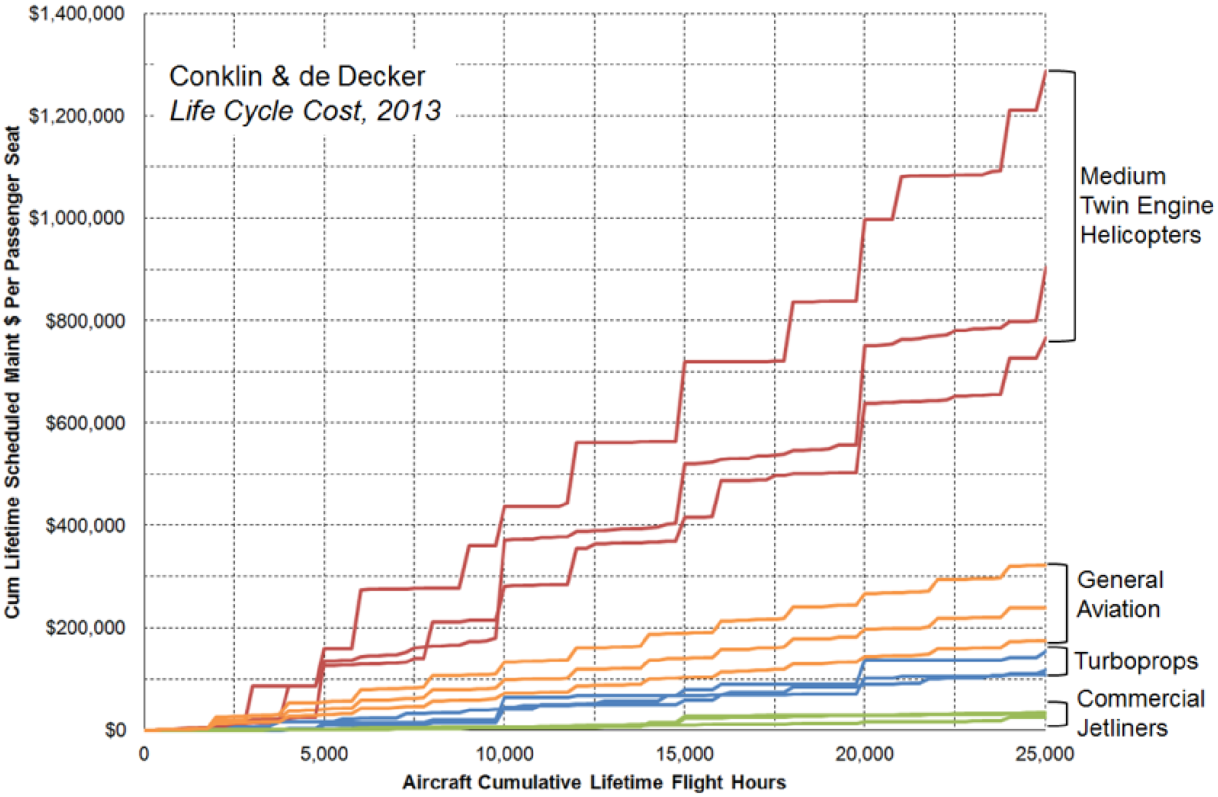


Figure 1-8. Cumulative scheduled maintenance cost per passenger seat of selected fixed wing and rotary wing aircraft (Ref. 1-6)

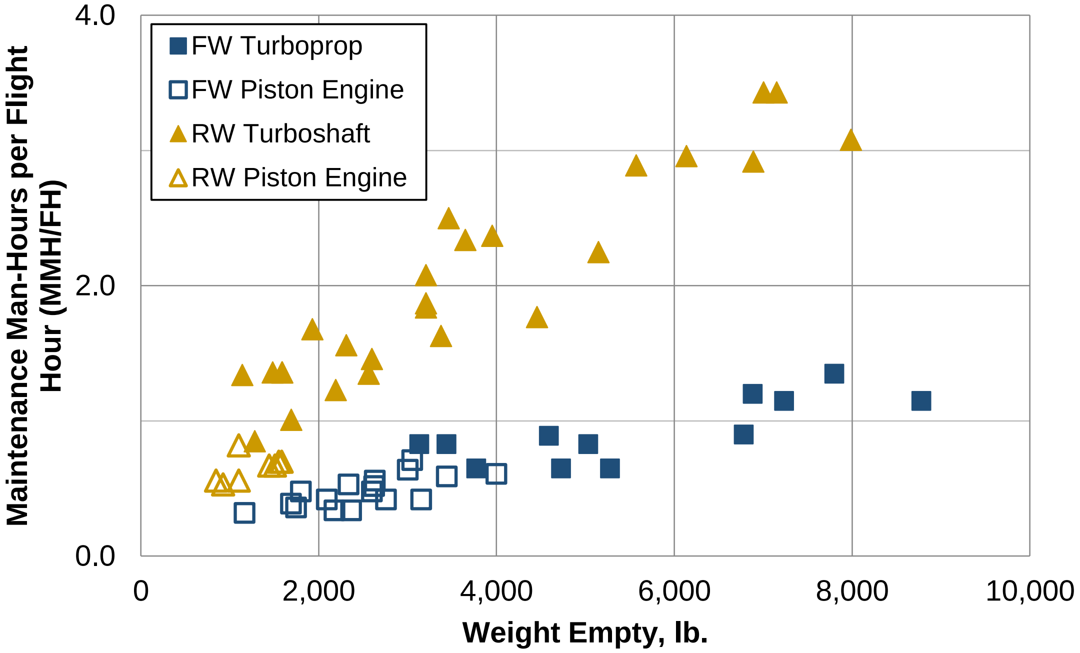


Figure 1-9. Comparison of MMH/FH in fixed wing (FW) and rotary wing (RW) piston and turboshaft powered aircraft. (Ref. 1-6)

The same phenomenon is also apparent in Figure 1-9 when the aircraft maintenance burden is measured in terms of the amount of labor hours (maintenance man-hours per flight hour) required to perform both the scheduled maintenance activities given in Figure 1-8 as well as the inspections and corrective actions referred to as unscheduled maintenance. Multiple ongoing projects aimed at different aspects of maintenance cost reduction and reliability improvement confirm the priority placed upon removing cost, reliability, and availability from acting as obstacles to rotorcraft utilization. Table 1-2 provides a description of selected examples of improvement efforts.

Table 1-2. Selected rotorcraft reliability improvement initiatives and goals

Program	Cost / Reliability Goal
Capability-Based O&S Technology – Aviation (COST-A), Ref. 1-22	+15% component TBO -12% MMH/FH
Future Advanced Rotorcraft Drive System (FARDS), Ref. 1-23	-35% drive system maintenance cost
Improved Turbine Engine Program (ITEP), Ref. 1-24	-20% engine maintenance cost
Ultra-Reliable Designs (URD), Ref. 1-25	$A_o > 95\%$

In spite of ongoing efforts to reduce maintenance cost and improve reliability in rotorcraft, extrapolation of Carlson's historical study of rotorcraft performance trends to reliability level observed in contemporary rotorcraft systems reveals yet another performance limit. The plateau in the flight hours between engine and drive system overhaul as shown in Figures 1-10 and 1-11 represents two major contributing factors to the frequency of maintenance actions plotted in Figure 1-8 (Ref. 1-17). If other major rotorcraft components have experienced a similar lack of service life improvement as have engines over the past decade, the question arises whether the lack of progress is due to non-prioritization of reliability, lack of business case for increased reliability, or even perhaps to the simple magnitude and degree of the technical challenge.

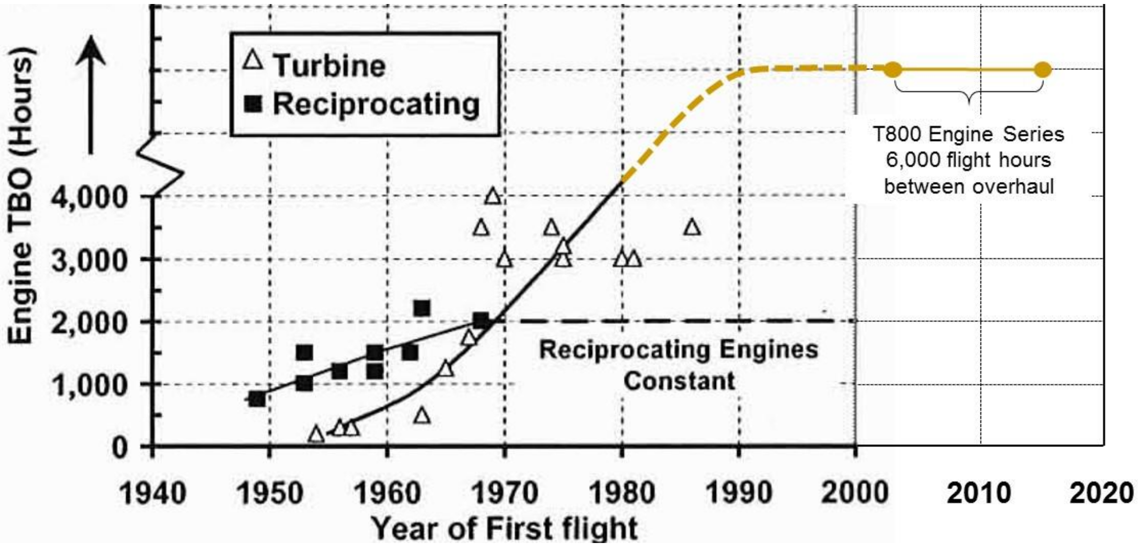


Figure 1-10. Historical trend in design time between overhaul interval (flight hours) of rotorcraft propulsion systems. (Ref.1-3)

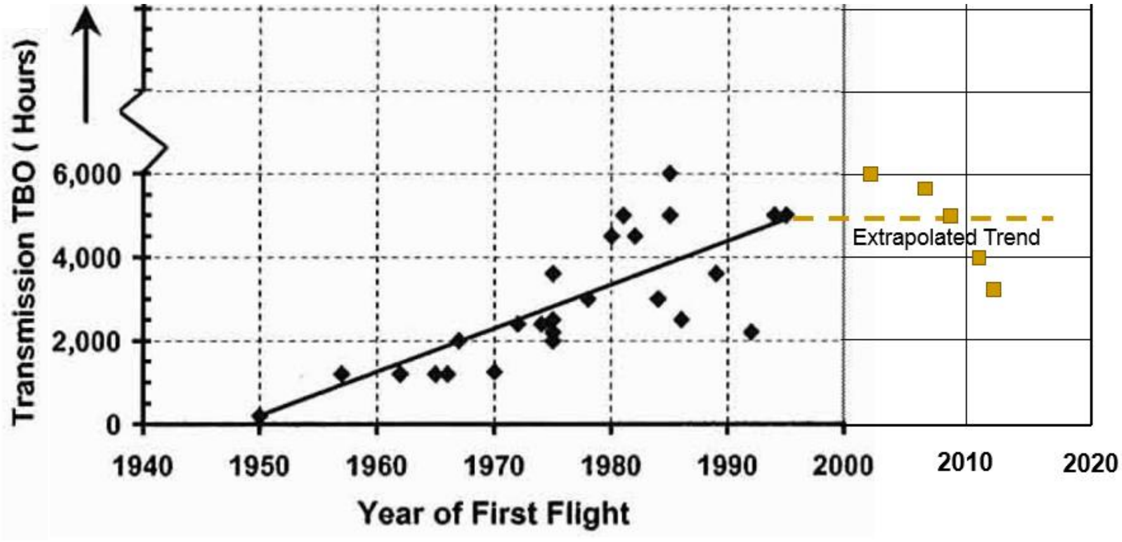


Figure 1-11. Historical trend in overhaul interval (flight hours) of rotorcraft drive system components. (Ref. 1-3)

Rotorcraft Reliability Modeling Challenges

In order to address the question of rotorcraft reliability improvement and its impact to life-cycle cost, the engineer and acquisition decision maker need a cost model which considers both the design sizing effects and the specific RAM-focused technologies present in the aircraft and is adjustable to consider the sensitivity of design and cost to various levels of reliability investment. This RAM-focused method of rotorcraft life-cycle cost assessment would quantify the sensitivity of cost to reliability effects while considering both the anticipated affordability improvement due to increased reliability while also considering the possible investment costs and the design impact of the technologies needed to achieve the reliability improvement. No rotorcraft cost model presently exists with this capability. The possibility of rotorcraft having unique reliability characteristics influenced by their operating conditions and the need to quantify the design and cost impact related to the improvement of these reliability characteristics leads to research questions 2 and 3.

Research Question 2: Does the inclusion of reliability, availability, and maintainability (RAM) factors in life-cycle cost assessment enhance the accuracy of the prediction?

Research Question 3: Does technology related to the improvement of reliability, availability, and maintainability (RAM) have an appreciable effect on rotorcraft design when it is included in a sizing routine?

Based on the noted cost trends, a new rotorcraft design framework incorporating cost and reliability is proposed. The framework will account for the mutual effects between each of the three factors, providing the ability to account for new technology and practices designed to improve RAM metrics and reduce life-cycle cost.

The abundance of recent technology development efforts focused on high reliability rotorcraft subsystems open the possibility of incorporating new data into a conceptual design routine. The challenge to executing the envisioned methodology is compiling enough of the data to perform a sufficiently broad sensitivity sweep of RAM technologies to gauge the full spectrum of design, cost, and risk impact. Thanks to their basis in the generally mature theoretical understanding of aircraft performance, today’s design methods can easily accommodate the subcomponent data needed to perform technology excursions on conceptual aircraft designs. Many of these studies have also performed an accompanying cost assessment of the technology effects on the design. (Ref. 1-14,15, and 16). While keeping with the analytical precedent of these previous works, the distinguishing characteristic of the proposed research work as shown in Figure 1-12 is the tiered and coupled nature of the assessment analysis with the estimated reliability and availability characteristics directly and explicitly impacting both the design and the cost assessment.

Finally, the analytical capability gap related to design, cost, and reliability as identified in Research Questions 1, 2, and 3 also suggests the need for practical application of such a model. Empowered with a design framework that accept a certain level of reliability as an additional input along with design conditions and flight constraints, Research Question 4 represents the intersection of the aircraft designer's work with the interests of the cost analyst and the acquisition decision maker.

Research Question 4: For a given set of sizing, acquisition, and operating assumptions, can reliability be used as a design parameter to maximize the affordability of a rotorcraft design?

To answer Research Question 4, a pertinent design problem must be formulated with an accompanying life-cycle cost scenario. The assumptions which define the life-cycle scenario must represent the need for paradigm-shifting affordability in addition to improved performance in future rotorcraft programs. They must also illustrate technology and design features currently in development which attempt to address VTOL's simultaneous and potentially conflicting performance, cost, and reliability requirements. Just as new technology is pursued as a means of enabling a shift in the previously feasible design space of an aircraft, a new analysis method must be developed in parallel to formalize and quantify the design and cost effects. While research questions 2 and 3 focus on the means of quantifying reliability effects, research question 4 focuses on the validation of the entire premise of the work and requires background research to document the approach and justify the assumptions used in its application.

CHAPTER 2

ROTORCRAFT DESIGN AND ASSESSMENT METHODS

Identification of Analytical Need

The initial challenge to assembling a design, cost, and reliability assessment framework is the identification of cost and reliability models suitable for use in conjunction with rotorcraft sizing and synthesis. Based on the survey of rotorcraft cost trends motivated by Research Question 1, the next step in the plan outlined by Table 1-2 and Figure 1-12 is the quantification of reliability effects on all aspects of life-cycle cost. This objective can be abstracted to a set of basic mathematical expressions standing for the aircraft sizing process. Representing the basic physical design characteristics of an aircraft as a vector D_{design}, the role of a conceptual sizing tool is to produce the dataset represented by D_{design} from a set of assumptions related to performance requirements R_{design} and design assumptions H_{design}. The results of the sizing routine are thus a function of both requirements and assumptions.

$$D_{design} = f\left(R_{design}, H_{design}\right) \qquad (2-1)$$

Assuming all external programmatic and corporate influences on the development and fielding of an aircraft are equal and constant, the life-cycle cost of an aircraft C_{LCC} can be expressed as a function of the design along with a set of economic factors H_{cost} which includes labor rates, material prices, production quantities, fuel prices, and inflation among many possible parameters.

$$C_{LCC} = f\left(D_{design}, H_{cost}\right) \qquad (2-2)$$

Absent from Eqn. 2-1 and 2-2 are cost inputs related to reliability, availability, and maintainability, (RAM). Historically, aircraft conceptual cost analysis has depended upon parametric cost estimating relationships (CER’s). Parametric CER’s are generated through statistical regression of historical cost data against aircraft characteristics and other cost driving variables. As represented by Eqn. 2-2, such CER's typically do not explicitly consider any RAM characteristics. An aircraft which exhibits high predicted maintenance cost might be assumed to also exhibit low reliability, and hence require frequent and expensive maintenance actions. This conclusion, while reasonable to common sense, cannot be proven unless actual reliability parameters are included in the cost analysis. Maintenance costs, as noted by Refs. 1-18 and 1-19 in Table 1-1 and illustrated in Figure 1-8, are a function of both the cost of maintenance actions and the frequency at which they occur. A purely parametric cost model which computes maintenance expenses in terms of dollars per flight hour blurs these two effects. Ideally, the operating cost assessment should be conducted estimating maintenance in separate steps considering both cost and frequency. Parametric analysis is also limited in the assessment of new concepts due to its dependence on historical trends. Correction is required to account for the effects of new technology. The new framework should also provide a means of assessing the effect of technology rather than simply taking this as an assumption and only estimating the life-cycle cost impact.

The essential and distinguishing feature of the proposed design framework is an explicit separation of reliability and maintainability characteristics from cost assumption so that they are treated as a coequal set of characteristics D_{RAM} based on requirements and assumptions in the same way design and cost parameters are treated in Eqns. 2-1 and 2-2.

$$D_{RAM} = f\left(D_{design}, H_{RAM}\right) \qquad (2-3)$$

The new design and assessment framework will furthermore distinguish itself from the previously existing methods by considering the effect of the estimated RAM qualities on both the design and cost parameters in contrast to Eqns. 2-1 and 2-2. As eqns. 2-3 and 2-4 imply, and as Figure 2-1 illustrates, an essential feature of the framework is additionally that the design and RAM characteristics, D_{design} and D_{RAM}, are mutually effectual.

$$D_{design} = f\left(R_{design}, H_{design}, D_{RAM}\right) \qquad (2-4)$$

$$C_{LCC} = f\left(D_{design}, H_{cost}, D_{RAM}\right) \qquad (2-5)$$

The practical implementation of the analytical components represented by Eqns. 2-3 through 2-5 illustrates the multidisciplinary nature of rotorcraft life-cycle cost assessment. No single unifying model covers all of the topics illustrated in Figure 2-1. Although multiple efforts have investigated individual subcomponents or limited subsets of the subcomponents and interconnecting cost-reliability effects, a new contribution is required to connect the effects within the context of rotorcraft conceptual design.

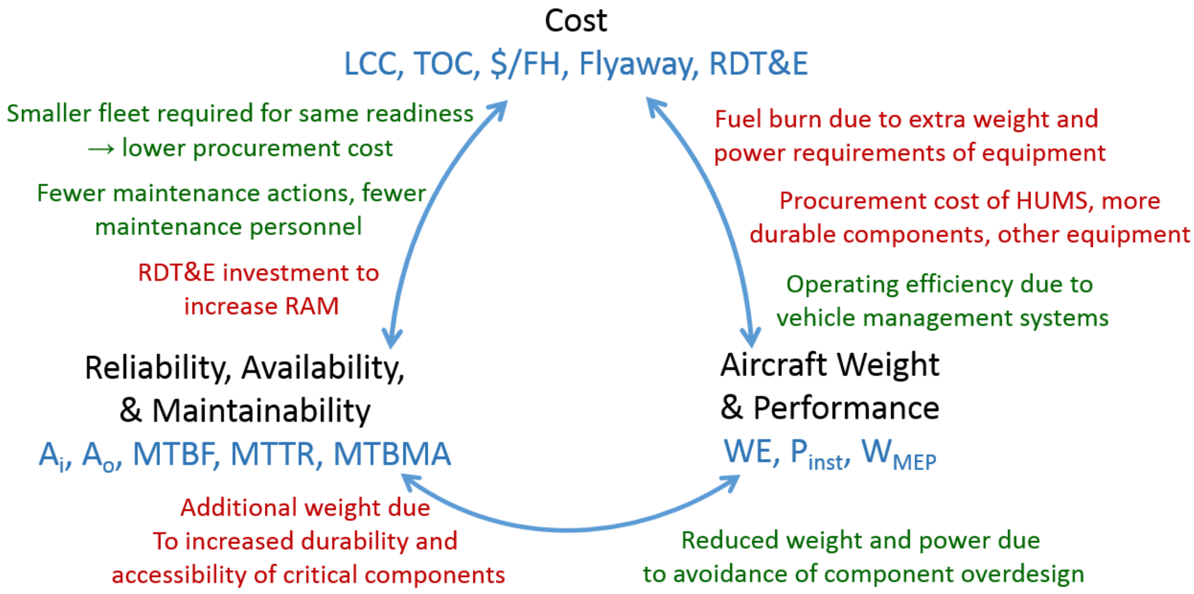


Figure 2-1. Interconnections between reliability, cost, and design issues in rotorcraft

Several of the analysis components which will be combined in this study to create a multidisciplinary design and assessment framework are derived or inspired by historical works from previous studies of rotorcraft design and life-cycle cost. Table 2-1 organizes a selection of works significant to design, reliability, and cost assessment in rotorcraft according to topic and chronological order.

In parallel to the historical identification of rotorcraft cost and reliability challenges given in Table 1-1, even the earliest analytical contributions to design synthesis contain a combination of design philosophies or attempts at quantification of the design impact of affordability considerations. The evolving understanding of rotorcraft affordability is apparent in the modifications made to the affordability design philosophy over time.

Table 2-1. Significant works relating rotorcraft design, cost, and reliability topics

Design	Cost	Design-Cost	Design-Reliability	Cost-Reliability
Joy, Simonds, Wagner (1956) Ref. 2-1, 2-2	Schnebly, Carlson (1955) Ref. 1-18, 1-21			
Stepniewski, Schneider (1964) Ref. 2-3	Stoessel, Gallager (1967) Ref. 2-5			
Tishchenko, Nekrasov (1976) Ref. 2-4		Kingston, DeTore (1976) Ref. 7-4	Unger (1974) Ref. 2-6	Veca (1974) Ref. 3-2
		Levine (1981) Ref. 3-7		
	Harris, Scully (1998) Ref. 5-1	Baker, Schrage, Mavris (1996) Ref. 7-2		
	Biggs, Key (2001) Ref. 3-4	Coy (2001) Ref. 3-3	Biggs, Key (2001) Ref. 3-4	Dellert (2001) Ref. 2-7
				LMI (2004) Ref. 3-5
Johnson (2010) Ref. 4-10	Harris (2012) Ref. 1-20			Scott (2015) Ref. 3-6

History of Rotorcraft Design Analysis

This being a conceptual design study, the estimation of aircraft parameters finds its analytical basis in the fuel balance method of sizing, first applied to rotorcraft design as the R_F Method of minimum gross weight (Ref. 2-1, 2-2). The mathematical algorithm established in this method of balancing design mission fuel required with fuel available through iteration of gross weight continues to be fundamental basis of modern sizing tools. (Ref. 4-10).

Early rotorcraft design and design for cost philosophy at the time of the R_F Method's analytical development generally amounted to an axiomatic practice of minimizing the gross weight and empty weight of a design (Ref. 1-18, 1-21, 2-4). This approach is valid as a recognition of the first order effect of airframe weight on cost since acquisition and operation cost in some respects both depend on a correlation of cost to weight – that is, they both scale with aircraft size in some manner with all other factors of complexity and performance being equal. In an effort to consider the efficiency and capability of an aircraft in addition to its weight, later design studies such as those by Stepniewski (Ref. 2-3) and Kingston (Ref. 7-4) proposed the use of efficiency metrics like growth factor and productivity index as alternative parameters which may indicate the optimal design point. In the intervening years, analysis has progressed beyond exclusively weight-based design philosophy to actual models which predict aircraft cost. Rotorcraft cost modeling has progressed from purely weight-based analogy methods (Ref. 1-18) to methods which include factors such as installed power, rotor complexity, and individual subcomponent weights and complexities (Ref. 5-1).

History of Rotorcraft Affordability Analysis

While these models offer improvement to the accuracy of life-cycle cost prediction by considering additional cost driving effects, they do not include direct consideration of reliability and maintainability. The reliability effects remain implicit to the modeling trends, meaning the life-cycle cost of an aircraft which is inherently more reliable due to specific technology insertion will be over-predicted if not for specific adjustment by means of technology factors. By the same token, concepts of similar size and complexity but different inherent RAM qualities will be assessed as equals when in reality the more reliable concept will cost less to own over time, all other factors being equal. Without direct assessment of an aircraft's reliability quantities, parametric life-cycle cost modeling must perpetually readjust its weight and complexity trends downward as RAM technology matures. The simpler and more precise solution is to capture the reliability effects immediately by directly including their defining characteristics in the modeling procedure.

While many aspects of rotorcraft operation and effectiveness have received analytical treatment with the realm of conceptual synthesis, the topics of reliability and maintainability have received comparatively little attention. Multiple design studies since 1975 included cost assessment in conjunction with aircraft synthesis, but no prominent example of reliability assessment with consideration for life-cycle cost and design is readily available in the literature until 2001 when Dellert (Ref. 2-2) considers the sensitivity of O&S costs to variation in the mean time between maintenance actions (MTBMA) and the mean time to repair (MTTR). More recently, the maintenance free operating period (MFOP) has been proposed as a metric of reliability, although more detailed approaches such as real time simulation and stochastic analysis are typically used to estimate such a quantity (Ref. 2-3).

In this phase of the study, priority is placed on the identification of models which provide the necessary theoretical linkages identified in Figure 2-1. Conventional sizing and cost modeling tools serve as the starting point of the framework, provided that the tools selected for use are sufficiently flexible to be modified for consideration of the reliability and maintainability effects of interest. In some cases, new models are developed or existing models are modified to obtain the desired framework. The effects of the particular choice of models used will be examined further when the model is applied to a pertinent design and life-cycle cost case. For the purposes of constructing the design and assessment framework, the analytical needs identified in Figure 2-1 but not completely satisfied in the references list in Table 2-1 consist of:

1. An aircraft sizing tool and a cost modeling tool which can accommodate multiple design requirements and technology assumptions simultaneously.
2. Capability within the cost model to consider the sensitivity of cost to reliability and maintainability

3. A means of modifying sizing assumptions to consider the design impact of technology insertion related to reliability and maintainability in the most general sense possible.

4. A selection of RAM assessment metrics which can be predicted based on the conceptual design characteristics produced by the tools within the framework.

5. A baseline use case as well as a trade space of design excursions related to design, cost, reliability, and maintainability on which the model can be applied.

Conceptual Design Tool Evaluation & Selection

Having identified the analytical components required to construct the new design framework along with a relevant literature set, the research can proceed to implementing and the methodology and validating its approach. The first requirement can be satisfied by nearly any of the basic design and cost methodologies listed in the first and second columns from the left in Table 2-1. The only stringent requirement is that the models selected possess an adequate amount of technical detail while maintaining the speed of analysis which has allowed conceptual designers to survey large trade spaces rapidly since the development of the R_F Method. Since the systems expected to be surveyed for design and reliability impact however are subcomponents and modifications to subcomponents though, the sizing tool used must predict the aircraft characteristics at a sufficiently granular level to account for the accompanying changes in weight and power. As shown in Figure 2-2, the cost model must be equally detailed in order to readily accept the granularity of information present in the design tool's output and predict the overall impact to cost of ownership while still isolating the driving factors to the same low level of detail. The government and industry standards of weight and cost reporting are sufficient to describe this level of detail. For weight this standard is RP-8A (Ref. 5-4) / MIL-STD 1374 (Ref. 5-5) and for cost it is MIL-STD 881C (Ref. 5-3).

The two most prevalent and modern design and assessment tools for this purpose are the NASA Design and Analysis of Rotorcraft Code (NDARC) and the Bell PC-Based Cost Model (Bell PC). NDARC estimates vehicle weights in RP-8A format with options for the user to modify each weight component with either a technology factor or a constant fixed weight. As shown in Figure 2-2, Bell PC uses a weight format easily translatable from NDARC's output to produce procurement and operating and support cost estimates from a buildup of cost drivers predicted at the 3rd and 4th level of the MIL-STD 811C work breakdown structure (WBS). Both tools have been utilized separately and in concert with one another in multiple literature references to assess the impact of advanced technology on a variety of rotorcraft configurations. These qualities make NDARC and Bell PC ideal starting points, with flexibility to fulfill the first requirement combined with sufficient specificity to fulfill the second and third requirements. The remaining requirements involve researching reliability metrics and modeling methods and making the necessary modifications to the selected conventional design and assessment tools to consider RAM effects. Table 2-2 and Figure 2-3 outline the research procedure proposed to establish and apply the new design framework.

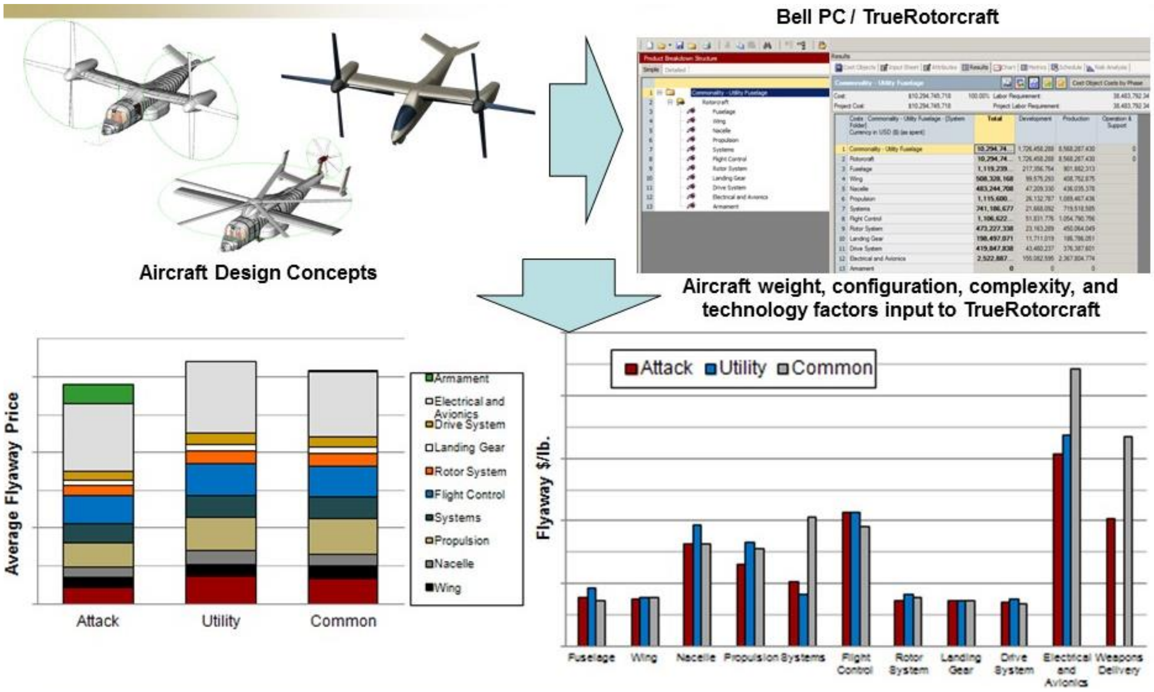


Figure 2-2 Bell PC / Price TrueRotorcraft modeling process. (Ref. 2-13)

Table 2-2. Research plan observations and hypotheses.

Observation	Research Question	Hypothesis	Desired Result
High life-cycle cost limits application and utilization of rotorcraft.	What drives rotorcraft life-cycle cost?	The stressing nature of VTOL flight causes rotorcraft acquisition and operating costs to be higher in rotorcraft than in other forms of aviation.	Demonstrate rotorcraft affordability deficiency from existing trends and trace to VTOL performance and design challenges.
Operation and support represent the largest component of a rotorcraft's life-cycle cost, and depend on the reliability and maintainability of the system.	Does the inclusion of reliability and maintainability factors in O&S cost modeling enhance the accuracy of the cost estimates across rotorcraft concepts?	Traditional parametric modeling of O&S costs contains an implicit level of reliability and maintainability. Without the ability to adjust this implicit assumption, the model applies it uniformly to every use case.	Contrast conventional and improved parametric O&S cost estimation methods to a use case based on existing aircraft which demonstrates the cost effects of different levels of RAM technology and investment.
Attempts to improve reliability and maintainability incur additional acquisition costs.	Does technology related to the improvement of RAM have an appreciable effect on rotorcraft design when it is included in a sizing routine?	RAM technology impacts the design as well as the acquisition cost because it adds new design features to the aircraft which incur weight penalties among many possible effects.	Develop and a set of models pertinent to aircraft conceptual design which quantify the design and acquisition cost impact of deliberate design efforts to improve reliability and maintainability. Implement the models within a new conceptual design framework.
Assuming the design and acquisition impact of RAM technology is quantifiable, no design and assessment capability exists to weigh the potential tradeoffs to total life-cycle cost.	For a given set of sizing, acquisition, and operating assumptions, can reliability be used as a design parameter to maximize the affordability of a rotorcraft design?	An optimum value of RAM investment exists for every aircraft concept beyond the current level of RAM technology, but still depends on the assumptions used in the design and assessment analysis.	Develop a pertinent use case demonstrating rotorcraft affordability challenges in vehicle performance, cost, and reliability. Apply the new conceptual design and assessment framework to obtain the estimated optimal affordability design point.

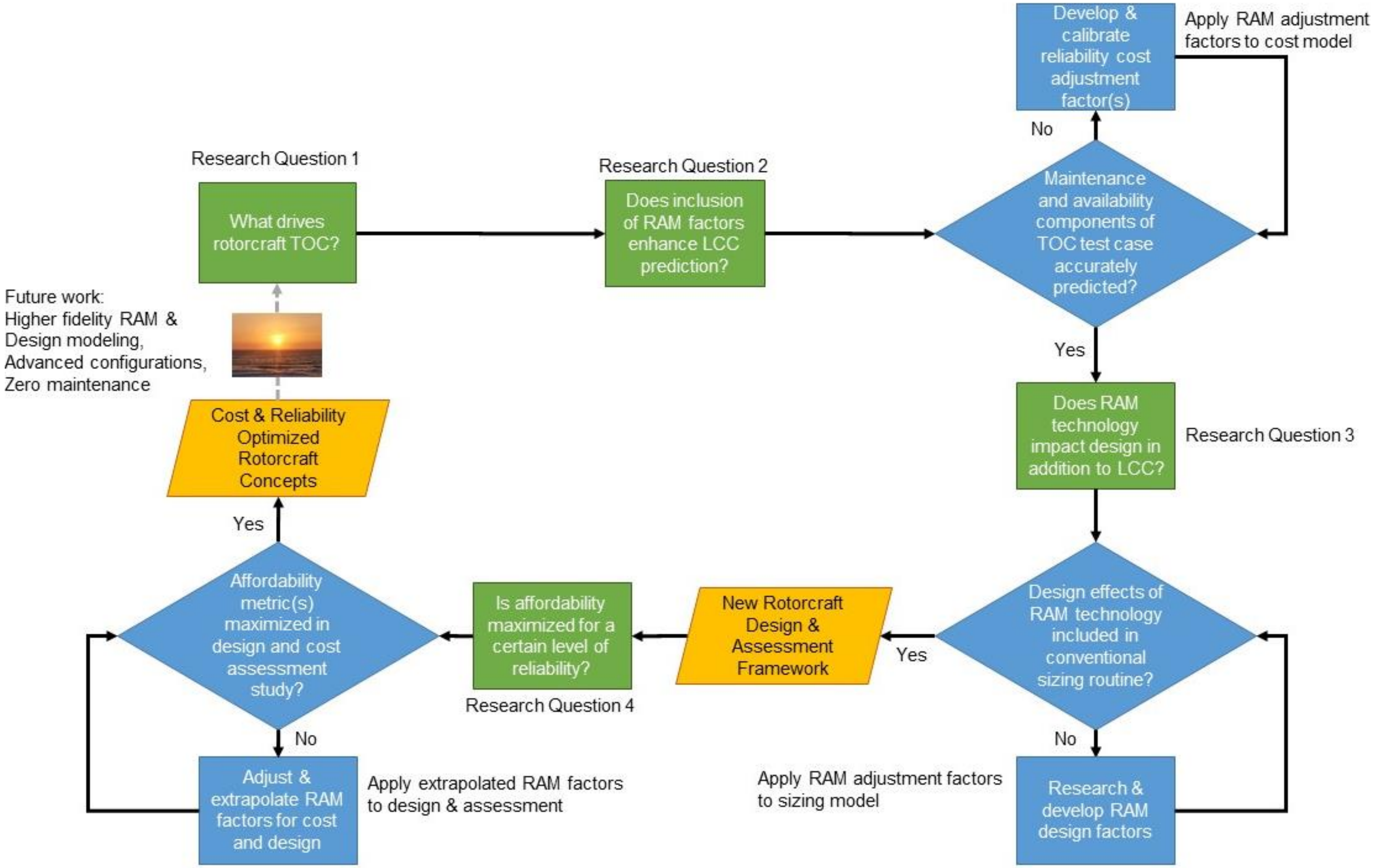


Figure 2-3. Research Questions and Study Approach

CHAPTER 3

ROTORCRAFT RELIABILITY ASSESSMENT METHODS

Reliability Cost Effects

In order to prove that the new modeling approach proposed by this work is both pertinent to rotorcraft design and useful for the cost appraisal of VTOL concepts, reliability and maintainability must be demonstrated as significant and discriminating life-cycle cost drivers. In the context of this study, the labeling of these two effects as cost drivers means that reliability and maintainability are linked to cost by both physical mechanism and statistical correlation. Besides proving the significance of RAM effects to life-cycle cost, the study must also prove that they may be analytically modeled with acceptable accuracy using data sets that do not carry a severe data collection burden which would make their use burdensome to conceptual design. In order to satisfy this burden of conceptual significance as it is posed by Research Question 2 in Figure 3-1, parametric cost modeling augmented with direct consideration of reliability and maintainability must be shown to produce a more accurate estimate of the life-cycle cost elements in question. Figure 3-1 illustrates a generalized iterative procedure of connecting RAM concepts to conventional cost modeling methods within the larger framework of the study provided in Figure 2-3.

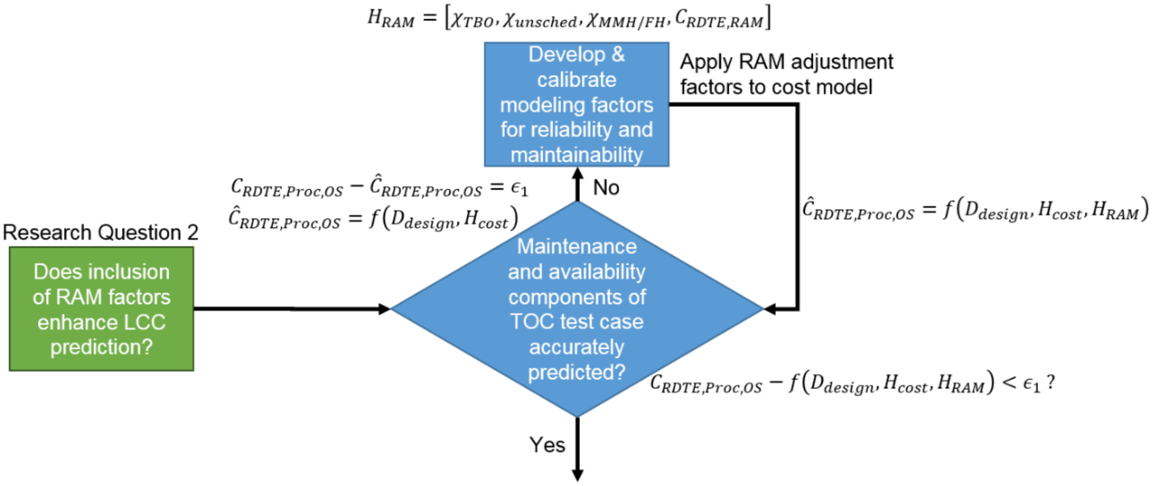


Figure 3-1. Reliability augmentation process and cost modeling validation.

The procedure given in Figure 3-1 begins with a conventional parametric cost model and the estimated components of life-cycle cost which it generates in its default mode. These estimated quantities are denoted $\hat{C}_{RDTE}$, $\hat{C}_{Proc}$, and $\hat{C}_{OS}$. The prediction error between these quantities and their actual values is denoted ϵ_1. The burden of proof which must be met in order to proceed with the new assessment framework is a demonstrated reduction in this prediction error which is attributable to the inclusion in the model of the set of RAM characteristics, H_{RAM}.

Rotorcraft already in production and operation (frequently called the legacy rotorcraft fleet) can serve as use cases for the application of a new cost modeling procedure based on the upgrades which they have gone through over the course of their family life-cycle. The upgraded families of rotorcraft designs in operation across the joint US military services provide particularly useful test cases due the public documentation of their design features and cost trends. Since the general paradigm of rotorcraft acquisition and sustainment of late has favored upgrades rather than new aircraft, the actual changes to the basic aircraft designs have been minimal. The upgrade programs in most cases have left the basic aircraft platforms largely unchanged while adding new mission equipment or improving the design of individual subsystems. Notably, many of the new features in these upgrade programs are specifically intended to improve the reliability, sustainability, and affordability of the aircraft (Ref. 3-8, 3-9, 3-10). The incremental nature of this design progression provides an example supported by fleet-representative data of the principle noted in Chapter 2 which distinguishes reliability-augmented cost estimation – that two rotorcraft of similar design but different RAM characteristics exhibit different ownership cost behavior which the model should account for without manual adjustment on the part of the user. As shown in Figure 3-1, this test case thus serves to confirm or disprove the validity of the new contribution of the model. If successful, the study can proceed to extending the advanced reliability modeling and cost assessment working in combination with the conceptual sizing of new rotorcraft configurations.

Figure 3-2 plots the progression in size and procurement cost of the most recent models of legacy Army and Navy rotorcraft which have undergone upgrade or redesign programs. The procurement cost is plotted against the size parameter f_{H-S}, derived as a high level indicator of overall aircraft cost in Ref. 5-1 as:

$$f_{H-S} = WE^{0.4638}SHP^{0.5945} \qquad (3-1)$$

As would be predicted by weight-based conventional cost models, the aircraft size and procurement scale commensurately with one another. Slight growth in weight and installed power is accompanied by slight increases in unit procurement price for the AH-64E, CH-47F, and UH-60M. The more substantial design changes and weight growth in the CH-53K cause larger cost growth. The fundamental shortcoming of conventional methods reveals itself however when the documented operating costs of the same aircraft are plotted versus the same size parameter in Figure 3-3. The operating costs reported for each of the aircraft exhibit a variety of trends, in some cases becoming less expensive to operate in spite of the incremental increase in vehicle size which is incurred by their upgraded design features. Using a simple size-scaled estimate in Table 3-1 to illustrate the difference between the expected and actual change in direct maintenance cost per flight hour again demonstrates the limitation of a strictly size-based prediction. Although this example serves to highlight a shortcoming in existing methods, the only conclusion which can be drawn at this point is that additional effects are present in the trends which are not capture by the parameters of the model. The next step is to test the key hypothesis behind Research Questions 2 and 3 – that the effects missing from the conventional modeling methodology exemplified in Table 3-1 are reliability and maintainability, and furthermore that they are phenomena distinct from aircraft size.

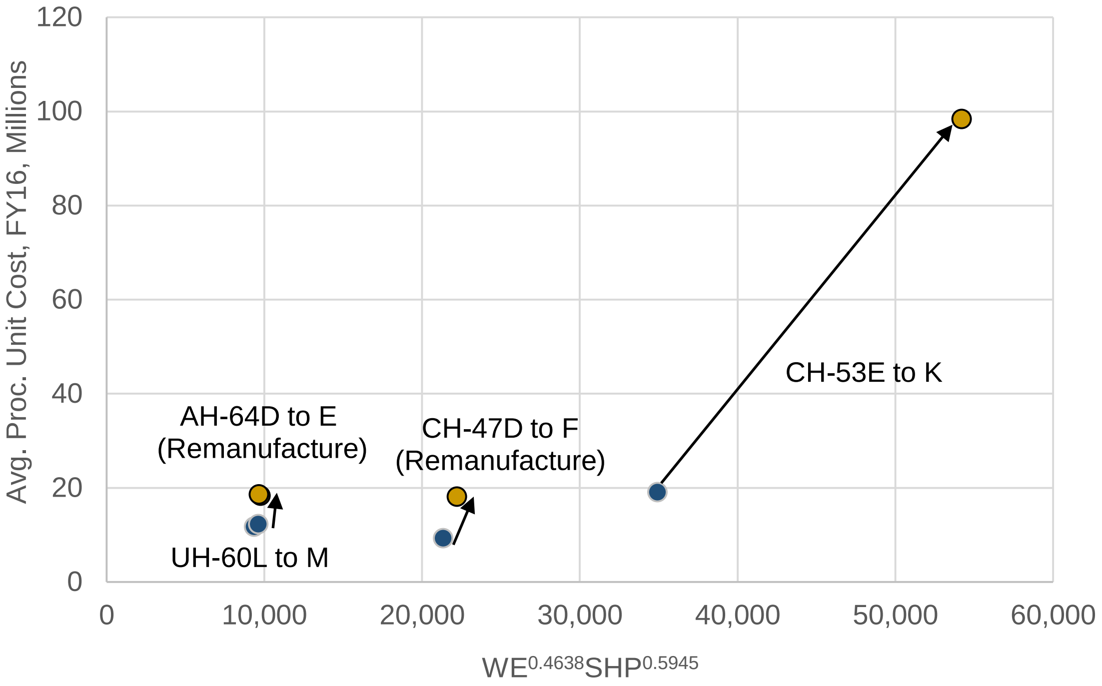


Figure 3-2. Procurement cost growth in upgraded Army and Navy rotorcraft

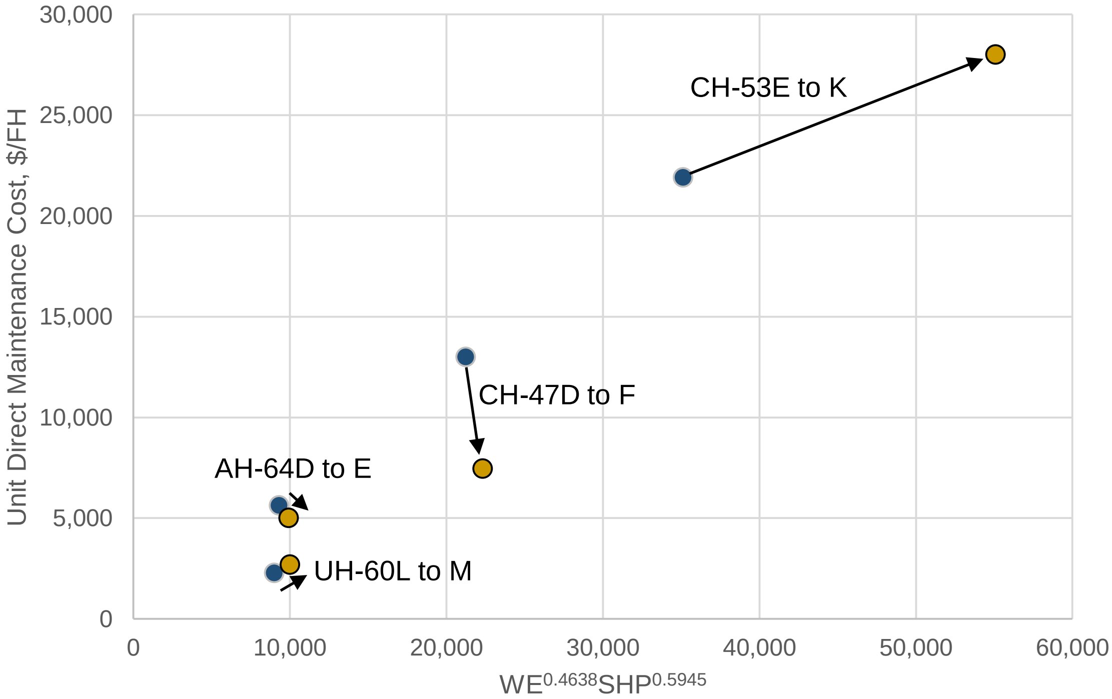


Figure 3-3. Operating cost change in upgraded Army and Navy rotorcraft

Table 3-1. Estimation of upgraded O&S cost trends by weight-based methods

	UH-60M (Ref. 2-9)	AH-64E (Ref. 2-11)	CH-47F (Ref. 2-10)	CH-53K (Ref. 2-12)
APUC	$18.34 M	$18.60 M(1)	$18.13 M(1)	$98.43 M
Total RDT&E	$0.929 B	$1.660 B	$0.224 B	$6.836 B
Antecedent Model	UH-60L	AH-64D	CH-47D	CH-53E
Antecedent DMC ($/FH)	$2,285	$5,644	$13,015	$21,927
Upgrade DMC ($/FH)	$2,702	$5,020	$7,470	$28,017
Predicted Upgrade c_{maint} (2)	$2,539	$6,017	$13,692	$34,403
Actual c_{maint}, Upgrade / Antecedent(2)	1.182	0.889	0.574	1.278
Scaled f_{H-S} c_{maint}, Upgrade / Antecedent	1.111	1.066	1.052	1.569
Antecedent f_{H-S}, $(WE^{0.4638} SHP^{0.5945})$	8,994	9,302	21,217	35,108
Upgrade f_{H-S}, $(WE^{0.4638} SHP^{0.5945})$	9,991	9,917	22,316	55,082

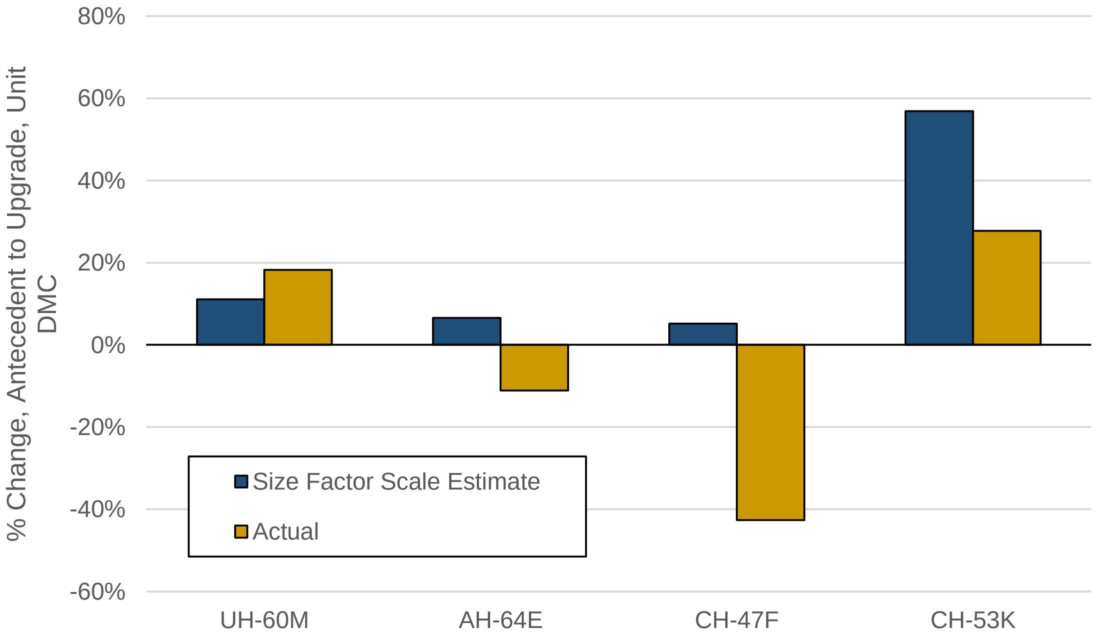


Figure 3-4. Predicted vs. actual direct maintenance cost using weight-based methods

Modeling of Reliability Cost Effects

To investigate the questions of relevance and feasibility of RAM modeling posed at the beginning of Chapter 3, an example cost analysis case is required which is indicative of reliability-targeted technology insertion. While each of the examples in Figure 3-4 may include some design features related to reliability and maintainability, the most pronounced discrepancy between actual and conventionally-predicted operating cost is observed in the D to F model upgrade of the CH-47 Chinook. The CH-47 is particularly useful as an example case study for cost modeling because nearly all of the upgraded systems which define the most current F model Chinook in relation to its predecessors are either specifically intended to improve reliability or offer RAM improvements as a secondary effect in addition to new capabilities. While possibly more germane to the design study of a medium utility aircraft, the UH-60 Black Hawk family incorporates additional design features and mission equipment in its upgrade progression which causes the UH-60M to have a higher operating cost than the UH-60L (Ref. 2-9) as Figure 3-3 also shows. This combination of competing design and technology effects obscures the reliability effect in a way not expected to be observed in the Chinook example.

CH-47D Helicopter (planespotters.net)

CH-47F (army-technology.com)

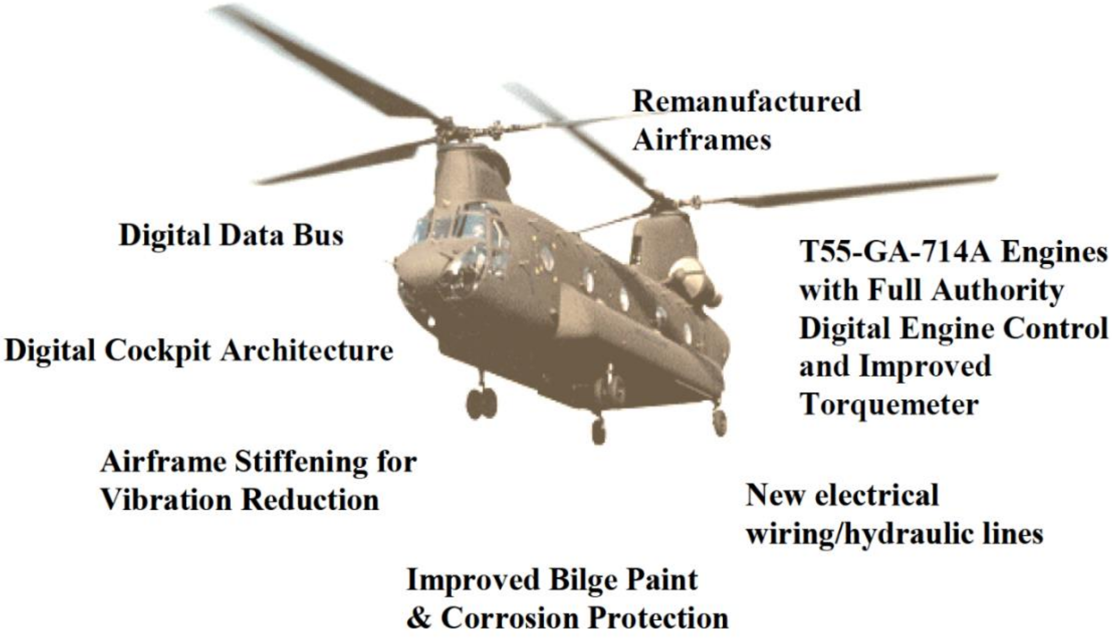


Figure 3-5. Upgraded design features of the CH-47F (Ref. 3-8)

Table 3-2. CH-47D and F basic design characteristics (Ref. 2-10, 1-179)

	CH-47D	CH-47F
Prototype Year of First Flight	1979	2001
Empty Weight (Approx.)	23,000 lb.	25,000 lb.
Power (Max Uninstalled)	8,000 hp	9,734 hp
Maximum Takeoff Gross Weight (Approx. Cargo Mission)	49,500 lb.	50,000 lb.

Figure 3-5, taken from Ref. 3-8 points out some of the distinguishing attributes of the CH-47F. The updated F-model Chinook model is clearly characterized by multiple reliability-improving design features. These include:

- Modernized airframe with improved durability and survivability and reduced vibration

- Monolithic machined structure (reduced component and fastener count)
- Advanced digital cockpit, Electronic Flight Instrument System (EFIS) Display and Controller
- Advanced Digital automatic flight control system
- Health and usage monitoring of dynamic components
- Upgraded engines featuring full authority digital control (FADEC) system and increased power
- Possible future provision for installation of new design, low maintenance "dry" rotor hub (Ref. 3-14)

Each of the new components listed above aligns with one or more principles identified by other works as a best practice for reliability and maintainability in rotorcraft. The modernized airframe, avionics, and electronics contribute to a reduced part count and a greater degree of accessibility for maintenance (Ref. 3-8, 3-11). The airframe additionally features improved protection to environmental fatigue factors such as corrosion (Ref. 3-10, 3-12). The additional measures taken in the airframe and rotor to absorb vibration serve to extend the life of the airframe itself as well as all of the subsystems throughout the fuselage, cabin, and cockpit. Multiple studies have identified vibration as a significant driving factor to reliability and cost (Ref. 3-2, 3-11, 3-12).

To assess the reliability and operating cost characteristics of the CH-47 D and F models, the two aircraft as described in Table 2-1 are modeled in the O&S module of the Bell PC-Based Cost Model as a set of component weights and configuration options. As mentioned in Chapter 1, Bell PC in its basic form represents a conventional parametric cost model of sufficient detail to estimate rotorcraft costs at the assembly and subassembly levels defined by Ref. 5-3. The time between overhaul (TBO) parameter within Bell PC's operating cost module can account for the improvement in scheduled maintenance, and the routine preventative and unscheduled maintenance dollar per flight hour components of operating cost can be adjusted using tech factors provided a relationship can be found or developed to quantify the decrease of cost in these terms along with the increase scheduled component service life effect.

Conventional O&S Cost Modeling Deficiencies

Tables 2-2 and 2-3 summarize the estimates of maintenance costs calculated in Bell PC for the two helicopters. The initial predicted results represent the unadjusted, uncalibrated output of the model. The results in Table 2-2 show the model predicts the conventional CH-47D maintenance costs with reasonable accuracy. The cost of parts in dollars per flight hour is estimated to within 10% accuracy, and the maintenance man-hours per flight hour is estimated to within 20% accuracy. On the other hand, the model's assessment of the more advanced CH-47F highlights the need for reliability-based adjustment of a conventional parametric model. Bell PC's maintenance module being primarily sensitive to size and configuration parameters as cost drivers, the uncalibrated model predicts dollars per flight hour and MMH/FH for the CH-47F on the same trend as the CH-47D. In reality, the advanced reliability features of the CH-47F nearly halve the newer helicopter's cost and maintenance requirements compared to its D model predecessor by virtue of the reliability improvements detailed in Ref. 3-8.

Table 3-3. CH-47D and F predicted versus actual maintenance metrics

	CH-47D Actual	CH-47D Predicted	CH-47F Predicted	CH-47F Actual
Unit Flyaway Cost FY15 $	--	--	\$25.24 M	\$28.14 M
Direct Maintenance Parts Cost, \$/FH	\$3,545	\$3,309	\$3,461	\$2,922
MMH/FH (Total)	9.20	10.76	11.07	4.80

Reliability-Augmented Cost Modeling

For this simplified example, a single tech factor can be derived to adjust the model for the cumulative effects of the reliability technologies applied to the CH-47F. From the estimated quantities listed in Table 3-3, the tech factors for maintenance operating cost and for maintenance man-hours respectively are

$$k_{OS} = \frac{c_{os}\ (Actual)}{c_{OS}\ (Predicted)} = \frac{\$2{,}922}{\$3{,}461} = 0.844 \qquad (3-2)$$

$$k_{MMH/FH} = \frac{MMH/FH\ (Actual)}{MMH/FH\ \ (Predicted)} = \frac{4.80}{11.07} = 0.434 \qquad (3-3)$$

These tech factors can be applied to the prediction of additional components of operating cost to further bolster the accuracy of the cost estimate. Besides maintenance, the Department of Defense organizes operating cost into Unit-Level Manpower, Unit Operations (fuel), Sustaining Support, Continuing System Improvements, and Indirect Support. Unit-Level Manpower indicates the cost of personnel directly associated with the operation and sustainment of the aircraft, including the crew, maintainers, and anyone the partial time of administrative personnel. Manpower requirements are calculated using the baseline 180 flight hours per year per aircraft stated in the CH-47F Selected Acquisition Report. Eqn. 1 from Appendix A is applied as Eqn. 3-4 assuming the aircraft maintain a 95% operational availability rate, with organic maintenance performed by enlisted personnel with one non-aviation officer assigned to every 10 enlisted maintainers. The crew of each aircraft is assumed to be two officers and one enlisted personnel. Annual salary and benefits costs for officers and enlisted are estimated as \$110,000 per year and \$75,000 per year respectively.

$$0.95 = \frac{1 - \frac{OPR}{N_{maint}}(MMH/FH)_{prevent}}{1 + \frac{OPR}{N_{maint}}(MMH/FH)_{correct}} \qquad (3-4)$$

Calculating N_{maint} using the both the originally predicted MMH/FH and the reliability-corrected MMH/FH for the CH-47F in Eqn. 3-4 yields the predicted and adjusted annual manpower costs shown in Table 3-4. The CH-47D’s manpower costs are assessed with reasonable accuracy using the assumptions and the MMH/FH estimates computed by Bell PC. The CH-47F’s manpower costs require the reliability adjustment factors obtained in Eqns. 3-2 and 3-3 to improve the prediction accuracy to a reasonable first estimate.

While the factor-based correction approach helps to correct the predictions of the operating cost components which follow from the maintenance cost, an even more conceptually powerful and generalized method would allow for an assessment of the technology itself without need for analogies to existing examples. The Logistics Management Institute (LMI) study completed by Long and Forbes (Ref. 3-5) provides one such example. The model supplied by the study predicts reliability improvement as a function of RDT&E investment. This approach is useful in this example because the data source of the O&S costs – the Selected Acquisition report of the CH-47F (Ref. 2-10) – also supplies the amount of RDT&E made. From the design features detailed in Ref. 3-8 it is also assumed that nearly all of the RDT&E investment can be linked to reliability improvement.

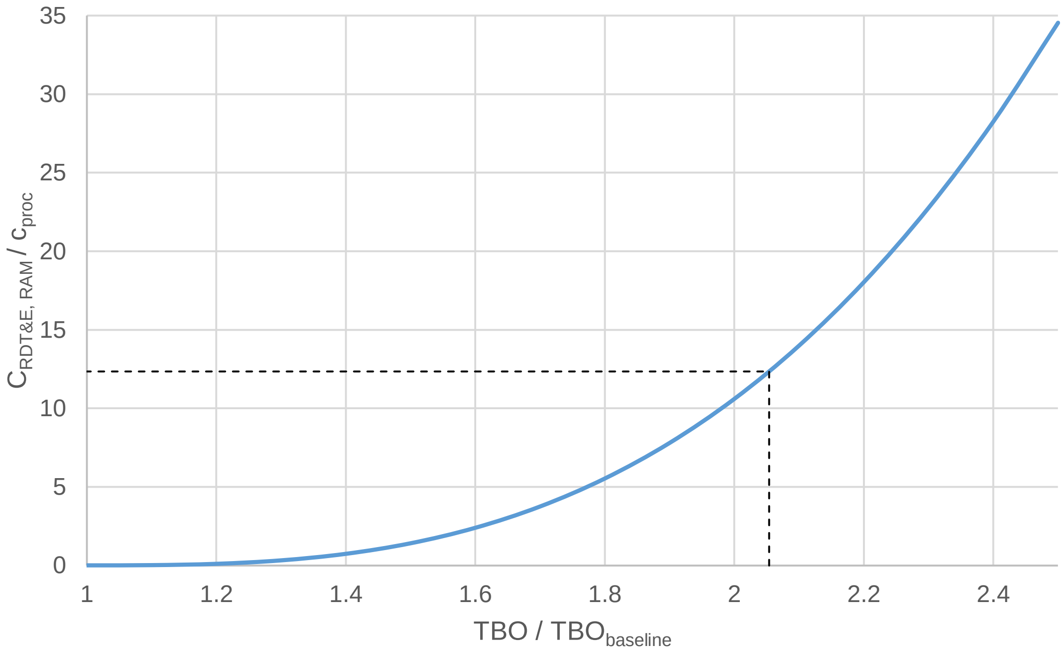


Figure 3-6. Estimation of reliability improvement based on RDT&E expenditure from Ref. 3-5

Using the function in Figure 3-6 supplied by Ref. 3-5, a second set of reliability improvement factors are derived according to the equations:

$$C_{RDT\&E} = \$223.8\ M,\ c_{proc} = \$18.13\ M \qquad (3-5)$$

$$\frac{C_{RDT\&E}}{c_{proc}} = 12.35 \rightarrow \chi_{TBO} = 2.054 \qquad (3-6)$$

$$\chi_{MMH/FH} = \frac{1}{\chi_{TBO}} = 0.487 \qquad (3-7)$$

Applying these factors to the predicted cost of the CH-47F yields similar results compared to the manually corrected analogy method. The advantage of extending the parametric methodology to include RAM consideration as is done in Ref. 3-5 is the increase in generality. The user requires no prior example of improvement to base the expected change of the new program upon, and is not forced to make the assumption of the technology being equally applicable and effective across platforms. Ref. 3-5 also provides a method to estimate the necessary RDT&E investment needed to improve reliability when this quantity is not known a priori.

Table 3-4. CH-47F predicted and adjusted manpower requirements

		CH-47D Predicted	CH-47F Predicted	CH-47F (Manually Corrected)	CH-47F (Model Adjusted)
Direct Maint. (DMC), $/FH	Estimated	$3,309	$3,461	$2,540	$2,556
	Actual	$3,545	$2,922	$2,922	$2,922
	Error	7.13%	18.45%	13.07%	12.53%
MMH/FH	Estimated	10.76	11.07	4.80	5.39
	Actual	9.20	4.80	4.80	4.80
	Error	16.96%	130.63%	--	12.29%
Manpower ($/AC/Yr)	Estimate	$692.37k	$700.35k	$489.13k	$508.04k
	Actual	$811.96k	$494.58k	$494.58k	$494.58k
	Error	14.73%	41.60%	1.10%	2.72%

Finally, the effects noted in the maintenance and manpower cost examples can be rolled up to a total annual operating cost calculation to demonstrate the overall impact of adding reliability effects to the cost model. Table 3-4 compares the predicted direct cost elements compared to their actual values as reported in Ref. 2-10. Sustaining support and continuing system improvements are estimated as 25% of the total of manpower and maintenance costs for the purpose of this simplified example. The RAM-adjusted CH-47F predicted annual operating cost displays better than 30% improvement in accuracy over the original prediction of Bell PC in its uncalibrated mode.

From this basic example of operating cost assessment performed on the legacy Chinook family platforms, the emerging results imply in relation to Research Questions 1 and 2 that (1) reliability and maintainability do indeed drive operating costs in addition to size and configuration, even if the effect is implicit to a traditional parametric type of analysis; (2) technology which improves reliability and maintainability can yield a substantial impact to operating costs; and (3) including RAM effects on top of a basic parametric cost assessment method has the potential to improve the veracity of the results it generates.

Reliability Design Effects

It is apparent from the topics covered in the literature sources as well as the basic O&S model demonstration performed on the CH-47 D and F aircraft that the operating and support components of life-cycle cost feel the most immediate effects of an aircraft's reliability and maintainability qualities. Operating and support costs are typically the largest driver of life-cycle cost for aircraft, and thus have the largest influence on the utilization and long term viability of an aircraft (Ref. 3-1). As a major driver of the maintenance components of O&S, reliability and maintainability accordingly have received the majority of attention within the already limited number of conceptual studies related to RAM.

In spite of the importance of O&S costs, a study which considers only the O&S impact of RAM effects to the exclusion of the acquisition phase of the life-cycle is inherently limited in its usefulness to an acquisition strategist because it does not consider any affordability tradeoff in the application of solutions as would be required by the type of business case analysis mandated by the Department of Defense for major acquisition programs. In the absence of a formal method to perform cost trades, the decision maker would be left to perform a rough comparison of the speculated technology against the costs of previous efforts or to depend purely on speculation to evaluate the cost effectiveness of reliability investment.

The effect of RAM on acquisition cost depends on the level of reliability and maintainability designed and built into the aircraft. In most cases, reliability investment is not specifically named and quantified in aircraft development programs. In such cases, the analysis cannot progress beyond the baseline level of reliability implicit to conventional parametric cost models for maintenance dollars per flight hour and maintenance man-hours per flight hour. If specific development effort is made to improve reliability beyond the contemporary state of the art, the acquisition cost impact depends on the level of RDT&E investment devoted to the reliability engineering and the procurement cost of implementing RAM technology and design features in the new aircraft. The impact to design and acquisition cost also depends on the nature of the specific reliability or maintainability measures. Figure 3-7 depicts the desired modeling effects as a set of factors, $[k_i]$, which relates to weight, procurement, and development cost, and is a component of the set of RAM characteristics D_{RAM} described in Eqn. 2-3.

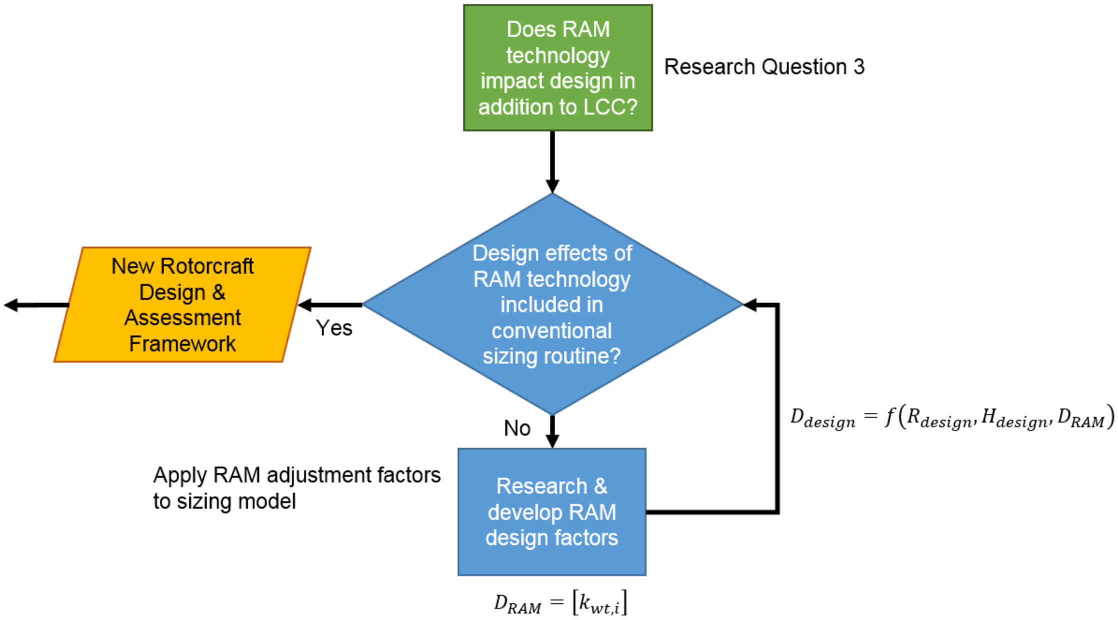


Figure 3-7. Design process with reliability modeling

A select number of studies have provided building block methodologies and cost relationships, pieces of which could be integrated and collectively implemented for use in quantifying the acquisition cost aspects of RAM engineering in forms suitable for conceptual analysis. Unger (Ref. 2-6), provides an early example of design and reliability assessment, using a simple estimate of maintenance man-hours per flight hour (MMH/FH) as a metric of overall reliability. Another of the earliest examples of affordability assessment of reliability technology comes not from conceptual design, but from an experimental effort performed by Veca (Ref. 3-2) in 1974. Veca documents and compares the operating costs of two fleets of helicopters, one of which has received bifilar systems to reduce vibration and component fatigue damage. Although the scope of Veca’s study is limited to one particular add-on technology on one specific pre-existing helicopter where the design impact is minimal and the investment cost related to the subsystem in question is neglected, the documentation of the work provides a basic business case evaluation framework which could be modified to include conceptual design impact, RDT&E costs, and long-term economic effects in a broader spectrum assessment of multiple RAM technologies. As already mentioned in Chapter 2, Unger (Ref. 2-6) produced a similar top level assessment of reliability and maintainability, this time applied in a conceptual design environment and generalized to multiple different types of aircraft, although the analysis did not directly consider the life-cycle cost implications of the differences in reliability and maintainability between the different aircraft. More recently, Coy (Ref. 3-3) provides an example of the type of conceptual design – centric study with simultaneous cost assessment which can be used to draw conclusions about acquisition strategy. Coy approaches the investment cost of technology insertion using an inverse method of first deriving the cost improvement in maintenance, fuel efficiency, and procurement price that would need to be achieved for rotorcraft concepts to be commercially competitive against conventional airliners. The savings realized in the O&S phase is then left as a contingency budget of which the total value can be compared to the cost of previous rotorcraft research and development efforts. While Coy's study carries design and cost analysis far enough to reach significant conclusions on affordability and technology feasibility in the context of the commercial aircraft scenario considered, the cost analysis depends on top level overall system parametric CER's and the ground rules of the analysis assume a commercial aviation application. Additional insight could be found by employing more detailed procurement and maintenance cost models, directly computing RDT&E costs, and extending the design survey and cost analysis philosophy to a government acquisition scenario in addition to the commercial case considered. The sensitivity study performed by Dellert (Ref. 2-7) provides one of the few recent references to link multiple concepts together. Similar to the Veca study, Dellert examines the life-cycle cost impact of changes to a helicopter's reliability and maintainability, this time in an analytical rather than experimental environment, and furthermore extends the results to program-level affordability metrics.

The works of Veca, Unger, Coy, and Dellert provide examples solutions to different aspects of the design-cost-reliability problem in rotorcraft. Unger performs reliability assessment along with conceptual design, but does not consider the cost impact. Coy performs cost assessment along with conceptual design, but leaves reliability as a characteristic implicit to the historical cost model. Veca and Dellert analyze the life-cycle cost ramifications of reliability and maintainability, but consider the air vehicle as a fixed quantity with limited change to acquisition price commensurate with reliability improvement – in effect assuming the reliability is free to both the aircraft performance and the program cost. None of the works consider all three of the core disciplines shown in Figure 2-1 in an interrelated manner.

Modeling of Reliability Design Effects

One possible obstacle to the lack of analytical integration with respect to reliability effects is the identification of sufficiently general conceptual modeling relationships. Few conventional models provide the flexibility to quantify the impact to rotorcraft subsystems in terms of the changes to both design characteristics and investment costs when reliability and maintainability are improved above an established baseline state of the art. One such conceptual element is provided within the Bell PC cost model by Biggs and Key (Ref. 3-4). Although not a design tool, the Bell PC cost model does include a function which recommends adjustment of dynamic components to include additional weight if the service life of the component, measured in mean time between removal (MTBR), is set by the designer above 1,500 flight hours as shown in Eqn. 3-1 and Figure 3-8.

$$k_{wt} = \frac{w_{i,TBO}}{w_{i,1500}} = \left(\frac{TBO}{1{,}500}\right)^{0.05418} \qquad (3-1)$$

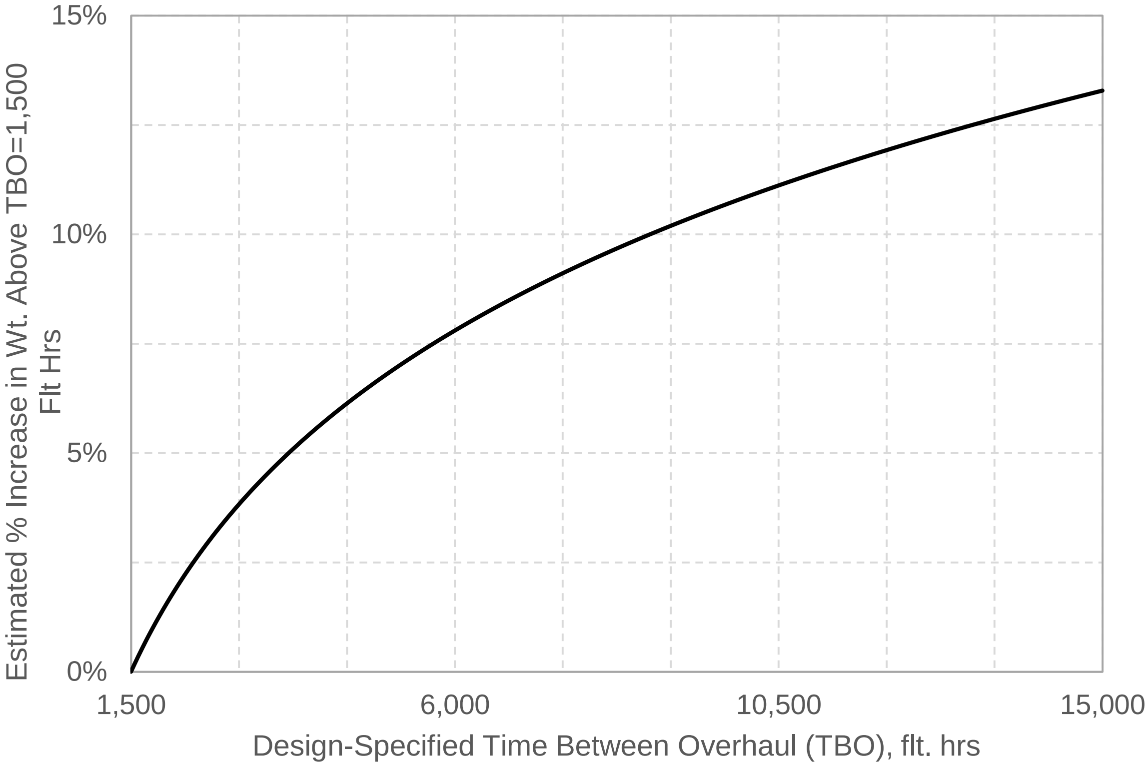


Figure 3-8. Biggs & Key (Ref. 3-4) reliability factor for weight adjustment

Producing a functionally similar parametric relationship through a more generalized approach in Equation 3-2, Long, Forbes, Hees, and Stouffer at the Logistics Management Issue (Ref. 3-5) used statistical regression to survey multiple reliability improvement initiatives of differing extent and degree of improvement across a variety of aerospace platforms and subsystems. Their finding, shown in Figure 3-9 (the same relationship used in the earlier CH-47 assessment example), concludes that a single exponential function regression curve accurately predicts the RDT&E cost of all the surveyed projects.

$$\frac{\Delta C_{RDT\&E}}{c_{proc}} = 10.597\left(\frac{MTBR_{new}}{MTBR_{old}} - 1\right)^{2.915} \qquad (3-2)$$

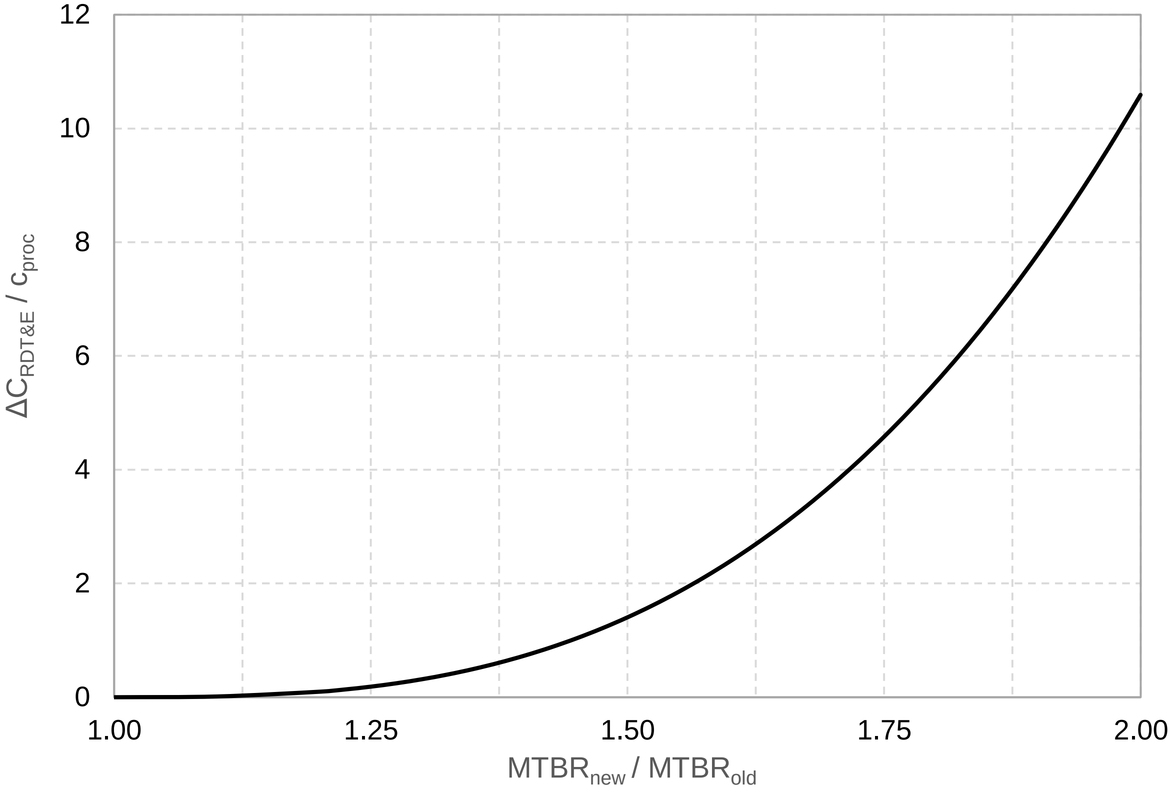


Figure 3-9. RDT&E Investment required for RAM improvement (Ref. 3-5)

Recent research inspired by the relationships surveyed in the literature has found a similar relationship in the procurement cost of turboshaft engines for rotorcraft. Ref. 3-6 uses the same procedure of statistical regression used to produce the parametric weight and cost estimating relationships exemplified in Figure 3-9 which also drive NDARC and Bell PC. Equation 3-3 gives the newly developed cost estimating relationship for procurement cost per turboshaft engine. Eqn. 3-3 replicates the finding of a reliability parameter – in this case time between overhaul TBO, the same RAM parameter used in the Bell PC O&S model – as a statistically significant cost driver to procurement as well as O&S cost. Applying the same question of accuracy posed at the beginning of the chapter with regard to predicted O&S cost in Figure 3-1, the results of the new model shown in Figure 3-10 and Table 3-5 show that Eqn. 3-3 provides at least as much accuracy (less than 20% absolute error on average) as contemporary parametric equations used to determine the weight of aircraft components in conceptual rotorcraft design (Ref. 3-13).

