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INVESTIGATION OF ADVANCED HELICOPTER STRUCTURAL DESIGNS

Volume I - Advanced Structural Component Design Concepts Study

Sikorsky Aircraft Division
United Technologies Corporation
Stratford, Conn. 06603

May 1976

Final Report

Prepared for

EUSTIS DIRECTORATE
U. S. ARMY AIR MOBILITY RESEARCH AND DEVELOPMENT LABORATORY
Fort Eustis, Va. 23604

EUSTIS DIRECTORATE POSITION STATEMENT

This effort is one of two parallel contractual studies to define advanced structural configurations, advanced materials, and fabrication technology to satisfy requirements for a complete helicopter. The associated study program was conducted by Boeing-Vertol under the terms of Contract DAAJ02-74-C-0066.

Numerous design concepts, material selections, and manufacturing techniques were investigated for the various helicopter components (e.g., body group, main rotor, and transmission). The best overall concepts were selected and integrated into a complete advanced helicopter design, with predictions of improved weight, cost, and aircraft performance.

Mr. L. Thomas Mazza, Technology Application Division, served as project engineer, with Mr. E. Rouzee Givens directing the "Free Planetary Transmission Drive" study portion of the program.

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Advanced composite materials	Advanced configuration
Medium-range utility tactical transport helicopter	Lower gross weight
Structural efficiency	Lower fuel consumption

20. ABSTRACT (*Continue on reverse side if necessary and identify by block number*)

Design studies have shown that weight and cost of a medium-size utility helicopter can be reduced through application of advanced concepts and materials.

A baseline helicopter of conventional design was compared with designs employing advanced concepts and materials for the same gross weight. Results showed that weight empty (less engines, avionics, contingency) was reduced 12%, cost was reduced 3%, and payload was increased 70% (960 to 1634 pounds).

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AB

20. Abstract - continued

By incorporating the advanced concepts and materials into the initial design for the same payload, even greater reductions were found in weight and cost. Gross weight was reduced 14%, weight empty (less engines, avionics, contingency) 21%, and weight empty costs 14%.

A risk and feasibility assessment was made for the airframe and landing gear, rotor and control system, and transmission structures. The airframe and landing gear were found to be of medium risk and feasibility. Rotor and control system risk is low, and feasibility is high. The transmission structures have medium risk and high feasibility.

Volume II of this report presents findings of the "Free Planetary Transmission Drive" study portion of the program.

19. Key Words - continued

Smaller rotor disk area
Competitive costs
Applied development
Significant improvements

PREFACE

This study of the application of advanced concepts and materials to a medium-size utility transport helicopter was conducted under Contract DAAJ02-74-C-0061 with the Eustis Directorate, U. S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia.

The work was performed under the general direction of Mr. L. Thomas Mazza of the Technology Applications Division. Sikorsky Aircraft's principal participants were Melvin Rich, Project Manager; David Lowry, Airframe and Landing Gear Structures; John Longobardi, Rotor and Control Systems; Patrick Romano, Transmission System; David Unsworth, Weights; Neville Kefford, Helicopter Design Modeling; George Howard, Helicopter Design; Ralph Monte, Composite Fabrication; James B. Foulk, Vulnerability/Detection; and Alfred Wolf, Reliability and Maintainability.

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INTRODUCTION

The objective of this study was to assess the advantage of advanced helicopter structural concepts and materials for application in a medium-size utility transport helicopter. For the purpose of the study a baseline helicopter design was established using current UTTAS technology.

In the initial portion of the investigation, the advantages were determined for an advanced helicopter of the same design gross weight as that of the baseline. The resultant improvements were reflected in cost, weight, and payload. The initial investigation grouped the advanced concepts into two categories: low cost and low weight. The most promising advanced concepts were then selected on the basis of best payoff in weight and cost, with fail-safety and safety considered as additional primary factors, detectability, crashworthiness, vulnerability, reliability, and maintainability were considered secondary attributes.

Having selected the most promising advanced design incorporating the advanced concepts, the overall weight and cost comparison was made with the baseline conventional design. The results were used to derive trending weight and cost data. These data were then processed in a Helicopter Design Model (HDM) computer program to find the results for a helicopter incorporating the advanced structural design, but maintaining the same payload as the baseline conventional helicopter. Each of the advanced designs was then reviewed for risk and feasibility in future production.

BASELINE CONVENTIONAL DESIGN

Basic Requirements

The specification (Reference 1) establishes the basic aircraft performance and requirements for a Medium Range Utility Transport (M.U.T.) baseline helicopter design. The pertinent requirements are summarized as follows:

Design Limit Load Factor N_z = 3.5

Design Gross Weight W = to be established

Cruise Speed V_c = 150 kt (minimum with payload of 960 pounds with not more than maximum continuous power @ S.L.)

Endurance = 2.3 hours (plus reserve fuel for 30 minutes, for specification mission)

Landing Sink Speed = 10 fps at design gross weight, and crashworthy capabilities

Crashworthiness: in compliance with MIL-STD-1290 (AV)

Damage Tolerance: limit load capability of primary structure from .30 cal APM2 projectiles (tumbled), as defined in Reference (1)

Transportability: in C-130 and C-141 aircraft, as specified in Reference (1)

General Structural Criteria: MIL-S-8698 for Class I aircraft

General: Twin engines, 3 litters, 7 passengers, 140 cubic feet cargo compartment, wheel type gear, IR suppressor, low detectability

Hover Out-of-ground Effect: 4000 ft 95°F at not more than 95% of intermediate power.

Vertical Rate of Climb: 450 fpm from hover OGE, at not more than 95% of intermediate power.

Crew: 2

Basic Requirements - continued

Reliability: Mean time between failure of not less than 39 aircraft flight hours between mission aborting failures.

Mean time between removal for aircraft dynamic components (scheduled and unscheduled) of 1500 aircraft flight hours.

Maintainability: Mean time between maintenance for preventive and corrective maintenance not less than 3.5 flight hours.

Replacement time for each major component less than 3.0 hours.

Baseline Design

The baseline design was established by using UTTAS technology and investigating the configurations of internal volume requirements (for crew, litters, passengers, cargo volume, estimated fuel, transportability, and equipment). Estimates were then put into the Sikorsky-developed Helicopter Design Model (HDM) which is a computerized mathematical design model.

The HDM output is the sizing, weights, and costs for the estimated configuration. The process is iterative, and the result is the baseline aircraft. A detailed description of the system design modeling is presented in Appendix "A" of this report.

Figure 1 is a three-view drawing of the baseline configuration. Driving factors in the configuration were litter and cargo space, and air transportability. For air transportability, the main landing gear is a close-in design. Only the horizontal stabilizer and one blade of the tail rotor must be folded. The main rotor blades can be folded or removed. The tail gear is designed for kneeling.

Table 1 is the data sheet for the baseline conventional design, listing the attributes and output of the HDM results.

Baseline Weight and Costs

Table 2 supplies the group weight summary for the baseline design. Group weight and percentage of group weight empty are listed for reference. Table 2 also presents the percentage of group weight empty less engines, avionics, and contingency. Since the investigation was limited to group weight empty, the percentages shown were used later to identify relative costs and weights and to identify areas in conventional design in which costs are most important.

The HDM program also provides a costing trend and was used to project weight empty item costs. For this investigation, the following considerations were applied in projecting flyaway costs of components:

(a) Costs are stated in 1974 dollars both for current conventional materials and for advanced materials in 1978. Costs of advanced materials are especially significant for the advanced concepts, since they will use a large proportion of advanced composites.

(b) Labor costs are based on $22.50 a man-hour for fabrication.

(c) Material costs include a 35% factor to account for aircraft manufacture handling charges.

(d) Production costs are based on a 500-aircraft production.

(e) No tooling or development costs are included.

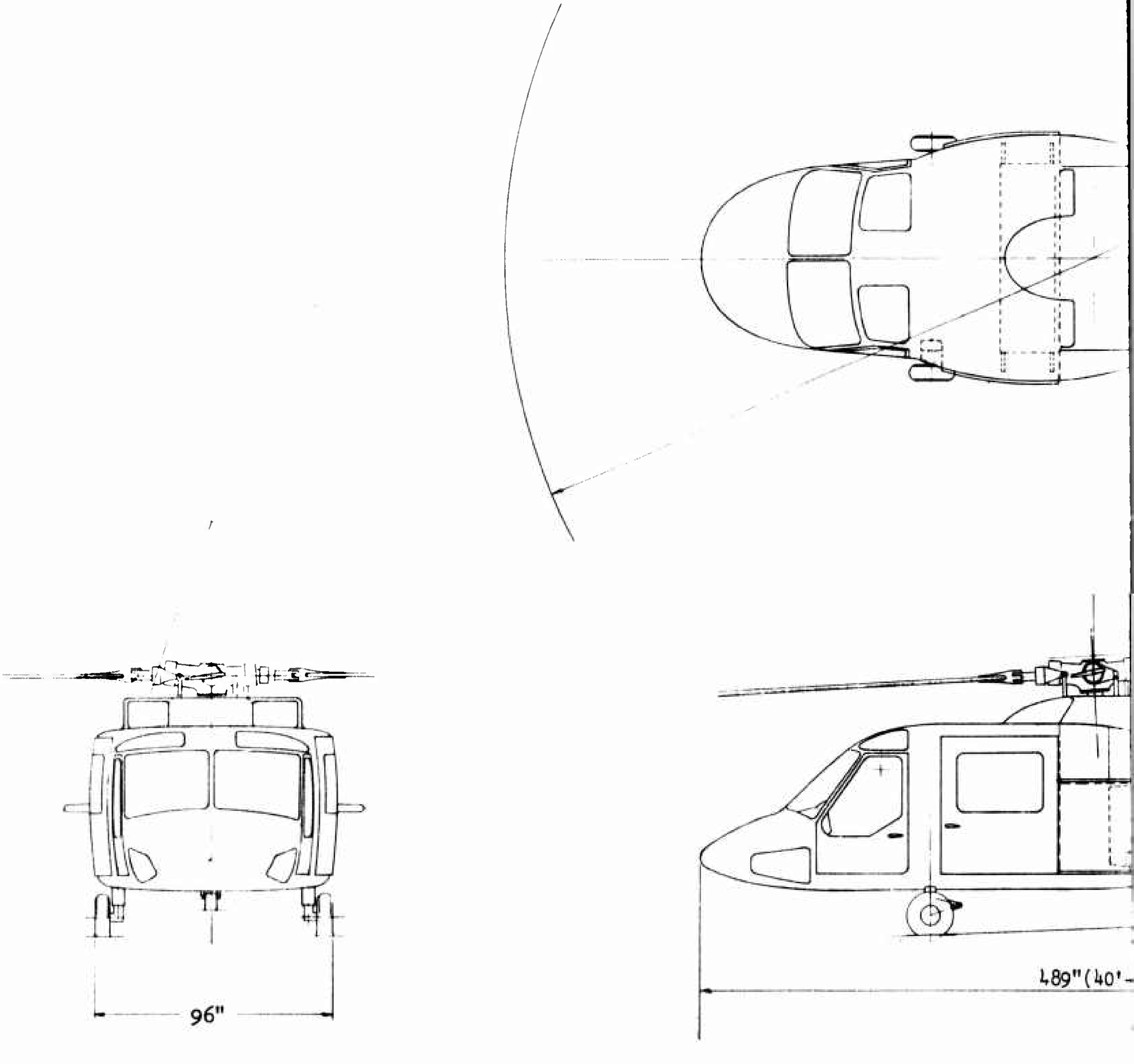

FIGURE 1. M.U.T. BASELINE CONVENTIONAL DESIGN.

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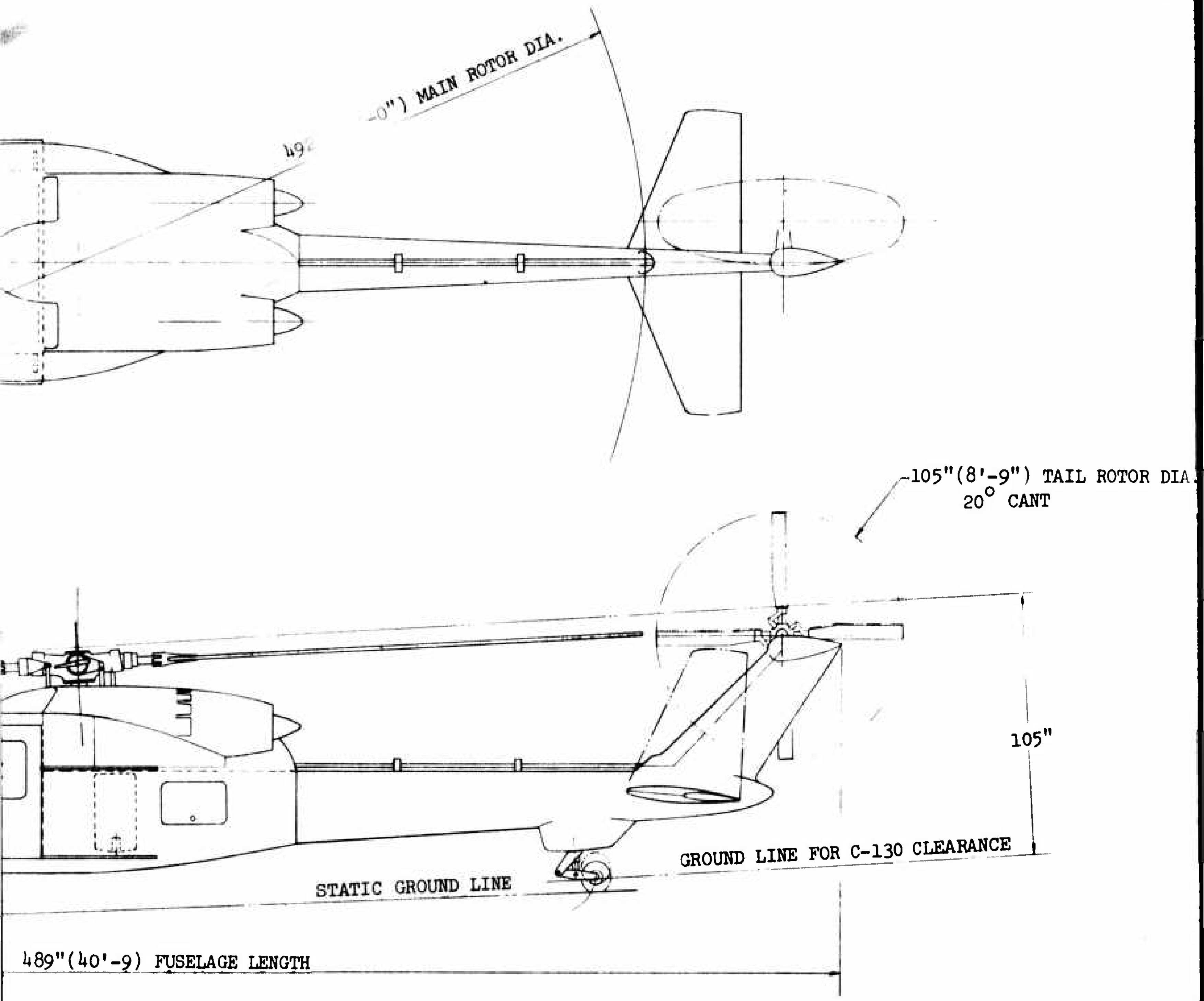

