N77-18130

NASA CR-145113

RESEARCH REQUIREMENTS TO REDUCE EMPTY WEIGHT OF HELICOPTERS BY USE OF ADVANCED MATERIALS

By

Donald J. Hoffstedt

Prepared under Contract No. NAS1-13624
By
Boeing Vertol Company
Philadelphia, Pennsylvania

for

NASA

National Aeronautics and
Space Administration

December 1976

NASA CR-145113

RESEARCH REQUIREMENTS TO REDUCE EMPTY WEIGHT OF HELICOPTERS BY USE OF ADVANCED MATERIALS

By Donald J. Hoffstedt

Prepared under Contract No. NAS1-13624 by
Boeing Vertol Company
Philadelphia, Pennsylvania

for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

FOREWORD

This report was prepared by the Boeing Vertol Company for the National Aeronautics and Space Administration, Langley Research Center, under NASA Contract NAS1-13624. William Snyder was NASA Program Manager for these studies. The Boeing Project Manager was Wayne Wiesner.

SUMMARY

Helicopter structural-weight saving through use of advanced structural materials is investigated. Improvement trends in metals technology, while significant, do not translate into major weight reductions. Utilization of the new, lightweight, high-strength, aerospace structural-composite (filament/matrix) materials, when specifically designed into a new aircraft, promises reductions in structural empty weight of 12 percent at recurring costs competitive with metals. A program of basic and applied research and demonstration is identified with the objective of advancing the state of the art to the point where civil helicopters can be confidently designed, produced, certified, and marketed by 1985. A structural empty-weight reduction of 12 percent has previously been shown to significantly reduce energy consumption in modern high-performance helicopters (ref. 1).

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

1.0 INTRODUCTION AND BACKGROUND

1.1 Introduction

A very significant improvement in the fuel economy of vertical-takeoff aircraft, specifically helicopters, may be achieved through a reduction in the empty weight of the helicopter. This effect was explored and reported by Davis (ref. 1).

In the course of helicopter evolution, numerous design configurations and materials of construction have been used. Contemporary helicopters of the 1970 time period generally employ stiffened, sheetmetal, riveted fuselage construction of one or more aluminum alloys. The weight of the structure of the many diverse models in use by military and civil agencies can be predicted quite accurately by trending factors – a universal practice in preliminary-design exercises (ref. 2).

New materials of construction, termed composites, have evolved under government-sponsored research and development to support space-structure requirements for lightweight, high-strength, environment-tolerant hardware. These fiber-reinforced plastic or metal materials exhibit strength-to-weight and stiffness-to-weight properties which are substantially improved over existing metal properties.

This study was undertaken to examine the current and planned research and development application of these materials to helicopter structures and to identify and plan the additional developmental effort required to assure use of these materials to reduce the empty weight of civil helicopters by a significant but practical percentage by 1985.

1.2 Background

The fatigue environment inherent to rotating components and pulsating forces dictates stringent attention to detail design with metals to assure safety and satisfactory component life. Allowable stress levels are based upon notch-fatigue data as opposed to smooth-specimen data, with attendant reductions of design-allowable cyclic stress of 2 to 3. See Figure 1, constructed from the data of reference 3.

The weight penalty imposed upon dynamic components and fatigue-critical airframe structure is significant, and on some components may approach the ratio of smooth-to-notched fatigue strength.

The strength of metal components, and hence weight, is also adversely affected by fretting corrosion, atmospheric corrosion, galvanic corrosion, and crack-propagation rates.

A literature survey fails to reveal any major breakthroughs in metals technology applicable to advanced helicopter structures. Cost-reduction and structural-improvement are progressing through sophistication in analysis, metal alloying designed to produce combinations of increased strength and improved fracture toughness, improved fabrication processes, and increased processing efficiency.

The major potential for improved structural efficiency lies in increased utilization of filamentary reinforced materials, referred to in the technical community as composite structure. A comparison of notch-fatigue strength of several metals and composites is shown in Figure 2, reproduced from reference 4.