As Figure 3-11 shows, Ref. 3-6 also finds the same improving trend in engine overhaul interval observed by Carlson in Fig. 1-11. Viewing this trend in relation to the overall trend in engine procurement price plotted in Figure 3-12 also suggests that reliability improvement may have actively contributed to the increase in cost per horsepower of turboshaft propulsion shown by its outpacing of standard economic inflation.

Estimated procurement cost of Nth production engine in 2015 dollars (Ref. 3-6):

$$\hat{c}_{eng} = 5.3080\, SHP^{0.81520} SP^{0.83044} Pr_{avg}^{0.75567} TBO^{0.36565} \times (Yr - 1955)^{-0.24750} \times N_{eng}{}^{-0.07585} \times H \qquad (3-3)$$

$$\text{Where} \quad H = \kappa_{Mar}\kappa_{FADEC}$$

$$\kappa_{Mar} = \begin{cases} 1.0 & \text{Non}-\text{Marinized} \\ 1.1644 & \text{Marinized} \end{cases}$$

$$\kappa_{FADEC} = \begin{cases} 1.0 & \text{No FADEC} \\ 0.7298 & \text{FADEC equipped} \end{cases}$$

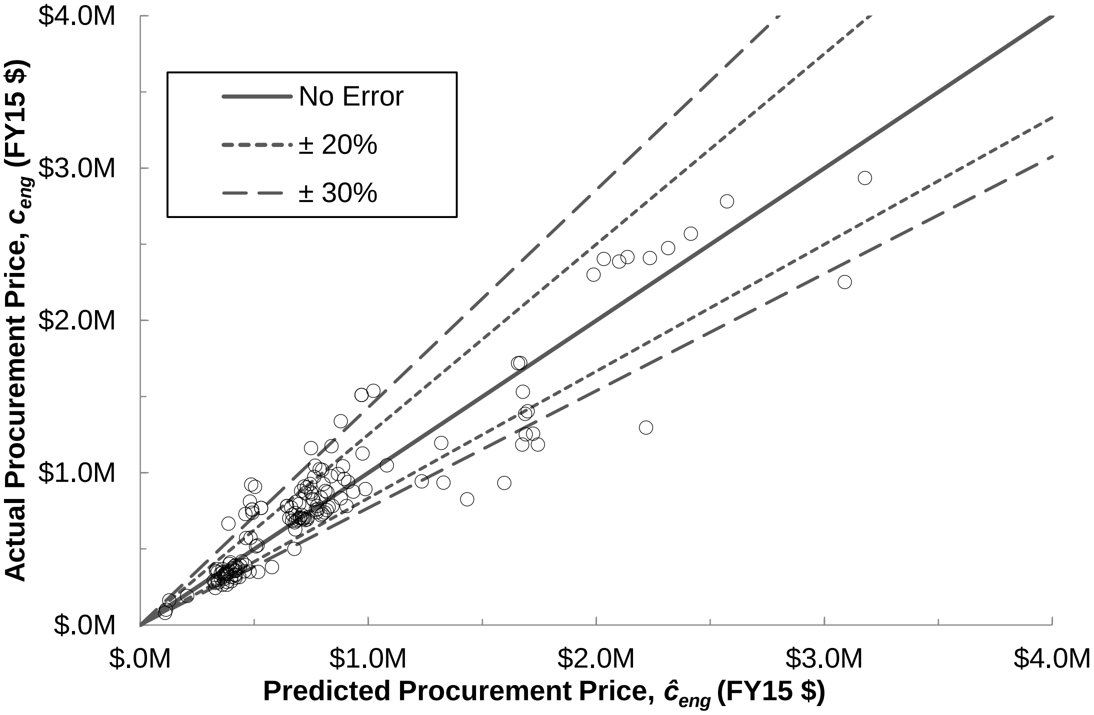


Figure 3-10. Actual vs. Predicted engine unit procurement price (Ref. 3-6)

Table 3-5. Predicted engine procurement cost error trends by decade (Ref. 3-6)

	Avg. Absolute Error	Number of Data Points
1950-1959	23.04%	5
1960-1969	21.57%	59
1970-1979	15.92%	23
1980-1989	18.99%	30
1990-1999	6.77%	20
2000-2009	16.25%	13
2010-present	3.88%	5
Overall	17.35%	155

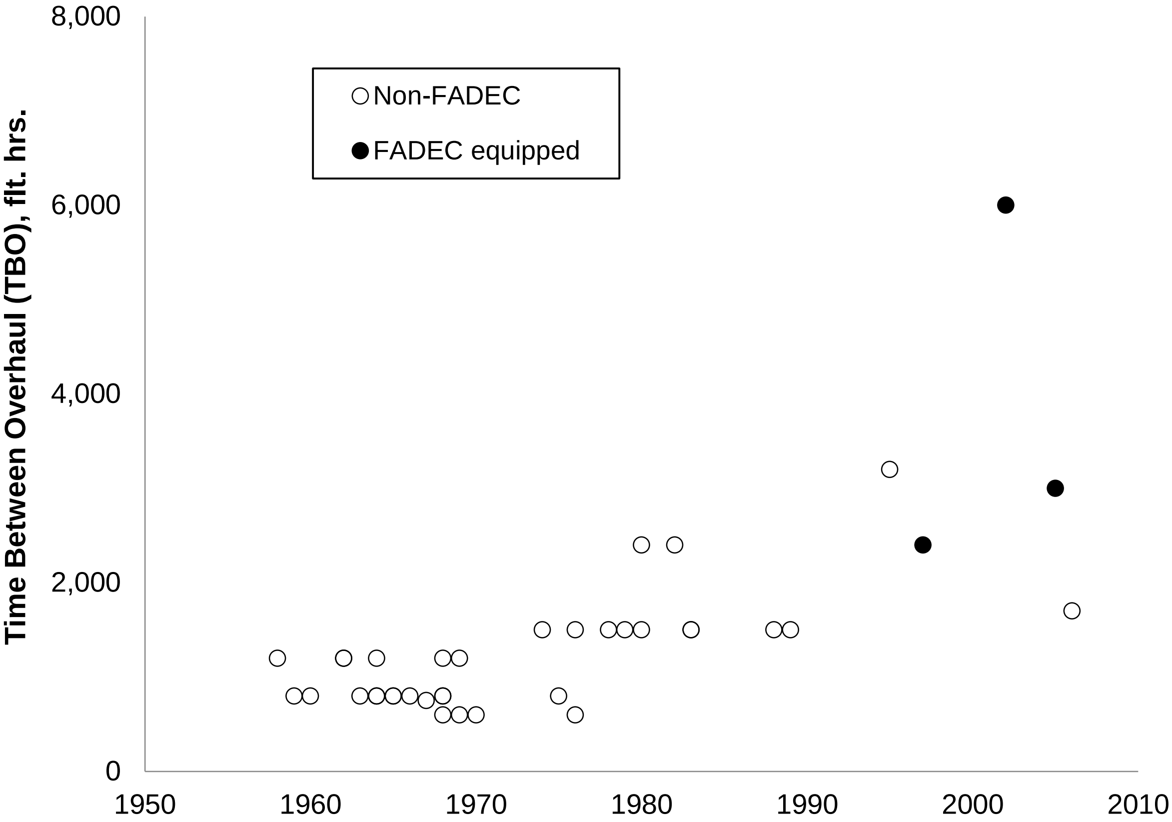


Figure 3-11. Historical trend in turboshaft engine design TBO (Ref. 3-6)

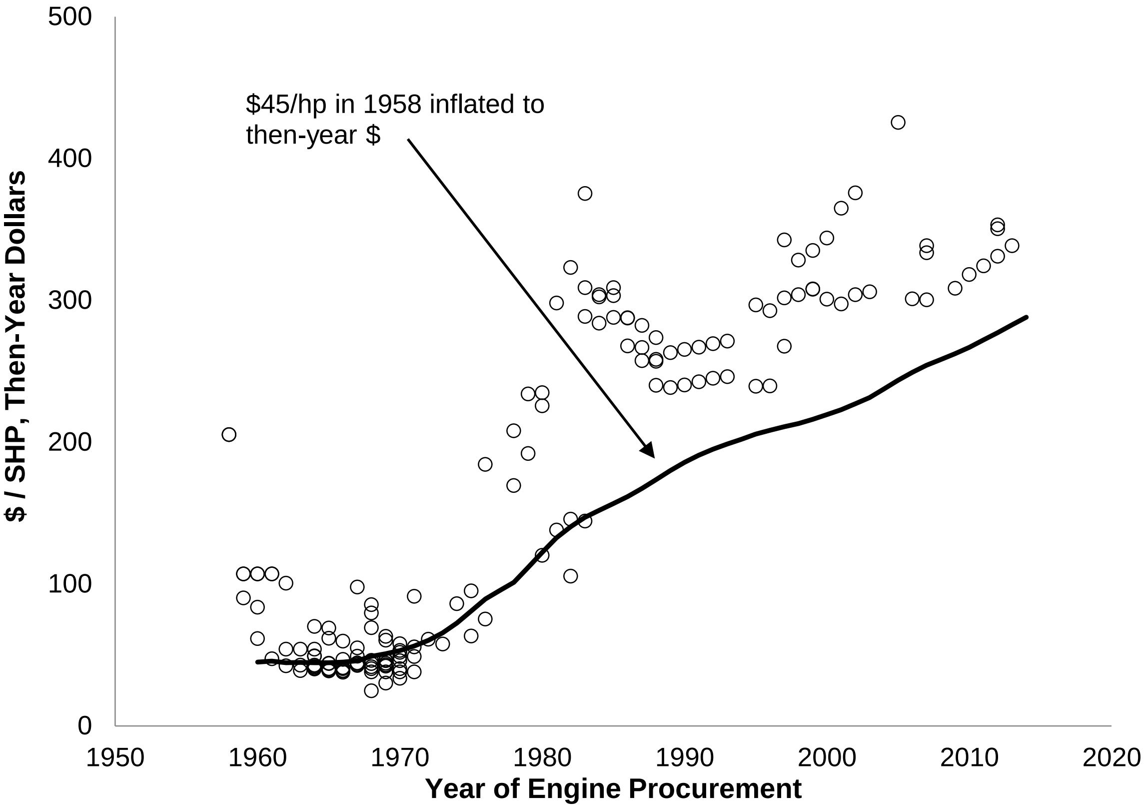


Figure 3-12. Historical trend in turboshaft $/hp procurement price (Ref. 3-6)

Based on the surveyed literature linking the physical effects of reliability to life-cycle cost and the preponderance of statistical analysis evidence correlating RAM effects to cost as a modeling effect for conceptual analysis, the study concludes in response to Research Question 3 that there is indeed a design effect of RAM improvement on the sizing of a highly rotorcraft. In addition to the influence of reliability on O&S expenses, two acquisition cost effects are identified: (1) the change in size and performance of the rotorcraft; and (2) the direct increase in acquisition cost that is caused by the upfront expenses of implementing reliability-enhancing technology. Direct application of the trends observed in the literature review to the conceptual aircraft generated in the baseline design process is now needed in order to answer the degree to which reliability consideration affects sizing, and as hypothesized by Research Question 4, whether an optimum level of reliability exists for a given conceptual design and life-cycle scenario.

Reliability Assumptions for Concept Assessment

Research Questions 3 and 4 deal with the possibility of incorporating RAM requirements into early aircraft synthesis, leading to the subsequent possibility of design optimization focused on reliability and maintainability. As these questions necessitate conducting a set of sensitivity studies on design, cost, and reliability, the baseline designs also require baseline RAM assumptions. The historical trends plotted in Figures 1-10, 1-11 and 3-3 provide the basis of the baseline RAM quantities enumerated in Table 3-6. Considering that the assumptions related to weight and performance were selected to represent an appraisal of the technology portfolio available to the helicopter designer in the future vertical program timeline of 10-20 years into the future, the baseline RAM assumptions are similarly fixed to the upper limit or slightly better than the upper limit of the service life and time between overhaul observed by Carlson.

Table 3-6. Baseline RAM assumptions for scheduled and routine corrective (unscheduled) maintenance.

	RAM Baseline	Weight Adjustment	Cost Adjustment
Drive, Rotor, Flt. Ctrl.	5,000 Flt. Hrs. TBO	Biggs & Key (Eqn. 3-1)	LMI (Eqn. 3-2)
Airframe	10,000 Flt. Hrs. Service Life	Biggs & Key (Eqn. 3-1)	LMI (Eqn. 3-2)
Engines, Propulsion	6,000 Flt. Hrs. TBO	--	LMI (Eqn. 3-2), Scott (Eqn. 3-3)
MMH/FH	$\chi_{MMH/FH} = 1$ $\kappa_{MMH/FH} = 0.75$	--	LMI (Eqn. 3-2)
Unscheduled Maintenance	$\chi_{unsched} = 1$ $\kappa_{unsched} = 0.75$	--	LMI (Eqn. 3-2)

The factors related to maintenance man hours per flight hour and unscheduled maintenance are applied to Bell PC's O&S cost estimate relationships in a similar manner to the NDARC tech factor terms. In the same manner that an improved service life is translated into a tech factor applied to the Bell PC cost estimating relationships based on service life categorized components as in Eqn. 3-3, the MMH/FH and unscheduled component equations are modified by tech factors which are related to the service life tech factors χ_{TBO} through a maintainability factor κ as in Equations 3-8 and 3-9.

$$c_{O\&S/FH,TBO} = \frac{f_{O\&S}}{\chi_{TBO} TBO} \tag{3-4}$$

$$\chi_{TBO} = \frac{TBO_{new}}{TBO_{old}} \tag{3-5}$$

$$MMH/FH = \chi_{MMH/FH} f_{MMH/FH} \tag{3-6}$$

$$c_{O\&S/FH,unsched} = \chi_{unsched} f_{O\&S,unsched} \tag{3-7}$$

$$\chi_{MMH/FH} = 1 - \kappa_{MMH/FH} \left(1 - \frac{1}{\chi_{TBO}}\right) \tag{3-8}$$

$$\chi_{unsched} = 1 - \kappa_{unsched} \left(1 - \frac{1}{\chi_{unsched}}\right) \tag{3-9}$$

The baseline reliability values and relationships in Table 3-1 serve to complete the linkages of the new design and reliability-cost-based design. The study can now proceed to a set of design excursions and sensitivities from the baseline rotorcraft designs to measure the impact of reliability and maintainability on aircraft design and life-cycle cost.

CHAPTER 4

ROTORCRAFT DESIGN METHODS

In order to accurately represent the impact of reliability to rotorcraft conceptual design and total ownership cost, the proposed design framework requires a pertinent sets of design specifications, technology assumptions; and a life-cycle cost scenario. Performance specifications expressed as design conditions and design missions in effect are the reverse of a performance analysis problem. Instead of starting from an assumed aircraft technical description and predicting the performance capabilities, the engineer develops the technical characteristics of the aircraft from the desired performance capabilities. While design conditions can often include a detailed set of cruise, hover, and maneuvering data points, this work will focus primarily on the cruise and hover conditions which distinguish rotorcraft from other types of aviation in terms of both performance and reliability, as well as the extended range and stressing atmospheric requirements demanded of rotorcraft by current operational considerations. The available details of one particularly important and recent set of design conditions related to the Army’s Future Vertical Lift (FVL) medium aircraft are given in Table 4-1.

Table 4-1. Potential future military VTOL mission requirements (Ref. 4-1)

Requirement	Performance
Payload	12 passengers + equipment
Range	424 kilometers (229 nautical miles) radius + station time + reserve
Cruise Speed	230 knots sustained cruise
Atmosphere	6,000 feet, 95°F on objective operating capability

Design Mission Selection

In spite of the plateau in the efficiency of production rotorcraft demonstrated by Figures 1-4 and 1-5, multiple studies conducted as early as the 1950's have investigated the hypothetical efficiency benefits of advanced rotorcraft. A previous literature search of these studies (Ref. 4-2) was leveraged as an alternative to taking the design mission as a simple assumption in order to help establish a contextual background of sizing conditions against which the FVL type of mission requirements can be compared.

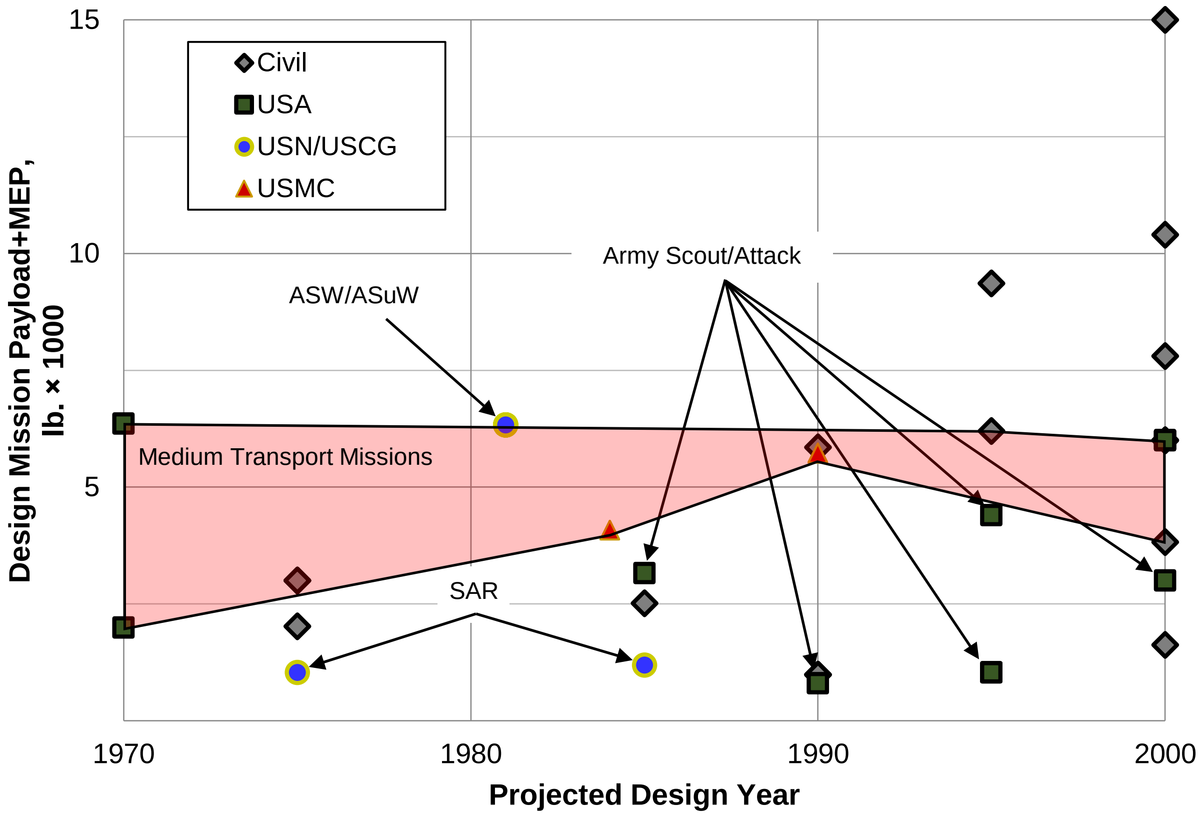


Figure 4-1. Trends in design mission payload used in sizing studies of future rotorcraft.

Figure 4-1 shows that the utility transport missions available in the literature have focused on a design capability of between 2,500 and 6,000 pounds of payload and mission equipment. Helicopters designed for this type of load are often referred to informally as "medium" in the rotorcraft industry, and represent the largest piece of the U.S. military rotorcraft inventory. Assuming 200-300 pounds of payload per passenger, the FVL medium mission falls within this categorization. Plotting the total effective design mission ranges in Fig. 4-2 corresponding to the payloads shown in Fig. 4-1 shows that medium utility design missions have consistently focused on 300 to 400 nautical miles of total range, more recently looked at mission of up to 600 nautical miles of total range.

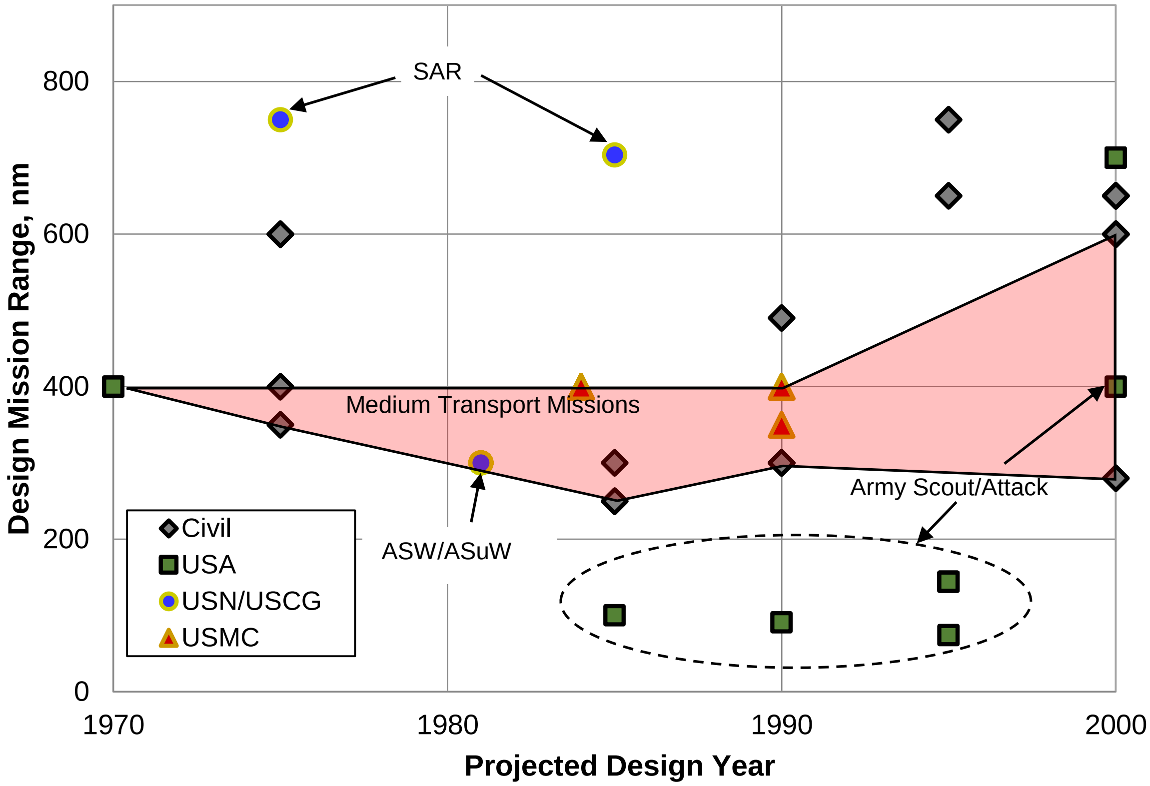


Figure 4-2. Trends in design mission range used in sizing studies of future rotorcraft.

Of the design missions plotted in Fig. 4-2, those with appreciable loiter and hover time not including initial takeoff and final landing segments are outside of the set of medium transport/utility missions. As shown in Figure 4-3, these missions include scout & observation, search & rescue (SAR), and anti-surface/anti-submarine warfare (ASW/ASuW). With the exception of SAR missions, which assume a smaller crew and passenger load, the general trend among hypothesized design missions up to *the year 2000* emphasized either range or station time, but not both. Due to the interest in a multirole medium FVL aircraft fulfilling both utility and attack aircraft, Figure 4-3 speculates up to

30 minutes of station time built into an FVL-like design mission. Historical precedent exists for this level of on-station capability in the Army's and the Marine Corps' historical employment of utility and attack airframe commonality in the H-1 airframe, not only historically across services in early UH-1 models, but also in the Marine Corps' present employment of a high degree of commonality across the UH-1Y transport and AH-1Z attack helicopters (Ref. 4-3).

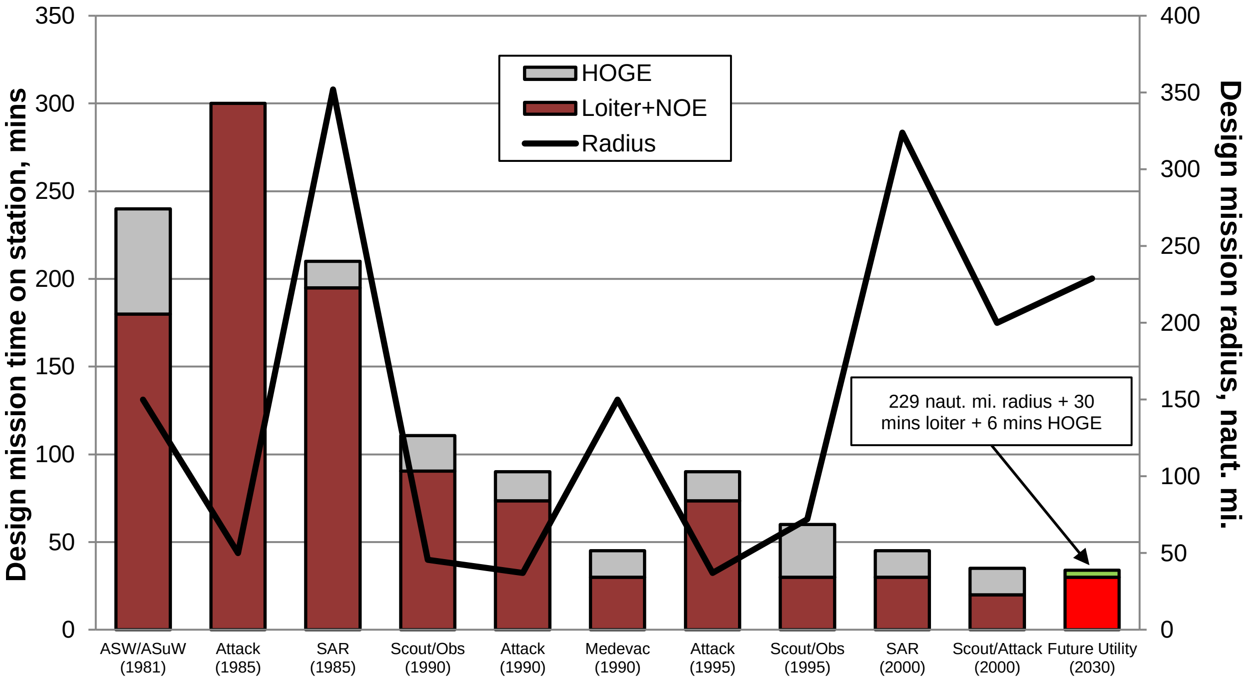


Figure 4-3. Trends in design mission time on station used in sizing studies of future rotorcraft.

When compared to previously-used range, payload, and atmospheric requirements, the projected JMR and FVL operational needs for payload and range are generally in line with most of the theorized military missions, as evidenced by the future mission's place near the very center of the graph in Fig. 4-4. The differentiating requirements, as shown in Fig. 4-3, is that the future utility mission retains customary transport mission requirements along with the time on station requirements and additional speed and environment requirements. The multirole combination of these requirements is particularly stressing because the aircraft must now cruise efficiently enough to carry fuel for loiter and hover at its midpoint objective area, then return to base while retaining its full payload weight. Based on the trends observed in previous conceptual design studies, the baseline design mission for this study is of the form depicted in Figure 4-5, featuring extended cruising range for operational reach and also including midpoint loiter and hover segments. The reserve fuel segment of the mission is a 30 minute loiter period flown at the best endurance speed of the aircraft in keeping with FAA Part 91 mission planning regulations (Ref. 4-4).

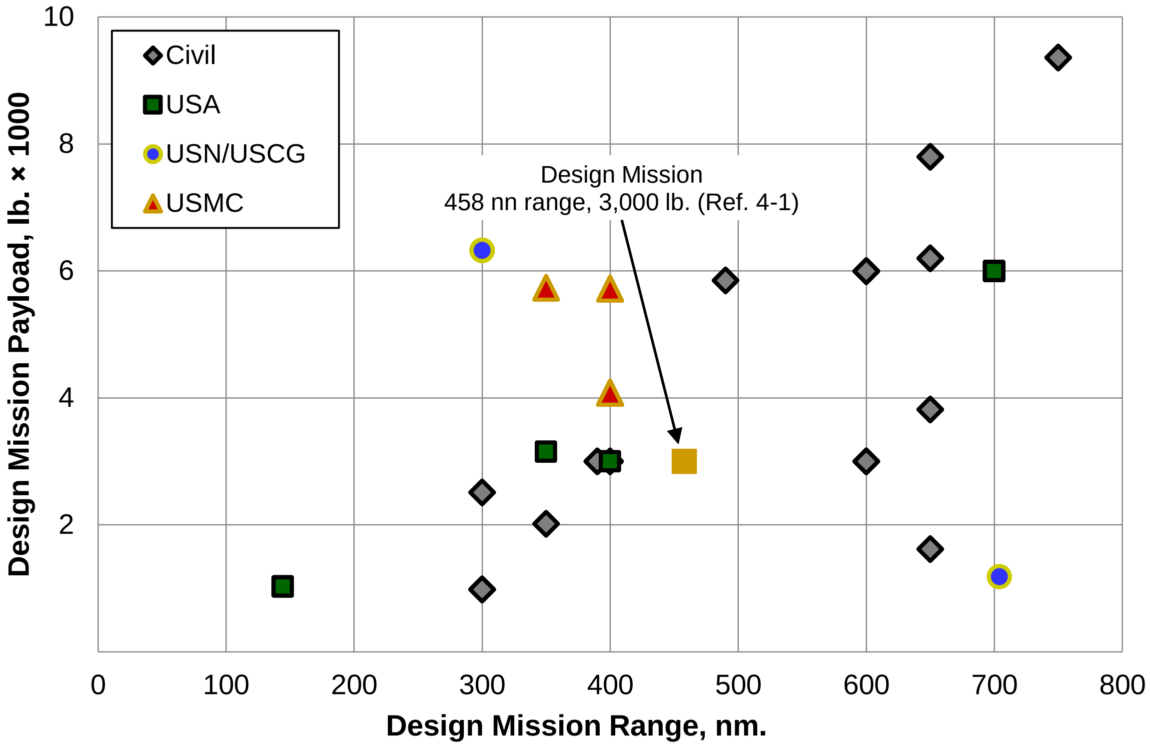


Figure 4-4. FVL-like medium design mission in the historical context of payload-range design mission combinations

The mission ranges examined by the design studies in Fig. 4-2 and 4-4 represent substantial growth beyond the capabilities of the existing legacy rotorcraft fleet. The need for increased cruise efficiency implied by these requirements seems to correlate to a general shift in designer preference for advanced configurations such as compounds and tiltrotors. As already noted in Figure 1-7, these advanced configurations offer the potential to fly efficiently at faster speeds over longer distances. This study adopts the same design preference in order to measure the effects of reliability and maintainability on rotorcraft design and life-cycle cost while simultaneously remaining focused on the impact to the potential future requirements which are currently of greatest interest in the VTOL community.

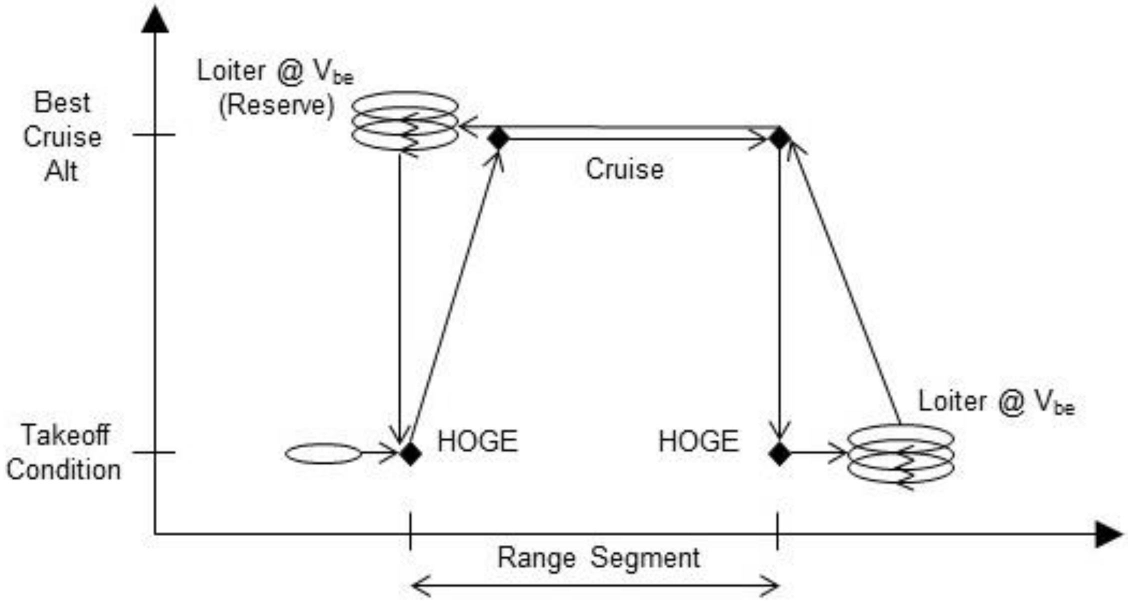


Figure 4-5. Generic mission form including range, loiter, and midpoint HOGE segments.

Rotorcraft Configuration Assumptions

Two advanced configurations, a tiltrotor and a lift-offset compound helicopter, will be sized to the design mission profile and range. An advanced helicopter, while necessarily slower and less efficient in cruise, is also sized in order to maintain the generality of the study across rotorcraft configurations. The helicopter is retained in the design study purely to keep a cost and reliability point of comparison with the advanced configurations, in spite of the fact it lacks sufficient speed capability and scales above the allowable size footprint due its large single main rotor. Comparison of the different configurations also allows for quantification of the reliability and maintainability impact within the context of the inherent differences in weight, performance, and complexity between the two advanced configurations and the more mature,7 conventional platform represented by the helicopter. Winged compounds are excluded from this design study because they suffer the same challenge in operational footprint as the single main rotor helicopter while also adding the complexity of an advanced configuration.

Selection of a particular configuration implies a selection of feasible cruise speeds due the fundamental efficiency limits of the different lift, thrust, and structural mechanisms at a given level of technology. Figure 4-6 shows that the consensus among previous design studies is that the conventional helicopter design is viable up to maximum cruise speeds of about 170 to 180 knots. Tiltrotor and compound designs become most prevalent above 180 knots, realizing their full potential when designed to a sustained cruise speed of at least 225 knots. This trend in design practice closely matches the cruise speed capability given in Table 4-1.

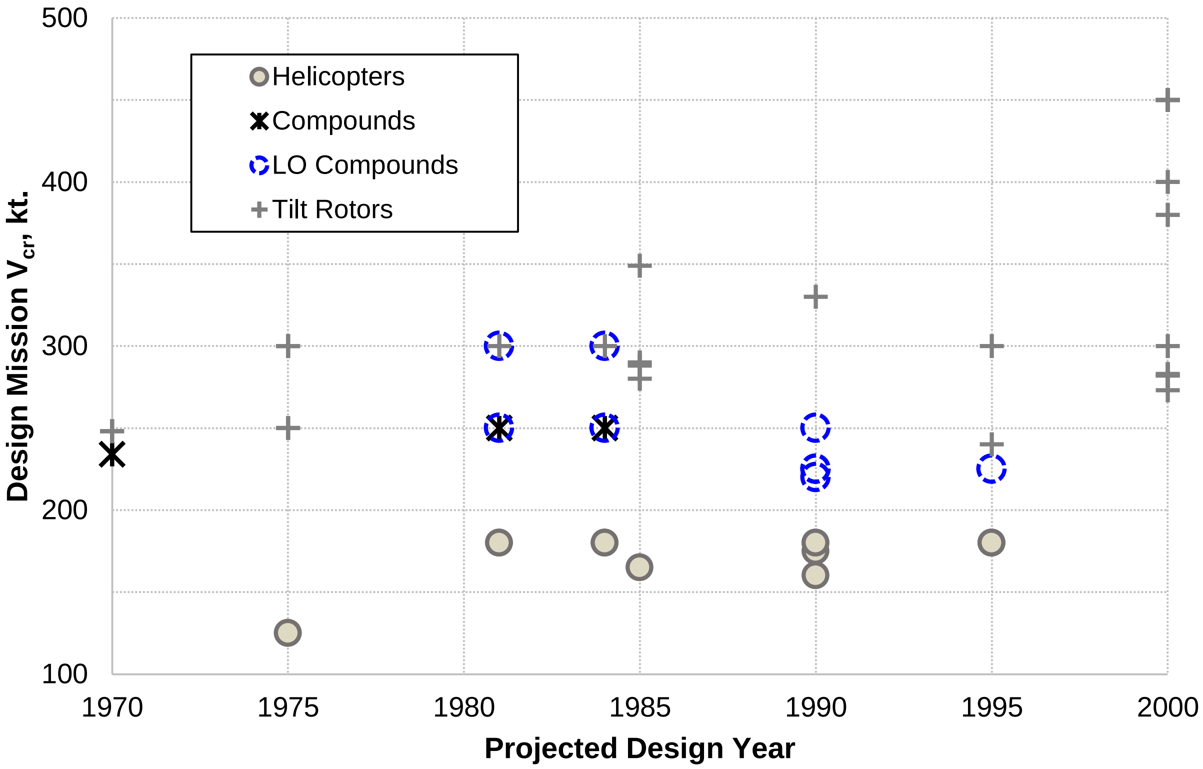


Figure 4-6. Design study trends in cruise speed and configuration

Sizing Condition Selection

Table 4-2 and summarizes the parameters of the mission of the form shown in Fig. 2-5 which is used as the sizing mission in this study. The 4,000 feet, 95°F conditions selected for takeoff and midpoint hover segments were chosen based on their prevalence in design missions for Army rotorcraft as shown in Fig. 4-7. The 4k95 design point also balances acceptable off-design capability at 6k95 while avoiding the overwhelming cost impact of designing for full capability at such a rare set of conditions. No other specific atmospheric requirements are applied except that cruise occurs at conditions not less than the density altitude corresponding to 4,000 ft., 95°F, with each aircraft allowed to cruise at an optimal altitude if above 4k95.

Table 4-2. Design Study Mission Description

Segment	1	2	3	4	5	6	7	8	9	10
Type	Warmup	HOGE	Climb	Cruise	HOGE	Loiter	Climb	Cruise	HOGE	Reserve
Atmos.	4k95	4k95	--	Best ISA	4k95	4k95	--	Best ISA		4k95
Power	100% MCP	90% MRP	100% IRP	100% MCP	100% MRP	100% MCP	100% IRP	100% MCP		100% MCP
Speed	--	--	Best Climb	≥225 kts	--	V_{be}	Best climb	≥225 kts		V_{be}
Distance	--	--	Range credit	229 nm (424 km)	--	--	Range credit	229 nm (424 km)		--
Time	2 mins	2 mins	--	--	2 mins	30 mins	--	--	1 min	30 mins

The operational considerations listed at the bottom of Table 4-3 provide an upper limit to aircraft footprint which implies a general conformity with the existing aviation infrastructure of the joint services. Limitation of the operating dimensions to no greater than the V-22 (Ref. 4-5) recognizes the growth in size expected even in spite of advanced technology due to the stressing set of performance requirements employed for the study. Restriction of disc loading to no more than 20 lb/ft^2 allows for landing and unloading at unimproved sites with loading and offloading of personnel and equipment.

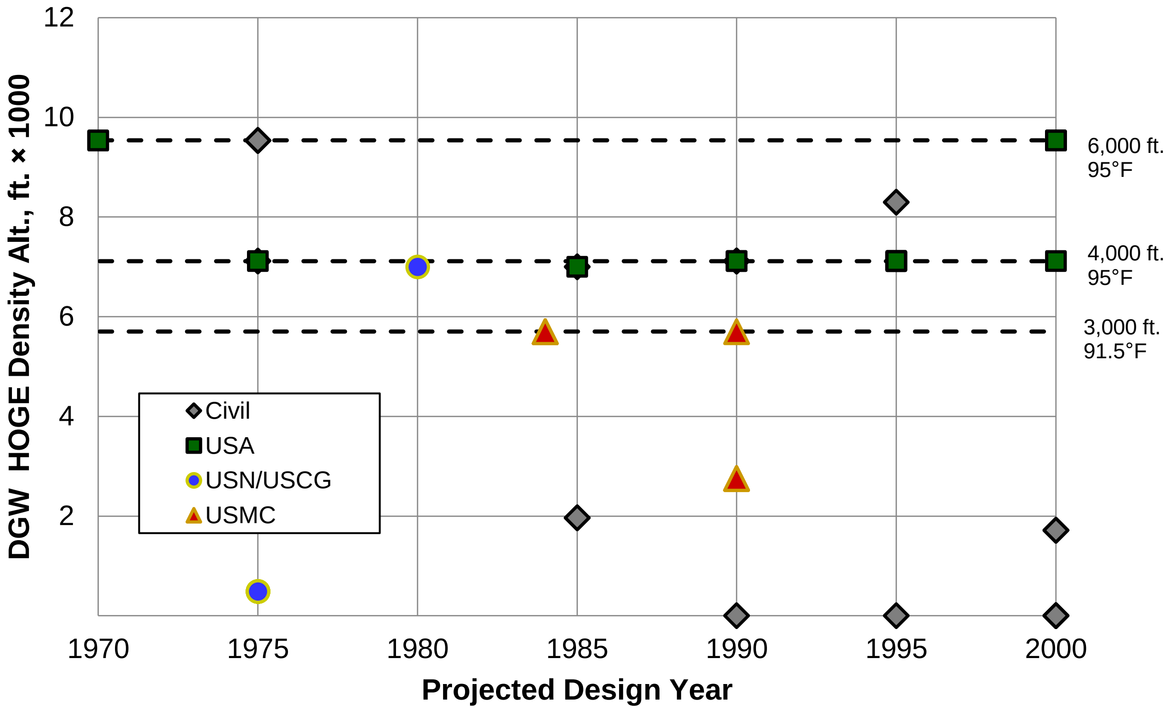


Figure 4-7. Trends in atmospheric conditions for HOGE takeoff used in sizing studies of future rotorcraft.

Table 4-3. Design Conditions and Assumptions

Design Quantity	Assumption	Notes
Design Payload	3,000 lb.	Figs. 2-1 and 2-4 Unpressurized UH-60 sized cabin
Avionics (MEQ)	1,000 lb.	Mission specific avionics, excluding AFCS, Flt. Ctrl., Instruments
V_{MCP}	≥ 225 kts.	At DGW, 4k95 or greater density altitude
n_Z	5.25 g	3.5 g ultimate load w/ 50% safety factor
SDGW	4k95 Midpt. HOGE Wt.	From design mission segment 5, Table 4-2
WMTO	100% MRP, SL103 Wt.	Helicopter uses 100% IRP, 4k95 HOGE Wt. to limit WE/GW
Engine/XMSN	4k95, 100% MRP	Sufficient for LOC, Helo V_{MCP} 225 kts and Tiltrotor V_{MCP} 280 kts
Disc Loading	Approx. < 20 lb/ft^2	Not exceeding pre-existing legacy aircraft disc loading
Operating Size	Less than 58 × 84 feet	Compatible with V-22 land-based and shipboard parking areas, No folding provision
Engines	Scalable FAATE/ITEP-level engine technology	Ref. 3-6

Technology Assumptions

In addition to the flight conditions and sizing mission specified in Tables 4-2 and 4-3, any aircraft design process also requires a set of technology factor assumptions which quantify the level of design technology present in the aircraft concept. When departures from historical design trends are predicted by external analysis or otherwise taken as assumptions, the parametric equations on which conceptual design routines depend must be adjusted accordingly. To date, no formalized analytical capability has established a way to incorporate reliability and maintainability considerations into conceptual design. As shown in Table 4-4 in the case of historical weight equations, and as already noted in the case of trend-based cost methods, the absence of metrics or parameters directly related to reliability and maintainability in the equations which predict aircraft weight and cost implies that any change in reliability, maintainability, or RAM-based technology is invisible to the existing modeling methods. Beyond the example in Table 4-4, a survey of existing design codes and weight equations finds none which provide the capability to adjust performance using any metrics related to reliability, availability, or maintainability.

Table 4-4. Examples of rotorcraft historical weight equations, showing lack of reliability and maintainability parameters.

Equation	Reference
$\frac{w_{blade}}{N_{rotor}} = \kappa \frac{1}{V_T} \left(\frac{GW}{DL}\right)^{0.205}$	Hiller 1960 (Ref. 4-6)
$\frac{w_{blade}}{N_{rotor}} = \kappa \frac{n_Z DGW\ R^2(R-r)}{10^7} \frac{N_b c R^{1.6}}{1200\ (t/c)_b}$	HESCOMP (Ref. 4-7)
$\frac{w_{blade}}{N_{rotor}} = \kappa N_b^{0.66} c R^{1.3} V_T^{0.67}$	Prouty (Ref. 4-8)
$\frac{w_{blade}}{N_{rotor}} = \kappa N_b^{0.6592} R^{1.3371} c^{0.9959} V_{tip}^{0.6682} \nu^{2.523}$	AFDD82 (Ref. 4-9)

As noted in Chapter 2, this study uses the NASA Design and Analysis of Rotorcraft Code (NDARC) (Ref. 4-10) due in part to its inclusion of a set of generic tech factors which can model design effects external to those directly considered in the parametric weight equations. NDARC applies the tech factors as a set of user-input constants which the code applies as multiplicative factors to the weight equations. This approach has already been used in limited cases to assess the design impact of new technology not specifically addressed by trend-based parametric models (Ref. 1-14, 1-16).

Ref. 4-10 provides the NDARC tech factors corresponding to legacy fleet examples of the rotorcraft configurations considered in this study. Tables 4-5 through 4-7 summarize the adjustments made to the legacy weight calibrations for each configuration. The adjustments are intended to roughly estimate an overall advanced technology portfolio representative of the 2025-2030 timeframe when future rotorcraft concepts currently in early design stages are proposed to reach a full scale production level of maturity. The tech factors in form the baseline starting point for each configuration from which design excursions and sensitivity studies on reliability and maintainability design considerations will be performed. Table 4-8 details the set of assumptions related to systems, fixed weights, and fixed useful load items which are applied to each of the configurations in the sizing process.

Table 4-5. Advanced Helicopter weight calibration / technology assumptions

Component	Legacy Tech Factor (UH-60A)	Adv. Technology Assumption	Baseline Assumption
Airframe			
Fuselage	1.03	0.75	0.7725
Horizontal Tail	1.0	0.75	0.75
Vertical Tail	2.47	0.75	1.8525
Landing Gear	0.74	0.75	0.555
Cowling	0.91	0.75	0.6825
Pylon	1.0	0.75	0.75
Engine Support	1.27	0.75	0.9525
Air Induction	1.27	0.75	0.9525
Rotor			
Blade	1.02	0.75	0.765
Hub	0.98	0.75	0.735
Tail Rotor	1.0	0.75	0.75
Propulsion			
Engine	0.94	0.75	0.705
Accessory	0.71	0.75	0.5325
Fuel System	0.83	0.75	0.6225
Exhaust	0.94	0.75	0.705
Drive			
Gearbox	0.91	0.75	0.6825
Rotor Shaft	0.91	0.75	0.6825
Drive Shaft	0.85	0.75	0.6375
Rotor Brake	1.0	0.75	0.75
Flight Controls			
Rotary Wing – boosted	1.06	0.75	0.795
Rotary Wing – boost mech.	1.17	0.75	0.8775
Rotary Wing – non-boosted	1.17	0.75	0.8775
Rotary Wing – hydraulic actuators	1.17	0.75	0.8775
Fixed Wing – non-boosted	1.15	0.75	0.8625
Fixed Wing – boost mech.	1.15	0.75	0.8625
Systems			
De-Ice System	1.0	0.75	0.75
De-Ice Electrical	1.0	0.75	0.75

Table 4-6. Lift Offset Compound weight calibration / technology assumptions

Component	Legacy Tech Factor (XH-59A)	Adv. Technology Assumption	Baseline Assumption
Airframe			
Fuselage	1.06	0.75	0.795
Horizontal Tail	1.06	0.75	0.795
Vertical Tail	1.06	0.75	0.795
Landing Gear	0.98	0.75	0.735
Cowling	0.99	0.75	0.7425
Pylon	1.71	0.75	1.2825
Engine Support	1.71	0.75	1.2825
Air Induction	1.71	0.75	1.2825
Rotor			
Blade	1.0	0.55	0.55
Hub	1.0	0.55	0.55
Interconnect Shaft	1.0	0.55	0.55
Propulsion			
Engine	1.0	0.75	0.75
Accessory	1.44	0.75	1.08
Fuel System	0.97	0.75	0.7275
Exhaust	1.0	0.75	0.75
Aux Prop	1.0	0.75	0.75
Drive			
Gearbox	1.06	0.75	0.795
Rotor Shaft	1.06	0.75	0.795
Drive Shaft	1.06	0.75	0.795
Rotor Brake	1.06	0.75	0.795
Flight Controls			
Rotary Wing – boosted	2.29	0.75	1.7175
Rotary Wing – boost mech.	1.13	0.75	0.8475
Rotary Wing – non-boosted	1.08	0.75	0.81
Rotary Wing – hydraulics	1.13	0.75	0.8475
Fixed Wing – non-boosted	0.57	0.75	0.4275
Fixed Wing – boost mech.	0.57	0.75	0.4275
Systems			
De-Ice System	1.0	0.75	0.75
De-Ice Electrical	1.0	0.75	0.75

Table 4-7. Tiltrotor weight calibration / technology assumptions

Component	Legacy Tech Factor (XV-15)	Adv. Technology Assumption	Baseline Assumption
Airframe			
Fuselage	1.06	0.75	0.795
Wing	0.98	0.75	0.735
Horizontal Tail	1.42	0.75	1.065
Vertical Tail	0.60	0.75	0.45
Landing Gear	0.96	0.75	0.72
Cowling	0.56	0.75	0.42
Pylon	0.85	0.75	0.6375
Engine Support	0.85	0.75	0.6375
Air Induction	0.85	0.75	0.6375
Rotor			
Blade	0.93	0.75	0.6975
Hub	0.88	0.75	0.66
Propulsion			
Engine	1.0	0.75	0.75
Accessory	0.62	0.75	0.465
Fuel System	2.25	0.75	1.6875
Exhaust	1.0	0.75	0.75
Drive			
Gearbox	1.35	0.75	1.0125
Rotor Shaft	1.35	0.75	1.0125
Drive Shaft	0.62	0.75	0.465
Rotor Brake	1.35	0.75	1.0125
Flight Controls			
Rotary Wing – boosted	1.02	0.75	0.765
Rotary Wing – boost mech.	1.08	0.75	0.81
Rotary Wing – non-boosted	0.94	0.75	0.705
Rotary Wing – hydraulics	1.08	0.75	0.81
Fixed Wing – non-boosted	0.72	0.75	0.54
Fixed Wing – boost mech.	0.72	0.75	0.54
Fixed Wing – hydraulics	0.72	0.75	0.54
Systems			
De-Ice System	1.0	0.75	0.75
De-Ice Electrical	1.0	0.75	0.75

Table 4-8. Fixed weight / useful load, and systems weight assumptions

Component	Weight	Notes
Payload	3,000 lb.	8-10 Passengers (300-375 lb. each) Unpressurized, UH-60 size cabin
Crew	1,000 lb.	4 Crew, 250 lb. each
Seats & Accommodation	570 lb.	2 Pilot (75 lb. each), 12 Passenger (35 lb. each)
Trapped Fluids	70 lb.	Ref. 4-9, pg. 244
Misc. Furnishings	200 lb.	
Cockpit Controls	100 lb.	
Auto. Flt. Ctrl. System	50 lb.	
Auxiliary Power Unit	130 lb.	
Instruments	150 lb.	
Electrical	250 lb.	
Armor	100 lb.	
Air Conditioning	100 lb.	
Load & Handling	50 lb.	
Mission Equipment	1,000 lb.	Ref. 5-5
Flight Control	$f_{\text{RWred}} = 3$	UTTAS/AAH level of redundancy/survivability
De-Ice Electrical	0.25 lb./ft^2	lb. per ft^2 of rotor area
De-Ice Rotor	0.25 lb./ft^2	lb. per ft^2 of rotor area
De-Ice Wing	0.28 lb./ft	lb. per ft. of wing span
De-Ice Air Intake	0.006	0.6% of air induction weight
Vibration Treatment	0.005	0.5% of Weight Empty
Contingency Weight	0.05	5% of Weight Empty

CHAPTER 5

RELIABILITY-BASED DESIGN FRAMEWORK

Baseline Design Results

Before the design framework can be fully applied to consider the life-cycle cost effect of reliability, the study must designate a point of departure which represents each of the rotorcraft configurations as they would be calculated by a conventional design routine. Using the performance requirements and technology assumptions compiled through research of historical trends, NDARC generates the baseline vehicle concepts described in Table 5-1 and Figure 5-1. Detailed weights and design summaries for each baseline aircraft are provided in Appendix F, along with additional layout information. Figure 5-1 plots the equivalent flat plate drag area of each design in relation to extant rotorcraft.

Consistent with the ground rules of the performance requirements, the sizing speed of the advanced concepts is 225 knots at 100% maximum continuous power. Each aircraft is assumed to have a clean, low drag airframe and a feasible high performance overall flat plate drag area for its configuration. Each of the three baseline designs display the immediate effects of the advanced technology weight and drag assumptions. The baseline aircraft have low empty weight fractions in relation to contemporary examples of their respective configuration. Figures A-3 through A-5 show that all of the baseline designs not only fit inside the V-22’s operational footprint, but are noticeably more compact than the V-22 while providing similar range and speed capability at greater structural efficiency.

In addition to the weight assumptions given in Tables 4-5 through 4-7, each of the three concepts used in the design study relies on a set of enabling technologies and design practices innate to the respective configurations which are derived from published literature. The intent of the study is to represent each design based on the best current understanding of their subcomponent technology levels as well as the manner in which the subcomponents are integrated together by the configuration. The objective of the study is not to determine which, if any, of the configurations are universally better suited to the design requirements used for sizing. The motivation behind including multiple configurations is to consider the effect of reliability and maintainability in conceptual design and life-cycle cost assessment in VTOL aircraft, including types which are beyond those currently considered conventional. The tiltrotor and lift offset starting points are germane to current interest in design requirements for future rotorcraft simply because they satisfy the speed, range, and operational footprint requirements. Other configurations such as incrementally faster compounds based on legacy designs have been shown to exceed most operational footprint constraints, even using highly efficient design assumptions (Refs. 5-7).

Table 5-1. Performance and weight summary of baseline design aircraft

	Helicopter	**Lift Offset**	**Tiltrotor**
Design Gross Wt., lb.	19,131	23,180	21,886
Weight Empty, lb.	10,084	15,317	14,698
Design Mission Fuel, lb.	4,977	3,793	3,118
Design Payload, lb.	3,000	3,000	3,000
Fixed Useful Load, lb.	1,070	1,070	1,070
Max Takeoff Wt., lb.	23,797	27,933	23,917
Structural Design. Gross Wt., lb.	16,534	21,667	20,652
Installed Power, hp	6,712	6,210	6,144
V_{MCP}, kt.	170	225	283
V_{LRC}, kt.	145	168	224
Operating Length, ft.	61.9	53.7	47.6
Operating Width, ft.	52.0	40.5	70.3
Operating Height, ft.	11.7	12.6	14.2
Empty Weight Fraction	0.53	0.66	0.67
Disc Loading, lb/ft^2	9.0	9.0	14.0
Cruise Drag, D/q, ft^2	17.06	17.01	14.37

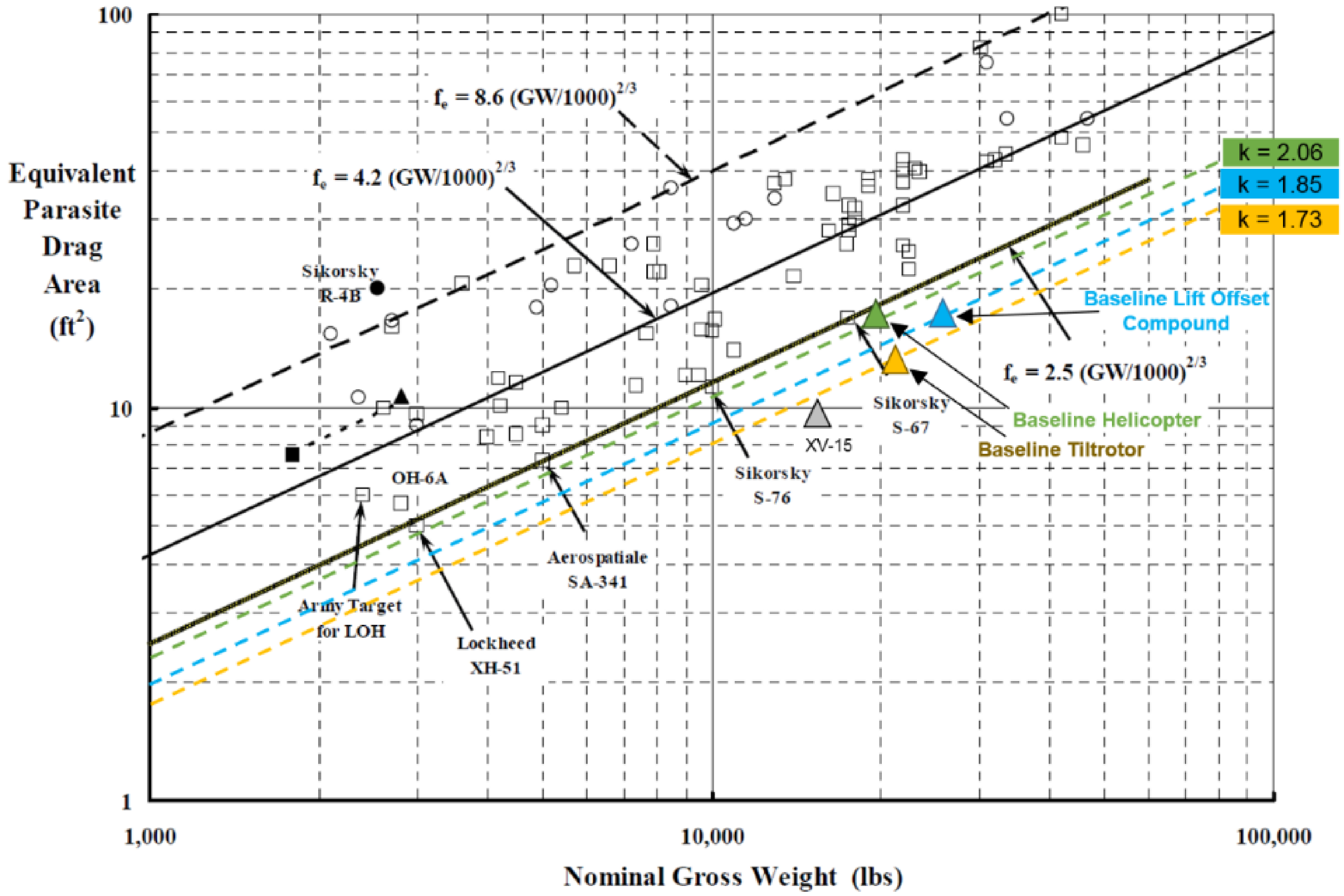


Figure 5-1. Baseline aircraft total parasite drag plotted against legacy aircraft drag trends (Ref. 5-1)

Advanced Helicopter Design Features

Figure 5-3 provides a layout view of the baseline advanced helicopter. The advantages of a highly efficient conventional helicopter design compared to various advanced configurations lie in the relative maturity of the platform and its simplicity compared to other VTOL types. Under the advanced weight assumptions used in the sizing routine, the helicopter has exceptionally low weight fraction, especially considering the high rotor solidity and the installed power required by the design to fly at the 170 knot cruise design condition at 100% MCP and 4,000 feet, 95 degree atmosphere (4k95). This requirement, while less than the 225 kt. sustained cruise speed used for the lift offset and tiltrotor, still sizes the engines of the advanced helicopter. In spite of the extremely clean parasite drag assumptions detailed in Figure 5-1 and Appendix F as well as its lower cruise maximum cruise speed, the advanced helicopter still has the highest installed power of the three baseline designs. Figure 5-2 plots the power required curve of the advanced helicopter flying at design gross weight in 4k95 atmospheric conditions up to its 100% maximum continuous power speed of 170 knots.

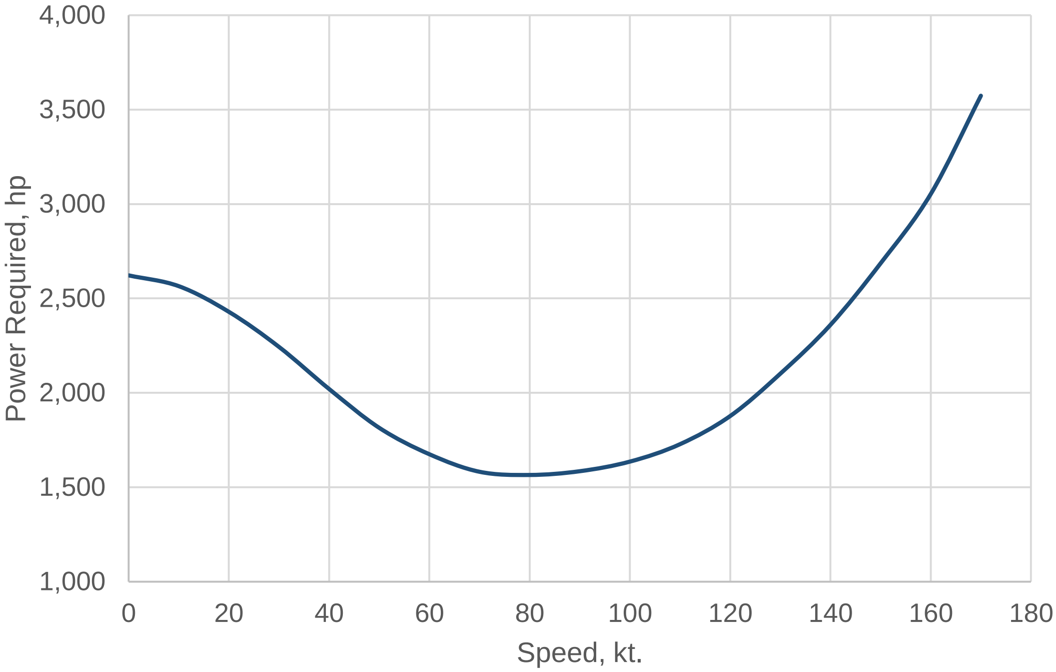


Figure 5-2. Adv. helicopter power required, (DGW at 4k95 atmosphere)

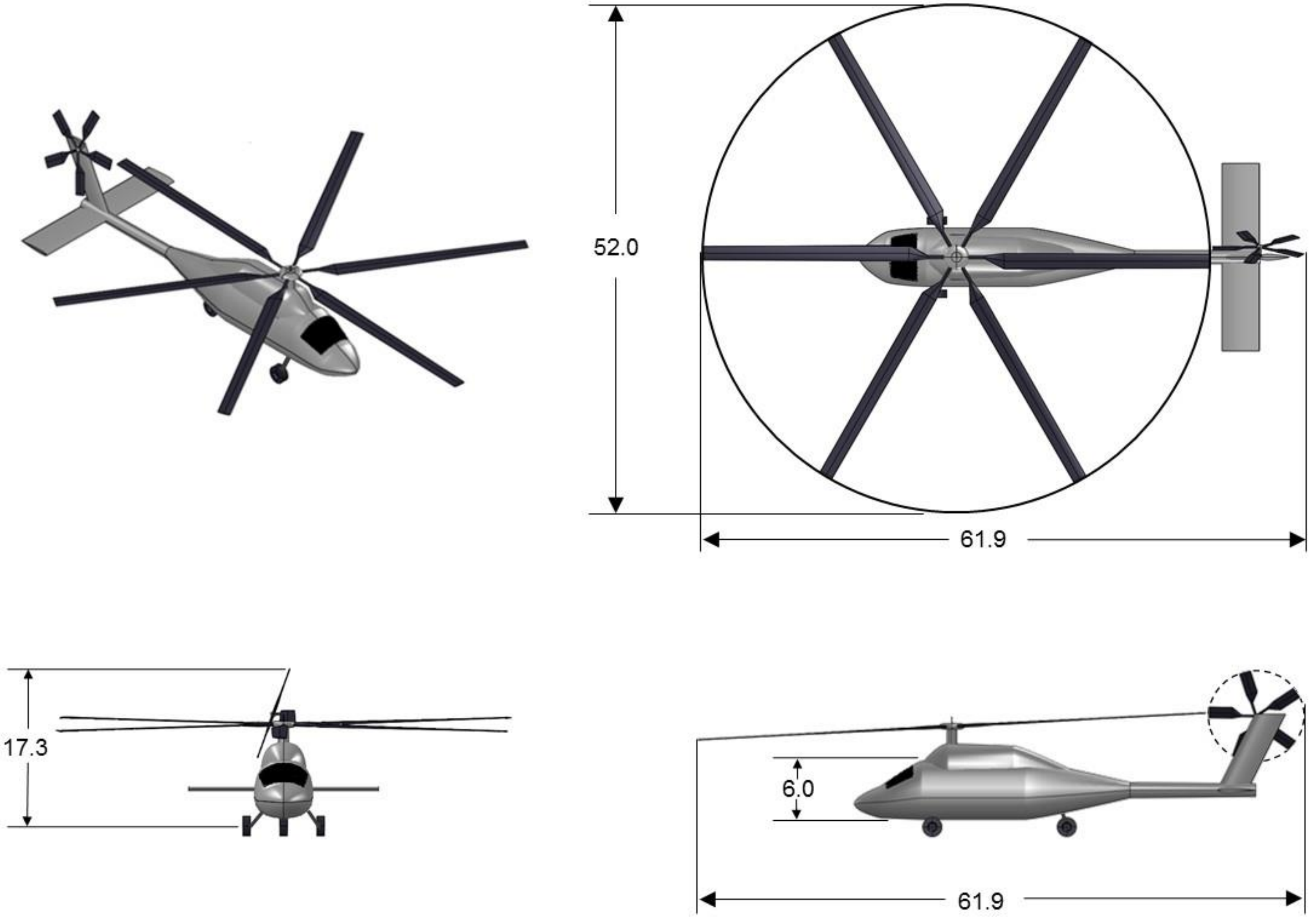


Figure 5-3. Baseline advanced helicopter design layout

Lift Offset Compound Design Features

As detailed in References 1-12, the lift offset compound depends on a rigid rotor system to sustain lift on the opposing top and bottom advancing blades while also eliminating the need for a dedicated anti-torque rotor. The baseline lift offset layout in Figure 5-5 highlights the propeller mounted on the back of the fuselage to provide propulsive thrust in high speed flight. As Figure 5-4 shows, the lift offset compound possesses two modes of flight: the low speed mode where the auxiliary thrust propeller is feathered and the aircraft operates effectively as a coaxial helicopter without compounded propulsive thrust. The second, higher speed mode of flight engages the propeller and increases the difference in advancing versus retreating side rotor lift. The speed and efficiency obtainable in this flight mode depend on the installed power and the lift to drag ratio attained by the main rotor system. Sikorsky’s X2 demonstrator aircraft has proven that speeds up to and exceeding 250 knots are attainable by the lift offset configuration.

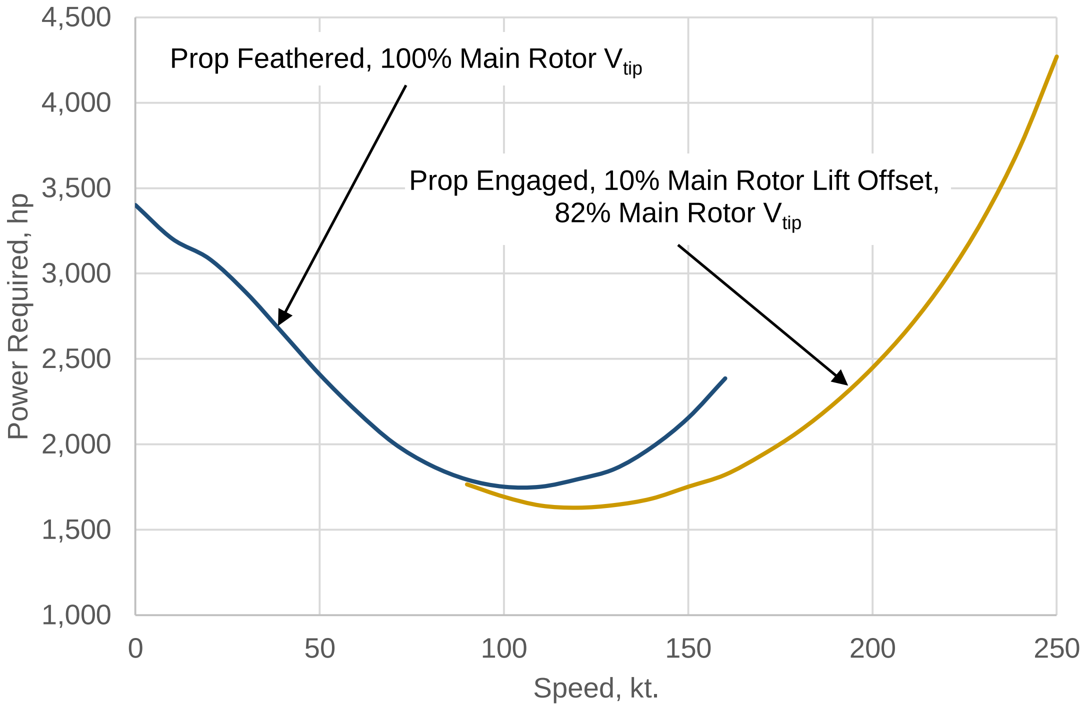


Figure 5-4. Lift offset power required, (DGW at 4k95 atmosphere)

In general, the sizing of the lift offset follows the design philosophy exemplified in Ref. 5-8. For this study, the rotor is designed to 10% lift offset ($L_x = 0.1$) as defined by Eqn. 5-1, with the main rotor tip speed slowed by 18% at maximum cruise and unloaded to carry 70% of the design gross weight at 230 knots. The remaining lift is produced by the tail and fuselage at this speed. As Eqn. 5-1 shows, the amount of lift offset each rotor carries is limited by the allowable flapping and hub stiffness K_{hub}. The balancing of these terms signifies the design tradeoff between more lift offset and higher rotor lift to drag against the accompanying rise in rotor system weight due to increased hub stiffness.

$$\begin{bmatrix} \beta_s \\ \beta_c \end{bmatrix} = \frac{1}{K_{hub}} \begin{bmatrix} M_x \\ -M_y \end{bmatrix} = \frac{TR}{K_{hub}} \begin{bmatrix} L_x \\ -L_y \end{bmatrix} \qquad (5-1)$$

The detailed optimization of this configuration and specifically its rotor system with weight, cost, and reliability is a topic for potential future work. The key design feature enabling high speed flight in an edgewise rotor is the high lift to drag ratio of the coaxial rotor system, which depends on many factors. In addition to the assumption of very low hub drag, blade profile drag is managed by slowing and unloading the rotor at high speed. Since the lift offset design along with the tiltrotor and advanced helicopter all assume a conventional, single speed transmission, the configuration as it is presented in this study should be considered an example of an advanced rotorcraft design generated primarily to demonstrate cost and reliability analysis.

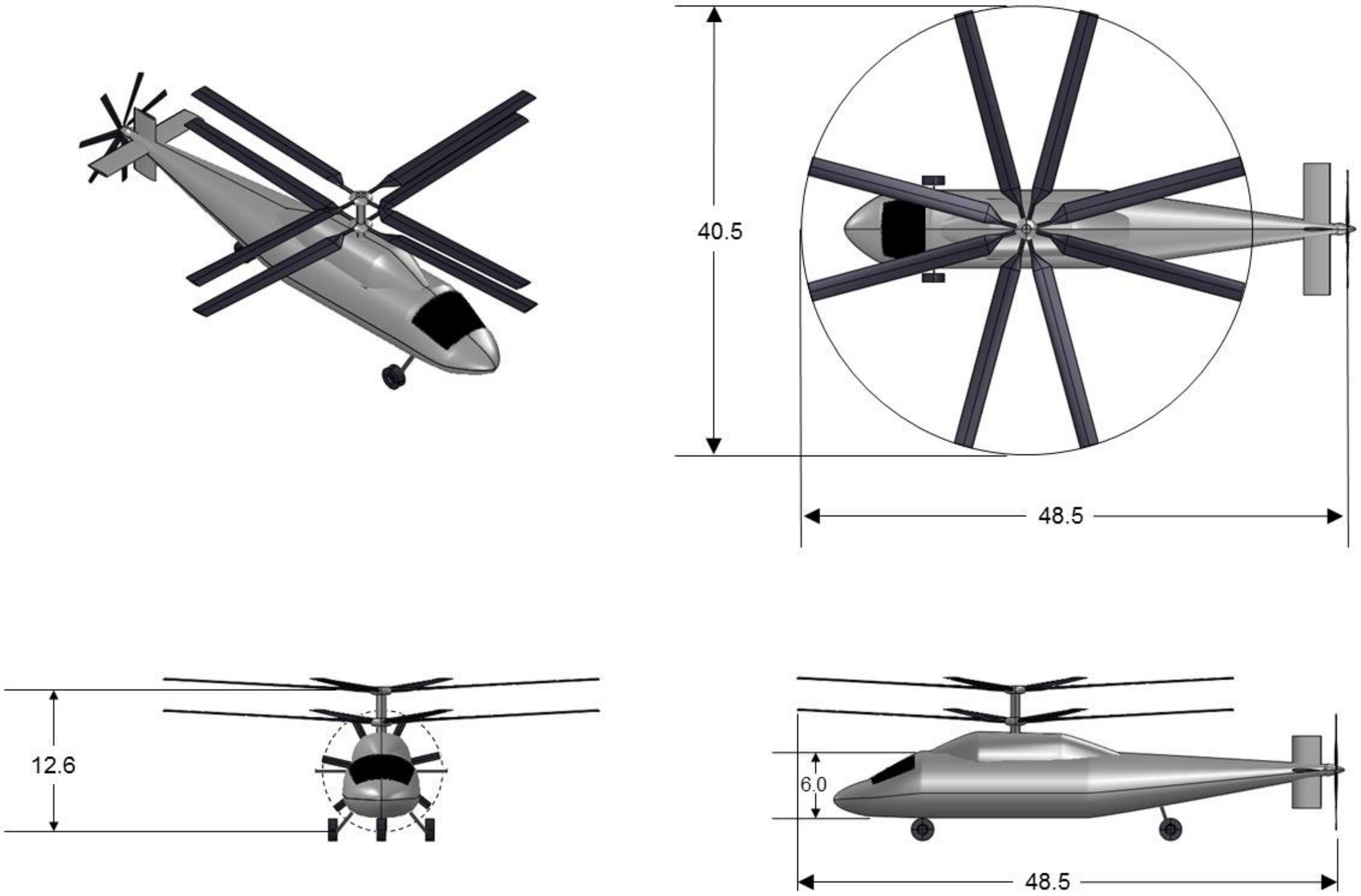


Figure 5-5. Baseline Lift Offset Design Layout

Tiltrotor Design Features

Tiltrotors derive their greatest advantage from their ability to completely unload the rotor system in cruise. As noted by Glauert in his seminal paper, wings are almost always more efficient than edgewise rotors as a lift-producing mechanism in cruising flight. The key design challenge inherent to the tiltrotor is controlling the weight, complexity, and cost incurred by the combination of wing, rotor, transmission, and flight control systems in a single aircraft.

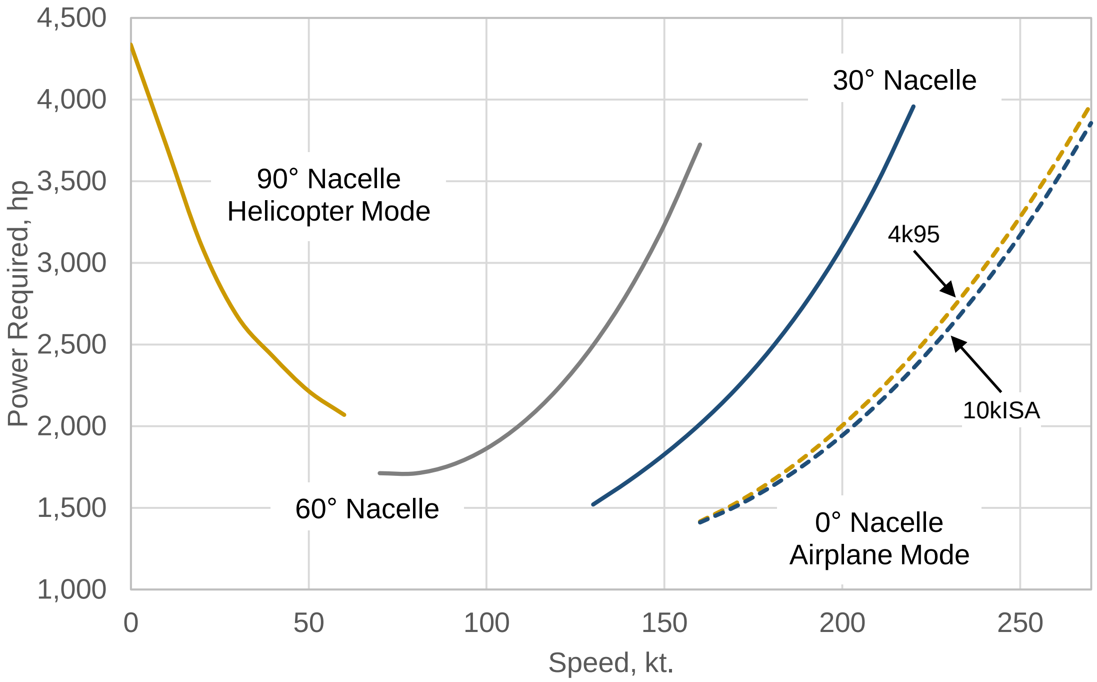


Figure 5-6. Tiltrotor power required, (DGW at 4k95/10kISA atmospheres)

Figure 5-6 plots the power curves of the baseline tiltrotor at multiple flight modes throughout the conversion corridor between helicopter mode and airplane mode. Unlike the helicopter and lift offset compound, the tiltrotor's engine and transmission are sized by hover conditions rather than the 225 knot cruise condition. As Table 5-1 notes, the tiltrotor's cruise efficiency enables the design to fly the design mission range segments at a fallout maximum continuous power speed almost 60 knots faster than the minimum requirement.

Operational experience has shown that the primary advantage of the tiltrotor is its combination of airplane-like speed and range with low speed VTOL capability. The efficiency of wing-born lift at high speed is evidenced in Figure 5-6 by the reduction in power required at equal cruise speed above about 125 knots when the nacelles are rotated progressively further downward, transferring lift from the rotors to the wing. The same experience has also shown existing iterations of the tiltrotor to require extensive maintenance attention. Many modifications have been proposed to improve the affordability and efficiency of the tiltrotor with minimal technical risk, one particular portfolio of which has been generically designated in concept as the high efficiency tiltrotor (HETR) (Ref. 1-15). Some technology credit related to tiltrotor weight trends featured in the HETR concept is utilized in this study to represent a near future, low risk design of comparable technology level to the helicopter and lift offset designs.

Like the HETR, the baseline tiltrotor shown in Figure 5-7 is structurally efficient and has a low disc loading of 14 pounds per square foot compared to the V-22 disc loading of greater than 20 at maximum takeoff weight. It also reduces rotor speed in cruise to improve efficiency. Unlike the HETR, this design varies tip speed by no more than 10% directly through the engine speed as opposed to depending on a two speed transmission system. Like the V-22 and V-280 tiltrotor concepts, the cockpit and cabin are not pressurized, the wing does not feature extensions, and the optimal cruise is found at approximately 10,000 feet density altitude. Like the lift offset compound, the tiltrotor configuration presents many opportunities for further optimization from a design perspective. The sizing outcomes of the two advanced configurations in this study do not necessarily signify their relative merits and performance attributes as they might be realized were they to reach the production life-cycle stage.