-0") MAIN ROTOR DIA.
492
105"(8'-9") TAIL ROTOR DIA.
20° CANT
105"
GROUND LINE FOR C-130 CLEARANCE
STATIC GROUND LINE
489"(40'-9) FUSELAGE LENGTH

TABLE 1. BASELINE CONVENTIONAL M.U.T. DATA SHEET

Vehicle Attribute	DESIGN DATA		
Performance @ G.W. 9471 LB	V_C = 150 KT V_{MAX} = 173 KT Endurance = 2.3 HR, based on design mission at sea level. Vertical R.O.C. = 450 FPM, 4000 FT 95°F Service Ceiling = 17,700 (Std Day)	O.E.I., V = 47 to 126 KT	
Aerodynamic	Rotor Tip Speed: Main Rotor 730 FPS; Tail Rotor 700 FPS Rotor Solidity: Main Rotor .082; Tail Rotor .15 Disk Loading: 7 PSF @ D.G.W.		Vertical Drag = 2% Parasite Drag = 14.9
Structural	N_Z = 3.5 limit @ D.G.W. of 9471 LB V-N, Factor of Safety of 1.5 For MUT Design Envelope (Fig. I of MUT Specification Ref. (1))	Compliance with MIL-S-8698, MUT Specification, Crashworthiness For MIL-STD-1290 (AV), Damage Tolerance for .30 Cal. (MUT Spec)	Fail-Safety for Residual Life, Strength for Limit Design Load. Transmission Design HP = 1564 Basic Design Loads as Presented in Loads Summary
Weight	Weight Breakdown as Presented in Weight/Cost Summary.	Body Wetted (Structural) Area = 530 Ft^2	
Geometric	Diameter: Main Rotor 41 FT; Tail Rotor 8 Ft, 10 IN Aerodynamic Chord: Main Rotor 15.9 IN; Tail Rotor 6.42 IN Blade Taper Ratio: Main Rotor 1.0; Tail Rotor 1.0 Number of Blades: Main Rotor 4; Tail Rotor 4 Blade Twist: Main Rotor -16°; Tail Rotor -16°		Tail Rotor Cant 20° Horizontal Tail Area, 21.6 FT^2 Vertical Tail Area 21.8 FT^2 Airframe (See Design Layout Dwg.)
General Design	Fuel Capacity 1389 LB UTTAS Technology, Airframe: 2024-T3 Skins, 7075-T6 Stringers, 7075-T73 Forgings, Riveted Construction Main Rotor: Titanium Spar, Composite Cover Dynamic Components: General use of Titanium, 4130 Steels, and some 2024-T3 Aluminum		
Performance of Mission Equipment	Per MUT Spec (UTTAS Avionics Package)		
Power Plant	Engines (Per Fig 2 of MUT Specification), Available Takeoff Engine Power: 1842 HP (SLS), 1327 [illegible]000 FT/95°F), Reduction Ratio: 88.2:1, Accessory and Installation Losses: 40 HP, Mechanical Losses (Total): 2% IR Suppressor Losses: 3%		

TABLE 2. BASELINE GROUP WEIGHT SUMMARY

GROUP		GROUP WEIGHT LB (PERCENT)	PERCENT OF WEIGHT EMPTY*
MAIN ROTOR GROUP		820 (12.4)	14.5
. Main Rotor Blades 371 lb			
. Main Rotor Hub 449 lb			
TAIL GROUP		152 (2.3)	2.7
. Tail Rotor 47 lb			
. Tail Surfaces 105 lb			
BODY GROUP		1055 (15.9)	18.6
ALIGHTING GEAR		380 (5.7)	6.7
FLIGHT CONTROLS		638 (9.6)	11.3
. Servos, etc.	407		
. Rotor Controls, Rods etc.	231		
ENGINE SECTION		100 (1.5)	1.8
PROPULSION GROUP		1907 (28.8)	26.1 (less engines)
. Engines	422		
. Air Induction	40		
. Exhaust System	297		
. Fuel System	269		
. Engine Controls	25		
. Starting System	19		
. Drive System	835		
Transmission			
Housing			
Gears, Shafting, etc.			
EQUIPMENT AND OTHERS		1567 (23.7)	18.6 (less contingency and avionics)
. Instruments	135		
. Electrical	247		
. Avionics	460		
. Armament Group	53		
. Furnishings	422		
. Anti-Ice	48		
. Auxiliary Gear	60		
. Suppression Vibration	76		
. Contingency	66		
WEIGHT EMPTY		6618	

(Continued)

TABLE 2. (CONCLUDED)

GROUP		GROUP WEIGHT LB (PERCENT)	PERCENT OF WEIGHT EMPTY*
FIXED USEFUL LOAD		504	
. Pilot and Copilot	470		
. Oil-Engine	14		
. Trapped Oil	6		
. Fuel-Trapped	14		
FUEL USABLE		1389	
PAYLOAD		960	
DESIGN GROSS WEIGHT (at takeoff)		9471	

*Percent of weight empty less engines, avionics, and contingency

Table 3 summarizes baseline aircraft weights and costs. The average cost is \$93.4/lb for the weight empty groups. Structures with highest cost per pound generally are those in which parts are complex and require many labor hours, for example, rotor blades. Lower cost items generally are those that are massive, such as the drive system and alighting gear. Material costs generally are a small portion of the costs in a conventional helicopter design. For example, the airframe is made primarily of aluminum alloys costing \$1.20 per pound. For this reason, the material costs are estimated at about six percent of helicopter cost. In estimating material costs, actual material costs must be differentiated from processed parts costs, which are incurred, for example, when airframe stringers are purchased from outside sources and then processed by the aircraft manufacturer. Another example is forgings.

Once the larger weight areas and cost areas are identified, the study can investigate the use of higher strength materials and means of reducing labor costs. The true value of the improvements is reflected in changes of weight and cost ($\Delta\$/\Delta$ lb) from the baseline components. Other factors in judging these improvements are primary attributes of fail-safety and safety, and the secondary factors of vulnerability, crashworthiness, detectability, reliability, and maintainability.

TABLE 3. BASELINE AIRCRAFT WEIGHT/COST SUMMARY

GROUP	GROUP WEIGHT (LB)	GROUP COST ($)	COST ($/LB)
MAIN ROTOR GROUP	820	74,210	90.5
. Main Rotor Blades 371 lb			
. Main Rotor Hub 449 lb			
TAIL GROUP	152	15,548	102.3
. Tail Rotor 47 lb		(5,720)	(121.7)
. Tail Surfaces 105 lb		(9,828)	(93.6)
BODY GROUP	1055	98,748	93.6
ALIGHTING GEAR	380	16,606	43.7
FLIGHT CONTROLS	638	77,645	121.7
ENGINE SECTION	100	9,880	98.8
PROPULSION (LESS ENGINES)	1485	147,454	99.3
. Air Induction	40	(6,324)	(158.1)
. Exhaust System	297	(46,956)	(158.1)
. Fuel System	269	(34,970)	(130.0)
. Engine Controls	25	(3,953)	(158.1)
. Starting System	19	(2,312)	(121.7)
. Drive System	835	(52,939)	(62.4)
. Transmission			
. Gears, Shafts, etc.			
EQUIPMENT & OTHERS (LESS AVIONICS & CONTINGENCY)	1041	89,445	85.9
. Instruments	135	(16,983)	(125.8)
. Electrical	247	(19,266)	(78.0)
. Armament Group	53	(1,908)	26.0
. Furnishings	422	(36,883)	(81.4)
. Anti-Ice	48	(5,347)	(111.4)
. Auxiliary Gear	60	(3,996)	(66.6)
. Suppression Vibration	76	(5,062)	(66.6)
TOTALS	5670	529,536	93.4

DESIGN CRITERIA

Design Loads

The baseline design was used to establish design loads for the advanced concept components. Since the design gross weights of the baseline and advanced design helicopters were the same, the only difference in loads would be the difference in inertial forces. However, most loads result from applied external forces with some inertial relief, so within the accuracy of a preliminary stress analysis, the effect of weight changes can be assumed to be small.

In determining airframe loads, panel point weights were established and external forces were applied to resolve forces and moments as required. Tables 4 and 5 summarize the load factors, accelerations, and applied resultant loads to the various airframe and landing gear structures. Limit loads are given except as specified. Ultimate loads are 1.5 times limit loads as required in Ref. (2). In addition, the miscellaneous loads, as listed in Table 5, are applicable to the specified structures. Figures 2, 3, and 4 present the shears, moments, and torsions (limit) for the airframe structures.

The design data sheet of Table 1 also lists component criteria and loads for use as applicable.

In addition, the design spectra of Table 6 apply to mechanical components.

Design Allowables

Design allowables for metallic materials were based on those specified in Ref. (3). "A" allowables were used for primary nonredundant structures, and "B" allowables were used for redundant structures and for secondary members (not essential to flight).

Advanced composites design "B" allowables are specified in Table 7. In general, the composite design allowables are typical strength values that were reduced statistically by 1.3 standard deviations to obtain "B" design strengths. Whenever specific data were not available, estimates were used to derive "B" strength allowables. Elastic properties specified are typical values, since these data generally do not have a scatter as great as that of strength properties.

The usual safety factor of 1.5 times limit load covers all yield conditions. As stated in Table 7, however, where specific values are not available, the properties can be further estimated from the stated data. The ultimate tension and compression allowables used are for the σ degree orientation. The ultimate shear allowables would be for panel shear flow (in-plane).

TABLE 4. AIRFRAME AND LANDING GEAR
LOAD/CRITERIA SUMMARY

Design Condition (Limit Unless Otherwise Specified)	Load Factors And Accelerations(1)							FORCES AND MOMENTS						DATA REQ'D	COMPONENT AFFECTED
	N_x	N_y	N_z	α_x	α_y	α_z		F_x (LB)	F_y (LB)	F_z (LB)	M_x (IN-LB)	M_y (IN-LB)	M_z (IN-LB)		
Sym. Dive and Pullout	.77	.07	2.51	1.96	1.89	.33	Main Rotor	4710	980	23750	61750	235000	350000	Shears,	Cabin & Tail
							Tail Rotor(2)	--	-372	135	---	-9700	3530	Moments,&	Cone Structures
							Stabilizer(2)	-55	0	595	---	---	---	Torsions	
							Vert.Fin.	61	-383	--	---	---	-4140		
Rolling Pullout Left	-.60	.33	2.84	1.68	-3.29	-2.03	Main Rotor	-5500	2300	23300	-22700	308000	345000	Shears,	Tailcone
							Tail Rotor(2)	----	-1590	580	---	-19350	7035	Moments,&	
							Stabilizer(2)	29	0	668	---	---	---	Torsions	
							Vert.Fin.	-90	398	---			-1585		
Rolling Pullout	.08	-.20	.34	1.19	-1.16	.34	Main Rotor	470	823	3030	-72600	-172000	343000	Shears,	Vertical Fin
							Tail Rotor(2)		-2350	852	---	-14600	5225	Moments,&	
							Stabilizer(2)	-146	0	-620	---		---	Torsions	
							Vert. Fin.	0	-227	---	---		-1550		
Rolling Pullout Right	.50	-.55	2.18	-2.72	.17	-.17	Main Rotor	3790	-2585	14250	-212000	110500	336500	Shears,	Horizontal
							Tail Rotor(2)		140	50	---	-27450	10000	Moments,	Stabilizer
							Stabilizer(2)	-168	0	3210	---	---	---	&	
							Vert. Fin.	-66	-1370	---	---	---	-4000	Torsions	
Landing Impact (15 FPS)	0	0	3.93	0	0	0								Shears, Moments, & Torsions	No yield for airframe, Ultimate for L.G.
Crash Condition (High Mass Items)	10	±9	-20	-	-	-								Local Support Structure	Support Structure for High Mass Items
	-20	±9	-10	-	-	-									

NOTES
(1) Rad/Sec^2
(2) Total Load

TABLE 5. MISCELLANEOUS AIRFRAME AND LANDING GEAR LOADS/CRITERIA

Design Condition (Limit Unless Otherwise Specified)	LOADING TYPE	REMARKS	COMPONENT AFFECTED
Dive Speed (174 KT)	Aerodynamic Loading	Use .7 psi average (limit) pressure for design	Canopy Framework
Floor Loading	300 N'_z psf for Cargo Floor	$N'_z = N_z + \frac{1}{g} \alpha y$ From Airframe Conditions or $N_z = 3.5$ Use 3.5 (limit) for design	Cargo Floor
Crash (95th percentile per MIL STD-1290, Ultimate)	Vertical (Downward) 42 fps Lateral 30 fps Longitudinal (Fwd) 50 fps	Energy absorption to meet requirements Landing gear design for 15 fps (No yield airframe), and 20 fps (ultimate for gear)	Cockpit, Main Cabin, Landing Gear

TABLE 6. DESIGN SPECTRA

MAIN ROTOR FLAPPING SPECTRUM

Flapping (Degrees)	% Time
13	.0001
12	.0002
11	.0003
10	.0014
9	.0025
8	.0125
7	.028
6	.095
5	.4049
4	1.95
3	97.51

MAIN ROTOR MOMENT DATA

DATA: 1
R = 20.5
b = 4
e = .986 FT
W_B = 92.8 LB
Ω = 35.6 RAD/SEC
Tip Speed (730 FPS)