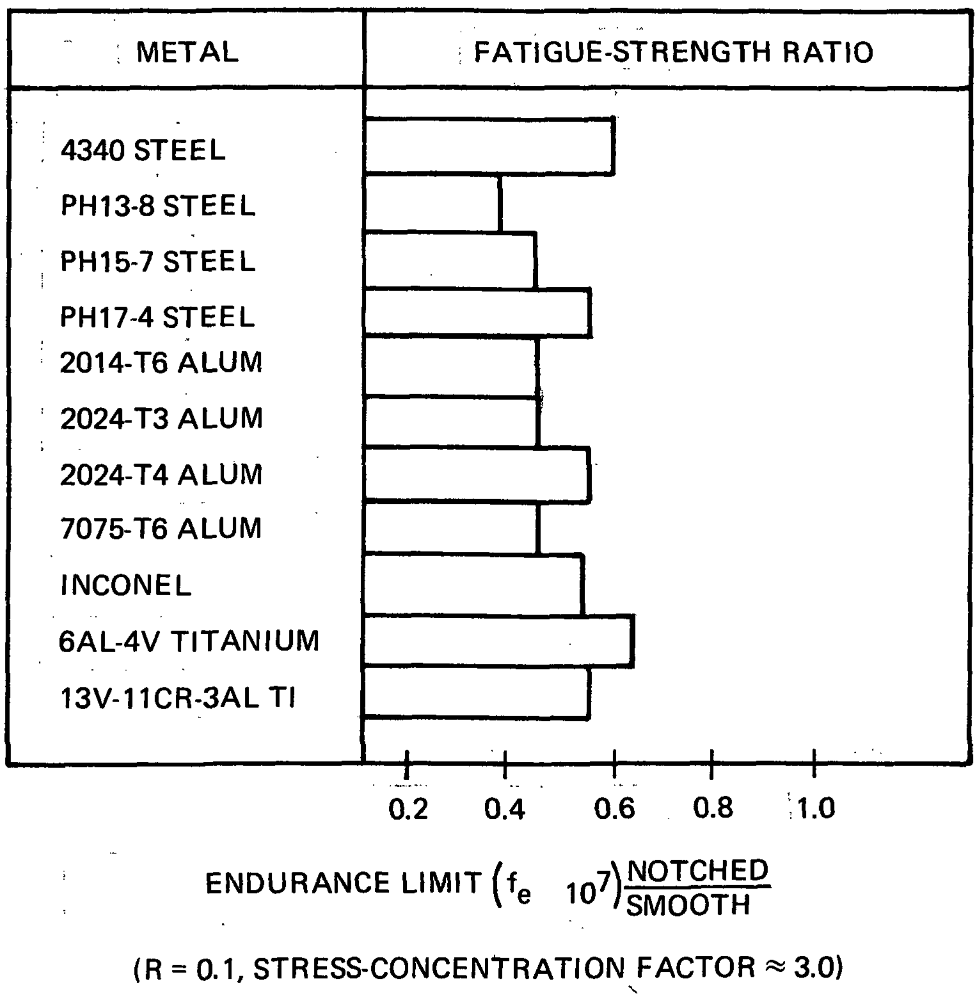

Figure 1. Loss in fatigue strength of metal due to notch effect

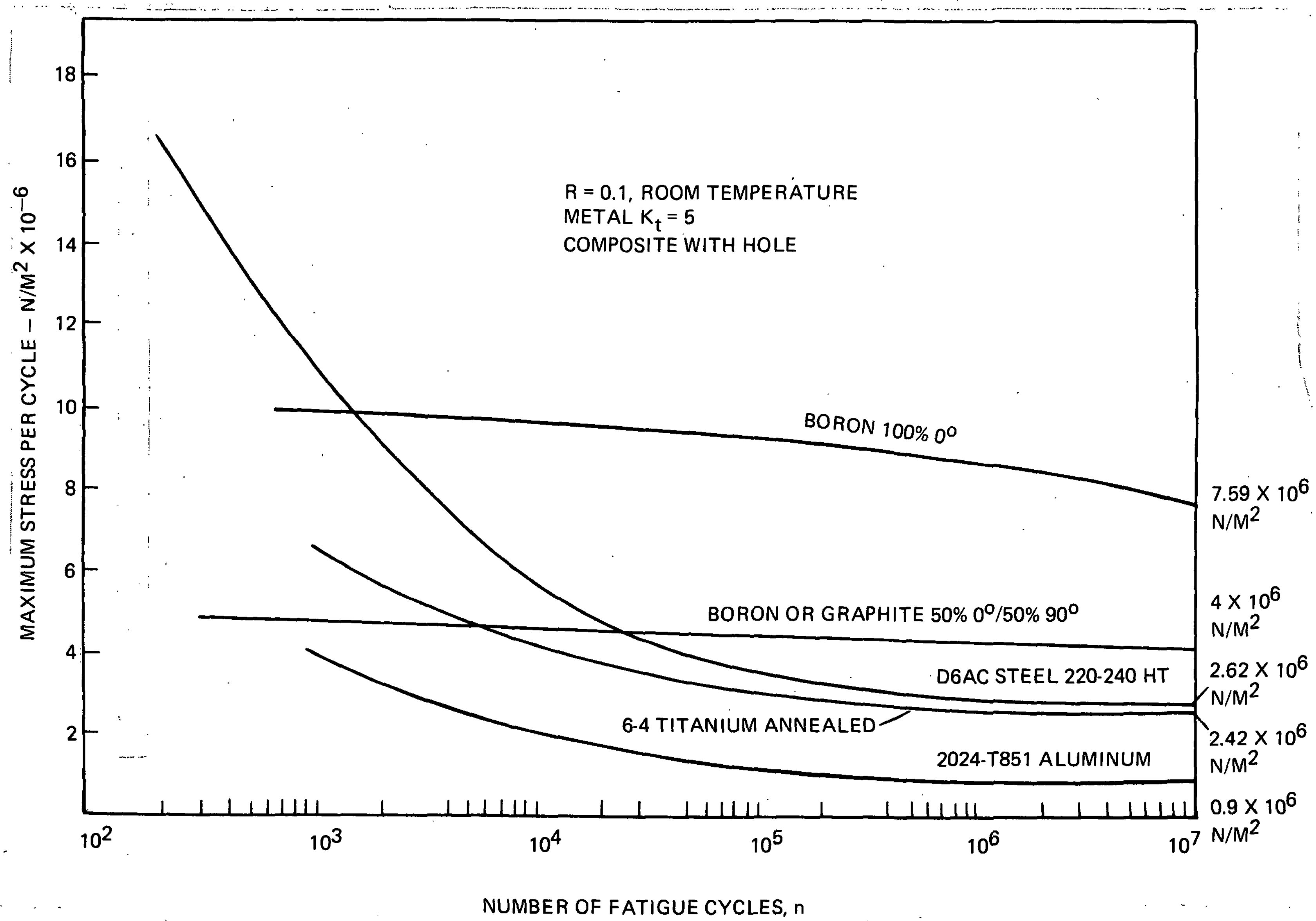

Figure 2. Comparison of notch-fatigue strength of metals and composites in constant-amplitude fatigue

2.0 STATE OF THE ART

Improvements in metallic structural strength/weight ratios are typified by the introduction of Vasco X-2 steel in transmission gears, the use of ZE-41A magnesium casting alloy, and continued improvement in titanium forging and processing techniques. The aluminum 2000 series (copper-magnesium alloy) is superior to the 7000 series (zinc-magnesium-copper alloy) in fracture toughness, particularly in the T3 temper, but new alloys such as 7050 (excellent high strength and improved stress corrosion) and 7475 (improved fracture toughness and high yield and compression strength) are under development.

New INCONEL® alloys for high-temperature applications have been developed recently; these include INCONEL® MA754 and 617 as well as INCOLOY® MA356E and 903. These nickel and ferritic alloys are promising for gas-turbine engine improvement in helicopter power trains but have little application to basic airframe systems. Titanium alloying, forging, casting, and heat treatments are improving the fatigue strength and notch sensitivity of the material and increased use of titanium net-tolerance casting applications may be expected to contribute to reduced structural weight (ref. 5, 6, and 7).

It appears unlikely that steel, aluminum, and titanium concentrated-load fittings will be cost-effectively replaced by molded composite structure in the next decade. This is particularly true of transmission gearing, bearing races, hydraulic actuators (other than pressure cylinder), engine mounts, and landing-gear attachments. Improvements must continue in the alloying of metals for helicopter applications such as these.

Composite structure, on the basis of improved strength/weight, stiffness/weight, and crack propagation, plus reduced notch sensitivity of many constructions in fatigue, has been identified as an improvement over metal for many helicopter components (ref. 8, 9, 10, 11).

The current status of helicopter-component development is presented in Table 1.

Known plans to expand the development efforts are outlined in Table 2.

Materials which are currently being considered for helicopter components, along with the areas of prime consideration, are outlined in Table 3.

® Registered trademarks of Huntington Alloys, Inc., Huntington, West Virginia.