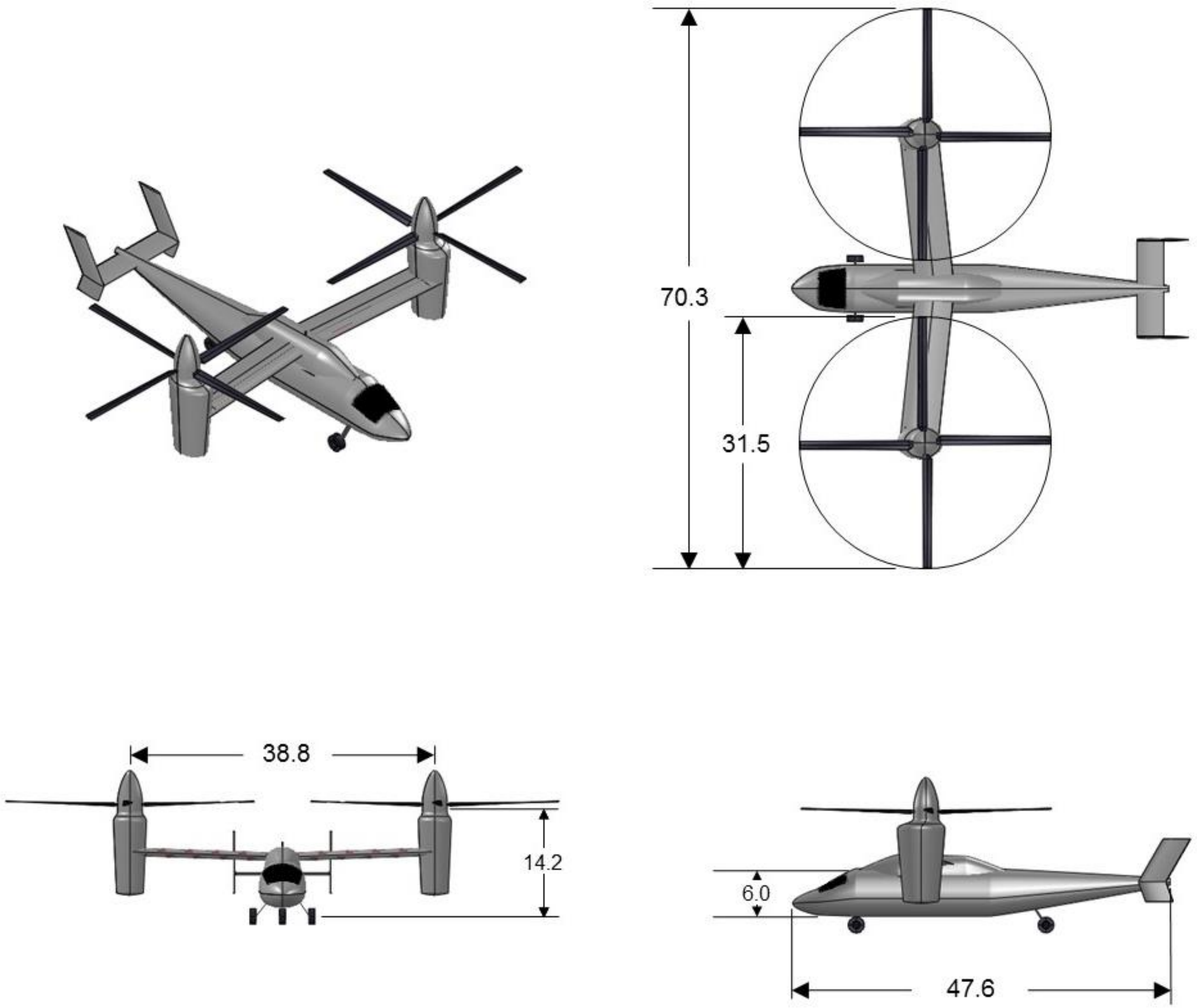


Figure 5-7. Baseline Tiltrotor Design Layout

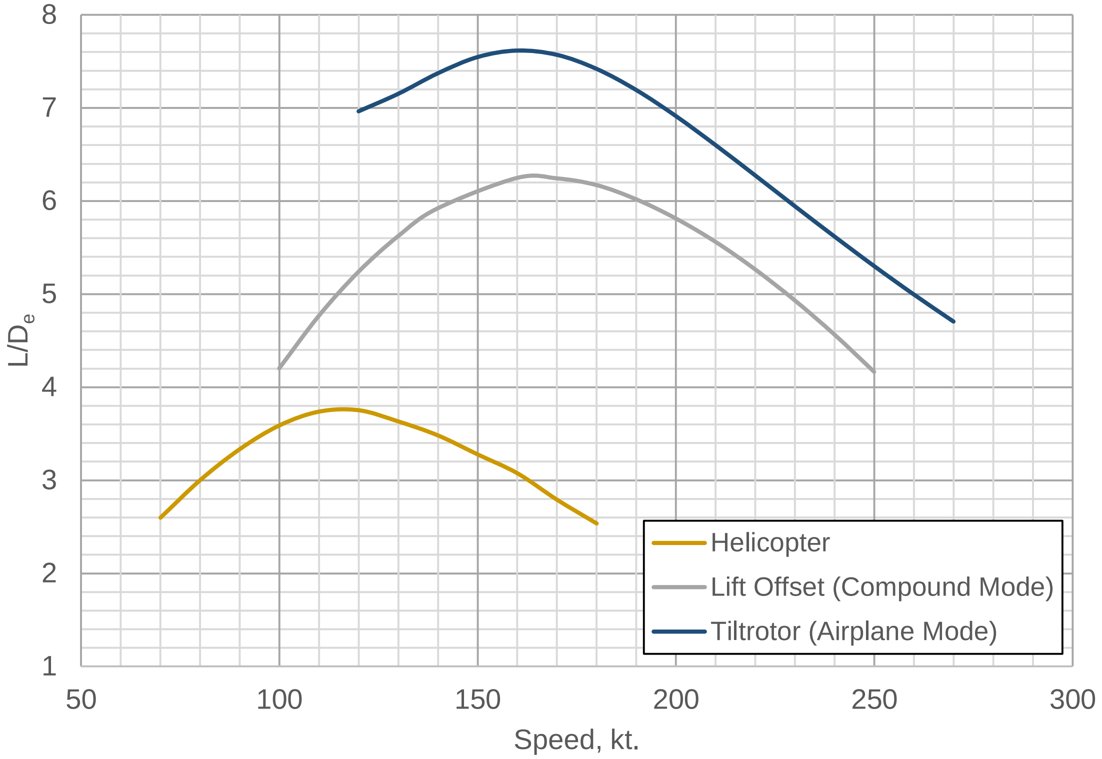


Figure 5-8. Cruise efficiency comparison of baseline designs.

Figure 5-8 compares the cruise efficiencies of each baseline design in terms of their lift to equivalent drag ratio. In spite of the assumptions of low drag airframes, the baseline designs shown in Figure 5-8 still strongly resemble the legacy helicopter and tiltrotor cruise performance characteristics in Figure 1-4. This limited improvement at some of the cruise speeds suggests that the configurations may each benefit from improvement of the rotor performance derived from adjustment of rotor parameters such as disc loading, tip speed, and solidity. The tiltrotor is the most efficient of the designs in forward flight, with the lift offset compound displaying a compromise in cruise efficiency between the tiltrotor and the helicopter. Figure 5-8 also illustrates the impact of the performance requirement for the advanced configurations to fly the design missions at a minimum of 225 knots, evidenced by the drop in efficiency between the maximum lift to drag point (analogous to the maximum endurance speed) and the 225 knot point beyond the maximum endurance and range conditions.

The limitations of each configuration are also apparent in spite of the aggressive technology assumptions which enable the aircraft to meet the design requirements. All three of the designs require large, high solidity rotor systems. The weight of the rotors and the complexity implied by the number of rotors and blades works to increase the cost of the aircraft. All of the designs also require propulsion systems much larger than the 2,000 horsepower class T700 engines which currently power the majority of medium utility rotorcraft. The aerodynamic disadvantage of the single main rotor configuration is such that its design speed, relaxed to 170 knots from the 225 knots considered the practical lower limit, is still the engine sizing condition, driving its installed horsepower above that of the other two aircraft, which fly 60 – 110 knots faster. The majority of the useful load weight fraction made available in the helicopter by the technology assumptions is ultimately consumed by the fuel weight needed to fly the 229 nautical mile operational radius. Additionally, the combination of main rotor size and tail length for anti-torque causes the helicopter to violate the operating dimension ground rule, making it less compatible with existing land and sea-based VTOL aviation infrastructure. In spite of its performance shortcomings relative to the lift offset compound and the tiltrotor, the advanced helicopter is nevertheless carried forward into the cost and RAM analysis in order to provide a reference point corresponding to the most mature configuration of the three and to increase the range of aircraft weight and performance considered for the sake of generality of the methodology and its conclusions.

Cost Analysis of Baseline Designs

As noted in Chapter 2, cost analysis for this study is performed in the Bell PC-Based Cost Model. Bell PC (also called the Concept Cost Model) was developed in the early 2000’s by Biggs and Key (Ref. 3-4) in collaboration with the National Rotorcraft Technology Center. Subsequent updates from government, industry and academia have been made to a version of the tool marketed as the TrueRotorcraft cost model by PRICE

Systems from 2013 to 2014 and onwards (Ref. 5-2). The tool predicts the total ownership cost components using empirical models at the third and fourth level of work breakdown structure as defined by MIL-STD 881C (Ref. 5-3), with the O&S component based on parametric estimates of maintenance material cost per flight hour and scheduled & unscheduled maintenance man-hours per flight hour (MMH/FH). Engine procurement cost is predicted externally from Bell PC and compiled into the total unit procurement price as a pass-through using the cost estimating relationship given in Equation 3-3. A previous calibration of the model (Ref. 5-5) is utilized to provide realism to the baseline cost estimate values. The data flow shown in Figure 3-2 and detailed in Appendix D is used to translate the estimated aircraft component weights output from NDARC (Table 3-1) in SAE RP-8A format (Ref. 5-4) to the MIL-STD 881C format used by Bell PC. While this level of detail makes the model more complex to operate and validate than most parametric models, the principal advantage to the level of detail in Bell PC is its ability to model all types of aircraft configurations, including those which may depart in weight proportion trend from the conventional configurations upon which many top-level system-based parametric cost models are based. The cost metrics in Table 5-2 form the foundation of the total ownership cost elements used to assess the different aircraft concepts. Starting from the estimates of unit procurement cost and dollars per flight hour; Production quantity, OPTEMPO, labor rate, and life-cycle sustainment assumptions are added to form estimates of unit acquisition cost, annual operating cost, and life-cycle cost.

Table 5-2. Rotorcraft life-cycle cost metrics predicted directly by Bell-PC

Cost Component	Metric(s)
Procurement	Unit Flyaway, Unit Procurement
Operating & Support	$/FH, MMH/FH, $/AC/yr

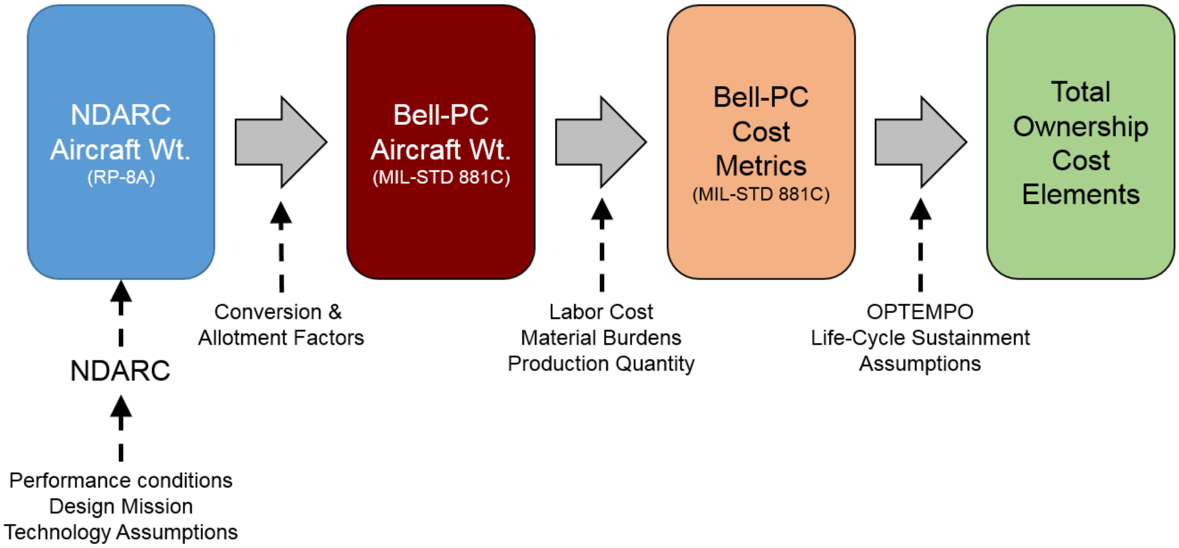


Figure 5-9. Total ownership cost estimating process, standards, and cost elements

Table 5-4 provides a top-level comparison of the predicted procurement costs of the three baseline designs at a production quantity of 800 aircraft using the learning curve assumptions listed in Table 5-3. The learning curve effect, explained in Appendix C, provides a major affordability benefit that reduces the unit cost of each aircraft as larger quantities are procured. As demonstrated in Appendix C, the average prices in Table 5-4 represent a discount of about 55% over the first unit price thanks to the quantity learning effect in production. Taken together, the combination of learning curve affordability benefit and reduced airframe weight due to technology assumptions cause the predicted average unit procurement price over 800 units of the helicopter to be approximately equal to the base price of the medium utility UH-60M Blackhawk (Ref. 2-9); with the high speed capability of the compound and tiltrotor coming at only a 25% premium above the Blackhawk price. It should be noted that in an actual acquisition program, these features would be considered key enablers to the viability of the program and would receive a thorough business case risk evaluation.

Table 5-3. Learning curve & procurement cost factor assumptions for production estimates.

Component	Learning Curve Assumption
Structure & Systems	87.0%
Propulsion	94.9% (Ref. 3-6)
Avionics	$4,500/lb., no learning
Component	Cost Factor Assumption (% of prime equipment cost)
Contingency Cost	5.0%
Final Assembly & Integration	6.0%
Profit & Fee	12.0%
SE/PM, Data, & Training	2.4%
Initial Spares	1.0%

As listed in Table 5-4, the propulsion and MEQ groups emerge as the most significant cost drivers in each of the three designs due to the size of the engines, the constant $4,500 per pound cost assumption for avionics, and the slower rate of production learning assumed for the propulsion group. The cost components which discriminate the lower cost helicopter from the two more expensive rotorcraft illuminate the fundamental design and performance differences between the vehicles. The tiltrotor and lift offset compound designs are heavier, with higher gross weights and empty weight fractions than the advanced helicopter. Consequently, they are more expensive than the helicopter, due primarily to the weight-driven additional cost of the heavier rotor, airframe, and drive systems. Figure 5-10 shows that the rotor, airframe, and drive system form a much larger percentage of the total first unit flyaway cost of the already heavier tiltrotor and compound when compared to the helicopter. The additional complexity and size of the flight control systems of the lift offset and tiltrotor also contribute to the overall difference in cost. The remaining components – propulsion, avionics, vehicles systems, furnishings, and equipment – are similar in cost across the three designs. Figure 5-11 plots the progression of average procurement unit cost due to the learning curve effect, with the endpoint of each curve at 1,000 production units corresponding to the unit cost breakdown given in Table 5-4.

Table 5-4. Avg. unit procurement cost over first 1,000 production aircraft, FY16 $

	Helicopter	Lift Offset Compound	Tiltrotor
Production Quantity	1,000	1,000	1,000
Rotor	$1.083 M	$3.740 M	$2.029 M
Airframe	$2.499 M	$3.150 M	$3.789 M
Alighting Gear	$0.195 M	$0.240 M	$0.179 M
Air Induction + Nacelle	$0.352 M	$0.432 M	$0.872 M
Propulsion System	$4.583 M	$4.422 M	$4.644 M
Drive System	$0.651 M	$1.330 M	$1.199 M
Flight Controls	$1.020 M	$2.871 M	$2.639 M
Vehicle Systems	$1.377 M	$1.390 M	$1.305 M
Avionics	$4.500 M	$4.500 M	$4.500 M
Furnishings & Equip.	$0.198 M	$0.198 M	$0.198 M
Total Prime Equip.	**$16.457 M**	**$22.273 M**	**$21.353 M**
Contingency	$0.823 M	$1.114 M	$1.068 M
Final Assembly & Integration	$0.987 M	$1.336 M	$1.281 M
Profit & Fee	$1.975 M	$2.673 M	$2.562 M
Flyaway Price ($/lb.)	**$20.242 M ($2,007/lb.)**	**$27.396 M ($1,789/lb.)**	**$26.264 M ($1,787/lb.)**
SE/PM, Data, Training	$0.395 M	$0.535 M	$0.517 M
Initial Spares	$0.165 M	$0.223 M	$0.214 M
Procurement Cost	**$20.802 M**	**$28.153 M**	**$26.994 M**

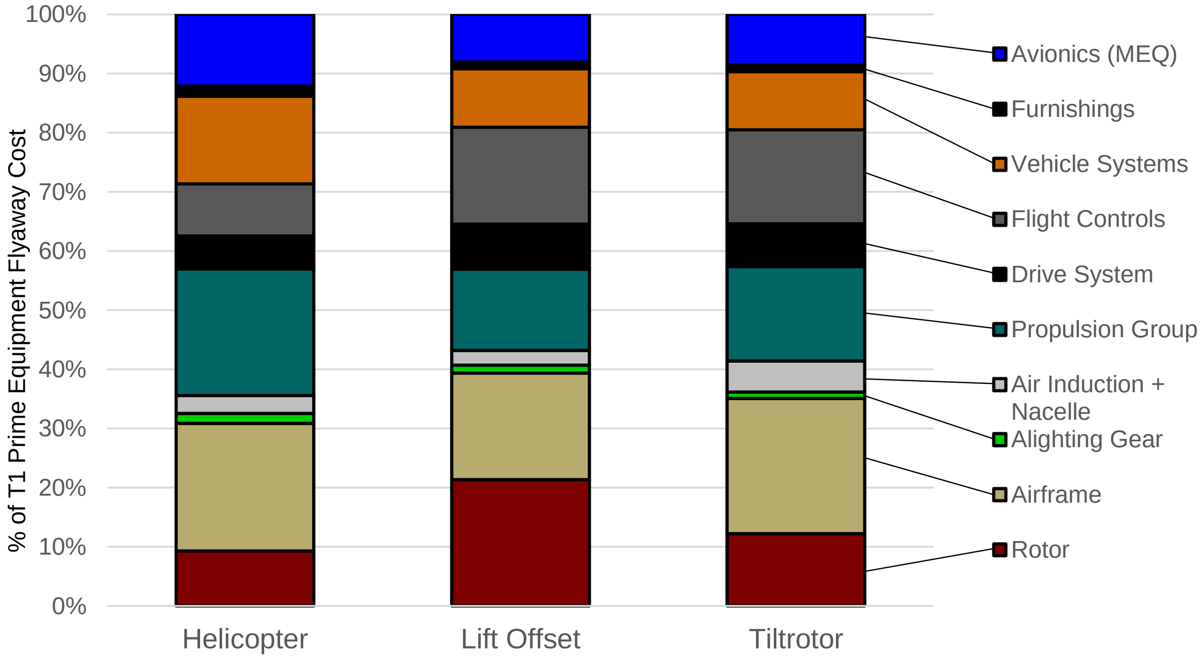


Figure 5-10. Percentage buildup of first unit (T1) flyaway cost

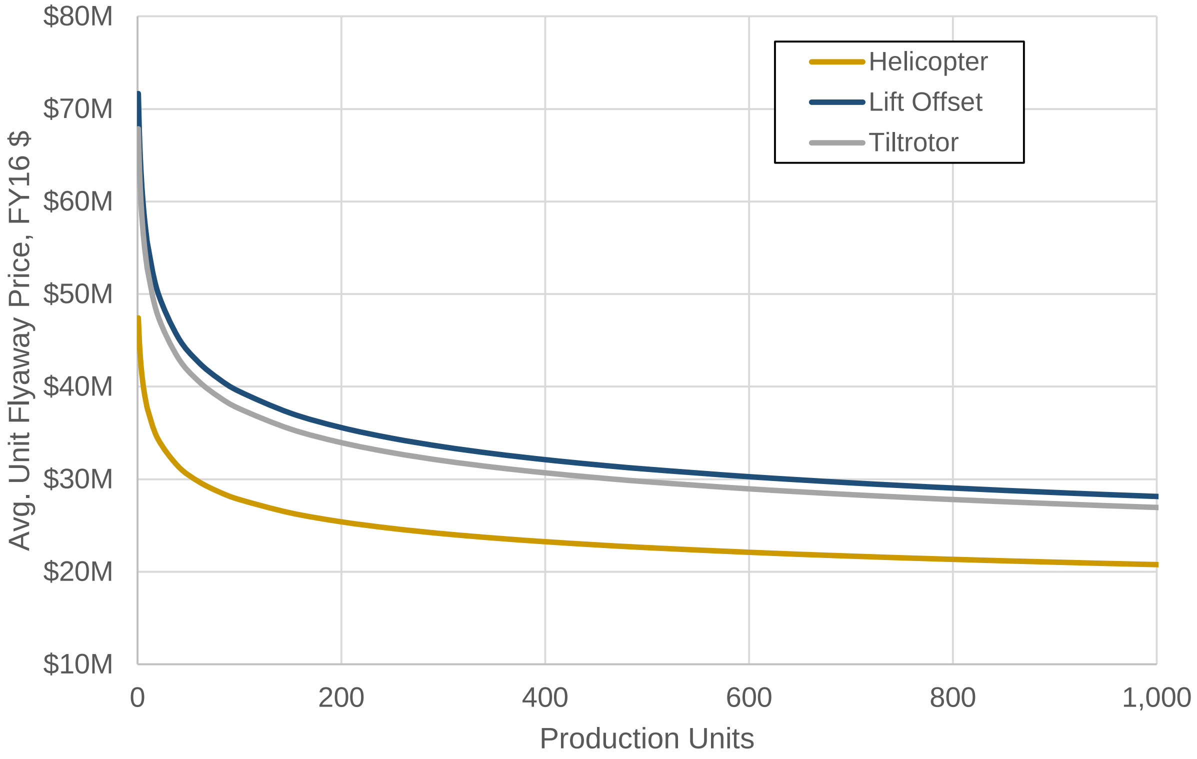


Figure 5-11. Average procurement unit cost variation with production quantity

The differences in weight characteristics of the three designs will also affect the operating costs of the vehicles relative to one another. Table 5-5 lists the ground rules applied to the Bell PC operating and support results to calculate the direct operating cost figures for each design. Bell PC predicts the direct maintenance costs and the maintenance man-hours per flight hour. The operating cost due to fuel consumption comes from the mission fuel estimate generated in NDARC. The remaining components are estimated from the ground rule assumptions. A fixed $300,000 per year annual cost is included in the improved RAM designs above the 5% Continuing System Improvement Cost to model the point of minimum reliability improvement used as the basis of Eqn. 3-2.

Table 5-5. Direct operating cost calculation assumptions

Cost Element	Assumption
1.0 Unit Level Manpower	Organic, two level maintenance; 4 crew per aircraft; Average standard military officer & enlisted pay; additional benefits, recruitment, and training included as 10% crew overhead, 5% maintainer overhead
2.0 Unit Operations	Fuel costs only - $5/gal, 200 flight hours per year at design mission average fuel flow rate
3.0 Maintenance	Annual direct maintenance parts cost per aircraft, 200 flight hours per year
4.0 Sustaining Support	2% of annual direct maint. parts cost per aircraft
5.0 Cont. Sys. Impr.	5% of base year prime equipment cost reinvested over one airframe service lifespan

Table 5-6 provides the direct operating costs for the aircraft predicted by Bell PC. The breakdown of the direct operating costs by component is provided in Appendix E along with the baseline design descriptions. Maintenance contributes about 50% of the total direct operating cost in every case, making it a critical life-cycle affordability metric closely related to reliability and maintainability. As with the procurement cost, lift offset compound and tiltrotor demand higher maintenance costs. The higher airframe maintenance cost of the lift offset compound in particular is due to the high number of dynamic components inherent to configurations multiple lift and thrust compounding rotors which require periodic overhaul and retirement.

Although the engines sized for the tiltrotor and compound are rated to slightly lower installed power than the helicopter's engines, Bell PC applies a complexity factor related to the maintenance accessibility of the engines for the advanced configurations, making them slightly higher cost per flight hour. Table 5-7 shows that the ultimate result of the analytical ground rules used is a set of cost metrics for the advanced baseline rotorcraft which are largely comparable to medium utility rotorcraft in operation today.

Table 5-6. Baseline design concept estimated direct operating costs, FY16 dollars

	Helicopter	**Lift Offset**	**Tiltrotor**
DMC - Airframe	$1,435	$2,194	$1,555
DMC - Engine	$ 997	$1,192	$1,172
Fuel	$ 990	$ 931	$ 872
Total Direct $/Flt. Hr.	**$3,421**	**$4,317**	**$3,598**
$\text{MMH/FH}_{\text{preventative}}$	2.618	2.804	2.786
$\text{MMH/FH}_{\text{corrective}}$	1.367	1.816	1.784
Total MMH/FH	**3.985**	**4.620**	**4.570**

Figure 5-10 and Table 5-8 give the estimated annual operating costs calculated for the direct operating metrics of each of the vehicles. Manpower costs are computed based on the percentage of a crew of maintainer man-year incurred at the 200 flight hour per year OPTEMPO. The manpower does not present itself as a major cost driver in the context of the direct operating costs, its secondary effects will be examined further in relation to reliability and maintainability.

Table 5-7. Procurement (Avg. 1,000 production units) and direct operating costs of baseline concepts compared to legacy military & commercial medium utility/transport helicopters

	Avg. Procurement Unit Cost	Direct Cost $/FH (Maintenance)	Direct Cost. $/FH (Fuel)	Total Direct Operating Cost $/FH	MMH/FH
UH-60M Black Hawk[1]	$19.11 M	$1,593	$ 720	$2,313	4.10
S-92A[2]	$26.97 M	$ 995	$ 890	$1,885	4.75
Baseline Helicopter[3]	$20.80 M	$ 997	$ 990	$3,421	3.99
Baseline Lift Offset Compound	$28.15 M	$1,192	$ 931	$4,317	4.62
Baseline Tiltrotor	$26.99 M	$1,172	$ 872	$3,598	4.57

Table 5-8. Estimated annual unit operating costs of baseline designs, FY16 dollars

	Helicopter	Lift Offset	Tiltrotor
1.0 Unit Level Manpower	$198	$211	$210
2.0 Unit Operations (Fuel)	$495	$465	$436
3.0 Maintenance	$1,216	$1,693	$1,363
4.0 Sustaining Support	$61	$85	$68
5.0 Continuing System Improvements	$118	$177	$168
Total	**$2,087**	**2,632**	**2,246**

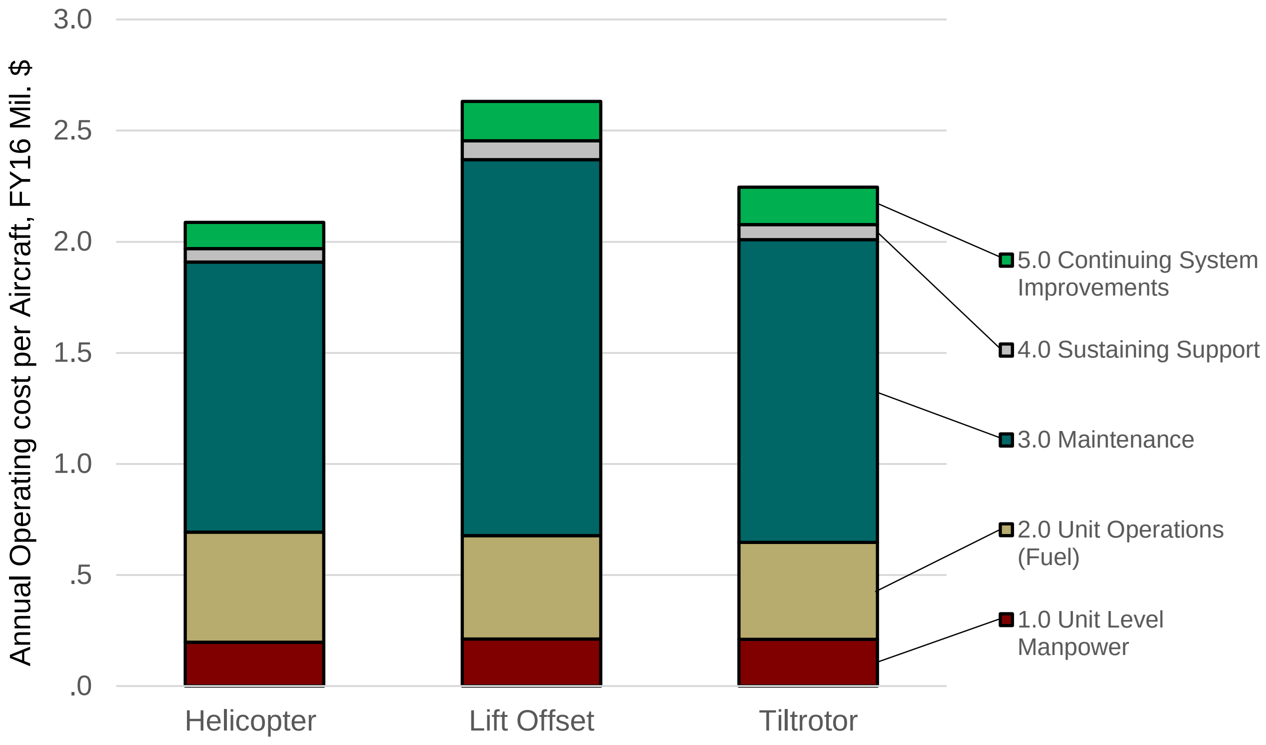


Figure 5-12. Estimated annual unit operating cost of baseline designs

With additional assumptions about life-cycle employment, sustainment, and retirement, the aircraft concepts generated in NDARC along with their corresponding baseline procurement and operating and support cost estimates can form the basis of a total ownership cost analysis. The next step of extrapolating this core set of results out along a future aircraft life-cycle is needed to determine the economic effects of reliability and maintainability in rotorcraft as proposed in Research Question 3 and whether an optimal level of reliability and maintainability exists in rotorcraft as hypothesized in Research Question 4.

CHAPTER 6

DESIGN FRAMEWORK IMPLEMENTATION

Affordability Optimization Concept

Figure 6-1 illustrates the final step of affordability optimization for conceptual design as envisioned in this study, which follows the development of design and assessment methods for modeling the impact of RAM on rotorcraft performance and life-cycle cost. Expressed mathematically, the key outcome needed to answer Research Question 4 is the presence of a minimum life-cycle cost design point represented as $C_{LCC,i+1} < C_{LCC} < C_{LCC,i-1}$ in the iterative sweep of reliability parameters contained in the set of design assumptions $D_{RAM,i}$.

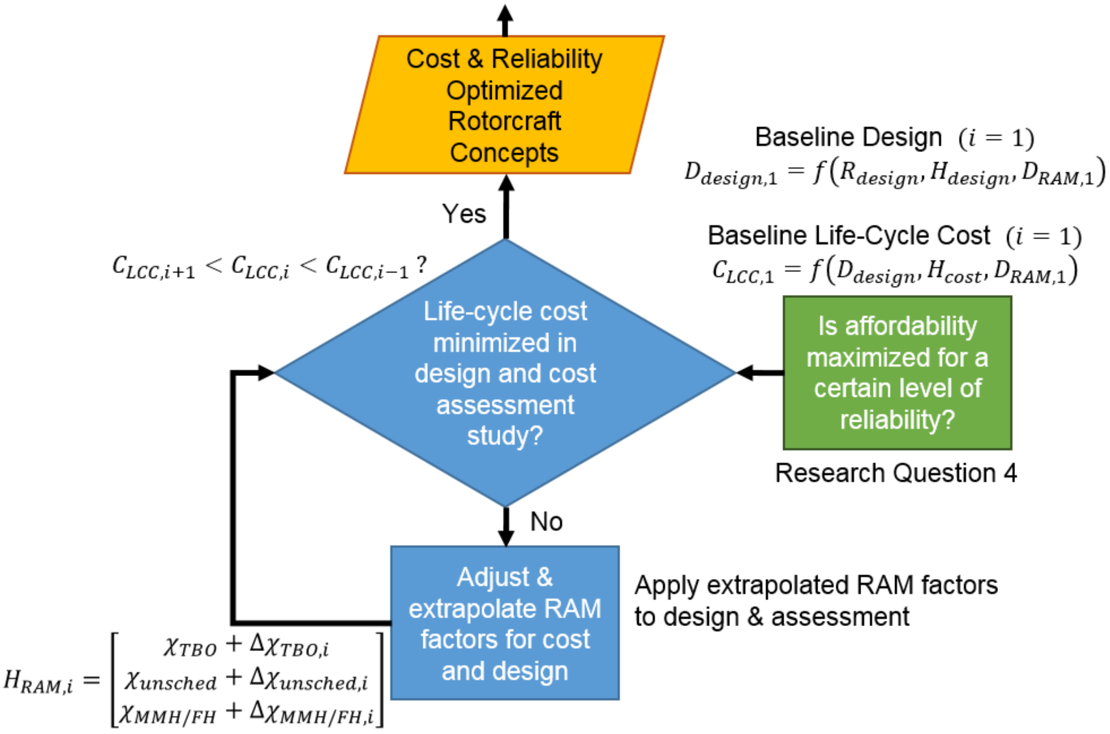


Figure 6-1. Design framework affordability optimization process

The sensitivity study scales the aircraft designs in NDARC and the estimated costs in Bell PC according the weight relationship in Eqn. 3-1 and the tech factors in equations

Table 4-5 through 4-7. The design framework is implemented as a set of executables, Excel spreadsheets, and Matlab scripts using the ModelCenter software integration tool. Figure 6-2 shows the design framework components and linkages. The data flow between the components and calculations is detailed in Appendix D. The maintainability tech factors for unscheduled maintenance and maintenance man-hours per flight hour given in Table 6-1 are used for the sensitivity sweep. The RDT&E required to raise each component's mean time between overhaul is calculated according to the predicted T1 unit cost of the component and the cost relationship in Eqn. 3-2.

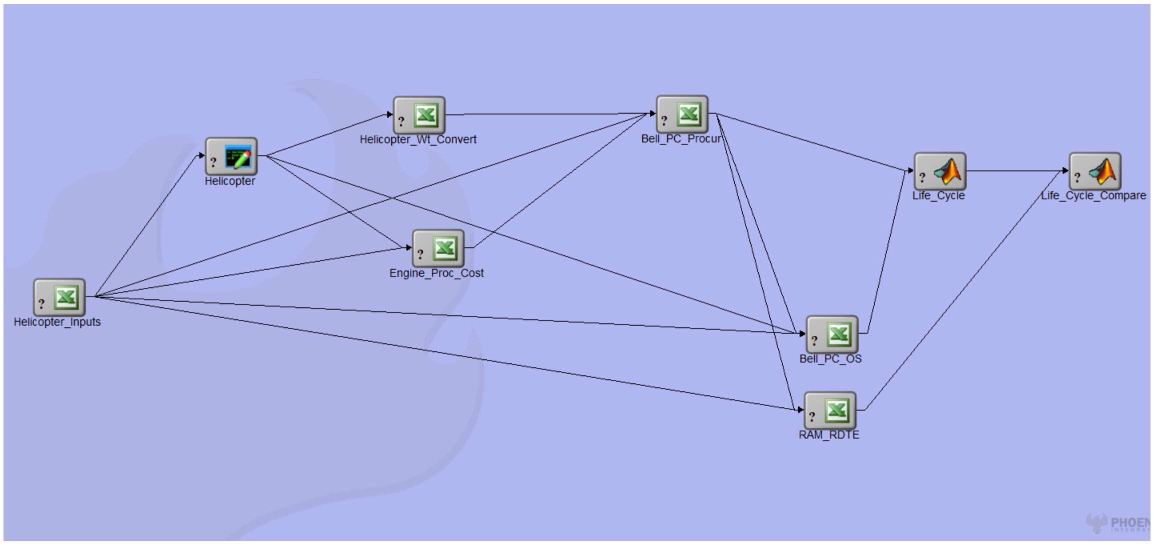


Figure 6-2. ModelCenter implementation of cost and reliability augmented rotorcraft design framework

Tradespace Characterization

The sensitivity study is conducted in two segments as described in Table 6-1. The first segment scales the TBO's of the rotors, drive system, flight controls, and engines up from their baseline 5,000 and 6,000 flight hour design specifications to the same 10,000 flight hour interval used as the baseline service life of the airframe. This point represents in theory an aircraft which is designed to require on average zero major maintenance actions over the course of one standard service life of 10,000 flight hours. The second segment of the trade study scales the overhaul interval of each component – now including the service life of the airframe itself – up to 20,000 flight hours. The 20,000 flight hour upper limit of the tradespace represents a design specification of twice the standard military rotorcraft service life, meaning the upfront acquisition investment in improved reliability enables the conceptual aircraft to fly twice as long while not requiring a service life extension program (SLEP).

Table 6-1. Reliability and Maintainability design study tradespace

	RAM Baseline	10,000 FH Interval Zero Major Maintenance over one standard aircraft service life	20,000 FH Interval Zero Major Maintenance over two standard aircraft service lives with no SLEP
Drive, Rotor, Flt. Ctrl.	5,000 Flt. Hrs. TBO (χ_{TBO} = 1.2)	10,000 Flt. Hrs. TBO (χ_{TBO} = 2)	20,000 Flt. Hrs. TBO (χ_{TBO} = 4)
Airframe	10,000 Flt. Hrs. Service Life, (χ_{TBO} = 1)	10,000 Flt. Hrs. Service Life (χ_{TBO} = 1)	20,000 Flt. Hrs. Service Life, (χ_{TBO} = 2)
Engines, Propulsion	6,000 Flt. Hrs. TBO (χ_{TBO} = 1)	10,000 Flt. Hrs. TBO (χ_{TBO} = 1.67)	20,000 Flt. Hrs. TBO, (χ_{TBO} = 3.33)
MMH/FH	$\chi_{MMH/FH}$ = 1 (Dyn.) $\chi_{MMH/FH}$ = 1 (Airf.) $\chi_{MMH/FH}$ = 1 (Eng.)	$\chi_{MMH/FH}$ = 0.625 (Dyn.) $\chi_{MMH/FH}$ = 0.625 (Airf.) $\chi_{MMH/FH}$ = 0.625 (Eng.)	$\chi_{MMH/FH}$ = 0.4375 (Dyn.) $\chi_{MMH/FH}$ = 0.625 (Airf.) $\chi_{MMH/FH}$ = 0.475 (Eng.)
Unscheduled Maintenance	$\chi_{unsched}$ = 1 (Dyn.) $\chi_{unsched}$ = 1 (Airf.) $\chi_{unsched}$ = 1 (Eng.)	$\chi_{unsched}$ = 0.625 (Dyn.) $\chi_{unsched}$ = 1.0 (Airf.) $\chi_{unsched}$ = 0.7 (Eng.)	$\chi_{unsched}$ = 0.4375 (Dyn.) $\chi_{unsched}$ = 0.6250 (Airf.) $\chi_{unsched}$ = 0.4750 (Eng.)

Figure 6-3 illustrates the change in the weight tech factors due to the trade study ground rules. The maintenance components defined by a TBO interval use tech factors which are applied to the TBO parameters in flight hours in the denominator in Eqn. 3-4, thus these tech factors increase to represent positive maintenance improvement. The tech factors for the unscheduled and manpower calculations decrease to with reliability improvement since Bell PC directly estimates the dollars per flight hour part cost of unscheduled maintenance and the maintenance man-hours per flight hour as represented in Eqns. 3-6 through 3-9. The sweep of reliability is performed running the ModelCenter environment shown in Figure 6-2 for each of the designs in increments of 500 flight hours TBO. The dashed curves in Figure 6-3 represent the technology factors applied to the cost model to represent the effect of reliability improvement, while the solid curves represent the increase in TBO applied the scheduled, life-limited maintenance components.

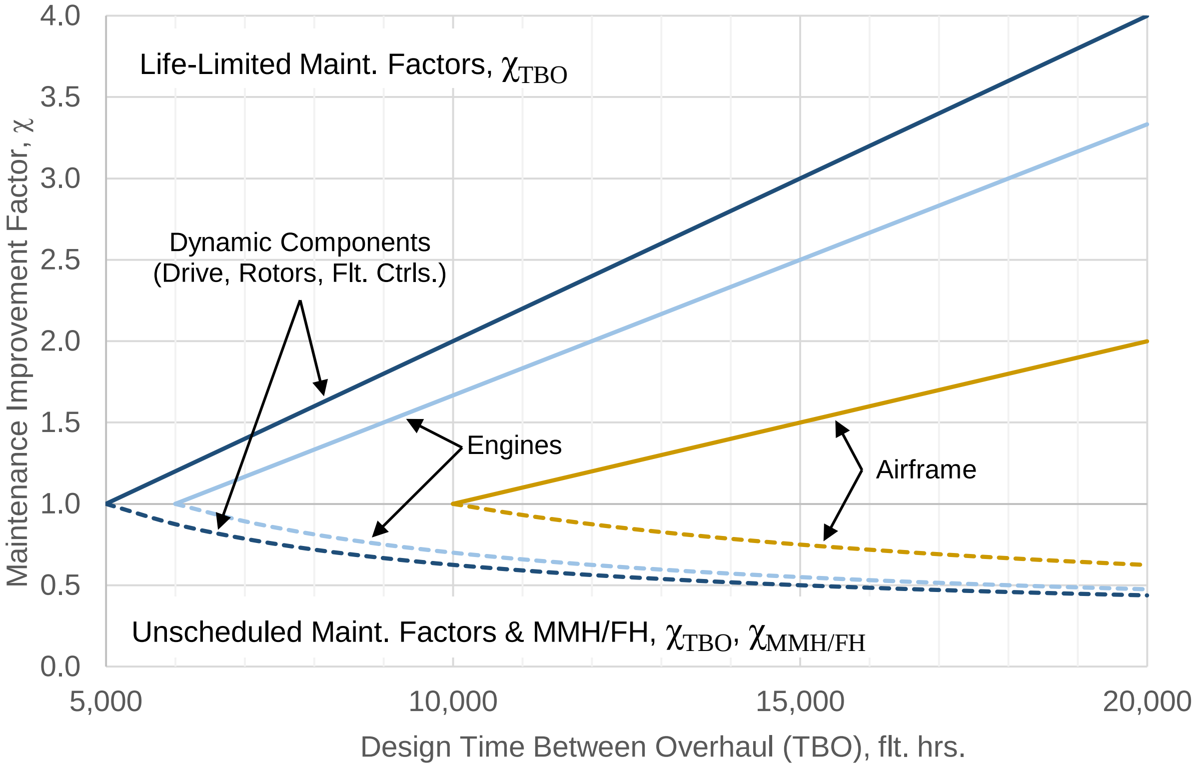


Figure 6-3. Maintenance improvement factor tradespace

Trade Study Design Results

Figure 6-4 plots the change in the design gross weight and empty weight of the three designs as the weight adjustment factor is applied to the structural and dynamics components of the aircraft starting from a baseline of 5,000 flight hours TBO up to a maximum of 20,000 flight hours TBO. The tiltrotor and lift offset experience greater increases in weights than the helicopter due to the higher empty weight fraction and growth factor of their baseline designs compared to the low weight of the advanced helicopter.

On the other hand, the two advanced configurations are more aerodynamically efficient than the helicopter, even at its lower gross weight. The compounding of lift and thrust mechanisms in the two configurations also allows them to tolerate engine scaling slightly better than the helicopter with its single main rotor providing both lift and thrust. Consequently, the lift offset compound helicopter and the tiltrotor require less power across the tradespace of design specified maintenance and reliability technology as shown in Figure 6-5.

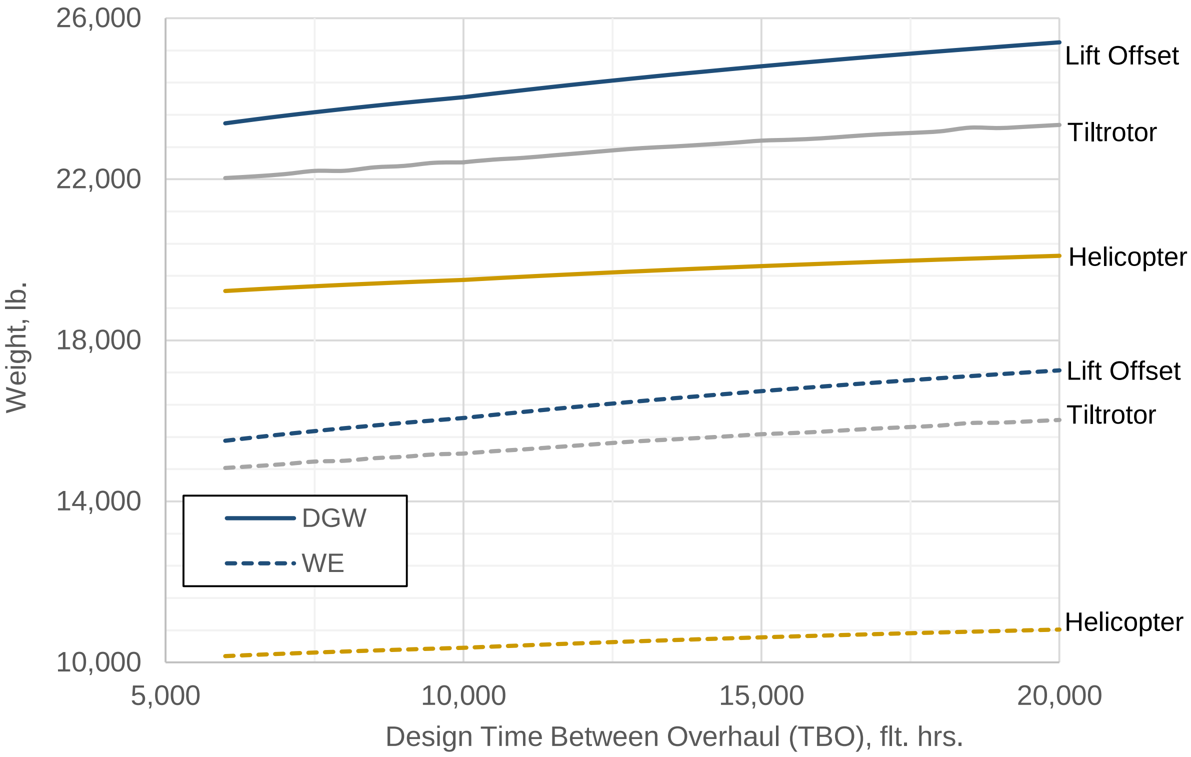


Figure 6-4. Gross weight and empty weight vs. TBO study

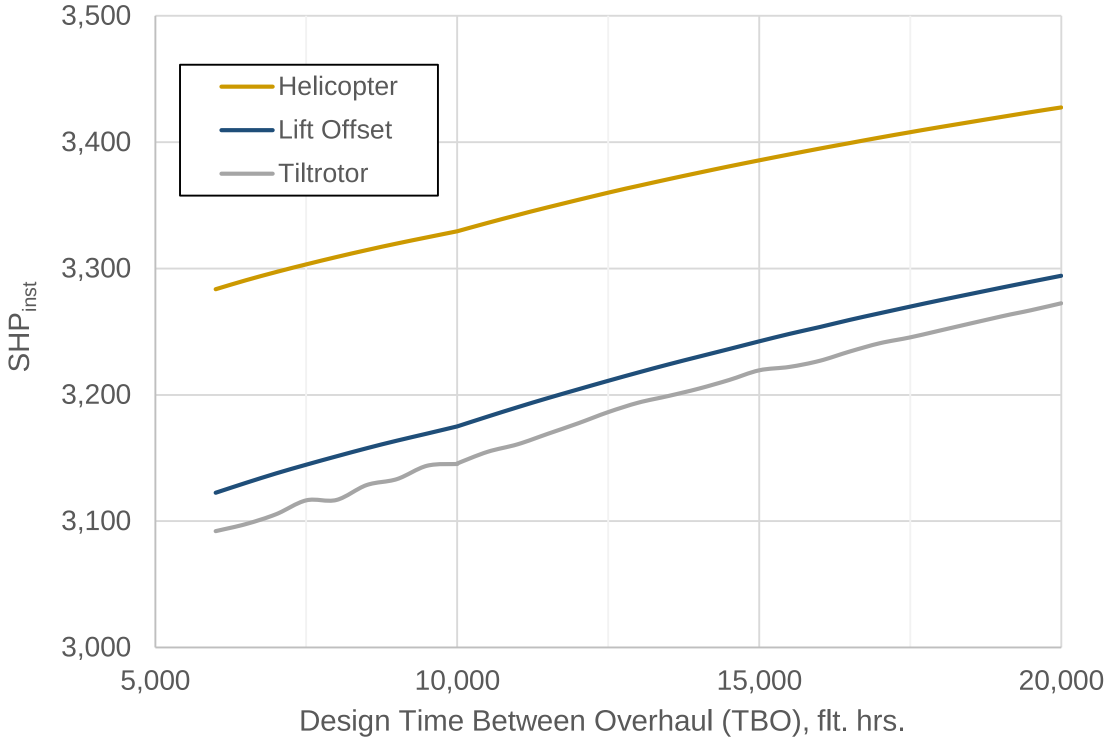


Figure 6-5. Installed horsepower vs. TBO study

Trade Study Reliability Results

Simultaneous to the growth in weight due to the insertion of structural fatigue strength and RAM technology, the same effects observed in the Chinook example calculation from Chapter 3 emerge as the reliability tech factors in Table 6-1 are applied to the O&S cost model. Figure 6-6 plots the predicted maintenance man-hours per flight hour of the concepts against the operational availability predicted according to Equation A-1 in Appendix A. Operational availability is used in this example with logistical downtime not considered in order to measure the inherent reliability quality of the aircraft. Future work may apply the design methodology to a larger scale and broader scope fleet simulation to include fleet sustainment strategy and materiel availability (A_M) according to Ref. A-2. The joint between the two line segments in each of the curves in the plots signifies the aircraft concepts designed to 10,000 flight hours of zero major maintenance. The segments on the left side of the joints represent the A_o and MMH/FH trends of the aircraft designed while varying only the life-limited drive, rotor, and flight control, and engine components. The line segments to the right of the joint represent the sizing trends when the aircraft are designed to for a single scheduled maintenance interval greater than 10,000 flight hours for the entire vehicle, including both the life-limited components and the rated service life of the airframe structure.

Figure 6-6 shows that the high speed tiltrotor and lift offset compound, with their higher baseline maintenance manpower burdens are slightly more sensitive than the helicopter to the technology improvement applied in the trade study. This effect is evidenced by the narrowing gap in MMH/FH between the helicopter and the two high speed configurations, which decreases from 0.6 MMH/FH difference at the baseline design run to 0.3 MMH/FH at the 20,000 TBO design point. The operational availability ability plotted in Figure 6-6 for a 200 flight hour per year OPTEMPO also improves above 90% for all of the configurations within the boundaries of the RAM technology tradespace.

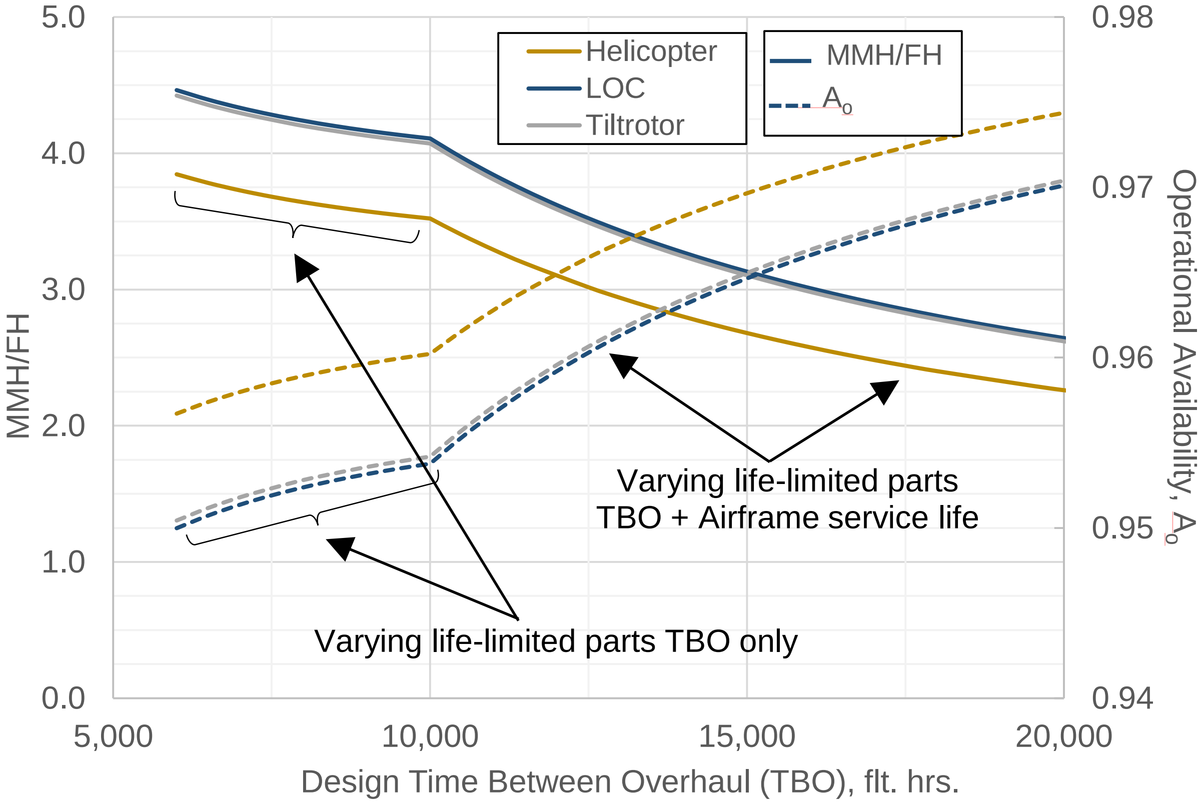


Figure 6-6. MMH/FH and operational availability vs. TBO study

Trade Study Cost Results

Figure 6-7 plots the dollars per flight hour direct operating cost (DOC) impact due to the design and RAM effects which are varied in the study, the net effect of the reduction in both scheduled and unscheduled maintenance emerges as a major reduction in total direct maintenance cost per flight hour between the boundaries of the sensitivity analysis. The lift offset compound, which is particularly challenged from a maintenance perspective with its large quantity of rotor and propeller hub and blade components, experiences an approximately 40% reduction in direct cost per flight hour. The tiltrotor also experiences significant improvement in maintenance cost per flight hour as a result of increasing TBO. The cruise efficiency of the tiltrotor in particular allows the configuration to sustain the increase in empty weight due to RAM considerations with minimal growth in cruise fuel compared to the helicopter. As a result, the tiltrotor's direct operating cost pulls nearly even to that of the helicopter at the 20,000 flight hour TBO point.

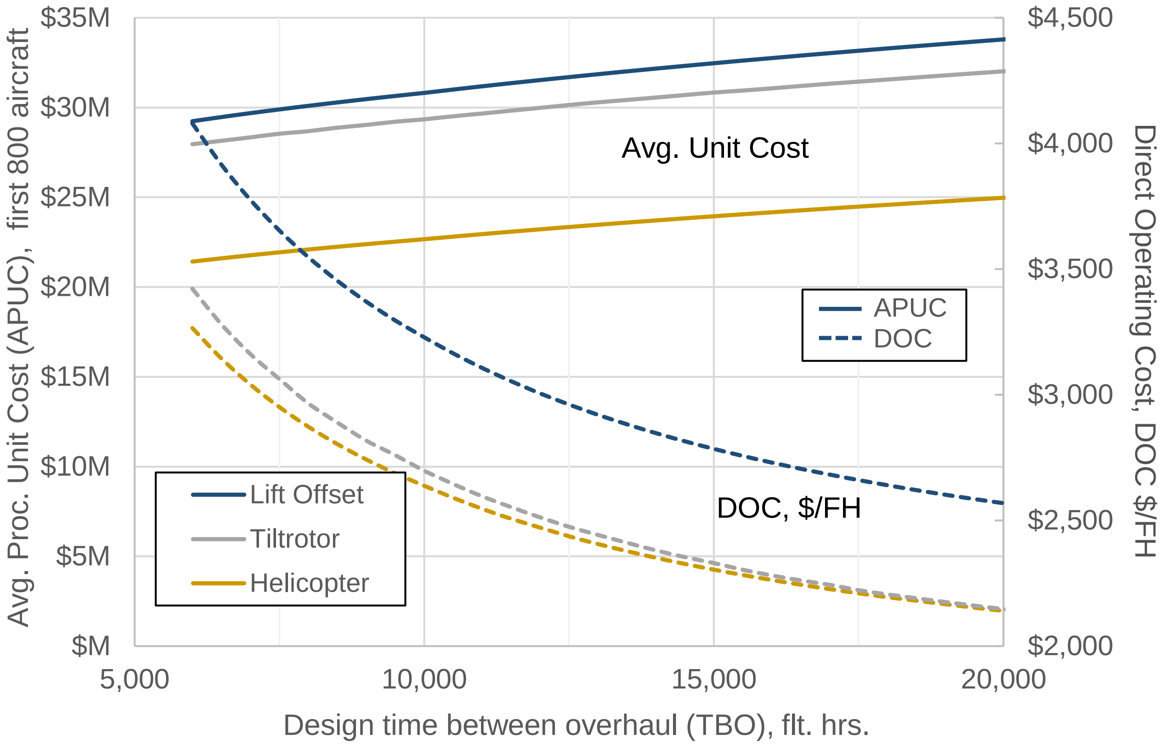


Figure 6-7. DOC and Avg. Unit Procurement cost vs. TBO study

The price of the maintenance improvement in Figure 6 6-7 is manifest at the platform level as an increase in increase in average unit procurement cost. The lightweight helicopter is the most resistant to procurement cost growth, adding approximately $3.5 Million per aircraft between the baseline and upper limits of the reliability improvement. Conversely, the scaled up version of the tiltrotor and lift offset are between $4.5 and $5.0 Million more expensive than their baseline designs.

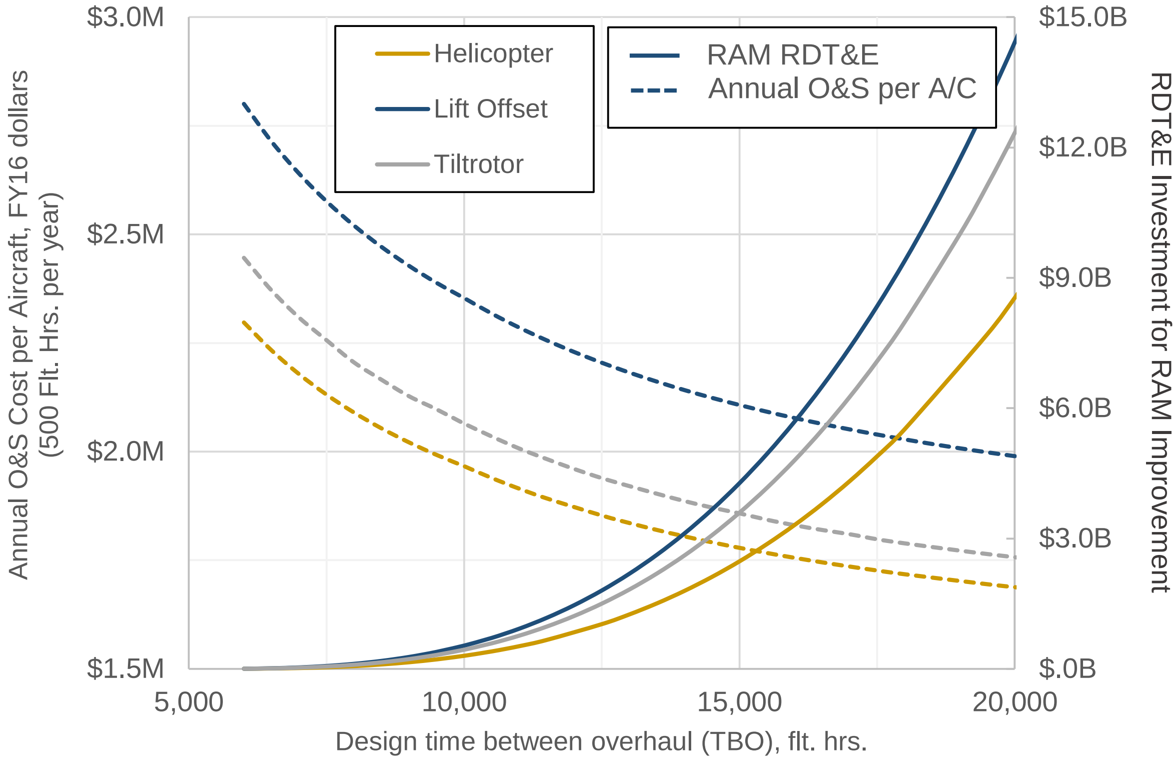


Figure 6-8. Annual O&S per aircraft and RDT&E investment vs. TBO study

The reductions in direct cost per flight hour and MMH/FH feed up to the annual operating cost per aircraft and result in a potential savings of almost $500,000 per aircraft per year at the 10,000 flight hour TBO point and $750,000 at the maximum 20,000 flight hour TBO design point. This result trend appears to present a promising opportunity for life-cycle cost reduction since the avoidance of as much as $750,000 dollars per year in ownership expense could easily pay back the $3.5 – $5.0 Million up front increase in purchase price per aircraft given the 20+ year life of the platform suggested by the 10,000 to 20,000 flight hour component lives considered in the trade study. On the other hand, the RDT&E component of the acquisition cost predicted by Equation 3-2 and plotted in Figure 6-8, implies that the tradespace may contain a limit of cost-effectiveness in investment dollars beyond which further reduction in operating cost may not be justifiable due to the prohibitive RDT&E investment required to improve the strength and the longevity of the materials and to mature the vehicle management technologies which enable extended maintenance-free operation. In contrast to the seemingly gentle slope of weight increase with added TBO shown in Appendix G, the cost results tabulated in Appendix H – specifically those for RDT&E cost – indicate a price of nearly $700 Million in total program cost for each successive 1,000 flight hours of additional service above 12,000 FH TBO and greater than $1 Billion for each 1,000 flight hours above 16,000 FH TBO.

Life-Cycle Cost Simulation

The counteracting effects of acquisition versus operating and support cost clearly illustrated at the aircraft level in Figures 6-6 and 6-7 demand a full life-cycle cost evaluation in order to answer Research Question 4. To demonstrate how this assessment could be accomplished, additional assumptions are needed to compose a representative acquisition program scenario for the three aircraft in the cost and reliability focused rotorcraft design tradespace. Table 6-2 provides the assumptions used to simulate the long term average operating costs of the aircraft over its life-cycle. These assumptions are based on current practices of military rotorcraft fleet size, procurement pace, and operational rates in medium utility rotorcraft as listed in public data sources such as Ref. 6-1. Although the design study considers many future technology features which mitigate cost growth, the affordability benefit inherent to a leveraging of technology toward a smaller fleet of more reliable and operationally effective aircraft is not considered in great depth. Considerations of force structure and institutional practices present complex organizational issues, whose interlinking affordability effects may be considered in future work using the reliability-augmented assessment methodology presented in this study. Ref. 6-3 provides one example of a fleet-wide approach to this issue which could be combined with the individual aircraft reliability and cost analysis conducted in this work.

Table 6-2. Life-cycle cost assessment scenario assumptions

	Assumption	Rationale
Production Quantity	1,000 production aircraft (Table 5-3 learning curve assumptions)	Rough order of magnitude estimate for initial phase, joint service medium utility replacement (Ref. 6-1)
OPTEMPO	200 flight hours per year	Military rotorcraft peacetime OPTEMPO
Personnel, Fuel	Standard average officer & enlisted pay, $5/gal fuel	Rough order magnitude estimate for long term fuel cost average
Disposal Cost	$50,000 per aircraft	Rough order magnitude estimate
Other Components	Contractor Sust. Support Cont. Sys. Improvements	Rough order magnitude estimate Other indirect costs not considered

Figure 6-9 provides an example graph of the expected behavior of the cumulative program cost over time of an aircraft development, acquisition, and operation sequence. The change in accumulated life-cycle cost between the baseline conventional aircraft and a high reliability aircraft would be expected as a higher cost acquisition phase followed by a lower cost operating phase. The higher acquisition cost due to the additional RDT&E and procurement investments made to improve the reliability for this example is provided by the effects in Figures 6-7 and 6-8.

The decrease in O&S cost per aircraft shown in Figure 6-7 confirms the RAM effect expected in the operating phase of the life-cycle. Ref. 1-16 has shown these factors create a life-cycle cost difference between the baseline and excursion aircraft presenting the shape shown in Figure 6-10. For a non-commercial application where the value of the aircraft procured does not depend on generated revenue, Figure 6-10 works as a cash flow curve drawn in reverse, with the curve’s final value being the difference between the life-cycle cost of the aircraft with and without technology insertion. A negative value at the end of the program curve means the operating cost savings derived from the technology insertion are sufficient to repay the change in acquisition cost due to RDT&E and additional procurement cost and furthermore yield net savings.

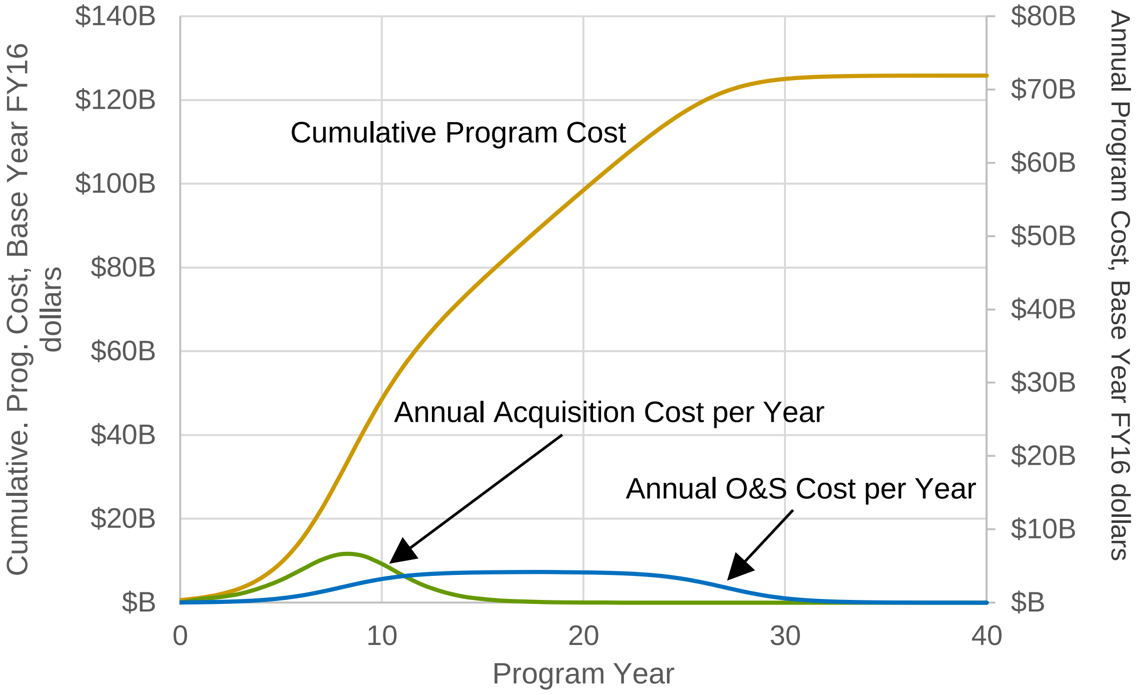


Figure 6-9. Life-cycle cost components for 12,500 flt. hr. TBO design advanced helicopter

Plotting the relative program RAM investment cash flow curves for the simulated program life-cycle cost estimated at several levels of design time between overhaul shows the effects of the multiple design and assessment models incorporated into the framework illustrated in Figure 6-11. Examining the difference in RAM investment gain between the 7k, 10k, and 13k flight hour TBO designs, the predicted difference in life-cycle cost between the improved reliability designs and the baseline displays a trend of increased savings for increased investment. At the upper extreme of the tradespace, the 20,000 flight hour TBO curve shows that the savings dividend which the maximum RDT&E investment yields in the O&S phase of the program is barely sufficient to repay its own initial cost in base year dollars. The 20,000 flight hour design point is clearly both riskier due to its upfront cost required and less economically viable due to its lower overall savings compared to the other design points shown in Figure 6-11. At the same time, the steep curve in Eqn. 6-10 for the predicted RDT&E causes the initial investment offset at program year zero to rise rapidly. The increase in the ordinate value of the initial point in is sufficiently rapid that at some point the increase in annual O&S savings indicated by the magnitude of the downward slopes of the curves through the operating life-cycle phases no longer produces additional net life-cycle savings. This effect is illustrated in by the equal life-cycle costs of the 10,000 and 16,000 flight hour curves, and the greater overall savings of the 7,000 flight hour curve compared to the 20,000 flight hour TBO aircraft.

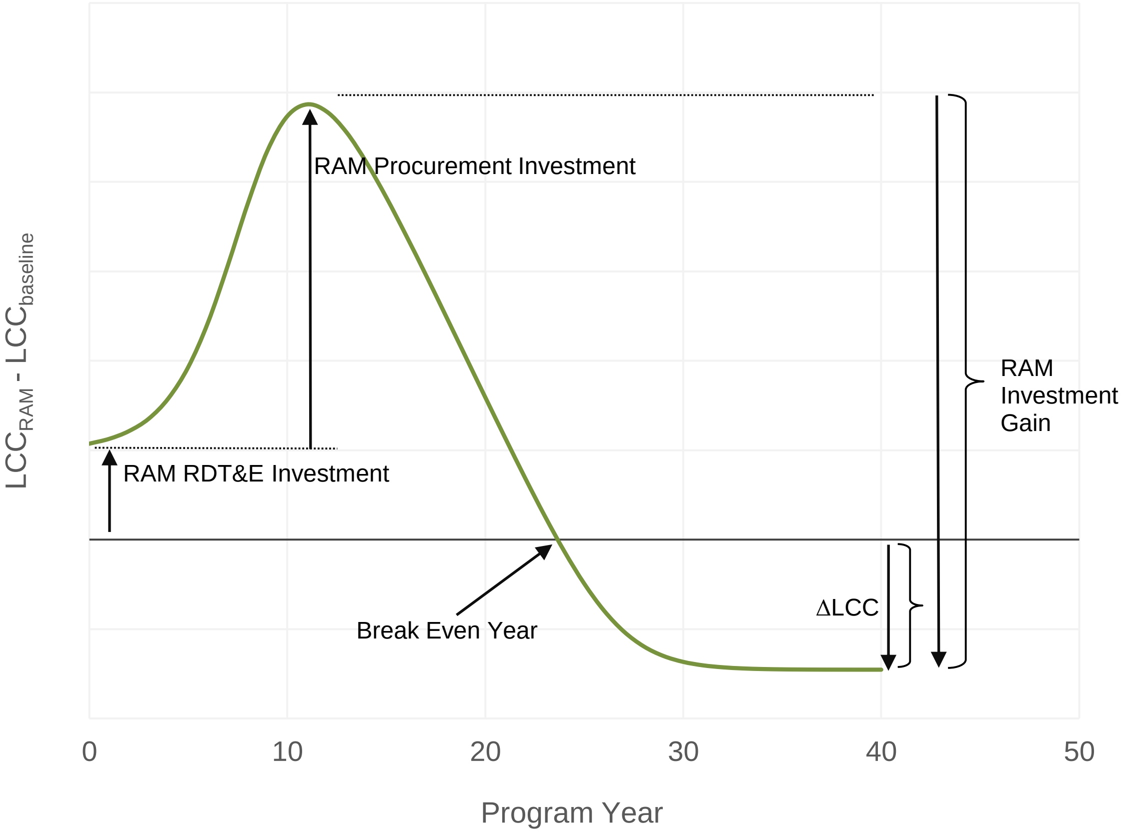


Figure 6-10. Relative LCC behavior for notional RAM investment scenario

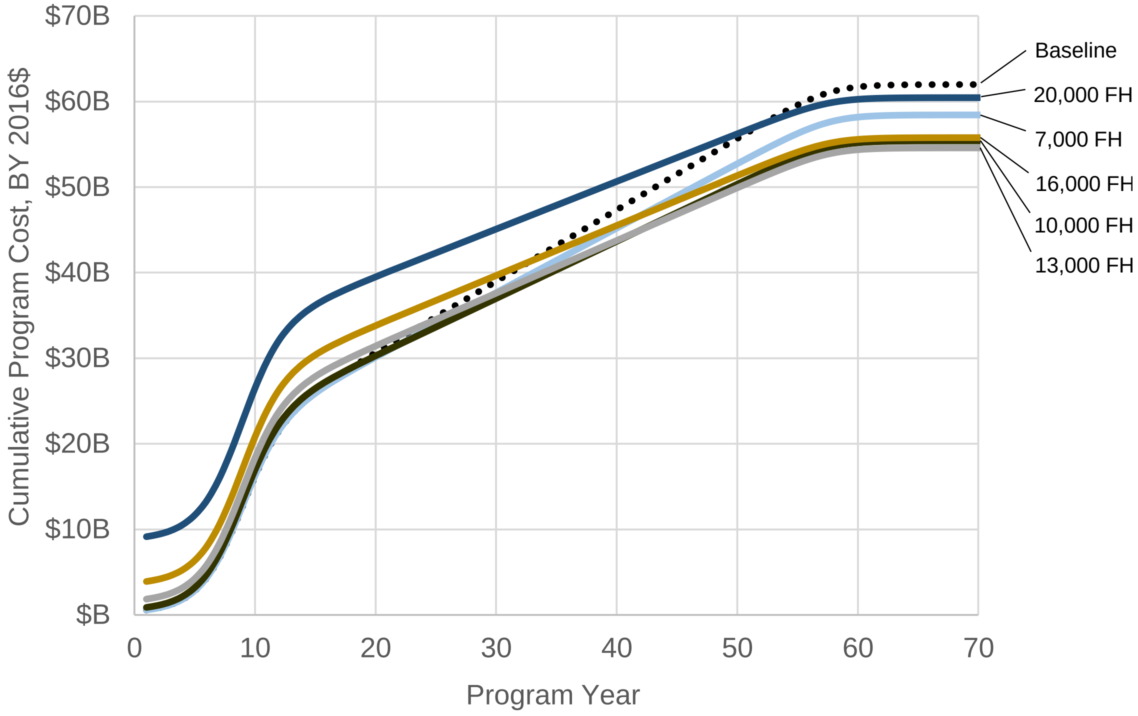


Figure 6-11. Cumulative program cost curves for multiple advanced helicopter trade study points

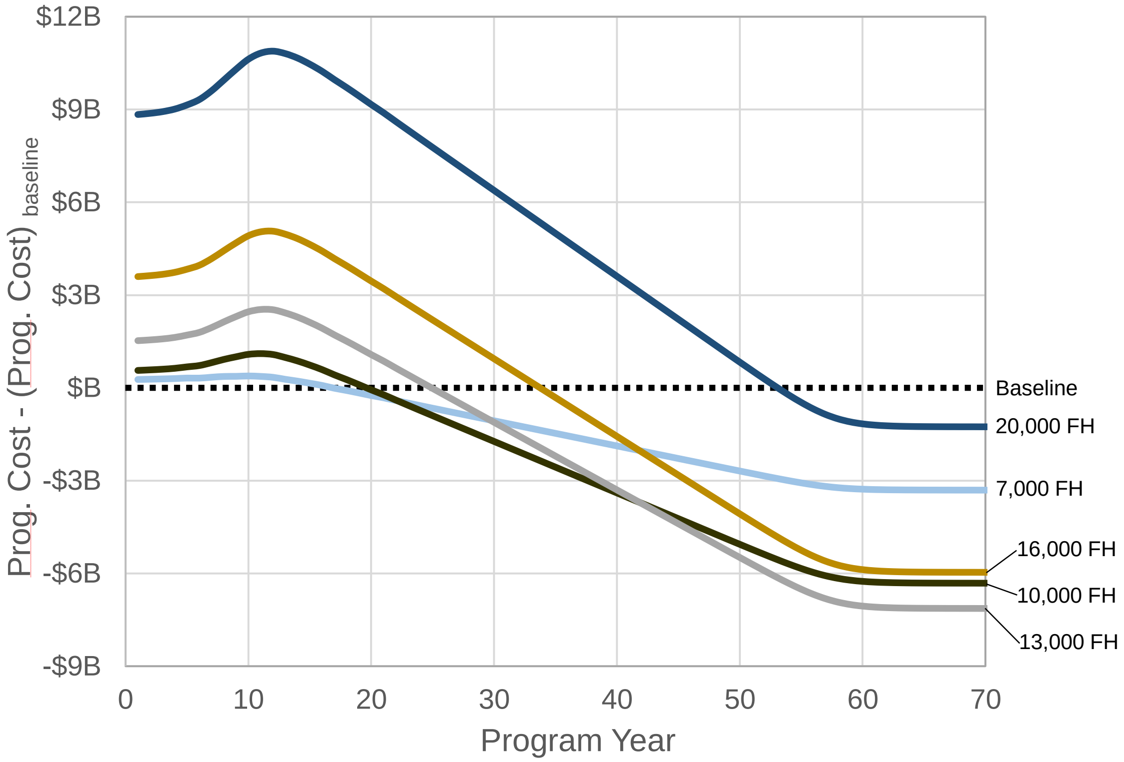


Figure 6-12. Program cost comparison curves for multiple advanced helicopter trade study points

Figures 6-13 through 6-15 plot the life-cycle cost as measured in this scenario, normalized to the life-cycle cost of the respective configuration's baseline design which assumes no RAM improvement. The abbreviated design and cost results of the trade study are tabulated in Appendices G and H. Figure 6-13 through 6-15 also plot the break-even year for recoupment of the increased acquisition investment above the price of the baseline design as it is defined in Figure 6-10. The life-cycle calculations are performed in both base year 2016 dollars and then year, as spent dollars assuming a 2% annual inflation rate extrapolated from DoD-defined economic trends as shown in Figure 6-16. The 2% inflation factor is applied uniformly to all components of the annual cost, thus representing a range of possible inflationary factors including economic inflation, maintenance escalation due to aging of the airframe, and escalation in fuel cost among many possible factors.

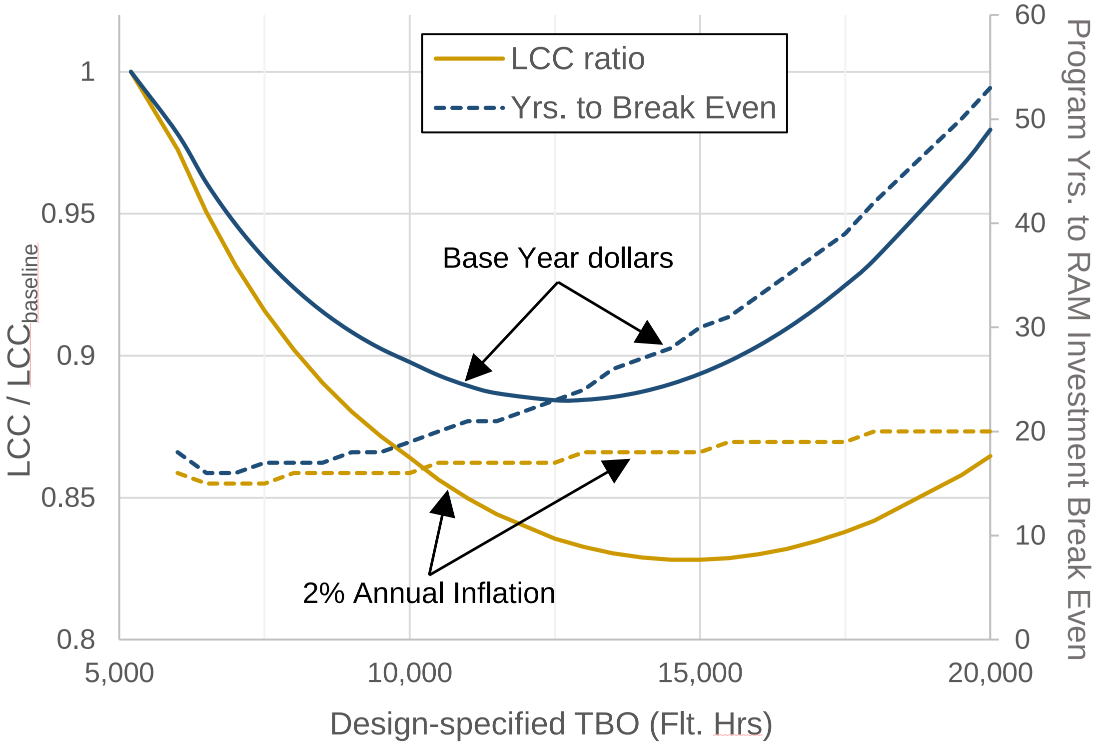


Figure 6-13. Normalized helicopter life-cycle cost and break-even year.