M_{HUB} = Kβ, FT-LB
K = b/2 C.F. (e)/57.3
= 1402 FT-LB/Degree

M_R Spectrum From Flapping Spectrum

MAIN ROTOR HUB MOMENT SPECTRUM

M_R (IN-LB)	% Time	Average Thrust Angle (Degrees)
218,710	.0001	13.5
201,890	.0002	12.1
185,040	.0003	11.4
168,240	.0014	13.7
151,420	.0025	11.8
134,590	.0125	11.2
117,770	.028	10.7
100,940	.095	9.7
840,120	.4049	9.2
67,300	1.95	8.7
50,470	97.51	8.0

MAIN ROTOR PUSHROD LOADS

Vibr. Load LBS	Steady Load	% Time
1110	.8 of Vibratory Load	.0005
1000		.0009
9400		.0031
8900		.9355
6600		1.5
6100		3.154
4400		6.406
220		8.0
110		80.0

POWER SPECTRUM

Horsepower	% Time
0	1.0
260	1.0
500	7.5
740	24.0
1040	21.2
1850	26.0
1560	19.3

TABLE 7. DESIGN ALLOWABLES FOR COMPOSITE MATERIALS

Material	Strength Properties ***			Elastic Properties					
	Ult. Tension F_{tu} ksi	Ult. Compress. F_{cu} ksi	Ult. Shear F_{su} ksi	Tension Modulus $E_{(t)}$ msi	Compr. Modulus $E_{(c)}$ msi	Shear Modulus G msi	Density lb/in^3	Ref.	Notes
Graphite/Epoxy									
0°	160	160	10	17		.6	.055	4	A/S Fiber
0°/90°	87	88		9.5				4	
1 ±45°	22	22	50	2.2		4.5		4	
Kevlar-49/Epoxy									
0°	189	34	8	10.8	10.5	.3	.050	5	Unidirectional
0°/90°	39	21	13	4.0	3.8	.3		6	181 Style Fabric
±45°	20	15*	27	7.7	1.0	3.0		5	181 Style Fabric
E-Glass/Epoxy									
0°	147	83	2.5	5.7	4.6	.45	.065	7	Unidirectional
0°/90°	39	45	14	2.8				6	181 Style Fabric
±45°	20	12	36	1.9		1.6		**	181 Style Fabric

Notes * Yield 5.5 ksi
** Estimated
*** Estimated "B" Allowables

Design Costs

The criteria for acquisition costs were based on the following:

(a) Production of 500 aircraft.

(b) Labor cost of $22.50 per hour.

(c) Material costs as presented in Table 8.

(d) No tooling, engineering, or development costs. It should be noted that the tooling costs are relatively small for production helicopters (approximately 3 percent). Development costs are not included, since it is presumed that prior programs of manufacturing technology would be required to achieve production of the advanced structural concepts.

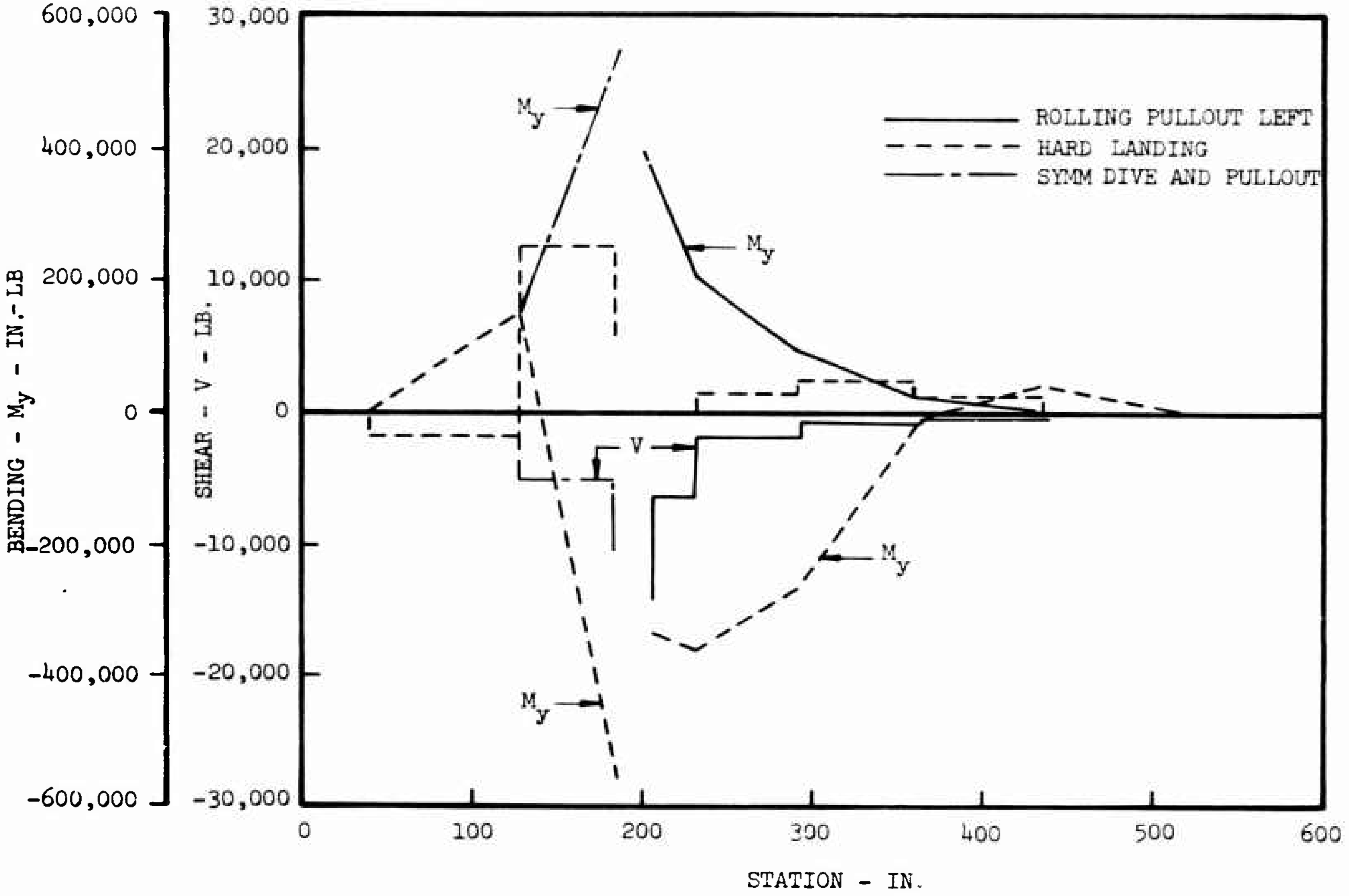


FIGURE 2. AIRFRAME VERTICAL SHEAR AND BENDING ENVELOPE (V & M_y LIMIT).

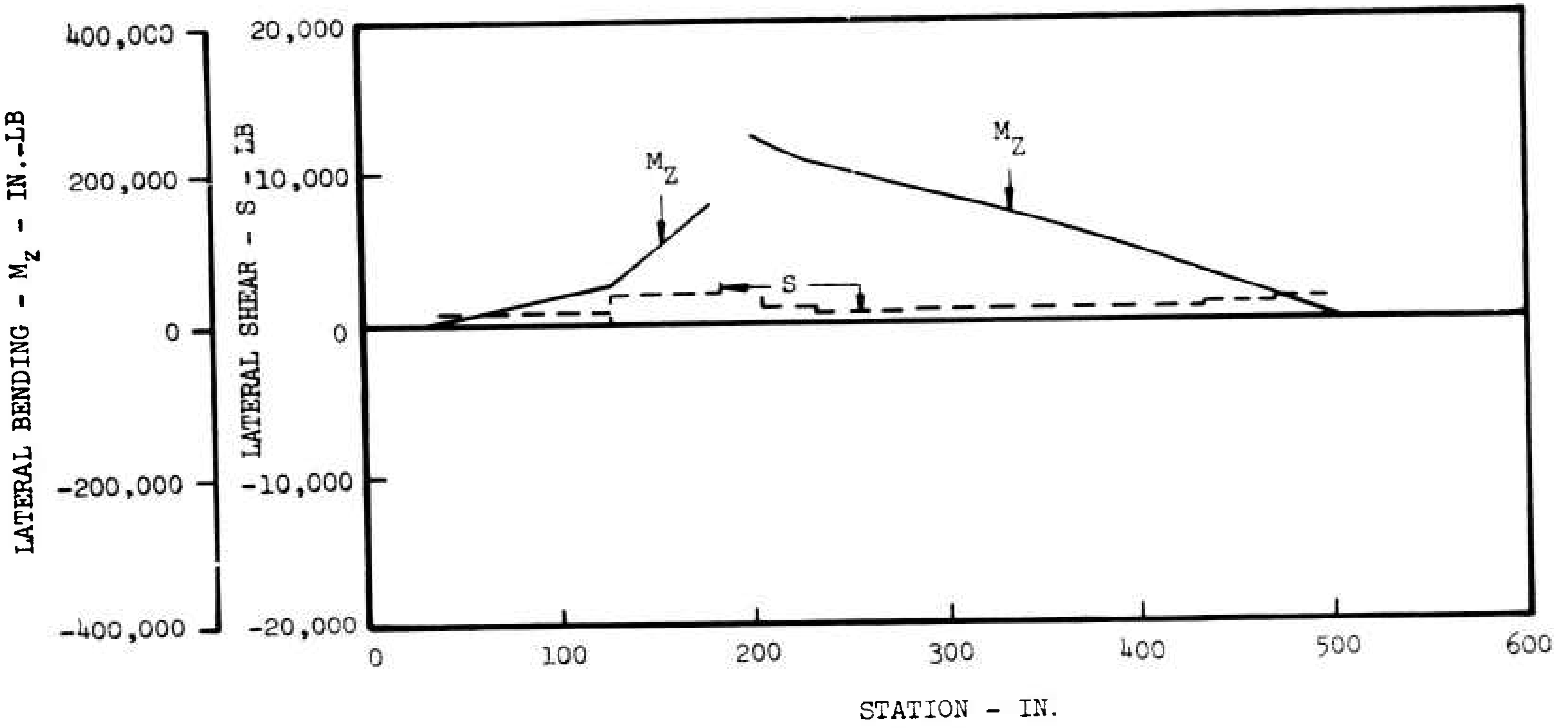


FIGURE 3. **AIRFRAME** LATERAL SHEAR AND BENDING (S & M_Z) (LIMIT) - ROLLING PULLOUT LEFT (N_Z = 2.84).

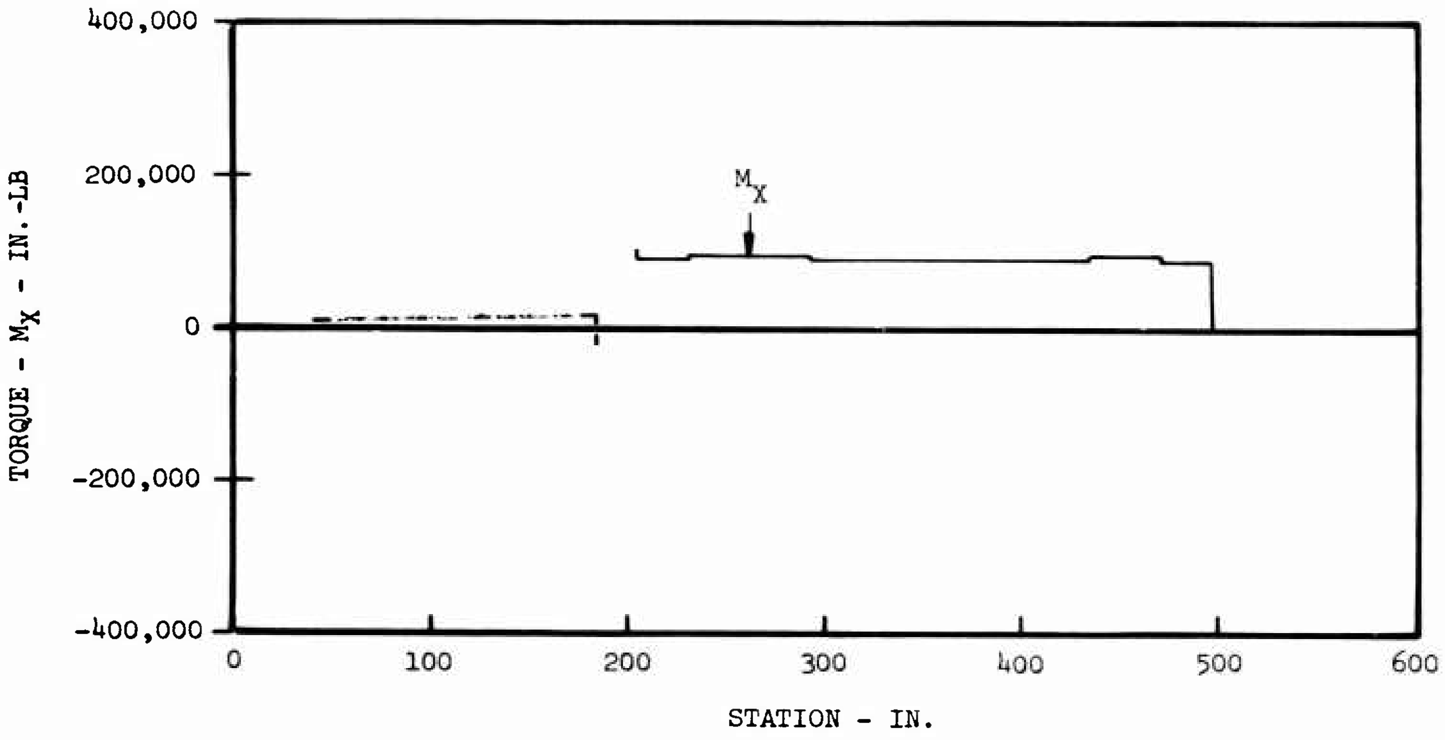


FIGURE 4. **AIRFRAME** TORQUE M_X (LIMIT) - ROLLING PULLOUT LEFT (N_Z = 2.84).