TABLE 1. CURRENT STATE OF THE ART OF COMPOSITE STRUCTURE IN HELICOPTERS

Subsystem Component	Developmental Status				Operational Status	
	Basic Development	Component Dev/Bench Test	Flight Evaluation	Production Engineering	Military	Civil
Rotor Blades	Complete	In process	In process (1)	In process (2)	In use (3)	In use (4)
Rotor Hubs	In process	In process (5)	In process (6)	None	None	None
Landing Gear	In process	In process (7)	None	None	None	None
Tail Rotor	Complete	Complete	Complete	In process	In use (8)	In use (9)
Tailboom	In process	In process	Complete (10)	None	None	None
Horizontal Stabilizer	Complete	Complete	Complete	In process	In use (11)	None
Secondary Structure	Complete	Complete	Complete	In process (12)	In use (13)	In use (14)
Tail-Rotor Drive Shafting	Complete	In process (15)	None	None	None	None
Xmsn Cases	In process (16)	In process (17)	None	None	None	None
Primary Airframe	In process (18)	In process (19)	In process (20)	None	None	None
Control-System Components	In process	In process	Complete	Complete	In use (21)	None
Engine Components	In process	In process (22)	–	–	–	–

Supplementary Information and Comments

(1) AH-1G R&D, multiple-tube spar
(2) AH-1Q, filament-wound fiberglass/NOMEX
CH-47D, automated tape layup, fiberglass
CH-46E, automated tape layup, fiberglass
UTTAS YUH-61A, automated tape layup, fiberglass
(3) YUH-61A prototypes
(4) MBB BO-105
(5) CH-54, BO-105
(6) Bell, Aerospatiale
(7) YAH-64 R&D (Link)
(8) YUH-60, YUH-61, YAH-64
(9) MBB BO-105
(10) AH-1J Experimental R&D
(11) YUH-61A Prototype
(12) Sikorsky Model 76, Bell Model 222, UH-61A, KEVLAR 49
(13) YUH-60A, YUH-61A, KEVLAR 49
(14) Common use, fiberglass
(15) USAAMRDL R&D, Industry R&D
(16) Graphite polyimide, graphite aluminum, USAAMRDL/AMMRC
(17) Graphite polyimid, Army R&D
(18) Numerous studies, elements
(19) Elements, fuselage sections, CH-53, NASA
(20) CH-54, YUH-61A structural dynamic tuning
(21) YAH-63 quadrants
(22) Derivative data from cold end R&E sponsored by NASA/USAF

TABLE 2. PLANNED DEVELOPMENT PROGRAMS FOR IMPROVED COMPOSITE STRUCTURES IN HELICOPTERS

Subsystem or Component	Basic Development	Component Dev/Bench Test	Flight Evaluation	Production Engineering	Production Implementation	Civil Helicopter Implementation	Supplementary Information and Comments
Rotor Blades	–	Yes	Yes	Yes	1978 (1)	1970 (2)	(1) UH-61
Flight Controls	–	Yes	Yes	Yes	1978 (3)	?	(2) MBB BO-105
Tail Rotor	–	–	–	Yes	1978 (1)	1970 (2)	(3) AH-63
Transmission Housing	Yes	Yes	Yes	Yes	1985 (4)	?	(4) Potential ASH Application
							(5) Not likely to be cost-effective
Fuselage							
Cockpit/Cabin	Yes	Yes	Yes	Yes	1985 (4)	?	
Tailboom	Yes	Yes	Yes	Yes	1985 (4)	?	
Empennage	Yes	Yes	Yes	Yes	1978 (1)	?	
Rotor Hub	Yes	Yes	Yes	Yes	1985 (4)	?	
Landing Gear	Yes	Yes	Yes	?	? (5)	?	
Drive Shafting	Yes	Yes	Yes	Yes	1985 (4)	?	
Secondary Structure	–	Yes	Yes	Yes	1978 (1)	1977	

TABLE 3. ADVANCED STRUCTURAL MATERIALS CONSIDERED FOR HELICOPTER COMPONENTS

Subsystem or Component	Epoxy Laminates						Molding Resins		Alum. Matrix Diffusion Bonded			Alum. or Mag Matrix Cast			Phenolic or Polyimide Resins			Thermoplastic Laminates				Core Matl			
	E-Glass	Graphite	Boron	Alum. Oxide	KEVLAR 49	S-Glass	Chopped E-Glass	Chopped Graphite	Graphite	Boron	Alum. Oxide	Graphite	Boron	Alum. Oxide	Graphite	S-Glass	Boron	E-Glass	Graphite	KEVLAR 49	S-Glass	NOMEX H/C	Struct Foam	Glass H/C	Alum. H/C
Rotor Blades	P	P	S	–	P	P	S	S	–	–	–	–	–	–	–	–	–	P	P	P	P	P	S	–	–
Rotor Hubs	–	P	–	–	–	P	S	S	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Landing Gear	P	P	P	–	–	–	S	S	P	P	P	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Tail Rotor	P	P	P	P	S	P	S	S	–	–	–	–	–	–	–	–	–	P	P	S	P	P	–	–	P
Tailboom	S	P	S	S	P	S	S	S	–	–	–	–	–	–	S	S	S	S	P	P	S	P	S	–	P
Horizontal Stabilizer	P	P	S	S	P	P	S	S	–	–	–	–	–	–	S	S	S	P	P	P	P	P	S	–	P
Secondary Structure	P	P	–	–	P	P	S	S	–	–	–	–	–	–	S	S	–	P	P	P	P	P	S	–	P
Tail-Rotor Drive Shafting	–	P	P	–	S	S	–	–	–	–	–	–	–	–	S	S	S	–	–	–	–	P	–	–	P
Xmsn Cases	–	–	–	–	–	–	S	S	P	P	P	P	P	P	P	–	S	–	–	–	–	–	–	S	–
Primary Airframe	P	P	S	S	P	P	S	S	S	S	S	–	–	–	S	S	S	S	P	P	S	P	S	S	P
Control-System Components	P	P	S	S	S	P	P	P	S	S	S	S	S	S	–	–	–	P	P	S	P	S	S	–	S
Engine Components	–	–	–	–	–	–	S	S	P	P	P	S	S	S	P	P	P	–	S	–	–	–	–	S	S
Fittings	–	P	P	–	–	P	S	S	P	P	P	–	–	–	S	S	S	–	–	–	–	–	–	–	–
Interior Appointments	S	–	–	–	S	–	S	S	–	–	–	–	–	–	–	S	–	P	–	P	–	P	–	–	S

P – Primary Usage
S – Secondary Usage

NOTE: Material usage indicates materials versus applications known to be in use or where more than passing consideration is given, dependent on design usage. This does not exclude use of materials not indicated or omitted. Reference use only.

3.0 ESTABLISHMENT OF GOALS FOR EMPTY-WEIGHT REDUCTION

The difference between advanced-structure weight reductions achievable by substitution hardware versus those achievable by synergism and the attendant resizing during initial design is illustrated in two design studies performed for USAAMRDL on a 4 308-kg (9,500-lb) utility helicopter, references 8 and 9.

ADVANCED-COMPOSITE EFFECT ON EMPTY WEIGHT (kg, lb)

	Baseline	Advanced Structure (No resizing)	Advanced Structure (Resized)
Contractor A	3 001 (6,618)	2 690 (5,931)	2 467 (5,439)
Contractor B	2 916 (6,431)	2 607 (5,749)	2 355 (5,193)

There is good agreement displayed on empty-weight reduction available without resizing – namely 10.4 percent and 10.6 percent. With resizing, reductions become 17.8 percent and 19.2 percent.