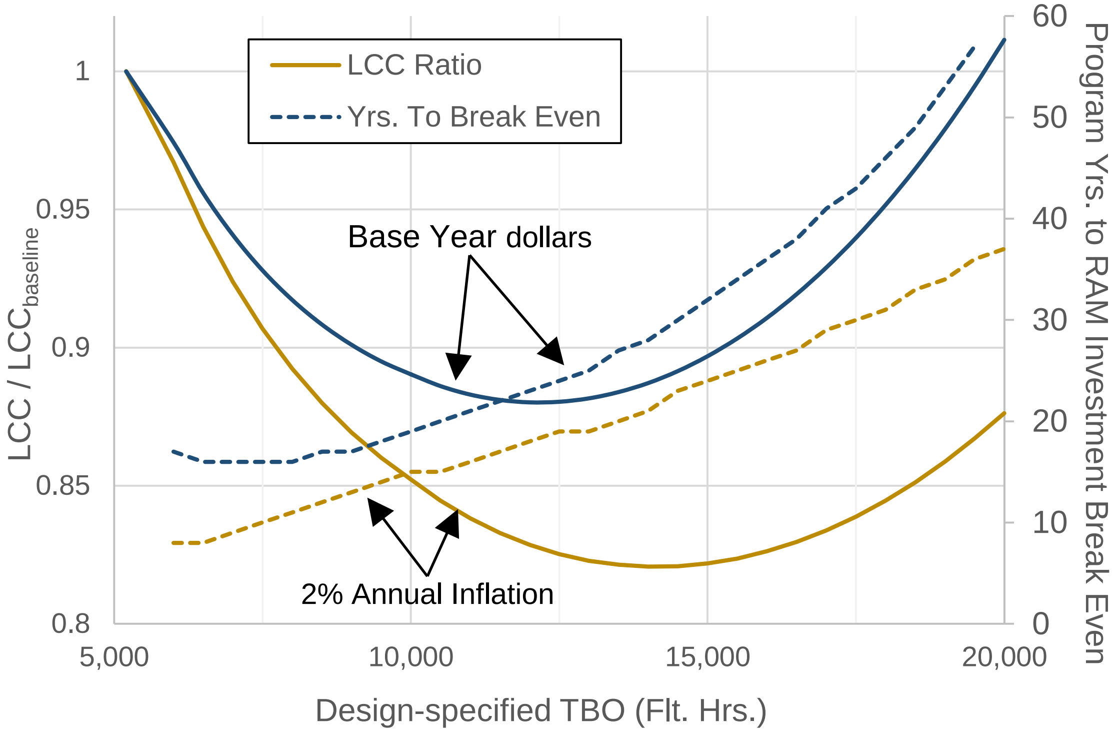


Figure 6-14. Normalized lift offset life-cycle cost and break-even year.

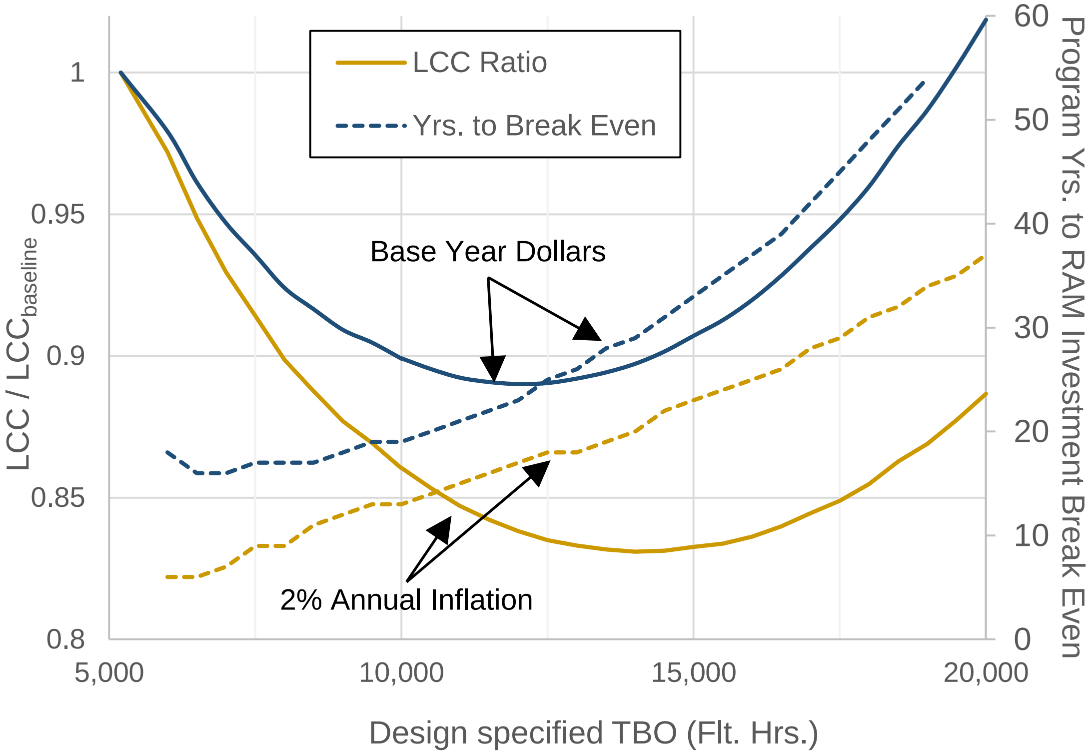


Figure 6-15. Normalized tiltrotor life-cycle cost and break-even year.

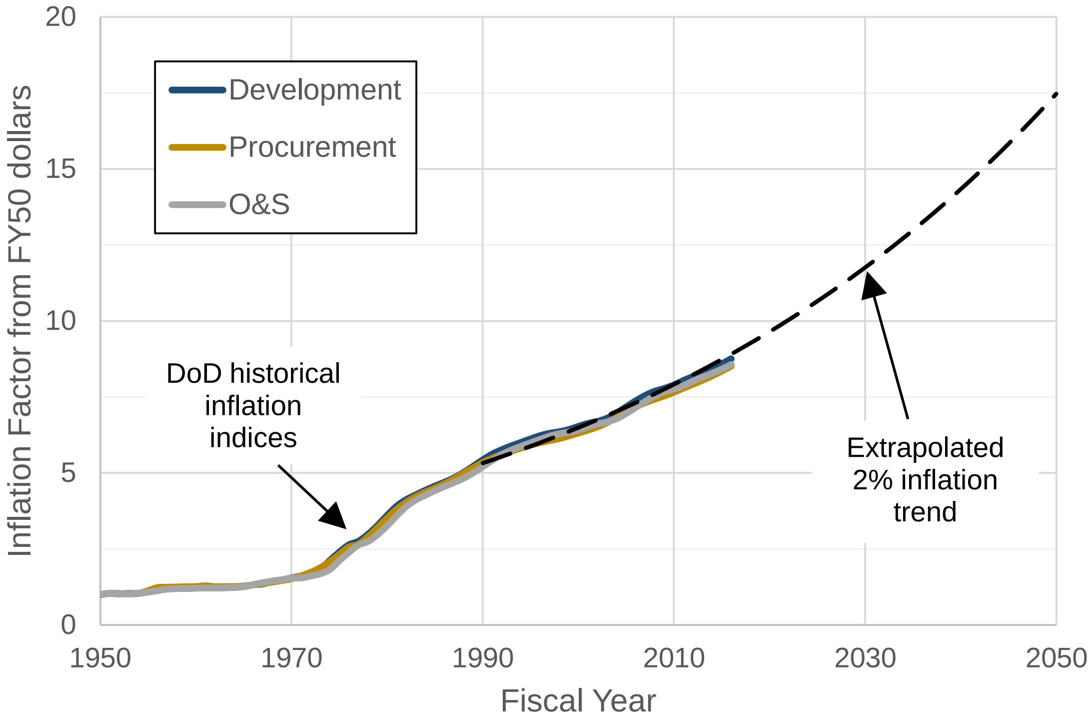


Figure 6-16. DoD inflation trends with 2% annual inflation extrapolated beyond 2016 (Ref. 6-2)

Life-Cycle Cost Metrics

The technology investment cash flow curve drawn in Figure 6-10 illustrates several measures of success for a technology investment program. Since the obvious goal of any investment in the context of this study is to yield net program savings, the first success criterion is that the investment gain exceeds the total investment, meaning the value of the curve is negative at the time of program retirement. In addition to simply achieving net savings, a program decision maker would also naturally want to maximize the net savings, minimize upfront investment, and break even on the initial increase in program cost as soon as possible. The concept of return on investment (ROI) is introduced in Equation 6-1 to evaluate the relative economic efficiency of the different levels of aircraft reliability surveyed in the design exploration.

$$ROI = \frac{Gain - Investment}{Investment} \qquad (6-1)$$

Figure 6-17 plots the same normalized life-cycle cost curves against the estimated return on RAM investment for the range of the sensitivity sweep in base years 2016 dollars. The total investment is calculated by adding the RDT&E cost from Equation 3-1 with the additional procurement cost incurred by the high reliability aircraft over the production run as shown in Figure 6-7. The gain is the net reduction in life-cycle cost from the baseline measured from the upward extreme of investment difference represented as the peak of the cash flow curve notionally represented in Figure 6-10. As Figure 6-12 shows, the life-cycle cost tradeoff is observed as a higher starting point of up-front investment for higher reliability against a steeper downward slope toward the break-even point due to the reduction in annual fleet O&S expenses. Table 6-3 compares the design points in the tradespace study where the minimum life-cycle cost, maximum return on investment, and timeliest break even on acquisition investment occur. As Figure 6-17 and Table 6-3 show, the maximum return on investment design point occurs closer to the baseline point of departure and corresponds strongly to the points of earliest investment break even as shown in Figures 6-13 through 6-15. Design points above 20,000 flight hours are not seriously considered in the analysis due to the extrapolation of the RDT&E model required to evaluate the life-cycle cost at these extremes as well as the obvious implication of unaffordability implied by the acquisition costs beyond 15,000 flight hours TBO.

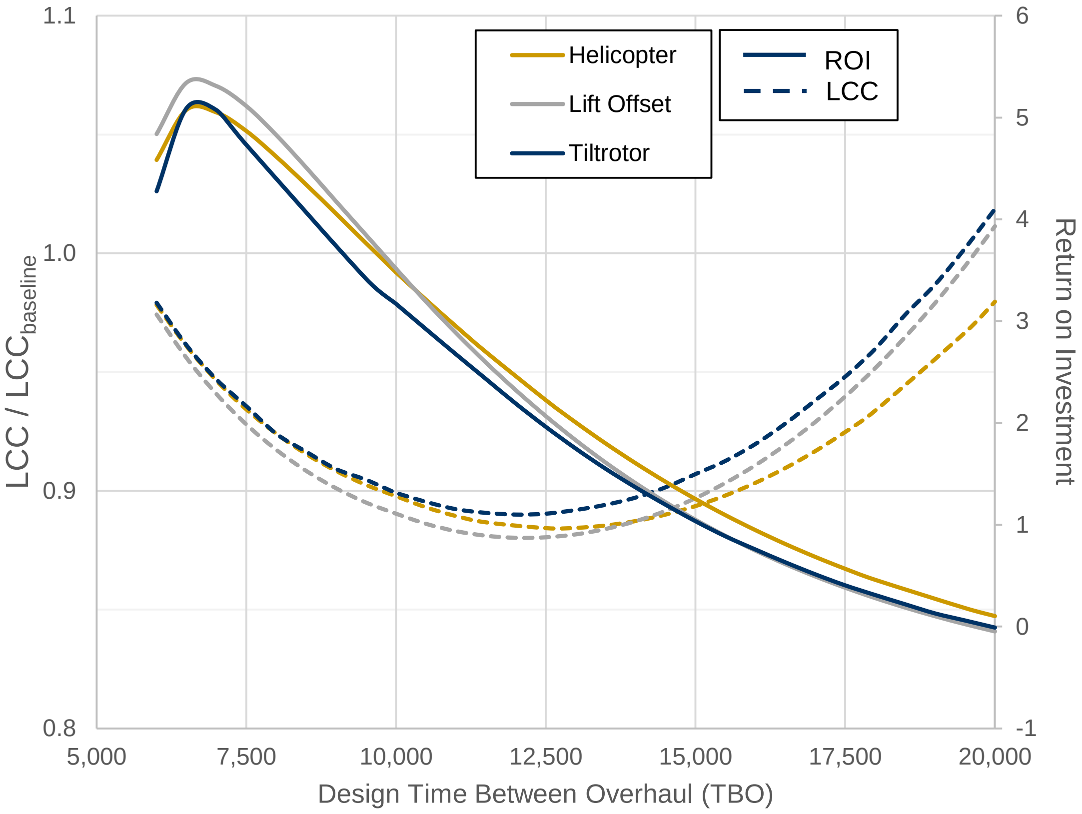


Figure 6-17. Tradespace sweep of life-cycle cost ratio and return on investment

Evaluating the future feasibility of such an improvement in an aircraft's inherent reliability likely requires advanced analysis of specific technologies judging from the current state of the art in component design life noted in Chapter 1. Even if such an aircraft with components approaching near-zero maintenance operation were technically feasible the implications of the model trends at today's level of design technology, the modeling framework still predicts that such aircraft would be prohibitively expensive to procure, and would ultimately be economically non-competitive in spite of having a very low expected maintenance burden. Future work in this topic is required to adequately quantify the broad spectrum impact of a zero maintenance aircraft. Consideration of the full scope of infrastructure costs related to spares inventory, support personnel, support facilities, and doctrinal issues related to employment and deployment within a larger of multiple rotorcraft types might ultimately improve the case for such an aircraft.

Table 6-3. Design points of optimum cost reduction and return on investment (Base year dollar life-cycle cost scenario

	Min. $LCC_{RAM}/LCC_{baseline}$ (TBO Design Pt.) (Break-even Prog. Yr.)	Max. ROI (TBO Design Pt.) (Break-even Prog. Yr.)	Earliest Break Even (TBO Design Pt.) ($LCC_{RAM}/LCC_{baseline}$)
Helicopter	0.8844 (12,500 flt. hrs.) (23 years)	5.0767 (6,500 flt. hrs.) (16 years)	16 years (7,000 flt. hrs.) (0.9464)
Lift Offset	0.8207 (14,000 flt. hrs.) (21 years)	5.3432 (6,500 flt. hrs.) (16 years)	16 years (7,500 flt. hrs.) (0.9069)
Tiltrotor	0.8900 (12,000 flt. hrs.) (23 years)	5.0938 (6,500 flt. hrs.) (16 years)	16 years (7,000 flt. hrs.) (0.9469)

The design & cost study on RAM sensitivity has shown several factors not presently incorporated into rotorcraft design and assessment in a formalized way. In terms of the impact to the design itself, Research Question 4 posed the question of whether a conceptual rotorcraft design can be optimized around the level of technology insertion to achieve minimum life-cycle cost within the ground rules of the analysis. The results shown in Figures 6-11 through 6-13 provide a clear answer in the affirmative to this question of optimization. However, the additional tracking of break-even year and return on investment suggests that although a minimum life-cycle cost result is clearly possible, it may not be the design point of lowest risk or highest effectiveness of investment. These new implications open the analysis to a broader spectrum of possible acquisition considerations which can provide inputs to the choice of reliability incorporated into a conceptual design.

CHAPTER 7

COST, RELIABILITY, AND VALUE IMPLICATIONS

Design Study Generalization

The design study presented in Chapters 5 and 6 has demonstrated a method for evaluating the business case viability of technology investment related to rotorcraft reliability at three distinct design points. An advanced helicopter, a lift offset compound, and a tiltrotor have been resized across a tradespace in which reliability is used as a design input. The life-cycle cost predictions of each of the designs has indicated that for a given baseline configuration, the minimum life-cycle cost and the maximum investment cost effectiveness solutions may occur at separate and distinct design points in the tradespace. The results presented in Table 6-3 find that these points are closely correlated to each other across configurations under the assumptions of the trade study. Nevertheless, further generalization is needed to understand the influence of each of the design, cost, and reliability variables since the results may change based on the assumptions of the life-cycle study.

The life-cycle cost of an aircraft is defined in Eqn. 7-1 as the sum of development, procurement, and operating costs, where operating costs for simplicity are also assumed to include disposal.

$$C_{LCC} = C_{RDTE} + C_{Proc} + C_{OS} \qquad (7-1)$$

Supposing Equation 7-1 represents a starting point design concept sized to conventional levels of reliability, a design excursion within the bounds of the tradespace surveyed in Chapter 6 would have a different life-cycle cost, and the change from the baseline, ΔC_{LCC} , would take the form:

$$\Delta C_{LCC} = \Delta C_{RDTE} + \Delta C_{Proc} + \Delta C_{OS} \qquad (7-2)$$

Conditions for Program Affordability

In order to achieve lower total life-cycle cost, the balance of Equation 7-2 must satisfy the relationship:

$$0 > \Delta C_{RDTE} + \Delta C_{Proc} + \Delta C_{OS} \qquad (7-3)$$

The trade study in presented Chapter 6 as well as data from other studies (Ref. 1-14) indicate that the life-cycle cost outcome for a design study investigating reliability improvement as measured by the sign and magnitude of ΔC_{LCC} (negative ΔC_{LCC} corresponding to a net reduction in life-cycle cost) amounts to the relative values of increasing acquisition cost $(C_{RDTE} + C_{Proc})$ versus decreasing operating cost $C_{O\&S}$.

$$0 > \uparrow \Delta C_{RDTE} \ + \ \uparrow \Delta C_{Proc} \ + \ \downarrow \Delta C_{OS} \qquad (7-4)$$

In order to achieve an overall reduction in life-cycle cost, the reduction in total life-cycle operating cost must outweigh the increase in total acquisition cost.

$$\Delta C_{RDTE} + \Delta C_{proc} < -\Delta C_{OS} \qquad (7-5)$$

Multiple variables affect each of the terms in Eqn. 7-4. Since many of these variables change over the course of the aircraft life-cycle in ways that can only be modeled to the best of an expert analyst's prognostications, the development of each of the three major cost terms is effectively an unbounded problem. For the purpose of simplification, $\Delta C_{O\&S}$ is modeled as an annual sum of the average number of aircraft, $N_{a/c}$, times the average annual flight hours per aircraft, (FH/yr), times the change in total cost per flight hour due to technology insertion averaged over the entire operating fleet, Δc_{FH}.

$$\Delta C_{RDTE} + \Delta C_{proc} + \sum_{i=1}^{LC\ years} \left(\Delta c_{OS} N_{a/c}(FH/yr)\right)_i = \Delta C_{LCC} \qquad (7-6)$$

The condition for net life-cycle cost reduction is thus:

$$\Delta C_{RDTE} + \Delta C_{proc} < -\Delta c_{OS}\left[N_{a/c}(FH/yr)\right]_{avg} \times N_{LC\ yrs} \qquad (7-7)$$

ΔC_{proc}, the total net change in procurement cost over the full production run of aircraft, is a function of the change in unit production cost for a fixed quantity of aircraft .

$$\Delta C_{proc} = \Delta c_{proc} N_{a/c} \qquad (7-7)$$

Using Eqn. 3-2 to model ΔC_{RDTE} as a single investment applied to the entire fleet of aircraft, the inequality expressed in Eqn. 7-5 becomes

$$\frac{\Delta C_{RDTE}}{N_{LC\,yrs}\left[N_{a/c}(FH/yr)\right]_{avg}} + \frac{\Delta c_{proc}}{N_{LC\,yrs}(FH/yr)_{avg}} < -\Delta c_{FH} \qquad (7-8)$$

Where the total cost per flight hour, c_{FH}, may be further decomposed into its constituent components of direct maintenance, fuel, and manpower as defined by Ref. 3-1. Eqn. 7-8 in effect represents a direct comparison of the change in hourly operating cost to the change in acquisition cost by amortizing the RDT&E and procurement costs over the life-cycle flight hours of the total fleet. The application of this expression over a complete aircraft program life-cycle could also include the economic effects of inflation and discount rate, as defined by Ref. 6-2.

$$\sum_{j=1}^{N_{acq\,years}} \left[\frac{\Delta C_{RDTE}}{N_{acq\,yrs}\left[N_{a/c}(FH/yr)\right]_{avg}} + \frac{\Delta c_{proc}}{N_{acq\,yrs}(FH/yr)_{avg}}\right] \times \frac{(1+i)^j}{(1+d)^j}$$

$$< \sum_{k=1}^{N_{op\,years}} -\Delta c_{FH} \times \frac{(1+i)^k}{(1+d)^k} \qquad (7-9)$$

Since the current practice in fleet management is to operate aircraft to an age exceeding the number of years of development and production, the effect of inflation in Eqn. 7-9 with respect to the life-cycle savings is to bias the outcome to solutions which reduce operating cost the most (largest Δc_{FH}) due to the larger effect of inflation over the larger number of operating years $N_{op\,years}$. This effect is confirmed by the difference in base year versus then year life-cycle cost simulations shown in Figures 6-13 through 6-15. If net present value were considered, the discount rate d would act as an economic force opposing inflation, and would place higher value on dollars spent up front.

The inequality given in Eqn. 7-9 represents the condition required for technology insertion to save the operator money over an aircraft's life-cycle. The degree to how much money is saved depends upon the magnitude of operating cost savings compared to the investment cost. Eqn. 7-10 rewrites Eqn. 7-2 in terms of the life-cycle cost ratio used in Figure 6-13 through 6-15.

$$\frac{LCC}{LCC_{baseline}} = \frac{(C_{RDTE} + \Delta C_{RDTE}) + (C_{Proc} + \Delta C_{Proc}) + (C_{O\&S} + \Delta C_{OS})}{C_{RDTE} + C_{Proc} + C_{OS}} \qquad (7-10)$$

Taking the baseline life-cycle cost as a constant, the ratio can be rewritten as

$$\frac{LCC}{LCC_{baseline}} = \frac{LCC_{baseline} + \Delta LCC}{LCC_{baseline}}$$

$$= \frac{1}{(C_{RDTE} + C_{Proc} + C_{O\&S})} \left\{ \begin{array}{c} (C_{RDTE} + C_{Proc} + C_{OS}) + \sum_{j=1}^{N_{acq\ years}} \left[\Delta C_{RDTE} + \Delta c_{proc} N_{a/c}\right] \times \frac{(1+i)^j}{(1+d)^j} + \\ \sum_{k=1}^{N_{op\ years}} \Delta c_{FH} \times \frac{(1+i)^k}{(1+d)^k} N_{op\ yrs} \left[N_{a/c}(FH/yr)\right]_{avg} \end{array} \right\}$$

$$(7-11)$$

Treating the baseline life-cycle cost as a constant, the life-cycle cost ratio becomes effectively a mathematical sum of the life-cycle cost components. In the life-cycle scenario used in Chapter 6, the operating costs act as the reduction mechanism working against the escalation in RDT&E and procurement costs. Depending on the particular life-cycle cost scenario in question, the cost analyst could use Eqn. 7-11 to evaluate any technology affecting any phase of the life-cycle provided that the cost impact in question can be quantified parametrically.

Return On Investment

In contrast to the life-cycle cost savings, the return on investment and break-even year metrics are mathematical ratios of the respective life-cycle cost components rather than differences. Defining a net reduction in life-cycle cost as a negative value of ΔLCC, the definition of ROI can be expanded as:

$$ROI = \frac{Gain - Cost}{Cost} = \frac{(\Delta C_{RDTE} + \Delta C_{proc} - \Delta LCC) - (\Delta C_{RDTE} + \Delta C_{proc})}{(\Delta C_{RDTE} + \Delta C_{proc})} \qquad (7-12)$$

$$ROI = \frac{-\Delta LCC}{\left(\Delta C_{RDTE} + \Delta C_{proc}\right)} = \frac{-\left(\Delta C_{RDTE} + \Delta C_{proc} + \Delta C_{O\&S}\right)}{\left(\Delta C_{RDTE} + \Delta C_{proc}\right)} \qquad (7-13)$$

$$ROI = \frac{\sum_{j=1}^{N_{acq\,years}} \left[\frac{\Delta C_{RDTE}}{N_{acq\,yrs}\left[N_{a/c}(FH/yr)\right]_{avg}} + \frac{\Delta c_{proc}}{N_{acq\,yrs}(FH/yr)_{avg}}\right] \times \frac{(1+i)^j}{(1+d)^j}}{\sum_{k=1}^{N_{op\,years}} -\Delta c_{OS} \times \frac{(1+i)^k}{(1+d)^k}} \qquad (7-14)$$

Break-Even Year

The economic concept of break-even point refers to the exact point in time at which the cumulative sum of net cash flow is zero. Since the cash flow in this study is calculated on a yearly basis, the break-even point is simplified to a program year estimate. The break-even year of the program on its reliability investment, calculated as the program year starting from zero at the first year of production is calculated as

$$Yr_{BE} = \frac{\Delta LCC_0}{\left(-\Delta LCC/N_{LC\,yrs}\right)} \qquad (7-15)$$

Where ΔLCC_0 represents the change in the upfront life-cycle costs applied at the program outset and $\Delta LCC/Yr$ represents the average change in annual program cost, retaining the convention of defining net reduction in annual cost as $\Delta LCC < 0$. In the Chapter 6 scenario, ΔLCC_0 is the RDT&E investment ($\Delta LCC_0 = C_{RDTE}$), as shown in by the initial program year starting point y-axis values of life-cycle cost in Figure 6-11. The change in the annual program cost is then the difference between the procurement cost and the operating cost per year, represented in Eqn. 7-16 as the average annual procurement cost over the program life-cycle, $\overline{\left(\frac{\Delta c_{proc} N_{a/c}}{N_{LC\,yrs}}\right)}$, and the average annual operating cost over the program life-cycle, $\overline{\left(\Delta c_{OS} N_{a/c} \times \frac{FH}{yr}\right)}$.

$$Yr_{BE} = \frac{\Delta C_{RDTE}}{\overline{\left(\frac{\Delta c_{proc} N_{a/c}}{N_{LC\,yrs}}\right)} - \overline{\left(\Delta c_{OS} N_{a/c} \times \frac{FH}{yr}\right)}} \qquad (7-16)$$

Affordability Assessment Generalization

The three expressions given in Eqns. 7-11, 7-14, and 7-16 formalize a set of program-level metrics which can be used to evaluate different aspects of affordability. Since O&S costs have been identified as the dominating component of life-cycle cost (Ref. 3-1), the key to improving a program as it is assessed by each of the three metrics is clearly to produce the maximum reduction possible in one of the life-cycle cost components (preferably O&S costs) while simultaneously minimizing any increase in the other cost components. The difference between the design points at which each of the metrics is optimized underlines the tradespace behavior of each component of life-cycle cost. The trade study results show that RDT&E and operating cost have the highest sensitivity to the level of reliability improvement factored into the life-cycle simulation and thus represent the two primary factors of affordability opposing each other in the Chapter 6 life-cycle example. Since the life-cycle cost ratio as computed in Eqn. 7-11 is thus driven primarily by the difference between the total O&S savings and the total RDT&E investment required, the design points representing the lowest life-cycle cost ratio between 12,000 and 13,000 flight hours TBO can be thought of as the design points which derive the maximum reduction in operating cost that is justifiably cost effective under the ground rules of the study. In contrast, the design points around 6,500 flight hours which yield the maximum ROI and quickest time to break even represent the RAM investment solutions which derive the maximum O&S reduction per acquisition investment. Due to the flatness of the RDT&E cost estimating relationship in Eqn. 3-2 used to facilitate the simulation, the largest amount of improvement per investment is derived over the first 1,000 to 2,000 flight hours of service life improvement.

Response Surface Analysis

If the values of each of the variables in expressions 7-7 through 7-9 are expressed as ratios of their values for the baseline and excursion iterations of the trade study as in 7-10 and 7-11,

$$\lambda_{proc} = \frac{c_{proc}}{c_{proc,baseline}} \qquad (7-10)$$

$$\lambda_{OS} = \frac{c_{OS}}{c_{OS,baseline}} \qquad (7-11)$$

$$\lambda_{RDTE} = \frac{\Delta C_{RDTE}}{\Delta C_{RDTE,baseline}} \qquad (7-12)$$

Then the change in the corresponding variables can also be rewritten using the λ ratio factors.

$$c_{OS} = c_{maint/FH} + c_{fuel/FH} + c_{manp/FH} \qquad (7-13)$$

$$\Delta c_{OS} = (1-\lambda_{maint})c_{maint/FH} + \left(1-\lambda_{fuel}\right)c_{fuel/FH} + \left(1-\lambda_{manp}\right)c_{\frac{manp}{FH}} \qquad (7-14)$$

$$\Delta c_{proc} = \left(1-\lambda_{proc}\right)c_{proc} \qquad (7-15)$$

Rewriting expression 7-8 in terms of the λ cost ratio terms produces:

$$\frac{\lambda_{RDTE}C_{RDTE}}{N_{FH,LC}} + \frac{(1-\lambda_{proc}c_{proc})}{N_{FH,LC}/N_{a/c}} < -[(1-\lambda_{OS})c_{OS}] \qquad (7-16)$$

Eqn. 7-16 can be rewritten using the expansion of operating costs in 7-13 through 7-15 if a trade study similar to the example in Chapter 6 is performed where the components of operating cost are tracked according to the cost structure of Ref. 3-1.

$$\frac{\lambda_{RDTE}C_{RDTE}}{N_{FH,LC}} + \frac{(1-\lambda_{proc}c_{proc})}{N_{FH,LC}/N_{a/c}} < -\left[(1-\lambda_{maint})c_{\frac{maint}{FH}} + \left(1-\lambda_{fuel}\right)c_{\frac{fuel}{FH}} + \left(1-\lambda_{manp}\right)c_{\frac{manp}{FH}}\right] \qquad (7-17)$$

This expression distills the governing conditions for the curves for normalized life-cycle cost in Figure 6-14 to a problem of five factors which are determined by sizing trends, economic factors, and technology. The cost effectiveness of RAM investment can also be quickly estimated hypothetically based on a single baseline design case in this case. In this “what-if?” type of analysis, the lambda factors could be varied as sensitivity parameters and the design routine would not necessarily need to be re-run unless a recalibration of the sensitivity study about a new design point were needed. When implemented in the modeling environment shown in Figure 6-1, the reliability and maintainability features of the new model as described in Table 6-1 collectively account for the λ_{maint} factor modifying the direct cost of maintenance replacement parts. The remaining λ's are applied to their respective cost quantities as technology adjustment factors operating in the same manner as the NDARC tech factors described for the design study cases in Tables 4-5, 4-6, and 4-7. This framework provides a means to generalize the results of the three configurations to aircraft with an arbitrary distribution of life-cycle costs among RDT&E, procurement, and O&S components. Linear regression and response surface methodology is one approach to producing such a generalized result (Ref. 7-1, 7-2). As demonstrated for the design and assessment of rotorcraft in Ref. 7-2, the response surface approach simplifies all of the design effects to a second order polynomial of the form in Eqn. 7-16.

$$R = \alpha_o + \sum_i \alpha_i x_i + \sum_i \alpha_{ii} x_i^2 + \sum_i \sum_j \alpha_{ij} x_i x_j \qquad (7-16)$$

In the simplified case of the tech factors in Eqn. 7-15, the objective is to observe the sensitivity of total life-cycle cost reduction in addition to the reliability-driven reduction as plotted in Figure 6-14. At a given reliability design point, the life-cycle cost of the vehicle normalized to its baseline conventional reliability variant is given by the simple linear response equation:

$$\frac{LCC}{LCC_{base}} = \alpha_{RDTE}\lambda_{RDTE} + \alpha_{Proc}\lambda_{Proc} + \alpha_{MMH/FH}\lambda_{MMH/FH} + \alpha_{fuel}\lambda_{fuel} + \alpha_{DMC}\lambda_{DMC} \; (7-17)$$

In this case Eqn. 7-17 does not include the second order terms of Eqn. 7-17 because the variables are mutually orthogonal. Tables 7-1 through 7-3 list the results.

Table 7-1. Helicopter Life-Cycle Model Regression Coefficients

	α_o	RDT&E	Procurement	DMC	MMH/FH	Fuel
Baseline	0.1592	0	0.3690	0.3856	0.0260	0.0299
13,000 FH (Min LCC)	0.1621	0.0100	0.4230	0.2201	0.0192	0.1538
20,000 FH	0.1641	0.0679	0.4614	0.1751	0.0147	0.0313

Table 7-2. Lift Offset Life-Cycle Model Regression Coefficients

	α_o	RDT&E	Procurement	DMC	MMH/FH	Fuel
Baseline	0.1403	0	0.3703	0.4249	0.0238	0.0223
13,000 FH (Min LCC)	0.1439	0.0138	0.4197	0.2444	0.0177	0.0232
20,000 FH	0.1463	0.0908	0.4545	0.1969	0.0136	0.0239

Table 7-3. Tiltrotor Life-Cycle Model Regression Coefficients

	α_o	RDT&E	Procurement	DMC	MMH/FH	Fuel
Baseline	0.1544	0	0.3991	0.3826	0.0264	0.0233
12,500 FH (Min LCC)	0.1575	0.0106	0.4474	0.2218	0.0201	0.0239
20,000 FH	0.1600	0.0868	0.4869	0.1730	0.0151	0.0244

For this simplified example of the response equation method applied to the reliability and cost-based approach of rotorcraft assessment, the regression coefficients are functions of the percentages of the total life-cycle cost influenced by RDT&E, procurement, maintenance manpower, and fuel respectively. Even in this simple case however, the usefulness of the approach is illustrated when considering the cost-benefit tradeoffs of different approaches to improving affordability. If, for example, a program manager was attempting to justify the development and acquisition of new technology features for a legacy vehicle on the basis of a 10% to 15% reduction in life-cycle cost, a set of conditions starting from one of the design points in Figure 6-14 would need to satisfy the condition:

$$0.8 = \alpha_{RDTE}\lambda_{RDTE} + \alpha_{Proc}\lambda_{Proc} + \alpha_{MMH/FH}\lambda_{MMH/FH} + \alpha_{fuel}\lambda_{fuel} + \alpha_{DMC}\lambda_{DMC} \quad (7-18)$$

Using the baseline helicopter design as the starting point for this hypothetical analysis, and then moving to the optimum aircraft service interval identified in Table 6-3 as 13,000 flight hours, Table 7-4 and Figure 7-1 show the +/- cost progression of the different programmatic measures taken to improve the overall affordability of the aircraft through its life-cycle utilizing the same assumptions listed in Chapter 6. Assuming 5 – 10% improvements in the procurement, maintainability, RDT&E, and fuel consumption of the aircraft leaves the remainder of cost reduction required to meet the target to the maintenance components which have already been adjusted according the RAM relationships in Chapter 3. Based on Figure 7-1, the RAM improvements fall 16-39 percent short of the affordability required to achieve a 10-15% reduction in overall program cost.

Table 7-4. Affordability steps for example program assessment

	1	2	3	4	5	6	7	8
Effect	RAM RD&TE Investment	Procurement RDT&E Investment	RAM DMC Reduction	-10% MMH/FH	-5% Hourly Fuel Cost	10% Extra Procurement Reduction	16.5% Extra DMC. Reduction	39.2% Extra DMC Reduction
Impact to Baseline LCC	+1.00%	+0.54%	-2.72%	-0.19%	-0.77%	-4.23%	-3.63%	-8.63%
Cumulative Total LCC Change	+1.00%	+1.54%	-1.18%	-1.37%	-2.14%	-6.37%	-10.0%	-15.0%

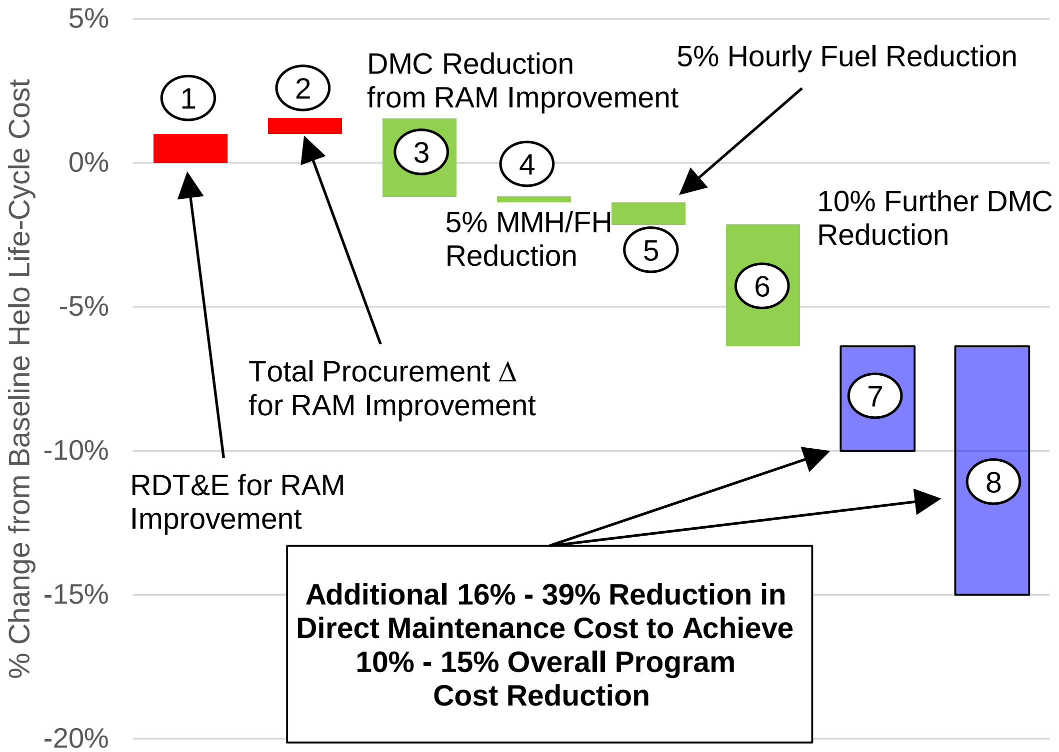


Figure 7-1. Hypothetical program affordability plan waterfall chart

If the new design and assessment methodology is to be used for the evaluation of program-level affordability impact as demonstrated in the example shown in Figure 7-1, the certainty of its predictions must be quantified. Figure 7-1 exemplifies a "waterfall chart" type of program affordability approach which can be used to evaluate the program-level contribution of individual affordability measures which collectively present a path toward an overall cost target. Multiple design studies have utilized probabilistic risk assessment to predict the upper and lower bounds of possible outcomes based on predicted maximum levels of variance in the lower level design variables (Refs. 7-2, 7-3, and 7-5). Risk assessment represents a critical step to the new model's application because it informs decision makers to the level of contingency and business protection they should build into the program's contracts and agreements.

To provide one further application in the context of the business case affordability analysis shown in Figure 7-1, a probabilistic analysis is performed on the predicted direct maintenance cost of the advanced helicopter to assess the risk built into a program which is sold on the claim of 10-15% overall life-cycle cost reduction. The variations applied to the individual weight, power, and learning curve components are taken as a representative percentage of the originally predicted values based on the historical progression of actual versus predicted weight in rotorcraft development programs (Ref. 7-6)

Table 7-5. Variable ranges used for DMC and OEC Monte Carlo analyses.

Effect	Standard Deviation
Weight, each component (See Appendix C)	+/- 10%
Installed Horsepower	+/- 10%
Learning Curve (Airframe & Engine Only)	+/- 5%

Based on the results of a Monte Carlo analysis run using the variable values in Table 7-5, Figures 7-2 and 7-3 show that the 16% to 39% reduction in direct operating cost on top of the maintenance cost reduction already achieved due to RAM investment is attained only in the lower quarter of percentile outcomes of the study, meaning no more than 25% confidence could be ascribed to the successful attainment of the minimum overall affordability goal. The more ambitious 39% goal of further DMC reduction is achieved in less than one percent of the population of Monte Carlo results, meaning it occurs only for the most fortuitous of possible over-predictions of weight and power, ultimately resulting in a vehicle much smaller and more affordable than expected. Although the assumptions of this hypothetical analysis have resulted in the acknowledgement that success is highly unlikely, the methodology itself remains an important tool which can be used to help avoid undertaking development and procurement of a system with unreasonable program goals. The results also speak to the need for continued investment in fundamental research immaterial of business cases toward systems that will ultimately make highly reliable rotorcraft more affordable to procure.

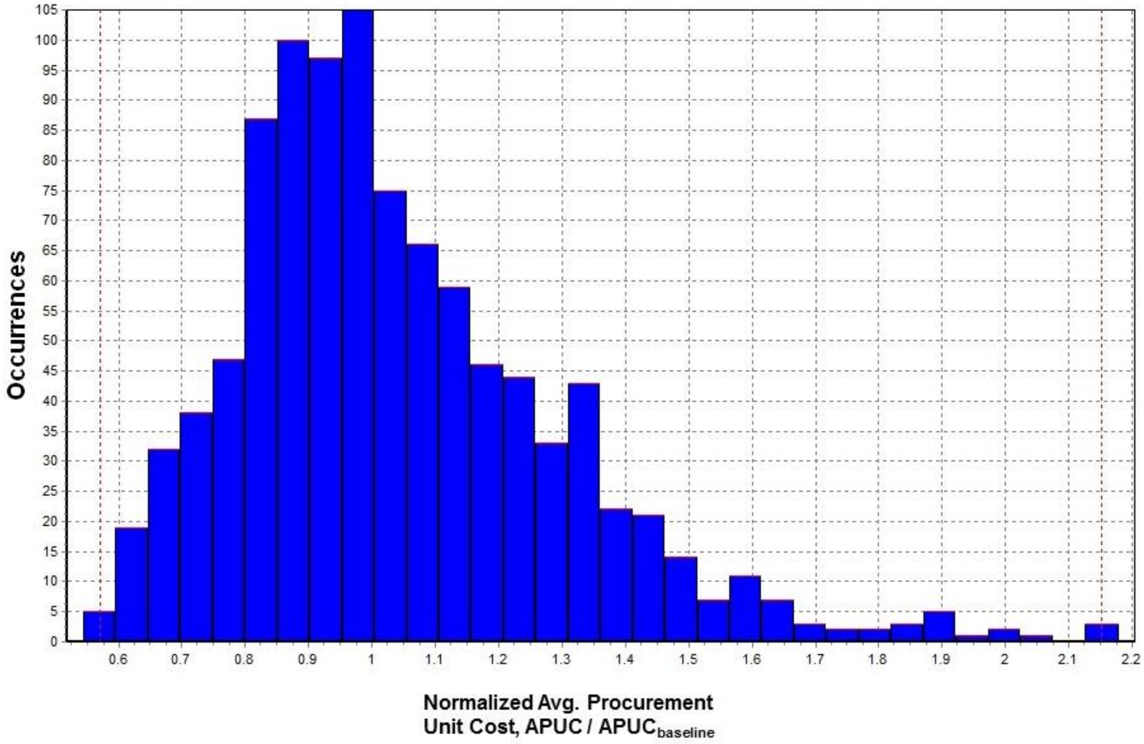


Figure 7-2. Normalized Direct Maintenance Cost (DMC) Monte Carlo results probability density function (PDF).

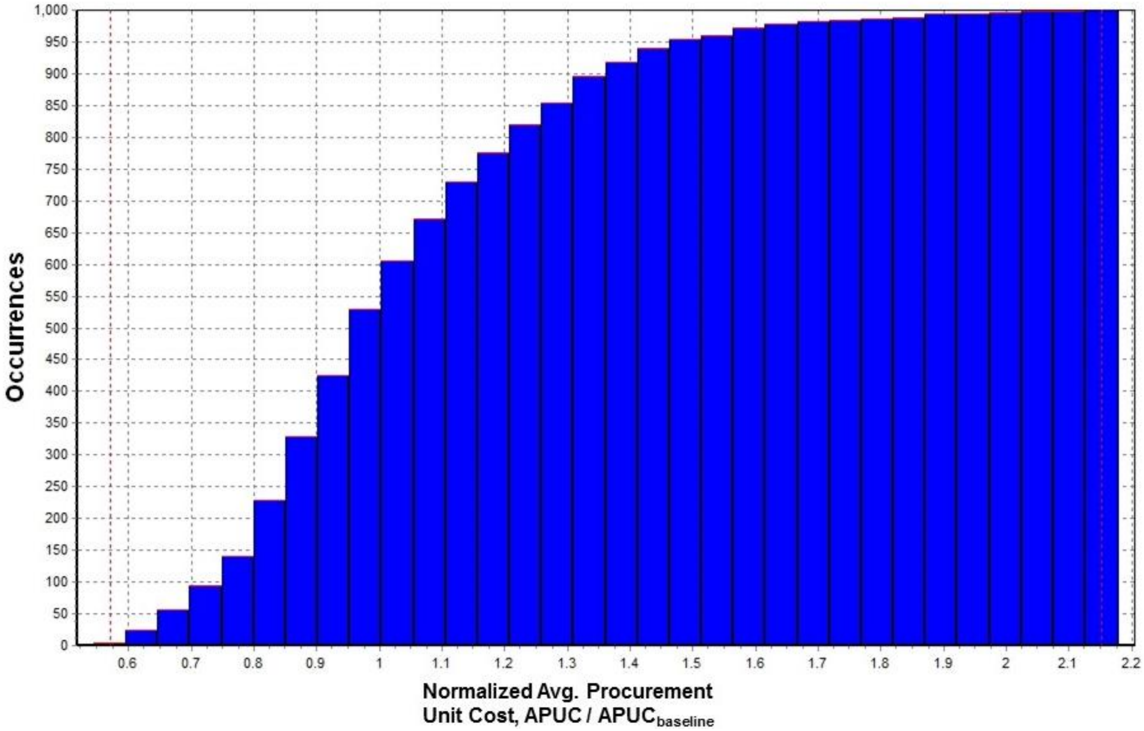


Figure 7-3. Normalized Direct Maintenance Cost (DMC) Monte Carlo results cumulative density function (CDF).

Table 7-6. Percentiles of normalized DMC occurrences in Monte Carlo analysis.

Mean	1.03922
Std. Dev.	0.255999
Quantiles:	**Norm. APUC**
100%	2.151835
99.50%	1.995796
97.50%	1.6343
90%	1.371121
75%	1.177094
50%	0.990718
25%	0.86507
10%	0.762934
2.50%	0.648938
0.50%	0.597782
0.00%	0.570818

In addition to the assessment of strictly life-cycle cost, the affordability and reliability-augmented design framework is equally applicable to value-based acquisition approaches as exemplified in Ref. 7-2, 7-3, 7-5 and 7-7 among many examples in various aerospace design applications. Figure 7-4, 7-5, and Table 7-7 show the Monte Carlo analysis run for the same range of design variables while evaluating an overall evaluation criterion (OEC) represented by

$$OEC = \zeta\left(\frac{PI}{PI_{baseline}}\right) + \eta\left(\frac{A_o}{A_{o,baseline}}\right) + \theta\left(\frac{LCC_{baseline}}{LCC}\right) \qquad (7-19)$$

Where PI stands for the productivity index defined as (Ref. 7-4), where the payload weight, fuel weight, mission distance, and mission block time correspond to the aircraft design mission in this example:

$$PI = \frac{W_{pay}}{WE + W_{fuel}}\left(\frac{Dist}{Time}\right)_{mission} \qquad (7-20)$$

And the baseline values each of the variables in Eqn. 7-19 are those of the 13,000 flight hour TBO design point advanced helicopter. Although the previous example evaluating affordability found a substantial deficit between the predicted and required helicopter life-cycle cost improvement, the OEC example does show that the reliability investment still improves the overall value of the aircraft as measures by Eqn. 7-19 in more than 99% of possible outcomes.

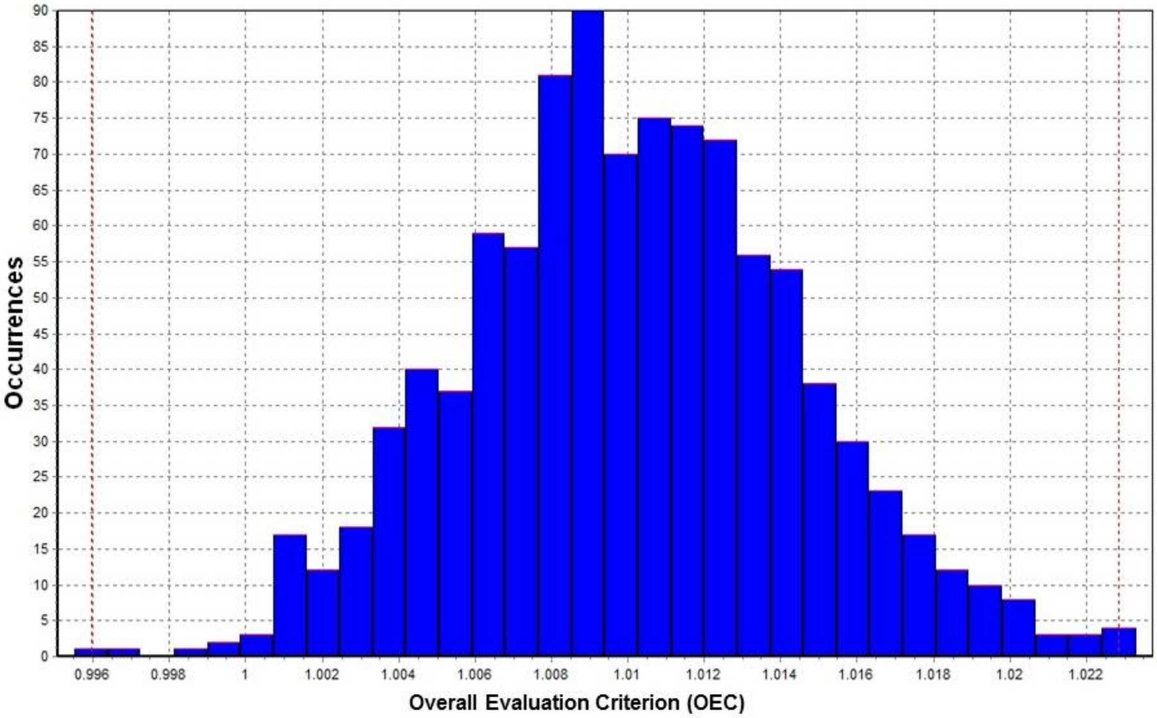


Figure 7-4. OEC Monte Carlo results probability density function (PDF).

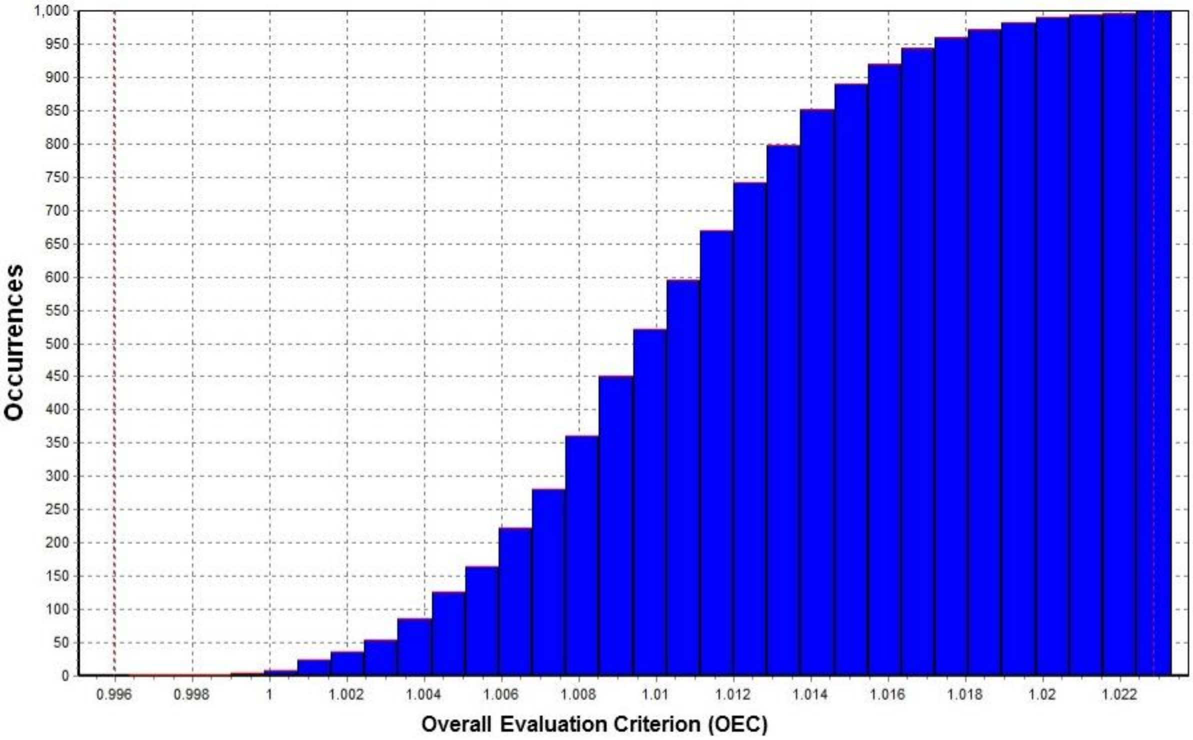


Figure 7-5. OEC Monte Carlo results cumulative distribution function (CDF).

Table 7-7. OEC percentile occurrences in Monte Carlo analysis.

Mean	1.010144597
Std. Dev.	4.36E-03
Quantiles:	**OEC**
100%	1.022849
99.50%	1.021656
97.50%	1.019249
90%	1.015685
75%	1.013038
50%	1.010065
25%	1.007277
10%	1.004507
2.50%	1.001663
0.50%	0.999933
0.00%	0.995963

CHAPTER 8

CONCLUSIONS

Research Findings

Based on the design study documented in Chapters 5 and 6, and the mathematical generalization of the study's results conducted in Chapter 7, the research effort has found that reliability-focused conceptual optimization of rotorcraft is feasible provided the correct assumptions are applied to the sizing and cost assessment. The discussion transitions at this point to an examination of the future work which could be developed from the rotorcraft design framework, beginning with a review of the major findings as they relate to each of the research questions proposed in Chapter 1.

Research Question 1:
What drives rotorcraft total ownership costs?

The reference data compiled and displayed in Figures 1-3 and 1-7 illustrates the efficiency limitations inherent to VTOL capability which cause rotorcraft to exhibit high power loading (horsepower per pound of lift) and low cruise efficiency. These effects drive rotorcraft to high acquisition costs and high fuel consumption. As shown in Figs.1-8 and 1-9, rotorcraft also suffer poor reliability and consequently exhibit high maintenance costs. Due to the well-established technical difficulty in achieving total parity in design efficiency between rotorcraft and conventional fixed wing aircraft, reliability is identified in Chapter 1 as area of improvement which may yield larger return on investment toward mitigating affordability deficiency observed in rotorcraft.

The historical trends in Figures 1-10 and 1-11 as well as the example case of the CH-47D/F upgrades in Chapter 3 show that it is possible to improve rotorcraft reliability through design upgrades which include new technology. However, the CH-47 example also demonstrates that the extant methods of aircraft cost assessment fail to capture the effects reliability improvement due to technology insertion because they lack any consideration for reliability and maintainability a design & input variable. They consequently require manual adjustment based on the engineer's judgement of the new design and/or new technology. This modeling deficiency leads to Research Question 2, which deals with the mathematical abstraction of reliability as a fundamental cost driver within parametric cost models.

Research Question 2:
Does the inclusion of reliability, availability, and maintainability (RAM) factors in life-cycle cost assessment enhance the accuracy of the prediction?

As Figure 1-8 shows, the maintenance component of O&S cost per flight hour is a function of reliability and maintainability at a nearly axiomatic level. Maintenance costs accumulate as a function of time and component value, with scheduled maintenance actions having a pre-determined upper limit of cycle time and unscheduled maintenance actions defined in terms of an overall frequency of occurrence based on long term trends. The effects manifest their cost impact in Figure 1-8 as the horizontal length of each step denoting the time between maintenance actions (reliability) and the vertical length of each step denoting of the cost of respective maintenance actions (maintainability and cost).

Conventional cost modeling methods which estimate O&S based on weight succeed in principle recognizing the fact that larger (and thus heavier) rotorcraft tend to represent both a larger quantity of maintenance components and a higher maintenance cost per component. The equally important set of effects which these models generally do not consider is that reliability as an aircraft characteristic may vary based on factors which depend more on technology and design practice and less on weight as a first order influence. This study adopts the approach of including reliability as a design and cost parameter. The Bell PC cost model facilitates this approach for scheduled maintenance by its inclusion of time between overhaul as an input. A translating function, provided in Eqns. 3-8 and 3-9 was used in this case to extend the analysis to unscheduled as well. The result of this approach, documented in Table 3-4, is a 6% (12.53% versus 18.45%) error reduction in dollar per flight hour O&S cost estimate generated by Bell PC and a greater than 100%

error reduction in predicted maintenance man-hour per flight hour (12.29% versus 130.63%). Additionally, the derivation of the TBO value used in the CH-47 example achieved by integrating Ref. 3-5 into the methodology results in an improved cost framework capable of considering both the cost and benefit of reliability improvement. Previous studies (Ref. 2-7, 3-3) have either ignored this component of the life-cycle tradeoff or considered it only by indirect means. The new ability to consider both the benefits and the costs of reliability with regard to rotorcraft design leads to the questions of application and optimization posed by Research Questions 3 and 4.

Trade Study Findings

Research Question 3:
Does technology related to the improvement of reliability, availability, and maintainability (RAM) have an appreciable effect on rotorcraft design when it is included in a sizing routine?

Research Question 3 moves from the direct cost effects of reliability improvement to the means by which the improvement is achieved. Upgrade programs performed on legacy rotorcraft (Refs. 3-8, 3-9, 3-10) provide historical design reference points which suggest that RAM considerations produce tangible, non-negligible design, performance, and acquisition cost impacts. While the cost and reliability analysis performed on the CH-47D and F in Chapter 3 calculates a system level cost while referencing the specific technologies, the design application in Chapter 4 aims to treat reliability in a more general sense. To this end, the trade study conducted in Chapter 4 uses the weight relationship developed in Ref. 3-4 as a scaling function of weight with design-specified service life which is non-specific to the means of reliability improvement. Refs. 3-5 and 3-6 are also employed in the life-cycle cost study due to their generic mathematical characterization of acquisition costs specifically attributable to RAM considerations.

When this set of conceptual affects are used to simulate the tradeoffs in design and cost related to a hypothetical RAM technology portfolio, the sizing and cost assessment results show a clear and discernable effect on the acquisition characteristics of the aircraft as evidenced by change in gross weight, empty weight, and installed power as shown in Figures 6-4 and 6-5. The ability of the assembled collection of models to directly consider multiple life-cycle aspects of reliability tradeoffs represents a new capability in conceptual aircraft design. Based on the multidisciplinary characterization of reliability effects now available within this analysis framework, Research Question 4 considers the application of the new capability.

Research Question 4:
For a given set of sizing, acquisition, and operating assumptions, can reliability be used as a design parameter to maximize the affordability of a rotorcraft design?

Figures 6-7 and 6-8 illustrate the tradeoff in decreasing O&S annual unit ownership price versus increasing average unit procurement cost and total RDT&E investment which occurs as the design-specified reliability of the three example aircraft concepts is increased. As Figs. 6-13 through 6-15 clearly show, the balance of these effects results in the lowest total life-cycle cost for each of the three configurations occurs between 12,000 and 13,000 flight hours of airframe and dynamic component service life. (Within the trade space defined by Eqn. 3-8 and 3-9, plotted in Figure 6-3, these design points also imply a roughly 40-50% reduction in unscheduled maintenance and maintenance man hours per flight hour.) These results confirm that it is possible to obtain a conceptual design of optimal reliability for lowest life-cycle cost based on a set of reasonable life-cycle assumptions. As Table 6-3 shows, it is also possible to arrive at entirely different optimal design points using a cost metric such as return on reliability investment as opposed to life-cycle cost savings. Although this finding arises as a result of the mathematical nature of the functions used to model the RAM-related acquisition costs versus the accompanying O&S savings, the demonstration of its occurrence is significant when considered against the baseline case which contains no design provision for the RAM improvement. The particular design point which minimizes life-cycle cost will vary as a function of the aircraft design and its life-cycle economic assumptions. Considering that the assumptions applied to the examples in Chapters 6 and 7 were selected to represent a realistic progression from the OPTEMPO and maintenance concept of the legacy fleet to a future advanced technology fleet, the difference between the baseline and minimum LCC design points indicates that future rotorcraft may be designed to an insufficient level of reliability using conventional methods.

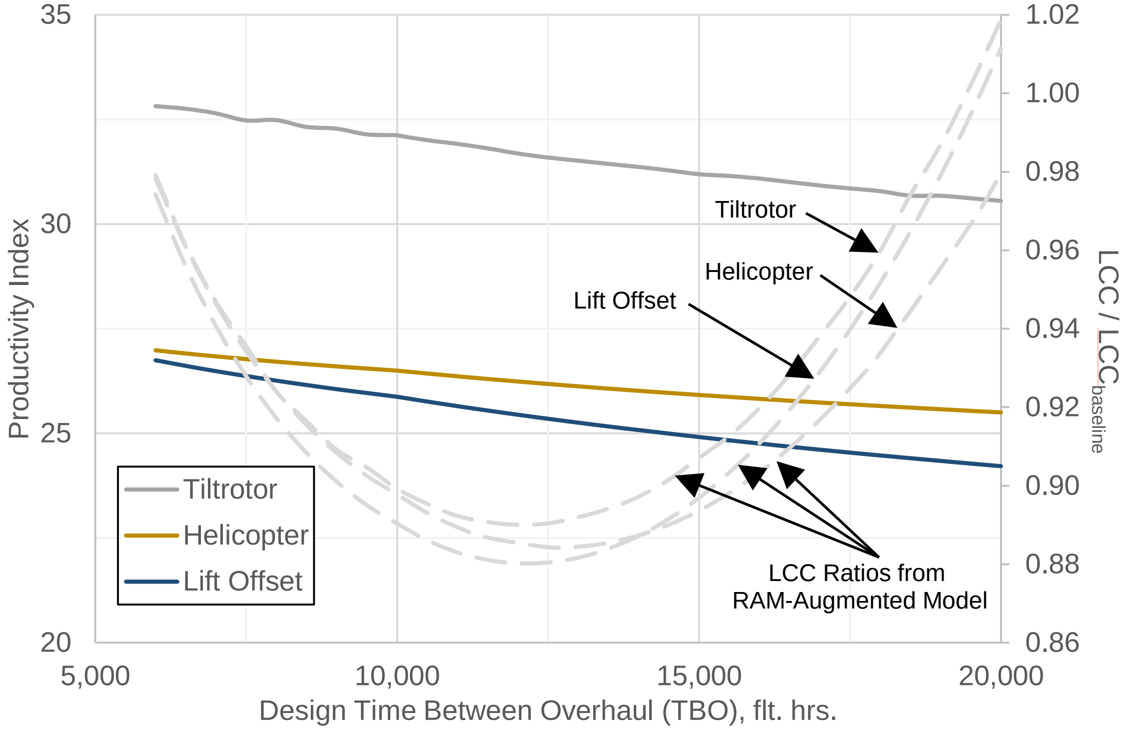


Figure 8-1. Comparison of productivity index versus reliability-augmented life-cycle cost prediction as indicators of optimum design points.

Thus far, the results generated in response to Research Questions 2 and 3 have shown an improvement in rotorcraft cost assessment accuracy and the added capability of design and acquisition cost impact of RAM improvement where previously no such capability had been implemented. To illustrate the benefit of the new design framework at the highest level of analysis, the top-level results of the trade study must be contrasted to the analytical options previously available.

Returning to one example of the historical assessment methods given in Table 2-1, Figure 8-1 plots the same predicted life-cycle cost ratios of the three concepts seen in Figure 6-13 through 6-15 versus the productivity index expressed in Eqn. 7-20 for the three concepts. Since the productivity index is strictly a weight-based parameter, the change in

O&S cost is not visible, and the metric predicts only a monotonically decreasing value function with no local optimum point. Using this parameter alone, the designer would likely choose to forego any reliability investment without a direct means of assessing its life-cycle value.

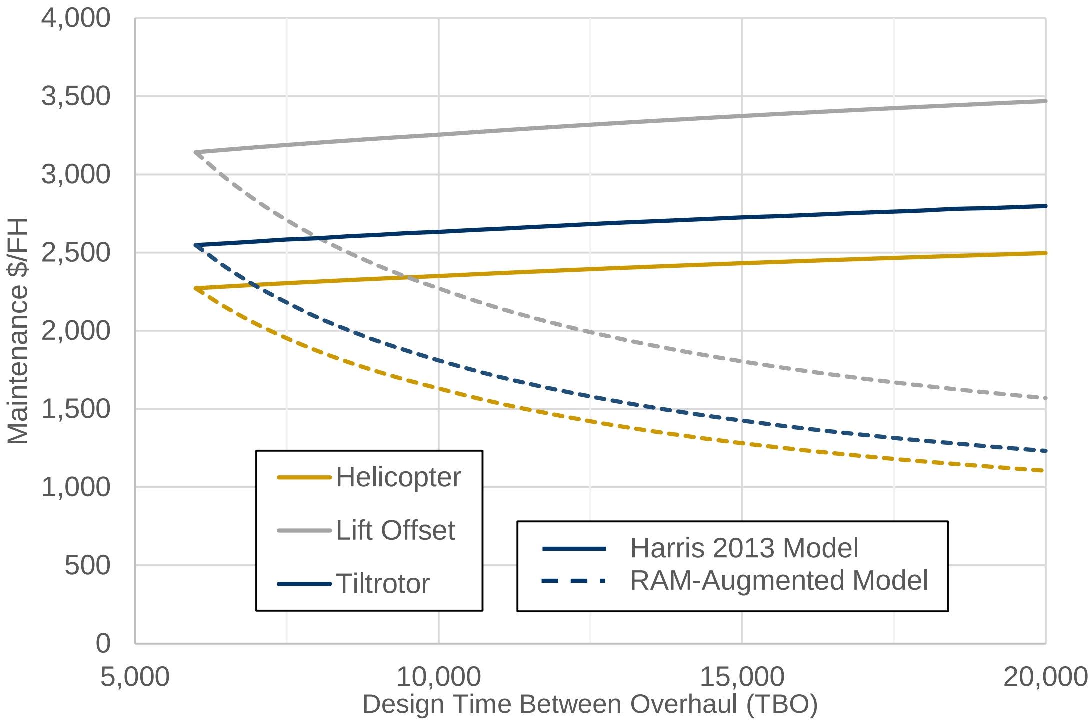


Figure 8-2. Comparison of conventional parametric weight-based versus reliability-augmented maintenance cost per flight hour estimates

Similarly, even the more current examples of weight-based parametric analysis such as the 2013 Harris Model described in Appendix E do not directly account for the change in cost trend due to reliability investment. As Figure 8-2 shows (adjusting the Harris models reliability coefficients so the two models begin at the same $/FH estimate at the starting point of the trade space), the Harris weight-based parametric model still predicts an increase in maintenance costs, driven by the increase in weight of the aircraft due to the effects of Eqn. 3-1. Although the Harris model includes a technology factor coefficient to adjust the maintenance trend, this factor would require recalibration at every design point in the trade space in order to reproduce the effect of the improved model which accounts for reliability as a design parameter.

The implication of this result is not only to suggest that Research Question 4 may be answered in the affirmative, but also that the potential benefit of the new cost and reliability focused design framework is to obtain a lower cost design solution at the earliest life-cycle stage. The improved and expanded set of cost effects considered by this design and assessment framework will in turn drive the aircraft preliminary and detailed design phases toward a lower life-cycle cost solution by virtue of a better-informed conceptual starting point.

Across all three of the aircraft types, life-cycle cost is minimized at a point roughly twice the service life length represented by the current state of the art as surveyed in Chapter 1 for life-limited dynamic components and 30% longer for design-specified airframe service life. Multiple contributing factors may explain the disparity between the analytically-suggested optimum design point and the current state of the art, many of which present motivating factors for future work. Economic factors external to design such as inflation and discount rate must also be examined when considering the business case for investment in reliability improvement. While the effect of inflation is to increase the importance of operating cost reduction in the program out years, rotorcraft manufacturers and customers may ultimately be too risk averse, effectively building too high a discount rate into their analysis, to justify the type of investment required to yield such an increase in service life. The prevalence of rotorcraft service life extension programs suggests this risk aversion should be re-examined in business case analyses due to the reliability effects observed throughout the trade study, regardless of the economic ground rules.

Key Contributions and Future Work

The implementation of a RAM-augmented parametric design and assessment framework has allowed for a tradespace survey of multiple types of rotorcraft across a conceptual representation of wide range of technology investment for reliability and maintainability. Table 8-1 summarizes each of the key contributions of the work as they relate to the research questions posed in Table 2-2. The discussion which follows elaborates upon possible means of incorporating higher fidelity analysis into the new design and assessment framework.

Table 8-1. Summary of key contributions of research

Observation (Research Question)	New Approach / Key Contribution of Methodology
High life-cycle cost limits application and utilization of rotorcraft. (RQ 1)	The end result of the new methodology developed in response to Research Questions (RQ's) 2-4 provides a means of selecting a less expensive conceptual design point at the earliest stage of a development of a new rotorcraft configuration. (Figs. 6-13 through 6-15)
Operation and support represent the largest components of a rotorcraft's life-cycle cost, and depend on the reliability and maintainability of the system. (RQ 2)	The new approach improves parametric rotorcraft cost modeling methods by allowing for direct assessment of reliability as a cost parameter beyond traditional models with are strictly weight-based. Using the TBO input parameter of the Bell PC along with the translating relationships developed in Eqns. 3-8 and 3-9, reliability and maintainability are added as primary inputs to existing O&S cost estimating relationships. The accuracy of the new CER's is demonstrated to improve with the additional input parameters, as shown in Table 3-4.
Attempts to improve reliability and maintainability incur additional acquisition costs. (RQ 3)	The cost assessment framework developed in the study provides the analytical capability to specifically address this tradeoff where none previously existed. The tradeoff in reliability vs. acquisition cost is quantified using the relationships found in the literature search and plotted in Figs. 3-8 and 3-9. The relationships are applied to a rotorcraft design problem as described in Chapter 6.
Assuming the design and acquisition impact of RAM technology is quantifiable, no design and assessment capability exists to weigh the potential tradeoffs to total life-cycle cost. (RQ 4)	In combination with an advanced conceptual design tool as accomplished in Chapter 6, the new unified design, reliability, and cost assessment framework allows the designer to select an optimal conceptual sizing point based on a reasonable set of design and life-cycle cost assumptions which maximizes reliability, affordability, return on investment, or value as defined by an overall evaluation metric. Figure 8-1 and 8-2 contrast the new capability against traditional assessment methods.

Although speed and flexibility of analysis highlight the advantages of the parametric methods used in this work for design and cost analysis, the approach still depends on higher fidelity analysis to inform its accuracy and realism, especially in the case of new technologies not incorporated into the historical data population. Ideally, each new technology proposed for rotorcraft would receive an appraisal of its effectiveness through all levels of analysis represented in Figure 8-3, followed by application to a tradespace survey as demonstrated in Chapter 6 to determine the design point of minimum life-cycle cost. As with any research which involves parametric relationships and regression analysis, it is important to note that the implications of the trade study, while in line with the early hypotheses of the study, could have spuriously reached these conclusions due to a coincidental correlation among weight growth, cost growth, and reliability improvement in rotorcraft design trends. Eventually, detailed design work is also needed to follow up the conceptual sizing with a more rigorous layout and weight allocation of the aircraft in order to quantify the impact of the reliability features with greater detail and certainty beyond the historical design trend basis of the parametric relationships.

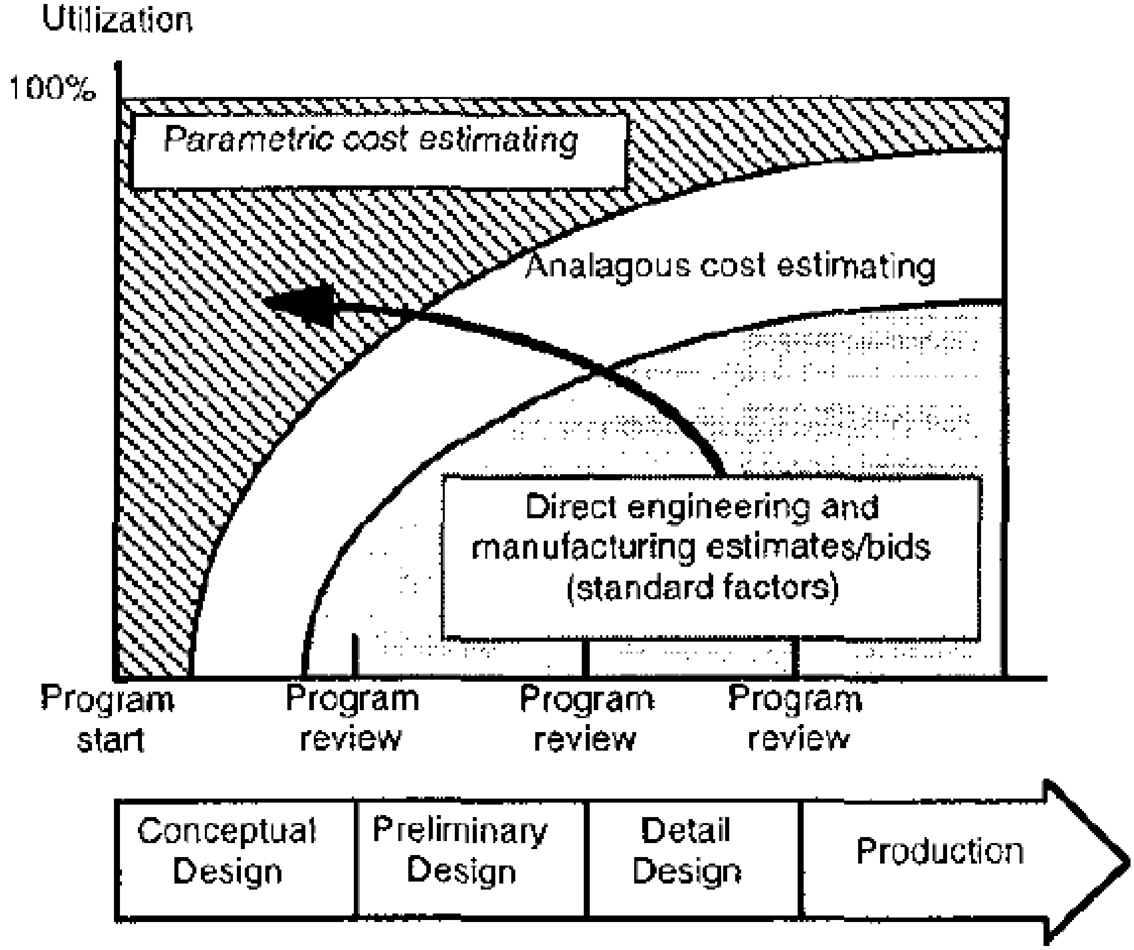
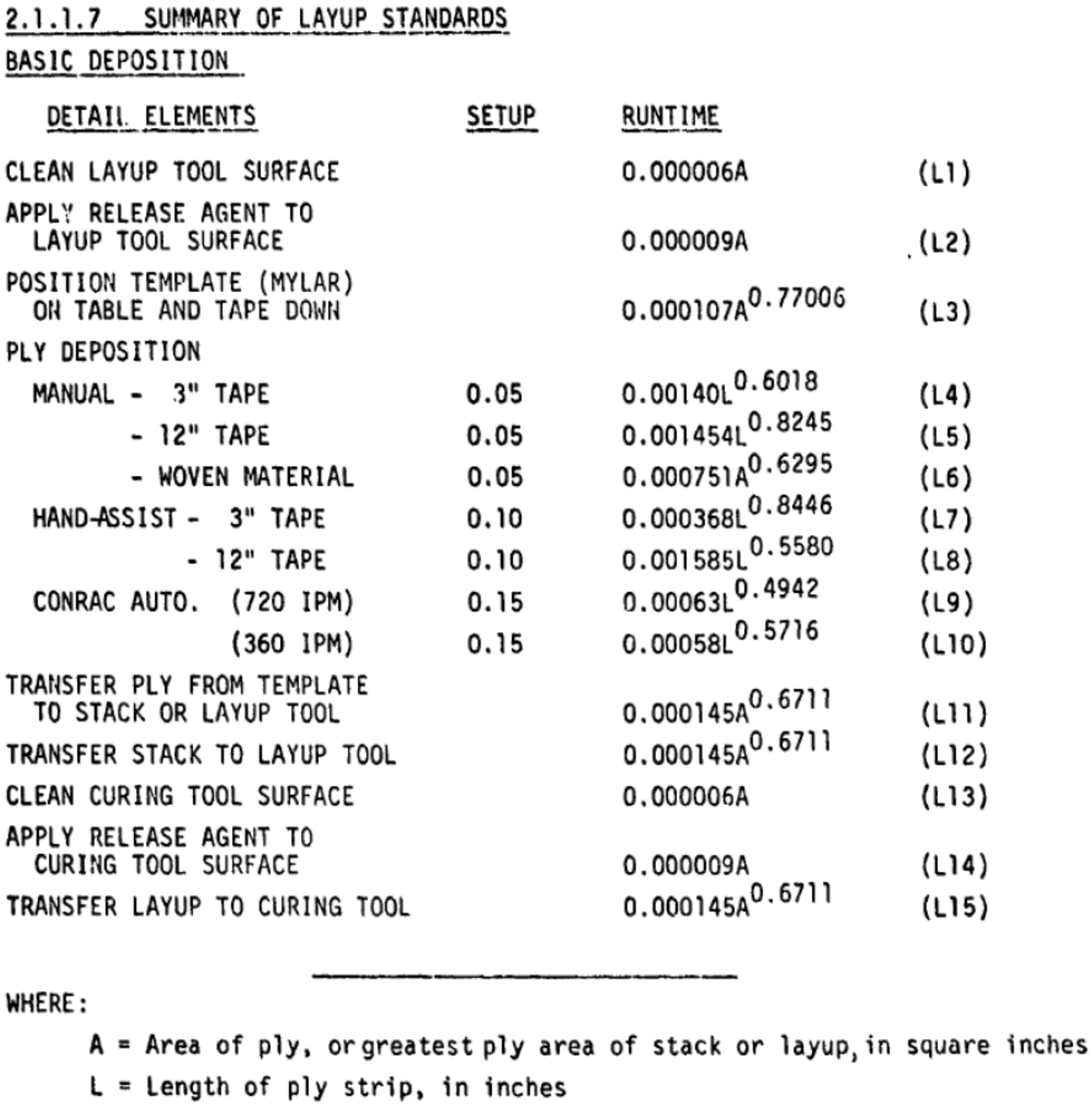


Figure 8-3. Role of parametric methods in cost assessment hierarchy. (Ref. 8-1)

Bottoms Up Cost Modeling

Bottoms up cost modeling methods represent the most straightforward progression toward higher fidelity analysis from the parametric methods inherent to Bell PC. Bottoms up methods, which include activity based cost models (Ref. 8-2) and engineering cost models, replicate the principle used in Bell PC of a basic buildup of component costs to a system level cost. Instead of building up the component costs from the 3rd and 4th level of work breakdown structure as is representative of conceptual parametric models, the bottoms up family of methods breaks the aircraft down to its finest, most detailed set of constituent tasks and material parts. Depending on the particular model, the bottoms up method may extend the level of detail in the estimation to all phases of aircraft life-cycle. As Figure 8-4 shows, this may result in a part previously assessed using one cost estimating relationship to be divided among ten or more cost estimating relationships. Bottoms up methods make their most important contribution to the assessment process in the higher level of certainty added to their predictions. The detail which bottoms up methods add over strictly parametric methods also facilitates the consideration of new technology more easily. The major burden of incorporating such approaches is the amount of time and background data required for their implementation. Future work in this realm requires a deep basis of reference data on individual aircraft components and practices, and is best suited for the individual consideration of specific technologies applied to aircraft subsystems.



2.1.1.7 SUMMARY OF LAYUP STANDARDS

BASIC DEPOSITION

DETAIL ELEMENTS	SETUP	RUNTIME	
CLEAN LAYUP TOOL SURFACE		0.000006A	(L1)
APPLY RELEASE AGENT TO LAYUP TOOL SURFACE		0.000009A	(L2)
POSITION TEMPLATE (MYLAR) ON TABLE AND TAPE DOWN		$0.000107A^{0.77006}$	(L3)
PLY DEPOSITION			
MANUAL - 3" TAPE	0.05	$0.00140L^{0.6018}$	(L4)
- 12" TAPE	0.05	$0.001454L^{0.8245}$	(L5)
- WOVEN MATERIAL	0.05	$0.000751A^{0.6295}$	(L6)
HAND-ASSIST - 3" TAPE	0.10	$0.000368L^{0.8446}$	(L7)
- 12" TAPE	0.10	$0.001585L^{0.5580}$	(L8)
CONRAC AUTO. (720 IPM)	0.15	$0.00063L^{0.4942}$	(L9)
(360 IPM)	0.15	$0.00058L^{0.5716}$	(L10)
TRANSFER PLY FROM TEMPLATE TO STACK OR LAYUP TOOL		$0.000145A^{0.6711}$	(L11)
TRANSFER STACK TO LAYUP TOOL		$0.000145A^{0.6711}$	(L12)
CLEAN CURING TOOL SURFACE		0.000006A	(L13)
APPLY RELEASE AGENT TO CURING TOOL SURFACE		0.000009A	(L14)
TRANSFER LAYUP TO CURING TOOL		$0.000145A^{0.6711}$	(L15)

WHERE:

A = Area of ply, or greatest ply area of stack or layup, in square inches

L = Length of ply strip, in inches

Figure 8-4. Example of a component bottoms up cost estimation (Ref. 8-2)

Event-Based Reliability Models

Many of the advanced practices proposed as significant affordability enablers in rotorcraft employ dynamic maintenance schedules aimed at improving availability above current trends. Measures such as condition based maintenance (CBM), time limited dispatch (TLD), and maintenance free operating period (MFOP) all depend on health monitoring of components and advanced planning of maintenance actions to increase availability. Since each of these strategies are largely event-driven, an assessment of their impact requires a time-centric modeling approach. Event-driven models such as fault trees, phased mission state space methods, and petri nets can specifically address this strategy in conjunction with parametric methods.