TABLE 8. MATERIAL COSTS (1974 $)

Material	$/LB
2024-T3 Aluminum	1.20
Titanium (Ti-6-4)	16.00
Graphite/Epoxy (A/S)	20.00
Kevlar-49/Epoxy	10.00
E-Glass (Fabric)	2.35
E-Glass (Roving)	1.00
Miscellaneous	1.00

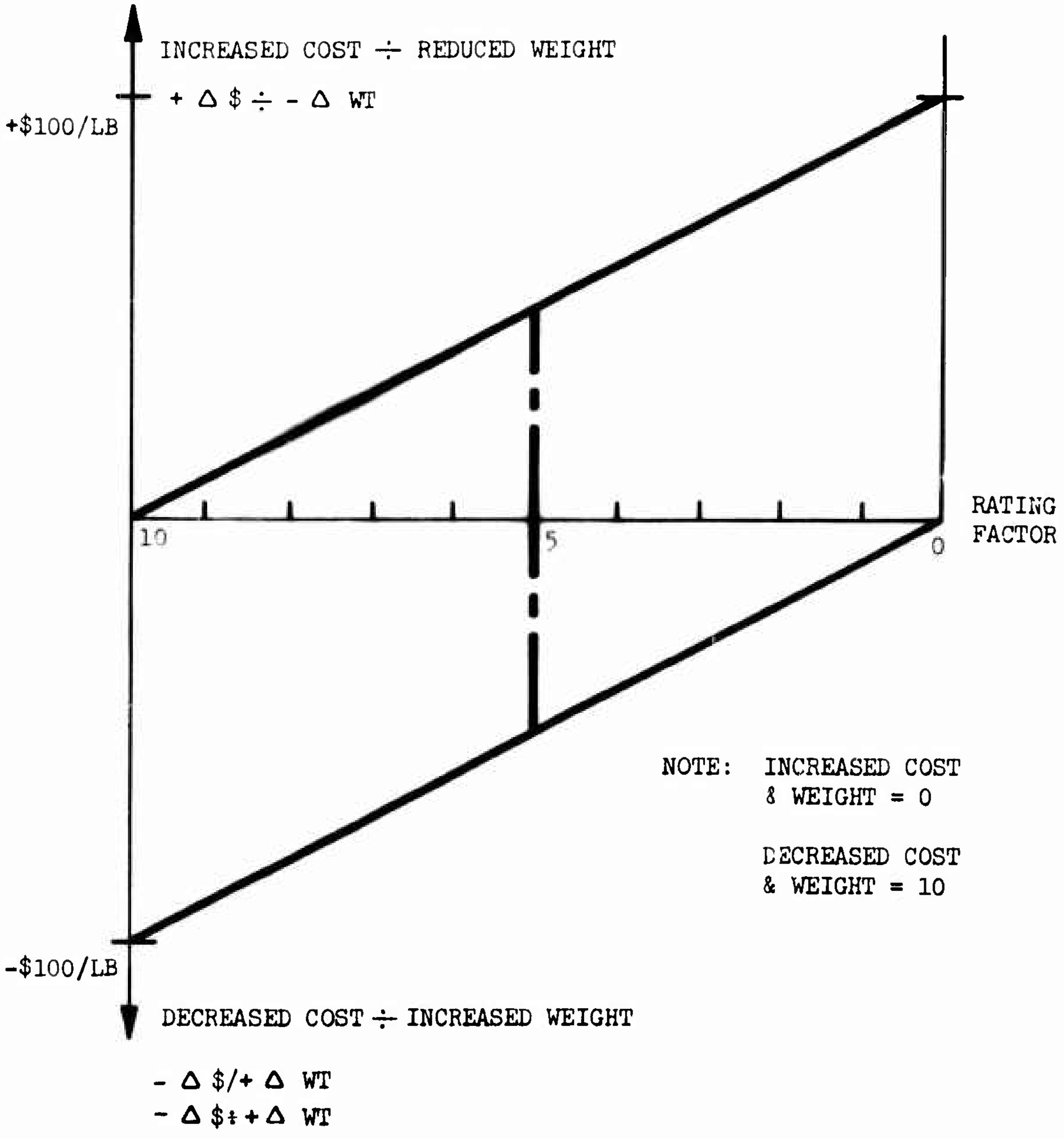


FIGURE 5. COST AND WEIGHT RATING DIAGRAM

ADVANCED DESIGN CONCEPTS

General

The baseline design helicopter of Figure 1 was investigated for application of advanced concepts involving both configuration and advanced materials. The investigation first required determination of the affected structural weight of the baseline design and development of means of reducing weight and cost.

The advanced design concepts were in the structural areas of airframe and landing gear, rotor and control systems, transmission systems, and selected areas of propulsion. The cost and weight comparisons of the baseline design and the advanced designs are presented here only for the affected structures. A rating system was used to enable the comparisons to include the primary factors of weight and cost, fail-safety, and safety. Ratings are also provided for the secondary factors of detectability, crashworthiness, vulnerability, reliability, and maintainability.

Data sheets were prepared for each structural system. The data sheets were then reviewed to rate each advanced design concept as: (a) a lower cost grouping, (b) a lower weight grouping, and (c) a recommended grouping for integration of the concepts into an advanced design helicopter. All advanced designs were required to meet the criteria and loads specified for the baseline helicopter.

Rating Procedure

The specified primary factors were: (a) weight and cost, (b) fail-safety, and (c) safety. For cost and weight, the rating was based on Δ cost + Δ weight, which was obtained from the baseline cost and weight data for the structural component. The rating of Δ cost + Δweight is from zero to ten. As illustrated in Figure 5, the study considered areas in which weight savings were achieved at increased cost and areas in which decreased costs were achieved at increased weight.

A weight saving of $50 per pound was assigned the median value of 5. A weight saving achieved at no additional cost over the baseline design was assigned a value of 10. Any increased cost without a weight saving was assigned a zero value. Any configuration producing a saving in weight and cost was assigned a value of 10.

The combined rating of an advanced structural concept is a weighted average of the cost + weight rating plus the ratings for fail-safety and safety.

Values assigned for fail-safety and safety were made by expert, specialized design personnel. The factors were defined as follows:

Fail-Safety: Ability to carry limit flight loads after loss of a single member. Residual strength and life

	after damage within a mission period of 3 hours. Ability to detect and inspect for damage.
Safety:	Operational safety, such as hazards due to clearances, flammability, toxic gas emission, structural penetration into critical areas, overall safety in crashes.

Both fail-safety and safety were rated from zero to a maximum value of ten. The baseline design was assigned a rating of 5 for purposes of comparison.

The weighted rating of the primary factors was as follows:

$$\begin{aligned} \text{Overall rating (primary factors)} = {} & .50\ \Delta\text{cost} + \Delta\text{weight rating} \\ & + .25\ \text{fail-safety rating} \\ & + .25\ \text{safety rating} \end{aligned}$$

Secondary factors were rated subjectively by expert, specialized design personnel, using a zero to ten scale. The following definitions were employed:

Detectability	Radar Cross Section IR Suppression Noise
Crashworthiness	Capability for Crash Conditions for MIL-STD-1290 (AV) "Light Fixed and Rotary Wing Aircraft Crashworthiness"
Vulnerability (Survivability)	.30 Caliber Damage
Reliability and Maintainability	MTBF 39 hrs MTBM 3.5 hrs Replacement time 3 hrs Operational Availability 78%

Airframe and Landing Gear System

The airframe structures consist of the cockpit, cabin, flooring, transition (between cabin and tail cone), tail cone, tail pylon, and fairings (secondary structures). The horizontal stabilizers were also considered airframe structures, since their construction is similar to that of the body groupings. The landing gear consists of the main and tail landing gear structures.

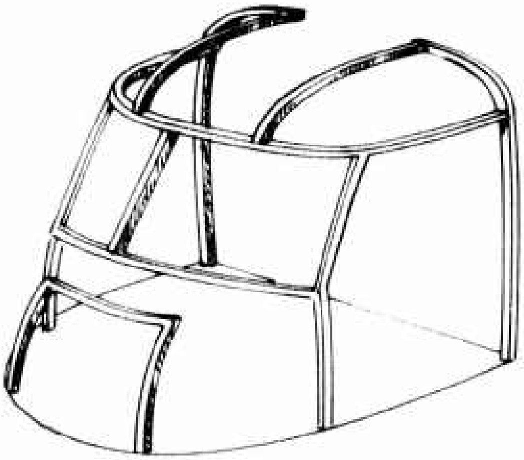
Cockpit Section

The advanced concepts considered for the cockpit section are shown in Figure 6. The areas considered were the canopy structure and the lower section (tub). The conventional baseline structure is shown for reference and comparison with the advanced structures. The baseline canopy frame work is made of fiberglass/epoxy. Advanced concept A-1 of Figure 6 uses a combination of Kevlar-49/epoxy and graphite/epoxy. The graphite is used only to reinforce sections in compression. Kevlar-49 is used throughout, mainly for its high specific strength in tension.

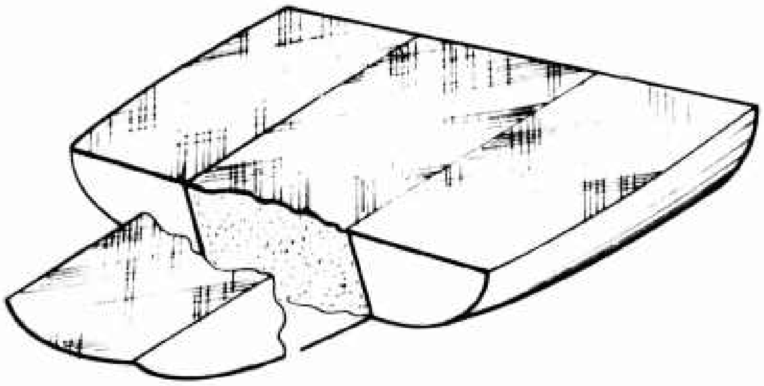
Three tub concepts are presented in Figure 6 (A-2, A-3 and A-4). A-2 and A-3 are of composite construction, using Kevlar-49 and graphite/epoxy. A-2 uses a molded foam core (polyurethane, 8 lb/ft^3 density) to provide stability and to increase crashworthiness.

Construction graphite/epoxy (A/S fiber) carries axial loadings, and Kevlar -49 ($\pm$ 45 degrees) is used as the skin to carry shear loads. The light Kevlar-49 skins are designed to work in a post-buckled state (diagonal tension) to take advantage of their light weight. This concept was proposed in Ref. (7), and some verification of the post-buckled capability of composites is cited in Ref. (8). Tub concept A-4 is of spot weld-bonded aluminum construction. Spot welds are an inexpensive means of clamping parts to be bonded adhesively. The advantages are lower cost of fabrication and moderate weight reduction due to increased skin effectiveness acting with the stringer. This type of bonded construction also improves skin/stringer panel interaction strength (combined shear, and axial compression loading) compared with conventional riveted construction. This construction has been used in Soviet aerospace construction for over twenty years (Ref. (9)) and in the Sikorsky Blackhawk TM S-67 helicopter. It is currently being investigated for wider use under an Air Force contract (Ref. (10).

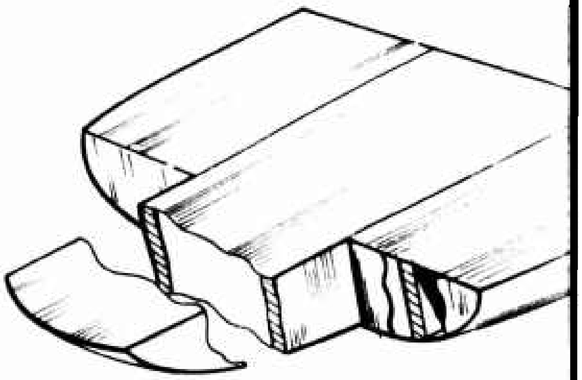
Table 9 is a summary data sheet for the airframe and cockpit and includes primary factors, secondary factors, and ratings.



A-1 HYBRID COMPOSITE
CANOPY FRAMEWORK
WT - 33 LB
COST - $5062

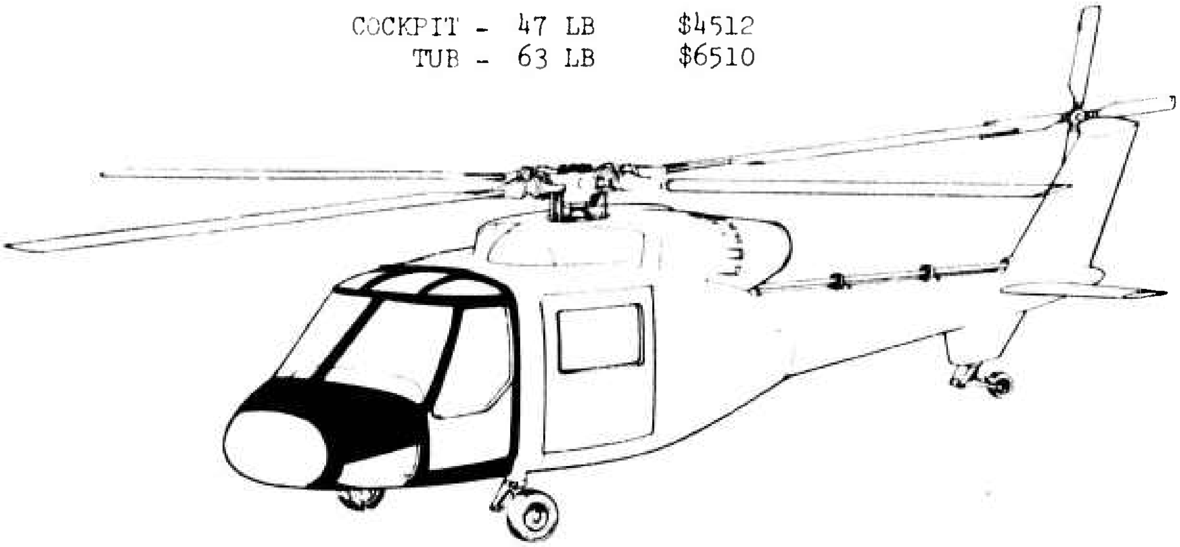


A-2 MOLDED LOWER COCKPIT
WT - 65 LB
COST - $9,400

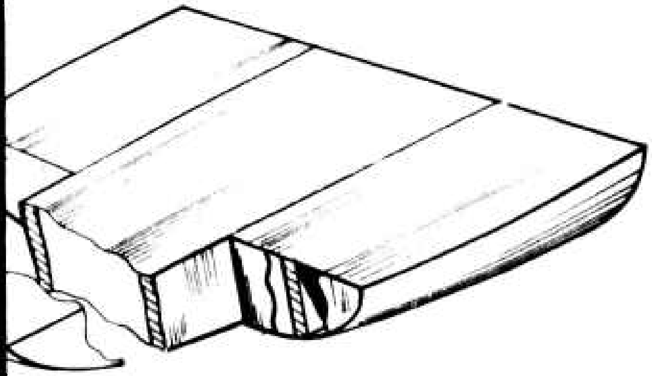


A-3 COMPOSITE SKINS, SAN
LOWER COCKPIT
WT - 39 LB
COST - $6903

FIGURE 6. ADVANCED CONCEPTS - COCKPIT SECTION.