When the helicopter is examined by subsystem to determine those areas where composite structure might best be incorporated to effect a significant decrease in empty weight, the results are as shown in Table 4.

3.1 Weight Savings, No Cost Constraints

There have been numerous studies made and prototypes built over the last decade which point to weight savings on aerospace structural elements, or entire components, ranging from 15 to 40 percent. The first column of Table 5 has been prepared from a review of published information and some license in subjective selection of achievable savings on helicopter components without regard to cost-effectiveness.

3.2 Discussion of Cost Constraints in Establishing Weight-Reduction Goals

There is no hard evidence in the literature that price reductions by filament suppliers have been accurately forecast. The major changes in pricing have come about as a result of changing from laboratory to production facilities, and through increased sales volume. Efforts to reduce processing costs of boron and graphite filament are continuing, centering mostly on reducing the cost of precursor materials, modifying filament diameters, and varying the number of filaments in an end.

It is difficult to predict demand; hence, dependence on increased-volume effects to forecast prices results in uncertainty. There is little doubt that aerospace-grade, composite-structure raw materials will cost more than metallic raw materials in the foreseeable future.

TABLE 4. IMPACT OF ADVANCED STRUCTURAL SUBSYSTEMS ON HELICOPTER EMPTY WEIGHT

Subsystem	Effect of Subsystem 20% Weight Reduction on Empty-Weight Reduction (%)		Rank for Potential Payoff
	No Resize	Resize	
Rotor Group	1.87	2.82	4
Flight Controls	1.87	3.94	3*
Landing Gear	0.96	1.93	5
Drive System	3.24	6.95	2
Body Group	3.33	7.57	1

*Based on military helicopter with dual-mechanical control system for survivability.

TABLE 5. HELICOPTER SUBSYSTEM WEIGHT-REDUCTION POTENTIAL AND EFFECT ON EMPTY WEIGHT

Subsystem	Potential Subsystem Weight Reduction (%)		Potential Effect on Empty Weight (%)	
	No Cost Constraint	Competitive Cost	Substitution	Re-Sized
Rotor Group	20	15	– 1.40	– 2.12
Flight Controls	8	5	– 0.47	– 0.99
Landing Gear	25	10	– 0.48	– 0.96
Drive System	18	12	– 1.94	– 4.16
Body Group	36	22	– 3.66	– 8.35
			– 7.95 (– 6.4)*	–16.58 (–12.3)*

*Equivalent structural weight-to-gross weight ratio as defined in reference 1.

The problem that then arises is to find a way to make structurally and functionally acceptable, lightweight, composite components in fewer manufacturing manhours than an equivalent metal structure.

This cost problem has been the subject of numerous developmental contracts and studies, generally emphasizing reduction in number of parts, reduction in number of mechanical fasteners, and reliance on automated or semiautomated processes such as tape layup machines, filament and tape winding, braiding, and pultrusion. Other efforts are being made to simplify and shorten the polymerization or cure cycle by substituting dielectric processes such as RF and microwave molecular agitation in lieu of autoclave or oven heating, and use of selected thermoplastic-resin matrices requiring greater tooling investment but greatly reduced processing time.

The reductions in weight achievable on helicopter fuselage and empennage structures are constrained by practical considerations such as survival of the components in the wear and tear of the operational environment. Reduction in raw-material costs is dependent on volume of the particular form of material desired which, in turn, requires the use of standard material forms. A balanced laminate is required to avoid thermal distortion and/or high residual and operating internal shear stresses. When helicopter fuselage structure is designed with balanced laminates using standardized material forms in thicknesses resistant to environmental damage, the resulting structure is generally considerably stronger than that designed specifically to resist operating structural loads. This situation favors reduction in fabrication costs: material nonuniformity and some processing flaws can be tolerated, and fabrication processes such as automated tape layup can benefit by opening up gap and overlap tolerances. The way is also open to use thermoplastic matrices with some loss in properties. Thus, the seeming adversity in weight saving on the helicopter fuselage can be turned beneficially toward reducing composite-structure costs while preserving acceptable structural design.

Components such as helicopter landing-gear oleo assemblies have been examined, however, with the conclusion that the relative cost of composite versus metal construction does not justify the weight savings achievable (ref. 8 and 10).

3.3 Adjusted Weight-Savings Goals

When cost constraints are considered and metallic versus composite components are evaluated for quantity production, the weight-savings goals must be adjusted. These adjusted goals are shown in column 2 of Table 5, with columns 3 and 4 reflecting their impact on empty weight.

It should be noted that achievement of a reduction in empty weight of 16.5 percent by 1985 is dependent upon helicopter system design which anticipates composite-structure utilization, and sizes the rotor, powerplant, landing gear, etc, synergistically. It is impractical to expect to achieve this weight savings through substitution of composite structure for existing metal structure on a helicopter system in being.

It is necessary that all subsystem improvements be achieved concurrently, permitting the benefits of full synergism (resizing effect) to attain a goal of 12-percent reduction in structural empty weight by 1985. The surest way to achieve this objective is to concentrate immediately and fully on defining and eliminating the deterrents.

4.0 BASIC DETERRENTS TO ACHIEVING ESTABLISHED GOALS

It has been established that a 12-percent reduction in helicopter structural empty weight by 1985 is a reasonable goal for civil helicopters. Achievement of this goal, however, requires a definition of the deterrents to this achievement and a suitable program for resolving obstacles.

Achievement of the desired weight savings on civil helicopters through incorporation of advanced structural materials requires acceptance by the helicopter manufacturer, the helicopter user, and the federal regulatory agencies. The concerns of each of these parties are illustrated in Figure 3, which identifies the deterrents as objectives requiring timely programs and solutions if the goal of a 12-percent reduction in structural empty weight is to be achieved by 1985.