The salient characteristic of event-driven models is the need to quantify all possible states of operation and all possible failure modes and outcomes of a system. When all of the system states are characterized in all of the possible mission phases of uptime and downtime, specific practices such as inherent reliability improvement, lifing policy, and system redundancy can be considered with respect to their effects on overall improvement of aircraft reliability (Ref. 2-8). Figure 8-5 provides a diagram of one example of a single aircraft subsystem and how it could be modeled as a set of three components, with separate Petri nets modeling the overall aircraft state and the phases of the mission respectively. Petri net methods are based on Monte Carlo methods. The output of the simulation is a set of confidence levels corresponding to a particular value of maintenance free operating period (MFOP).

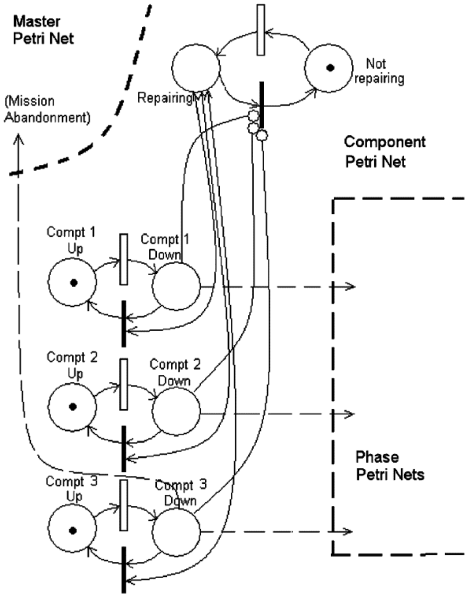


Figure 8-5. Petri net representation of a repairable component (Ref. 8-5)

Bridging the different characterization of uptime and downtime forms the key challenge in integrating event-based methods with parametric cost methods. Table 8-2 reiterates the O&S maintenance modeling structure of the Bell PC tool used for this study. Bell PC predicts major periodic overhaul maintenance costs and labor on a per flight hour basis by first calculating the predicted dollar and man-hour cost of the maintenance action and then dividing by the overhaul interval (TBO). Unscheduled and small routine inspections and preventative measures are predicted using continuous functions which simply calculate the cost in terms of dollars per flight hour and maintenance man-hours per flight hour.

Table 8-2. Bell PC maintenance cost estimating structure

DoD O&S Component	Bell PC Designation	Typical Maintenance Interval	Prediction Method
1.0 Manpower	Unscheduled & Routine Preventative Maintenance Labor	1 – 500 Flight Hours	Parametric MMH/FH
	Major Period Maintenance Labor	500 – 10,000 Flight Hours	Parametric MMH + User Input TBO
3.0 Maintenance	Unscheduled & Routine Replacement Consumables	1 – 500 Flight Hours	Parametric $/FH
	Major Period Maintenance (Overhaul) Parts	500 – 10,000 Flight Hours	Parametric Part Cost + User Input TBO

Due its specific inclusion of the frequency of each maintenance action, Bell PC's overhaul maintenance module contains at least a minimal set of parameters which are translatable to the state-based analysis. These actions only account for a portion of the total maintenance cost and total downtime of a typical helicopter. The remaining components consist of unscheduled corrective actions and small routine actions which occur at much greater frequency than major periodic overhauls. Since Bell PC and nearly all parametric methods predict these costs directly on a per flight hour basis, they obscure the frequency of occurrence and the downtime contribution of each. The previous calculation of operational availability bypasses this dilemma by specifically selecting a definition of operational availability which can be formulated in terms of maintenance man-hours per flight hour (derived in Appendix A). The limiting assumption inherent to this approach however is that the calculated operational availability for a particular aircraft concept only signifies the estimated value of A_o over a long term period of operation.

One possible method of translation offered here as a potential step toward future work using parametric and event-driven availability analysis in conjunction with one another is a conceptual formulation of aircraft components in terms of an assumed part count and average maintenance action intervals and costs. The premise of this proposed solution follows from the basic progression of aircraft designs which begins at conceptual sizing and matures through preliminary and detailed design, and is also mirrored in the progression of cost assessment methods illustrated in Figure 8-3. Knowing that the parametric maintenance estimate of a vehicle system's maintenance cost is given in dollars per flight hour $c_{\$/FH}$, the estimate can be modeled as a set of components, each with a time between maintenance action $MTBMA_i$ given in flight hours, a part cost c_i given in dollars, and an average part cost $\bar{c}$. The same form can be used to for maintenance man-hours per flight hour.

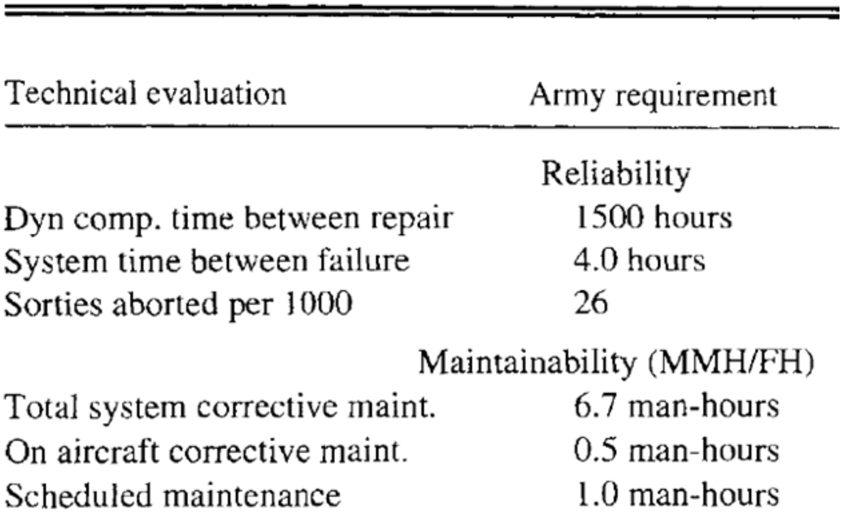
$$c_{\$/FH} = \sum_{i=1}^{n} \frac{c_i}{MTBMA_i} = \bar{c} \sum_{i=1}^{n} \frac{1}{MTBMA_i} \qquad (8-1)$$

$$\frac{MMH}{FH} = \sum_{i=1}^{n} \frac{MMH_i}{MTBMA_i} = \overline{MMH} \sum_{i=1}^{n} \frac{1}{MTBMA_i} \qquad (8-2)$$

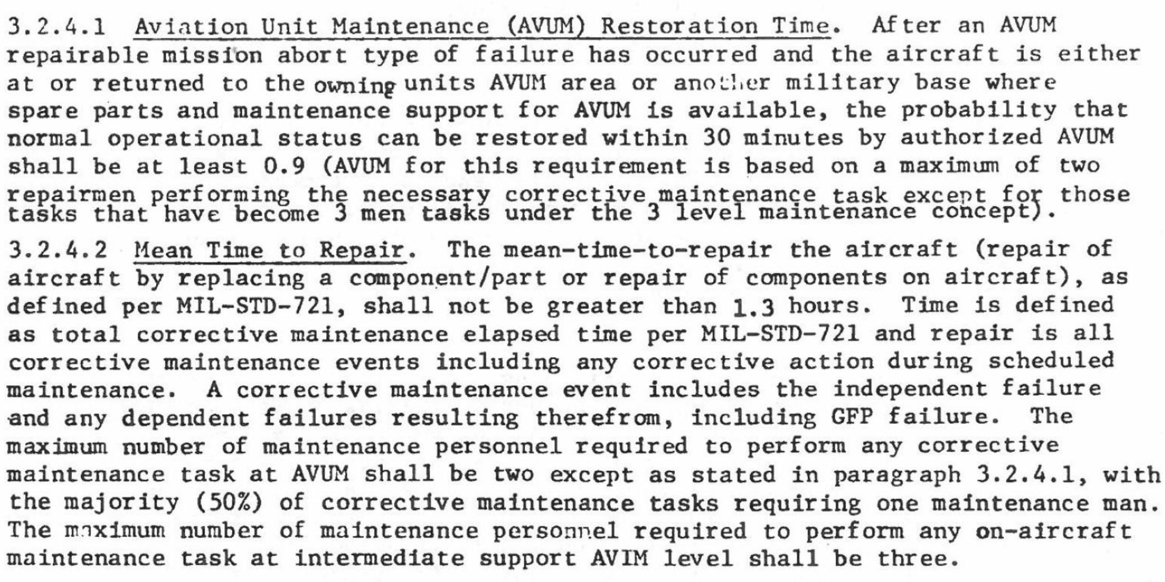
The generic $MTBMA$ term is used in this case because the smaller maintenance attributable to the parts in question may be either life-limited or corrective in nature depending on the design of the component (including any redundancy of part functions) and the lifing policy of the operator (Ref. 8-4). The important theoretical step taken at this point is establishing the number of components impacting the overall mean time between maintenance actions so that it may be estimated from the parametric model's prediction of maintenance man-hours per flight hour. In most cases, the average routine maintenance time $\overline{MMH}$, is an aircraft maintainability requirement specified by most military and commercial operators alike. One example from the Army UTTAS requirement set of such a requirement is provided in Table 8-3 and Figure 8-6.

Calculation of the maintenance free operating period requires an expected value of flight time in which maintenance is not anticipated with an acceptable degree of certainty, irrespective of design-specified time between overhaul. As this could impose a potentially overly complex analytical task for rotorcraft assemblies containing 1,000 or more replaceable parts, grouping and simplification of the parts list to a manageable inventory with a composite maintenance time assigned to each of the groups might be performed. Table 8-4 lists the expected number of inputs depending upon the WBS level of detail desired in the event-based simulation.

Table 8-3. Army UTTAS reliability requirements (Ref. 8-3)



Technical evaluation	Army requirement
	Reliability
Dyn comp. time between repair	1500 hours
System time between failure	4.0 hours
Sorties aborted per 1000	26
	Maintainability (MMH/FH)
Total system corrective maint.	6.7 man-hours
On aircraft corrective maint.	0.5 man-hours
Scheduled maintenance	1.0 man-hours



3.2.4.1 Aviation Unit Maintenance (AVUM) Restoration Time. After an AVUM repairable mission abort type of failure has occurred and the aircraft is either at or returned to the owning units AVUM area or another military base where spare parts and maintenance support for AVUM is available, the probability that normal operational status can be restored within 30 minutes by authorized AVUM shall be at least 0.9 (AVUM for this requirement is based on a maximum of two repairmen performing the necessary corrective maintenance task except for those tasks that have become 3 men tasks under the 3 level maintenance concept).

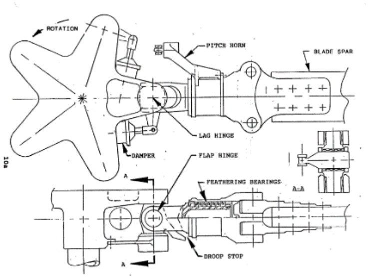
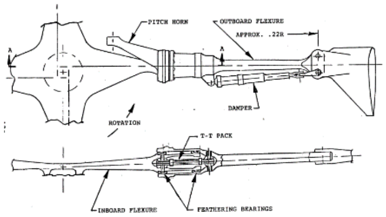
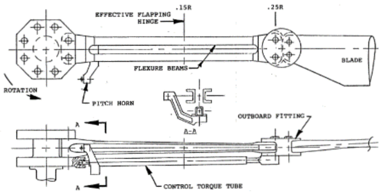
3.2.4.2 Mean Time to Repair. The mean-time-to-repair the aircraft (repair of aircraft by replacing a component/part or repair of components on aircraft), as defined per MIL-STD-721, shall not be greater than 1.3 hours. Time is defined as total corrective maintenance elapsed time per MIL-STD-721 and repair is all corrective maintenance events including any corrective action during scheduled maintenance. A corrective maintenance event includes the independent failure and any dependent failures resulting therefrom, including GFP failure. The maximum number of maintenance personnel required to perform any corrective maintenance task at AVUM shall be two except as stated in paragraph 3.2.4.1, with the majority (50%) of corrective maintenance tasks requiring one maintenance man. The maximum number of maintenance personnel required to perform any on-aircraft maintenance task at intermediate support AVIM level shall be three.

Figure 8-6. Army UTTAS maintainability requirements (Ref. 8-3)

Table 8-4. Rotor hub O&S modeling and metric hierarchy (Ref. 8-3)

Component (WBS Level)	Primary O&S Modeling Method	Metrics
Vehicle System (Level 1-3)	Parametric	\$/FH, MMH/FH, MFOP, MRP, A_o, A_i
Rotor Hub (Level 4)	Parametric, Event Tree / State-Space	\$/FH, TBO, MMH/FH
Rotor Hub Hinge (Level 5)	Event Tree / State-Space	MTBMA, MTTR
Rotor Hinge Pin (Level 5+)	Event Tree / State-Space	MTBF, λ_{MA}

Table 8-5. Rotor hub complexity and maintainability trends

Rotor Hub Type	Representative Geometry (Ref. 8-7)	Literature-based Part Count, n_{part}
Fully Articulated		500 – 1,500 Parts (Ref. 8-6)
Hingeless		200 – 500 Parts (Ref. 8-6)
Bearingless		30-200 Parts (Ref. 8-6)

Using the example of a rotor hub as described in Table 8-5, a starting point estimate of the number of replaceable parts contained within a major assembly such as a rotor hub could be developed from existing design trends and basic design parameters. In the case of a rotor hub, the part count estimate depends on the type of hub, the number of rotor blades, and the level of rotor performance needed for the aircraft design in terms of loads and vibrations among many possible design considerations, as well as the level of design technology. For other components, similar judgements would need to be made based on general assessments of configuration type, manufacturing skill, and historical trends among many possible factors.

The starting point estimate of part count along with the specified maintenance time and the parametric estimate of maintenance man-hours per flight hour can be used to calculate a composite expected value of mean time between maintenance actions

$E[MTBMA]$. The expected values of each of the main aircraft components can be used together to perform the event based analysis exemplified by the Monte Carlo based Petri net method shown in Figure 8-7. Rewriting Eqn. 8-2

$$\frac{(MMH/FH)}{\overline{MMH}} = \sum_{i=1}^{n_{part}} MTBMA_i = n_{part}\bar{\lambda}_{MA} \tag{8-3}$$

The average frequency of routine preventative and corrective maintenance actions $\bar{\lambda}_{MA}$ for the rotor hub in this example can now be reformulated at the expected value of maintenance free operating time for the given aircraft component.

$$\bar{\lambda}_{MA} = \frac{1}{E[MTBMA]} \tag{8-4}$$

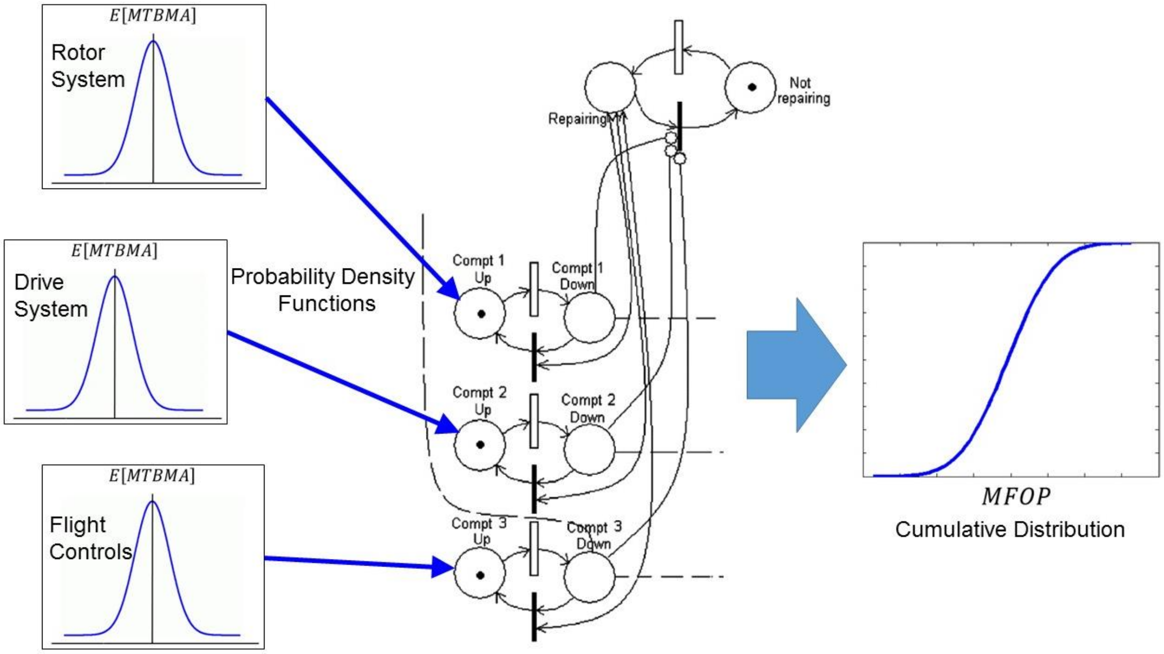


Figure 8-7. Integration of parametric and stochastic methods for MFOP prediction.

Concluding Insights

In the context of the rotorcraft design trade study performed in Chapter 6, the overarching theme of the new analytical capabilities developed in this thesis is the question of how much reliability and maintainability can be feasibly and economically designed into future advanced rotorcraft. Due to the limited rotorcraft reliability assessment capabilities found in the literature and cost models surveyed in Chapter 2, a new reliability-focused cost and design framework was developed to quantitatively and objectively answer this question. Besides providing an improved modeling tool in theoretical principle, as demonstrated by the increase in cost modeling accuracy shown in Chapter 3, the study adds both further insights and questions in relation to reliability investment for rotorcraft design.

The results of the trade study application of the framework detailed in Chapter 6 suggest that legacy rotorcraft operate at a cost disadvantage due in part to a conservatively short design service life. While Figures 6-13 through 6-15 indicate that all of the configurations experience optimal affordability at design service lives between 10,000 and 15,000 flight-hours depending on inflation assumptions, the best in class of contemporary medium rotorcraft exhibit no better than 5,000 to 6,000 flight hours of service life, with commensurately higher rates of routine maintenance and inspection occurrences. In simplest terms, the new design and assessment framework grants the designer with the ability to size aircraft to the lowest life-cycle cost sizing point, and empowers the requirements writer to demand a twofold or greater improvement in reliability in future rotorcraft even providing justification for the added acquisition cost such a requirement incurs.

That such a substantial change in design and acquisition cost can be quantifiably substantiated as advantageous to overall life-cycle affordability speaks to the need for a reevaluation of the fundamental objective of conceptual design and evaluation. Even allowing for the possibility that a recalibration of the point of departure or the cost-benefit slope of the reliability relationships diminishes some of the value of reliability to overall life-cycle cost, the findings of the trade study indicate that reliability improvement is likely the best available opportunity to enable future rotorcraft development programs within expected affordability constraints. If the analytical abilities of the reliability-augmented framework have truly not existed previously in any form (as the dearth of content in the literature suggests), then the discrepancy in optimal reliability between legacy rotorcraft and the minimum life-cycle design points found in Chapter 6 could potentially be attributed to a simple lack of design tools. Another possible explanation for this discrepancy is competing interests between manufacturers' and operators' business cases. Finally, as suggested by the consideration of cost metrics such as return on investment and break-even year, it is also possible that cost and affordability measured in dollars of life-cycle cost have been displaced as measures of program success to overly risk averse acquisition practices. In this case, the critical insight provided by the new framework is the ability to formalize such priorities and weight the potential total savings against other considerations. If upon incorporation of the advanced modeling effects listed as suggestions for future work, the optimal design points within the tradespace shift closer to the original starting point, the model will still serve as a tool for appraising the value of reliability technology as it becomes available. Whatever innovative approaches the rotorcraft community in general offers in the future to improve reliability and affordability, the design community in particular must produce sizing and cost assessment tools capable of assessing their impact *in the year 2000* and beyond.

APPENDICES

APPENDIX A

LIFE-CYCLE COST, RELIABILITY & MAINTAINABILITY TERMINOLOGY

When used informally, reliability can stand for several characteristics. In simple terms, reliability can be characterized as the quality of providing a needed function with consistent and trustworthy results. According to this definition, the informal usage of reliability as a quality from a maintenance perspective will denote a system which accomplishes its mission consistently, with a low frequency of maintenance actions required.

The formal definitions of reliability, availability, maintainability, and their related concepts are defined by the DoD Manual for the Joint Capabilities Integration and Development System (JCIDS) (Ref. A-1) and the Reliability, Availability, Maintainability, and Cost Rationale (RAM-C) Manual (Ref. A-2) in Table A-1 :

Table A-1. RAM metrics and symbols

Characteristic	Metric(s)	Definition
Reliability	MTBR	Mean time between removal/repair
	MTBF	Mean time between failure
	MTBMA	Mean time between mission abort
Availability	A_o	Operational availability
	A_m	Materiel availability
	A_i	Inherent availability
	OPR	Operational rate
Maintainability	MTTR	Mean time to repair
	MCMT	Mean corrective maintenance time
	ALDT	Administrative logistical/downtime

Reliability - the probability that the system will perform its assigned task without failure over a specified time interval under the nominal conditions in which it is designed to operate

Availability – depending on the type of availability, the percentage of time that a system or group of systems within a unit are operationally capable of performing an assigned mission

Operational Availability – the percentage of time that a system is operationally capable of performing its assigned task

Materiel Availability – the percentage of the total inventory of a system which is operationally capable

Maintainability – the ability of an item to be retained in, or restored to, a specified condition when maintenance is performed by personnel having specified skill levels, using prescribed procedures and resources, at each prescribed level of maintenance and repair.

Among the technical challenges to integrating cost and reliability considerations into preliminary design is the development of a model which predicts the availability metrics of a conceptual aircraft design. The direct impact of maintenance downtime to life-cycle cost is the amount of billable time which personnel spend servicing the aircraft, measured in maintenance man-hours per flight hour (MMH/FH). Accordingly, the parametric O&S maintenance models which this thesis uses as its starting point for the theoretical development of rotorcraft assessment predict maintenance labor in terms of MMH/FH. This necessitates a means of translating from cost-centric metrics to metrics from which availability may be predicted. Pryor (Ref. A-3) has provided one method for making this conversion by deriving an expression for availability written in terms of maintenance downtime for corrective and scheduled maintenance, and the additional maintenance time spent on inspection and preventative maintenance. These terms are easily obtained from the forms of preventative and corrective maintenance man-hours predicted by Bell PC. Pryor's formulation begins with the standard DoD expression for operational availability (Ref. A-1).

$$A_o = \frac{MTBR}{MTBR + MTTR} = \frac{Uptime}{Uptime + Downtime} \qquad (A-1)$$

Pryor expresses $MTBF$ in terms of flight hours, meaning the ideal uptime in clock hours in a system free of maintenance is

$$Uptime_{ideal} = \frac{MTBR}{OPR} \qquad (A-2)$$

Where the operational rate, OPR, is the ratio of flight hours to clock hours per year

$$OPR = \frac{FH/yr}{8{,}760\,\frac{CH}{yr}} \qquad (A-3)$$

So the actual uptime, including the inspection and preventative maintenance which is essential to the aircraft duty cycle and must be performed as a fraction of the uptime prior to takeoff and shutdown, is expressed as

$$Uptime_{actual} = \frac{MTBR}{OPR} - MTBR \times CMR_{ESS} \qquad (A-4)$$

Where CMR_{ESS} is the ratio of inspection and preventative maintenance time per flight time.

$$CMR_{ESS} = \frac{1}{N_{maint}}\left(\frac{MMH}{FH}\right)_{inspection+preventative} \qquad (A-5)$$

The scheduled and corrective downtime is written in terms of a mean corrective maintenance time plus an overhead term which stands for administrative and logistical downtime plus any additional downtime which is not attributable to actual maintenance labor activity taking place on the aircraft. The derivation for the new expression of operational availability is:

$$A_o = \frac{Uptime}{Uptime + Downtime} = \frac{(MTBR/OPR - MTBF \times CMR_{ESS})}{(MTBR/OPR - MTBF \times CMR_{ESS}) + (MCMT + ALDT + MTBR \times CMR_{ESS})}$$

Multiplying the top and bottom of the expression yields

$$A_o = \frac{1 - OPR \times CMR_{ESS}}{1 + OPR\left[\frac{(MCMT + ALDT)}{MTBR}\right]} \qquad (A-6)$$

In order to rewrite this expression in terms of maintenance man-hours as is needed for integration with parametric cost models, the total corrective and scheduled maintenance downtime is cast in terms similar to the CMR_{ESS} maintenance ratio term.

$$MCMT + ALDT = \frac{1}{N_{maint}}(MMH/FH)_{corrective+scheduled} \qquad (A-7)$$

Resulting in a final form which can be applied using the information from conceptual aircraft sizing and cost assessment models:

$$A_o = \frac{1 - \left(\frac{OPR}{N_{maint}}\right) \times \left(\frac{MMH}{FH}\right)_{preventative+inspection}}{1 + \left(\frac{OPR}{N_{maint}}\right) \times \left(\frac{MMH}{FH}\right)_{corrective+scheduled}} \qquad (A-8)$$

Additional derivation and application of this cost and availability model is provided in Ref. 1-16.

APPENDIX B

AIRCRAFT WEIGHT ORGANIZATION AND CONVERSION

The input Bell PC accepts from NDARC is the empty weight of the vehicle, broken down by component. The weight is organized in a format unique to Bell PC, but roughly following the MIL-STD 881C format (Ref. 5-3). Since the empty weight estimate of the conceptual vehicle generated in NDARC is organized according the SAE RP-8A standard (Ref. 5-4), but must be translated to 881C format for analysis in Bell PC, the

Table B-1. NDARC to Bell PC weight conversion

NDARC (SAWE RP-8A)	Bell PC (MIL-STD 881C)
STRUCTURE wing group basic structure secondary struct fairings fittings control surfaces	Wing
fold/tilt	Wing Fold
rotor group	
blade assembly	Rotor Blade
hub & hinge basic shaft	Rotor Hub Rotor Coupling
fairing/spinner	Spinner
blade fold	Rotor Fold
empennage group horizontal tail basic fold	Horizontal Stabilizer
vertical tail basic fold	Vertical Stabilizer
tail rotor blades hub & hinge	Tail Rotor
fuselage group basic crashworthiness	Basic Structure Crew / Passenger Doors Baggage / Compartment Aft Cargo Door Floor, Windows
alighting gear basic retraction crashworthiness	Landing Gear
engine sect/nac engine support	Support Structure
engine cowling	Firewall, Cowling
pylon support	Pylon Support Spindle
air induction	Air Inlet Inlet Particle Separator
PROPULSION GROUP engine system	
engine	Engine Installation Engine Controls / Start
exhaust system	IR Suppressor
accessories	Accessory Gearbox
fuel system tanks and supp plumbing	Fuel System
drive system	
gear boxes	Main Transmission Proprotor Gearbox Tailrotor / Tiltaxis Int./Midwing Gearbox Freewheel Unit Lubrication System
trans drive	Driveshaft
rotor shaft	Engine Input Shaft
rotor brake	Rotor Brake
SYSTEMS AND EQUIP flight controls	
cockpit controls	Cockpit Controls
auto flight cont	AFCS AFCS Wiring
system controls	
fixed wing sys non-boosted boost mech	Flap Actuators & Ctrls Rudder Act’s & Ctrls
rotary wing sys non-boosted boost mech boosted	Non-rotating Controls Rotating Controls – Main Rotor
conversion sys non-boosted boost mech	Pylon Conversion Controls
auxiliary power	Aux Power Unit
instruments group	Instruments
hydraulic group fixed wing rotary wing conversion equipment	Hydraulics
pneumatic group	Bleed Air Heat Defog
electrical group	Electrical
aircraft anti-icing	Anti-Icing
avionics (MEQ)	Avionics
armament group armament prov armor	Armament
furnish & equip	Crew, Passenger Seats Fire Extinguishing Soundproofing Misc.Furnishings
environ control	Bleed Air Heat Defog Environ Ctrl Unit
anti-icing group load & handling	Anti-Icing Load Handling
VIBRATION	Rotor Vib. Suppression

APPENDIX C

LEARNING CURVE EFFECTS IN AIRCRAFT COST ASSESSMENT

The estimation of the procurement cost of future systems depends on a well-established and confirmed concept called the learning curve. Production learning and its effect on cost has been documented since the earliest examples of the application of mass production to aircraft (Ref. D). The form of the learning curve used here is derived using the notation of Marx and Schrage (Ref. E). Supposing the unit production cost of the first production unit of a system can be represented by the function

$$c_1 = \alpha x^{\beta} \qquad (A-9)$$

The unit cost of the nth production unit is c_n and the cost of the (2 x n)-th production unit is c_{2n}. Furthermore, the the (2 x n)-th production unit cost can be represented as a function of the nth production unit as νc_n

$$c_n = c_1 n^{\beta} \qquad (A-10)$$

$$\nu c_n = c_1 (2n)^{\beta} \qquad (A-11)$$

$$\log c_n = \log c_1 + \beta \log n \qquad (A-12)$$

$$\log \nu + \log c_n = \log c_1 + \beta \log 2 + \beta \log n \qquad (A-13)$$

$$\log \nu = \beta \log 2$$

And therefore

$$\beta = \frac{\log \nu}{\log 2} \qquad (A-14)$$

The parameter ν is typically referred to as either the learning curve slope or the learning curve factor, LCF. The learning curve expression for the unit price of the nth production unit is thus

$$c(n) = c_1 n^{\frac{\ln LCF}{\ln 2}} \qquad (A - 15)$$

The effect of the learning curve factor on the unit price $c(n)$ as modeled in the equation is to modify the unit cost by the learning curve factor LCF for each successive doubling of the production quantity. Figure C-1 plots the average procurement cost taken from the unit procurement cost computed by Eqn. A-15 normalized to a first production unit procurement price of 1 and an LCF of 90%.

Figure C-1 illustrates the sensitivity of unit cost to the quantity of production units and the value of LCF. It is apparent that production learning is a major factor in the procurement component of life-cycle cost. The unit cost of the 1,000th production unit is reduced to less than 40% of the first unit at 90% learning.

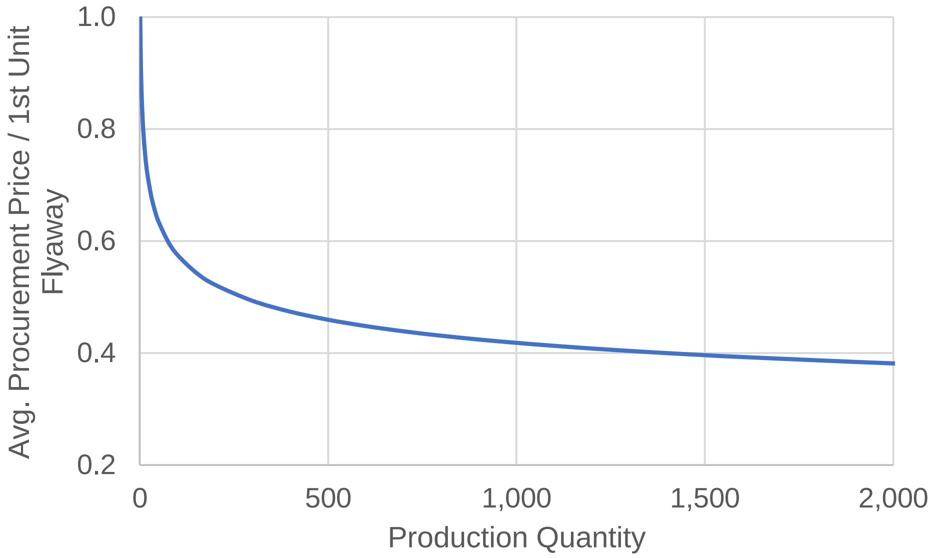


Figure C-1. 90% Learning curve effect on average procurement unit price

The significant influence of the learning curve makes its appropriate application equally critical to a reasonable cost estimate. The cost analysis conducted in this thesis typically assumes sufficient production rate and quantity to make learning curve a relevant opportunity for affordability improvement. Although many opinions exist in aviation manufacturing as to the exact conditions under which production learning will occur, this work operates under the general assumption of production rate of no less than 100 aircraft per year as the lower bound of learning curve effect. Ref. A-6 documents the history of production costs observed in the H-1 helicopter, noting the prolonged learning curve cost reduction observed over several years and thousands of production aircraft consistent with these general assumptions.

APPENDIX D

DESIGN ENVIRONMENT CALCULATION PROCEDURES

Component	Input	Calculation	Output	Reference
Helicopter Inputs (Excel)	Economic Assumptions (Proc. Qty, LCF $/gal fuel, TBO, inflation)	Eqn. 3-1, Fig. 3-1	Eqn. 3-1 Component RAM Wt. Factors	Ref. 3-4
Helicopter (NDARC)	Weight Factors Design Mission Vehicle Aerodynamics	Vehicle Sizing	Vehicle Weight, Installed HP Mission Fuel	Ref. 4-9
Wt. Conversion (Excel)	Aircraft Wt. (RP-8A)	Wt. Format Conversion	Aircraft Wt. (881C/Bell PC)	Appendix C
Engine Procurement Cost (Excel)	Installed hp Engine Complexity	Eqn. 3-3	Engine Unit Procurement Cost	Ref. 3-6
Bell PC Procurement Cost (Excel)	Engine Procurement Cost Aircraft Wt. Aircraft Configuration	Procurement Cost, calculated at 3rd and 4th Component WBS Level	Aircraft Procurement Unit Cost (APUC)	Ref. 3-4
Bell PC OS (Excel)	Aircraft Wt. Aircraft Procurement Cost	Operating and Support Cost	Unit O&S Cost per flight hour	Ref. 3-4 Table 6-1
RAM RDTE Cost (Excel)	Aircraft Procurement Cost	Eqn. 3-2	Total RDT&E invested in RAM	Ref. 3-5
LifeCycle (MATLAB)	Unit Procurement & Operating Cost, Total RAM RDT&E	Annual Ownership Cost	Aircraft Life-Cycle Cost	Table 5-5, Table 6-2
LifeCycle Compare (MATLAB)	Baseline aircraft life-cycle cost, Economic Assumptions	Design Excursion / Baseline Aircraft Comparison	Life-cycle cost difference due to RAM, RAM Investment break-even year, Return on RAM Investment	Table 5-5, Table 6-2

APPENDIX E

HARRIS-SCULLY COST MODELS

Refs. 1-20 and 5-1 together form a simple example of a set of size-based parametric cost models covering the basic system-level components of procurement and operating cost. The model is used in multiple instances in this study as an example of the advantages and disadvantages of system level conceptual models as well as an example of conventional cost assessment methods where reliability and maintainability considerations are largely implicit to the cost per flight hour O&S estimate. Figure E-1 diagrams the Harris-Scully's level of fidelity in relation to various commercial and military cost reporting structures as well as other examples of parametric cost models, including the Bell PC-based cost model.

The procurement cost model predicts the unit flyaway cost of rotorcraft according to the formula:

$$c_{FA} = 269\, WE^{0.4638} SHP^{0.5945}\, N_{bl}^{0.1643} H \qquad (A-16)$$

Where WE is the aircraft empty weight, SHP is the installed horsepower, N_{bl} is the number of blades per rotor, and H is a complexity factor defined by

$$H = \kappa_{eng} \kappa_{N,eng} \kappa_{rotor} \kappa_{LG} \qquad (A-17)$$

$$\kappa_{eng} = \begin{cases} 1.0 & \text{Piston} \\ 1.794 & \text{Turbine} \end{cases} \qquad (A-18)$$

$$\kappa_{N,eng} = \begin{cases} 1.0 & \text{Single} \\ 1.344 & \text{Multi} \end{cases} \qquad (A-19)$$

$$\kappa_{rotor} = \begin{cases} 1.0 & \text{Single Rotor} \\ 1.031 & \text{Twin Rotors} \end{cases} \qquad (A-20)$$

$$\kappa_{LG} = \begin{cases} 1.0 & \text{Fixed} \\ 1.115 & \text{Retractable} \end{cases} \qquad (A-21)$$

The rotorcraft size-related terms in Eqn. A-22 are frequently combined into a single scaling factor for use as a general indicator of size-driven cost.

$$f_{H-S} = WE^{0.4638} SHP^{0.5945} \qquad (A-22)$$

The direct operating cost per flight hour is also estimated at the top level, organized according to maintenance replacement parts, airframe overhaul repair, and engine overhaul repair. The sum of these components would form the 3.0 Maintenance component in the DoD's operating cost structure.

$$c_{OS,parts} = \kappa_{parts} c_{FA}^{0.68} \qquad (A-23)$$

$$\kappa_{parts} = \begin{cases} 56 & \text{Current State of Art} \\ 34 & \text{Current Best Practice} \end{cases} \qquad (A-24)$$

$$c_{OS,engOH} = \kappa_{engOH} SHP^{0.67} \qquad (A-25)$$

$$\kappa_{engOH} = \begin{cases} 1.74 & \text{Current State of Art} \\ 1.45 & \text{Current Best Practice} \end{cases} \qquad (A-26)$$

$$c_{OS,afOH} = \kappa_{afOH} c_{FA} \qquad (A-27)$$

$$\kappa_{afOH} = \begin{cases} 28 & \text{Current State of Art} \\ 18 & \text{Current Best Practice} \end{cases} \qquad (A-28)$$

The maintenance manpower (component 1.0 in the DoD cost structure) is estimated in terms of maintenance man-hours per flight hour according to

$$MMH/FH = \kappa_{MMH/FH} WE^{0.78} \qquad (A-29)$$

$$\kappa_{MMH/FH} = \begin{cases} 0.0027 & \text{Current State of Art} \\ 0.0017 & \text{Current Best Practice} \end{cases} \qquad (A-30)$$

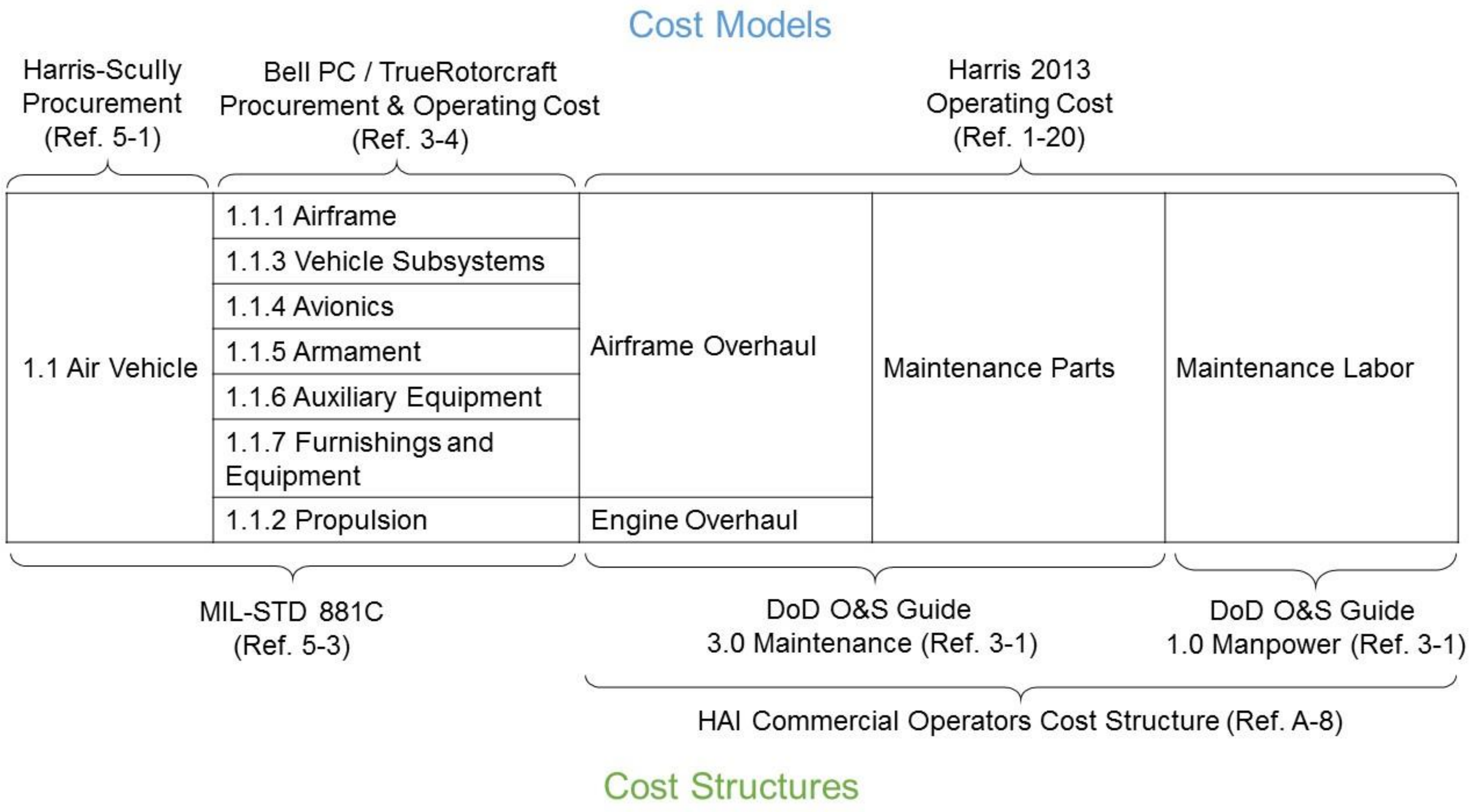


Figure E-1. Commercial and military acquisition and operation cost structures mapped to selected examples of parametric cost models

APPENDIX F

BASELINE AIRCRAFT CONCEPT DESCRIPTIONS

Baseline Helicopter Design Parameters

Rotors	**Units**	**Main Rotor**	**Tail Rotor**
Disk Loading	lb/ft^2	9	30
Design C_W/σ		0.07	0.08
Radius	ft	26.01	4.86
Solidity		0.119	0.400
Blade Aspect Ratio		15.50	3.99
Number of Blades		6	5
Rotation Direction		CCW	CCW
Hover Tip Speed	ft/s	750	700
Cruise Tip Speed	ft/s	750	700
Rotor Incidence	deg	-3	0
Rotor Cant	deg	0	20
Blade 1st Flap Freq.		1.035	
Aero Surfaces		**Horiz. Tail**	**Vert. Tail**
Area	ft^2	76.07	28.53
Aspect Ratio		5.00	2.00
Span	ft	19.50	7.55
Chord	ft	3.90	3.78
Size		**Fuselage**	**Operating Dimension**
Length	ft	41.11	61.94
Width	ft	6.00	52.02
Height	ft	6.00	11.71
Propulsion System			
Fuel Tank Capacity	lb	4,977	
Drive System Limit	hp	3,574	
Number of Engines		2	
Takeoff Power (MRP)	hp (each)	3,268	
SLS Power MCP	hp (each)	2,573	
MCP SLS SFC	lb/hp-hr	0.4068	
Engine Weight	lb	368.6	
Engine Weight/Power	lb/hp	0.113	
Aerodynamics			
f, Cruise Drag (D/q)	ft^2	17.06	
k_{drag}, $(D/q)/(GW/1000)^{2/3}$		2.063	
Hover Download, (DL/T)		0.0260	
Cruise L/D_e, Rotor		4.83	4k95 V_{br}, DGW (145 kts)
Cruise L/D_e, Aircraft		3.39	4k95 V_{br}, DGW (145 kts)
Aircraft Fig. Merit		0.642	4k95 HOGE, DGW

Baseline Helicopter Weight Summary

	lb.	tech factor		lb.	tech factor
STRUCTURE	3,300.6		SYSTEMS AND EQUIP	3,638.5	
wing group	0.0		flight controls	881.3	
basic structure	0.0		cockpit controls	100.0	
rotor group	1,058.2		auto flight cont	50.0	
blade assembly	669.0	0.663	system controls	731.3	
hub & hinge	389.2		fixed wing sys	0.0	
basic	389.2	0.637	non-boosted	0.0	0.863
shaft	0.0	1	boost mech	0.0	0.863
fairing/spinner	0.0	0.75	rotary wing sys	731.3	
blade fold	0.0	0.75	non-boosted	204.2	0.877
empennage group	328.1		boost mech	283.6	0.877
horizontal tail	149.0		boosted	243.6	0.795
basic	149.0	0.75	conversion sys	0.0	
fold	0.0	1	non-boosted	0.0	1
vertical tail	105.3		boost mech	0.0	1
basic	105.3	1.852	auxiliary power	130.0	
fold	0.0	1	instruments group	150.0	
tail rotor	73.8		hydraulic group	94.5	
blades	63.5		fixed wing	0.0	0.863
hub & hinge	10.2		rotary wing	94.5	0.877
rotor supports	0.0		conversion	0.0	1
rotor/fan duct	0.0		equipment	0.0	
fuselage group	1,368.3		pneumatic group	0.0	
basic	1,313.2	0.721	electrical group	304.7	
crashworthiness	0.0	0.7	aircraft	250.0	
alighting gear	0.0	0.7	anti-icing	54.7	0.75
basic	0.0	0.7	avionics (MEQ)	1,000.0	
retraction	0.0	0.7	armament group	100.0	
crashworthiness	55.2	0.7	armament prov	0.0	
engine sect/nac	372.0		armor	100.0	
engine support	330.5	0.555	furnish & equip	770.0	
engine cowling	14.7	0.555	environ control	100.0	
pylon support	26.8	0.555	anti-icing group	58.0	0.75
air induction	143.4		load & handling	50.0	
PROPULSION GROUP	2,590.5		VIBRATION	50.4	
engine system	1,103.9		CONTINGENCY	504.2	
engine	737.2	0.705	FIXED USEFUL LOAD	1,070.0	
exhaust system	276.5	0.705	crew	1,000.0	
accessories	90.2	0.533	fluids	70.0	
prop/fan install	0.0				
blades	0.0				
hub & hinge	0.0		WEIGHT EMPTY	10,084.2	
rotor supports	0.0		Fixed UL for DGW	1,070.0	
rotor/fan duct	0.0		OPERATING WEIGHT	11,154.2	
fuel system	201.4		Fuel for DGW	4,976.5	
tanks and supp	152.7	0.623	Payload for DGW	3,000.0	
plumbing	48.8	0.623	USEFUL LOAD for DGW	9,046.5	
drive system	1,285.2		DESIGN GROSS WEIGHT	19,130.7	
gear boxes	1,082.3	0.683			
trans drive	71.3	0.637			
rotor shaft	107.0	0.683	Growth Factor	3.189	
rotor brake	24.6	0.75	Empty Weight Fraction	0.527	

Baseline Lift Offset Compound Design Parameters

Rotors	**Units**	**Upper Rotor**	**Lower Rotor**	**Propeller**
Disk Loading	lb/ft^2	9.0	9.0	35.0
Design C_W/σ		0.075	0.075	0.09
Radius	ft	20.25	20.25	5.38
Solidity		0.11	0.112	0.25
Blade Aspect Ratio		11.31	11.31	8.91
Number of Blades		4	4	7
Rotation Direction		CCW	CW	CCW
Hover Tip Speed	ft/s	750	750	900
Cruise Tip Speed	ft/s	615	615	738
Rotor Incidence	deg	0	0	0
Rotor Cant	deg	0	0	0
Blade 1st Flap Freq.		1.46	1.46	
Design Lift Offset	M_{hub}/TR	0.10	0.10	
Aero Surfaces		**Horiz. Tail**	**Vert. Tail**	
Area	ft^2	27.99	16.80	
Aspect Ratio		5.00	2.50	
Span	ft	11.83	6.48	
Chord	ft	2.37	2.59	
Size		**Fuselage**	**Operating Dimension**	
Length	ft	44.54	53.65	
Width	ft	7.00	40.49	
Height	ft	6.00		
Propulsion System				
Fuel Tank Capacity	lb	3,793		
Drive System Limit	hp	4,181		
Number of Engines		2		
Takeoff Power (MRP)	hp (each)	3,105		
SLS Power MCP	hp (each)	2,445		
MCP SLS SFC	lb/hp-hr	0.4074		
Engine Weight	lb	372.6		
Engine Weight/Power	lb/hp	0.120		
Aerodynamics				
f, Cruise Drag (D/q)	ft^2	18.06		
k_{drag}, (D/q)/(GW/1000)$^{2/3}$		1.874		
Hover Download, (DL/T)		0.0382		
Cruise L/D_e, Rotor		12.80	4k95 V_{br}, DGW (168 kts)	
Cruise L/D_e, Aircraft		6.57	4k95 V_{br}, DGW (168 kts)	
Aircraft Fig. Merit		0.852	4k95 HOGE, DGW	

Baseline Lift Offset Compound Weight Summary

	lb.	tech factor		lb.	tech factor
STRUCTURE	6,425.3		SYSTEMS AND EQUIP	4,723.0	
wing group	0.0		flight controls	1,932.5	
basic structure	0.0		cockpit controls	100.0	
secondary struct	0.0		auto flight cont	50.0	
control surfaces	0.0		system controls	1,782.5	
rotor group	3,543.3		fixed wing sys	21.1	
blade assembly	1,462.7	0.55	non-boosted	2.1	0.428
hub & hinge	2,080.6		boost mech	19.0	0.428
basic	1,866.5	0.55	rotary wing sys	1,761.4	
shaft	214.1	0.55	non-boosted	524.9	0.81
fairing/spinner	0.0	0.65	boost mech	357.3	0.848
blade fold	0.0	0.65	boosted	879.2	1.717
rotor support	0.0	1	conversion sys	0.0	
duct	0.0	1	non-boosted	0.0	1
empennage group	69.2		boost mech	0.0	1
horizontal tail	49.8		auxiliary power	130.0	
basic	49.8	0.795	instruments group	150.0	
fold	0.0	1	hydraulic group	119.9	
vertical tail	19.4		fixed wing	0.8	0.428
basic	19.4	0.795	rotary wing	119.1	0.848
fold	0.0	1	conversion	0.0	1
tail rotor	0.0		equipment	0.0	
blades	0.0		pneumatic group	0.0	
hub & hinge	0.0		electrical group	308.6	
fuselage group	2,022.6		aircraft	250.0	
basic	1,930.5	0.795	anti-icing	58.6	0.75
wing&rtr fld/ret	0.0	0.795	avionics (MEQ)	1,000.0	
tail fold/tilt	0.0	0.795	armament group	100.0	
marinization	0.0	0.795	armament prov	0.0	
pressurization	0.0	0.795	armor	100.0	
crashworthiness	92.1	0.795	furnish & equip	770.0	
alighting gear	568.6		environ control	100.0	
basic	487.0	0.735	anti-icing group	62.0	0.75
retraction	28.6	0.735	load & handling	50.0	
crashworthiness	53.1	0.735	VIBRATION	76.6	
engine sect/nac	179.7		CONTINGENCY	765.8	
engine support	77.6	1.283	FIXED USEFUL LOAD	1,070.0	
engine cowling	102.1	0.743	crew	1,000.0	
pylon support	0.0	1.283	fluids	70.0	
air induction	41.8	1.283			
PROPULSION GROUP	3,325.9				
accessories	184.1	1.08	WEIGHT EMPTY	15,316.6	
prop/fan install	181.3	0.65	Fixed UL for DGW	1,070.0	
fuel system	201.6		OPERATING WEIGHT	16,386.6	
tanks and supp	144.7	0.728	Fuel for DGW	3,793.1	
plumbing	56.9	0.728	Payload for DGW	3,000.0	
drive system	1,734.2		USEFUL LOAD for DGW	7,863.1	
gear boxes	1,449.1	0.795	DESIGN GROSS WEIGHT	23,179.7	
trans drive	84.8	0.795			
rotor shaft	143.3	0.795	Growth Factor	3.864	
rotor brake	57.0	0.795	Empty Weight Fraction	0.661	

Baseline Tiltrotor Design Parameters

Rotors	**Units**	**Right Rotor**	**Left Rotor**	
Disk Loading	lb/ft^2	14.0	14.0	
Design C_W/σ		0.13	0.13	
Radius	ft	15.77	15.77	
Solidity		0.106	0.106	
Blade Aspect Ratio		12.06	12.06	
Number of Blades		4	4	
Rotation Direction		CCW	CW	
Hover Tip Speed	ft/s	750	750	
Cruise Tip Speed	ft/s	675	675	
Rotor Incidence	deg	0	0	
Rotor Cant	deg	0	0	
Blade 1st Flap Freq.		1.02	1.02	
Aero Surfaces		**Wing**	**Horiz. Tail**	**Vert.Tail (2)**
Wing Loading	lb/ft^2	116.6		
Area	ft^2	187.7	40.69	24.65
Aspect Ratio		8.0	3.50	2.50
Span	ft	38.75	11.93	7.85
Chord	ft	4.84	3.41	3.14
Size		**Fuselage**	**Operating Dimension**	
Length	ft	47.55	47.55	
Width	ft	6.00	70.29	
Height	ft	6.00	14.20	(rotors at 90°)
Propulsion System				
Fuel Tank Capacity	lb	3,118		
Drive System Limit	hp	4,449		
Number of Engines		2		
Takeoff Power (MRP)	hp	3,072		
SLS Power MCP	hp	2,419		
MCP SLS SFC	lb/hp-hr	0.4076		
Engine Weight	lb	491.5		
Engine Weight/Power	lb/hp	0.160		
Aerodynamics				
f, Cruise Drag (D/q)	ft^2	14.37		
k_{drag}, (D/q)/(GW/1000)$^{2/3}$		1.732		
Hover Download, (DL/T)		0.136		
Cruise L/D_e, Rotor		--	12kISA V_{br}, DGW (224 kts)	
Cruise L/D_e, Aircraft		6.90	12kISA V_{br}, DGW (224 kts)	
Aircraft Fig. Merit		0.580	4k95 HOGE, DGW	

Baseline Tiltrotor Weight Summary

	lb.	tech factor		lb.	tech factor
STRUCTURE	5,647.0		SYSTEMS AND EQUIP	4,489.9	
wing group	1,173.8		flight controls	1,734.3	
basic structure	886.9	0.735	cockpit controls	100.0	
secondary struct	209.3		auto flight cont	50.0	
fairings	81.2	0.735	system controls	1,584.3	
fittings	128.1	0.735	fixed wing sys	208.3	
fold/tilt	0.0	0.735	non-boosted	20.8	0.54
control surfaces	77.6	0.735	boost mech	187.5	0.54
rotor group	1,453.2		rotary wing sys	849.8	
blade assembly	843.3	0.697	non-boosted	429.4	0.705
hub & hinge	609.9		boost mech	225.1	0.81
basic	483.0	0.66	boosted	195.3	0.765
shaft	0.0	1	conversion sys	526.2	
fairing/spinner	127.0	0.728	non-boosted	47.8	1
blade fold	0.0	0.75	boost mech	478.3	1
empennage group	212.3	1	auxiliary power	130.0	
horizontal tail	122.5	1	instruments group	150.0	
basic	122.5		hydraulic group	133.0	
fold	0.0		fixed wing	10.1	0.54
vertical tail	89.8		rotary wing	75.0	0.81
basic	89.8	0.45	conversion	47.8	1
fold	0.0	1	equipment	281.0	
tail rotor	0.0		pneumatic group	250.0	
blades	0.0		electrical group	31.0	
hub & hinge	0.0		aircraft	1,000.0	
fuselage group	1,988.6		anti-icing	100.0	0.75
basic	1,898.1	0.772	avionics (MEQ)	0.0	
crashworthiness	90.5	0.795	armament group	100.0	
alighting gear	500.8		armament prov	770.0	
basic	430.2	0.72	armor	100.0	
retraction	24.8	0.72	furnish & equip	41.7	
crashworthiness	45.9	0.72	environ control	50.0	
engine sect/nac	293.2		anti-icing group	73.5	0.75
engine support	46.7	0.637	load & handling	734.9	
engine cowling	89.9	0.42	VIBRATION	281.0	
pylon support	156.7	0.637	CONTINGENCY	250.0	
air induction	25.1	0.637	FIXED USEFUL LOAD	1,070.0	
PROPULSION GROUP	3,752.8		crew	1,000.0	
engine system	1,344.9		fluids	70.0	
engine	860.2	0.75			
exhaust system	322.6	0.75	WEIGHT EMPTY	14,698.1	
accessories	162.2	0.465	Fixed UL for DGW	1,070.0	
fuel system	414.9		OPERATING WEIGHT	15,768.1	
tanks and supp	288.4	1.688	Fuel for DGW	3,118.1	
plumbing	126.4	1.688	Payload for DGW	3,000.0	
drive system	1,993.0		USEFUL LOAD for DGW	7,187.4	
gear boxes	1,713.8	1.013	DESIGN GROSS WEIGHT	21,885.5	
trans drive	67.9	0.465			
rotor shaft	169.5	1.013	Growth Factor	3.648	
rotor brake	41.8	1.013	Empty Weight Fraction	0.672	

Baseline Aircraft Forward Flight Drag

	Helicopter	**Lift Offset**	**Tiltrotor**
Fuselage	4.33	3.42	4.85
Fuselage Fittings	2.29	2.39	3.40
Rotor 1 Hub	3.19	3.09	0.0
Rotor 1 Pylon	3.03	0.0	1.24
Rotor 2 Hub	1.49	3.09	0.0
Rotor 2 Pylon	0.0	0.0	1.24
Wing	0.0	0.0	2.81
Tail 1 (Horizontal)	1.11	0.42	0.49
Tail 2 (Vertical)	0.55	0.34	0.34
Engine Nacelles	1.08	2.86	0.0
TOTAL *f*, ft^2	**17.06**	**17.01**	**14.37**
***f* / (GW/1000)$^{2/3}$**	**2.063**	**1.848**	**1.732**

Notes:

Fuselage and wing drag components include rotor-fuselage and wing-fuselage interference drag.

Tiltrotor nacelle drag is bookkept as pylon drag in NDARC.

Helicopter Direct Maintenance Summary

Category	Maintenance man hours per flight hour	Part cost per flight hour
Scheduled Maintenance		
Inspection	2.6178	
Drive System	0.0581	
Proprotor Gearbox		$23.69
Tiltaxis Gearbox		8.72
Midwing Gearbox		4.97
Combining Gearbox		0.00
Accessory Gearbox		8.34
Rotor System	0.0085	
Main Rotor		$22.48
		10.94
Flight Controls		27.65
Part Retirements	0.0538	
Drive System		$20.96
Main Rotor		86.11
		19.51
Flight Controls		134.66
Contingency (5%)		
Total Scheduled	**2.7382**	**$368.04**
Unscheduled Maintenance		
Airframe Structure	0.0399	$90.18
Landing Gear	0.0132	40.64
Flight Controls	0.1247	280.93
Electrical and Avionics	0.4191	313.05
Rotor	0.1523	179.86
Systems	0.2646	34.22
Propulsion	0.2005	54.44
Drive	0.0324	73.47
Armament	0.0000	0.00
Contingency (5%)		
Total Unscheduled	**1.2468**	**$1,066.80**
Powerplant Maintenance		**$996.87**
Total MMH/FH	**3.9850**	
Total Direct Operating Cost ($/FH)		**$2,431.71**

Lift Offset Direct Maintenance Summary

Category	Maintenance man hours per flight hour	Part cost per flight hour
Scheduled Maintenance		
Inspection	2.8041	
Drive System	0.0593	
Proprotor Gearbox		$34.05
Tiltaxis Gearbox		0.00
Midwing Gearbox		5.99
Combining Gearbox		0.00
Accessory Gearbox		13.66
Rotor System	0.0155	
Main Rotor		$80.38
		25.89
Flight Controls		49.27
Part Retirements	0.1278	
Drive System		$23.47
Main Rotor		227.11
		25.95
Flight Controls		167.19
Contingency (5%)		
Total Scheduled	**3.0067**	**$652.94**
Unscheduled Maintenance		
Airframe Structure	0.2015	$98.69
Landing Gear	0.0552	52.52
Flight Controls	0.1068	495.39
Electrical and Avionics	0.4193	313.60
Rotor	0.1541	403.63
Systems	0.2674	34.46
Propulsion	0.2014	54.99
Drive	0.2080	87.67
Armament	0.0000	0.00
Contingency (5%)		
Total Unscheduled	**1.6137**	**$1,540.95**
Powerplant Maintenance		**$1,192.05**
Total MMH/FH	**4.6203**	
Total Direct Operating Cost ($/FH)		**$3,385.94**

Tiltrotor Direct Maintenance

Category	Maintenance man hours per flight hour	Part cost per flight hour
Scheduled Maintenance		
Inspection	2.7856	
Drive System	0.0288	
Proprotor Gearbox		$44.13
Tiltaxis Gearbox		22.64
Midwing Gearbox		13.86
Combining Gearbox		0.00
Accessory Gearbox		12.51
Rotor System	0.0122	
Main Rotor		$54.40
		0.00
Flight Controls		32.20
Part Retirements	0.1038	
Drive System		$17.96
Main Rotor		104.47
		0.00
Flight Controls		154.07
Contingency (5%)		
Total Scheduled	**2.9305**	**$456.24**
Unscheduled Maintenance		
Airframe Structure	0.2179	$59.01
Landing Gear	0.0539	24.32
Flight Controls	0.1639	233.36
Electrical and Avionics	0.3743	309.69
Rotor	0.1705	276.86
Systems	0.2178	32.27
Propulsion	0.2250	70.34
Drive	0.2162	92.53
Armament	0.0000	0.00
Contingency (5%)		
Total Unscheduled	**1.6395**	**$1,098.38**
Powerplant Maintenance		**$1,171.67**
Total MMH/FH	**4.5700**	
Total Direct Operating Cost ($/FH)		**$2,726.29**

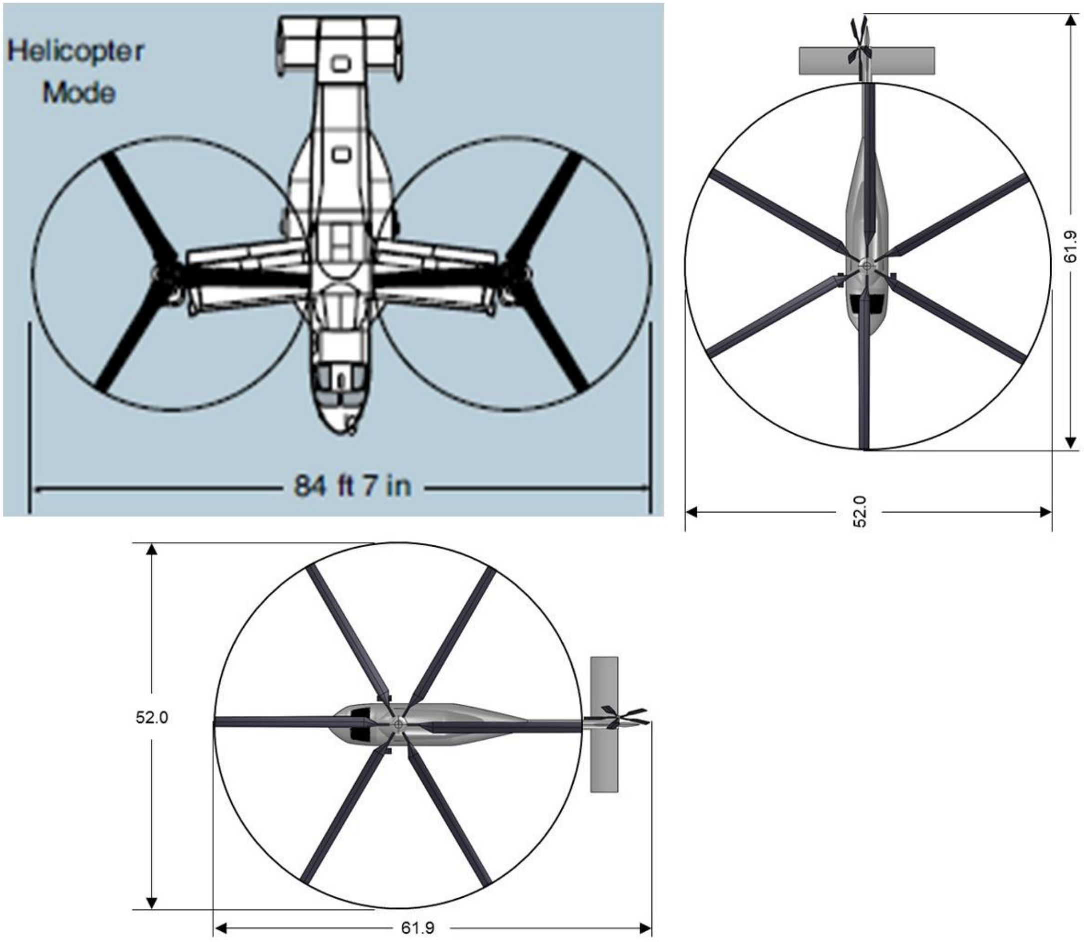


Figure F-1. Baseline Helicopter operational footprint, V-22 comparison (Ref. A-7)

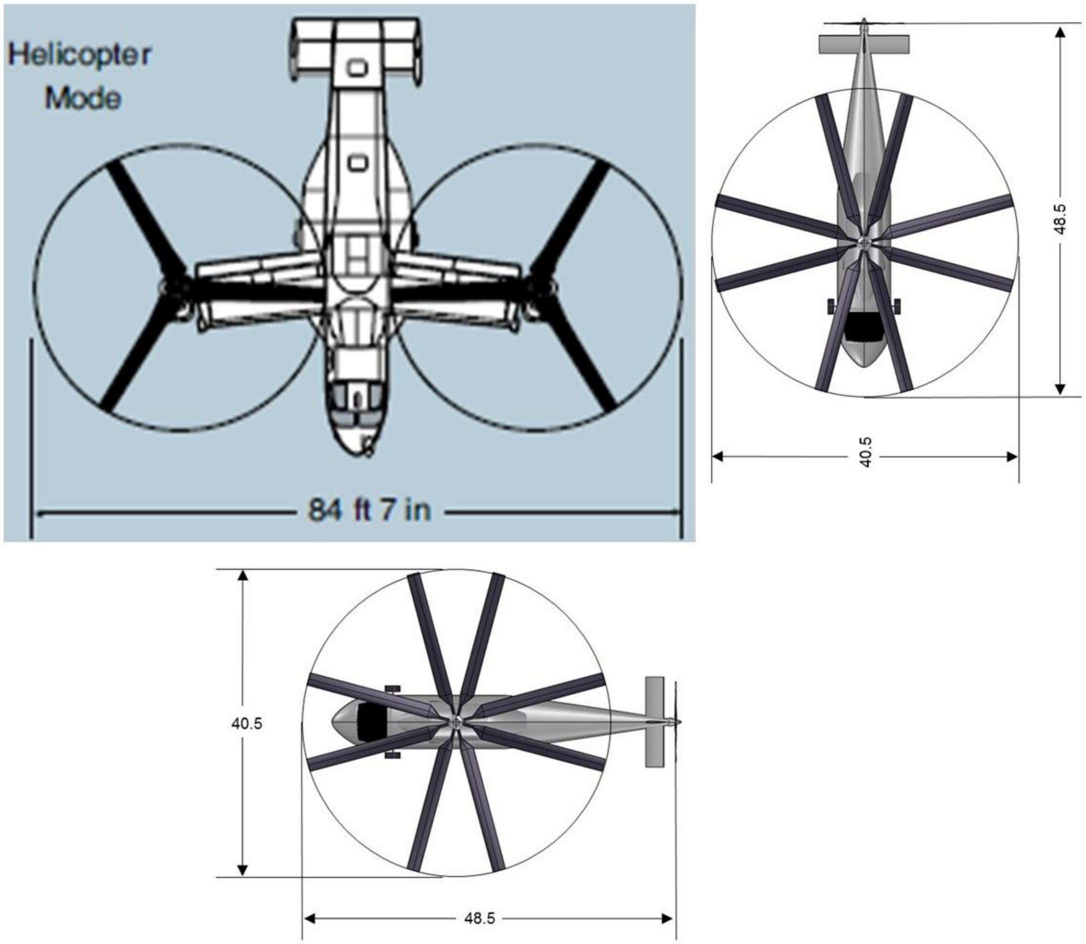


Figure F-2. Baseline Lift Offset operational footprint, V-22 comparison (Ref. A-7)

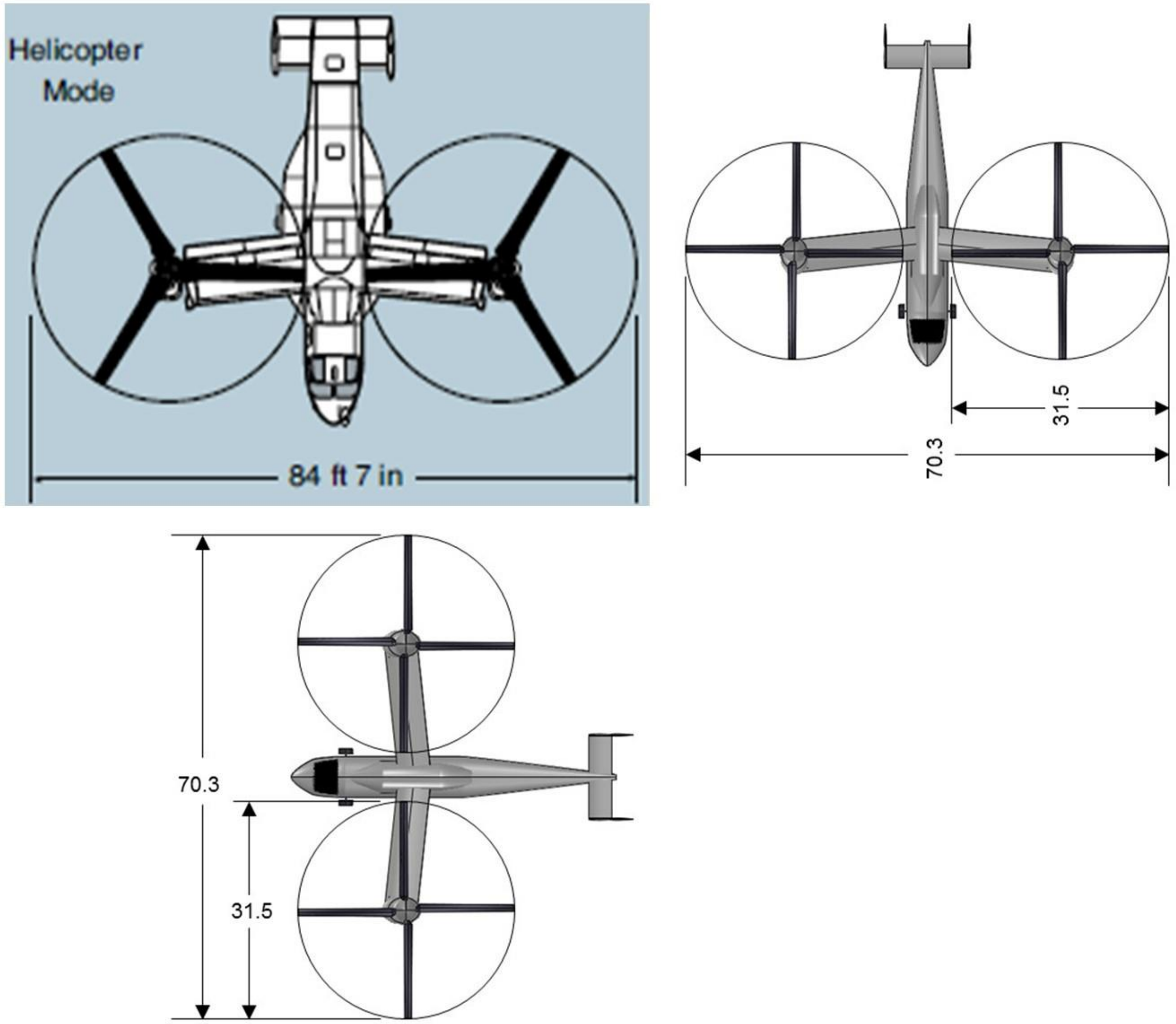


Figure F-3. Baseline Tiltrotor operational footprint, V-22 comparison (Ref. A-7)

APPENDIX G

TRADE STUDY AIRCRAFT WEIGHT RESULTS

Helicopter Weight, TBO = 6,000 flt. hrs.

	lb.	tech factor		lb.	tech factor
STRUCTURE	3330		SYSTEMS AND EQUIP	3650.2	
wing group	0		flight controls	891.3	
basic structure	0		cockpit controls	100	
secondary struct	0		auto flight cont	50	
fairings	0		system controls	741.3	
fittings	0		fixed wing sys	0	
fold/tilt	0		non-boosted	0	0.871
control surfaces	0		boost mech	0	0.871
rotor group	1077.5		rotary wing sys	741.3	
blade assembly	679.5	0.67	non-boosted	206.6	0.886
hub & hinge	398		boost mech	287.3	0.886
basic	398	0.643	boosted	247.4	0.803
shaft	0	1	conversion sys	0	
fairing/spinner	0	0.75	non-boosted	0	1
blade fold	0	0.75	boost mech	0	1
empennage group	330.6		auxiliary power	130	
horizontal tail	149.8		instruments group	150	
basic	149.8	0.75	hydraulic group	95.8	
fold	0	1	fixed wing	0	0.871
vertical tail	105.8		rotary wing	95.8	0.886
basic	105.8	1.852	conversion	0	1
fold	0	1	equipment	0	
tail rotor	75		pneumatic group	0	
blades	64.5		electrical group	304.9	
hub & hinge	10.5		aircraft	250	
fuselage group	1373.8		anti-icing	54.9	0.75
basic	1318.4	0.721	avionics (MEQ)	1000	
crashworthiness	55.4	0.7	armament group	100	
alighting gear	373.2		armament prov	0	
basic	331.6	0.555	armor	100	
retraction	14.7	0.555	furnish & equip	770	
crashworthiness	26.9	0.555	environ control	100	
engine sect/nac	144.1		anti-icing group	58.3	0.75
engine support	57.2	0.952	load & handling	50	
engine cowling	86.9	0.683	VIBRATION	50.8	
pylon support	0	0.75	CONTINGENCY	507.8	
air induction	30.8	0.952	FIXED USEFUL LOAD	1070	
PROPULSION GROUP	2616.5		crew	1000	
engine system	1109		fluids	70	
engine	740.8	0.705			
exhaust system	277.8	0.705	WEIGHT EMPTY	10155.3	
accessories	90.5	0.533	Fixed UL for DGW	1070	
fuel system	202.2		OPERATING WEIGHT	11225.3	
tanks and supp	153.2	0.623	Fuel for DGW	4999.7	
plumbing	49	0.623	Payload for DGW	3000	
drive system	1305.3		USEFUL LOAD for DGW	9069.7	
gear boxes	1098.9	0.689	DESIGN GROSS WEIGHT	19224.2	
trans drive	72.4	0.644			
rotor shaft	108.7	0.689	Growth Factor	3.204	
rotor brake	25.2	0.757	Empty Weight Fraction	0.528	

Helicopter Weight, TBO = 7,000 flt. hrs.

	lb.	tech factor		lb.	tech factor
STRUCTURE	3355.4		SYSTEMS AND EQUIP	3660.3	
wing group	0		flight controls	899.8	
basic structure	0		cockpit controls	100	
secondary struct	0		auto flight cont	50	
fairings	0		system controls	749.8	
fittings	0		fixed wing sys	0	
fold/tilt	0		non-boosted	0	0.878
control surfaces	0		boost mech	0	0.878
rotor group	1094.1		rotary wing sys	749.8	
blade assembly	688.6	0.675	non-boosted	208.7	0.894
hub & hinge	405.6		boost mech	290.5	0.894
basic	405.6	0.649	boosted	250.6	0.81
shaft	0	1	conversion sys	0	
fairing/spinner	0	0.75	non-boosted	0	1
blade fold	0	0.75	boost mech	0	1
empennage group	332.9		auxiliary power	130	
horizontal tail	150.6		instruments group	150	
basic	150.6	0.75	hydraulic group	96.8	
fold	0	1	fixed wing	0	0.878
vertical tail	106.2		rotary wing	96.8	0.894
basic	106.2	1.852	conversion	0	1
fold	0	1	equipment	0	
tail rotor	76		pneumatic group	0	
blades	65.4		electrical group	305.2	
hub & hinge	10.7		aircraft	250	
fuselage group	1378.5		anti-icing	55.2	0.75
basic	1322.9	0.721	avionics (MEQ)	1000	
crashworthiness	55.6	0.7	armament group	100	
alighting gear	374.2		armament prov	0	
basic	332.5	0.555	armor	100	
retraction	14.8	0.555	furnish & equip	770	
crashworthiness	27	0.555	environ control	100	
engine sect/nac	144.7		anti-icing group	58.5	0.75
engine support	57.5	0.952	load & handling	50	
engine cowling	87.2	0.683	VIBRATION	51.1	
pylon support	0	0.75	CONTINGENCY	510.8	
air induction	31	0.952	FIXED USEFUL LOAD	1070	
PROPULSION GROUP	2638.8		crew	1000	
engine system	1113.5		fluids	70	
engine	743.8	0.705			
exhaust system	278.9	0.705	WEIGHT EMPTY	10216.4	
accessories	90.7	0.533	Fixed UL for DGW	1070	
fuel system	202.8		OPERATING WEIGHT	11286.4	
tanks and supp	153.7	0.623	Fuel for DGW	5019.7	
plumbing	49.1	0.623	Payload for DGW	3000	
drive system	1322.5		USEFUL LOAD for DGW	9089.7	
gear boxes	1113.3	0.695	DESIGN GROSS WEIGHT	19305.3	
trans drive	73.3	0.649			
rotor shaft	110.1	0.695	Growth Factor	3.218	
rotor brake	25.8	0.764	Empty Weight Fraction	0.529	

Helicopter Weight, TBO = 8,000 flt. hrs.

	lb.	tech factor		lb.	tech factor
STRUCTURE	3377.8		SYSTEMS AND EQUIP	3669.2	
wing group	0		flight controls	907.4	
basic structure	0		cockpit controls	100	
secondary struct	0		auto flight cont	50	
fairings	0		system controls	757.4	
fittings	0		fixed wing sys	0	
fold/tilt	0		non-boosted	0	0.885
control surfaces	0		boost mech	0	0.885
rotor group	1108.9		rotary wing sys	757.4	
blade assembly	696.6	0.68	non-boosted	210.5	0.9
hub & hinge	412.3		boost mech	293.4	0.9
basic	412.3	0.653	boosted	253.5	0.816
shaft	0	1	conversion sys	0	
fairing/spinner	0	0.75	non-boosted	0	1
blade fold	0	0.75	boost mech	0	1
empennage group	334.8		auxiliary power	130	
horizontal tail	151.3		instruments group	150	
basic	151.3	0.75	hydraulic group	97.8	
fold	0	1	fixed wing	0	0.885
vertical tail	106.6		rotary wing	97.8	0.9
basic	106.6	1.852	conversion	0	1
fold	0	1	equipment	0	
tail rotor	77		pneumatic group	0	
blades	66.1		electrical group	305.4	
hub & hinge	10.8		aircraft	250	
fuselage group	1382.7		anti-icing	55.4	0.75
basic	1326.9	0.721	avionics (MEQ)	1000	
crashworthiness	55.7	0.7	armament group	100	
alighting gear	375.1		armament prov	0	
basic	333.3	0.555	armor	100	
retraction	14.8	0.555	furnish & equip	770	
crashworthiness	27	0.555	environ control	100	
engine sect/nac	145.2		anti-icing group	58.7	0.75
engine support	57.7	0.952	load & handling	50	
engine cowling	87.5	0.683	VIBRATION	51.4	
pylon support	0	0.75	CONTINGENCY	513.5	
air induction	31.1	0.952	FIXED USEFUL LOAD	1070	
PROPULSION GROUP	2658.5		crew	1000	
engine system	1117.4		fluids	70	
engine	746.5	0.705			
exhaust system	280	0.705	WEIGHT EMPTY	10270.3	
accessories	90.9	0.533	Fixed UL for DGW	1070	
fuel system	203.3		OPERATING WEIGHT	11340.3	
tanks and supp	154.1	0.623	Fuel for DGW	5037.4	
plumbing	49.2	0.623	Payload for DGW	3000	
drive system	1337.8		USEFUL LOAD for DGW	9107.4	
gear boxes	1126	0.7	DESIGN GROSS WEIGHT	19376.9	
trans drive	74.2	0.654			
rotor shaft	111.4	0.7	Growth Factor	3.229	
rotor brake	26.3	0.769	Empty Weight Fraction	0.530	

Helicopter Weight, TBO = 9,000 flt. hrs.