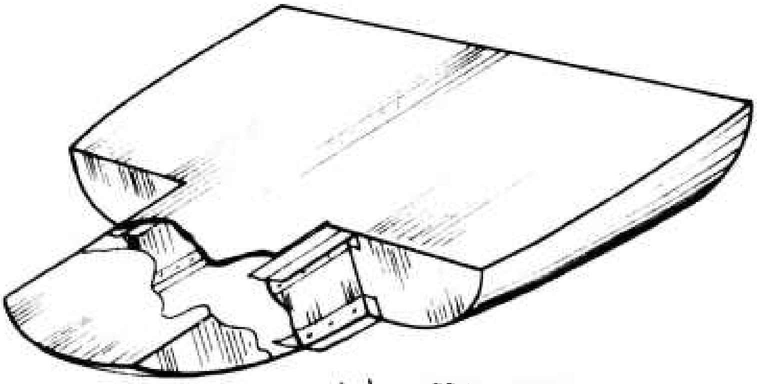


COCKPIT - 47 LB $4512
TUB - 63 LB $6510



A-3 COMPOSITE SKINS, SANDWICH BEAMS
LOWER COCKPIT

WT - 39 LB
COST - $6903



A-4 SPOT-WELDED BONDED
ALUMINUM LOWER COCKPIT

WT - 57 LB
COST - $5896

TABLE 9. ADVANCED AIRFRAME CONCEPTS - COCKPIT SECTION, DATA SHEET

		PRIMARY						SECONDARY			
DESCRIPTION/CONCEPT	CRITERIA	WT, LB	COST,$	Δ$/Δ LB (Rating)	FAIL SAFETY	SAFETY	OVERALL RATING	DETECT.	CRASH WORTH	VUL.	R&M
	1) Canopy airloads 2) Pilot-Copilot seat support structure crash loads. 3) Crash loads due to plowing. 4) Control loads.										
<u>Conventional Baseline</u>											
Canopy - Molded fiber-glass framework.		47	4512								
Tub - Built-up aluminum beams, intercostals, frames and stringers		63	6510								
<u>Advanced Concept A-1</u>		33	5062	7.2	5	5	6.1	5	5	6	5
Canopy framework of hybrid composites, graphite/epoxy and Kevlar.											
<u>Advanced Concept A-2</u>		65	9400	0	6	7	3.3	5	7	7	7
Tub - Molded foam and graphite/epoxy axial members, Kevlar skins.											
<u>Advanced Concept A-3</u>		39	6903	7.0	6	5	6.3	5	4	6	6
Tub - Kevlar skins, graphite/epoxy, Kevlar and foam sandwich beams.											
<u>Advanced Concept A-4</u>		57	5896	10	6	6	8	5	6	5	5
Tub - Conventional construction spot/bonded.											

Main Cabin Section

The main cabin section consists of the upper cabin assembly, floor, and lower cabin. The advanced concepts considered are illustrated in Figure 7, which also shows cost and weight comparisons with the baseline design. The upper cabin advanced concepts are shown as A-5a, b, and c. A-5a is a hybrid combination of Kevlar-49 and graphite epoxy using sandwich construction. The skin surfaces are of Kevlar-49 (sandwich) and polyurethane foam stabilized frames for the high loads induced by fuselage bending and the landing gear loads. A-5a, b are similar in use of materials, but employ laminate Kevlar skins and foam stabilized stringers and frames. A-5c construction is similar to that of A-4, employing spot-welded bonded aluminum.

A-6 is a hybrid composite floor using Kevlar-49 for tension stresses and graphite for compression stresses.

The lower cabin concepts are A-7, A-8, and A-9. A-7 employs a molded hybrid sandwich construction similar to that of A-2. A-8 is of built-up hybrid skin/stringer/beam/frame construction similar to that of A-3. A-9 is of spot-welded bonded aluminum construction similar to that of A-4.

Cost and weight trends for the various upper and lower cabin concepts are very similar to those presented for the tub in the cockpit section. The lowest cost structure is the spot-weld bonded. The lowest weight structure is built-up hybrid composite.

Table 10 summarizes weight, cost and ratings for the main cabin section.

Transition and Tail Cone Sections

The transition section consists of an inner structure containing equipment and fuel cells. The advanced concepts are shown in Figure 8. Concept A-10 is a hybrid composite sandwich construction that is very adaptable to attachments for shelves of equipment and capable of withstanding fuel cell loads as well as flight and ground loading conditions.

The outer shell of the transition section is adaptable to concepts A-11, A-12 and A-13. A-11 is of Kevlar sandwich construction. A-12 is a built-up hybrid composite. A-13 is of spot-welded bonded aluminum construction. The built-up composite shows up best in weight reduction. The spot-welded bonded design shows a moderate weight saving and some cost saving compared with conventional riveted aluminum airframe construction.

Three advanced concepts for tail cones are shown in Figure 8. A-12 is of hybrid composite sandwich construction. A-13 is a hybrid composite employing built-up stabilized skins/stringers/frames. A-14 is of spot-welded aluminum skin/stringer/frame construction.

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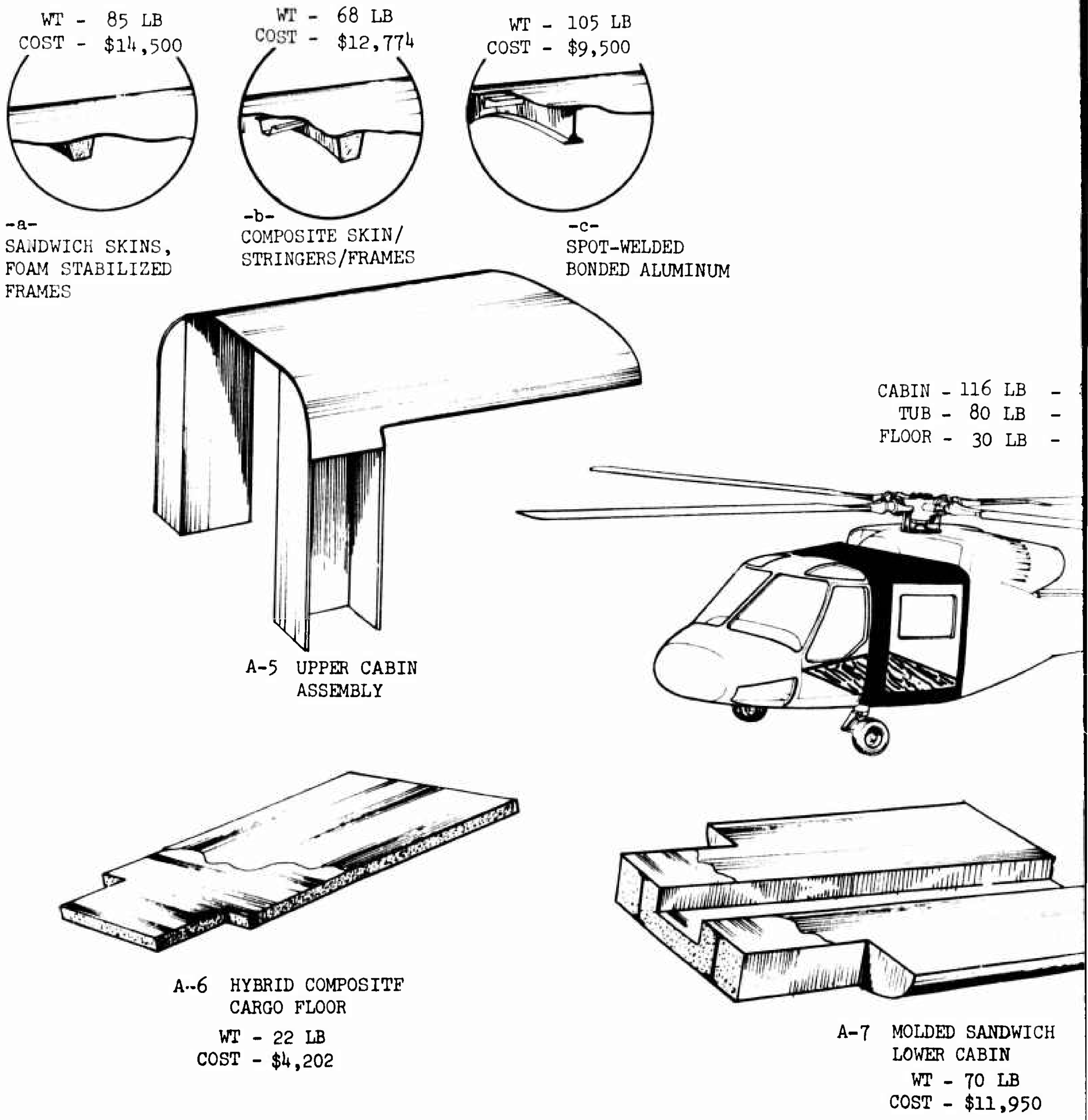
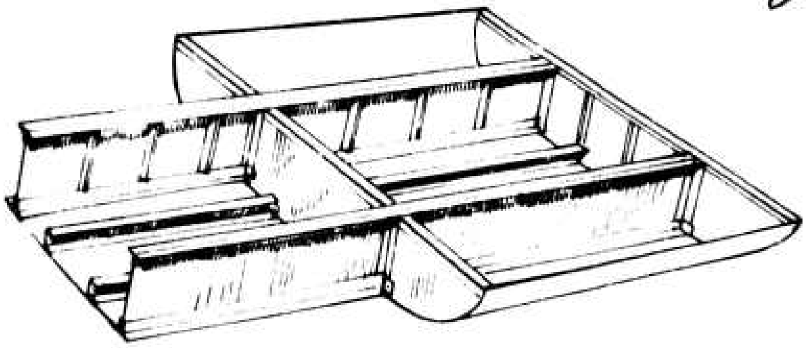


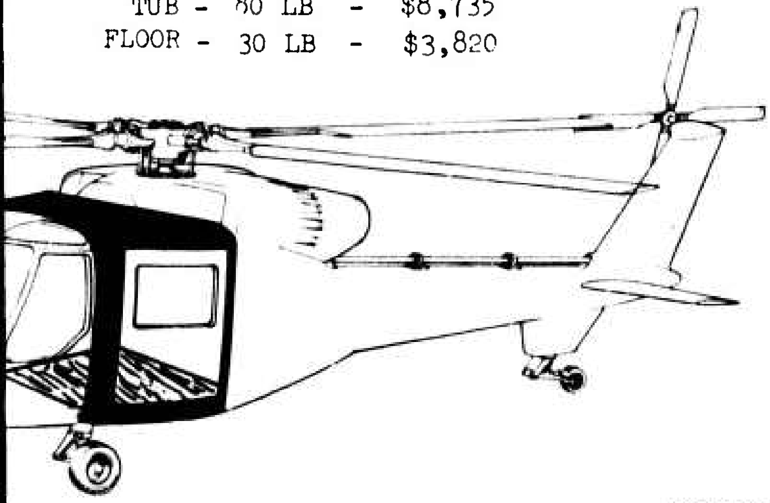
FIGURE 7. ADVANCED AIRFRAME CONCEPTS - MAIN CABIN.

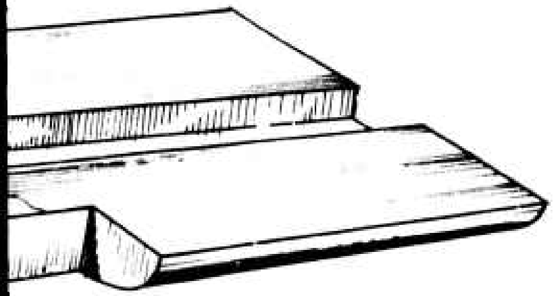
2



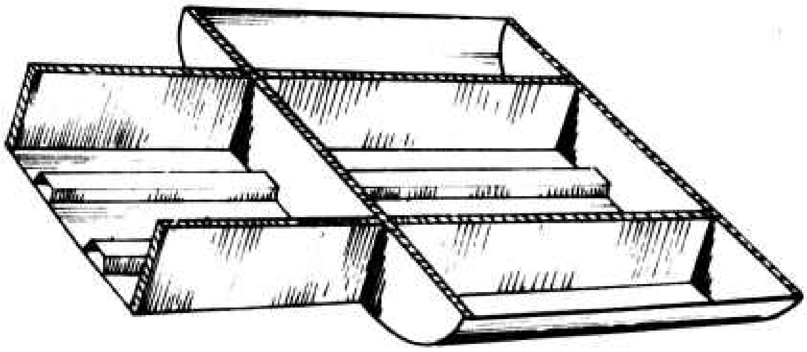
A-9 SPOT-WELDED
BONDED ALUMINUM
WT - 72 LB
COST - $7,862

CABIN	116 LB	$12,693
TUB	80 LB	$8,735
FLOOR	30 LB	$3,820





A-7 MOLDED SANDWICH
LOWER CABIN
WT - 70 LB
COST - $11,950



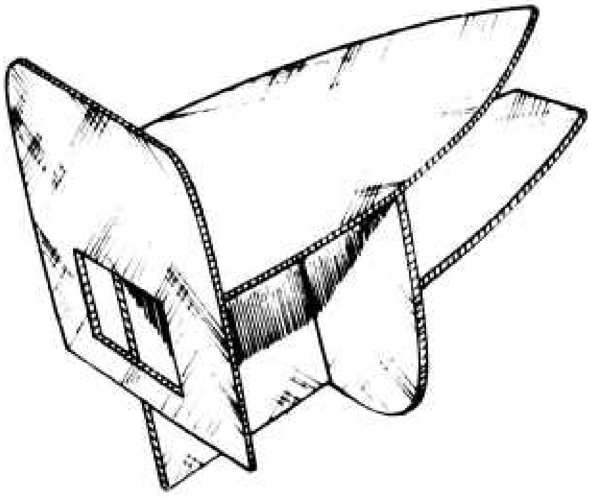
A-8 COMPOSITE SKIN/STRINGER/
FRAMES/BEAMS
WT - 45 LB
COST - $8,328