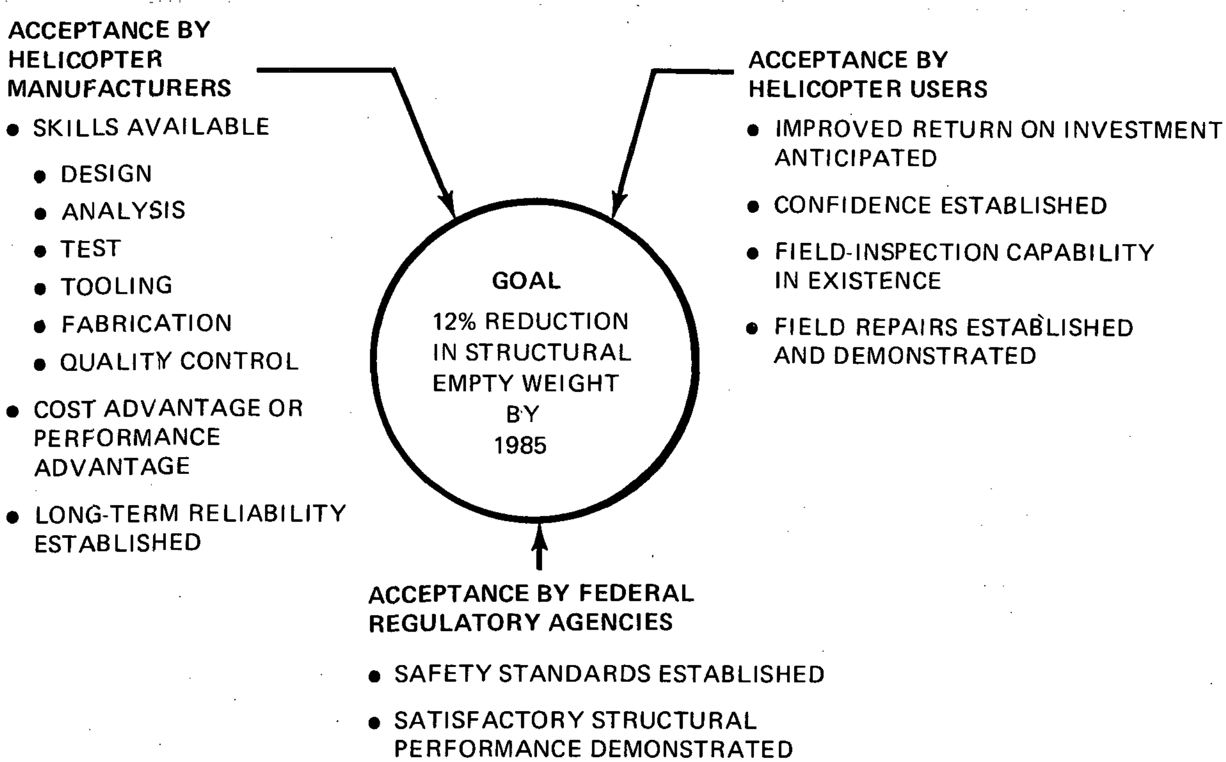

Figure 3. Objectives which must be met to achieve goal of reduction of 12 percent in structural empty weight by 1985

5.0 IDENTIFICATION OF RESEARCH AND DEMONSTRATION REQUIREMENTS

The program objectives identified in Figure 3 may be analyzed to determine whatever basic or applied research and demonstration are required.

Consider each of the areas of concern:

5.1 Helicopter Manufacturer Concerns

Utilization of advanced composites in civil helicopter basic structures will not occur unless the manufacturer is convinced that he possesses or can acquire the necessary skills and facilities to design, tool, fabricate, inspect, assemble, test, deliver, and guarantee flightworthy structure. In most cases it will require a substantial investment in skill and facilities. The motivation to the manufacturer is improved performance and/or payload, or increased economy of operation at a competitive sales price. The manufacturer must be confident that risks are minimal before making the necessary investment. The areas of concern are discussed below.

5.1.1 Skills. – Design – Joint configurations, weight- and cost-effective modular constructions, attachment of bracketry, subsystem routing, approved materials and processes, environmental-protection solutions.

- Analysis – Adequate correlation of isotropic/anisotropic analysis methods versus test data and factor of safety/failure criteria to permit adequate safety at minimal cost.

- Test – Sufficient expertise in structural test to properly introduce and react loads in composite structure without generation of test-fixture-associated failure; knowledge of differences, if any, in instrumentation installation and requirements; establishment and recognition of failure modes/definitions.

- Tooling – Demonstrated ability to design, fabricate, and use low-cost, trouble-free tooling principles and materials capable of manufacturing parts to predetermined material-and-process specifications. Ability to estimate cost of such tooling.

- Fabrication – Demonstrated ability to fabricate good-quality components/modules/ assemblies designed in reinforced plastics employing preestablished materials/processes and tooling in a reproducible manner. Ability to accurately estimate and control costs of such parts.

- Quality Control – Demonstrated equipment/skill to inspect composite components/ modules/assemblies in process and as finished articles to assure flightworthy hardware, ability to correlate nondestructive-test indications with probable defect, and comparison to preestablished acceptance standards from engineering test or analysis.

5.1.2 Competitive advantage. – The investment and risk incurred by a U.S. helicopter manufacturer can only be expected to take place if there is a reasonable expectation of improvement in competitive posture. This improvement must show, preferably, as a cost reduction offering the same performance and direct operating costs at a reduced acquisition cost. Improved performance for the same cost may also encourage the manufacturer to employ composite structure, particularly if he expects to offer reductions in direct operating costs to customers.

5.1.3 Long-term reliability. – It is unlikely that the manufacturer will risk using composite structures in primary load applications without adequate assurance of long-term structural reliability. Product-liability risks are far too high in today's judicial/social/economic environment to expect otherwise. Functional reliability, as affecting maintenance rather than safety, is also of concern.

5.2 Helicopter Users Concerns

The helicopter user (or customer) must be convinced that new advanced structures will benefit him. If there is insufficient interest or outright rejection of the incorporation of new materials in 1985 helicopter models, the helicopter manufacturers will be less likely to risk their skills and resources in aggressive pursuit of reduction in empty weight where primary structure is involved. The user must be sure that the improvements offered will not create unforeseen problems. The return on his investment will not be realized unless the helicopter is available, in flight status, at least as much as his current fleet. If structural damage occurs he must be able to detect it, repair it, and restore the aircraft to service in a minimum of time. This will require training and equipment investment over and above his cost of aircraft acquisition. User concerns are examined in more detail below.

5.2.1 Improved return on investment (ROI). – The user will consider the unit price (based on estimated manufacturing cost) of the improved helicopter, the anticipated direct operating costs (maintenance, fuel, crew, insurance depreciation), indirect operating costs, projected route, and passenger or cargo load factors to determine the potential payoffs in new structural technology. The economic study in reference 1 concluded that direct operating costs will be reduced and a slight reduction in flyaway costs is achievable through incorporation of advanced materials alone.

5.2.2 Establishment of confidence. – A research and demonstration program must be planned to build the confidence of potential users through progressive elimination of concerns and solution of known problems.

A literature review, reference 12, indicates that the commercial user is actively following the problems and progress of advanced-composite structural application to transport aircraft. Since the problems are very similar to those in helicopter applications, user confidence may be seen to waver on:

- Environmental Protection
  - – Structural-laminate deterioration
  - – Structural-bonding deterioration
  - – Lightning-strike damage
  - – Erosion damage
  - – Impact damage

- Impact on Downtime or Utilization of Aircraft
  - – Damage detection, static and fatigue
  - – Damage repair
  - – Modular-replacement capability
  - – Establishment of structural acceptance/rejection criteria

- Demonstration Paucity
  - – Inspection-interval basis lacking
  - – Maintenance factors not established
  - – Reliability factors not established

5.2.3 Field-inspection capability. – Inspection techniques are required to assure rapid, effective location of defects in inaccessible interior surfaces of composite assemblies which are nonremovable from aircraft, i.e., primary structural components.