	lb.	tech factor		lb.	tech factor
STRUCTURE	3397.8		SYSTEMS AND EQUIP	3677.1	
wing group	0		flight controls	914.1	
basic structure	0		cockpit controls	100	
secondary struct	0		auto flight cont	50	
fairings	0		system controls	764.1	
fittings	0		fixed wing sys	0	
fold/tilt	0		non-boosted	0	0.89
control surfaces	0		boost mech	0	0.89
rotor group	1122.1		rotary wing sys	764.1	
blade assembly	703.7	0.684	non-boosted	212.1	0.906
hub & hinge	418.3		boost mech	295.9	0.906
basic	418.3	0.658	boosted	256.1	0.821
shaft	0	1	conversion sys	0	
fairing/spinner	0	0.75	non-boosted	0	1
blade fold	0	0.75	boost mech	0	1
empennage group	336.6		auxiliary power	130	
horizontal tail	151.8		instruments group	150	
basic	151.8	0.75	hydraulic group	98.6	
fold	0	1	fixed wing	0	0.89
vertical tail	106.9		rotary wing	98.6	0.906
basic	106.9	1.852	conversion	0	1
fold	0	1	equipment	0	
tail rotor	77.8		pneumatic group	0	
blades	66.8		electrical group	305.5	
hub & hinge	11		aircraft	250	
fuselage group	1386.4		anti-icing	55.5	0.75
basic	1330.5	0.721	avionics (MEQ)	1000	
crashworthiness	55.9	0.7	armament group	100	
alighting gear	376		armament prov	0	
basic	334	0.555	armor	100	
retraction	14.8	0.555	furnish & equip	770	
crashworthiness	27.1	0.555	environ control	100	
engine sect/nac	145.7		anti-icing group	58.9	0.75
engine support	58	0.952	load & handling	50	
engine cowling	87.7	0.683	VIBRATION	51.6	
pylon support	0	0.75	CONTINGENCY	515.9	
air induction	31.2	0.952	FIXED USEFUL LOAD	1070	
PROPULSION GROUP	2676.1		crew	1000	
engine system	1120.8		fluids	70	
engine	748.9	0.705			
exhaust system	280.9	0.705	WEIGHT EMPTY	10318.6	
accessories	91	0.533	Fixed UL for DGW	1070	
fuel system	203.8		OPERATING WEIGHT	11388.6	
tanks and supp	154.5	0.623	Fuel for DGW	5053.2	
plumbing	49.4	0.623	Payload for DGW	3000	
drive system	1351.4		USEFUL LOAD for DGW	9123.2	
gear boxes	1137.3	0.705	DESIGN GROSS WEIGHT	19440.9	
trans drive	74.9	0.658			
rotor shaft	112.5	0.705	Growth Factor	3.240	
rotor brake	26.7	0.774	Empty Weight Fraction	0.531	

Helicopter Weight, TBO = 10,000 flt. hrs.

	lb.	tech factor		lb.	tech factor
STRUCTURE	3416		SYSTEMS AND EQUIP	3684.3	
wing group	0		flight controls	920.1	
basic structure	0		cockpit controls	100	
secondary struct	0		auto flight cont	50	
fairings	0		system controls	770.1	
fittings	0		fixed wing sys	0	
fold/tilt	0		non-boosted	0	0.896
control surfaces	0		boost mech	0	0.896
rotor group	1134.1		rotary wing sys	770.1	
blade assembly	710.2	0.688	non-boosted	213.6	0.911
hub & hinge	423.8		boost mech	298.2	0.911
basic	423.8	0.661	boosted	258.4	0.825
shaft	0	1	conversion sys	0	
fairing/spinner	0	0.75	non-boosted	0	1
blade fold	0	0.75	boost mech	0	1
empennage group	338.2		auxiliary power	130	
horizontal tail	152.4		instruments group	150	
basic	152.4	0.75	hydraulic group	99.4	
fold	0	1	fixed wing	0	0.896
vertical tail	107.2		rotary wing	99.4	0.911
basic	107.2	1.852	conversion	0	1
fold	0	1	equipment	0	
tail rotor	78.5		pneumatic group	0	
blades	67.4		electrical group	305.7	
hub & hinge	11.1		aircraft	250	
fuselage group	1389.7		anti-icing	55.7	0.75
basic	1333.7	0.721	avionics (MEQ)	1000	
crashworthiness	56	0.7	armament group	100	
alighting gear	376.7		armament prov	0	
basic	334.7	0.555	armor	100	
retraction	14.9	0.555	furnish & equip	770	
crashworthiness	27.2	0.555	environ control	100	
engine sect/nac	146.1		anti-icing group	59.1	0.75
engine support	58.2	0.952	load & handling	50	
engine cowling	87.9	0.683	VIBRATION	51.8	
pylon support	0	0.75	CONTINGENCY	518.1	
air induction	31.3	0.952	FIXED USEFUL LOAD	1070	
PROPULSION GROUP	2692.1		crew	1000	
engine system	1124		fluids	70	
engine	751.1	0.705			
exhaust system	281.7	0.705	WEIGHT EMPTY	10362.3	
accessories	91.2	0.533	Fixed UL for DGW	1070	
fuel system	204.3		OPERATING WEIGHT	11432.3	
tanks and supp	154.8	0.623	Fuel for DGW	5067.5	
plumbing	49.5	0.623	Payload for DGW	3000	
drive system	1363.8		USEFUL LOAD for DGW	9137.5	
gear boxes	1147.6	0.709	DESIGN GROSS WEIGHT	19498.9	
trans drive	75.6	0.662			
rotor shaft	113.5	0.709	Growth Factor	3.250	
rotor brake	27.1	0.779	Empty Weight Fraction	0.531	

Helicopter Weight, TBO = 11,000 flt. hrs.

	lb.	tech factor		lb.	tech factor
STRUCTURE	3445.4		SYSTEMS AND EQUIP	3691.9	
wing group	0		flight controls	926.5	
basic structure	0		cockpit controls	100	
secondary struct	0		auto flight cont	50	
fairings	0		system controls	776.5	
fittings	0		fixed wing sys	0	
fold/tilt	0		non-boosted	0	0.9
control surfaces	0		boost mech	0	0.9
rotor group	1147		rotary wing sys	776.5	
blade assembly	717.3	0.692	non-boosted	215	0.916
hub & hinge	429.7		boost mech	300.5	0.916
basic	429.7	0.665	boosted	260.9	0.83
shaft	0	1	conversion sys	0	
fairing/spinner	0	0.75	non-boosted	0	1
blade fold	0	0.75	boost mech	0	1
empennage group	341.5		auxiliary power	130	
horizontal tail	153.9		instruments group	150	
basic	153.9	0.754	hydraulic group	100.2	
fold	0	1	fixed wing	0	0.9
vertical tail	108.2		rotary wing	100.2	0.916
basic	108.2	1.862	conversion	0	1
fold	0	1	equipment	0	
tail rotor	79.4		pneumatic group	0	
blades	68.1		electrical group	305.9	
hub & hinge	11.3		aircraft	250	
fuselage group	1398		anti-icing	55.9	0.75
basic	1341.5	0.723	avionics (MEQ)	1000	
crashworthiness	56.5	0.702	armament group	100	
alighting gear	379.9		armament prov	0	
basic	337.3	0.558	armor	100	
retraction	15.1	0.558	furnish & equip	770	
crashworthiness	27.5	0.558	environ control	100	
engine sect/nac	147.5		anti-icing group	59.3	0.75
engine support	58.7	0.957	load & handling	50	
engine cowling	88.8	0.686	VIBRATION	52.1	
pylon support	0	0.754	CONTINGENCY	521.1	
air induction	31.6	0.957	FIXED USEFUL LOAD	1070	
PROPULSION GROUP	2711.6		crew	1000	
engine system	1129.7		fluids	70	
engine	754.1	0.705			
exhaust system	284.2	0.709	WEIGHT EMPTY	10422.1	
accessories	91.4	0.533	Fixed UL for DGW	1070	
fuel system	204.9		OPERATING WEIGHT	11492.1	
tanks and supp	155.3	0.623	Fuel for DGW	5086.6	
plumbing	49.6	0.623	Payload for DGW	3000	
drive system	1377		USEFUL LOAD for DGW	9156.6	
gear boxes	1158.6	0.712	DESIGN GROSS WEIGHT	19577.9	
trans drive	76.3	0.665			
rotor shaft	114.6	0.712	Growth Factor	3.263	
rotor brake	27.5	0.783	Empty Weight Fraction	0.532	

Helicopter Weight, TBO = 12,000 flt. hrs.

	lb.	tech factor		lb.	tech factor
STRUCTURE	3476.5		SYSTEMS AND EQUIP	3699.9	
wing group	0		flight controls	933.1	
basic structure	0		cockpit controls	100	
secondary struct	0		auto flight cont	50	
fairings	0		system controls	783.1	
fittings	0		fixed wing sys	0	
fold/tilt	0		non-boosted	0	0.9
control surfaces	0		boost mech	0	0.9
rotor group	1160.6		rotary wing sys	783.1	
blade assembly	724.7	0.692	non-boosted	216.6	0.916
hub & hinge	435.9		boost mech	303	0.916
basic	435.9	0.665	boosted	263.6	0.83
shaft	0	1	conversion sys	0	
fairing/spinner	0	0.75	non-boosted	0	1
blade fold	0	0.75	boost mech	0	1
empennage group	345		auxiliary power	130	
horizontal tail	155.5		instruments group	150	
basic	155.5	0.754	hydraulic group	101	
fold	0	1	fixed wing	0	0.9
vertical tail	109.2		rotary wing	101	0.916
basic	109.2	1.862	conversion	0	1
fold	0	1	equipment	0	
tail rotor	80.2		pneumatic group	0	
blades	68.8		electrical group	306.2	
hub & hinge	11.4		aircraft	250	
fuselage group	1406.8		anti-icing	56.2	0.75
basic	1349.8	0.723	avionics (MEQ)	1000	
crashworthiness	57	0.702	armament group	100	
alighting gear	383.2		armament prov	0	
basic	340.1	0.558	armor	100	
retraction	15.3	0.558	furnish & equip	770	
crashworthiness	27.9	0.558	environ control	100	
engine sect/nac	149		anti-icing group	59.6	0.75
engine support	59.3	0.957	load & handling	50	
engine cowling	89.7	0.686	VIBRATION	52.4	
pylon support	0	0.754	CONTINGENCY	524.3	
air induction	31.9	0.957	FIXED USEFUL LOAD	1070	
PROPULSION GROUP	2732.3		crew	1000	
engine system	1135.7		fluids	70	
engine	757.1	0.705			
exhaust system	286.9	0.709	WEIGHT EMPTY	10485.3	
accessories	91.6	0.533	Fixed UL for DGW	1070	
fuel system	205.5		OPERATING WEIGHT	11555.3	
tanks and supp	155.7	0.623	Fuel for DGW	5106.8	
plumbing	49.7	0.623	Payload for DGW	3000	
drive system	1391.1		USEFUL LOAD for DGW	9176.8	
gear boxes	1170.3	0.712	DESIGN GROSS WEIGHT	19661.3	
trans drive	77.1	0.665			
rotor shaft	115.7	0.712	Growth Factor	3.277	
rotor brake	27.9	0.783	Empty Weight Fraction	0.533	

Helicopter Weight, TBO = 13,000 flt. hrs.

	lb.	tech factor		lb.	tech factor
STRUCTURE	3497.9		SYSTEMS AND EQUIP	3705.3	
wing group	0		flight controls	937.7	
basic structure	0		cockpit controls	100	
secondary struct	0		auto flight cont	50	
fairings	0		system controls	787.7	
fittings	0		fixed wing sys	0	
fold/tilt	0		non-boosted	0	0.908
control surfaces	0		boost mech	0	0.908
rotor group	1170.1		rotary wing sys	787.7	
blade assembly	729.9	0.698	non-boosted	217.6	0.924
hub & hinge	440.2		boost mech	304.7	0.924
basic	440.2	0.671	boosted	265.4	0.837
shaft	0	1	conversion sys	0	
fairing/spinner	0	0.75	non-boosted	0	1
blade fold	0	0.75	boost mech	0	1
empennage group	347.4		auxiliary power	130	
horizontal tail	156.6		instruments group	150	
basic	156.6	0.761	hydraulic group	101.6	
fold	0	1	fixed wing	0	0.908
vertical tail	109.9		rotary wing	101.6	0.924
basic	109.9	1.879	conversion	0	1
fold	0	1	equipment	0	
tail rotor	80.8		pneumatic group	0	
blades	69.2		electrical group	306.3	
hub & hinge	11.6		aircraft	250	
fuselage group	1412.8		anti-icing	56.3	0.75
basic	1355.4	0.726	avionics (MEQ)	1000	
crashworthiness	57.3	0.705	armament group	100	
alighting gear	385.6		armament prov	0	
basic	342	0.563	armor	100	
retraction	15.4	0.563	furnish & equip	770	
crashworthiness	28.2	0.563	environ control	100	
engine sect/nac	150		anti-icing group	59.7	0.75
engine support	59.7	0.966	load & handling	50	
engine cowling	90.3	0.692	VIBRATION	52.6	
pylon support	0	0.761	CONTINGENCY	526.4	
air induction	32.2	0.966	FIXED USEFUL LOAD	1070	
PROPULSION GROUP	2746.5		crew	1000	
engine system	1139.8		fluids	70	
engine	759.3	0.705			
exhaust system	288.8	0.715	WEIGHT EMPTY	10528.8	
accessories	91.8	0.533	Fixed UL for DGW	1070	
fuel system	205.9		OPERATING WEIGHT	11598.8	
tanks and supp	156.1	0.623	Fuel for DGW	5120.8	
plumbing	49.9	0.623	Payload for DGW	3000	
drive system	1400.7		USEFUL LOAD for DGW	9190.8	
gear boxes	1178.3	0.719	DESIGN GROSS WEIGHT	19718.6	
trans drive	77.6	0.671			
rotor shaft	116.5	0.719	Growth Factor	3.286	
rotor brake	28.2	0.79	Empty Weight Fraction	0.534	

Helicopter Weight, TBO = 14,000 flt. hrs.

	lb.	tech factor		lb.	tech factor
STRUCTURE	3521.6		SYSTEMS AND EQUIP	3711.4	
wing group	0		flight controls	942.7	
basic structure	0		cockpit controls	100	
secondary struct	0		auto flight cont	50	
fairings	0		system controls	792.7	
fittings	0		fixed wing sys	0	
fold/tilt	0		non-boosted	0	0.912
control surfaces	0		boost mech	0	0.912
rotor group	1180.5		rotary wing sys	792.7	
blade assembly	735.5	0.701	non-boosted	218.8	0.928
hub & hinge	445		boost mech	306.6	0.928
basic	445	0.674	boosted	267.4	0.841
shaft	0	1	conversion sys	0	
fairing/spinner	0	0.75	non-boosted	0	1
blade fold	0	0.75	boost mech	0	1
empennage group	350		auxiliary power	130	
horizontal tail	157.9		instruments group	150	
basic	157.9	0.764	hydraulic group	102.2	
fold	0	1	fixed wing	0	0.912
vertical tail	110.7		rotary wing	102.2	0.928
basic	110.7	1.887	conversion	0	1
fold	0	1	equipment	0	
tail rotor	81.5		pneumatic group	0	
blades	69.8		electrical group	306.5	
hub & hinge	11.7		aircraft	250	
fuselage group	1419.4		anti-icing	56.5	0.75
basic	1361.7	0.728	avionics (MEQ)	1000	
crashworthiness	57.7	0.706	armament group	100	
alighting gear	388.1		armament prov	0	
basic	344.1	0.565	armor	100	
retraction	15.6	0.565	furnish & equip	770	
crashworthiness	28.5	0.565	environ control	100	
engine sect/nac	151.2		anti-icing group	59.9	0.75
engine support	60.2	0.97	load & handling	50	
engine cowling	91	0.695	VIBRATION	52.9	
pylon support	0	0.764	CONTINGENCY	528.8	
air induction	32.4	0.97	FIXED USEFUL LOAD	1070	
PROPULSION GROUP	2762.2		crew	1000	
engine system	1144.4		fluids	70	
engine	761.6	0.705			
exhaust system	290.9	0.718	WEIGHT EMPTY	10577	
accessories	92	0.533	Fixed UL for DGW	1070	
fuel system	206.4		OPERATING WEIGHT	11647	
tanks and supp	156.4	0.623	Fuel for DGW	5136.2	
plumbing	50	0.623	Payload for DGW	3000	
drive system	1411.4		USEFUL LOAD for DGW	9206.2	
gear boxes	1187.2	0.722	DESIGN GROSS WEIGHT	19782.2	
trans drive	78.2	0.674			
rotor shaft	117.4	0.722	Growth Factor	3.297	
rotor brake	28.6	0.793	Empty Weight Fraction	0.535	

Helicopter Weight, TBO = 15,000 flt. hrs.

	lb.	tech factor		lb.	tech factor
STRUCTURE	3543.9		SYSTEMS AND EQUIP	3717.1	
wing group	0		flight controls	947.5	
basic structure	0		cockpit controls	100	
secondary struct	0		auto flight cont	50	
fairings	0		system controls	797.5	
fittings	0		fixed wing sys	0	
fold/tilt	0		non-boosted	0	0.915
control surfaces	0		boost mech	0	0.915
rotor group	1190.4		rotary wing sys	797.5	
blade assembly	740.9	0.704	non-boosted	219.8	0.931
hub & hinge	449.5		boost mech	308.3	0.931
basic	449.5	0.676	boosted	269.3	0.844
shaft	0	1	conversion sys	0	
fairing/spinner	0	0.75	non-boosted	0	1
blade fold	0	0.75	boost mech	0	1
empennage group	352.5		auxiliary power	130	
horizontal tail	159		instruments group	150	
basic	159	0.767	hydraulic group	102.8	
fold	0	1	fixed wing	0	0.915
vertical tail	111.4		rotary wing	102.8	0.931
basic	111.4	1.894	conversion	0	1
fold	0	1	equipment	0	
tail rotor	82.1		pneumatic group	0	
blades	70.3		electrical group	306.7	
hub & hinge	11.8		aircraft	250	
fuselage group	1425.6		anti-icing	56.7	0.75
basic	1367.6	0.729	avionics (MEQ)	1000	
crashworthiness	58.1	0.708	armament group	100	
alighting gear	390.5		armament prov	0	
basic	346.1	0.567	armor	100	
retraction	15.7	0.567	furnish & equip	770	
crashworthiness	28.7	0.567	environ control	100	
engine sect/nac	152.2		anti-icing group	60.1	0.75
engine support	60.6	0.974	load & handling	50	
engine cowling	91.6	0.698	VIBRATION	53.1	
pylon support	0	0.767	CONTINGENCY	531.1	
air induction	32.6	0.974	FIXED USEFUL LOAD	1070	
PROPULSION GROUP	2777		crew	1000	
engine system	1148.7		fluids	70	
engine	763.8	0.705			
exhaust system	292.8	0.721	WEIGHT EMPTY	10622.3	
accessories	92.1	0.533	Fixed UL for DGW	1070	
fuel system	206.8		OPERATING WEIGHT	11692.3	
tanks and supp	156.8	0.623	Fuel for DGW	5150.6	
plumbing	50.1	0.623	Payload for DGW	3000	
drive system	1421.5		USEFUL LOAD for DGW	9220.6	
gear boxes	1195.6	0.724	DESIGN GROSS WEIGHT	19841.9	
trans drive	78.7	0.677			
rotor shaft	118.2	0.724	Growth Factor	3.307	
rotor brake	28.9	0.796	Empty Weight Fraction	0.535	

Helicopter Weight, TBO = 16,000 flt. hrs.

	lb.	tech factor		lb.	tech factor
STRUCTURE	3565		SYSTEMS AND EQUIP	3722.4	
wing group	0		flight controls	952	
basic structure	0		cockpit controls	100	
secondary struct	0		auto flight cont	50	
fairings	0		system controls	802	
fittings	0		fixed wing sys	0	
fold/tilt	0		non-boosted	0	0.919
control surfaces	0		boost mech	0	0.919
rotor group	1199.7		rotary wing sys	802	
blade assembly	746	0.706	non-boosted	220.9	0.935
hub & hinge	453.7		boost mech	310	0.935
basic	453.7	0.678	boosted	271.1	0.847
shaft	0	1	conversion sys	0	
fairing/spinner	0	0.75	non-boosted	0	1
blade fold	0	0.75	boost mech	0	1
empennage group	354.9		auxiliary power	130	
horizontal tail	160.1		instruments group	150	
basic	160.1	0.769	hydraulic group	103.3	
fold	0	1	fixed wing	0	0.919
vertical tail	112.1		rotary wing	103.3	0.935
basic	112.1	1.9	conversion	0	1
fold	0	1	equipment	0	
tail rotor	82.6		pneumatic group	0	
blades	70.7		electrical group	306.8	
hub & hinge	11.9		aircraft	250	
fuselage group	1431.5		anti-icing	56.8	0.75
basic	1373.1	0.73	avionics (MEQ)	1000	
crashworthiness	58.4	0.709	armament group	100	
alighting gear	392.8		armament prov	0	
basic	347.9	0.569	armor	100	
retraction	15.8	0.569	furnish & equip	770	
crashworthiness	29	0.569	environ control	100	
engine sect/nac	153.3		anti-icing group	60.3	0.75
engine support	61	0.977	load & handling	50	
engine cowling	92.3	0.7	VIBRATION	53.3	
pylon support	0	0.769	CONTINGENCY	533.3	
air induction	32.8	0.977	FIXED USEFUL LOAD	1070	
PROPULSION GROUP	2791		crew	1000	
engine system	1152.8		fluids	70	
engine	765.9	0.705			
exhaust system	294.6	0.723	WEIGHT EMPTY	10665	
accessories	92.3	0.533	Fixed UL for DGW	1070	
fuel system	207.3		OPERATING WEIGHT	11735	
tanks and supp	157.1	0.623	Fuel for DGW	5164.3	
plumbing	50.2	0.623	Payload for DGW	3000	
drive system	1431		USEFUL LOAD for DGW	9234.3	
gear boxes	1203.5	0.727	DESIGN GROSS WEIGHT	19898.3	
trans drive	79.2	0.679			
rotor shaft	119	0.727	Growth Factor	3.316	
rotor brake	29.2	0.799	Empty Weight Fraction	0.536	

Helicopter Weight, TBO = 17,000 flt. hrs.

	lb.	tech factor		lb.	tech factor
STRUCTURE	3585		SYSTEMS AND EQUIP	3727.5	
wing group	0		flight controls	956.2	
basic structure	0		cockpit controls	100	
secondary struct	0		auto flight cont	50	
fairings	0		system controls	806.2	
fittings	0		fixed wing sys	0	
fold/tilt	0		non-boosted	0	0.922
control surfaces	0		boost mech	0	0.922
rotor group	1208.5		rotary wing sys	806.2	
blade assembly	750.8	0.708	non-boosted	221.8	0.938
hub & hinge	457.8		boost mech	311.6	0.938
basic	457.8	0.681	boosted	272.8	0.849
shaft	0	1	conversion sys	0	
fairing/spinner	0	0.75	non-boosted	0	1
blade fold	0	0.75	boost mech	0	1
empennage group	357.1		auxiliary power	130	
horizontal tail	161.2		instruments group	150	
basic	161.2	0.772	hydraulic group	103.9	
fold	0	1	fixed wing	0	0.922
vertical tail	112.8		rotary wing	103.9	0.938
basic	112.8	1.907	conversion	0	1
fold	0	1	equipment	0	
tail rotor	83.2		pneumatic group	0	
blades	71.2		electrical group	307	
hub & hinge	12		aircraft	250	
fuselage group	1437.1		anti-icing	57	0.75
basic	1378.4	0.731	avionics (MEQ)	1000	
crashworthiness	58.7	0.71	armament group	100	
alighting gear	394.9		armament prov	0	
basic	349.7	0.571	armor	100	
retraction	16	0.571	furnish & equip	770	
crashworthiness	29.2	0.571	environ control	100	
engine sect/nac	154.2		anti-icing group	60.4	0.75
engine support	61.4	0.98	load & handling	50	
engine cowling	92.8	0.702	VIBRATION	53.5	
pylon support	0	0.772	CONTINGENCY	535.3	
air induction	33.1	0.98	FIXED USEFUL LOAD	1070	
PROPULSION GROUP	2804.3		crew	1000	
engine system	1156.6		fluids	70	
engine	767.9	0.705			
exhaust system	296.4	0.726	WEIGHT EMPTY	10705.6	
accessories	92.4	0.533	Fixed UL for DGW	1070	
fuel system	207.7		OPERATING WEIGHT	11775.6	
tanks and supp	157.4	0.623	Fuel for DGW	5177.3	
plumbing	50.3	0.623	Payload for DGW	3000	
drive system	1440		USEFUL LOAD for DGW	9247.3	
gear boxes	1211	0.729	DESIGN GROSS WEIGHT	19951.9	
trans drive	79.7	0.681			
rotor shaft	119.8	0.729	Growth Factor	3.325	
rotor brake	29.5	0.801	Empty Weight Fraction	0.537	

Helicopter Weight, TBO = 18,000 flt. hrs.

	lb.	tech factor		lb.	tech factor
STRUCTURE	3603.9		SYSTEMS AND EQUIP	3732.4	
wing group	0		flight controls	960.3	
basic structure	0		cockpit controls	100	
secondary struct	0		auto flight cont	50	
fairings	0		system controls	810.3	
fittings	0		fixed wing sys	0	
fold/tilt	0		non-boosted	0	0.924
control surfaces	0		boost mech	0	0.924
rotor group	1217		rotary wing sys	810.3	
blade assembly	755.3	0.711	non-boosted	222.7	0.941
hub & hinge	461.6		boost mech	313.1	0.941
basic	461.6	0.683	boosted	274.4	0.852
shaft	0	1	conversion sys	0	
fairing/spinner	0	0.75	non-boosted	0	1
blade fold	0	0.75	boost mech	0	1
empennage group	359.3		auxiliary power	130	
horizontal tail	162.2		instruments group	150	
basic	162.2	0.774	hydraulic group	104.4	
fold	0	1	fixed wing	0	0.924
vertical tail	113.4		rotary wing	104.4	0.941
basic	113.4	1.912	conversion	0	1
fold	0	1	equipment	0	
tail rotor	83.7		pneumatic group	0	
blades	71.6		electrical group	307.1	
hub & hinge	12.1		aircraft	250	
fuselage group	1442.4		anti-icing	57.1	0.75
basic	1383.3	0.733	avionics (MEQ)	1000	
crashworthiness	59	0.711	armament group	100	
alighting gear	396.9		armament prov	0	
basic	351.4	0.573	armor	100	
retraction	16.1	0.573	furnish & equip	770	
crashworthiness	29.5	0.573	environ control	100	
engine sect/nac	155.1		anti-icing group	60.6	0.75
engine support	61.7	0.983	load & handling	50	
engine cowling	93.4	0.705	VIBRATION	53.7	
pylon support	0	0.774	CONTINGENCY	537.2	
air induction	33.2	0.983	FIXED USEFUL LOAD	1070	
PROPULSION GROUP	2816.9		crew	1000	
engine system	1160.3		fluids	70	
engine	769.8	0.705			
exhaust system	298	0.728	WEIGHT EMPTY	10744.1	
accessories	92.5	0.533	Fixed UL for DGW	1070	
fuel system	208		OPERATING WEIGHT	11814.1	
tanks and supp	157.7	0.623	Fuel for DGW	5189.6	
plumbing	50.4	0.623	Payload for DGW	3000	
drive system	1448.6		USEFUL LOAD for DGW	9259.6	
gear boxes	1218.1	0.732	DESIGN GROSS WEIGHT	20002.7	
trans drive	80.2	0.683			
rotor shaft	120.5	0.732	Growth Factor	3.334	
rotor brake	29.7	0.804	Empty Weight Fraction	0.537	

Helicopter Weight, TBO = 19,000 flt. hrs.

	lb.	tech factor		lb.	tech factor
STRUCTURE	3624.7		SYSTEMS AND EQUIP	3737.6	
wing group	0		flight controls	964.7	
basic structure	0		cockpit controls	100	
secondary struct	0		auto flight cont	50	
fairings	0		system controls	814.7	
fittings	0		fixed wing sys	0	
fold/tilt	0		non-boosted	0	0.928
control surfaces	0		boost mech	0	0.928
rotor group	1226.2		rotary wing sys	814.7	
blade assembly	760.3	0.713	non-boosted	223.7	0.944
hub & hinge	465.8		boost mech	314.7	0.944
basic	465.8	0.685	boosted	276.2	0.855
shaft	0	1	conversion sys	0	
fairing/spinner	0	0.75	non-boosted	0	1
blade fold	0	0.75	boost mech	0	1
empennage group	361.6		auxiliary power	130	
horizontal tail	163.2		instruments group	150	
basic	163.2	0.777	hydraulic group	104.9	
fold	0	1	fixed wing	0	0.928
vertical tail	114.1		rotary wing	104.9	0.944
basic	114.1	1.919	conversion	0	1
fold	0	1	equipment	0	
tail rotor	84.3		pneumatic group	0	
blades	72.1		electrical group	307.3	
hub & hinge	12.2		aircraft	250	
fuselage group	1448.1		anti-icing	57.3	0.75
basic	1388.8	0.734	avionics (MEQ)	1000	
crashworthiness	59.4	0.712	armament group	100	
alighting gear	399.2		armament prov	0	
basic	353.2	0.575	armor	100	
retraction	16.2	0.575	furnish & equip	770	
crashworthiness	29.7	0.575	environ control	100	
engine sect/nac	156.1		anti-icing group	60.8	0.75
engine support	62.1	0.987	load & handling	50	
engine cowling	94	0.707	VIBRATION	53.9	
pylon support	0	0.777	CONTINGENCY	539.3	
air induction	33.5	0.987	FIXED USEFUL LOAD	1070	
PROPULSION GROUP	2830.7		crew	1000	
engine system	1164.3		fluids	70	
engine	771.8	0.705			
exhaust system	299.8	0.73	WEIGHT EMPTY	10786.3	
accessories	92.7	0.533	Fixed UL for DGW	1070	
fuel system	208.4		OPERATING WEIGHT	11856.3	
tanks and supp	158	0.623	Fuel for DGW	5203.1	
plumbing	50.5	0.623	Payload for DGW	3000	
drive system	1457.9		USEFUL LOAD for DGW	9273.1	
gear boxes	1225.9	0.734	DESIGN GROSS WEIGHT	20058.3	
trans drive	80.7	0.686			
rotor shaft	121.2	0.734	Growth Factor	3.343	
rotor brake	30	0.807	Empty Weight Fraction	0.538	

Helicopter Weight, TBO = 20,000 flt. hrs.

	lb.	tech factor		lb.	tech factor
STRUCTURE	3639.4		SYSTEMS AND EQUIP	3741.3	
wing group	0		flight controls	967.8	
basic structure	0		cockpit controls	100	
secondary struct	0		auto flight cont	50	
fairings	0		system controls	817.8	
fittings	0		fixed wing sys	0	
fold/tilt	0		non-boosted	0	0.93
control surfaces	0		boost mech	0	0.93
rotor group	1232.7		rotary wing sys	817.8	
blade assembly	763.9	0.715	non-boosted	224.4	0.946
hub & hinge	468.8		boost mech	315.9	0.946
basic	468.8	0.687	boosted	277.5	0.857
shaft	0	1	conversion sys	0	
fairing/spinner	0	0.75	non-boosted	0	1
blade fold	0	0.75	boost mech	0	1
empennage group	363.3		auxiliary power	130	
horizontal tail	164		instruments group	150	
basic	164	0.779	hydraulic group	105.3	
fold	0	1	fixed wing	0	0.93
vertical tail	114.6		rotary wing	105.3	0.946
basic	114.6	1.923	conversion	0	1
fold	0	1	equipment	0	
tail rotor	84.7		pneumatic group	0	
blades	72.4		electrical group	307.4	
hub & hinge	12.3		aircraft	250	
fuselage group	1452.2		anti-icing	57.4	0.75
basic	1392.6	0.735	avionics (MEQ)	1000	
crashworthiness	59.6	0.713	armament group	100	
alighting gear	400.7		armament prov	0	
basic	354.5	0.576	armor	100	
retraction	16.3	0.576	furnish & equip	770	
crashworthiness	29.9	0.576	environ control	100	
engine sect/nac	156.8		anti-icing group	60.9	0.75
engine support	62.4	0.989	load & handling	50	
engine cowling	94.4	0.709	VIBRATION	54.1	
pylon support	0	0.779	CONTINGENCY	540.8	
air induction	33.6	0.989	FIXED USEFUL LOAD	1070	
PROPULSION GROUP	2840.4		crew	1000	
engine system	1167.1		fluids	70	
engine	773.3	0.705			
exhaust system	301.1	0.732	WEIGHT EMPTY	10816	
accessories	92.8	0.533	Fixed UL for DGW	1070	
fuel system	208.7		OPERATING WEIGHT	11886	
tanks and supp	158.2	0.623	Fuel for DGW	5212.5	
plumbing	50.5	0.623	Payload for DGW	3000	
drive system	1464.6		USEFUL LOAD for DGW	9282.5	
gear boxes	1231.4	0.736	DESIGN GROSS WEIGHT	20097.5	
trans drive	81.1	0.687			
rotor shaft	121.8	0.736	Growth Factor	3.350	
rotor brake	30.3	0.809	Empty Weight Fraction	0.538	

Lift Offset Weight, TBO = 6,000 flt. hrs.

	lb.	tech factor		lb.	tech factor
STRUCTURE	6529.6		SYSTEMS AND EQUIP	4756.8	
wing group	0		flight controls	1963.2	
basic structure	0		cockpit controls	100	
secondary struct	0		auto flight cont	50	
fairings	0		system controls	1813.2	
fittings	0		fixed wing sys	21.5	
fold/tilt	0		non-boosted	2.1	0.432
control surfaces	0		boost mech	19.3	0.432
rotor group	3629.2		rotary wing sys	1791.8	
blade assembly	1498.1	0.555	non-boosted	531.6	0.818
hub & hinge	2131.1		boost mech	363.1	0.856
basic	1912.9	0.555	boosted	897.1	1.735
shaft	218.2	0.555	conversion sys	0	
fairing/spinner	0	0.65	non-boosted	0	1
blade fold	0	0.65	boost mech	0	1
empennage group	70		auxiliary power	130	
horizontal tail	50.4		instruments group	150	
basic	50.4	0.795	hydraulic group	121.9	
fold	0	1	fixed wing	0.8	0.432
vertical tail	19.6		rotary wing	121	0.856
basic	19.6	0.795	conversion	0	1
fold	0	1	equipment	0	
tail rotor	0		pneumatic group	0	
blades	0		electrical group	309.2	
hub & hinge	0		aircraft	250	
fuselage group	2036.4		anti-icing	59.2	0.75
basic	1943.7	0.795	avionics (MEQ)	1000	
crashworthiness	92.7	0.795	armament group	100	
alighting gear	571.3		armament prov	0	
basic	489.2	0.735	armor	100	
retraction	28.8	0.735	furnish & equip	770	
crashworthiness	53.3	0.735	environ control	100	
engine sect/nac	180.7		anti-icing group	62.5	0.75
engine support	78.1	1.283	load & handling	50	
engine cowling	102.6	0.743	VIBRATION	77.5	
pylon support	0	0.743	CONTINGENCY	775.2	
air induction	42.1	1.283	FIXED USEFUL LOAD	1070	
PROPULSION GROUP	3365.8		crew	1000	
engine system	1215.1		fluids	70	
engine	749.4	0.75			
exhaust system	281	0.75	WEIGHT EMPTY	15504.9	
accessories	184.7	1.08	Fixed UL for DGW	1070	
fuel system	202.6		OPERATING WEIGHT	16574.9	
tanks and supp	145.4	0.728	Fuel for DGW	3819.6	
plumbing	57.1	0.728	Payload for DGW	3000	
drive system	1765.5		USEFUL LOAD for DGW	7889.6	
gear boxes	1474.4	0.803	DESIGN GROSS WEIGHT	23393	
trans drive	86.4	0.803			
rotor shaft	145.8	0.803	Growth Factor	3.899	
rotor brake	58.9	0.803	Empty Weight Fraction	0.663	

Lift Offset Weight, TBO = 7,000 flt. hrs.

	lb.	tech factor		lb.	tech factor
STRUCTURE	6621.3		SYSTEMS AND EQUIP	4786.2	
wing group	0		flight controls	1990	
basic structure	0		cockpit controls	100	
secondary struct	0		auto flight cont	50	
fairings	0		system controls	1840	
fittings	0		fixed wing sys	21.8	
fold/tilt	0		non-boosted	2.2	0.435
control surfaces	0		boost mech	19.6	0.435
rotor group	3704.8		rotary wing sys	1818.2	
blade assembly	1529.2	0.56	non-boosted	537.4	0.825
hub & hinge	2175.6		boost mech	368.1	0.863
basic	1953.7	0.56	boosted	912.8	1.749
shaft	221.8	0.56	conversion sys	0	
fairing/spinner	0	0.65	non-boosted	0	1
blade fold	0	0.65	boost mech	0	1
empennage group	70.6		auxiliary power	130	
horizontal tail	50.8		instruments group	150	
basic	50.8	0.795	hydraulic group	123.5	
fold	0	1	fixed wing	0.9	0.435
vertical tail	19.8		rotary wing	122.7	0.863
basic	19.8	0.795	conversion	0	1
fold	0	1	equipment	0	
tail rotor	0		pneumatic group	0	
blades	0		electrical group	309.6	
hub & hinge	0		aircraft	250	
fuselage group	2048.5		anti-icing	59.6	0.75
basic	1955.2	0.795	avionics (MEQ)	1000	
crashworthiness	93.3	0.795	armament group	100	
alighting gear	573.6		armament prov	0	
basic	491.2	0.735	armor	100	
retraction	28.9	0.735	furnish & equip	770	
crashworthiness	53.5	0.735	environ control	100	
engine sect/nac	181.5		anti-icing group	63	0.75
engine support	78.5	1.283	load & handling	50	
engine cowling	103	0.743	VIBRATION	78.4	
pylon support	0	0.743	CONTINGENCY	783.5	
air induction	42.3	1.283	FIXED USEFUL LOAD	1070	
PROPULSION GROUP	3400.7		crew	1000	
engine system	1220.7		fluids	70	
engine	753.1	0.75			
exhaust system	282.4	0.75	WEIGHT EMPTY	15670	
accessories	185.3	1.08	Fixed UL for DGW	1070	
fuel system	203.5		OPERATING WEIGHT	16740	
tanks and supp	146.1	0.728	Fuel for DGW	3843.3	
plumbing	57.3	0.728	Payload for DGW	3000	
drive system	1792.9		USEFUL LOAD for DGW	7913.3	
gear boxes	1496.4	0.81	DESIGN GROSS WEIGHT	23581.9	
trans drive	87.8	0.81			
rotor shaft	148	0.81	Growth Factor	3.930	
rotor brake	60.7	0.81	Empty Weight Fraction	0.664	

Lift Offset Weight, TBO = 8,000 flt. hrs.

	lb.	tech factor		lb.	tech factor
STRUCTURE	6703		SYSTEMS AND EQUIP	4812.2	
wing group	0		flight controls	2013.7	
basic structure	0		cockpit controls	100	
secondary struct	0		auto flight cont	50	
fairings	0		system controls	1863.7	
fittings	0		fixed wing sys	22.1	
fold/tilt	0		non-boosted	2.2	0.439
control surfaces	0		boost mech	19.9	0.439
rotor group	3772.1		rotary wing sys	1841.6	
blade assembly	1556.9	0.564	non-boosted	542.5	0.831
hub & hinge	2215.2		boost mech	372.5	0.869
basic	1990.2	0.564	boosted	926.7	1.762
shaft	225	0.564	conversion sys	0	
fairing/spinner	0	0.65	non-boosted	0	1
blade fold	0	0.65	boost mech	0	1
empennage group	71.2		auxiliary power	130	
horizontal tail	51.3		instruments group	150	
basic	51.3	0.795	hydraulic group	125	
fold	0	1	fixed wing	0.9	0.439
vertical tail	19.9		rotary wing	124.2	0.869
basic	19.9	0.795	conversion	0	1
fold	0	1	equipment	0	
tail rotor	0		pneumatic group	0	
blades	0		electrical group	310	
hub & hinge	0		aircraft	250	
fuselage group	2059.2		anti-icing	60	0.75
basic	1965.4	0.795	avionics (MEQ)	1000	
crashworthiness	93.8	0.795	armament group	100	
alighting gear	575.7		armament prov	0	
basic	493	0.735	armor	100	
retraction	29	0.735	furnish & equip	770	
crashworthiness	53.7	0.735	environ control	100	
engine sect/nac	182.3		anti-icing group	63.4	0.75
engine support	78.9	1.283	load & handling	50	
engine cowling	103.4	0.743	VIBRATION	79.1	
pylon support	0	0.743	CONTINGENCY	790.8	
air induction	42.5	1.283	FIXED USEFUL LOAD	1070	
PROPULSION GROUP	3431.6		crew	1000	
engine system	1225.7		fluids	70	
engine	756.3	0.75			
exhaust system	283.6	0.75	WEIGHT EMPTY	15816.7	
accessories	185.7	1.08	Fixed UL for DGW	1070	
fuel system	204.3		OPERATING WEIGHT	16886.7	
tanks and supp	146.7	0.728	Fuel for DGW	3863.9	
plumbing	57.5	0.728	Payload for DGW	3000	
drive system	1817.1		USEFUL LOAD for DGW	7933.9	
gear boxes	1515.9	0.816	DESIGN GROSS WEIGHT	23749.1	
trans drive	89	0.816			
rotor shaft	149.9	0.816	Growth Factor	3.958	
rotor brake	62.2	0.816	Empty Weight Fraction	0.666	

Lift Offset Weight, TBO = 9,000 flt. hrs.

	lb.	tech factor		lb.	tech factor
STRUCTURE	6777.5		SYSTEMS AND EQUIP	4835.7	
wing group	0		flight controls	2035.1	
basic structure	0		cockpit controls	100	
secondary struct	0		auto flight cont	50	
fairings	0		system controls	1885.1	
fittings	0		fixed wing sys	22.4	
fold/tilt	0		non-boosted	2.2	0.441
control surfaces	0		boost mech	20.1	0.441
rotor group	3833.5		rotary wing sys	1862.8	
blade assembly	1582.2	0.568	non-boosted	547	0.836
hub & hinge	2251.4		boost mech	376.5	0.875
basic	2023.4	0.568	boosted	939.3	1.773
shaft	228	0.568	conversion sys	0	
fairing/spinner	0	0.65	non-boosted	0	1
blade fold	0	0.65	boost mech	0	1
empennage group	71.7		auxiliary power	130	
horizontal tail	51.7		instruments group	150	
basic	51.7	0.795	hydraulic group	126.4	
fold	0	1	fixed wing	0.9	0.441
vertical tail	20		rotary wing	125.5	0.875
basic	20	0.795	conversion	0	1
fold	0	1	equipment	0	
tail rotor	0		pneumatic group	0	
blades	0		electrical group	310.4	
hub & hinge	0		aircraft	250	
fuselage group	2069		anti-icing	60.4	0.75
basic	1974.8	0.795	avionics (MEQ)	1000	
crashworthiness	94.2	0.795	armament group	100	
alighting gear	577.6		armament prov	0	
basic	494.6	0.735	armor	100	
retraction	29.1	0.735	furnish & equip	770	
crashworthiness	53.9	0.735	environ control	100	
engine sect/nac	183		anti-icing group	63.8	0.75
engine support	79.3	1.283	load & handling	50	
engine cowling	103.7	0.743	VIBRATION	79.8	
pylon support	0	0.743	CONTINGENCY	797.5	
air induction	42.7	1.283	FIXED USEFUL LOAD	1070	
PROPULSION GROUP	3459.7		crew	1000	
engine system	1230.2		fluids	70	
engine	759.3	0.75			
exhaust system	284.7	0.75	WEIGHT EMPTY	15950.1	
accessories	186.2	1.08	Fixed UL for DGW	1070	
fuel system	205		OPERATING WEIGHT	17020.1	
tanks and supp	147.3	0.728	Fuel for DGW	3883.2	
plumbing	57.7	0.728	Payload for DGW	3000	
drive system	1839		USEFUL LOAD for DGW	7953.2	
gear boxes	1533.6	0.821	DESIGN GROSS WEIGHT	23901.8	
trans drive	90.1	0.821			
rotor shaft	151.7	0.821	Growth Factor	3.984	
rotor brake	63.6	0.821	Empty Weight Fraction	0.667	

Lift Offset Weight, TBO = 10,000 flt. hrs.

	lb.	tech factor		lb.	tech factor
STRUCTURE	6845.3		SYSTEMS AND EQUIP	4857.1	
wing group	0		flight controls	2054.6	
basic structure	0		cockpit controls	100	
secondary struct	0		auto flight cont	50	
fairings	0		system controls	1904.6	
fittings	0		fixed wing sys	22.6	
fold/tilt	0		non-boosted	2.3	0.444
control surfaces	0		boost mech	20.3	0.444
rotor group	3889.6		rotary wing sys	1882	
blade assembly	1605.2	0.571	non-boosted	551.1	0.841
hub & hinge	2284.3		boost mech	380.1	0.88
basic	2053.7	0.571	boosted	950.8	1.783
shaft	230.6	0.571	conversion sys	0	
fairing/spinner	0	0.65	non-boosted	0	1
blade fold	0	0.65	boost mech	0	1
empennage group	72.1		auxiliary power	130	
horizontal tail	52		instruments group	150	
basic	52	0.795	hydraulic group	127.6	
fold	0	1	fixed wing	0.9	0.444
vertical tail	20.1		rotary wing	126.7	0.88
basic	20.1	0.795	conversion	0	1
fold	0	1	equipment	0	
tail rotor	0		pneumatic group	0	
blades	0		electrical group	310.7	
hub & hinge	0		aircraft	250	
fuselage group	2077.8		anti-icing	60.7	0.75
basic	1983.2	0.795	avionics (MEQ)	1000	
crashworthiness	94.6	0.795	armament group	100	
alighting gear	579.3		armament prov	0	
basic	496.1	0.735	armor	100	
retraction	29.2	0.735	furnish & equip	770	
crashworthiness	54	0.735	environ control	100	
engine sect/nac	183.6		anti-icing group	64.2	0.75
engine support	79.6	1.283	load & handling	50	
engine cowling	104	0.743	VIBRATION	80.4	
pylon support	0	0.743	CONTINGENCY	803.6	
air induction	42.9	1.283	FIXED USEFUL LOAD	1070	
PROPULSION GROUP	3485.1		crew	1000	
engine system	1234.3		fluids	70	
engine	762	0.75			
exhaust system	285.7	0.75	WEIGHT EMPTY	16071.4	
accessories	186.5	1.08	Fixed UL for DGW	1070	
fuel system	205.6		OPERATING WEIGHT	17141.4	
tanks and supp	147.8	0.728	Fuel for DGW	3900.1	
plumbing	57.8	0.728	Payload for DGW	3000	
drive system	1858.9		USEFUL LOAD for DGW	7970.1	
gear boxes	1549.6	0.825	DESIGN GROSS WEIGHT	24040	
trans drive	91.1	0.825			
rotor shaft	153.3	0.825	Growth Factor	4.007	
rotor brake	64.9	0.825	Empty Weight Fraction	0.669	

Lift Offset Weight, TBO = 11,000 flt. hrs.

	lb.	tech factor		lb.	tech factor
STRUCTURE	6934.1		SYSTEMS AND EQUIP	4880	
wing group	0		flight controls	2075.3	
basic structure	0		cockpit controls	100	
secondary struct	0		auto flight cont	50	
fairings	0		system controls	1925.3	
fittings	0		fixed wing sys	22.9	
fold/tilt	0		non-boosted	2.3	0.446
control surfaces	0		boost mech	20.6	0.446
rotor group	3952.5		rotary wing sys	1902.4	
blade assembly	1631.1	0.574	non-boosted	555.3	0.845
hub & hinge	2321.3		boost mech	383.9	0.884
basic	2087.6	0.574	boosted	963.3	1.792
shaft	233.8	0.574	conversion sys	0	
fairing/spinner	0	0.65	non-boosted	0	1
blade fold	0	0.65	boost mech	0	1
empennage group	73.1		auxiliary power	130	
horizontal tail	52.7		instruments group	150	
basic	52.7	0.799	hydraulic group	128.9	
fold	0	1	fixed wing	0.9	0.446
vertical tail	20.4		rotary wing	128	0.884
basic	20.4	0.799	conversion	0	1
fold	0	1	equipment	0	
tail rotor	0		pneumatic group	0	
blades	0		electrical group	311.2	
hub & hinge	0		aircraft	250	
fuselage group	2094.7		anti-icing	61.2	0.75
basic	1999.1	0.797	avionics (MEQ)	1000	
crashworthiness	95.6	0.797	armament group	100	
alighting gear	585		armament prov	0	
basic	500.6	0.739	armor	100	
retraction	29.6	0.739	furnish & equip	770	
crashworthiness	54.8	0.739	environ control	100	
engine sect/nac	185.6		anti-icing group	64.6	0.75
engine support	80.5	1.289	load & handling	50	
engine cowling	105.1	0.746	VIBRATION	81.1	
pylon support	0	0.746	CONTINGENCY	811.1	
air induction	43.3	1.289	FIXED USEFUL LOAD	1070	
PROPULSION GROUP	3515.9		crew	1000	
engine system	1241.3		fluids	70	
engine	765.6	0.75			
exhaust system	288.6	0.754	WEIGHT EMPTY	16222.2	
accessories	187.1	1.08	Fixed UL for DGW	1070	
fuel system	206.5		OPERATING WEIGHT	17292.2	
tanks and supp	148.4	0.728	Fuel for DGW	3921.8	
plumbing	58	0.728	Payload for DGW	3000	
drive system	1880.7		USEFUL LOAD for DGW	7991.8	
gear boxes	1567.2	0.83	DESIGN GROSS WEIGHT	24212.5	
trans drive	92.3	0.83			
rotor shaft	155	0.83	Growth Factor	4.035	
rotor brake	66.3	0.83	Empty Weight Fraction	0.670	

Lift Offset Weight, TBO = 12,000 flt. hrs.

	lb.	tech factor		lb.	tech factor
STRUCTURE	7017.4		SYSTEMS AND EQUIP	4901.3	
wing group	0		flight controls	2094.7	
basic structure	0		cockpit controls	100	
secondary struct	0		auto flight cont	50	
fairings	0		system controls	1944.7	
fittings	0		fixed wing sys	23.1	
fold/tilt	0		non-boosted	2.3	0.448
control surfaces	0		boost mech	20.8	0.448
rotor group	4011.6		rotary wing sys	1921.5	
blade assembly	1655.5	0.577	non-boosted	559.1	0.849
hub & hinge	2356.2		boost mech	387.4	0.889
basic	2119.4	0.577	boosted	975.1	1.801
shaft	236.7	0.577	conversion sys	0	
fairing/spinner	0	0.65	non-boosted	0	1
blade fold	0	0.65	boost mech	0	1
empennage group	74		auxiliary power	130	
horizontal tail	53.4		instruments group	150	
basic	53.4	0.803	hydraulic group	130.1	
fold	0	1	fixed wing	0.9	0.448
vertical tail	20.6		rotary wing	129.1	0.889
basic	20.6	0.803	conversion	0	1
fold	0	1	equipment	0	
tail rotor	0		pneumatic group	0	
blades	0		electrical group	311.6	
hub & hinge	0		aircraft	250	
fuselage group	2110.4		anti-icing	61.6	0.75
basic	2013.9	0.799	avionics (MEQ)	1000	
crashworthiness	96.5	0.799	armament group	100	
alighting gear	590.3		armament prov	0	
basic	504.7	0.742	armor	100	
retraction	30	0.742	furnish & equip	770	
crashworthiness	55.6	0.742	environ control	100	
engine sect/nac	187.3		anti-icing group	65	0.75
engine support	81.2	1.295	load & handling	50	
engine cowling	106.1	0.75	VIBRATION	81.8	
pylon support	0	0.75	CONTINGENCY	818.2	
air induction	43.7	1.295	FIXED USEFUL LOAD	1070	
PROPULSION GROUP	3544.5		crew	1000	
engine system	1247.8		fluids	70	
engine	769	0.75			
exhaust system	291.2	0.757	WEIGHT EMPTY	16363.2	
accessories	187.6	1.08	Fixed UL for DGW	1070	
fuel system	207.3		OPERATING WEIGHT	17433.2	
tanks and supp	149	0.728	Fuel for DGW	3942.7	
plumbing	58.2	0.728	Payload for DGW	3000	
drive system	1901		USEFUL LOAD for DGW	8012.7	
gear boxes	1583.5	0.834	DESIGN GROSS WEIGHT	24374.3	
trans drive	93.3	0.834			
rotor shaft	156.6	0.834	Growth Factor	4.062	
rotor brake	67.6	0.834	Empty Weight Fraction	0.671	

Lift Offset Weight, TBO = 13,000 flt. hrs.

	lb.	tech factor		lb.	tech factor
STRUCTURE	7095.6		SYSTEMS AND EQUIP	4921.3	
wing group	0		flight controls	2112.8	
basic structure	0		cockpit controls	100	
secondary struct	0		auto flight cont	50	
fairings	0		system controls	1962.8	
fittings	0		fixed wing sys	23.4	
fold/tilt	0		non-boosted	2.3	0.45
control surfaces	0		boost mech	21	0.45
rotor group	4067.2		rotary wing sys	1939.4	
blade assembly	1678.3	0.579	non-boosted	562.6	0.853
hub & hinge	2388.9		boost mech	390.7	0.893
basic	2149.4	0.579	boosted	986.1	1.809
shaft	239.5	0.579	conversion sys	0	
fairing/spinner	0	0.65	non-boosted	0	1
blade fold	0	0.65	boost mech	0	1
empennage group	74.8		auxiliary power	130	
horizontal tail	54		instruments group	150	
basic	54	0.806	hydraulic group	131.2	
fold	0	1	fixed wing	0.9	0.45
vertical tail	20.8		rotary wing	130.2	0.893
basic	20.8	0.806	conversion	0	1
fold	0	1	equipment	0	
tail rotor	0		pneumatic group	0	
blades	0		electrical group	311.9	
hub & hinge	0		aircraft	250	
fuselage group	2125.2		anti-icing	61.9	0.75
basic	2027.8	0.801	avionics (MEQ)	1000	
crashworthiness	97.4	0.801	armament group	100	
alighting gear	595.2		armament prov	0	
basic	508.6	0.746	armor	100	
retraction	30.3	0.746	furnish & equip	770	
crashworthiness	56.2	0.746	environ control	100	
engine sect/nac	189		anti-icing group	65.4	0.75
engine support	82	1.301	load & handling	50	
engine cowling	107	0.753	VIBRATION	82.5	
pylon support	0	0.753	CONTINGENCY	824.8	
air induction	44.1	1.301	FIXED USEFUL LOAD	1070	
PROPULSION GROUP	3571.5		crew	1000	
engine system	1254		fluids	70	
engine	772.2	0.75			
exhaust system	293.7	0.761	WEIGHT EMPTY	16495.6	
accessories	188	1.08	Fixed UL for DGW	1070	
fuel system	208		OPERATING WEIGHT	17565.6	
tanks and supp	149.6	0.728	Fuel for DGW	3961.8	
plumbing	58.4	0.728	Payload for DGW	3000	
drive system	1920.1		USEFUL LOAD for DGW	8031.8	
gear boxes	1598.9	0.837	DESIGN GROSS WEIGHT	24525.8	
trans drive	94.3	0.837			
rotor shaft	158.1	0.837	Growth Factor	4.088	
rotor brake	68.8	0.837	Empty Weight Fraction	0.673	

Lift Offset Weight, TBO = 14,000 flt. hrs.

	lb.	tech factor		lb.	tech factor
STRUCTURE	7169.1		SYSTEMS AND EQUIP	4940	
wing group	0		flight controls	2129.7	
basic structure	0		cockpit controls	100	
secondary struct	0		auto flight cont	50	
fairings	0		system controls	1979.7	
fittings	0		fixed wing sys	23.6	
fold/tilt	0		non-boosted	2.4	0.452
control surfaces	0		boost mech	21.2	0.452
rotor group	4119.6		rotary wing sys	1956.2	
blade assembly	1699.9	0.582	non-boosted	565.9	0.856
hub & hinge	2419.7		boost mech	393.7	0.896
basic	2177.6	0.582	boosted	996.5	1.816
shaft	242.1	0.582	conversion sys	0	
fairing/spinner	0	0.65	non-boosted	0	1
blade fold	0	0.65	boost mech	0	1
empennage group	75.6		auxiliary power	130	
horizontal tail	54.6		instruments group	150	
basic	54.6	0.81	hydraulic group	132.2	
fold	0	1	fixed wing	1	0.452
vertical tail	21		rotary wing	131.2	0.896
basic	21	0.81	conversion	0	1
fold	0	1	equipment	0	
tail rotor	0		pneumatic group	0	
blades	0		electrical group	312.3	
hub & hinge	0		aircraft	250	
fuselage group	2139		anti-icing	62.3	0.75
basic	2040.7	0.802	avionics (MEQ)	1000	
crashworthiness	98.2	0.802	armament group	100	
alighting gear	599.8		armament prov	0	
basic	512.2	0.749	armor	100	
retraction	30.7	0.749	furnish & equip	770	
crashworthiness	56.9	0.749	environ control	100	
engine sect/nac	190.6		anti-icing group	65.8	0.75
engine support	82.7	1.306	load & handling	50	
engine cowling	107.9	0.756	VIBRATION	83.1	
pylon support	0	0.756	CONTINGENCY	831	
air induction	44.5	1.306	FIXED USEFUL LOAD	1070	
PROPULSION GROUP	3596.7		crew	1000	
engine system	1259.8		fluids	70	
engine	775.2	0.75			
exhaust system	296.1	0.764	WEIGHT EMPTY	16619.9	
accessories	188.5	1.08	Fixed UL for DGW	1070	
fuel system	208.7		OPERATING WEIGHT	17689.9	
tanks and supp	150.1	0.728	Fuel for DGW	3979.4	
plumbing	58.6	0.728	Payload for DGW	3000	
drive system	1938		USEFUL LOAD for DGW	8049.4	
gear boxes	1613.3	0.841	DESIGN GROSS WEIGHT	24667.8	
trans drive	95.2	0.841			
rotor shaft	159.6	0.841	Growth Factor	4.111	
rotor brake	70	0.841	Empty Weight Fraction	0.674	

Lift Offset Weight, TBO = 15,000 flt. hrs.

	lb.	tech factor		lb.	tech factor
STRUCTURE	7239.9		SYSTEMS AND EQUIP	4957.9	
wing group	0		flight controls	2146	
basic structure	0		cockpit controls	100	
secondary struct	0		auto flight cont	50	
fairings	0		system controls	1996	
fittings	0		fixed wing sys	23.8	
fold/tilt	0		non-boosted	2.4	0.454
control surfaces	0		boost mech	21.4	0.454
rotor group	4170.2		rotary wing sys	1972.2	
blade assembly	1720.7	0.584	non-boosted	569.1	0.86
hub & hinge	2449.5		boost mech	396.7	0.899
basic	2204.9	0.584	boosted	1006.4	1.823
shaft	244.6	0.584	conversion sys	0	
fairing/spinner	0	0.65	non-boosted	0	1
blade fold	0	0.65	boost mech	0	1
empennage group	76.4		auxiliary power	130	
horizontal tail	55.2		instruments group	150	
basic	55.2	0.813	hydraulic group	133.2	
fold	0	1	fixed wing	1	0.454
vertical tail	21.2		rotary wing	132.2	0.899
basic	21.2	0.813	conversion	0	1
fold	0	1	equipment	0	
tail rotor	0		pneumatic group	0	
blades	0		electrical group	312.6	
hub & hinge	0		aircraft	250	
fuselage group	2152.2		anti-icing	62.6	0.75
basic	2053.2	0.804	avionics (MEQ)	1000	
crashworthiness	99	0.804	armament group	100	
alighting gear	604.2		armament prov	0	
basic	515.7	0.751	armor	100	
retraction	31	0.751	furnish & equip	770	
crashworthiness	57.5	0.751	environ control	100	
engine sect/nac	192.1		anti-icing group	66.1	0.75
engine support	83.3	1.311	load & handling	50	
engine cowling	108.8	0.759	VIBRATION	83.7	
pylon support	0	0.759	CONTINGENCY	837	
air induction	44.9	1.311	FIXED USEFUL LOAD	1070	
PROPULSION GROUP	3621		crew	1000	
engine system	1265.3		fluids	70	
engine	778.2	0.75			
exhaust system	298.3	0.767	WEIGHT EMPTY	16739.5	
accessories	188.9	1.08	Fixed UL for DGW	1070	
fuel system	209.4		OPERATING WEIGHT	17809.5	
tanks and supp	150.6	0.728	Fuel for DGW	3997.3	
plumbing	58.7	0.728	Payload for DGW	3000	
drive system	1955.2		USEFUL LOAD for DGW	8067.3	
gear boxes	1627.1	0.844	DESIGN GROSS WEIGHT	24805.2	
trans drive	96.1	0.844			
rotor shaft	160.9	0.844	Growth Factor	4.134	
rotor brake	71.1	0.844	Empty Weight Fraction	0.675	

Lift Offset Weight, TBO = 16,000 flt. hrs.

	lb.	tech factor		lb.	tech factor
STRUCTURE	7306.8		SYSTEMS AND EQUIP	4974.8	
wing group	0		flight controls	2161.3	
basic structure	0		cockpit controls	100	
secondary struct	0		auto flight cont	50	
fairings	0		system controls	2011.3	
fittings	0		fixed wing sys	24	
fold/tilt	0		non-boosted	2.4	0.455
control surfaces	0		boost mech	21.6	0.455
rotor group	4218		rotary wing sys	1987.3	
blade assembly	1740.4	0.586	non-boosted	572	0.863
hub & hinge	2477.6		boost mech	399.4	0.903
basic	2230.7	0.586	boosted	1015.8	1.829
shaft	247	0.586	conversion sys	0	
fairing/spinner	0	0.65	non-boosted	0	1
blade fold	0	0.65	boost mech	0	1
empennage group	77.1		auxiliary power	130	
horizontal tail	55.7		instruments group	150	
basic	55.7	0.816	hydraulic group	134.1	
fold	0	1	fixed wing	1	0.455
vertical tail	21.4		rotary wing	133.1	0.903
basic	21.4	0.816	conversion	0	1
fold	0	1	equipment	0	
tail rotor	0		pneumatic group	0	
blades	0		electrical group	312.9	
hub & hinge	0		aircraft	250	
fuselage group	2164.7		anti-icing	62.9	0.75
basic	2064.9	0.805	avionics (MEQ)	1000	
crashworthiness	99.8	0.805	armament group	100	
alighting gear	608.3		armament prov	0	
basic	518.9	0.754	armor	100	
retraction	31.3	0.754	furnish & equip	770	
crashworthiness	58.1	0.754	environ control	100	
engine sect/nac	193.5		anti-icing group	66.5	0.75
engine support	84	1.316	load & handling	50	
engine cowling	109.5	0.762	VIBRATION	84.3	
pylon support	0	0.762	CONTINGENCY	842.6	
air induction	45.2	1.316	FIXED USEFUL LOAD	1070	
PROPULSION GROUP	3643.8		crew	1000	
engine system	1270.5		fluids	70	
engine	780.9	0.75			
exhaust system	300.4	0.769	WEIGHT EMPTY	16852.3	
accessories	189.3	1.08	Fixed UL for DGW	1070	
fuel system	210		OPERATING WEIGHT	17922.3	
tanks and supp	151.1	0.728	Fuel for DGW	4013.7	
plumbing	58.9	0.728	Payload for DGW	3000	
drive system	1971.3		USEFUL LOAD for DGW	8083.7	
gear boxes	1640.1	0.847	DESIGN GROSS WEIGHT	24934.4	
trans drive	96.9	0.847			
rotor shaft	162.2	0.847	Growth Factor	4.156	
rotor brake	72.2	0.847	Empty Weight Fraction	0.676	

Lift Offset Weight, TBO = 17,000 flt. hrs.

	lb.	tech factor		lb.	tech factor
STRUCTURE	7370.9		SYSTEMS AND EQUIP	4991	
wing group	0		flight controls	2175.9	
basic structure	0		cockpit controls	100	
secondary struct	0		auto flight cont	50	
fairings	0		system controls	2025.9	
fittings	0		fixed wing sys	24.2	
fold/tilt	0		non-boosted	2.4	0.457
control surfaces	0		boost mech	21.8	0.457
rotor group	4263.9		rotary wing sys	2001.7	
blade assembly	1759.2	0.588	non-boosted	574.8	0.866
hub & hinge	2504.7		boost mech	402.1	0.906
basic	2255.4	0.588	boosted	1024.8	1.835
shaft	249.3	0.588	conversion sys	0	
fairing/spinner	0	0.65	non-boosted	0	1
blade fold	0	0.65	boost mech	0	1
empennage group	77.8		auxiliary power	130	
horizontal tail	56.2		instruments group	150	
basic	56.2	0.818	hydraulic group	135	
fold	0	1	fixed wing	1	0.457
vertical tail	21.5		rotary wing	134	0.906
basic	21.5	0.818	conversion	0	1
fold	0	1	equipment	0	
tail rotor	0		pneumatic group	0	
blades	0		electrical group	313.3	
hub & hinge	0		aircraft	250	
fuselage group	2176.6		anti-icing	63.3	0.75
basic	2076.1	0.807	avionics (MEQ)	1000	
crashworthiness	100.5	0.807	armament group	100	
alighting gear	612.3		armament prov	0	
basic	522	0.756	armor	100	
retraction	31.6	0.756	furnish & equip	770	
crashworthiness	58.6	0.756	environ control	100	
engine sect/nac	194.9		anti-icing group	66.8	0.75
engine support	84.6	1.32	load & handling	50	
engine cowling	110.3	0.764	VIBRATION	84.8	
pylon support	0	0.764	CONTINGENCY	848	
air induction	45.5	1.32	FIXED USEFUL LOAD	1070	
PROPULSION GROUP	3665.7		crew	1000	
engine system	1275.5		fluids	70	
engine	783.5	0.75			
exhaust system	302.4	0.772	WEIGHT EMPTY	16960.5	
accessories	189.6	1.08	Fixed UL for DGW	1070	
fuel system	210.6		OPERATING WEIGHT	18030.5	
tanks and supp	151.6	0.728	Fuel for DGW	4029.4	
plumbing	59	0.728	Payload for DGW	3000	
drive system	1986.8		USEFUL LOAD for DGW	8099.4	
gear boxes	1652.5	0.849	DESIGN GROSS WEIGHT	25058.2	
trans drive	97.7	0.849			
rotor shaft	163.4	0.849	Growth Factor	4.176	
rotor brake	73.2	0.849	Empty Weight Fraction	0.677	

Lift Offset Weight, TBO = 18,000 flt. hrs.

	lb.	tech factor		lb.	tech factor
STRUCTURE	7431.9		SYSTEMS AND EQUIP	5006.3	
wing group	0		flight controls	2189.8	
basic structure	0		cockpit controls	100	
secondary struct	0		auto flight cont	50	
fairings	0		system controls	2039.8	
fittings	0		fixed wing sys	24.4	
fold/tilt	0		non-boosted	2.4	0.458
control surfaces	0		boost mech	21.9	0.458
rotor group	4307.7		rotary wing sys	2015.4	
blade assembly	1777.2	0.59	non-boosted	577.5	0.868
hub & hinge	2530.4		boost mech	404.6	0.908
basic	2279	0.59	boosted	1033.3	1.841
shaft	251.4	0.59	conversion sys	0	
fairing/spinner	0	0.65	non-boosted	0	1
blade fold	0	0.65	boost mech	0	1
empennage group	78.4		auxiliary power	130	
horizontal tail	56.7		instruments group	150	
basic	56.7	0.821	hydraulic group	135.9	
fold	0	1	fixed wing	1	0.458
vertical tail	21.7		rotary wing	134.9	0.908
basic	21.7	0.821	conversion	0	1
fold	0	1	equipment	0	
tail rotor	0		pneumatic group	0	
blades	0		electrical group	313.5	
hub & hinge	0		aircraft	250	
fuselage group	2187.8		anti-icing	63.5	0.75
basic	2086.7	0.808	avionics (MEQ)	1000	
crashworthiness	101.1	0.808	armament group	100	
alighting gear	616		armament prov	0	
basic	525	0.759	armor	100	
retraction	31.9	0.759	furnish & equip	770	
crashworthiness	59.2	0.759	environ control	100	
engine sect/nac	196.1		anti-icing group	67.1	0.75
engine support	85.1	1.324	load & handling	50	
engine cowling	111	0.767	VIBRATION	85.3	
pylon support	0	0.767	CONTINGENCY	853.2	
air induction	45.8	1.324	FIXED USEFUL LOAD	1070	
PROPULSION GROUP	3686.4		crew	1000	
engine system	1280.2		fluids	70	
engine	786	0.75			
exhaust system	304.3	0.774	WEIGHT EMPTY	17063.1	
accessories	190	1.08	Fixed UL for DGW	1070	
fuel system	211.2		OPERATING WEIGHT	18133.1	
tanks and supp	152	0.728	Fuel for DGW	4044.1	
plumbing	59.2	0.728	Payload for DGW	3000	
drive system	2001.5		USEFUL LOAD for DGW	8114.1	
gear boxes	1664.3	0.852	DESIGN GROSS WEIGHT	25175.6	
trans drive	98.4	0.852			
rotor shaft	164.6	0.852	Growth Factor	4.196	
rotor brake	74.2	0.852	Empty Weight Fraction	0.678	

Lift Offset Weight, TBO = 19,000 flt. hrs.

	lb.	tech factor		lb.	tech factor
STRUCTURE	7490.4		SYSTEMS AND EQUIP	5020.9	
wing group	0		flight controls	2203.1	
basic structure	0		cockpit controls	100	
secondary struct	0		auto flight cont	50	
fairings	0		system controls	2053.1	
fittings	0		fixed wing sys	24.5	
fold/tilt	0		non-boosted	2.5	0.46
control surfaces	0		boost mech	22.1	0.46
rotor group	4349.7		rotary wing sys	2028.5	
blade assembly	1794.5	0.591	non-boosted	580	0.871
hub & hinge	2555.2		boost mech	407	0.911
basic	2301.7	0.591	boosted	1041.5	1.846
shaft	253.5	0.591	conversion sys	0	
fairing/spinner	0	0.65	non-boosted	0	1
blade fold	0	0.65	boost mech	0	1
empennage group	79		auxiliary power	130	
horizontal tail	57.2		instruments group	150	
basic	57.2	0.823	hydraulic group	136.7	
fold	0	1	fixed wing	1	0.46
vertical tail	21.9		rotary wing	135.7	0.911
basic	21.9	0.823	conversion	0	1
fold	0	1	equipment	0	
tail rotor	0		pneumatic group	0	
blades	0		electrical group	313.8	
hub & hinge	0		aircraft	250	
fuselage group	2198.6		anti-icing	63.8	0.75
basic	2096.8	0.809	avionics (MEQ)	1000	
crashworthiness	101.8	0.809	armament group	100	
alighting gear	619.6		armament prov	0	
basic	527.8	0.761	armor	100	
retraction	32.1	0.761	furnish & equip	770	
crashworthiness	59.7	0.761	environ control	100	
engine sect/nac	197.4		anti-icing group	67.4	0.75
engine support	85.7	1.328	load & handling	50	
engine cowling	111.7	0.769	VIBRATION	85.8	
pylon support	0	0.769	CONTINGENCY	858.1	
air induction	46.1	1.328	FIXED USEFUL LOAD	1070	
PROPULSION GROUP	3706.2		crew	1000	
engine system	1284.8		fluids	70	
engine	788.3	0.75			
exhaust system	306.1	0.777	WEIGHT EMPTY	17161.4	
accessories	190.3	1.08	Fixed UL for DGW	1070	
fuel system	211.7		OPERATING WEIGHT	18231.4	
tanks and supp	152.4	0.728	Fuel for DGW	4058.2	
plumbing	59.3	0.728	Payload for DGW	3000	
drive system	2015.6		USEFUL LOAD for DGW	8128.2	
gear boxes	1675.6	0.855	DESIGN GROSS WEIGHT	25287.9	
trans drive	99.1	0.855			
rotor shaft	165.7	0.855	Growth Factor	4.215	
rotor brake	75.1	0.855	Empty Weight Fraction	0.679	

Lift Offset Weight, TBO = 20,000 flt. hrs.

	lb.	tech factor		lb.	tech factor
STRUCTURE	7547		SYSTEMS AND EQUIP	5035	
wing group	0		flight controls	2215.9	
basic structure	0		cockpit controls	100	
secondary struct	0		auto flight cont	50	
fairings	0		system controls	2065.9	
fittings	0		fixed wing sys	24.7	
fold/tilt	0		non-boosted	2.5	0.46
control surfaces	0		boost mech	22.2	0.46
rotor group	4390.4		rotary wing sys	2041.2	
blade assembly	1811.3	0.591	non-boosted	582.4	0.871
hub & hinge	2579.2		boost mech	409.3	0.911
basic	2323.6	0.591	boosted	1049.5	1.846
shaft	255.5	0.591	conversion sys	0	
fairing/spinner	0	0.65	non-boosted	0	1
blade fold	0	0.65	boost mech	0	1
empennage group	79.7		auxiliary power	130	
horizontal tail	57.6		instruments group	150	
basic	57.6	0.823	hydraulic group	137.4	
fold	0	1	fixed wing	1	0.46
vertical tail	22		rotary wing	136.4	0.911
basic	22	0.823	conversion	0	1
fold	0	1	equipment	0	
tail rotor	0		pneumatic group	0	
blades	0		electrical group	314.1	
hub & hinge	0		aircraft	250	
fuselage group	2209		anti-icing	64.1	0.75
basic	2106.6	0.809	avionics (MEQ)	1000	
crashworthiness	102.4	0.809	armament group	100	
alighting gear	623		armament prov	0	
basic	530.5	0.761	armor	100	
retraction	32.4	0.761	furnish & equip	770	
crashworthiness	60.1	0.761	environ control	100	
engine sect/nac	198.5		anti-icing group	67.6	0.75
engine support	86.2	1.328	load & handling	50	
engine cowling	112.3	0.769	VIBRATION	86.3	
pylon support	0	0.769	CONTINGENCY	862.8	
air induction	46.4	1.328	FIXED USEFUL LOAD	1070	
PROPULSION GROUP	3725.4		crew	1000	
engine system	1289.1		fluids	70	
engine	790.6	0.75			
exhaust system	307.8	0.777	WEIGHT EMPTY	17256.6	
accessories	190.7	1.08	Fixed UL for DGW	1070	
fuel system	212.2		OPERATING WEIGHT	18326.6	
tanks and supp	152.8	0.728	Fuel for DGW	4072	
plumbing	59.4	0.728	Payload for DGW	3000	
drive system	2029.1		USEFUL LOAD for DGW	8142	
gear boxes	1686.5	0.855	DESIGN GROSS WEIGHT	25396.9	
trans drive	99.8	0.855			
rotor shaft	166.8	0.855	Growth Factor	4.233	
rotor brake	76.1	0.855	Empty Weight Fraction	0.679	

Tiltrotor Weight, TBO = 6,000 flt. hrs.

	lb.	tech factor		lb.	tech factor
STRUCTURE	5702.5		SYSTEMS AND EQUIP	4510.4	
wing group	1184.9		flight controls	1752.6	
basic structure	896.3	0.735	cockpit controls	100	
secondary struct	210.6		auto flight cont	50	
fairings	81.7	0.735	system controls	1602.6	
fittings	128.9	0.735	fixed wing sys	211.2	
fold/tilt	0	0.735	non-boosted	21.1	0.545
control surfaces	78	0.735	boost mech	190.1	0.545
rotor group	1481.6		rotary wing sys	861.8	
blade assembly	858.2	0.704	non-boosted	434.8	0.712
hub & hinge	623.4		boost mech	228.4	0.818
basic	495	0.704	boosted	198.7	0.775
shaft	0	1	conversion sys	529.6	
fairing/spinner	128.4	0.735	non-boosted	48.1	1
blade fold	0	0.75	boost mech	481.5	1
empennage group	213.5		auxiliary power	130	
horizontal tail	123.2		instruments group	150	
basic	123.2	1.065	hydraulic group	134.6	
fold	0	1	fixed wing	10.4	0.545
vertical tail	90.3		rotary wing	76.1	0.818
basic	90.3	0.45	conversion	48.1	1
fold	0	1	equipment	0	
tail rotor	0		pneumatic group	0	
blades	0		electrical group	281.2	
hub & hinge	0		aircraft	250	
fuselage group	1999.1		anti-icing	31.2	0.75
basic	1908.1	0.795	avionics (MEQ)	1000	
crashworthiness	91	0.795	armament group	100	
alighting gear	503		armament prov	0	
basic	432	0.72	armor	100	
retraction	24.9	0.72	furnish & equip	770	
crashworthiness	46.1	0.72	environ control	100	
engine sect/nac	295.1		anti-icing group	42	0.75
engine support	47	0.637	load & handling	50	
engine cowling	90.4	0.42	VIBRATION	74.1	
pylon support	157.7	0.637	CONTINGENCY	741.3	
air induction	25.3	0.637	FIXED USEFUL LOAD	1070	
PROPULSION GROUP	3797.7		crew	1000	
engine system	1353.2		fluids	70	
engine	865.7	0.75			
exhaust system	324.7	0.75	WEIGHT EMPTY	14826	
accessories	162.8	0.465	Fixed UL for DGW	1070	
fuel system	416.7		OPERATING WEIGHT	15896	
tanks and supp	289.7	1.688	Fuel for DGW	3135.2	
plumbing	127	1.688	Payload for DGW	3000	
drive system	2027.9		USEFUL LOAD for DGW	7205.2	
gear boxes	1743.4	1.023	DESIGN GROSS WEIGHT	22030.3	
trans drive	69	0.47			
rotor shaft	172.4	1.023	Growth Factor	3.672	
rotor brake	43	1.023	Empty Weight Fraction	0.673	

Tiltrotor Weight, TBO = 7,000 flt. hrs.

	lb.	tech factor		lb.	tech factor
STRUCTURE	5743.9		SYSTEMS AND EQUIP	4526.3	
wing group	1193.2		flight controls	1767	
basic structure	903.4	0.735	cockpit controls	100	
secondary struct	211.5		auto flight cont	50	
fairings	82	0.735	system controls	1617	
fittings	129.5	0.735	fixed wing sys	213.5	
fold/tilt	0	0.735	non-boosted	21.4	0.55
control surfaces	78.3	0.735	boost mech	192.2	0.55
rotor group	1503.9		rotary wing sys	871.5	
blade assembly	869.9	0.71	non-boosted	439.2	0.718
hub & hinge	634		boost mech	231	0.825
basic	504.6	0.71	boosted	201.3	0.782
shaft	0	1	conversion sys	532	
fairing/spinner	129.4	0.741	non-boosted	48.4	1
blade fold	0	0.75	boost mech	483.6	1
empennage group	214.4		auxiliary power	130	
horizontal tail	123.7		instruments group	150	
basic	123.7	1.065	hydraulic group	135.9	
fold	0	1	fixed wing	10.6	0.55
vertical tail	90.6		rotary wing	77	0.825
basic	90.6	0.45	conversion	48.4	1
fold	0	1	equipment	0	
tail rotor	0		pneumatic group	0	
blades	0		electrical group	281.3	
hub & hinge	0		aircraft	250	
fuselage group	2006.2		anti-icing	31.3	0.75
basic	1914.9	0.795	avionics (MEQ)	1000	
crashworthiness	91.3	0.795	armament group	100	
alighting gear	504.5		armament prov	0	
basic	433.3	0.72	armor	100	
retraction	25	0.72	furnish & equip	770	
crashworthiness	46.2	0.72	environ control	100	
engine sect/nac	296.3		anti-icing group	42.1	0.75
engine support	47.3	0.637	load & handling	50	
engine cowling	90.7	0.42	VIBRATION	74.6	
pylon support	158.4	0.637	CONTINGENCY	746.1	
air induction	25.4	0.637	FIXED USEFUL LOAD	1070	
PROPULSION GROUP	3831.3		crew	1000	
engine system	1358.8		fluids	70	
engine	869.5	0.75			
exhaust system	326.1	0.75	WEIGHT EMPTY	14922.3	
accessories	163.2	0.465	Fixed UL for DGW	1070	
fuel system	417.2		OPERATING WEIGHT	15992.3	
tanks and supp	289.8	1.688	Fuel for DGW	3136.9	
plumbing	127.4	1.688	Payload for DGW	3000	
drive system	2055.3		USEFUL LOAD for DGW	7206.9	
gear boxes	1766.7	1.031	DESIGN GROSS WEIGHT	22128.1	
trans drive	69.9	0.474			
rotor shaft	174.7	1.031	Growth Factor	3.688	
rotor brake	43.9	1.031	Empty Weight Fraction	0.674	

Tiltrotor Weight, TBO = 8,000 flt. hrs.