TABLE 10. ADVANCED AIRFRAME CONCEPTS - MAIN CABIN SECTION, DATA SHEET

				PRIMARY					SECONDARY			
DESCRIPTION/CONCEPT	CRITERIA	WT, LB	COST,$	Δ$/Δ LB (Rating)	FAIL SAFETY	SAFETY	OVERALL RATING	DETECT.	CRASH WORTH	VUL.	R&M	REMARKS
	1) Airframe shears, bending & torsion from flight maneu. 2) High mass item crash loads. 3) Cargo loads. 4) Troop seat loads. 5) Landing loads. 6) Floor loads, 300 PSF @ N_z											
Conventional												
Airframe - riveted aluminum skins over formed aluminum stringers, forged and/or built-up aluminum beams, frames and bulk-heads. Cabin/tub/floor-titanium upper face, honey-comb (Al) core, fiberglass lower face supported on beams.		116 (cabin) 80 (tub) 30 (floor)	12693 8735 3820									The weights given are for primary structure (165 lb fairing, miscellaneous structure not included).
Advanced Concept A-5A		85	14500	4.2	6	5	4.9	6	3	6	6	
Cabin - Kevlar & graphite/epoxy sandwich construction. Stabilized foam filled frames & beams. Titanium hard points.												
Advanced Concept A-5B		68	12774	6.8	6	6	6.4	6	5	6	6	
Cabin - molded Kevlar skins, stabilized stringer, frames of												

TABLE 10. (CONCLUDED)

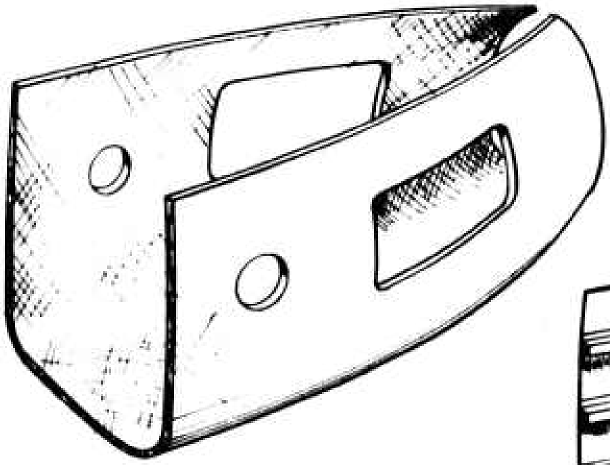
		PRIMARY						SECONDARY				
DESCRIPTION/CONCEPT	CRITERIA	WT, LB	COST,$	Δ$/Δ LB (Rating)	FAIL SAFETY	SAFETY	OVERALL RATING	DETECT.	CRASH WORTH	VUL.	R&M	REMARKS
Advanced Concept A-5b continued graphite/epoxy, Kevlar & foam. Titanium hard points. Mold in one assembly, splice at cabin tub.												
Advanced Concept A-5C Conventional construction, spot-welded bonded (cold bond).		105	9500	10	6	6	8	5	6	5	5	
Advanced Concept A-6 Floor - Kevlar, graphite/epoxy faces, honeycomb core, ships grip coating top face.		21	4202	7.1	5	4	5.9	5	1	6	5	
Advanced Concept A-7 Molded lower cabin of foam, Kevlar skins, graphite/epoxy axial members; Kevlar, G/E top surface coated with ships grip.		70	11950	0	6	6	3	5	6	7	6	Combines lower cabin structure with cargo floor. Mold with concept 2A-2
Advanced Concept A-8 Lower cabin, Kevlar skins, foam stabilized stringers of Kevlar & graphite/epoxy. Graphite/epoxy & Kevlar sandwich beams.		45	8328	7.1	6	5	6.4	5	3	6	5	Requires floor of concept 2A-6. Mold with concept 2A-3
Advanced Concept A-9 Spot/bond aluminum construction.		72	7862	10	6	6	8	5	6	5	5	



A-10 COMPOSITE SANDWICH BULKHEADS

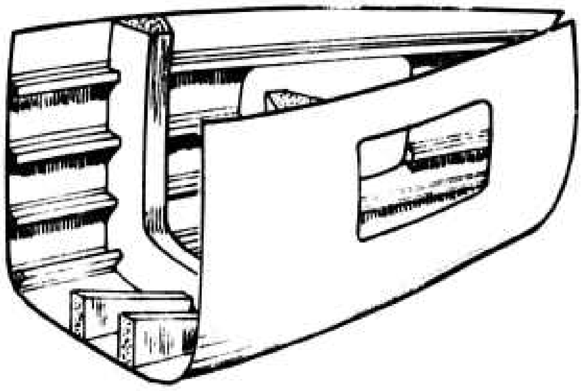
WT - 139 LB
COST - $19,316

WT - 41
COST - $4



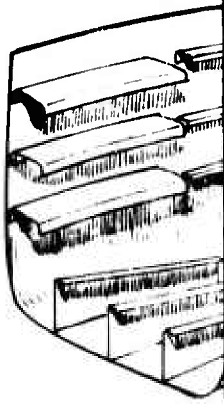
A-11A COMPOSITE SANDWICH SHELL

WT - 170 LB
COST - $25,600



A-11B COMPOSITE SKIN/STRINGER SHELL

WT - 118 LB
COST - $21,655

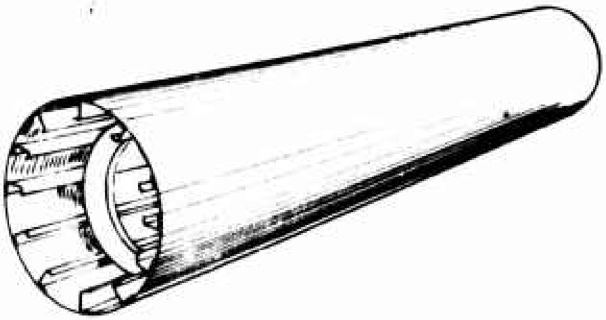


A-11C

FIGURE 8. ADVANCED AIRFRAME CONCEPTS - TRANSITION AND TAIL CONE

1

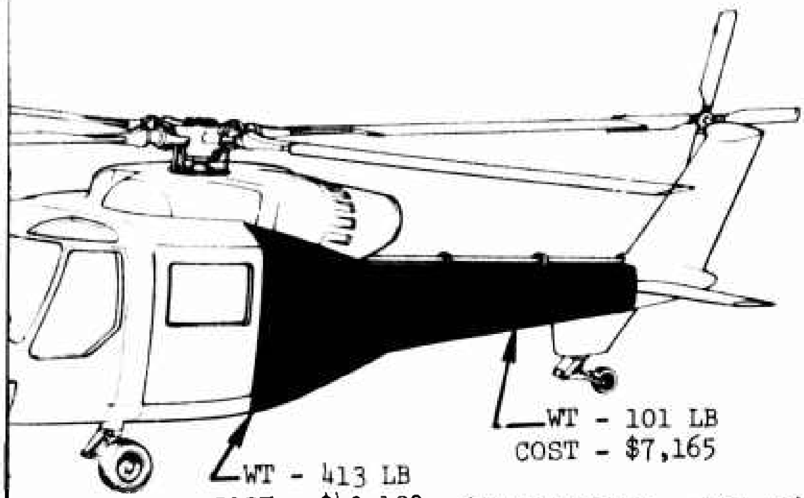
2



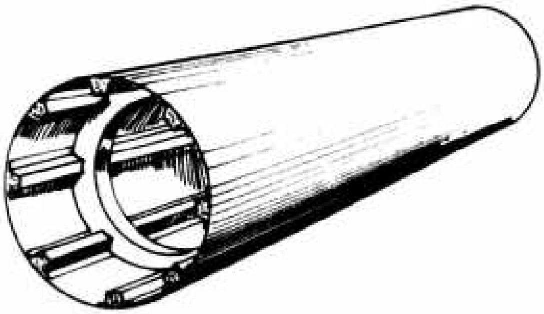
A-14 SPOT-WELDED BONDED ALUMINUM TAIL CONE

WT - 91 LB

COST - $6,449



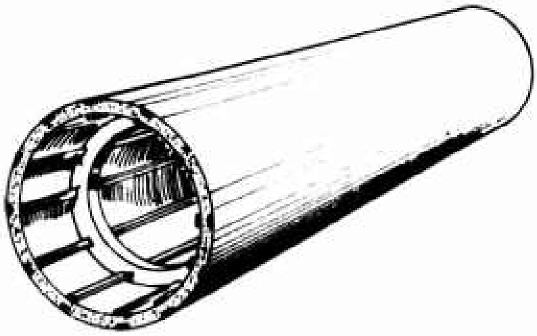
(BULKHEAD WT - 225 LB)



A-13 COMPOSITE SKIN/STRINGER TAIL CONE

WT - 68 LB

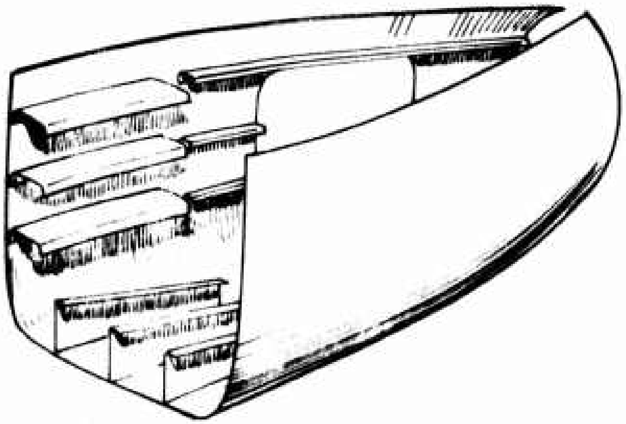
COST - $7,942



A-12 COMPOSITE SANDWICH TAIL CONE

WT - 87 LB

COST - $9,224



A-11C SPOT-WELDED BONDED ALUMINUM SHELL

WT - 161 LB

COST - $18,612

The trend is similar as for previous constructions. The built-up composite concept is lighter, and the spot-welded bonded concept provides moderate weight savings and some cost reduction.

The comparative costs, weights, and ratings for the transition and tail cone section are presented in Table 11.

Tail Pylon and Stabilizer

The tail pylon and stabilizer baseline design is of conventional riveted aluminum construction. Three advanced concepts for the pylon are shown in Figure 9 as concepts A-15, A-16, and A-17. A-15 is a foam-filled (polyurethane) core with Kevlar skins for shear, and graphite/epoxy for axial loaded members. A-16 is of built-up composite construction of Kevlar and graphite/epoxy. The skins are of Kevlar to carry shear loads. The stringers are foam filled for stabilization against crippling. They are made of Kevlar and graphite/epoxy. The front and rear spars are sandwich beams, Kevlar for shear, and graphite/epoxy for axial loads. A-17 is of spot-welded bonded aluminum construction.

Of the concepts, the composite hybrid built-up construction is lightest. The spot-welded bonded aluminum offers moderate weight savings and reduced cost compared with conventional riveted construction.

Figure 9 shows two advanced concepts for the stabilizers. A-18 is a hybrid built-up composite, similar in construction to A-16. A-19 is a foam core wrapped with Kevlar for shear and reinforced with graphite/epoxy for axial loading. No spot-welded bonded concept is presented, since it would have no advantages over conventional riveting. The built-up hybrid composite construction provides a weight saving.

Weight, costs, and ratings are given in Table 12.

Fairings and Landing Gear

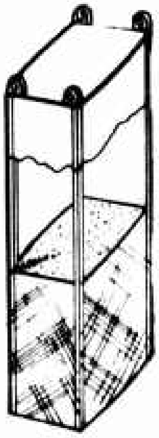
The baseline design employs a large number of fairings as aerodynamic covers, doors, and secondary structures. Current UTTAS technology uses fiberglass, Kevlar, and metal for these items. Advanced concept A-20, shown in Figure 10, is a waffle construction of two skin surfaces. The outside surface is formed to the contour required. The inside laminate skin is formed as a grid of structural shapes, stabilized with an inner core. Kevlar is the general material, and graphite/epoxy is intermixed in the inner and outer skins and the structural hat section shapes to form the grid of beams. The beam grid is a pattern 8 x 8 inches to withstand pressure loading.