5.2.4 Field repairs. – The user is dependent upon thorough demonstration instruction, and implementation capability to repair various degrees of damage to composite structure – both off the aircraft (removable components) and on the aircraft (primary fuselage structure). He must know the proper procedures, materials, and tooling required and must have adequately trained personnel. He must be particularly aware of differences in repair materials and processes for metal structure versus composite structure to avoid misapplication by repair personnel.

5.3 Acceptance by Federal Aviation Administration

A series of FAA/industry working sessions was instituted in 1976, with the purpose of establishing guidelines for certification of composite structure.

The guidelines for rotary-wing composite structures have been carefully considered by industry representatives as well as FAA administrators. The concerns on the part of the regulatory agencies may generally be seen to lie in:

- Material-system static and fatigue design allowables
- Effect of moisture absorption and temperature cycling on material design allowables

- Static-strength demonstration through full-scale components
- Effect of moisture and temperature on static strength
- Effect of repeated loads on static strength
- Careful process control through fabrication
- Fatigue-strength substantiation/environmental effects
- Crashworthiness/flammability/toxicity
- Lightning protection, electromagnetic shielding, and static-electricity dissipation
- Environmental protection
- Quality-control plan
- Repair techniques

A research and demonstration program plan must adequately address these FAA concerns, since failure to satisfy flightworthiness requirements for civil helicopters will result in delay or failure to obtain type certification. Such a problem on primary fuselage structure could be economically disastrous to the manufacturer, and perhaps to the user as well.

6.0 BASIC AND APPLIED RESEARCH AND DEMONSTRATION REQUIREMENTS

Basic research requirements will be defined as those fundamental considerations which must be resolved regardless of component or system application, whereas applied research will be concerned with advanced structure in a component form.

Table 6 sets forth the concerns of Section 5.0 and identifies the required basic- and applied-research areas.

Table 7 regroups the concerns and identifies program elements required for their resolution.

Figure 4 presents an estimate of the investment required by the technical community and sponsoring agencies in achieving the necessary research and development objectives. These costs are exclusive of associated R&D currently planned by NASA/USAF/NASC/USAAMRDL, and also exclude industry investment in facilities and training.

TABLE 6. SUMMARY OF REQUIRED BASIC AND APPLIED RESEARCH AND DEMONSTRATION AREAS

		Type of Research/ Demonstration Required	
User (Operator)		Basic	Applied
Environmental Protection	Laminate defects	X	
	Bond-line defects	X	
	Lightning damage	X	
	Erosion damage	X	
	Impact damage	X	
Utilization Factors	Damage detection	X	
	Damage repair	X	
	Module replacement		X
	Structural-acceptance criteria	X	
Demonstration Needs	Inspection-interval basis		X
	Maintenance-factor history		X
	Reliability-factor history		X
Field Inspection	Techniques for inaccessible areas on primary composite fuselage structures – nonremovable	X	X
Field Repairs	Detailed demonstrated repair procedures both on and off the aircraft	X	X
Manufacturer			
Design	Joint configurations	X	X
	Modular construction	X	X
	Attachment of brackets	X	
	Materials allowables	X	
	Processing constraints	X	
Analysis	Environmental vs test	X	
	Factor of safety/failure critieria	X	
Test	Test-fixture criteria	X	
	Instrumentation requirements	X	
	Failure modes/definitions	X	
Tooling	Design requirements		X
	Fabrication material & processes	X	X
	Cost estimating		X
Fabrication	Processing requirements		X
	Tolerances/reproducibility		X
	Cost estimating		X
	Cost control		X
Quality Control	Nondestructive inspection	X	X
	Defect determination	X	X
	Establishment acceptance standards	X	X
Federal Aviation Administration			
Material-system static and fatigue design allowables		X	
Effect of moisture absorption and temperature cycling on material design allowables		X	
Static-strength demonstration thru full-scale components		X	X
Effect of moisture and temperature on static strength		X	X
Effect of repeated loads on static strength		X	X
Careful process control through fabrication			X
Fatigue – strength substantiation/environmental effects		X	
Crashworthiness/flammability/toxicity		X	X
Lightning protection, electromagnetic shielding, static-electricity dissipation		X	
Environmental protection		X	
Quality-control plan			X
Repair techniques		X	X

TABLE 7. PROGRAM ELEMENTS OF NECESSARY BASIC AND APPLIED RESEARCH AND DEMONSTRATION IN ADVANCED STRUCTURES

Program Element	Basic			Applied		
Area of Concern	Laboratory-Specimen Development Program	Literature Surveys Design Studies Analytical Studies	Basic Structural-Element Testing	Structural-Component Development	Service Flight Demonstration	Production-Component Replication
Material Properties	X					
Design Trade-Study Factors		X				
Joints/Fasteners			X	X		
Module Size/Joining/Fab		X	X	X		X
Environmental Protection	X	X	X	X	X	
Analysis Methods vs Test		X	X	X		
Tooling Requirements		X		X		
Fab Matl/Processes	X	X		X		X
Cost Estimating		X				X
Fabrication Process Control		X		X		X
Cost Estimating		X		X		X
Quality Control Plan		X		X	X	X
Nondestructive-Insp Dev	X	X	X	X	X	X
Test Technology						
Static		X		X	X	
Fatigue		X	X	X	X	
Instrumentation/Fixturing		X	X	X		
Environmental Degradation Effects	X	X	X	X	X	
Production Cost Data				X		X
DOC Data		X			X	
Maintainability		X			X	
Reliability		X			X	
Repairability		X	X	X	X	