	lb.	tech factor		lb.	tech factor
STRUCTURE	5779.5		SYSTEMS AND EQUIP	4540.1	
wing group	1200.3		flight controls	1779.4	
basic structure	909.5	0.735	cockpit controls	100	
secondary struct	212.3		auto flight cont	50	
fairings	82.3	0.735	system controls	1629.4	
fittings	130	0.735	fixed wing sys	215.5	
fold/tilt	0	0.735	non-boosted	21.6	0.554
control surfaces	78.5	0.735	boost mech	194	0.554
rotor group	1523.3		rotary wing sys	879.9	
blade assembly	880	0.715	non-boosted	443.1	0.723
hub & hinge	643.2		boost mech	233.2	0.831
basic	513	0.715	boosted	203.6	0.787
shaft	0	1	conversion sys	534	
fairing/spinner	130.3	0.746	non-boosted	48.5	1
blade fold	0	0.75	boost mech	485.4	1
empennage group	215.1		auxiliary power	130	
horizontal tail	124.1		instruments group	150	
basic	124.1	1.065	hydraulic group	137	
fold	0	1	fixed wing	10.7	0.554
vertical tail	90.9		rotary wing	77.7	0.831
basic	90.9	0.45	conversion	48.5	1
fold	0	1	equipment	0	
tail rotor	0		pneumatic group	0	
blades	0		electrical group	281.4	
hub & hinge	0		aircraft	250	
fuselage group	2012.2		anti-icing	31.4	0.75
basic	1920.6	0.795	avionics (MEQ)	1000	
crashworthiness	91.6	0.795	armament group	100	
alighting gear	505.7		armament prov	0	
basic	434.4	0.72	armor	100	
retraction	25	0.72	furnish & equip	770	
crashworthiness	46.3	0.72	environ control	100	
engine sect/nac	297.4		anti-icing group	42.3	0.75
engine support	47.4	0.637	load & handling	50	
engine cowling	91	0.42	VIBRATION	75	
pylon support	159	0.637	CONTINGENCY	750.2	
air induction	25.5	0.637	FIXED USEFUL LOAD	1070	
PROPULSION GROUP	3860		crew	1000	
engine system	1363.5		fluids	70	
engine	872.7	0.75			
exhaust system	327.3	0.75	WEIGHT EMPTY	15004.9	
accessories	163.6	0.465	Fixed UL for DGW	1070	
fuel system	417.5		OPERATING WEIGHT	16074.9	
tanks and supp	289.8	1.688	Fuel for DGW	3136.7	
plumbing	127.8	1.688	Payload for DGW	3000	
drive system	2079		USEFUL LOAD for DGW	7206.7	
gear boxes	1786.8	1.039	DESIGN GROSS WEIGHT	22210.6	
trans drive	70.7	0.477			
rotor shaft	176.7	1.039	Growth Factor	3.702	
rotor brake	44.8	1.039	Empty Weight Fraction	0.676	

Tiltrotor Weight, TBO = 9,000 flt. hrs.

	lb.	tech factor		lb.	tech factor
STRUCTURE	5823.1		SYSTEMS AND EQUIP	4555.4	
wing group	1209		flight controls	1793.1	
basic structure	916.7	0.735	cockpit controls	100	
secondary struct	213.4		auto flight cont	50	
fairings	82.7	0.735	system controls	1643.1	
fittings	130.7	0.735	fixed wing sys	217.6	
fold/tilt	0	0.735	non-boosted	21.8	0.557
control surfaces	78.9	0.735	boost mech	195.9	0.557
rotor group	1544.7		rotary wing sys	888.6	
blade assembly	891.3	0.72	non-boosted	446.9	0.728
hub & hinge	653.4		boost mech	235.6	0.836
basic	522.1	0.72	boosted	206.2	0.792
shaft	0	1	conversion sys	536.9	
fairing/spinner	131.3	0.751	non-boosted	48.8	1
blade fold	0	0.75	boost mech	488.1	1
empennage group	216.1		auxiliary power	130	
horizontal tail	124.8		instruments group	150	
basic	124.8	1.065	hydraulic group	138.2	
fold	0	1	fixed wing	10.9	0.557
vertical tail	91.4		rotary wing	78.5	0.836
basic	91.4	0.45	conversion	48.8	1
fold	0	1	equipment	0	
tail rotor	0		pneumatic group	0	
blades	0		electrical group	281.6	
hub & hinge	0		aircraft	250	
fuselage group	2021		anti-icing	31.6	0.75
basic	1929	0.795	avionics (MEQ)	1000	
crashworthiness	92	0.795	armament group	100	
alighting gear	507.6		armament prov	0	
basic	436	0.72	armor	100	
retraction	25.1	0.72	furnish & equip	770	
crashworthiness	46.5	0.72	environ control	100	
engine sect/nac	299		anti-icing group	42.5	0.75
engine support	47.7	0.637	load & handling	50	
engine cowling	91.4	0.42	VIBRATION	75.5	
pylon support	159.8	0.637	CONTINGENCY	755.2	
air induction	25.7	0.637	FIXED USEFUL LOAD	1070	
PROPULSION GROUP	3895.2		crew	1000	
engine system	1370.4		fluids	70	
engine	877.3	0.75			
exhaust system	329	0.75	WEIGHT EMPTY	15104.5	
accessories	164.1	0.465	Fixed UL for DGW	1070	
fuel system	419.6		OPERATING WEIGHT	16174.5	
tanks and supp	291.4	1.688	Fuel for DGW	3159	
plumbing	128.2	1.688	Payload for DGW	3000	
drive system	2105.2		USEFUL LOAD for DGW	7229	
gear boxes	1809.1	1.045	DESIGN GROSS WEIGHT	22332.2	
trans drive	71.5	0.48			
rotor shaft	178.9	1.045	Growth Factor	3.722	
rotor brake	45.6	1.045	Empty Weight Fraction	0.676	

Tiltrotor Weight, TBO = 10,000 flt. hrs.

	lb.	tech factor		lb.	tech factor
STRUCTURE	5857.2		SYSTEMS AND EQUIP	4567.9	
wing group	1215.8		flight controls	1804.3	
basic structure	922.4	0.735	cockpit controls	100	
secondary struct	214.2		auto flight cont	50	
fairings	83	0.735	system controls	1654.3	
fittings	131.2	0.735	fixed wing sys	219.4	
fold/tilt	0	0.735	non-boosted	21.9	0.561
control surfaces	79.1	0.735	boost mech	197.5	0.561
rotor group	1562.4		rotary wing sys	895.9	
blade assembly	900.5	0.724	non-boosted	450.1	0.732
hub & hinge	661.8		boost mech	237.5	0.841
basic	529.7	0.724	boosted	208.3	0.797
shaft	0	1	conversion sys	539	
fairing/spinner	132.2	0.755	non-boosted	49	1
blade fold	0	0.75	boost mech	490	1
empennage group	216.9		auxiliary power	130	
horizontal tail	125.2		instruments group	150	
basic	125.2	1.065	hydraulic group	139.2	
fold	0	1	fixed wing	11.1	0.561
vertical tail	91.7		rotary wing	79.2	0.841
basic	91.7	0.45	conversion	49	1
fold	0	1	equipment	0	
tail rotor	0		pneumatic group	0	
blades	0		electrical group	281.7	
hub & hinge	0		aircraft	250	
fuselage group	2027.4		anti-icing	31.7	0.75
basic	1935.1	0.795	avionics (MEQ)	1000	
crashworthiness	92.3	0.795	armament group	100	
alighting gear	508.9		armament prov	0	
basic	437.1	0.72	armor	100	
retraction	25.2	0.72	furnish & equip	770	
crashworthiness	46.6	0.72	environ control	100	
engine sect/nac	300.1		anti-icing group	42.6	0.75
engine support	47.9	0.637	load & handling	50	
engine cowling	91.7	0.42	VIBRATION	75.9	
pylon support	160.5	0.637	CONTINGENCY	759.1	
air induction	25.8	0.637	FIXED USEFUL LOAD	1070	
PROPULSION GROUP	3922.7		crew	1000	
engine system	1375.4		fluids	70	
engine	880.7	0.75			
exhaust system	330.2	0.75	WEIGHT EMPTY	15182.9	
accessories	164.5	0.465	Fixed UL for DGW	1070	
fuel system	420.6		OPERATING WEIGHT	16252.9	
tanks and supp	292	1.688	Fuel for DGW	3168.1	
plumbing	128.6	1.688	Payload for DGW	3000	
drive system	2126.7		USEFUL LOAD for DGW	7238.1	
gear boxes	1827.3	1.051	DESIGN GROSS WEIGHT	22420.1	
trans drive	72.2	0.483			
rotor shaft	180.7	1.051	Growth Factor	3.737	
rotor brake	46.4	1.051	Empty Weight Fraction	0.677	

Tiltrotor Weight, TBO = 11,000 flt. hrs.

	lb.	tech factor		lb.	tech factor
STRUCTURE	5911.3		SYSTEMS AND EQUIP	4581.4	
wing group	1228.5		flight controls	1816.4	
basic structure	933.8	0.739	cockpit controls	100	
secondary struct	215.3		auto flight cont	50	
fairings	83.4	0.735	system controls	1666.4	
fittings	131.9	0.735	fixed wing sys	221.2	
fold/tilt	0	0.735	non-boosted	22.1	0.564
control surfaces	79.5	0.735	boost mech	199.1	0.564
rotor group	1581.3		rotary wing sys	903.5	
blade assembly	910.5	0.728	non-boosted	453.4	0.736
hub & hinge	670.8		boost mech	239.5	0.845
basic	537.7	0.728	boosted	210.5	0.801
shaft	0	1	conversion sys	541.7	
fairing/spinner	133.1	0.759	non-boosted	49.2	1
blade fold	0	0.75	boost mech	492.5	1
empennage group	218.7		auxiliary power	130	
horizontal tail	126.4		instruments group	150	
basic	126.4	1.071	hydraulic group	140.3	
fold	0	1	fixed wing	11.2	0.564
vertical tail	92.3		rotary wing	79.8	0.845
basic	92.3	0.452	conversion	49.2	1
fold	0	1	equipment	0	
tail rotor	0		pneumatic group	0	
blades	0		electrical group	281.9	
hub & hinge	0		aircraft	250	
fuselage group	2041		anti-icing	31.9	0.75
basic	1947.9	0.797	avionics (MEQ)	1000	
crashworthiness	93.2	0.797	armament group	100	
alighting gear	513.6		armament prov	0	
basic	440.9	0.724	armor	100	
retraction	25.5	0.724	furnish & equip	770	
crashworthiness	47.3	0.724	environ control	100	
engine sect/nac	302.1		anti-icing group	42.8	0.75
engine support	48.3	0.641	load & handling	50	
engine cowling	92.2	0.422	VIBRATION	76.4	
pylon support	161.6	0.641	CONTINGENCY	764.4	
air induction	26	0.641	FIXED USEFUL LOAD	1070	
PROPULSION GROUP	3954.1		crew	1000	
engine system	1382.6		fluids	70	
engine	885	0.75			
exhaust system	332.6	0.754	WEIGHT EMPTY	15287.6	
accessories	164.9	0.465	Fixed UL for DGW	1070	
fuel system	421.6		OPERATING WEIGHT	16357.6	
tanks and supp	292.6	1.688	Fuel for DGW	3176.1	
plumbing	129.1	1.688	Payload for DGW	3000	
drive system	2149.9		USEFUL LOAD for DGW	7246.1	
gear boxes	1847.1	1.057	DESIGN GROSS WEIGHT	22532.6	
trans drive	73	0.485			
rotor shaft	182.7	1.057	Growth Factor	3.755	
rotor brake	47.1	1.057	Empty Weight Fraction	0.678	

Tiltrotor Weight, TBO = 12,000 flt. hrs.

	lb.	tech factor		lb.	tech factor
STRUCTURE	5965.7		SYSTEMS AND EQUIP	4594.9	
wing group	1241.2		flight controls	1828.5	
basic structure	945	0.742	cockpit controls	100	
secondary struct	216.4		auto flight cont	50	
fairings	83.8	0.735	system controls	1678.5	
fittings	132.6	0.735	fixed wing sys	223	
fold/tilt	0	0.735	non-boosted	22.3	0.566
control surfaces	79.8	0.735	boost mech	200.7	0.566
rotor group	1600.5		rotary wing sys	910.8	
blade assembly	920.6	0.731	non-boosted	456.5	0.739
hub & hinge	679.9		boost mech	241.5	0.849
basic	545.8	0.731	boosted	212.8	0.805
shaft	0	1	conversion sys	544.6	
fairing/spinner	134.1	0.763	non-boosted	49.5	1
blade fold	0	0.75	boost mech	495.1	1
empennage group	220.5		auxiliary power	130	
horizontal tail	127.6		instruments group	150	
basic	127.6	1.076	hydraulic group	141.4	
fold	0	1	fixed wing	11.4	0.566
vertical tail	92.9		rotary wing	80.5	0.849
basic	92.9	0.454	conversion	49.5	1
fold	0	1	equipment	0	
tail rotor	0		pneumatic group	0	
blades	0		electrical group	282	
hub & hinge	0		aircraft	250	
fuselage group	2054.9		anti-icing	32	0.75
basic	1960.9	0.799	avionics (MEQ)	1000	
crashworthiness	94	0.799	armament group	100	
alighting gear	518.3		armament prov	0	
basic	444.5	0.727	armor	100	
retraction	25.9	0.727	furnish & equip	770	
crashworthiness	47.9	0.727	environ control	100	
engine sect/nac	304.2		anti-icing group	43	0.75
engine support	48.7	0.644	load & handling	50	
engine cowling	92.7	0.424	VIBRATION	77	
pylon support	162.8	0.644	CONTINGENCY	769.7	
air induction	26.2	0.644	FIXED USEFUL LOAD	1070	
PROPULSION GROUP	3986.5		crew	1000	
engine system	1390.2		fluids	70	
engine	889.7	0.75			
exhaust system	335	0.757	WEIGHT EMPTY	15393.9	
accessories	165.4	0.465	Fixed UL for DGW	1070	
fuel system	423.2		OPERATING WEIGHT	16463.9	
tanks and supp	293.7	1.688	Fuel for DGW	3191.8	
plumbing	129.6	1.688	Payload for DGW	3000	
drive system	2173.1		USEFUL LOAD for DGW	7261.8	
gear boxes	1866.9	1.062	DESIGN GROSS WEIGHT	22654.6	
trans drive	73.7	0.488			
rotor shaft	184.6	1.062	Growth Factor	3.776	
rotor brake	47.9	1.062	Empty Weight Fraction	0.680	

Tiltrotor Weight, TBO = 13,000 flt. hrs.

	lb.	tech factor		lb.	tech factor
STRUCTURE	6018.3		SYSTEMS AND EQUIP	4608	
wing group	1253.4		flight controls	1840.1	
basic structure	955.7	0.746	cockpit controls	100	
secondary struct	217.5		auto flight cont	50	
fairings	84.2	0.735	system controls	1690.1	
fittings	133.3	0.735	fixed wing sys	224.7	
fold/tilt	0	0.735	non-boosted	22.5	0.569
control surfaces	80.2	0.735	boost mech	202.2	0.569
rotor group	1619		rotary wing sys	917.9	
blade assembly	930.3	0.735	non-boosted	459.5	0.742
hub & hinge	688.7		boost mech	243.5	0.853
basic	553.6	0.735	boosted	215	0.808
shaft	0	1	conversion sys	547.6	
fairing/spinner	135.1	0.766	non-boosted	49.8	1
blade fold	0	0.75	boost mech	497.8	1
empennage group	222.2		auxiliary power	130	
horizontal tail	128.8		instruments group	150	
basic	128.8	1.08	hydraulic group	142.4	
fold	0	1	fixed wing	11.5	0.569
vertical tail	93.4		rotary wing	81.2	0.853
basic	93.4	0.456	conversion	49.8	1
fold	0	1	equipment	0	
tail rotor	0		pneumatic group	0	
blades	0		electrical group	282.2	
hub & hinge	0		aircraft	250	
fuselage group	2068.4		anti-icing	32.2	0.75
basic	1973.6	0.801	avionics (MEQ)	1000	
crashworthiness	94.8	0.801	armament group	100	
alighting gear	522.7		armament prov	0	
basic	448.1	0.73	armor	100	
retraction	26.2	0.73	furnish & equip	770	
crashworthiness	48.5	0.73	environ control	100	
engine sect/nac	306.2		anti-icing group	43.2	0.75
engine support	49	0.647	load & handling	50	
engine cowling	93.3	0.426	VIBRATION	77.5	
pylon support	163.9	0.647	CONTINGENCY	774.8	
air induction	26.4	0.647	FIXED USEFUL LOAD	1070	
PROPULSION GROUP	4018.2		crew	1000	
engine system	1397.6		fluids	70	
engine	894.3	0.75			
exhaust system	337.4	0.761	WEIGHT EMPTY	15496.9	
accessories	166	0.465	Fixed UL for DGW	1070	
fuel system	425		OPERATING WEIGHT	16566.9	
tanks and supp	295	1.688	Fuel for DGW	3209.9	
plumbing	130.1	1.688	Payload for DGW	3000	
drive system	2195.6		USEFUL LOAD for DGW	7279.9	
gear boxes	1886	1.066	DESIGN GROSS WEIGHT	22775.5	
trans drive	74.4	0.49			
rotor shaft	186.5	1.066	Growth Factor	3.796	
rotor brake	48.6	1.066	Empty Weight Fraction	0.680	

Tiltrotor Weight, TBO = 14,000 flt. hrs.

	lb.	tech factor		lb.	tech factor
STRUCTURE	6059.9		SYSTEMS AND EQUIP	4618.3	
wing group	1263.2		flight controls	1849.3	
basic structure	964.6	0.749	cockpit controls	100	
secondary struct	218.3		auto flight cont	50	
fairings	84.5	0.735	system controls	1699.3	
fittings	133.8	0.735	fixed wing sys	226	
fold/tilt	0	0.735	non-boosted	22.6	0.571
control surfaces	80.4	0.735	boost mech	203.4	0.571
rotor group	1633.7		rotary wing sys	923.7	
blade assembly	938	0.738	non-boosted	462	0.745
hub & hinge	695.7		boost mech	245	0.856
basic	559.9	0.738	boosted	216.7	0.812
shaft	0	1	conversion sys	549.5	
fairing/spinner	135.8	0.769	non-boosted	50	1
blade fold	0	0.75	boost mech	499.6	1
empennage group	223.6		auxiliary power	130	
horizontal tail	129.7		instruments group	150	
basic	129.7	1.085	hydraulic group	143.2	
fold	0	1	fixed wing	11.6	0.571
vertical tail	93.9		rotary wing	81.7	0.856
basic	93.9	0.458	conversion	50	1
fold	0	1	equipment	0	
tail rotor	0		pneumatic group	0	
blades	0		electrical group	282.3	
hub & hinge	0		aircraft	250	
fuselage group	2078.7		anti-icing	32.3	0.75
basic	1983.2	0.802	avionics (MEQ)	1000	
crashworthiness	95.5	0.802	armament group	100	
alighting gear	526.4		armament prov	0	
basic	450.9	0.733	armor	100	
retraction	26.5	0.733	furnish & equip	770	
crashworthiness	49	0.733	environ control	100	
engine sect/nac	307.7		anti-icing group	43.4	0.75
engine support	49.3	0.649	load & handling	50	
engine cowling	93.6	0.428	VIBRATION	77.9	
pylon support	164.8	0.649	CONTINGENCY	778.8	
air induction	26.5	0.649	FIXED USEFUL LOAD	1070	
PROPULSION GROUP	4041.7		crew	1000	
engine system	1402.9		fluids	70	
engine	897.4	0.75			
exhaust system	339.2	0.764	WEIGHT EMPTY	15576.5	
accessories	166.3	0.465	Fixed UL for DGW	1070	
fuel system	425.5		OPERATING WEIGHT	16646.5	
tanks and supp	295.2	1.688	Fuel for DGW	3212.5	
plumbing	130.4	1.688	Payload for DGW	3000	
drive system	2213.3		USEFUL LOAD for DGW	7282.5	
gear boxes	1901.1	1.071	DESIGN GROSS WEIGHT	22857.9	
trans drive	75	0.492			
rotor shaft	188	1.071	Growth Factor	3.810	
rotor brake	49.2	1.071	Empty Weight Fraction	0.681	

Tiltrotor Weight, TBO = 15,000 flt. hrs.

	lb.	tech factor		lb.	tech factor
STRUCTURE	6105.7		SYSTEMS AND EQUIP	4629.6	
wing group	1273.9		flight controls	1859.4	
basic structure	974	0.751	cockpit controls	100	
secondary struct	219.2		auto flight cont	50	
fairings	84.8	0.735	system controls	1709.4	
fittings	134.4	0.735	fixed wing sys	227.5	
fold/tilt	0	0.735	non-boosted	22.8	0.573
control surfaces	80.7	0.735	boost mech	204.8	0.573
rotor group	1649.9		rotary wing sys	929.9	
blade assembly	946.5	0.74	non-boosted	464.6	0.748
hub & hinge	703.4		boost mech	246.7	0.86
basic	566.8	0.74	boosted	218.6	0.815
shaft	0	1	conversion sys	552	
fairing/spinner	136.7	0.772	non-boosted	50.2	1
blade fold	0	0.75	boost mech	501.8	1
empennage group	225.1		auxiliary power	130	
horizontal tail	130.7		instruments group	150	
basic	130.7	1.089	hydraulic group	144.1	
fold	0	1	fixed wing	11.7	0.573
vertical tail	94.3		rotary wing	82.2	0.86
basic	94.3	0.46	conversion	50.2	1
fold	0	1	equipment	0	
tail rotor	0		pneumatic group	0	
blades	0		electrical group	282.5	
hub & hinge	0		aircraft	250	
fuselage group	2090.4		anti-icing	32.5	0.75
basic	1994.2	0.804	avionics (MEQ)	1000	
crashworthiness	96.2	0.804	armament group	100	
alighting gear	530.3		armament prov	0	
basic	454	0.736	armor	100	
retraction	26.7	0.736	furnish & equip	770	
crashworthiness	49.5	0.736	environ control	100	
engine sect/nac	309.5		anti-icing group	43.6	0.75
engine support	49.6	0.652	load & handling	50	
engine cowling	94.1	0.429	VIBRATION	78.3	
pylon support	165.8	0.652	CONTINGENCY	783.3	
air induction	26.7	0.652	FIXED USEFUL LOAD	1070	
PROPULSION GROUP	4069.3		crew	1000	
engine system	1409.4		fluids	70	
engine	901.4	0.75			
exhaust system	341.3	0.767	WEIGHT EMPTY	15666.3	
accessories	166.7	0.465	Fixed UL for DGW	1070	
fuel system	426.9		OPERATING WEIGHT	16736.3	
tanks and supp	296.1	1.688	Fuel for DGW	3226.1	
plumbing	130.8	1.688	Payload for DGW	3000	
drive system	2233		USEFUL LOAD for DGW	7296.1	
gear boxes	1917.8	1.075	DESIGN GROSS WEIGHT	22961.4	
trans drive	75.6	0.494			
rotor shaft	189.7	1.075	Growth Factor	3.827	
rotor brake	49.8	1.075	Empty Weight Fraction	0.682	

Tiltrotor Weight, TBO = 16,000 flt. hrs.

	lb.	tech factor		lb.	tech factor
STRUCTURE	6138.5		SYSTEMS AND EQUIP	4637.6	
wing group	1281.8		flight controls	1866.6	
basic structure	981.2	0.754	cockpit controls	100	
secondary struct	219.7		auto flight cont	50	
fairings	85	0.735	system controls	1716.6	
fittings	134.7	0.735	fixed wing sys	228.6	
fold/tilt	0	0.735	non-boosted	22.9	0.575
control surfaces	80.8	0.735	boost mech	205.8	0.575
rotor group	1661.6		rotary wing sys	934.6	
blade assembly	952.6	0.743	non-boosted	466.6	0.751
hub & hinge	709.1		boost mech	247.9	0.863
basic	571.8	0.743	boosted	220	0.817
shaft	0	1	conversion sys	553.4	
fairing/spinner	137.2	0.775	non-boosted	50.3	1
blade fold	0	0.75	boost mech	503.1	1
empennage group	226.1		auxiliary power	130	
horizontal tail	131.5		instruments group	150	
basic	131.5	1.092	hydraulic group	144.8	
fold	0	1	fixed wing	11.8	0.575
vertical tail	94.7		rotary wing	82.6	0.863
basic	94.7	0.462	conversion	50.3	1
fold	0	1	equipment	0	
tail rotor	0		pneumatic group	0	
blades	0		electrical group	282.6	
hub & hinge	0		aircraft	250	
fuselage group	2098.3		anti-icing	32.6	0.75
basic	2001.6	0.805	avionics (MEQ)	1000	
crashworthiness	96.7	0.805	armament group	100	
alighting gear	533.3		armament prov	0	
basic	456.3	0.739	armor	100	
retraction	27	0.739	furnish & equip	770	
crashworthiness	50	0.739	environ control	100	
engine sect/nac	310.6		anti-icing group	43.7	0.75
engine support	49.8	0.654	load & handling	50	
engine cowling	94.4	0.431	VIBRATION	78.6	
pylon support	166.4	0.654	CONTINGENCY	786.4	
air induction	26.8	0.654	FIXED USEFUL LOAD	1070	
PROPULSION GROUP	4086.8		crew	1000	
engine system	1413.1		fluids	70	
engine	903.5	0.75			
exhaust system	342.6	0.769	WEIGHT EMPTY	15728	
accessories	167	0.465	Fixed UL for DGW	1070	
fuel system	426.8		OPERATING WEIGHT	16798	
tanks and supp	295.8	1.688	Fuel for DGW	3221.6	
plumbing	131	1.688	Payload for DGW	3000	
drive system	2246.9		USEFUL LOAD for DGW	7291.6	
gear boxes	1929.7	1.078	DESIGN GROSS WEIGHT	23018.3	
trans drive	76.1	0.495			
rotor shaft	190.9	1.078	Growth Factor	3.836	
rotor brake	50.3	1.078	Empty Weight Fraction	0.683	

Tiltrotor Weight, TBO = 17,000 flt. hrs.

	lb.	tech factor		lb.	tech factor
STRUCTURE	6181.7		SYSTEMS AND EQUIP	4648.3	
wing group	1291.8		flight controls	1876.1	
basic structure	990	0.756	cockpit controls	100	
secondary struct	220.7		auto flight cont	50	
fairings	85.4	0.735	system controls	1726.1	
fittings	135.3	0.735	fixed wing sys	230	
fold/tilt	0	0.735	non-boosted	23	0.577
control surfaces	81.1	0.735	boost mech	207	0.577
rotor group	1676.9		rotary wing sys	940.3	
blade assembly	960.6	0.745	non-boosted	469	0.753
hub & hinge	716.3		boost mech	249.5	0.866
basic	578.3	0.745	boosted	221.8	0.82
shaft	0	1	conversion sys	555.8	
fairing/spinner	138	0.777	non-boosted	50.5	1
blade fold	0	0.75	boost mech	505.3	1
empennage group	227.6		auxiliary power	130	
horizontal tail	132.4		instruments group	150	
basic	132.4	1.096	hydraulic group	145.6	
fold	0	1	fixed wing	11.9	0.577
vertical tail	95.1		rotary wing	83.2	0.866
basic	95.1	0.463	conversion	50.5	1
fold	0	1	equipment	0	
tail rotor	0		pneumatic group	0	
blades	0		electrical group	282.7	
hub & hinge	0		aircraft	250	
fuselage group	2109.4		anti-icing	32.7	0.75
basic	2012	0.807	avionics (MEQ)	1000	
crashworthiness	97.4	0.807	armament group	100	
alighting gear	536.9		armament prov	0	
basic	459.2	0.741	armor	100	
retraction	27.2	0.741	furnish & equip	770	
crashworthiness	50.5	0.741	environ control	100	
engine sect/nac	312.3		anti-icing group	43.8	0.75
engine support	50.1	0.656	load & handling	50	
engine cowling	94.8	0.432	VIBRATION	79.1	
pylon support	167.4	0.656	CONTINGENCY	790.6	
air induction	27	0.656	FIXED USEFUL LOAD	1070	
PROPULSION GROUP	4113.2		crew	1000	
engine system	1419.4		fluids	70	
engine	907.4	0.75			
exhaust system	344.5	0.772	WEIGHT EMPTY	15812.9	
accessories	167.4	0.465	Fixed UL for DGW	1070	
fuel system	428.3		OPERATING WEIGHT	16882.9	
tanks and supp	296.9	1.688	Fuel for DGW	3237.1	
plumbing	131.4	1.688	Payload for DGW	3000	
drive system	2265.5		USEFUL LOAD for DGW	7307.1	
gear boxes	1945.5	1.082	DESIGN GROSS WEIGHT	23118.8	
trans drive	76.6	0.497			
rotor shaft	192.4	1.082	Growth Factor	3.853	
rotor brake	50.9	1.082	Empty Weight Fraction	0.684	

Tiltrotor Weight, TBO = 18,000 flt. hrs.

	lb.	tech factor		lb.	tech factor
STRUCTURE	6217.3		SYSTEMS AND EQUIP	4657	
wing group	1300.2		flight controls	1883.9	
basic structure	997.5	0.759	cockpit controls	100	
secondary struct	221.3		auto flight cont	50	
fairings	85.6	0.735	system controls	1733.9	
fittings	135.7	0.735	fixed wing sys	231.2	
fold/tilt	0	0.735	non-boosted	23.1	0.579
control surfaces	81.4	0.735	boost mech	208	0.579
rotor group	1689.5		rotary wing sys	945.1	
blade assembly	967.2	0.748	non-boosted	471.1	0.756
hub & hinge	722.4		boost mech	250.8	0.868
basic	583.7	0.748	boosted	223.3	0.823
shaft	0	1	conversion sys	557.6	
fairing/spinner	138.6	0.78	non-boosted	50.7	1
blade fold	0	0.75	boost mech	506.9	1
empennage group	228.7		auxiliary power	130	
horizontal tail	133.2		instruments group	150	
basic	133.2	1.099	hydraulic group	146.3	
fold	0	1	fixed wing	12	0.579
vertical tail	95.5		rotary wing	83.6	0.868
basic	95.5	0.465	conversion	50.7	1
fold	0	1	equipment	0	
tail rotor	0		pneumatic group	0	
blades	0		electrical group	282.8	
hub & hinge	0		aircraft	250	
fuselage group	2118.3		anti-icing	32.8	0.75
basic	2020.3	0.808	avionics (MEQ)	1000	
crashworthiness	97.9	0.808	armament group	100	
alighting gear	539.9		armament prov	0	
basic	461.6	0.743	armor	100	
retraction	27.4	0.743	furnish & equip	770	
crashworthiness	50.9	0.743	environ control	100	
engine sect/nac	313.6		anti-icing group	44	0.75
engine support	50.3	0.658	load & handling	50	
engine cowling	95.2	0.434	VIBRATION	79.4	
pylon support	168.1	0.658	CONTINGENCY	794.1	
air induction	27.1	0.658	FIXED USEFUL LOAD	1070	
PROPULSION GROUP	4133.8		crew	1000	
engine system	1424.1		fluids	70	
engine	910.3	0.75			
exhaust system	346.1	0.774	WEIGHT EMPTY	15881.7	
accessories	167.7	0.465	Fixed UL for DGW	1070	
fuel system	429		OPERATING WEIGHT	16951.7	
tanks and supp	297.3	1.688	Fuel for DGW	3242.7	
plumbing	131.8	1.688	Payload for DGW	3000	
drive system	2280.7		USEFUL LOAD for DGW	7312.7	
gear boxes	1958.4	1.085	DESIGN GROSS WEIGHT	23193.4	
trans drive	77.1	0.498			
rotor shaft	193.7	1.085	Growth Factor	3.866	
rotor brake	51.4	1.085	Empty Weight Fraction	0.685	

Tiltrotor Weight, TBO = 19,000 flt. hrs.

	lb.	tech factor		lb.	tech factor
STRUCTURE	6253.9		SYSTEMS AND EQUIP	4666	
wing group	1308.7		flight controls	1891.9	
basic structure	1005.1	0.761	cockpit controls	100	
secondary struct	222.1		auto flight cont	50	
fairings	85.9	0.735	system controls	1741.9	
fittings	136.2	0.735	fixed wing sys	232.3	
fold/tilt	0	0.735	non-boosted	23.2	0.581
control surfaces	81.6	0.735	boost mech	209.1	0.581
rotor group	1702.6		rotary wing sys	950	
blade assembly	974	0.75	non-boosted	473.1	0.758
hub & hinge	728.6		boost mech	252.1	0.871
basic	589.3	0.75	boosted	224.8	0.825
shaft	0	1	conversion sys	559.6	
fairing/spinner	139.3	0.782	non-boosted	50.9	1
blade fold	0	0.75	boost mech	508.7	1
empennage group	229.9		auxiliary power	130	
horizontal tail	134		instruments group	150	
basic	134	1.103	hydraulic group	147	
fold	0	1	fixed wing	12.1	0.581
vertical tail	95.9		rotary wing	84	0.871
basic	95.9	0.466	conversion	50.9	1
fold	0	1	equipment	0	
tail rotor	0		pneumatic group	0	
blades	0		electrical group	282.9	
hub & hinge	0		aircraft	250	
fuselage group	2127.4		anti-icing	32.9	0.75
basic	2028.9	0.809	avionics (MEQ)	1000	
crashworthiness	98.5	0.809	armament group	100	
alighting gear	543		armament prov	0	
basic	464	0.745	armor	100	
retraction	27.7	0.745	furnish & equip	770	
crashworthiness	51.3	0.745	environ control	100	
engine sect/nac	315		anti-icing group	44.1	0.75
engine support	50.5	0.66	load & handling	50	
engine cowling	95.5	0.435	VIBRATION	79.8	
pylon support	168.9	0.66	CONTINGENCY	797.6	
air induction	27.2	0.66	FIXED USEFUL LOAD	1070	
PROPULSION GROUP	4155.5		crew	1000	
engine system	1429.1		fluids	70	
engine	913.4	0.75			
exhaust system	347.7	0.777	WEIGHT EMPTY	15952.8	
accessories	168	0.465	Fixed UL for DGW	1070	
fuel system	430.1		OPERATING WEIGHT	17022.8	
tanks and supp	298	1.688	Fuel for DGW	3253.2	
plumbing	132.1	1.688	Payload for DGW	3000	
drive system	2296.3		USEFUL LOAD for DGW	7323.2	
gear boxes	1971.7	1.088	DESIGN GROSS WEIGHT	23275	
trans drive	77.6	0.5			
rotor shaft	195	1.088	Growth Factor	3.879	
rotor brake	51.9	1.088	Empty Weight Fraction	0.685	

Tiltrotor Weight, TBO = 20,000 flt. hrs.

	lb.	tech factor		lb.	tech factor
STRUCTURE	6288.7		SYSTEMS AND EQUIP	4674.5	
wing group	1316.9		flight controls	1899.5	
basic structure	1012.2	0.763	cockpit controls	100	
secondary struct	222.8		auto flight cont	50	
fairings	86.1	0.735	system controls	1749.5	
fittings	136.7	0.735	fixed wing sys	233.4	
fold/tilt	0	0.735	non-boosted	23.3	0.582
control surfaces	81.8	0.735	boost mech	210.1	0.582
rotor group	1715.1		rotary wing sys	954.7	
blade assembly	980.5	0.752	non-boosted	475	0.76
hub & hinge	734.6		boost mech	253.4	0.873
basic	594.6	0.752	boosted	226.3	0.827
shaft	0	1	conversion sys	561.4	
fairing/spinner	139.9	0.784	non-boosted	51	1
blade fold	0	0.75	boost mech	510.4	1
empennage group	231.1		auxiliary power	130	
horizontal tail	134.8		instruments group	150	
basic	134.8	1.106	hydraulic group	147.7	
fold	0	1	fixed wing	12.2	0.582
vertical tail	96.3		rotary wing	84.5	0.873
basic	96.3	0.467	conversion	51	1
fold	0	1	equipment	0	
tail rotor	0		pneumatic group	0	
blades	0		electrical group	283	
hub & hinge	0		aircraft	250	
fuselage group	2136.1		anti-icing	33	0.75
basic	2037.1	0.81	avionics (MEQ)	1000	
crashworthiness	99	0.81	armament group	100	
alighting gear	545.9		armament prov	0	
basic	466.3	0.748	armor	100	
retraction	27.9	0.748	furnish & equip	770	
crashworthiness	51.7	0.748	environ control	100	
engine sect/nac	316.3		anti-icing group	44.2	0.75
engine support	50.8	0.662	load & handling	50	
engine cowling	95.9	0.436	VIBRATION	80.1	
pylon support	169.6	0.662	CONTINGENCY	801	
air induction	27.3	0.662	FIXED USEFUL LOAD	1070	
PROPULSION GROUP	4176.3		crew	1000	
engine system	1433.9		fluids	70	
engine	916.3	0.75			
exhaust system	349.2	0.779	WEIGHT EMPTY	16020.7	
accessories	168.4	0.465	Fixed UL for DGW	1070	
fuel system	431.1		OPERATING WEIGHT	17090.7	
tanks and supp	298.8	1.688	Fuel for DGW	3263.4	
plumbing	132.4	1.688	Payload for DGW	3000	
drive system	2311.3		USEFUL LOAD for DGW	7333.4	
gear boxes	1984.5	1.091	DESIGN GROSS WEIGHT	23352.4	
trans drive	78.1	0.501			
rotor shaft	196.3	1.091	Growth Factor	3.892	
rotor brake	52.4	1.091	Empty Weight Fraction	0.686	

APPENDIX H

TRADE STUDY COST RESULTS

Helicopter Acquisition Cost Summary, TBO = 6,000 flt. hrs.

	RAM RDT&E	**Avg. Unit Procurement**	
Rotor	$.431M	$1.094M	
Airframe	$.000M	$2.507M	
Alighting Gear	$.000M	$.196M	
Air Induction + Nacelle	$.000M	$.353M	
Propulsion Group	$.000M	$4.601M	
Drive System	$.258M	$.656M	
Flight Controls	$.405M	$1.026M	
Vehicle Systems	$.644M	$1.378M	
Avionics (MEQ)	$.650M	$4.500M	
Furnishings	$.000M	$.198M	
Fixed RDT&E	**$250M**	**$16.507M**	**Unit Prime Equipment**
		$.825M	Contingency
		$.990M	Final Assembly & Integration
		$1.981M	Profit & Fee
		$20.304M	**Flyaway Price**
		$.399M	SE/PM, Data Training
		$.165M	Init. Spares & Support Equip.
Total RAM Improvement RDT&E	**$252.388M**	**$20.868M**	**Unit Procurement Cost**

Helicopter Acquisition Cost Summary, TBO = 7,000 flt. hrs.

	RDT&E	**Avg. Unit Procurement**	
Rotor	$3.278M	$1.103M	
Airframe	$.000M	$2.514M	
Alighting Gear	$.000M	$.196M	
Air Induction + Nacelle	$.000M	$.354M	
Propulsion Group	$.573M	$4.855M	
Drive System	$1.960M	$.659M	
Flight Controls	$3.068M	$1.032M	
Vehicle Systems	$4.860M	$1.379M	
Avionics (MEQ)	$4.905M	$4.500M	
Furnishings	$.000M	$.198M	
Fixed RDT&E	**$250M**	**$16.789M**	**Unit Prime Equipment**
		$.839M	Contingency
		$1.007M	Final Assembly & Integration
		$2.015M	Profit & Fee
		$20.651M	**Flyaway Price**
		$.406M	SE/PM, Data Training
		$.168M	Init. Spares & Support Equip.
Total RAM Improvement RDT&E	**$268.644M**	**$21.225M**	**Unit Procurement Cost**

Helicopter Acquisition Cost Summary, TBO = 8,000 flt. hrs.

	RDT&E	**Avg. Unit Procurement**	
Rotor	$10.766M	$1.111M	
Airframe	$.000M	$2.520M	
Alighting Gear	$.000M	$.196M	
Air Induction + Nacelle	$.000M	$.355M	
Propulsion Group	$4.520M	$5.088M	
Drive System	$6.427M	$.663M	
Flight Controls	$10.055M	$1.037M	
Vehicle Systems	$15.851M	$1.379M	
Avionics (MEQ)	$15.992M	$4.500M	
Furnishings	$.000M	$.198M	
Fixed RDT&E	**$250M**	**$17.047M**	**Unit Prime Equipment**
		$.852M	Contingency
		$1.023M	Final Assembly & Integration
		$2.046M	Profit & Fee
		$20.968M	**Flyaway Price**
		$.413M	SE/PM, Data Training
		$.170M	Init. Spares & Support Equip.
Total RAM Improvement RDT&E	**$313.610M**	**$21.551M**	**Unit Procurement Cost**

Helicopter Acquisition Cost Summary, TBO = 9,000 flt. hrs.

	RDT&E	**Avg. Unit Procurement**	
Rotor	$25.060M	$1.118M	
Airframe	$.000M	$2.526M	
Alighting Gear	$.000M	$.196M	
Air Induction + Nacelle	$.000M	$.356M	
Propulsion Group	$15.337M	$5.303M	
Drive System	$14.934M	$.666M	
Flight Controls	$23.361M	$1.042M	
Vehicle Systems	$36.670M	$1.380M	
Avionics (MEQ)	$36.990M	$4.500M	
Furnishings	$.000M	$.198M	
Fixed RDT&E	**$250M**	**$17.285M**	**Unit Prime Equipment**
		$.864M	Contingency
		$1.037M	Final Assembly & Integration
		$2.074M	Profit & Fee
		$21.260M	**Flyaway Price**
		$.418M	SE/PM, Data Training
		$.173M	Init. Spares & Support Equip.
Total RAM Improvement RDT&E	**$402.353M**	**$21.851M**	**Unit Procurement Cost**

Helicopter Acquisition Cost Summary, TBO = 10,000 flt. hrs.

	RDT&E	**Avg. Unit Procurement**	
Rotor	$48.302M	$1.124M	
Airframe	$.000M	$2.530M	
Alighting Gear	$.000M	$.196M	
Air Induction + Nacelle	$.000M	$.357M	
Propulsion Group	$36.775M	$5.505M	
Drive System	$28.744M	$.669M	
Flight Controls	$44.943M	$1.046M	
Vehicle Systems	$70.301M	$1.380M	
Avionics (MEQ)	$70.889M	$4.500M	
Furnishings	$.000M	$.198M	
Fixed RDT&E	**$250M**	**$17.506M**	**Unit Prime Equipment**
		$.875M	Contingency
		$1.050M	Final Assembly & Integration
		$2.101M	Profit & Fee
		$21.533M	**Flyaway Price**
		$.424M	SE/PM, Data Training
		$.175M	Init. Spares & Support Equip.
Total RAM Improvement RDT&E	**$549.954M**	**$22.131M**	**Unit Procurement Cost**

Helicopter Acquisition Cost Summary, TBO = 11,000 flt. hrs.

	RDT&E	**Avg. Unit Procurement**	
Rotor	$82.701M	$1.131M	
Airframe	$.133M	$2.542M	
Alighting Gear	$.010M	$.197M	
Air Induction + Nacelle	$.014M	$.360M	
Propulsion Group	$72.923M	$5.701M	
Drive System	$49.130M	$.672M	
Flight Controls	$76.791M	$1.050M	
Vehicle Systems	$119.664M	$1.381M	
Avionics (MEQ)	$120.623M	$4.500M	
Furnishings	$.000M	$.198M	
Fixed RDT&E	**$250M**	**$17.733M**	**Unit Prime Equipment**
		$.887M	Contingency
		$1.064M	Final Assembly & Integration
		$2.128M	Profit & Fee
		$21.812M	**Flyaway Price**
		$.429M	SE/PM, Data Training
		$.177M	Init. Spares & Support Equip.
Total RAM Improvement RDT&E	**$771.990M**	**$22.418M**	**Unit Procurement Cost**

Helicopter Acquisition Cost Summary, TBO = 12,000 flt. hrs.

	RDT&E	**Avg. Unit Procurement**	
Rotor	$138.764M	$1.138M	
Airframe	$1.243M	$2.555M	
Alighting Gear	$.096M	$.198M	
Air Induction + Nacelle	$.136M	$.363M	
Propulsion Group	$138.172M	$5.914M	
Drive System	$82.305M	$.675M	
Flight Controls	$128.570M	$1.055M	
Vehicle Systems	$199.611M	$1.382M	
Avionics (MEQ)	$201.105M	$4.500M	
Furnishings	$.000M	$.198M	
Fixed RDT&E	**$250M**	**$17.979M**	**Unit Prime Equipment**
		$.899M	Contingency
		$1.079M	Final Assembly & Integration
		$2.157M	Profit & Fee
		$22.114M	**Flyaway Price**
		$.435M	SE/PM, Data Training
		$.180M	Init. Spares & Support Equip.
Total RAM Improvement RDT&E	**$1,140.00M**	**$22.729M**	**Unit Procurement Cost**

Helicopter Acquisition Cost Summary, TBO = 13,000 flt. hrs.

	RDT&E	**Avg. Unit Procurement**	
Rotor	$193.376M	$1.143M	
Airframe	$3.294M	$2.563M	
Alighting Gear	$.255M	$.199M	
Air Induction + Nacelle	$.361M	$.365M	
Propulsion Group	$206.481M	$6.064M	
Drive System	$114.562M	$.677M	
Flight Controls	$178.904M	$1.058M	
Vehicle Systems	$276.990M	$1.382M	
Avionics (MEQ)	$279.015M	$4.500M	
Furnishings	$.000M	$.198M	
Fixed RDT&E	**$250M**	**$18.151M**	**Unit Prime Equipment**
		$.908M	Contingency
		$1.089M	Final Assembly & Integration
		$2.178M	Profit & Fee
		$22.325M	**Flyaway Price**
		$.439M	SE/PM, Data Training
		$.182M	Init. Spares & Support Equip.
Total RAM Improvement RDT&E	**$1,503.24M**	**$22.946M**	**Unit Procurement Cost**

Helicopter Acquisition Cost Summary, TBO = 14,000 flt. hrs.

	RDT&E	**Avg. Unit Procurement**	
Rotor	$273.908M	$1.149M	
Airframe	$7.649M	$2.573M	
Alighting Gear	$.592M	$.199M	
Air Induction + Nacelle	$.840M	$.368M	
Propulsion Group	$312.999M	$6.233M	
Drive System	$162.088M	$.680M	
Flight Controls	$252.993M	$1.061M	
Vehicle Systems	$390.595M	$1.383M	
Avionics (MEQ)	$393.313M	$4.500M	
Furnishings	$.000M	$.198M	
Fixed RDT&E	**$250M**	**$18.344M**	**Unit Prime Equipment**
		$.917M	Contingency
		$1.101M	Final Assembly & Integration
		$2.201M	Profit & Fee
		$22.563M	**Flyaway Price**
		$.444M	SE/PM, Data Training
		$.183M	Init. Spares & Support Equip.
Total RAM Improvement RDT&E	**$2,044.98M**	**$23.191M**	**Unit Procurement Cost**

Helicopter Acquisition Cost Summary, TBO = 15,000 flt. hrs.

	RDT&E	**Avg. Unit Procurement**	
Rotor	$374.072M	$1.154M	
Airframe	$14.709M	$2.582M	
Alighting Gear	$1.139M	$.200M	
Air Induction + Nacelle	$1.619M	$.370M	
Propulsion Group	$452.368M	$6.395M	
Drive System	$221.066M	$.682M	
Flight Controls	$344.992M	$1.065M	
Vehicle Systems	$531.204M	$1.384M	
Avionics (MEQ)	$534.713M	$4.500M	
Furnishings	$.000M	$.198M	
Fixed RDT&E	**$250M**	**$18.529M**	**Unit Prime Equipment**
		$.926M	Contingency
		$1.112M	Final Assembly & Integration
		$2.223M	Profit & Fee
		$22.791M	**Flyaway Price**
		$.448M	SE/PM, Data Training
		$.185M	Init. Spares & Support Equip.
Total RAM Improvement RDT&E	**$2,725.88M**	**$23.424M**	**Unit Procurement Cost**

Helicopter Acquisition Cost Summary, TBO = 16,000 flt. hrs.

	RDT&E	**Avg. Unit Procurement**	
Rotor	$495.965M	$1.159M	
Airframe	$25.106M	$2.590M	
Alighting Gear	$1.943M	$.200M	
Air Induction + Nacelle	$2.771M	$.372M	
Propulsion Group	$629.579M	$6.551M	
Drive System	$292.790M	$.684M	
Flight Controls	$456.771M	$1.068M	
Vehicle Systems	$701.450M	$1.384M	
Avionics (MEQ)	$705.961M	$4.500M	
Furnishings	$.000M	$.198M	
Fixed RDT&E	**$250M**	**$18.706M**	**Unit Prime Equipment**
		$.935M	Contingency
		$1.122M	Final Assembly & Integration
		$2.245M	Profit & Fee
		$23.009M	**Flyaway Price**
		$.453M	SE/PM, Data Training
		$.187M	Init. Spares & Support Equip.
Total RAM Improvement RDT&E	**$3,562.34M**	**$23.649M**	**Unit Procurement Cost**

Helicopter Acquisition Cost Summary, TBO = 17,000 flt. hrs.

	RDT&E	**Avg. Unit Procurement**	
Rotor	$641.722M	$1.164M	
Airframe	$39.472M	$2.598M	
Alighting Gear	$3.053M	$.201M	
Air Induction + Nacelle	$4.365M	$.374M	
Propulsion Group	$849.763M	$6.701M	
Drive System	$378.441M	$.686M	
Flight Controls	$590.196M	$1.070M	
Vehicle Systems	$904.278M	$1.385M	
Avionics (MEQ)	$909.776M	$4.500M	
Furnishings	$.000M	$.198M	
Fixed RDT&E	**$250M**	**$18.877M**	**Unit Prime Equipment**
		$.944M	Contingency
		$1.133M	Final Assembly & Integration
		$2.265M	Profit & Fee
		$23.219M	**Flyaway Price**
		$.457M	SE/PM, Data Training
		$.189M	Init. Spares & Support Equip.
Total RAM Improvement RDT&E	**$4,571.06M**	**$23.865M**	**Unit Procurement Cost**

Helicopter Acquisition Cost Summary, TBO = 18,000 flt. hrs.

	RDT&E	**Avg. Unit Procurement**	
Rotor	$813.381M	$1.168M	
Airframe	$58.422M	$2.606M	
Alighting Gear	$4.517M	$.201M	
Air Induction + Nacelle	$6.473M	$.376M	
Propulsion Group	$1118.130M	$6.846M	
Drive System	$479.241M	$.688M	
Flight Controls	$747.205M	$1.073M	
Vehicle Systems	$1142.114M	$1.385M	
Avionics (MEQ)	$1148.857M	$4.500M	
Furnishings	$.000M	$.198M	
Fixed RDT&E	**$250M**	**$19.041M**	**Unit Prime Equipment**
		$.952M	Contingency
		$1.142M	Final Assembly & Integration
		$2.285M	Profit & Fee
		$23.420M	**Flyaway Price**
		$.461M	SE/PM, Data Training
		$.190M	Init. Spares & Support Equip.
Total RAM Improvement RDT&E	**$5,768.34M**	**$24.072M**	**Unit Procurement Cost**

Helicopter Acquisition Cost Summary, TBO = 19,000 flt. hrs.

	RDT&E	**Avg. Unit Procurement**	
Rotor	$1045.638M	$1.173M	
Airframe	$86.695M	$2.614M	
Alighting Gear	$6.700M	$.202M	
Air Induction + Nacelle	$9.628M	$.378M	
Propulsion Group	$1493.397M	$7.007M	
Drive System	$615.463M	$.690M	
Flight Controls	$959.267M	$1.076M	
Vehicle Systems	$1462.753M	$1.386M	
Avionics (MEQ)	$1470.876M	$4.500M	
Furnishings	$.000M	$.198M	
Fixed RDT&E	**$250M**	**$19.223M**	**Unit Prime Equipment**
		$.961M	Contingency
		$1.153M	Final Assembly & Integration
		$2.307M	Profit & Fee
		$23.645M	**Flyaway Price**
		$.465M	SE/PM, Data Training
		$.192M	Init. Spares & Support Equip.
Total RAM Improvement RDT&E	**$7,400.42M**	**$24.302M**	**Unit Procurement Cost**

Helicopter Acquisition Cost Summary, TBO = 20,000 flt. hrs.

	RDT&E	**Avg. Unit Procurement**	
Rotor	$1243.100M	$1.176M	
Airframe	$112.566M	$2.620M	
Alighting Gear	$8.696M	$.202M	
Air Induction + Nacelle	$12.521M	$.379M	
Propulsion Group	$1821.279M	$7.122M	
Drive System	$731.202M	$.692M	
Flight Controls	$1139.267M	$1.078M	
Vehicle Systems	$1734.194M	$1.386M	
Avionics (MEQ)	$1743.520M	$4.500M	
Furnishings	$.000M	$.198M	
Fixed RDT&E	**$250M**	**$19.353M**	**Unit Prime Equipment**
		$.968M	Contingency
		$1.161M	Final Assembly & Integration
		$2.322M	Profit & Fee
		$23.805M	**Flyaway Price**
		$.468M	SE/PM, Data Training
		$.194M	Init. Spares & Support Equip.
Total RAM Improvement RDT&E	**$8,796.35M**	**$24.467M**	**Unit Procurement Cost**

Lift Offset Acquisition Cost Summary, TBO = 6,000 flt. hrs.

	RDT&E	**Avg. Unit Procurement**	
Rotor	$1.49M	3,791,604	
Airframe	$.00M	3,167,004	
Alighting Gear	$.00M	240,308	
Air Induction + Nacelle	$.00M	434,649	
Propulsion Group	$.00M	4,441,939	
Drive System	$.53M	1,344,828	
Flight Controls	$1.15M	2,904,996	
Vehicle Systems	$.69M	1,391,947	
Avionics (MEQ)	$.65M	4,500,000	
Furnishings	$.00M	197,630	
Fixed RDT&E	**$250M**	**22,414,904**	**Unit Prime Equipment**
		1,120,745	Contingency
		1,344,894	Final Assembly & Integration
		2,689,789	Profit & Fee
		27,570,332	**Flyaway Price**
		542,441	SE/PM, Data Training
		224,149	Init. Spares & Support Equip.
Total RAM Improvement RDT&E	**$254.51M**	**28,336,922**	**Unit Procurement Cost**

Lift Offset Acquisition Cost Summary, TBO = 7,000 flt. hrs.

	RDT&E	**Avg. Unit Procurement**	
Rotor	$11.41M	3,836,879	
Airframe	$.00M	3,181,436	
Alighting Gear	$.00M	240,780	
Air Induction + Nacelle	$.00M	436,304	
Propulsion Group	$.58M	4,688,914	
Drive System	$4.04M	1,358,182	
Flight Controls	$8.72M	2,934,252	
Vehicle Systems	$5.17M	1,393,395	
Avionics (MEQ)	$4.90M	4,500,000	
Furnishings	$.00M	197,630	
Fixed RDT&E	**$250M**	**22,767,772**	**Unit Prime Equipment**
		1,138,389	Contingency
		1,366,066	Final Assembly & Integration
		2,732,133	Profit & Fee
		28,004,360	**Flyaway Price**
		550,980	SE/PM, Data Training
		227,678	Init. Spares & Support Equip.
Total RAM Improvement RDT&E	**$284.82M**	**28,783,018**	**Unit Procurement Cost**

Lift Offset Acquisition Cost Summary, TBO = 8,000 flt. hrs.

	RDT&E	**Avg. Unit Procurement**	
Rotor	$37.58M	3,876,849	
Airframe	$.00M	3,194,239	
Alighting Gear	$.00M	241,211	
Air Induction + Nacelle	$.00M	437,957	
Propulsion Group	$4.38M	4,915,364	
Drive System	$13.28M	1,369,822	
Flight Controls	$28.69M	2,960,109	
Vehicle Systems	$16.89M	1,394,736	
Avionics (MEQ)	$15.99M	4,500,000	
Furnishings	$.00M	197,630	
Fixed RDT&E	**$250M**	**23,087,918**	**Unit Prime Equipment**
		1,154,396	Contingency
		1,385,275	Final Assembly & Integration
		2,770,550	Profit & Fee
		28,398,139	**Flyaway Price**
		558,728	SE/PM, Data Training
		230,879	Init. Spares & Support Equip.
Total RAM Improvement RDT&E	**$366.80M**	**29,187,746**	**Unit Procurement Cost**

Lift Offset Acquisition Cost Summary, TBO = 9,000 flt. hrs.

	RDT&E	**Avg. Unit Procurement**	
Rotor	$87.73M	3,913,140	
Airframe	$.00M	3,205,883	
Alighting Gear	$.00M	241,600	
Air Induction + Nacelle	$.00M	439,456	
Propulsion Group	$14.27M	5,125,691	
Drive System	$30.95M	1,380,458	
Flight Controls	$66.89M	2,983,491	
Vehicle Systems	$39.09M	1,396,077	
Avionics (MEQ)	$36.99M	4,500,000	
Furnishings	$.00M	197,630	
Fixed RDT&E	**$250M**	**23,383,427**	**Unit Prime Equipment**
		1,169,171	Contingency
		1,403,006	Final Assembly & Integration
		2,806,011	Profit & Fee
		28,761,615	**Flyaway Price**
		565,879	SE/PM, Data Training
		233,834	Init. Spares & Support Equip.
Total RAM Improvement RDT&E	**$525.92M**	**29,561,328**	**Unit Procurement Cost**

Lift Offset Acquisition Cost Summary, TBO = 10,000 flt. hrs.

	RDT&E	**Avg. Unit Procurement**	
Rotor	$169.54M	3,945,916	
Airframe	$.00M	3,216,269	
Alighting Gear	$.00M	241,948	
Air Induction + Nacelle	$.00M	440,800	
Propulsion Group	$33.00M	5,322,420	
Drive System	$59.72M	1,389,974	
Flight Controls	$129.08M	3,004,369	
Vehicle Systems	$74.98M	1,397,188	
Avionics (MEQ)	$70.89M	4,500,000	
Furnishings	$.00M	197,630	
Fixed RDT&E	**$250M**	**23,656,513**	**Unit Prime Equipment**
		1,182,826	Contingency
		1,419,391	Final Assembly & Integration
		2,838,782	Profit & Fee
		29,097,511	**Flyaway Price**
		572,488	SE/PM, Data Training
		236,565	Init. Spares & Support Equip.
Total RAM Improvement RDT&E	**$787.21M**	**29,906,564**	**Unit Procurement Cost**

Lift Offset Acquisition Cost Summary, TBO = 11,000 flt. hrs.

	RDT&E	**Avg. Unit Procurement**	
Rotor	$291.16M	3,982,587	
Airframe	$.17M	3,236,275	
Alighting Gear	$.01M	243,110	
Air Induction + Nacelle	$.02M	444,714	
Propulsion Group	$63.25M	5,515,530	
Drive System	$102.40M	1,400,687	
Flight Controls	$221.30M	3,026,921	
Vehicle Systems	$127.73M	1,398,757	
Avionics (MEQ)	$120.62M	4,500,000	
Furnishings	$.00M	197,630	
Fixed RDT&E	**$250M**	**23,946,210**	**Unit Prime Equipment**
		1,197,311	Contingency
		1,436,773	Final Assembly & Integration
		2,873,545	Profit & Fee
		29,453,839	**Flyaway Price**
		579,498	SE/PM, Data Training
		239,462	Init. Spares & Support Equip.
Total RAM Improvement RDT&E	**$1,176.67M**	**30,272,799**	**Unit Procurement Cost**

Lift Offset Acquisition Cost Summary, TBO = 12,000 flt. hrs.

	RDT&E	**Avg. Unit Procurement**	
Rotor	$460.28M	4,016,953	
Airframe	$1.28M	3,254,723	
Alighting Gear	$.10M	244,186	
Air Induction + Nacelle	$.13M	448,162	
Propulsion Group	$107.62M	5,698,536	
Drive System	$161.61M	1,410,397	
Flight Controls	$349.21M	3,047,627	
Vehicle Systems	$200.38M	1,400,096	
Avionics (MEQ)	$189.05M	4,500,000	
Furnishings	$.00M	197,630	
Fixed RDT&E	**$250M**	**24,218,311**	**Unit Prime Equipment**
		1,210,916	Contingency
		1,453,099	Final Assembly & Integration
		2,906,197	Profit & Fee
		29,788,523	**Flyaway Price**
		586,083	SE/PM, Data Training
		242,183	Init. Spares & Support Equip.
Total RAM Improvement RDT&E	**$1,719.66M**	**30,616,789**	**Unit Procurement Cost**

Lift Offset Acquisition Cost Summary, TBO = 13,000 flt. hrs.

	RDT&E	**Avg. Unit Procurement**	
Rotor	$684.71M	4,048,935	
Airframe	$4.21M	3,272,075	
Alighting Gear	$.32M	245,177	
Air Induction + Nacelle	$.44M	451,605	
Propulsion Group	$168.68M	5,873,212	
Drive System	$240.06M	1,419,579	
Flight Controls	$518.71M	3,067,287	
Vehicle Systems	$295.97M	1,401,207	
Avionics (MEQ)	$279.02M	4,500,000	
Furnishings	$.00M	197,630	
Fixed RDT&E	**$250M**	**24,476,706**	**Unit Prime Equipment**
		1,223,835	Contingency
		1,468,602	Final Assembly & Integration
		2,937,205	Profit & Fee
		30,106,349	**Flyaway Price**
		592,336	SE/PM, Data Training
		244,767	Init. Spares & Support Equip.
Total RAM Improvement RDT&E	**$2,442.11M**	**30,943,452**	**Unit Procurement Cost**

Lift Offset Acquisition Cost Summary, TBO = 14,000 flt. hrs.

	RDT&E	**Avg. Unit Procurement**	
Rotor	$972.36M	4,078,980	
Airframe	$9.78M	3,288,188	
Alighting Gear	$.73M	246,104	
Air Induction + Nacelle	$1.02M	454,892	
Propulsion Group	$248.94M	6,040,174	
Drive System	$340.46M	1,428,186	
Flight Controls	$735.55M	3,085,569	
Vehicle Systems	$417.61M	1,402,545	
Avionics (MEQ)	$393.31M	4,500,000	
Furnishings	$.00M	197,630	
Fixed RDT&E	**$250M**	**24,722,267**	**Unit Prime Equipment**
		1,236,113	Contingency
		1,483,336	Final Assembly & Integration
		2,966,672	Profit & Fee
		30,408,389	**Flyaway Price**
		598,279	SE/PM, Data Training
		247,223	Init. Spares & Support Equip.
Total RAM Improvement RDT&E	**$3,369.77M**	**31,253,890**	**Unit Procurement Cost**

Lift Offset Acquisition Cost Summary, TBO = 15,000 flt. hrs.

	RDT&E	**Avg. Unit Procurement**	
Rotor	$1,331.29M	4,107,834	
Airframe	$18.82M	3,303,865	
Alighting Gear	$1.41M	246,988	
Air Induction + Nacelle	$1.97M	458,021	
Propulsion Group	$350.92M	6,200,759	
Drive System	$465.52M	1,436,403	
Flight Controls	$1,005.62M	3,102,934	
Vehicle Systems	$568.16M	1,403,549	
Avionics (MEQ)	$534.71M	4,500,000	
Furnishings	$.00M	197,630	
Fixed RDT&E	**$250M**	**24,957,982**	**Unit Prime Equipment**
		1,247,899	Contingency
		1,497,479	Final Assembly & Integration
		2,994,958	Profit & Fee
		30,698,318	**Flyaway Price**
		603,983	SE/PM, Data Training
		249,580	Init. Spares & Support Equip.
Total RAM Improvement RDT&E	**$4,528.42M**	**31,551,881**	**Unit Procurement Cost**

Lift Offset Acquisition Cost Summary, TBO = 16,000 flt. hrs.

	RDT&E	**Avg. Unit Procurement**	
Rotor	$1,769.27M	4,134,993	
Airframe	$32.17M	3,318,493	
Alighting Gear	$2.40M	247,808	
Air Induction + Nacelle	$3.37M	460,785	
Propulsion Group	$477.08M	6,355,009	
Drive System	$617.90M	1,444,091	
Flight Controls	$1,334.68M	3,119,286	
Vehicle Systems	$750.71M	1,404,659	
Avionics (MEQ)	$705.96M	4,500,000	
Furnishings	$.00M	197,630	
Fixed RDT&E	**$250M**	**25,182,754**	**Unit Prime Equipment**
		1,259,138	Contingency
		1,510,965	Final Assembly & Integration
		3,021,930	Profit & Fee
		30,974,787	**Flyaway Price**
		609,423	SE/PM, Data Training
		251,828	Init. Spares & Support Equip.
Total RAM Improvement RDT&E	**$5,943.54M**	**31,836,038**	**Unit Procurement Cost**

Lift Offset Acquisition Cost Summary, TBO = 17,000 flt. hrs.

	RDT&E	**Avg. Unit Procurement**	
Rotor	$2,294.35M	4,160,893	
Airframe	$50.62M	3,332,281	
Alighting Gear	$3.78M	248,606	
Air Induction + Nacelle	$5.32M	463,546	
Propulsion Group	$629.87M	6,504,176	
Drive System	$800.32M	1,451,404	
Flight Controls	$1,728.61M	3,134,903	
Vehicle Systems	$968.29M	1,405,891	
Avionics (MEQ)	$909.78M	4,500,000	
Furnishings	$.00M	197,630	
Fixed RDT&E	**$250M**	**25,399,331**	**Unit Prime Equipment**
		1,269,967	Contingency
		1,523,960	Final Assembly & Integration
		3,047,920	Profit & Fee
		31,241,178	**Flyaway Price**
		614,664	SE/PM, Data Training
		253,993	Init. Spares & Support Equip.
Total RAM Improvement RDT&E	**$7,640.94M**	**32,109,835**	**Unit Procurement Cost**

Lift Offset Acquisition Cost Summary, TBO = 18,000 flt. hrs.

	RDT&E	**Avg. Unit Procurement**	
Rotor	$2,914.42M	4,185,492	
Airframe	$75.01M	3,345,458	
Alighting Gear	$5.59M	249,343	
Air Induction + Nacelle	$7.89M	466,000	
Propulsion Group	$811.72M	6,648,078	
Drive System	$1,015.46M	1,458,342	
Flight Controls	$2,193.24M	3,149,790	
Vehicle Systems	$1,223.42M	1,406,665	
Avionics (MEQ)	$1,148.86M	4,500,000	
Furnishings	$.00M	197,630	
Fixed RDT&E	**$250M**	**25,606,798**	**Unit Prime Equipment**
		1,280,340	Contingency
		1,536,408	Final Assembly & Integration
		3,072,816	Profit & Fee
		31,496,361	**Flyaway Price**
		619,685	SE/PM, Data Training
		256,068	Init. Spares & Support Equip.
Total RAM Improvement RDT&E	**$9,645.62M**	**32,372,114**	**Unit Procurement Cost**

Lift Offset Acquisition Cost Summary, TBO = 19,000 flt. hrs.

	RDT&E	**Avg. Unit Procurement**	
Rotor	$3,637.58M	4,209,089	
Airframe	$106.14M	3,358,206	
Alighting Gear	$7.90M	250,057	
Air Induction + Nacelle	$11.19M	468,604	
Propulsion Group	$1,025.03M	6,787,324	
Drive System	$1,266.04M	1,464,954	
Flight Controls	$2,734.18M	3,163,760	
Vehicle Systems	$1,519.51M	1,407,668	
Avionics (MEQ)	$1,425.88M	4,500,000	
Furnishings	$.00M	197,630	
Fixed RDT&E	**$250M**	**25,807,291**	**Unit Prime Equipment**
		1,290,365	Contingency
		1,548,437	Final Assembly & Integration
		3,096,875	Profit & Fee
		31,742,969	**Flyaway Price**
		624,536	SE/PM, Data Training
		258,073	Init. Spares & Support Equip.
Total RAM Improvement RDT&E	**$11,983.46M**	**32,625,578**	**Unit Procurement Cost**

Lift Offset Acquisition Cost Summary, TBO = 20,000 flt. hrs.

	RDT&E	**Avg. Unit Procurement**	
Rotor	$4,471.99M	4,231,887	
Airframe	$144.82M	3,370,203	
Alighting Gear	$10.77M	250,730	
Air Induction + Nacelle	$15.29M	470,902	
Propulsion Group	$1,272.20M	6,922,568	
Drive System	$1,554.93M	1,471,443	
Flight Controls	$3,357.73M	3,177,456	
Vehicle Systems	$1,859.18M	1,408,565	
Avionics (MEQ)	$1,743.52M	4,500,000	
Furnishings	$.00M	197,630	
Fixed RDT&E	**$250M**	**26,001,383**	**Unit Prime Equipment**
		1,300,069	Contingency
		1,560,083	Final Assembly & Integration
		3,120,166	Profit & Fee
		31,981,701	**Flyaway Price**
		629,233	SE/PM, Data Training
		260,014	Init. Spares & Support Equip.
Total RAM Improvement RDT&E	**$14,680.43M**	**32,870,948**	**Unit Procurement Cost**

Tiltrotor Acquisition Cost Summary, TBO = 6,000 flt. hrs.

	RDT&E	**Avg. Unit Procurement**	
Rotor	$.809M	$2.052M	
Airframe	$.000M	$3.806M	
Alighting Gear	$.000M	$.179M	
Air Induction + Nacelle	$.000M	$.876M	
Propulsion Group	$.000M	$4.668M	
Drive System	$.478M	$1.212M	
Flight Controls	$1.049M	$2.661M	
Vehicle Systems	$.643M	$1.305M	
Avionics (MEQ)	$.650M	$4.500M	
Furnishings	$.000M	$.198M	
Fixed RDT&E	**$250M**	**$21.457M**	**Unit Prime Equipment**
		$1.073M	Contingency
		$1.287M	Final Assembly & Integration
		$2.575M	Profit & Fee
		$26.392M	**Flyaway Price**
		$.519M	SE/PM, Data Training
		$.215M	Init. Spares & Support Equip.
Total RAM Improvement RDT&E	**$253.63M**	**$27.126M**	**Unit Procurement Cost**

Tiltrotor Acquisition Cost Summary, TBO = 7,000 flt. hrs.

	RDT&E	**Avg. Unit Procurement**	
Rotor	$6.153M	$2.070M	
Airframe	$.000M	$3.817M	
Alighting Gear	$.000M	$.179M	
Air Induction + Nacelle	$.000M	$.878M	
Propulsion Group	$.611M	$4.911M	
Drive System	$3.634M	$1.223M	
Flight Controls	$7.962M	$2.678M	
Vehicle Systems	$4.848M	$1.306M	
Avionics (MEQ)	$4.905M	$4.500M	
Furnishings	$.000M	$.198M	
Fixed RDT&E	**$250M**	**$21.761M**	**Unit Prime Equipment**
		$1.088M	Contingency
		$1.306M	Final Assembly & Integration
		$2.611M	Profit & Fee
		$26.766M	**Flyaway Price**
		$.527M	SE/PM, Data Training
		$.218M	Init. Spares & Support Equip.
Total RAM Improvement RDT&E	**$278.11M**	**$27.510M**	**Unit Procurement Cost**

Tiltrotor Acquisition Cost Summary, TBO = 8,000 flt. hrs.

	RDT&E	**Avg. Unit Procurement**	
Rotor	$20.213M	$2.085M	
Airframe	$.000M	$3.827M	
Alighting Gear	$.000M	$.180M	
Air Induction + Nacelle	$.000M	$.880M	
Propulsion Group	$4.797M	$5.134M	
Drive System	$11.936M	$1.231M	
Flight Controls	$26.101M	$2.693M	
Vehicle Systems	$15.812M	$1.306M	
Avionics (MEQ)	$15.992M	$4.500M	
Furnishings	$.000M	$.198M	
Fixed RDT&E	**$250M**	**$22.035M**	**Unit Prime Equipment**
		$1.102M	Contingency
		$1.322M	Final Assembly & Integration
		$2.644M	Profit & Fee
		$27.103M	**Flyaway Price**
		$.533M	SE/PM, Data Training
		$.220M	Init. Spares & Support Equip.
Total RAM Improvement RDT&E	**$344.85M**	**$27.856M**	**Unit Procurement Cost**

Tiltrotor Acquisition Cost Summary, TBO = 9,000 flt. hrs.

	RDT&E	**Avg. Unit Procurement**	
Rotor	$47.136M	$2.102M	
Airframe	$.000M	$3.842M	
Alighting Gear	$.000M	$.180M	
Air Induction + Nacelle	$.000M	$.884M	
Propulsion Group	$16.245M	$5.349M	
Drive System	$27.826M	$1.241M	
Flight Controls	$60.744M	$2.709M	
Vehicle Systems	$36.594M	$1.307M	
Avionics (MEQ)	$36.990M	$4.500M	
Furnishings	$.000M	$.198M	
Fixed RDT&E	**$250M**	**$22.312M**	**Unit Prime Equipment**
		$1.116M	Contingency
		$1.339M	Final Assembly & Integration
		$2.677M	Profit & Fee
		$27.443M	**Flyaway Price**
		$.540M	SE/PM, Data Training
		$.223M	Init. Spares & Support Equip.
Total RAM Improvement RDT&E	**$475.53M**	**$28.206M**	**Unit Procurement Cost**

Tiltrotor Acquisition Cost Summary, TBO = 10,000 flt. hrs.

	RDT&E	**Avg. Unit Procurement**	
Rotor	$90.932M	$2.116M	
Airframe	$.000M	$3.852M	
Alighting Gear	$.000M	$.180M	
Air Induction + Nacelle	$.000M	$.886M	
Propulsion Group	$38.848M	$5.546M	
Drive System	$53.669M	$1.249M	
Flight Controls	$116.981M	$2.723M	
Vehicle Systems	$70.147M	$1.307M	
Avionics (MEQ)	$70.889M	$4.500M	
Furnishings	$.000M	$.198M	
Fixed RDT&E	**$250M**	**$22.557M**	**Unit Prime Equipment**
		$1.128M	Contingency
		$1.353M	Final Assembly & Integration
		$2.707M	Profit & Fee
		$27.745M	**Flyaway Price**
		$.546M	SE/PM, Data Training
		$.226M	Init. Spares & Support Equip.
Total RAM Improvement RDT&E	**$691.47M**	**$28.517M**	**Unit Procurement Cost**

Tiltrotor Acquisition Cost Summary, TBO = 11,000 flt. hrs.

	RDT&E	**Avg. Unit Procurement**	
Rotor	$155.818M	$2.131M	
Airframe	$.202M	$3.874M	
Alighting Gear	$.009M	$.182M	
Air Induction + Nacelle	$.043M	$.890M	
Propulsion Group	$76.856M	$5.738M	
Drive System	$91.954M	$1.258M	
Flight Controls	$200.105M	$2.737M	
Vehicle Systems	$119.424M	$1.308M	
Avionics (MEQ)	$120.623M	$4.500M	
Furnishings	$.000M	$.198M	
Fixed RDT&E	**$250M**	**$22.815M**	**Unit Prime Equipment**
		$1.141M	Contingency
		$1.369M	Final Assembly & Integration
		$2.738M	Profit & Fee
		$28.063M	**Flyaway Price**
		$.552M	SE/PM, Data Training
		$.228M	Init. Spares & Support Equip.
Total RAM Improvement RDT&E	**$1,015.04M**	**$28.843M**	**Unit Procurement Cost**

Tiltrotor Acquisition Cost Summary, TBO = 12,000 flt. hrs.

	RDT&E	**Avg. Unit Procurement**	
Rotor	$245.938M	$2.146M	
Airframe	$1.536M	$3.896M	
Alighting Gear	$.072M	$.183M	
Air Induction + Nacelle	$.325M	$.894M	
Propulsion Group	$134.712M	$5.924M	
Drive System	$145.098M	$1.266M	
Flight Controls	$315.289M	$2.752M	
Vehicle Systems	$187.237M	$1.308M	
Avionics (MEQ)	$189.052M	$4.500M	
Furnishings	$.000M	$.198M	
Fixed RDT&E	**$250M**	**$23.067M**	**Unit Prime Equipment**
		$1.153M	Contingency
		$1.384M	Final Assembly & Integration
		$2.768M	Profit & Fee
		$28.372M	**Flyaway Price**
		$.558M	SE/PM, Data Training
		$.231M	Init. Spares & Support Equip.
Total RAM Improvement RDT&E	**$1,469.26M**	**$29.161M**	**Unit Procurement Cost**

Tiltrotor Acquisition Cost Summary, TBO = 13,000 flt. hrs.

	RDT&E	**Avg. Unit Procurement**	
Rotor	$365.405M	$2.161M	
Airframe	$5.034M	$3.917M	
Alighting Gear	$.236M	$.184M	
Air Induction + Nacelle	$1.066M	$.899M	
Propulsion Group	$217.087M	$6.102M	
Drive System	$215.552M	$1.275M	
Flight Controls	$467.735M	$2.766M	
Vehicle Systems	$276.480M	$1.309M	
Avionics (MEQ)	$279.015M	$4.500M	
Furnishings	$.000M	$.198M	
Fixed RDT&E	**$250M**	**$23.310M**	**Unit Prime Equipment**
		$1.165M	Contingency
		$1.399M	Final Assembly & Integration
		$2.797M	Profit & Fee
		$28.671M	**Flyaway Price**
		$.564M	SE/PM, Data Training
		$.233M	Init. Spares & Support Equip.
Total RAM Improvement RDT&E	**$2,077.61M**	**$29.468M**	**Unit Procurement Cost**

Tiltrotor Acquisition Cost Summary, TBO = 14,000 flt. hrs.

	RDT&E	**Avg. Unit Procurement**	
Rotor	$517.814M	$2.172M	
Airframe	$11.694M	$3.934M	
Alighting Gear	$.548M	$.184M	
Air Induction + Nacelle	$2.472M	$.901M	
Propulsion Group	$328.404M	$6.266M	
Drive System	$305.410M	$1.281M	
Flight Controls	$661.889M	$2.777M	
Vehicle Systems	$389.874M	$1.309M	
Avionics (MEQ)	$393.313M	$4.500M	
Furnishings	$.000M	$.198M	
Fixed RDT&E	**$250M**	**$23.523M**	**Unit Prime Equipment**
		$1.176M	Contingency
		$1.411M	Final Assembly & Integration
		$2.823M	Profit & Fee
		$28.933M	**Flyaway Price**
		$.569M	SE/PM, Data Training
		$.235M	Init. Spares & Support Equip.
Total RAM Improvement RDT&E	**$2,861.42M**	**$29.738M**	**Unit Procurement Cost**

Tiltrotor Acquisition Cost Summary, TBO = 15,000 flt. hrs.

	RDT&E	**Avg. Unit Procurement**	
Rotor	$708.044M	$2.185M	
Airframe	$22.516M	$3.952M	
Alighting Gear	$1.056M	$.185M	
Air Induction + Nacelle	$4.757M	$.905M	
Propulsion Group	$474.276M	$6.430M	
Drive System	$417.526M	$1.288M	
Flight Controls	$903.834M	$2.789M	
Vehicle Systems	$530.314M	$1.310M	
Avionics (MEQ)	$534.713M	$4.500M	
Furnishings	$.000M	$.198M	
Fixed RDT&E	**$250M**	**$23.742M**	**Unit Prime Equipment**
		$1.187M	Contingency
		$1.425M	Final Assembly & Integration
		$2.849M	Profit & Fee
		$29.203M	**Flyaway Price**
		$.575M	SE/PM, Data Training
		$.237M	Init. Spares & Support Equip.
Total RAM Improvement RDT&E	**$3,847.04M**	**$30.015M**	**Unit Procurement Cost**

Tiltrotor Acquisition Cost Summary, TBO = 16,000 flt. hrs.

	RDT&E	**Avg. Unit Procurement**	
Rotor	$938.637M	$2.194M	
Airframe	$38.434M	$3.965M	
Alighting Gear	$1.803M	$.186M	
Air Induction + Nacelle	$8.115M	$.908M	
Propulsion Group	$658.516M	$6.577M	
Drive System	$553.472M	$1.294M	
Flight Controls	$1196.929M	$2.797M	
Vehicle Systems	$700.336M	$1.310M	
Avionics (MEQ)	$705.961M	$4.500M	
Furnishings	$.000M	$.198M	
Fixed RDT&E	**$250M**	**$23.928M**	**Unit Prime Equipment**
		$1.196M	Contingency
		$1.436M	Final Assembly & Integration
		$2.871M	Profit & Fee
		$29.432M	**Flyaway Price**
		$.579M	SE/PM, Data Training
		$.239M	Init. Spares & Support Equip.
Total RAM Improvement RDT&E	**$5,052.20M**	**$30.250M**	**Unit Procurement Cost**

Tiltrotor Acquisition Cost Summary, TBO = 17,000 flt. hrs.

	RDT&E	**Avg. Unit Procurement**	
Rotor	$1216.111M	$2.205M	
Airframe	$60.502M	$3.982M	
Alighting Gear	$2.838M	$.187M	
Air Induction + Nacelle	$12.763M	$.911M	
Propulsion Group	$888.505M	$6.731M	
Drive System	$716.933M	$1.300M	
Flight Controls	$1548.729M	$2.809M	
Vehicle Systems	$902.761M	$1.311M	
Avionics (MEQ)	$909.776M	$4.500M	
Furnishings	$.000M	$.198M	
Fixed RDT&E	**$250M**	**$24.134M**	**Unit Prime Equipment**
		$1.207M	Contingency
		$1.448M	Final Assembly & Integration
		$2.896M	Profit & Fee
		$29.684M	**Flyaway Price**
		$.584M	SE/PM, Data Training
		$.241M	Init. Spares & Support Equip.
Total RAM Improvement RDT&E	**$6,508.92M**	**$30.510M**	**Unit Procurement Cost**

Tiltrotor Acquisition Cost Summary, TBO = 18,000 flt. hrs.

	RDT&E	**Avg. Unit Procurement**	
Rotor	$1542.406M	$2.215M	
Airframe	$89.608M	$3.997M	
Alighting Gear	$4.203M	$.187M	
Air Induction + Nacelle	$18.897M	$.914M	
Propulsion Group	$1167.840M	$6.874M	
Drive System	$909.197M	$1.306M	
Flight Controls	$1962.119M	$2.818M	
Vehicle Systems	$1140.392M	$1.311M	
Avionics (MEQ)	$1148.857M	$4.500M	
Furnishings	$.000M	$.198M	
Fixed RDT&E	**$250M**	**$24.319M**	**Unit Prime Equipment**
		$1.216M	Contingency
		$1.459M	Final Assembly & Integration
		$2.918M	Profit & Fee
		$29.912M	**Flyaway Price**
		$.589M	SE/PM, Data Training
		$.243M	Init. Spares & Support Equip.
Total RAM Improvement RDT&E	**$8,233.52M**	**$30.744M**	**Unit Procurement Cost**

Tiltrotor Acquisition Cost Summary, TBO = 19,000 flt. hrs.