TABLE 11. ADVANCED AIRFRAME CONCEPTS - TRANSITION AND TAIL CONE SECTIONS, DATA SHEET

		PRIMARY						SECONDARY				
DESCRIPTION/CONCEPT	CRITERIA	WT, LB	COST,$	Δ$/ΔLB RATING	FAIL SAFETY	SAFETY	OVERALL RATING	DETECT.	CRASH WORTH	VUL.	R&M	REMARKS
Conventional												
Transition	**Landing loads, airframe shears, moments and torsions.**	413	40130									
		(Inner) 225	(21140) (22,000)									
		(Steel) 178	(15020)									
Advanced Concept A-10												
Transition section-graphite/epoxy, Kevlar,and foam sandwich for bulkhead and decking.		139	19316	10	6	5	7.8	5	3	6	5	Sandwich construction required for equipment mounting.
Advanced Concept A-11A												
Transition outer shell-molded Kevlar and foam sandwich construction.		170	25600	0	6	4	2.5	5	3	5	6	
Advanced Concept A-11B												
Kevlar skins, foam stabilized stringers, intercostals, and frames.		118	21655	6.4	6	4	5.7	5	2	6	5	
Advanced Concept A-11C												
Conventional construction spot/bonded.		151	18612	10	6	6	8	5	6	5	4	

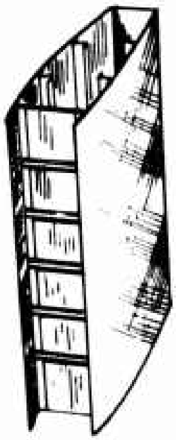
TABLE 11. (CONCLUDED)

DESCRIPTION/CONCEPT	CRITERIA	PRIMARY WT, LB	 COST,$	Δ$/ΔLB RATING	FAIL SAFETY	SAFETY	OVERALL RATING	SECONDARY DETECT.	 CRASH WORTH	VUL.	R&M	REMARKS
Conventional		101	7165									
Tail cone - aluminum skins riveted to formed aluminum stringers and frames, forged bulkheads with lugs.	Tail cone loads from pylon, stabilizer, and tail bumper											
Advanced Concept A-12												
Tail cone - molded Kevlar and graphite/epoxy, sandwich construction.		87	9224	0	6	6	2.5	5	5	6	6	
Advanced Concept A-13												
Tail cone - molded from composite (graphite/epoxy and Kevlar) skin/stringers, frame.		68	7942	7.8	6	6	6.4	5	5	5	5	
Advanced Concept A-14												
Tail cone - aluminum construction spot/bonded.		91	6449	10	6	6	8	5	6	5	5	



A-15 MOLDED COMPOSITE
BOX STRUCTURE, PYLON
WT - 48 LB
COST - $2,910

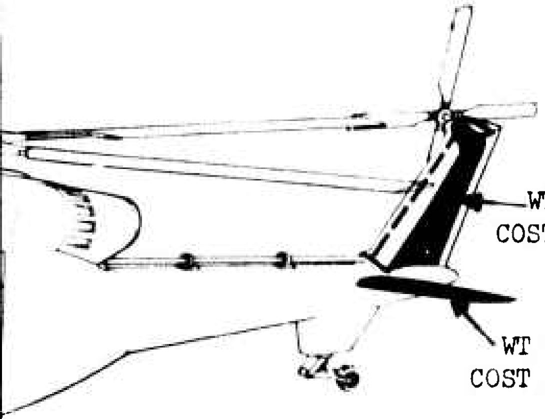
A-16 COMPOSITE SKIN/STRINGER
SANDWICH SPAR, PYLON
WT - 29 LB
COST - $4,888



A-17 SPOT-WELDED BONDED
ALUMINUM PYLON
WT - 43 LB
COST - $4,995

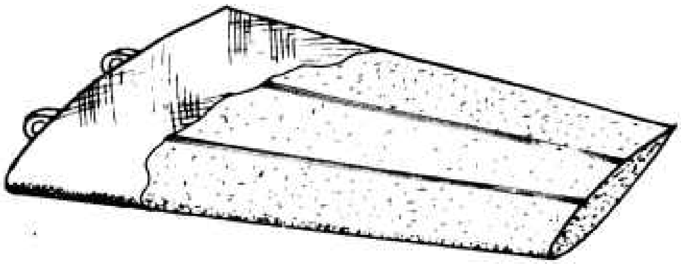
FIGURE 9. ADVANCED AIRFRAME CONCEPTS - TAIL PYLON AND STABILIZER.

1



WT - 48 LB
COST - $5,550

WT - 37 LB
COST - $4,300



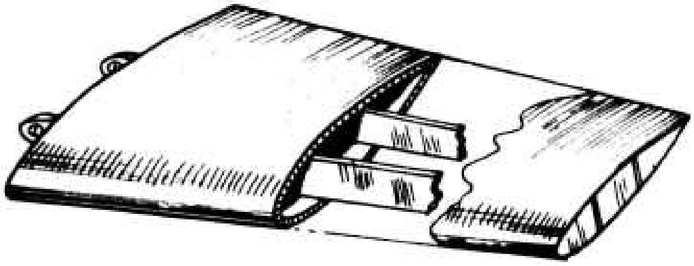
A-19 MOLDED COMPOSITE
STABILIZER

WT - 34 LB
COST - $1,450

OT-WELDED BONDED
UMINUM PYLON

- 43 LB
- $4,995

ER.



A-18 COMPOSITE SANDWICH
SKIN/SPAR STABILIZER

WT - 23 LB
COST - $3,102

TABLE 12. ADVANCED AIRFRAME CONCEPTS - TAIL PYLON STRUCTURE, DATA SHEET

		PRIMARY					SECONDARY				
DESCRIPTION/CONCEPT	CRITERIA	WT, LB	COST,$	Δ$/ΔLB RATING	FAIL SAFETY	SAFETY	OVERALL RATING	DETECT.	CRASH WORTH	VUL.	R&M
Conventional											
Pylon - aluminum spars built up, formed ribs or stiffeners, riveted aluminum skins. Mechanical attachment to tail cone.	1) Pylon, tail rotor thrust & torque, pylon airloads 2) Stabilizer, max airloads. (Walking loads.)	48	5550								
Stabilizers - built-up aluminum spars, formed ribs or stiffeners, or bead stiffened aluminum skins. Bolted to tail cone through lugs.		39	4300								
Advanced Concept A-15											
Pylon - molded foam filled with Kevlar skins, graphite/epoxy axial members.		48	2910	10	6	6	8	5	5	7	6
Advanced Concept A-16											
Pylon - composite Kevlar skins; foam stabilized Kevlar and graphite/epoxy stringers. Spars of Kevlar faced sandwich with graphite/epoxy members.		29	4828	10	6	6	8	5	5	6	5
Advanced Concept A-17											
Aluminum construction spot-welded bonded.		43	4995	10	6	6	8	5	5	5	5

TABLE 12. (CONCLUDED)

DESCRIPTION/CONCEPT	CRITERIA	WT, LB	COST,$	Δ$/ΔLB RATING	FAIL SAFETY	SAFETY	OVERALL RATING	DETECT.	CRASH WORTH	VUL.	R&M	REMARKS
<u>Advanced Concept A-18</u>												
Stabilizers - contoured Kevlar sandwich supported on sandwich spars of graphite/epoxy and Kevlar.		23	3102	10	6	6	8	5	5	5	4	
<u>Advanced Concept A-19</u>												
Stabilizers - symmetrical airfoil molded of varying density foam to lug fittings, covered with Kevlar skin and unidirectional graphite/epoxy		34	1450	10	6	6	8	5	5	6	6	Mold left and right stabilizers as one assembly.

The baseline design main gear responds to an air transportability requirement. As a result, it is designed to be close to the fuselage. The gear is designed for normal landing load conditions and for high-energy absorption crash landings. Thus, the gear has an upper cylinder and a lower cylinder. Advanced design concept A-21, shown in Figure 10,uses Kevlar and graphite/epoxy. The upper cylinder is filament wound and then cut into halves to form the sections for the left-hand gear and the right-hand gear. The axially loaded portion along the axis of the cylinder consists of polar-wound graphite/epoxy. Kevlar is then wound around the circumference of the upper cylinder to react internal pressure loads.

Similar construction is used for the lower cylinder of the gear. The lower cylinder is used for normal loadings,and oil actuation is the energy absorption mechanism. The upper cylinder has an aluminum honeycomb core that crushes during crash landings. The wheels are also a molded Kevlar reinforced with graphite/epoxy. Except for the axle, all fittings are of graphite/epoxy fiber-oriented molded construction.

The weights, costs, and ratings are shown in Table 13.

Rotor Systems

The baseline design consists of an elastomeric main rotor head and blades with a titanium spar to carry all structural loads. The aerodynamic blade cover is made of fiberglass and graphite/epoxy. The main rotor head is a machined titanium forging equipped with articulated elastomeric bearings. The tail rotor is a cross-beam design, using a graphite/epoxy spar. The aerodynamic cover is of fiberglass.

The advanced concepts (B1-B8) for the rotor system are illustrated in Figure 11. B-1 uses a graphite/epoxy/fiberglass spar, with a fiberglass cover. The blade is fabricated in halves, which are then bonded together. This construction concept is currently in experimental fabrication under a Navy contract (Ref. (11)). The paddle tip is considered to offer the advantage of increased hover performance without loss of forward speed capability. B-1 considers two types of root ends, which are not illustrated here. B-1 (a) is hingeless and uses the qualities of composites to provide the needed lower root torsional restraint for control of collective and cyclic pitch. B-1(b) is the normal hinged, articulated root end.

B-2 is similar to B-1 except for a swept tip, which provides increased forward speed capability, reduced control loads, and possible reduction in noise.

The other blade advanced concepts are lumped in B-3. They consist of hingeless and articulated composite blades. Both fiberglass and graphite/epoxy spars were considered, using a fiberglass aerodynamic cover with

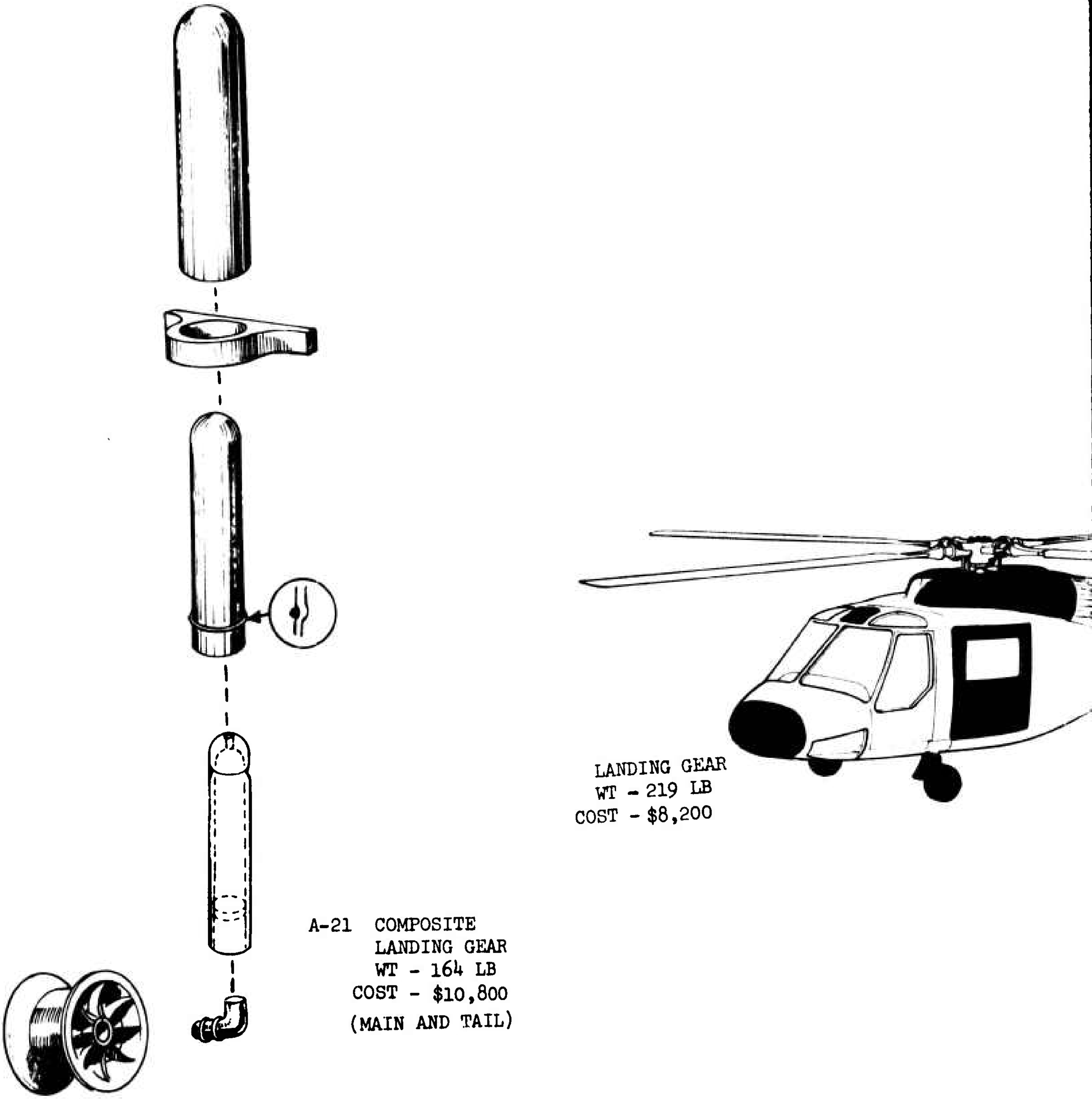
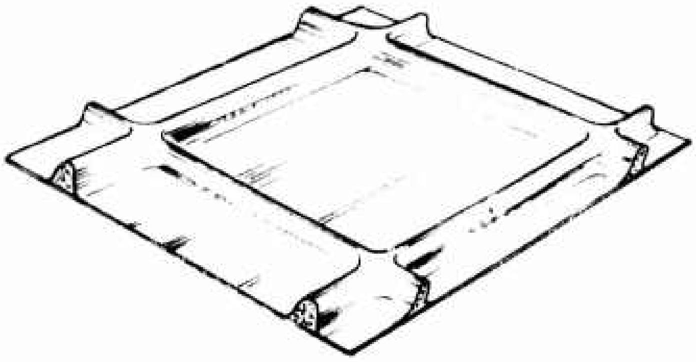
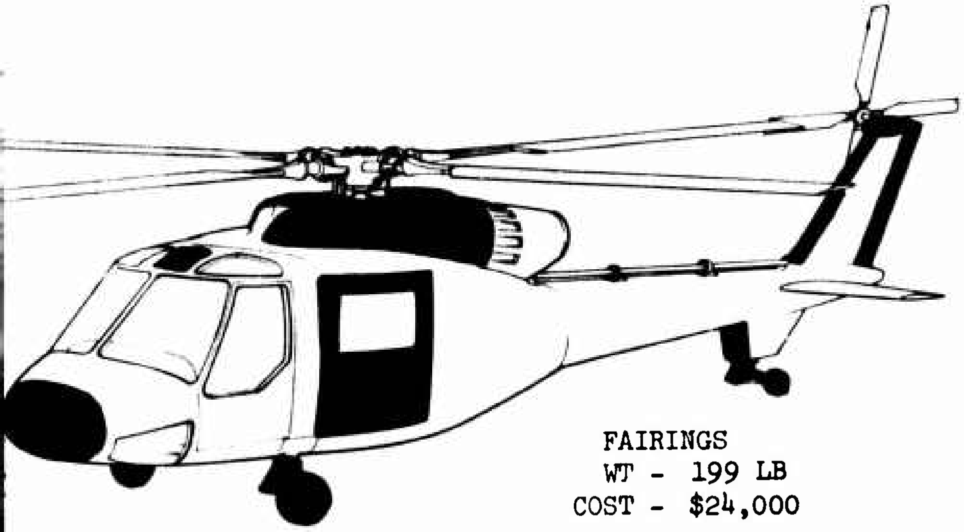


FIGURE 10. ADVANCED AIRFRAME CONCEPTS - LANDING GEARS, FAIRINGS, AND DOORS.