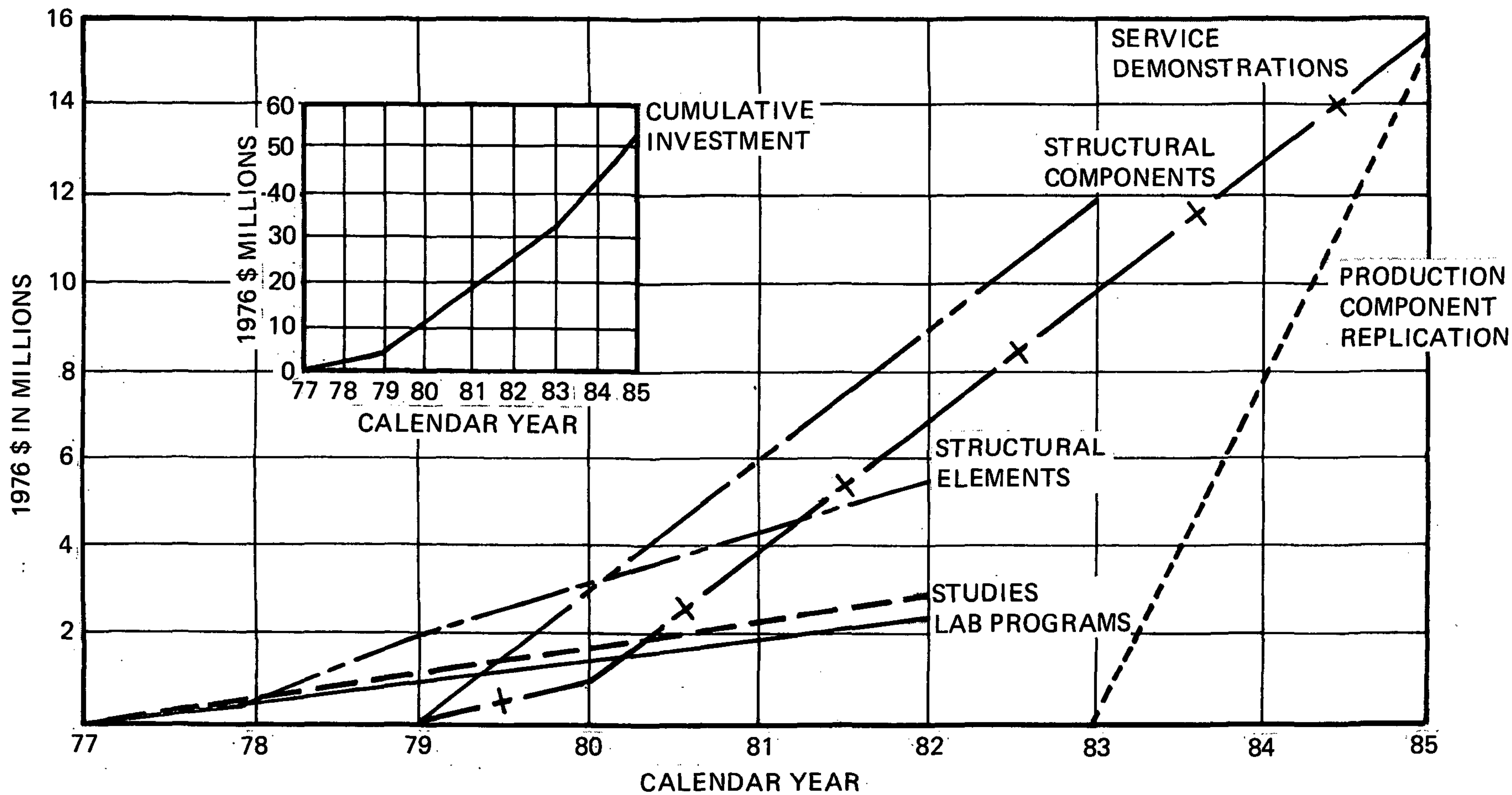

Figure 4. Estimated dollar-investment requirements in research and demonstration of advanced materials for helicopter application.

7.0 TECHNOLOGY INTERACTIONS

Table 8 has been prepared to identify and briefly consider the interaction of advanced-structure design incorporation versus each of 21 technological areas with regard to the interaction expected, limitations on use of advanced materials and/or impact on the technological area, and suggested solutions or approaches in design. These interactions can only be quantified by a design study or studies in reasonable depth, beyond the current effort.

TABLE 8. TECHNOLOGICAL INTERACTIONS

	Interaction Considerations	Resulting Limitations	Suggested Resolution
1. Fuselage Tuning for Vibration	Fuselage can be tuned with change in stiffness instead of weight.	Cost can get excessive if high-priced stiff matl used.	Baseline tuning vs adv struct must be compared.
2. Control of Interior Noise	Wt saved in airframe can be reinvested to dampen or tune interior noise producers.	Wt put into noise reduction will increase empty weight.	Where stiffness not significant use basic structure for tuning (compromise).
3. Production	Low-cost production methods tend to degrade structural efficiency, but needed to meet higher material costs.	Max wt reduction will result in increased costs; holding costs even will limit weight savings.	Cost criterion needed. Cost data needed. Impact on properties needed.
4. Airframe Drag	Aero surfaces more economically tailored with composites, especially thermoplastics.	Cost savings can be lost with excessive shaping.	Establish $/hp saved criterion; measure metal vs comp costs.
5. Maintenance	External surfaces must be scuff and tear-resistant to avoid excessive maintenance. Repair techniques must be established.	Scuff ply may be necessary on surface; min-gage skin will limit unit wt of structure.	Empirical evaluation of min-gage comp skin criteria on aircraft.
6. Main-Rotor Noise	Lighter-weight airframe could be traded for reduced rotor rpm, same mission performance.	Least-cost, least-size, least-energy aircraft limited by rpm (tipspeed) noise.	Keep tipspeed 750 fps but find other noise reduction.
7. Main-Rotor/Tail-Rotor or Rotor/Rotor Interaction Noise	Airframe shape and rotor/rotor spacing may be varied with less weight/cost penalty in composites.	Cost and weight savings with composites will be reduced if fuselage stretched.	Wt/cost bogey for noise $/decibel or lb/decibel needed.
8. Energy Use	Reduced empty wt, resized vehicle requires smaller engines, less fuel.	Payload compartment size limits wt of flightworthy structure.	
9. Vibration	Most efficient airframe is light and stiff. If modal tuning requires softening, some effect on load path and weight expected, also cost.	Vibration reduction requiring modal tuning will limit wt/cost savings with composites if performed structurally.	
10. Blade and Control-System Loads	Rotor will be resized as empty weight goes down; loads will be reduced if no resizing occurs.	Wt savings in airframe will not be max without resizing; studies have shown not load-critical, but min-gage-critical.	Keep wetted area to min, resize rotor.
11. Drive-System Noise	Tuning of xmsn housings with composite construction can reduce noise.	Fracture toughness vs fiber volume needed adds weight.	Trade off fracture toughness vs weight.
12. Safety	Interiors must consider smoke, toxicity, flammability; crashworthiness may be reduced; brittle modes.	Materials must be carefully screened; may cost more. Struct deformation energy-absorp reduced.	Trade weight of energy-absorption devices vs structural.
13. Transmission Eff/Wt	Reduced-wt xmsn affects support structure.	Struct mount weight is reduced for crash condition.	
14. Rotor Loads	Reduced hub moments improve airframe wt. Reduced a/f weight reduces hub moments.	Vehicle payload and mission sizing optimization base.	
15. Empty Weight		Min-gage structure is limiting weight, plus box size.	
16. Engine Noise	Polyimide cowling may be contributor to reduced amplification of engine noise.	Damping other than natural structural damping is parasitic weight.	Optimize attenuation thru orientation of fibers.
17. Drive-System Loads and Maintenance	Torque up if rpm down for rotor noise; parts count down, maint down composite shafting.	Flexures and bearings limit parts-count min on shafting. Rpm reduction.	Find other means of noise reduction; keep rpm up 750 fps tipspeed.
18. Reliability	Reduced wt composite airframe must be satisfactory in service environment for 15 years (?)	High malfunction rate, low availability, high operating costs if environmentally degraded.	Lab and service evaluation in real time.
19. Airframe Design and Drag	Better fairing lines for less cost.	Low cost requires good tools; changes costly.	Wind-tunnel development must be complete.
20. Performance	Reduced empty wt increases performance if not resized, holds same if resized.	If user getting desired perform. out of baseline design, Δ perform. not warranted for subst design.	Study operating costs vs weight savings.
21. Hover OEI	Improved if not resized, reengined as empty wt is reduced.	If vehicle already satisfactory, reduced empty wt not required.	Initial design with lower empty weight reduces energy cost at desired OEI.