	RDT&E	**Avg. Unit Procurement**	
Rotor	$1922.961M	$2.225M	
Airframe	$126.777M	$4.011M	
Alighting Gear	$5.947M	$.188M	
Air Induction + Nacelle	$26.707M	$.916M	
Propulsion Group	$1503.176M	$7.014M	
Drive System	$1133.335M	$1.311M	
Flight Controls	$2443.621M	$2.828M	
Vehicle Systems	$1415.746M	$1.312M	
Avionics (MEQ)	$1425.884M	$4.500M	
Furnishings	$.000M	$.198M	
Fixed RDT&E	**$250M**	**$24.503M**	**Unit Prime Equipment**
		$1.225M	Contingency
		$1.470M	Final Assembly & Integration
		$2.940M	Profit & Fee
		$30.139M	**Flyaway Price**
		$.593M	SE/PM, Data Training
		$.245M	Init. Spares & Support Equip.
Total RAM Improvement RDT&E	**$10,254.15M**	**$30.977M**	**Unit Procurement Cost**

Tiltrotor Acquisition Cost Summary, TBO = 20,000 flt. hrs.

	RDT&E	**Avg. Unit Procurement**	
Rotor	$2361.288M	$2.235M	
Airframe	$172.949M	$4.025M	
Alighting Gear	$8.113M	$.189M	
Air Induction + Nacelle	$36.430M	$.920M	
Propulsion Group	$1899.839M	$7.151M	
Drive System	$1391.661M	$1.317M	
Flight Controls	$2997.562M	$2.837M	
Vehicle Systems	$1731.575M	$1.312M	
Avionics (MEQ)	$1743.520M	$4.500M	
Furnishings	$.000M	$.198M	
Fixed RDT&E	**$250M**	**$24.682M**	**Unit Prime Equipment**
		$1.234M	Contingency
		$1.481M	Final Assembly & Integration
		$2.962M	Profit & Fee
		$30.358M	**Flyaway Price**
		$.597M	SE/PM, Data Training
		$.247M	Init. Spares & Support Equip.
Total RAM Improvement RDT&E	**$12,592.94M**	**$31.203M**	**Unit Procurement Cost**

Helicopter O&S Summary, TBO = 6,000 flt. hrs.

Category	Maintenance man hours per flight hour	Part cost per flight hour
Scheduled Maintenance		
Inspection	2.6207	
Drive System	0.0404	
Main Transmission		$19.89
Tailrotor Gearbox		7.29
Intermediate Gearbox		4.18
Combining Gearbox		0.00
Accessory Gearbox		6.97
Rotor System	0.0059	
Main Rotor		$19.03
Tail Rotor		9.19
Flight Controls		23.28
Part Retirements	0.0540	
Drive System		$17.56
Main Rotor		72.81
Tail Rotor		16.28
Flight Controls		113.24
Total Scheduled	**2.7210**	**$309.72**
Unscheduled Maintenance		
Airframe Structure	0.0400	$90.31
Landing Gear	0.0132	40.72
Flight Controls	0.1096	247.73
Electrical and Avionics	0.3667	273.95
Rotor	0.1343	159.41
Systems	0.2317	29.81
Propulsion	0.2009	54.66
Drive	0.0285	64.80
Armament	0.0000	0.00
Total Unscheduled	**1.1249**	**$961.38**
Powerplant Maintenance		**$999.74**
Airframe Maintenance	**3.5223**	**$1,271.10**
Total Direct Maintenance		**$2,270.84**
Fuel Cost		**$994.17**
Total Direct Operating Cost		**$3,265.01**

Helicopter O&S Summary, TBO = 7,000 flt. hrs.

Category	Maintenance man hours per flight hour	Part cost per flight hour
Scheduled Maintenance		
Inspection	2.6232	
Drive System	0.0297	
Main Transmission		$17.16
Tailrotor Gearbox		6.26
Intermediate Gearbox		3.62
Combining Gearbox		0.00
Accessory Gearbox		5.98
Rotor System	0.0044	
Main Rotor		$16.52
Tail Rotor		7.93
Flight Controls		20.13
Part Retirements	0.0542	
Drive System		$15.13
Main Rotor		63.19
Tail Rotor		13.96
Flight Controls		97.80
Total Scheduled	**2.7115**	**$267.69**
Unscheduled Maintenance		
Airframe Structure	0.0400	$90.42
Landing Gear	0.0132	40.78
Flight Controls	0.0988	223.92
Electrical and Avionics	0.3293	246.03
Rotor	0.1214	144.71
Systems	0.2082	26.78
Propulsion	0.1796	48.96
Drive	0.0257	58.58
Armament	0.0000	0.00
Total Unscheduled	**1.0162**	**$880.19**
Powerplant Maintenance		**$894.88**
Airframe Maintenance	**3.7277**	**$1,147.88**
Total Direct Maintenance		**$2,042.76**
Fuel Cost		**$998.14**
Total Direct Operating Cost		**$3,040.90**

Helicopter O&S Summary, TBO = 8,000 flt. hrs.

Category	Maintenance man hours per flight hour	Part cost per flight hour
Scheduled Maintenance		
Inspection	2.6255	
Drive System	0.0227	
Main Transmission		$15.10
Tailrotor Gearbox		5.49
Intermediate Gearbox		3.19
Combining Gearbox		0.00
Accessory Gearbox		5.24
Rotor System	0.0034	
Main Rotor		$14.62
Tail Rotor		6.99
Flight Controls		17.74
Part Retirements	0.0543	
Drive System		$13.29
Main Rotor		55.89
Tail Rotor		12.23
Flight Controls		86.16
Total Scheduled	**2.7059**	**$235.94**
Unscheduled Maintenance		
Airframe Structure	0.0400	$90.52
Landing Gear	0.0132	40.84
Flight Controls	0.0906	206.03
Electrical and Avionics	0.3012	225.08
Rotor	0.1117	133.65
Systems	0.1905	24.51
Propulsion	0.1637	44.69
Drive	0.0237	53.91
Armament	0.0000	0.00
Total Unscheduled	**0.9346**	**$819.24**
Powerplant Maintenance		**$816.16**
Airframe Maintenance	**3.6405**	**$1,055.18**
Total Direct Maintenance		**$1,871.34**
Fuel Cost		**$1,001.66**
Total Direct Operating Cost		**$2,873.01**

Helicopter O&S Summary, TBO = 9,000 flt. hrs.

Category	Maintenance man hours per flight hour	Part cost per flight hour
Scheduled Maintenance		
Inspection	2.6274	
Drive System	0.0180	
Main Transmission		$13.49
Tailrotor Gearbox		4.89
Intermediate Gearbox		2.85
Combining Gearbox		0.00
Accessory Gearbox		4.66
Rotor System	0.0027	
Main Rotor		$13.13
Tail Rotor		6.24
Flight Controls		15.88
Part Retirements	0.0545	
Drive System		$11.86
Main Rotor		50.15
Tail Rotor		10.88
Flight Controls		77.04
Total Scheduled	**2.7026**	**$211.07**
Unscheduled Maintenance		
Airframe Structure	0.0400	$90.61
Landing Gear	0.0132	40.90
Flight Controls	0.0843	192.08
Electrical and Avionics	0.2794	208.78
Rotor	0.1041	125.00
Systems	0.1768	22.75
Propulsion	0.1513	41.36
Drive	0.0220	50.26
Armament	0.0000	0.00
Total Unscheduled	**0.8712**	**$771.74**
Powerplant Maintenance		**$754.86**
Airframe Maintenance	**3.5737**	**$982.81**
Total Direct Maintenance		**1,737.67**
Fuel Cost		**$1,004.82**
Total Direct Operating Cost		**$2,742.48**

Helicopter O&S Summary, TBO = 10,000 flt. hrs.

Category	Maintenance man hours per flight hour	Part cost per flight hour
Scheduled Maintenance		
Inspection	2.6293	
Drive System	0.0146	
Main Transmission		$12.19
Tailrotor Gearbox		4.41
Intermediate Gearbox		2.58
Combining Gearbox		0.00
Accessory Gearbox		4.20
Rotor System	0.0022	
Main Rotor		$11.93
Tail Rotor		5.65
Flight Controls		14.38
Part Retirements	0.0546	
Drive System		$10.71
Main Rotor		45.53
Tail Rotor		9.80
Flight Controls		69.70
Total Scheduled	**2.7006**	**$191.06**
Unscheduled Maintenance		
Airframe Structure	0.0400	$90.69
Landing Gear	0.0132	40.95
Flight Controls	0.0792	180.89
Electrical and Avionics	0.2620	195.75
Rotor	0.0981	118.07
Systems	0.1659	21.34
Propulsion	0.1413	38.69
Drive	0.0207	47.34
Armament	0.0000	0.00
Total Unscheduled	**0.8204**	**$733.73**
Powerplant Maintenance		**$705.79**
Airframe Maintenance	**3.5210**	**$924.78**
Total Direct Maintenance		**$1,630.56**
Fuel Cost		**$1,007.65**
Total Direct Operating Cost		**$2,638.21**

Helicopter O&S Summary, TBO = 11,000 flt. hrs.

Category	Maintenance man hours per flight hour	Part cost per flight hour
Scheduled Maintenance		
Inspection	2.4523	
Drive System	0.0121	
Main Transmission		$11.14
Tailrotor Gearbox		4.01
Intermediate Gearbox		2.36
Combining Gearbox		0.00
Accessory Gearbox		3.83
Rotor System	0.0018	
Main Rotor		$10.95
Tail Rotor		5.16
Flight Controls		13.15
Part Retirements	0.0498	
Drive System		$9.77
Main Rotor		41.77
Tail Rotor		8.91
Flight Controls		63.71
Total Scheduled	**2.5159**	**$174.76**
Unscheduled Maintenance		
Airframe Structure	0.0373	$84.70
Landing Gear	0.0123	38.35
Flight Controls	0.0751	171.85
Electrical and Avionics	0.2477	185.09
Rotor	0.0932	112.55
Systems	0.1569	20.19
Propulsion	0.1333	36.58
Drive	0.0197	44.99
Armament	0.0000	0.00
Total Unscheduled	**0.7754**	**$694.29**
Powerplant Maintenance		**$666.17**
Airframe Maintenance	**3.2914**	**$869.05**
Total Direct Maintenance		**$1,535.22**
Fuel Cost		**$1,011.47**
Total Direct Operating Cost		**$2,546.69**

Helicopter O&S Summary, TBO = 12,000 flt. hrs.

Category	Maintenance man hours per flight hour	Part cost per flight hour
Scheduled Maintenance		
Inspection	2.2847	
Drive System	0.0099	
Main Transmission		$10.13
Tailrotor Gearbox		3.64
Intermediate Gearbox		2.15
Combining Gearbox		0.00
Accessory Gearbox		3.47
Rotor System	0.0015	
Main Rotor		$10.01
Tail Rotor		4.70
Flight Controls		11.98
Part Retirements	0.0452	
Drive System		$8.88
Main Rotor		38.18
Tail Rotor		8.08
Flight Controls		58.01
Total Scheduled	**2.3413**	**$159.22**
Unscheduled Maintenance		
Airframe Structure	0.0348	$79.03
Landing Gear	0.0115	35.88
Flight Controls	0.0712	163.27
Electrical and Avionics	0.2342	175.00
Rotor	0.0885	107.30
Systems	0.1484	19.11
Propulsion	0.1257	34.57
Drive	0.0186	42.75
Armament	0.0000	0.00
Total Unscheduled	**0.7329**	**$656.92**
Powerplant Maintenance		**$628.63**
Airframe Maintenance	**3.0742**	**$816.14**
Total Direct Maintenance		**$1,444.77**
Fuel Cost		**$1,015.49**
Total Direct Operating Cost		**$2,460.26**

Helicopter O&S Summary, TBO = 13,000 flt. hrs.

Category	Maintenance man hours per flight hour	Part cost per flight hour
Scheduled Maintenance		
Inspection	2.1798	
Drive System	0.0086	
Main Transmission		$9.50
Tailrotor Gearbox		3.40
Intermediate Gearbox		2.02
Combining Gearbox		0.00
Accessory Gearbox		3.25
Rotor System	0.0013	
Main Rotor		$9.42
Tail Rotor		4.41
Flight Controls		11.25
Part Retirements	0.0424	
Drive System		$8.32
Main Rotor		35.92
Tail Rotor		7.55
Flight Controls		54.43
Total Scheduled	**2.2321**	**$149.47**
Unscheduled Maintenance		
Airframe Structure	0.0332	$75.48
Landing Gear	0.0110	34.34
Flight Controls	0.0687	157.91
Electrical and Avionics	0.2257	168.69
Rotor	0.0856	104.02
Systems	0.1431	18.42
Propulsion	0.1210	33.32
Drive	0.0180	41.35
Armament	0.0000	0.00
Total Unscheduled	**0.7063**	**$633.55**
Powerplant Maintenance		**$605.15**
Airframe Maintenance	**2.9385**	**$783.01**
Total Direct Maintenance		**$1,388.16**
Fuel Cost		**$1,018.25**
Total Direct Operating Cost		**$2,406.42**

Helicopter O&S Summary, TBO = 14,000 flt. hrs.

Category	Maintenance man hours per flight hour	Part cost per flight hour
Scheduled Maintenance		
Inspection	2.0728	
Drive System	0.0075	
Main Transmission		$8.86
Tailrotor Gearbox		3.16
Intermediate Gearbox		1.88
Combining Gearbox		0.00
Accessory Gearbox		3.02
Rotor System	0.0011	
Main Rotor		$8.82
Tail Rotor		4.11
Flight Controls		10.49
Part Retirements	0.0395	
Drive System		$7.74
Main Rotor		33.60
Tail Rotor		7.02
Flight Controls		50.75
Total Scheduled	**2.1208**	**$139.46**
Unscheduled Maintenance		
Airframe Structure	0.0316	$71.85
Landing Gear	0.0104	32.76
Flight Controls	0.0662	152.43
Electrical and Avionics	0.2171	162.25
Rotor	0.0827	100.68
Systems	0.1377	17.73
Propulsion	0.1161	32.05
Drive	0.0174	39.93
Armament	0.0000	0.00
Total Unscheduled	**0.6792**	**$609.68**
Powerplant Maintenance		**$581.18**
Airframe Maintenance	**2.8000**	**$749.14**
Total Direct Maintenance		**$1,330.32**
Fuel Cost		**$1,021.32**
Total Direct Operating Cost		**$2,351.64**

Helicopter O&S Summary, TBO = 15,000 flt. hrs.

Category	Maintenance man hours per flight hour	Part cost per flight hour
Scheduled Maintenance		
Inspection	1.9799	
Drive System	0.0065	
Main Transmission		$8.30
Tailrotor Gearbox		2.96
Intermediate Gearbox		1.77
Combining Gearbox		0.00
Accessory Gearbox		2.82
Rotor System	0.0010	
Main Rotor		$8.29
Tail Rotor		3.85
Flight Controls		9.84
Part Retirements	0.0369	
Drive System		$7.25
Main Rotor		31.57
Tail Rotor		6.55
Flight Controls		47.56
Total Scheduled	**2.0243**	**$130.75**
Unscheduled Maintenance		
Airframe Structure	0.0302	$68.71
Landing Gear	0.0100	31.39
Flight Controls	0.0641	147.70
Electrical and Avionics	0.2096	156.67
Rotor	0.0801	97.79
Systems	0.1330	17.13
Propulsion	0.1119	30.94
Drive	0.0168	38.69
Armament	0.0000	0.00
Total Unscheduled	**0.6557**	**$589.01**
Powerplant Maintenance		**$560.39**
Airframe Maintenance	**2.6800**	**$719.75**
Total Direct Maintenance		**$1,280.15**
Fuel Cost		**$1,024.21**
Total Direct Operating Cost		**$2,304.36**

Helicopter O&S Summary, TBO = 16,000 flt. hrs.

Category	Maintenance man hours per flight hour	Part cost per flight hour
Scheduled Maintenance		
Inspection	1.8987	
Drive System	0.0057	
Main Transmission		$7.80
Tailrotor Gearbox		2.78
Intermediate Gearbox		1.66
Combining Gearbox		0.00
Accessory Gearbox		2.65
Rotor System	0.0009	
Main Rotor		$7.82
Tail Rotor		3.62
Flight Controls		9.26
Part Retirements	0.0347	
Drive System		$6.81
Main Rotor		29.78
Tail Rotor		6.14
Flight Controls		44.76
Total Scheduled	**1.9399**	**$123.09**
Unscheduled Maintenance		
Airframe Structure	0.0289	$65.95
Landing Gear	0.0096	30.19
Flight Controls	0.0622	143.56
Electrical and Avionics	0.2030	151.78
Rotor	0.0779	95.26
Systems	0.1289	16.60
Propulsion	0.1082	29.97
Drive	0.0163	37.62
Armament	0.0000	0.00
Total Unscheduled	**0.6351**	**$570.92**
Powerplant Maintenance		**$542.21**
Airframe Maintenance	**2.5750**	**$694.01**
Total Direct Maintenance		**$1,236.22**
Fuel Cost		**$1,026.91**
Total Direct Operating Cost		**$2,263.13**

Helicopter O&S Summary, TBO = 17,000 flt. hrs.

Category	Maintenance man hours per flight hour	Part cost per flight hour
Scheduled Maintenance		
Inspection	1.8270	
Drive System	0.0051	
Main Transmission		$7.37
Tailrotor Gearbox		2.61
Intermediate Gearbox		1.57
Combining Gearbox		0.00
Accessory Gearbox		2.49
Rotor System	0.0008	
Main Rotor		$7.41
Tail Rotor		3.42
Flight Controls		8.75
Part Retirements	0.0327	
Drive System		$6.42
Main Rotor		28.20
Tail Rotor		5.79
Flight Controls		42.27
Total Scheduled	**1.8655**	**$116.31**
Unscheduled Maintenance		
Airframe Structure	0.0278	$63.52
Landing Gear	0.0092	29.12
Flight Controls	0.0605	139.90
Electrical and Avionics	0.1973	147.47
Rotor	0.0759	93.04
Systems	0.1253	16.14
Propulsion	0.1050	29.12
Drive	0.0159	36.66
Armament	0.0000	0.00
Total Unscheduled	**0.6169**	**$554.97**
Powerplant Maintenance		**$526.18**
Airframe Maintenance	**2.4824**	**$671.28**
Total Direct Maintenance		**$1,197.46**
Fuel Cost		**$1,029.48**
Total Direct Operating Cost		**$2,226.94**

Helicopter O&S Summary, TBO = 18,000 flt. hrs.

Category	Maintenance man hours per flight hour	Part cost per flight hour
Scheduled Maintenance		
Inspection	1.7632	
Drive System	0.0045	
Main Transmission		$6.98
Tailrotor Gearbox		2.47
Intermediate Gearbox		1.49
Combining Gearbox		0.00
Accessory Gearbox		2.36
Rotor System	0.0007	
Main Rotor		$7.04
Tail Rotor		3.24
Flight Controls		8.30
Part Retirements	0.0310	
Drive System		$6.08
Main Rotor		26.78
Tail Rotor		5.47
Flight Controls		40.06
Total Scheduled	**1.7993**	**$110.26**
Unscheduled Maintenance		
Airframe Structure	0.0269	$61.35
Landing Gear	0.0089	28.17
Flight Controls	0.0590	136.67
Electrical and Avionics	0.1921	143.64
Rotor	0.0741	91.06
Systems	0.1221	15.72
Propulsion	0.1021	28.35
Drive	0.0155	35.82
Armament	0.0000	0.00
Total Unscheduled	**0.6008**	**$540.79**
Powerplant Maintenance		**$511.91**
Airframe Maintenance	**2.4001**	**$651.05**
Total Direct Maintenance		**$1,162.96**
Fuel Cost		**$1,031.92**
Total Direct Operating Cost		**$2,194.89**

Helicopter O&S Summary, TBO = 19,000 flt. hrs.

Category	Maintenance man hours per flight hour	Part cost per flight hour
Scheduled Maintenance		
Inspection	1.6981	
Drive System	0.0040	
Main Transmission		$6.58
Tailrotor Gearbox		2.33
Intermediate Gearbox		1.40
Combining Gearbox		0.00
Accessory Gearbox		2.22
Rotor System	0.0006	
Main Rotor		$6.66
Tail Rotor		3.06
Flight Controls		7.83
Part Retirements	0.0292	
Drive System		$5.73
Main Rotor		25.33
Tail Rotor		5.14
Flight Controls		37.79
Total Scheduled	**1.7319**	**$104.07**
Unscheduled Maintenance		
Airframe Structure	0.0259	$59.15
Landing Gear	0.0086	27.21
Flight Controls	0.0575	133.36
Electrical and Avionics	0.1869	139.73
Rotor	0.0723	89.05
Systems	0.1188	15.31
Propulsion	0.0992	27.58
Drive	0.0151	34.96
Armament	0.0000	0.00
Total Unscheduled	**0.5843**	**$526.34**
Powerplant Maintenance		**$497.37**
Airframe Maintenance	**2.3162**	**$630.41**
Total Direct Maintenance		**$1,127.78**
Fuel Cost		**$1,034.62**
Total Direct Operating Cost		**$2,162.40**

Helicopter O&S Summary, TBO = 20,000 flt. hrs.

Category	Maintenance man hours per flight hour	Part cost per flight hour
Scheduled Maintenance		
Inspection	1.6548	
Drive System	0.0037	
Main Transmission		$6.31
Tailrotor Gearbox		2.23
Intermediate Gearbox		1.35
Combining Gearbox		0.00
Accessory Gearbox		2.13
Rotor System	0.0006	
Main Rotor		$6.41
Tail Rotor		2.93
Flight Controls		7.52
Part Retirements	0.0280	
Drive System		$5.49
Main Rotor		24.36
Tail Rotor		4.92
Flight Controls		36.28
Total Scheduled	**1.6870**	**$99.93**
Unscheduled Maintenance		
Airframe Structure	0.0252	$57.68
Landing Gear	0.0083	26.57
Flight Controls	0.0565	131.17
Electrical and Avionics	0.1834	137.13
Rotor	0.0712	87.73
Systems	0.1166	15.02
Propulsion	0.0972	27.07
Drive	0.0149	34.39
Armament	0.0000	0.00
Total Unscheduled	**0.5734**	**$516.74**
Powerplant Maintenance		**$487.70**
Airframe Maintenance	**2.2604**	**$616.67**
Total Direct Maintenance		**$1,104.37**
Fuel Cost		**$1,036.50**
Total Direct Operating Cost		**$2,040.88**

Lift Offset O&S Summary, TBO = 6,000 flt. hrs.

Category	Maintenance man hours per flight hour	Part cost per flight hour
Scheduled Maintenance		
Inspection	2.8098	
Drive System	0.0412	
Main Transmission		$28.65
Tailrotor Gearbox		0.00
Intermediate Gearbox		5.04
Combining Gearbox		0.00
Accessory Gearbox		11.41
Rotor System	0.0108	
Main Rotor		$68.41
Tail Rotor		21.65
Flight Controls		41.60
Part Retirements	0.1287	
Drive System		$19.68
Main Rotor		193.01
Tail Rotor		25.96
Flight Controls		140.92
Total Scheduled	**2.9905**	**$556.33**
Unscheduled Maintenance		
Airframe Structure	0.2017	$98.94
Landing Gear	0.0553	52.67
Flight Controls	0.0941	439.00
Electrical and Avionics	0.3669	274.48
Rotor	0.1362	359.15
Systems	0.2342	30.20
Propulsion	0.2018	55.24
Drive	0.1832	77.40
Armament	0.0000	0.00
Total Unscheduled	**1.4734**	**$1,387.07**
Powerplant Maintenance		**$1,198.32**
Airframe Maintenance	**4.4639**	**$1,943.40**
Total Direct Maintenance		**$3,141.72**
Fuel Cost		**$937.47**
Total Direct Operating Cost		**$4,079.19**

Lift Offset O&S Summary, TBO = 7,000 flt. hrs.

Category	**Maintenance man hours per flight hour**	**Part cost per flight hour**
Scheduled Maintenance		
Inspection	2.8147	
Drive System	0.0303	
Main Transmission		$24.77
Tailrotor Gearbox		0.00
Intermediate Gearbox		4.36
Combining Gearbox		0.00
Accessory Gearbox		9.80
Rotor System	0.0080	
Main Rotor		$59.71
Tail Rotor		18.61
Flight Controls		36.06
Part Retirements	0.1294	
Drive System		$16.96
Main Rotor		168.26
Tail Rotor		25.97
Flight Controls		121.98
Total Scheduled	**2.9824**	**$486.48**
Unscheduled Maintenance		
Airframe Structure	0.2019	$99.15
Landing Gear	0.0553	52.80
Flight Controls	0.0850	398.52
Electrical and Avionics	0.3295	246.51
Rotor	0.1233	327.21
Systems	0.2106	27.16
Propulsion	0.1806	49.53
Drive	0.1654	70.04
Armament	0.0000	0.00
Total Unscheduled	**1.3516**	**$1,270.92**
Powerplant Maintenance		**$1,074.81**
Airframe Maintenance	**4.3340**	**$1,757.39**
Total Direct Maintenance		**$2,832.20**
Fuel Cost		**$943.26**
Total Direct Operating Cost		**$3,775.46**

Lift Offset O&S Summary, TBO = 8,000 flt. hrs.

Category	Maintenance man hours per flight hour	Part cost per flight hour
Scheduled Maintenance		
Inspection	2.8190	
Drive System	0.0232	
Main Transmission		$21.83
Tailrotor Gearbox		0.00
Intermediate Gearbox		3.85
Combining Gearbox		0.00
Accessory Gearbox		8.59
Rotor System	0.0061	
Main Rotor		$53.08
Tail Rotor		16.33
Flight Controls		31.86
Part Retirements	0.1301	
Drive System		$14.91
Main Rotor		149.42
Tail Rotor		25.98
Flight Controls		107.65
Total Scheduled	**2.9785**	**$433.49**
Unscheduled Maintenance		
Airframe Structure	0.2021	$99.34
Landing Gear	0.0554	52.91
Flight Controls	0.0781	368.05
Electrical and Avionics	0.3014	225.54
Rotor	0.1137	303.13
Systems	0.1928	24.87
Propulsion	0.1646	45.23
Drive	0.1520	64.50
Armament	0.0000	0.00
Total Unscheduled	**1.2601**	**$1,183.58**
Powerplant Maintenance		**$981.99**
Airframe Maintenance	**4.2386**	**$1,617.07**
Total Direct Maintenance		**$2,599.06**
Fuel Cost		**$948.23**
Total Direct Operating Cost		**$3,547.29**

Lift Offset O&S Summary, TBO = 9,000 flt. hrs.

Category	Maintenance man hours per flight hour	Part cost per flight hour
Scheduled Maintenance		
Inspection	2.8229	
Drive System	0.0184	
Main Transmission		$19.53
Tailrotor Gearbox		0.00
Intermediate Gearbox		3.45
Combining Gearbox		0.00
Accessory Gearbox		7.65
Rotor System	0.0049	
Main Rotor		$47.86
Tail Rotor		14.55
Flight Controls		28.57
Part Retirements	0.1307	
Drive System		$13.31
Main Rotor		134.59
Tail Rotor		25.99
Flight Controls		96.42
Total Scheduled	**2.9769**	**$391.92**
Unscheduled Maintenance		
Airframe Structure	0.2022	$99.51
Landing Gear	0.0554	53.02
Flight Controls	0.0728	344.30
Electrical and Avionics	0.2796	209.24
Rotor	0.1062	284.38
Systems	0.1791	23.10
Propulsion	0.1521	41.89
Drive	0.1416	60.19
Armament	0.0000	0.00
Total Unscheduled	**1.1890**	**$1,115.62**
Powerplant Maintenance		**$909.73**
Airframe Maintenance	**4.1659**	**$1,507.54**
Total Direct Maintenance		**$2,417.27**
Fuel Cost		**$952.92**
Total Direct Operating Cost		**$3,370.20**

Lift Offset O&S Summary, TBO = 10,000 flt. hrs.

Category	**Maintenance man hours per flight hour**	**Part cost per flight hour**
Scheduled Maintenance		
Inspection	2.8265	
Drive System	0.0149	
Main Transmission		$17.68
Tailrotor Gearbox		0.00
Intermediate Gearbox		3.12
Combining Gearbox		0.00
Accessory Gearbox		6.89
Rotor System	0.0040	
Main Rotor		$43.62
Tail Rotor		13.13
Flight Controls		25.91
Part Retirements	0.1313	
Drive System		$12.03
Main Rotor		122.58
Tail Rotor		25.99
Flight Controls		87.37
Total Scheduled	**2.9766**	**$358.33**
Unscheduled Maintenance		
Airframe Structure	0.2024	$99.67
Landing Gear	0.0554	53.11
Flight Controls	0.0685	325.24
Electrical and Avionics	0.2621	196.19
Rotor	0.1001	269.33
Systems	0.1680	21.68
Propulsion	0.1422	39.21
Drive	0.1333	56.74
Armament	0.0000	0.00
Total Unscheduled	**1.1321**	**$1,061.16**
Powerplant Maintenance		**$851.84**
Airframe Maintenance	**4.1087**	**$1,419.49**
Total Direct Maintenance		**$2,271.33**
Fuel Cost		**$957.07**
Total Direct Operating Cost		**$3,328.40**

Lift Offset O&S Summary, TBO = 11,000 flt. hrs.

Category	Maintenance man hours per flight hour	Part cost per flight hour
Scheduled Maintenance		
Inspection	2.6378	
Drive System	0.0123	
Main Transmission		$16.17
Tailrotor Gearbox		0.00
Intermediate Gearbox		2.86
Combining Gearbox		0.00
Accessory Gearbox		6.28
Rotor System	0.0033	
Main Rotor		$40.22
Tail Rotor		11.97
Flight Controls		23.75
Part Retirements	0.1200	
Drive System		$10.98
Main Rotor		112.91
Tail Rotor		26.00
Flight Controls		80.01
Total Scheduled	**2.7734**	**$331.16**
Unscheduled Maintenance		
Airframe Structure	0.1888	$93.16
Landing Gear	0.0517	49.79
Flight Controls	0.0651	310.00
Electrical and Avionics	0.2478	185.53
Rotor	0.0953	257.54
Systems	0.1590	20.52
Propulsion	0.1342	37.10
Drive	0.1265	53.96
Armament	0.0000	0.00
Total Unscheduled	**1.0685**	**$1,007.59**
Powerplant Maintenance		**$805.27**
Airframe Maintenance	**3.8420**	**$1,338.75**
Total Direct Maintenance		**$2,144.02**
Fuel Cost		**$962.39**
Total Direct Operating Cost		**$3,106.41**

Lift Offset O&S Summary, TBO = 12,000 flt. hrs.

Category	**Maintenance man hours per flight hour**	**Part cost per flight hour**
Scheduled Maintenance		
Inspection	2.4805	
Drive System	0.0104	
Main Transmission		$14.91
Tailrotor Gearbox		0.00
Intermediate Gearbox		2.64
Combining Gearbox		0.00
Accessory Gearbox		5.77
Rotor System	0.0028	
Main Rotor		$37.35
Tail Rotor		11.00
Flight Controls		21.94
Part Retirements	0.1105	
Drive System		$10.10
Main Rotor		104.78
Tail Rotor		26.01
Flight Controls		73.83
Total Scheduled	**2.6042**	**$308.34**
Unscheduled Maintenance		
Airframe Structure	0.1775	$87.73
Landing Gear	0.0487	47.01
Flight Controls	0.0622	297.29
Electrical and Avionics	0.2359	176.64
Rotor	0.0913	247.74
Systems	0.1515	19.56
Propulsion	0.1275	35.34
Drive	0.1209	51.64
Armament	0.0000	0.00
Total Unscheduled	**1.0156**	**$962.95**
Powerplant Maintenance		**$766.46**
Airframe Maintenance	**3.6198**	**$1,271.29**
Total Direct Maintenance		**$2,037.75**
Fuel Cost		**$967.44**
Total Direct Operating Cost		**$3,005.19**

Lift Offset O&S Summary, TBO = 13,000 flt. hrs.

Category	Maintenance man hours per flight hour	Part cost per flight hour
Scheduled Maintenance		
Inspection	2.3473	
Drive System	0.0088	
Main Transmission		$13.84
Tailrotor Gearbox		0.00
Intermediate Gearbox		2.45
Combining Gearbox		0.00
Accessory Gearbox		5.33
Rotor System	0.0024	
Main Rotor		$34.90
Tail Rotor		10.18
Flight Controls		20.39
Part Retirements	0.1025	
Drive System		$9.36
Main Rotor		97.82
Tail Rotor		26.02
Flight Controls		68.58
Total Scheduled	**2.4610**	**$288.88**
Unscheduled Maintenance		
Airframe Structure	0.1680	$83.13
Landing Gear	0.0461	44.65
Flight Controls	0.0598	286.57
Electrical and Avionics	0.2259	169.11
Rotor	0.0879	239.47
Systems	0.1452	18.75
Propulsion	0.1218	33.85
Drive	0.1162	49.69
Armament	0.0000	0.00
Total Unscheduled	**0.9708**	**$925.22**
Powerplant Maintenance		**$733.61**
Airframe Maintenance	**3.4318**	**$1,214.10**
Total Direct Maintenance		**$1,947.71**
Fuel Cost		**$972.08**
Total Direct Operating Cost		**$2,919.79**

Lift Offset O&S Summary, TBO = 14,000 flt. hrs.

Category	**Maintenance man hours per flight hour**	**Part cost per flight hour**
Scheduled Maintenance		
Inspection	2.2331	
Drive System	0.0076	
Main Transmission		$12.92
Tailrotor Gearbox		0.00
Intermediate Gearbox		2.29
Combining Gearbox		0.00
Accessory Gearbox		4.96
Rotor System	0.0020	
Main Rotor		$32.78
Tail Rotor		9.48
Flight Controls		19.06
Part Retirements	0.0956	
Drive System		$8.72
Main Rotor		91.79
Tail Rotor		26.03
Flight Controls		64.05
Total Scheduled	**2.3384**	**$272.07**
Unscheduled Maintenance		
Airframe Structure	0.1598	$79.19
Landing Gear	0.0438	42.62
Flight Controls	0.0577	277.40
Electrical and Avionics	0.2172	162.67
Rotor	0.0850	232.40
Systems	0.1398	18.05
Propulsion	0.1170	32.57
Drive	0.1121	48.01
Armament	0.0000	0.00
Total Unscheduled	**0.9324**	**$892.92**
Powerplant Maintenance		**$705.46**
Airframe Maintenance	**3.2708**	**$1,164.99**
Total Direct Maintenance		**$1,870.45**
Fuel Cost		**$976.44**
Total Direct Operating Cost		**$2,846.89**

Lift Offset O&S Summary, TBO = 15,000 flt. hrs.

Category	**Maintenance man hours per flight hour**	**Part cost per flight hour**
Scheduled Maintenance		
Inspection	2.1341	
Drive System	0.0066	
Main Transmission		$12.11
Tailrotor Gearbox		0.00
Intermediate Gearbox		2.15
Combining Gearbox		0.00
Accessory Gearbox		4.63
Rotor System	0.0018	
Main Rotor		$30.92
Tail Rotor		8.87
Flight Controls		17.90
Part Retirements	0.0896	
Drive System		$8.16
Main Rotor		86.54
Tail Rotor		26.04
Flight Controls		60.10
Total Scheduled	**2.2322**	**$257.43**
Unscheduled Maintenance		
Airframe Structure	0.1527	$75.77
Landing Gear	0.0419	40.86
Flight Controls	0.0559	269.47
Electrical and Avionics	0.2097	157.08
Rotor	0.0825	226.34
Systems	0.1351	17.45
Propulsion	0.1128	31.47
Drive	0.1086	46.56
Armament	0.0000	0.00
Total Unscheduled	**0.8992**	**$865.01**
Powerplant Maintenance		**$681.10**
Airframe Maintenance	**3.1313**	**$1,122.44**
Total Direct Maintenance		**$1,803.54**
Fuel Cost		**$980.75**
Total Direct Operating Cost		**$2,784.29**

Lift Offset O&S Summary, TBO = 16,000 flt. hrs.

Category	Maintenance man hours per flight hour	Part cost per flight hour
Scheduled Maintenance		
Inspection	2.0475	
Drive System	0.0058	
Main Transmission		$11.41
Tailrotor Gearbox		0.00
Intermediate Gearbox		2.02
Combining Gearbox		0.00
Accessory Gearbox		4.35
Rotor System	0.0016	
Main Rotor		$29.28
Tail Rotor		8.33
Flight Controls		16.88
Part Retirements	0.0843	
Drive System		$7.67
Main Rotor		81.89
Tail Rotor		26.05
Flight Controls		56.63
Total Scheduled	**2.1392**	**$244.53**
Unscheduled Maintenance		
Airframe Structure	0.1465	$72.78
Landing Gear	0.0402	39.32
Flight Controls	0.0543	262.54
Electrical and Avionics	0.2032	152.19
Rotor	0.0803	221.04
Systems	0.1310	16.92
Propulsion	0.1091	30.51
Drive	0.1055	45.30
Armament	0.0000	0.00
Total Unscheduled	**0.8701**	**$840.60**
Powerplant Maintenance		**$659.78**
Airframe Maintenance	**3.0093**	**$1,085.13**
Total Direct Maintenance		**$1,744.90**
Fuel Cost		**$984.76**
Total Direct Operating Cost		**$2,729.66**

Lift Offset O&S Summary, TBO = 17,000 flt. hrs.

Category	**Maintenance man hours per flight hour**	**Part cost per flight hour**
Scheduled Maintenance		
Inspection	1.9710	
Drive System	0.0052	
Main Transmission		$10.78
Tailrotor Gearbox		0.00
Intermediate Gearbox		1.91
Combining Gearbox		0.00
Accessory Gearbox		4.10
Rotor System	0.0014	
Main Rotor		$27.82
Tail Rotor		7.86
Flight Controls		15.98
Part Retirements	0.0796	
Drive System		$7.24
Main Rotor		77.76
Tail Rotor		26.05
Flight Controls		53.56
Total Scheduled	**2.0572**	**$233.08**
Unscheduled Maintenance		
Airframe Structure	0.1410	$70.13
Landing Gear	0.0387	37.96
Flight Controls	0.0529	256.46
Electrical and Avionics	0.1974	147.89
Rotor	0.0784	216.40
Systems	0.1273	16.45
Propulsion	0.1059	29.66
Drive	0.1028	44.18
Armament	0.0000	0.00
Total Unscheduled	**0.8444**	**$819.13**
Powerplant Maintenance		**$640.98**
Airframe Maintenance	**2.9017**	**$1,052.21**
Total Direct Maintenance		**$1,693.19**
Fuel Cost		**$988.60**
Total Direct Operating Cost		**$2,681.79**

Lift Offset O&S Summary, TBO = 18,000 flt. hrs.

Category	**Maintenance man hours per flight hour**	**Part cost per flight hour**
Scheduled Maintenance		
Inspection	1.9030	
Drive System	0.0046	
Main Transmission		$10.22
Tailrotor Gearbox		0.00
Intermediate Gearbox		1.82
Combining Gearbox		0.00
Accessory Gearbox		3.88
Rotor System	0.0013	
Main Rotor		$26.51
Tail Rotor		7.44
Flight Controls		15.17
Part Retirements	0.0755	
Drive System		$6.86
Main Rotor		74.06
Tail Rotor		26.06
Flight Controls		50.82
Total Scheduled	**1.9844**	**$222.83**
Unscheduled Maintenance		
Airframe Structure	0.1361	$67.78
Landing Gear	0.0374	36.75
Flight Controls	0.0517	251.07
Electrical and Avionics	0.1923	144.05
Rotor	0.0767	212.29
Systems	0.1241	16.04
Propulsion	0.1030	28.90
Drive	0.1004	43.19
Armament	0.0000	0.00
Total Unscheduled	**0.8216**	**$800.07**
Powerplant Maintenance		**$624.28**
Airframe Maintenance	**2.8060**	**$1,022.91**
Total Direct Maintenance		**$1,647.19**
Fuel Cost		**$992.20**
Total Direct Operating Cost		**$2,639.38**

Lift Offset O&S Summary, TBO = 19,000 flt. hrs.

Category	Maintenance man hours per flight hour	Part cost per flight hour
Scheduled Maintenance		
Inspection	1.8422	
Drive System	0.0041	
Main Transmission		$9.72
Tailrotor Gearbox		0.00
Intermediate Gearbox		1.73
Combining Gearbox		0.00
Accessory Gearbox		3.68
Rotor System	0.0011	
Main Rotor		$25.33
Tail Rotor		7.06
Flight Controls		14.44
Part Retirements	0.0717	
Drive System		$6.51
Main Rotor		70.73
Tail Rotor		26.07
Flight Controls		48.35
Total Scheduled	**1.9192**	**$213.62**
Unscheduled Maintenance		
Airframe Structure	0.1317	$65.68
Landing Gear	0.0362	35.67
Flight Controls	0.0506	246.25
Electrical and Avionics	0.1877	140.62
Rotor	0.0752	208.64
Systems	0.1212	15.67
Propulsion	0.1004	28.23
Drive	0.0982	42.31
Armament	0.0000	0.00
Total Unscheduled	**0.8012**	**$783.06**
Powerplant Maintenance		**$609.35**
Airframe Maintenance	**2.7204**	**$996.68**
Total Direct Maintenance		**$1,606.04**
Fuel Cost		**$995.60**
Total Direct Operating Cost		**$2,601.64**

Lift Offset O&S Summary, TBO = 20,000 flt. hrs.

Category	Maintenance man hours per flight hour	Part cost per flight hour
Scheduled Maintenance		
Inspection	1.7874	
Drive System	0.0037	
Main Transmission		$9.27
Tailrotor Gearbox		0.00
Intermediate Gearbox		1.65
Combining Gearbox		0.00
Accessory Gearbox		3.50
Rotor System	0.0010	
Main Rotor		$24.27
Tail Rotor		6.72
Flight Controls		13.78
Part Retirements	0.0684	
Drive System		$6.20
Main Rotor		67.71
Tail Rotor		26.07
Flight Controls		46.12
Total Scheduled	**1.8605**	**$205.30**
Unscheduled Maintenance		
Airframe Structure	0.1278	$63.78
Landing Gear	0.0351	34.69
Flight Controls	0.0496	241.95
Electrical and Avionics	0.1836	137.54
Rotor	0.0738	205.39
Systems	0.1186	15.33
Propulsion	0.0981	27.62
Drive	0.0963	41.52
Armament	0.0000	0.00
Total Unscheduled	**0.7829**	**$767.82**
Powerplant Maintenance		**$595.94**
Airframe Maintenance	**2.6434**	**$973.12**
Total Direct Maintenance		**$1,569.06**
Fuel Cost		**$999.00**
Total Direct Operating Cost		**$2,568.07**

Tiltrotor O&S Summary, TBO = 6,000 flt. hrs.

Category	Maintenance man hours per flight hour	Part cost per flight hour
Scheduled Maintenance		
Inspection	2.7896	
Drive System	0.0200	
Proprotor Gearbox		$37.13
Tiltaxis Gearbox		19.05
Midwing Gearbox		11.66
Combining Gearbox		0.00
Accessory Gearbox		10.45
Rotor System	0.0085	
Main Rotor		$46.11
		0.00
Flight Controls		27.12
Part Retirements	0.1043	
Drive System		$15.06
Main Rotor		88.48
		0.00
Flight Controls		129.60
Total Scheduled	**2.9225**	**$384.66**
Unscheduled Maintenance		
Airframe Structure	0.2182	$59.17
Landing Gear	0.0540	24.38
Flight Controls	0.1441	205.94
Electrical and Avionics	0.3275	271.01
Rotor	0.1504	245.61
Systems	0.1907	28.26
Propulsion	0.2256	70.71
Drive	0.1904	81.68
Armament	0.0000	0.00
Total Unscheduled	**1.5008**	**$986.76**
Powerplant Maintenance		**$1,176.02**
Airframe Maintenance	**4.4233**	**$1,371.42**
Total Direct Maintenance		**$2,547.45**
Fuel Cost		**$874.25**
Total Direct Operating Cost		**$3,421.69**

Tiltrotor O&S Summary, TBO = 7,000 flt. hrs.

Category	Maintenance man hours per flight hour	Part cost per flight hour
Scheduled Maintenance		
Inspection	2.7925	
Drive System	0.0147	
Proprotor Gearbox		$32.07
Tiltaxis Gearbox		16.45
Midwing Gearbox		10.07
Combining Gearbox		0.00
Accessory Gearbox		8.97
Rotor System	0.0063	
Main Rotor		$40.06
		0.00
Flight Controls		23.44
Part Retirements	0.1047	
Drive System		$12.97
Main Rotor		76.80
		0.00
Flight Controls		111.92
Total Scheduled	**2.9183**	**$332.75**
Unscheduled Maintenance		
Airframe Structure	0.2184	$59.28
Landing Gear	0.0540	24.43
Flight Controls	0.1298	186.17
Electrical and Avionics	0.2941	243.37
Rotor	0.1359	222.91
Systems	0.1713	25.39
Propulsion	0.2017	63.35
Drive	0.1718	73.85
Armament	0.0000	0.00
Total Unscheduled	**1.3770**	**$898.74**
Powerplant Maintenance		**$1,052.95**
Airframe Maintenance	**4.2953**	**$1,231.48**
Total Direct Maintenance		**$2,284.43**
Fuel Cost		**$877.75**
Total Direct Operating Cost		**$3,162.18**

Tiltrotor O&S Summary, TBO = 8,000 flt. hrs.

Category	Maintenance man hours per flight hour	Part cost per flight hour
Scheduled Maintenance		
Inspection	2.7951	
Drive System	0.0113	
Proprotor Gearbox		$28.24
Tiltaxis Gearbox		14.49
Midwing Gearbox		8.87
Combining Gearbox		0.00
Accessory Gearbox		7.87
Rotor System	0.0048	
Main Rotor		$35.45
		0.00
Flight Controls		20.66
Part Retirements	0.1050	
Drive System		$11.40
Main Rotor		67.92
		0.00
Flight Controls		98.56
Total Scheduled	**2.9163**	**$293.45**
Unscheduled Maintenance		
Airframe Structure	0.2185	$59.38
Landing Gear	0.0540	24.46
Flight Controls	0.1191	171.25
Electrical and Avionics	0.2690	222.63
Rotor	0.1250	205.78
Systems	0.1568	23.24
Propulsion	0.1838	57.81
Drive	0.1578	67.95
Armament	0.0000	0.00
Total Unscheduled	**1.2841**	**$832.51**
Powerplant Maintenance		**$960.45**
Airframe Maintenance	**4.2004**	**$1,125.96**
Total Direct Maintenance		**$2,086.41**
Fuel Cost		**$879.57**
Total Direct Operating Cost		**$2,965.98**

Tiltrotor O&S Summary, TBO = 9,000 flt. hrs.

Category	**Maintenance man hours per flight hour**	**Part cost per flight hour**
Scheduled Maintenance		
Inspection	2.7981	
Drive System	0.0089	
Proprotor Gearbox		$25.28
Tiltaxis Gearbox		12.97
Midwing Gearbox		7.94
Combining Gearbox		0.00
Accessory Gearbox		7.01
Rotor System	0.0038	
Main Rotor		$31.90
		0.00
Flight Controls		18.50
Part Retirements	0.1054	
Drive System		$10.18
Main Rotor		61.09
		0.00
Flight Controls		88.19
Total Scheduled	**2.9164**	**$263.04**
Unscheduled Maintenance		
Airframe Structure	0.2187	$59.50
Landing Gear	0.0541	24.52
Flight Controls	0.1109	159.84
Electrical and Avionics	0.2496	206.52
Rotor	0.1167	192.78
Systems	0.1455	21.57
Propulsion	0.1700	53.61
Drive	0.1470	63.43
Armament	0.0000	0.00
Total Unscheduled	**1.2124**	**$781.78**
Powerplant Maintenance		**$889.09**
Airframe Maintenance	**4.1288**	**$1,044.82**
Total Direct Maintenance		**$1,933.92**
Fuel Cost		**$883.74**
Total Direct Operating Cost		**$2,817.66**

Tiltrotor O&S Summary, TBO = 10,000 flt. hrs.

Category	Maintenance man hours per flight hour	Part cost per flight hour
Scheduled Maintenance		
Inspection	2.8005	
Drive System	0.0072	
Proprotor Gearbox		$22.88
Tiltaxis Gearbox		11.74
Midwing Gearbox		7.19
Combining Gearbox		0.00
Accessory Gearbox		6.32
Rotor System	0.0031	
Main Rotor		$29.00
		0.00
Flight Controls		16.76
Part Retirements	0.1058	
Drive System		$9.19
Main Rotor		55.50
		0.00
Flight Controls		79.80
Total Scheduled	**2.9166**	**$238.38**
Unscheduled Maintenance		
Airframe Structure	0.2189	$59.60
Landing Gear	0.0541	24.56
Flight Controls	0.1042	150.60
Electrical and Avionics	0.2340	193.62
Rotor	0.1099	182.21
Systems	0.1365	20.23
Propulsion	0.1589	50.19
Drive	0.1383	59.78
Armament	0.0000	0.00
Total Unscheduled	**1.1547**	**$740.80**
Powerplant Maintenance		**$831.67**
Airframe Maintenance	**4.0714**	**$979.17**
Total Direct Maintenance		**$1,810.84**
Fuel Cost		**$886.19**
Total Direct Operating Cost		**$2,697.03**

Tiltrotor O&S Summary, TBO = 11,000 flt. hrs.

Category	Maintenance man hours per flight hour	Part cost per flight hour
Scheduled Maintenance		
Inspection	2.6125	
Drive System	0.0060	
Proprotor Gearbox		$20.92
Tiltaxis Gearbox		10.73
Midwing Gearbox		6.57
Combining Gearbox		0.00
Accessory Gearbox		5.75
Rotor System	0.0026	
Main Rotor		$26.65
		0.00
Flight Controls		15.33
Part Retirements	0.0965	
Drive System		$8.39
Main Rotor		50.97
		0.00
Flight Controls		72.96
Total Scheduled	**2.7176**	**$218.28**
Unscheduled Maintenance		
Airframe Structure	0.2042	$55.72
Landing Gear	0.0505	23.01
Flight Controls	0.0988	143.15
Electrical and Avionics	0.2212	183.08
Rotor	0.1045	173.76
Systems	0.1291	19.14
Propulsion	0.1499	47.46
Drive	0.1313	56.84
Armament	0.0000	0.00
Total Unscheduled	**1.0895**	**$702.15**
Powerplant Maintenance		**$785.37**
Airframe Maintenance	**3.8071**	**$920.43**
Total Direct Maintenance		**$1,705.79**
Fuel Cost		**$890.39**
Total Direct Operating Cost		**$2,596.19**

Tiltrotor O&S Summary, TBO = 12,000 flt. hrs.

Category	Maintenance man hours per flight hour	Part cost per flight hour
Scheduled Maintenance		
Inspection	2.4561	
Drive System	0.0050	
Proprotor Gearbox		$19.30
Tiltaxis Gearbox		9.90
Midwing Gearbox		6.06
Combining Gearbox		0.00
Accessory Gearbox		5.28
Rotor System	0.0022	
Main Rotor		$24.69
		0.00
Flight Controls		14.14
Part Retirements	0.0888	
Drive System		$7.72
Main Rotor		47.20
		0.00
Flight Controls		67.24
Total Scheduled	**2.5521**	**$201.53**
Unscheduled Maintenance		
Airframe Structure	0.1920	$52.49
Landing Gear	0.0475	21.73
Flight Controls	0.0943	137.00
Electrical and Avionics	0.2106	174.28
Rotor	0.1000	166.86
Systems	0.1230	18.23
Propulsion	0.1424	45.21
Drive	0.1255	54.40
Armament	0.0000	0.00
Total Unscheduled	**1.0353**	**$670.20**
Powerplant Maintenance		**$746.96**
Airframe Maintenance	**3.5874**	**$871.73**
Total Direct Maintenance		**$893.81**
Fuel Cost		**$1,618.69**
Total Direct Operating Cost		**$2,512.50**

Tiltrotor O&S Summary, TBO = 13,000 flt. hrs.

Category	Maintenance man hours per flight hour	Part cost per flight hour
Scheduled Maintenance		
Inspection	2.3237	
Drive System	0.0043	
Proprotor Gearbox		$17.91
Tiltaxis Gearbox		9.19
Midwing Gearbox		5.63
Combining Gearbox		0.00
Accessory Gearbox		4.89
Rotor System	0.0019	
Main Rotor		$23.03
		0.00
Flight Controls		13.13
Part Retirements	0.0823	
Drive System		$7.15
Main Rotor		43.99
		0.00
Flight Controls		62.39
Total Scheduled	**2.4121**	**$187.31**
Unscheduled Maintenance		
Airframe Structure	0.1817	$49.75
Landing Gear	0.0450	20.64
Flight Controls	0.0906	131.83
Electrical and Avionics	0.2016	166.85
Rotor	0.0962	161.05
Systems	0.1178	17.46
Propulsion	0.1361	43.33
Drive	0.1206	52.35
Armament	0.0000	0.00
Total Unscheduled	**0.9895**	**$643.27**
Powerplant Maintenance		**$714.53**
Airframe Maintenance	**3.4016**	**$830.58**
Total Direct Maintenance		**$1,545.11**
Fuel Cost		**$897.33**
Total Direct Operating Cost		**$2,442.44**

Tiltrotor O&S Summary, TBO = 14,000 flt. hrs.

Category	Maintenance man hours per flight hour	Part cost per flight hour
Scheduled Maintenance		
Inspection	2.2097	
Drive System	0.0037	
Proprotor Gearbox		$16.71
Tiltaxis Gearbox		8.57
Midwing Gearbox		5.25
Combining Gearbox		0.00
Accessory Gearbox		4.55
Rotor System	0.0016	
Main Rotor		$21.56
		0.00
Flight Controls		12.25
Part Retirements	0.0766	
Drive System		$6.66
Main Rotor		41.16
		0.00
Flight Controls		58.18
Total Scheduled	**2.2917**	**$174.88**
Unscheduled Maintenance		
Airframe Structure	0.1729	$47.39
Landing Gear	0.0428	19.69
Flight Controls	0.0873	127.29
Electrical and Avionics	0.1939	160.47
Rotor	0.0929	155.90
Systems	0.1133	16.81
Propulsion	0.1307	41.65
Drive	0.1163	50.56
Armament	0.0000	0.00
Total Unscheduled	**0.9499**	**$619.76**
Powerplant Maintenance		**$686.40**
Airframe Maintenance	**3.2416**	**$794.64**
Total Direct Maintenance		**$1,481.04**
Fuel Cost		**$900.02**
Total Direct Operating Cost		**$2,381.07**

Tiltrotor O&S Summary, TBO = 15,000 flt. hrs.

Category	**Maintenance man hours per flight hour**	**Part cost per flight hour**
Scheduled Maintenance		
Inspection	2.1113	
Drive System	0.0032	
Proprotor Gearbox		$15.67
Tiltaxis Gearbox		8.04
Midwing Gearbox		4.92
Combining Gearbox		0.00
Accessory Gearbox		4.25
Rotor System	0.0014	
Main Rotor		$20.30
		0.00
Flight Controls		11.49
Part Retirements	0.0718	
Drive System		$6.24
Main Rotor		38.73
		0.00
Flight Controls		54.54
Total Scheduled	**2.1877**	**$164.18**
Unscheduled Maintenance		
Airframe Structure	0.1652	$45.35
Landing Gear	0.0409	18.88
Flight Controls	0.0845	123.45
Electrical and Avionics	0.1872	154.95
Rotor	0.0900	151.59
Systems	0.1095	16.24
Propulsion	0.1260	40.25
Drive	0.1127	49.04
Armament	0.0000	0.00
Total Unscheduled	**0.9159**	**$599.76**
Powerplant Maintenance		**$662.29**
Airframe Maintenance	**3.1036**	**$763.95**
Total Direct Maintenance		**$1,426.24**
Fuel Cost		**$904.20**
Total Direct Operating Cost		**$2,330.44**

Tiltrotor O&S Summary, TBO = 16,000 flt. hrs.

Category	**Maintenance man hours per flight hour**	**Part cost per flight hour**
Scheduled Maintenance		
Inspection	2.0246	
Drive System	0.0028	
Proprotor Gearbox		$14.74
Tiltaxis Gearbox		7.56
Midwing Gearbox		4.63
Combining Gearbox		0.00
Accessory Gearbox		3.99
Rotor System	0.0012	
Main Rotor		$19.15
		0.00
Flight Controls		10.81
Part Retirements	0.0674	
Drive System		$5.86
Main Rotor		36.53
		0.00
Flight Controls		51.31
Total Scheduled	**2.0961**	**$154.58**
Unscheduled Maintenance		
Airframe Structure	0.1584	$43.55
Landing Gear	0.0392	18.16
Flight Controls	0.0820	119.97
Electrical and Avionics	0.1813	150.12
Rotor	0.0875	147.60
Systems	0.1061	15.74
Propulsion	0.1218	38.95
Drive	0.1094	47.66
Armament	0.0000	0.00
Total Unscheduled	**0.8857**	**$581.73**
Powerplant Maintenance		**$640.80**
Airframe Maintenance	**2.9819**	**$736.31**
Total Direct Maintenance		**$1,377.11**
Fuel Cost		**$904.20**
Total Direct Operating Cost		**$2,281.31**

Tiltrotor O&S Summary, TBO = 17,000 flt. hrs.

Category	Maintenance man hours per flight hour	Part cost per flight hour
Scheduled Maintenance		
Inspection	1.9487	
Drive System	0.0025	
Proprotor Gearbox		$13.94
Tiltaxis Gearbox		7.15
Midwing Gearbox		4.38
Combining Gearbox		0.00
Accessory Gearbox		3.76
Rotor System	0.0011	
Main Rotor		$18.17
		0.00
Flight Controls		10.23
Part Retirements	0.0637	
Drive System		$5.53
Main Rotor		34.65
		0.00
Flight Controls		48.48
Total Scheduled	**2.0160**	**$146.29**
Unscheduled Maintenance		
Airframe Structure	0.1525	$41.98
Landing Gear	0.0378	17.53
Flight Controls	0.0798	117.03
Electrical and Avionics	0.1762	145.85
Rotor	0.0853	144.35
Systems	0.1031	15.29
Propulsion	0.1182	37.88
Drive	0.1066	46.50
Armament	0.0000	0.00
Total Unscheduled	**0.8595**	**$566.42**
Powerplant Maintenance		**$622.27**
Airframe Maintenance	**2.8755**	**$712.70**
Total Direct Maintenance		**$1,334.98**
Fuel Cost		**$909.03**
Total Direct Operating Cost		**$2,244.01**

Tiltrotor O&S Summary, TBO = 18,000 flt. hrs.

Category	Maintenance man hours per flight hour	Part cost per flight hour
Scheduled Maintenance		
Inspection	1.8809	
Drive System	0.0022	
Proprotor Gearbox		$13.22
Tiltaxis Gearbox		6.78
Midwing Gearbox		4.15
Combining Gearbox		0.00
Accessory Gearbox		3.56
Rotor System	0.0010	
Main Rotor		$17.27
		0.00
Flight Controls		9.69
Part Retirements	0.0603	
Drive System		$5.24
Main Rotor		32.93
		0.00
Flight Controls		45.95
Total Scheduled	**1.9444**	**$138.78**
Unscheduled Maintenance		
Airframe Structure	0.1473	$40.57
Landing Gear	0.0365	16.97
Flight Controls	0.0779	114.36
Electrical and Avionics	0.1716	142.06
Rotor	0.0834	141.35
Systems	0.1005	14.90
Propulsion	0.1150	36.90
Drive	0.1041	45.44
Armament	0.0000	0.00
Total Unscheduled	**0.8361**	**$552.56**
Powerplant Maintenance		**$605.62**
Airframe Maintenance	**2.7805**	**$691.34**
Total Direct Maintenance		**$1,296.96**
Fuel Cost		**$908.64**
Total Direct Operating Cost		**$2,205.60**

Tiltrotor O&S Summary, TBO = 19,000 flt. hrs.

Category	Maintenance man hours per flight hour	Part cost per flight hour
Scheduled Maintenance		
Inspection	1.8204	
Drive System	0.0020	
Proprotor Gearbox		$12.57
Tiltaxis Gearbox		6.45
Midwing Gearbox		3.95
Combining Gearbox		0.00
Accessory Gearbox		3.37
Rotor System	0.0009	
Main Rotor		$16.48
		0.00
Flight Controls		9.22
Part Retirements	0.0572	
Drive System		$4.98
Main Rotor		31.40
		0.00
Flight Controls		43.68
Total Scheduled	**1.8805**	**$132.08**
Unscheduled Maintenance		
Airframe Structure	0.1425	$39.32
Landing Gear	0.0353	16.47
Flight Controls	0.0762	112.01
Electrical and Avionics	0.1675	138.67
Rotor	0.0817	138.73
Systems	0.0981	14.55
Propulsion	0.1121	36.04
Drive	0.1019	44.51
Armament	0.0000	0.00
Total Unscheduled	**0.8152**	**$540.31**
Powerplant Maintenance		**$590.81**
Airframe Maintenance	**2.6957**	**$672.39**
Total Direct Maintenance		**$1,263.20**
Fuel Cost		**$912.17**
Total Direct Operating Cost		**$2,175.37**

Tiltrotor O&S Summary, TBO = 20,000 flt. hrs.

Category	Maintenance man hours per flight hour	Part cost per flight hour
Scheduled Maintenance		
Inspection	1.7659	
Drive System	0.0018	
Proprotor Gearbox		$11.98
Tiltaxis Gearbox		6.15
Midwing Gearbox		3.76
Combining Gearbox		0.00
Accessory Gearbox		3.21
Rotor System	0.0008	
Main Rotor		$15.75
		0.00
Flight Controls		8.79
Part Retirements	0.0545	
Drive System		$4.74
Main Rotor		30.01
		0.00
Flight Controls		41.63
Total Scheduled	**1.8230**	**$126.03**
Unscheduled Maintenance		
Airframe Structure	0.1383	$38.19
Landing Gear	0.0343	16.01
Flight Controls	0.0746	109.90
Electrical and Avionics	0.1638	135.62
Rotor	0.0801	136.38
Systems	0.0960	14.24
Propulsion	0.1095	35.26
Drive	0.0998	43.68
Armament	0.0000	0.00
Total Unscheduled	**0.7964**	**$529.28**
Powerplant Maintenance		**$577.49**
Airframe Maintenance	**2.6194**	**$655.31**
Total Direct Maintenance		**$1,232.80**
Fuel Cost		**$914.61**
Total Direct Operating Cost		**$2,147.41**

REFERENCES

Chapter 1: Introduction

1-1. Betz, A., “Considerations for Propeller Efficiency,” TM 481. National Advisory Committee for Aeronautics, Washington, D.C., 1928.

1-2. Glauert, H., “A General Theory of the Autogyro,” Aeronautical Research Committee, Farnborough. 1926.

1-3. Carlson, R., “Helicopter Performance – Transportation’s Latest Chromosome: The 21st Annual Alexander A. Nikolsky Lecture,” *Journal of the American Helicopter Society*, Vol. 47, (1), Jan. 2002, pp. 3.

1-4. Schrage, D.P., “Technology for Rotorcraft Affordability Through Integrated Product/Process Development (IPPD),” American Helicopter Society 55th Annual Forum Proceedings, Montreal, Quebec, May 1999.

1-5. Schrage, D.P., McCandless, W., “Integrated Product/Process Development Approach for Balancing Technology Push and Pull Between the User and Developer,” American Helicopter Society 68th Annual Forum Proceedings, Dallas, Texas, May 2012.

1-6. *Life Cycle Cost: Helicopters, Pistons, Turboprops*, Version 13.1, 2013. Conklin & deDecker Aviation Information. Arlington, Texas.

1-7. Bevilaqua, P., “The Shaft Driven Lift Fan Propulsion System for the Joint Strike Fighter,” American Helicopter Society 53rd Annual Forum Proceedings, Virginia Beach, Virginia, April 1997.

1-8. Ormiston, R., “Revitalizing Advanced Rotorcraft Research – and the Compound Helicopter: The 35th Annual Alexander A. Nikolsky Lecture,” *Journal of the American Helicopter Society*, Dec. 2015.

1-9. Harris, F. D., “Improving Rotorcraft Efficiency Through Aerodynamic Design,” Seminar. Georgia Institute of Technology, Atlanta, Georgia, June 2012.

1-10. Von Karman, T., Gabrielli, P., “What Price Speed? Specific Power Required for the Propulsion of Vehicles,” *Mechanical Engineering*, Vol. 72, 1950, pp. 775.

1-11. Sinsay, J.D., “The Path to Turboprop Competitive Rotorcraft: Aerodynamic Challenges,” American Helicopter Society Specialists’ Meeting on Aeromechanics, San Francisco, California, Jan. 2008.

1-12. Bagai, A., “Aerodynamic Design of the Sikorsky X2 Technology Demonstrator Main Rotor Blade,” American Helicopter Society 64th Annual Forum Proceedings, Montreal, Quebec, Apr. 2008.

1-13. Maisel, M., Guilianetti, D., Dugan, D., *The History of the XV-15 Tilt Rotor Research Aircraft: From Concept to Flight*, National Aeronautics and Space Administration, Washington, D.C., 2000., NASA SP-2000-4517.

1-14. Moodie, A., Yeo, H., “System Performance Assessment of Active Controls for an Advanced Helicopter Concept,” American Helicopter Society 69th Annual Forum Proceedings, Phoenix, Arizona, May 2013.

1-15. Silva, C., Calvert, M., Gallaher, A., Nunez, G., Scott, R., Sinsay, J., Vocke, R., “The High Efficiency Tiltrotor as a Solution to the Needs of a Mobile Military,”

American Helicopter Society Specialists' Meeting on Aeromechanics Design for Vertical Lift, San Francisco, California, Jan. 2016.
1-16. Scott, R., "Design and Affordability Assessment of a Highly Reliable Helicopter," American Helicopter Society Systems Engineering Specialists' Meeting, Capability and Affordability in the Future Vertical Lift Industry, Huntsville, Alabama, September 2015.
1-17. *IHS Jane's All the World's Aircraft: Development & Production 2014-2015*. IHS, Surrey, UK, 2014.
1-18. Schnebly, D., Carlson, R., "Optimum Design of Transport Helicopters for Maximum Net Profit," American Helicopter Society 10th Annual Forum Proceedings, Washington, D.C., May 1954.
1-19. Olson, J., "Reducing Helicopter Operating Costs," *Vertiflite*, 1993, Vol. 39 (1).
1-20. Harris, "Helicopter Operating Costs," AHS Technical Seminar, Moffett Field, California, October 2012.
1-21. Schnebly, D., "Transport Helicopter Operating Cost Analysis Methods," Report No. 360.1
1-22. Sheldon, J., Steele, J., Sarlashkar, A., Kasper, D., Watson, M., Davis, M., Fetty, J., "A Systematic Approach to Reducing Helicopter Tail Drive Shaft Maintenance," American Helicopter Society 69th Annual Forum Proceedings, Phoenix, Arizona, May 2013
1-23. "Bell Helicopter and US Army Sign Cooperative Agreement to Develop Drive System Technologies," Bell Helicopter Press Release. Ft. Worth, Texas, November 2010.
1-24. Advanced Turbine Engine Company (ATEC) Infographic (http://www.atecpower.net)
1-25. Ultra-Reliable Designs – Phase I (URD-PHI) Proposal Solicitation (fedbizopps.gov), Solicitation Number: W911W615R0012.

Chapter 2: Rotorcraft Performance Challenges

2-1. Joy, D.P., Simonds, R.M., Wagner, R.A., "Transport Helicopter Design Analysis Methods," Report No. 473.6, Office of Naval Research, Contract Nonr-1340(00), Hiller Helicopters Engineering Division. November, 1955.
2-2. Simonds, R.M., A Generalized Graphical Method of Minimum Gross Weight Estimation," National Conference of the Society of Aeronautical Weight Engineers, San Diego, California, May 1956.
2-3. Stepniewski, W. Z., "Design Philosophy and Operational Requirements of Subsonic VTOL Aircraft," *Journal of Aircraft*, 1964, Vol. 1 (3). pp. 148-156.
2-4. Tishchenko M.N., Nekrasov, A.V., Radin, A.S., *Helicopters, Selection of Design Parameters*, Mashinostroyeniye Press, Moscow, 1976.
2-5. Stoessel, R.F., Gallagher, J.E., "A Standard Method for Estimating VTOL Operating Expense (A More Realistic Approach)," AIAA Paper No. 67-828, AIAA Fourth Annual Meeting and Technical Display, Anaheim, California, October 1967.
2-6. Unger, G., "Navy/Marine 1980 Rotary Wing Candidates," American Helicopter Society 31st Annual Forum Proceedings, Washington, D.C., 1975.

2-7. Dellert, G.M., "An Analysis of the Impact of Reliability and Maintainability on the Operating and Support Costs and Operational Availability of the RAH-66 Comanche Helicopter," M.S. Thesis, Naval Postgraduate School, Monterrey, California, 2001.
2-8. Relf, M.N., "Maintenance-free Operating Periods – The Designer's Challenge," Quality and Reliability Engineering International, Vol. 27, No. 2, pp. 111-116, March/April 1999.
2-9. UH-60M Black Hawk Selected Acquisition Report (SAR). December 2014. Defense Acquistion Management Information Retrieval (DAMIR)
2-10. CH-47F Chinook Selected Acquisition Report (SAR). December 2014. Defense Acquistion Management Information Retrieval (DAMIR)
2-11. AH-64E Apache Remanufacture & New Build Selected Acquisition Reports (SAR). December 2012. Defense Acquistion Management Information Retrieval (DAMIR)
2-12. CH-53K Selected Acquisition Report (SAR). December 2014. Defense Acquistion Management Information Retrieval (DAMIR)
2-13. Scott, R., "Concept Design & Assessment Perspective on Government – Industry Cost Modeling Collaboration," Presentation to Vertical Lift Consortium Cost Modeling Review Session, July 2014.

Chapter 3:

3-1. Operating and Support Cost-Estimating Guide, 2014, Washington, D.C. Office of the Secretary of Defense, Cost Assessment and Program Evaluation.
3-2. Veca, A.C., "Vibration Effects on Helicopter Reliability and Maintainability," Technical Report 73-11, USAAMRDL, Sikorsky Aircraft, Fort Eustis, Virginia, 1973.
3-3. Coy, J.J., "Cost Analysis for Large Civil Transport Rotorcraft," American Helicopter Society Vertical Lift Aircraft Design Specialists' Meeting, San Francisco, California. January 2006.
3-4. Biggs, R., and Key, J., "PC-Based Development and Recurring Cost Model Users' Guide," National Rotorcraft Technology Center, 2001.
3-5. Long, E.A., Forbes, J., Hees, J., Stouffer, V., "Empirical Relationships Between Reliability Investments and Life-Cycle Support Costs," Logistics Management Institute, June 2007.
3-6. Scott, R. "Historical Trends in Turboshaft Procurement Cost," Internal Study, Concept Design & Assessment, US Army Aviation Development Directorate – AFDD, June 2015.
3-7. Levine, L.S., "Application of the ABC Helicopter to the Emergency Medical Service Role," AIAA Paper No. 81-2653, AIAA/NASA Ames V/STOL Conference, Palo Alto, California, December 1981.
3-8. Magonigal, S., West, J., "The First Combat Deployment of the CH-47F Improved Cargo Helicopter," American Helicopter Society 65th Annual Forum Proceedings, Grapevine, Texas. May 2009.

3-9. Stehle, B., “AHS Apache Update,” American Helicopter Society 69th Annual Forum Proceedings, Phoenix, Arizona, May 2013.
3-10. Durno, J., “Meeting the USMC Requirements for Amphibious Heavy Lift with the Sikorsky CH-53K,” American Helicopter Society 63rd Annual Forum, Virginia Beach, Virginia, May 2007
3-11. Donohue, T.M, “Black Hawk: A Logistic Success Story,” American Helicopter Society 39th Annual Forum Proceedings, St. Louis, Missouri, May 1983.
3-12. Ellis, C.W., Diamond, J., Fay, C.B., “Design, Development, and Testing of the Boeing Vertol / Army YUH-61A,” American Helicopter Society 32nd Annual Forum Proceedings, Washington, D.C., May 1976.
3-13. Johnson, W., “NASA Design and Analysis of Rotorcraft, Theory,” NASA Ames Research Center, Moffett Field, California, February 2015. Release 1.9.
3-14. “Boeing Developing Low Maintenance Rotor Hub for CH-47 Chinook,” Boeing Media Room Press Release. http://boeing.mediaroom.com/. August 1999.

Chapter 4:

4-1. Future Vertical Lift Capability Set 3 Request for Information, Solicitation No. W58RGZ-16-R-0170, Dept. of the Army, Army Contracting Command, Huntsville, AL. Feb. 2016.
4-2. Scott, R., “A Historical Survey of Operational Effectiveness in Relation to Preliminary Design,” American Helicopter Society 71st Annual Forum Proceedings, Virginia Beach, VA, May 2015.
4-3. H-1 Upgrades Selected Acquisition Report (SAR), President’s Budget 2016. March 2016. Defense Acquistion Management Information Retrieval (DAMIR)
4-4. FARS Part 91, §91.151, §91.167, Federal Aviation Administration, accessed March 7, 2016, http://www.faa.gov/regulations_policies/faa_regulations/
4-5. Bell-Boeing V-22 Data Brochure, accessed March 7, 2016, http://bellhelicopter.com/military/bell-boeing-v-22
4-6. Hiller 1960 LUH mass properties report
4-7. Rosenstein, H., Stanzione, K., “Computer Aided Helicopter Design,” American Helicopter Society 37th Annual Forum Proceedings, New Orleans, LA, May 1981.
4-8. Prouty, R.W., *Helicopter Performance, Stability, and Control*, Krieger Publishing, Malabar, FL, 2002.
4-9. Johnson, W., NDARC-NASA Design and Analysis of Rotorcraft Theory, Release 1.9, National Aeronautics and Space Administration, Feb. 2015.
4-10. Johnson, W., “NDARC – NASA Design and Analysis of Rotorcraft Validation and Demonstration,” American Helicopter Society Aeromechanics Specialists’ Meeting, San Francisco, CA. January 2010.

Chapter 5

5-1. Harris, F., Scully, M., “Rotorcraft Cost Too Much,” *Journal of the American Helicopter Society*, 1998, Vol. 43 (1).
5-2. TrueRotorcraft Theory Manual, PRICE Systems

5-3. “Department of Defense Standard Practice – Work Breakdown Structure for Defense Materiel Items,” MIL-STD 881C. October 2011.
5-4. Recommend Practice 8, Revision A (RP-8A), Weight and Balance Data Reporting Forms for Aircraft (Including Rotorcraft), Society of Allied Weight Engineers, Los Angeles, CA. June 1997.
5-5. Scott, R., Sinsay, J., Dinning, M., McMichael, S., “Consideration of Mission Effectiveness and Cost in the Assessment of Future Military Rotorcraft,” American Helicopter Society Specialists’ Meeting on Aeromechanics Design for Vertical Lift, San Francisco, CA, Jan. 2016.
5-6. Military Standard (MIL-STD-1374A) Weight and Balance Data Reporting Forms for Aircraft (Including Rotorcraft), Department of Defense. September 1977
5-7. Keen, E., Tenney, B., “A Conceptual Design Study of a Vertical Lift Family of Systems,” American Helicopter Society Specialists′ Meeting on Aeromechanics Design for Vertical Lift, San Francisco, California, Jan. 2016.
5-8. Johnson, W., Moodie, A.M., Yeo, H., “Design and Performance of Lift-Offset Rotorcraft for Short-Haul Missions,” American Helicopter Society Future Vertical Lift Aircraft Design Conference, San Francisco, California, January 2012.

Chapter 6:

6-1. “Modernizing the Army’s Rotary-Wing Aviation Fleet,” Congress of the United States, Congressional Budget Office. November 2007.
6-2. “National Defense Budget Estimates for FY 2015,” Office of the Under Secretary of Defense (Comptroller), Washington, D.C., April 2014.
6-3. Bhattacharya, S., Nagaraju, V., Fiondella, L., Spero, E., Ghoshal, A., “Process Improvement for Rotorcraft Tradespace Exploration Incorporating Reliability and Availability,” America Helicopter Society 72nd Annual Forum Proceedings, West Palm Beach, Florida, May 2016.

Chapter 7:

7-1. Box, G.E.P., Wilson, K.B., “On the Experimental Attainment of Optimum Conditions,” Journal of the Royal Statistical Society, 1951, Vol. 13. (1).
7-2. Baker, A.P., Mavris, D.N., Schrage, D.P., “The Role of Requirements in Conceptual Aircraft Design and Their Interactions with Technologies and Vehicle Attributes,” 1st AIAA Aircraft, Technology, Integration, and Operations Forum, Los Angeles, CA, Oct. 2011. AIAA 2001-5225
7-3. Patterson, F., Schrage, D., “Comparison of Probabilistic and Fuzzy Multi-Attribute Decision Making Methods for Capturing Uncertainty in Concept Selection,” American Helicopter Society 71st Annual Forum Proceedings, Virginia Beach, VA, May 2015.
7-4. Kingston, L., DeTore, J., “Tilt Rotor V/STOL Aircraft Technology,” 2nd European Rotorcraft and Powered Lift Aircraft Forum, Buckeburg, Germany, September 1976.

7-5. Schrage, D., Suhr, S., Sirirojvisuth, A., Mishra, S., “An IPPD Approach for Preliminary Design of Two-Place Training Helicopter,” AIAA Aerospace 2007 Conference and Exhibit, Rohnert Park, CA, May 2007.
7-6. Crawford, C., “Rotorcraft Analytical Improvement Needed to Reduce Developmental Risk—The 1989 Nikolsky Lecture,” *Journal of the American Helicopter Society*, 1990, Vol. 35 (1).
7-7. Collopy, P., Hollingsworth, P., “Value-Driven Design,” 9th AIAA Aviation Technology, Integration, and Operations Conference (ATIO), Hilton Head, South Carolina, September 2009.

Chapter 8: Conclusions

8-1. Marx, W., Mavris, D., Schrage, D., “A Hierarchical Aircraft Life Cycle Cost Analysis Model,” 1st AIAA Aircraft Engineering, Technology, and Operations Congress, Los Angeles, CA, September 1995. Los Angeles, CA. AIAA 95-3861.
8-2. Sirirojvisuth, A., Schrage, D., “Rotor Blade Manufacturing Process Tradeoffs Using a Cost/Time Analysis,” American Helicopter Society 68th Annual Forum Proceedings, Fort Worth, TX, May 2012.
8-3. Nagata, J., Skinner, G., “Government Competitive Test, Utility Tactical Transport Aircraft Systems (UTTAS), Sikorsky YUH-60A Helicopter,” November 1976. USAAEFA Project No. 74-06-1, ADB059738
8-4. Andrews, J., “System reliability modeling: The current capability and potential future developments,” *Journal of Mechanical Engineering Science*. Paper No. 2881. April 2009.
8-5. Chew, S.P., Dunnett, S.J., Andrews, J.D., “Phased mission modeling of systems with maintenance-free operating periods using simulated Petri nets,” *Reliability Engineering and System Safety*. 2008. Vol. 93 pp. 980-994.
8-6. Bousman, W.G., Ormiston, R.A., Mirick, P.H., “Design Considerations for Bearingless Rotor Hubs,” American Helicopter Society 39th Annual Forum Proceedings, St. Louis, Missouri, May 1983.
8-7. Hanson, T.A., *A Designer Friendly Handbook of Helicopter Rotor Hubs*, Hanson, Newhall, California, 1998.

Appendices

A-1. Manual for the Operation of the Joint Capabilities Integration and Development System (JCIDS), Defense Acquisition University, Feb. 2015.
A-2. Department of Defense Reliability, Availability, Maintainability, and Cost Rationale Report Manual. 2009. Washington, D.C.: Office of the Secretary of Defense.
A-3. Pryor, G.A., “Methodology for Estimation of Operational Availability as Applied to Military Systems,” *International Test and Evaluation Association Journal*, Vol. 29, 420-428, 2008.

A-4. Wright, T.P., “Factors Affecting the Cost of Airplanes,” *Journal of the Aeronautical Sciences*, 1936, Vol. 3 (4), pp. 122-128.

A-5. Marx, W., Mavris, D., Schrage, D., “Cost/Time Analysis for Theoretical Aircraft Production,” Journal of Aircraft, Vol. 35, No. 4, 1998. AIAA 96-1381.

A-6. Harris, F.D., *Introduction to Autogyros, Helicopters, and Other V/STOL Aircraft, Vol. II: Helicopters*, National Aeronautics and Space Administration, Moffett Field, CA, 2012, Chapters 2.8 and 2.9.

A-7. “V-22 2010 Osprey Guidebook,” NAVAIR PMA-275 Control Number 10-28. Boeing.com

A-8. “Guide for the Presentation of Helicopter Operating Costs,” Economics Committee, Helicopter Association International, Alexandria, Virginia, Oct. 2010.