8.0 CONCLUDING REMARKS

The utilization of advanced structures will have a significant impact on the reduction of aircraft weight and size, with accompanying reductions in energy consumption and direct operating costs for civil helicopters. When production costs are kept competitive with current metal structures, a savings in structural empty weight of 12 percent appears to be a practical objective without increasing the flyaway cost of present helicopters designed for equivalent missions.

A technology research and demonstration program requiring an investment of 55 million 1976 dollars, judiciously applied with the goal of employing this technology by 1985, has been identified.

Table 9 summarizes and prioritizes the effort required.

TABLE 9. SUMMARY OF RECOMMENDED RESEARCH AND DEMONSTRATION FOR THE USE OF ADVANCED-COMPOSITE MATERIALS

No.	Research Item or Area	Research Recommendation	Priority	Size Applicability	Payoff	Comments
1	Material Properties	Yes	High	All	High	
2	Environmental Effects	Yes	High	All	High	
3	Literature Reviews Design Studies Analytical Studies	Yes	High	All	High	
4	Component Development					
4a	Fuselage	Yes	High	All	High	
4b	Drive	Yes	High	All	High	
4c	Hub/Blade	Yes	Medium	All	Medium	
4d	Flight Controls	Yes	Medium	All	Low	
4e	Landing Gear	Yes	Low	Large	Low	
5	Service Evaluation	Yes	High	All	High	Emphasis on fuselage/drive
6	Production Quantity	Yes	High	All	High	

9.0 REFERENCES

1. Davis, S.J.; and Rosenstein, H.J.: Identifying and Analyzing Methods for Reducing the Energy Consumption of Helicopters. Boeing Vertol Company, Philadelphia, PA; NASA CR-144953, November 1975.

2. Davis, S.J.; and Wisniewski, J.S.: User's Manual for HESCOMP, the Helicopter Sizing and Performance Computer Program. Boeing Vertol Company, Philadelphia, PA; Report D210-10699-1, September 1973 (Developed under NASA Contract NAS2-6107).

3. MIL-HDBK-5A, dated February 8, 1966 as maintained; Metallic Materials and Elements for Aerospace Vehicle Structures.

4. Peterson, George, P.: Air Force Recent Progress in Composites. Conference presentations from "Advanced Composites – An Assessment of the Future", George Washington University, Washington, D.C., June 1975.

5. Herman, Walter, E.: Recent Developments in the Titanium Industry. RMI Company, Proceedings of the 8th National SAMPE Technical Conference, Seattle, WA; Volume 8, October 1976.

6. Tillack, D.J.: Recent Advances in Nickel Alloys for Aerospace Applications. Huntington Alloys, Inc., Proceedings of the 8th National SAMPE Technical Conference, Seattle, WA; Volume 8, October 1976.

7. Heine, P.J.: The Foundry Industry's High Performance Casting Technology. Penton, Inc., Proceedings of the 8th National SAMPE Technical Conference, Volume 8, October 1976.

8. Hoffstedt, D.J.; and Swatton, S.: Advanced Helicopter Structural Design Investigation, Volume I. Boeing Vertol Company, Philadelphia, PA; USAAMRDL TR75-56A, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, VA, March 1976.

9. Rich, M.J.: Investigation of Advanced Helicopter Structural Designs, Volume I. Sikorsky Aircraft Division, United Technologies Corporation, Bridgeport, CT; USAAMRDL TR75-59A, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, VA, May 1976.

10. Rich, M.J.; Ridgley, G.F.; and Lowry, D.W.: Application of Composites to Helicopter Airframe and Landing Gear Structures. Sikorsky Aircraft Division, United Technologies Corporation, Bridgeport, CT; NASA CR-112333, June 1973.

11. Hoffstedt, D.J.: Research and Development of Helicopter Rotor Blades Utilizing Advanced Composite Materials (Applications Analysis, page 65-154). Boeing Vertol Company, Philadelphia, PA; Technical Report AFML-TR-71-125, U.S. Air Force Materials Laboratory, Wright-Patterson AFB, OH; October 1971.

12. Kuperman, M.; and Wilson, R.G.: An Airline View of Composite Airframe Structure. United Air Lines, Inc.; Proceedings of 18th National Symposium and Exhibition, SAMPE, April 1973; excerpted from work performed under Contract NAS1-11751, Assessment of the Application of Advanced Technologies to Subsonic CTOL Transport Aircraft.

10.0 BIBLIOGRAPHY

Hundreds of abstracts, technical documents, and technical papers were reviewed in preparation for this report. Only the principal sources of information are listed below.

Air Force Technical Objective Document, Fiscal Year 1977, U.S. Air Force Materials Laboratory, AFML TR-76-14, Wright-Patterson Air Force Base, OH; March 1976.

Bicentennial of Materials – Part II. Proceedings of the 8th National SAMPE Technical Conference, Seattle, WA; October 1976.

Bicentennial of Materials Progress. Proceedings of the 21st National SAMPE Symposium and Exhibition, Los Angeles, CA; Volume 21, April 1976.

Impact of Composite Materials on Aerospace Vehicles and Propulsion Systems. AGARD-CP-112, AGARD Conference Proceedings No. 112, Advisory Group for Aerospace Research and Development, North Atlantic Treaty Organization; May 1973.

Manning, S.D.: Study of Structural Criteria for Composite Airframes, Volumes I, II, III. Convair Aerospace Division of General Dynamics; AFFDL-TR-73-4, April 1973.

Metal Matrix Composites: Status and Prospects. National Materials Advisory Board, National Academy of Science Report NMAB-313; December 1974.

Vehicle Technology for Civil Aviation – The Seventies and Beyond. NASA Special Publication, Proceedings of NASA Conference held at Langley Research Center, November 1971.

Winny, H.F.: The Use of Carbon Fiber Composites in Helicopters. Westland Helicopters, Ltd.; The Aeronautical Journal of the Royal Aeronautical Society, December 1971.