2



A-20
WAFFLE COMPOSITE
FAIRINGS
WT - 136 LB
COST - $13,100



FAIRINGS
WT - 199 LB
COST - $24,000

ND DOORS.

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TABLE 13. ADVANCED AIRFRAME CONCEPTS - LANDING GEAR AND FAIRING, DATA SHEET.

			PRIMARY					SECONDARY				
DESCRIPTION/CONCEPT	CRITERIA	WT, LB	COST,$	Δ $/Δ LB RATING	FAIL SAFETY	SAFETY	OVERALL RATING	DETECT.	CRASH WORTH	VUL.	R&M	REMARKS
Conventional												
Fairings												
Fiberglass, Kevlar, or metal. Usually sandwich construction.	1) Fairings rigidity & pressure loads	199	24000									
Landing Gear												
Forged aluminum wheels. Machined steel oleo and cylinders, air/oil system with double-acting oleo.	2) Landing gear normal & crash loadings for absorption	218	8200									
Advanced Concept A-20												
All fairings of Kevlar reinforced with graphite/epoxy where required for compression strength. Waffle pattern.		136	13100	10	6	6	8	5	5	6	5	
Advanced Concept A-21												
Molded composite wheels, polar-wound graphite/epoxy and Kevlar oleos and cylinders.		164	10800	6.8	7	7	6.9	5	4	5	5	

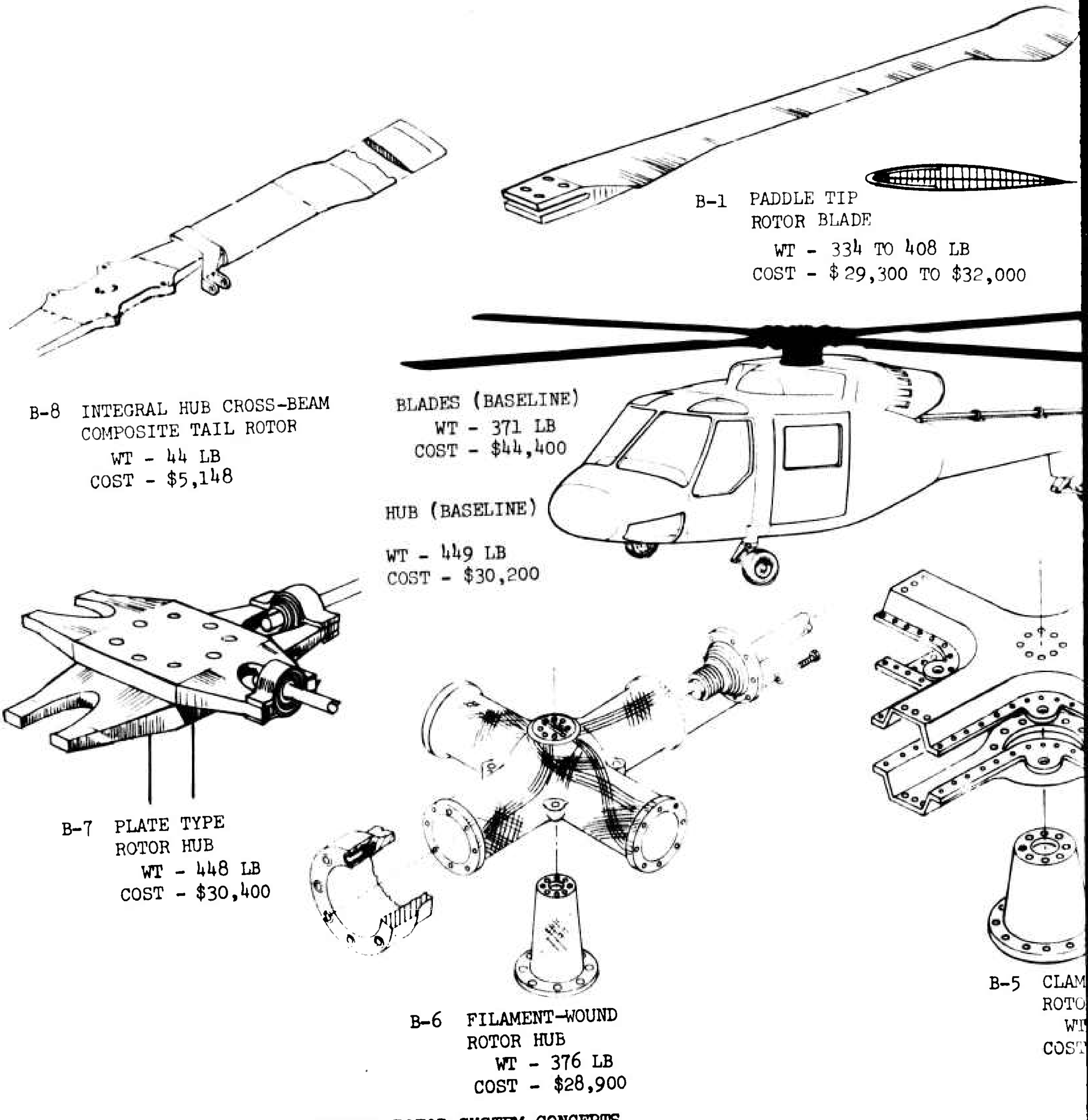
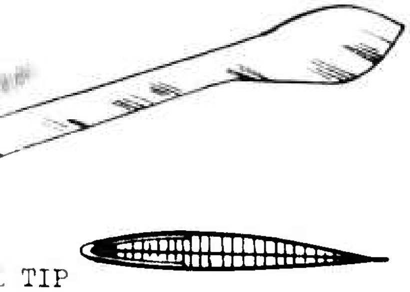
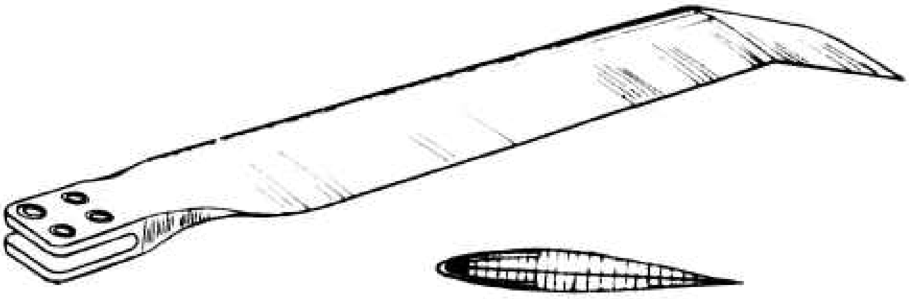


FIGURE 11. ADVANCED ROTOR SYSTEM CONCEPTS.

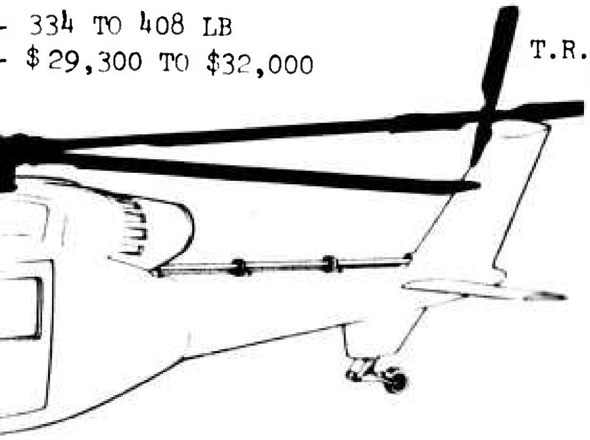
2



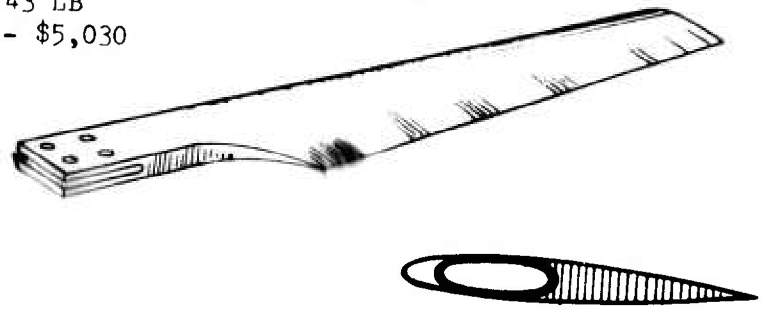
TIP
BLADE
- 334 TO 408 LB
- $29,300 TO $32,000



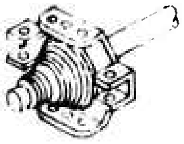
B-2 SWEPT TIP
ROTOR BLADE
WT - 334 TO 408 LB
COST - $29,300 TO $32,000

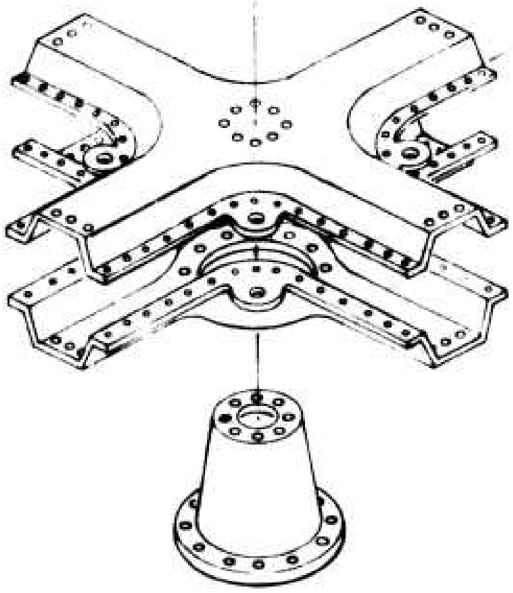


T.R. (BASELINE)
WT - 43 LB
COST - $5,030

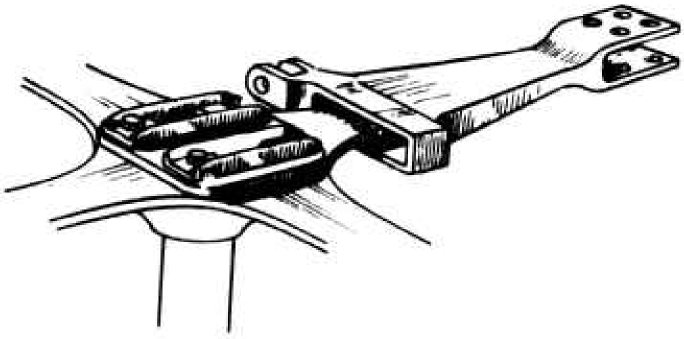


B-3 FILAMENT-WOUND AND
PULTRUDED SPAR BLADES
WT - 342 TO 477 LB
COST - $22,300 TO $41,200





B-5 CLAMSHELL
ROTOR HEAD
WT - 124 LB
COST - $31,250



B-4 COMPOSITE CROSS-BEAM
ROTOR HEAD
WT - 347 LB
COST - $28,600

honeycomb interior support for the trailing portion of the blade aft of the spar. Both pultruded fabrication and filament-wound fabrication were considered.

The articulated concepts for the blades are generally lighter and less costly, but consideration must be given to the effect on the hub concepts. The pultruded spar concept of B-3b, 4 is the lowest cost solution and reduces weight significantly. Pultrusion spar costs were the driving factor, since many fabrication operations were eliminated compared with other concepts.

The baseline rotor head is a titanium machined forging with elastomeric bearings. B-4 is a cross-beam design using graphite/epoxy and glass epoxy. The concept can be integrated with all the hingeless blade concepts (a). B-5, B-6, and B-7 are advanced hub concepts for articulated blade designs. All use graphite/epoxy for high strength and improved fatigue resistance compared with conventional metal designs.

Tail rotor concept B-8 is a moderate improvement over the baseline, which uses composites. The major advancement is made by machining the composite structure integrally with the root end.

Weights, costs, and ratings are presented in Table 14. Since the blade and hub designs must be integrated, Table 15 presents a further summary of weights and costs.

Control System

Figure 12 illustrates advanced concepts for portions of the control system. Concepts B-9 and B-10 are presented as substitutes for the conventional aluminum forged swash plate. B-10 provides the greater weight saving, with a moderate additional cost where graphite/epoxy is wound over a fiberglass X-section core.

B-11 and B-12 are advanced concepts for the rotating and stationary scissors. B-11 employs a corrugated steel diaphragm and appears to offer the best weight and cost saving compared to Concept B-12.

Composite control rods and bell cranks, concept B-13, provide only a moderate weight saving and an increase in cost.

In general, the control system concepts provide only a small advantage. The major improvement may well be in reduced vulnerability.

Table 16 presents weight, cost, and rating summaries.

TABLE 14. ADVANCED ROTOR CONCEPTS, DATA SHEET

		PRIMARY						SECONDARY				
DESCRIPTION/CONCEPT	CRITERIA	WT, LB	COST,$	Δ$/ΔLB RATING	FAIL SAFETY	SAFETY	OVERALL RATING	DETECT.	CRASH WORTH	VUL.	R&M	REMARKS
Rotor Blades, Main Rotor	**Static Analysis**	371	44400									
Conventional-titanium spar with fiberglass & graphite/epoxy aerodynamic cover, honeycomb core as required, articulated system.	All main blades & rotor heads are designed for limit flatwise static load factor of 2.67 & edgewise stiffness governed by starting torque of two times military rated power delivered to rotor, Designed for overspeed centrifugal force 1.25 X normal RPM.											Hot rolled titanium sheet formed to tubular spar. Hand layup of fiberglass/graphite/epoxy over skin.
Advanced Concept B-1, Paddle Tip Rotor Blade		408(a) 334(b)	32000 29300	See Table 15	7	7	See Table 4	7 7	5	6 6	5 5	
Automated graphite/epoxy/fiberglass spar, fiberglass skin, honeycomb sandwich core. Paddle tip for increased performance. Root retention articulated or rigid.												Increased performance in hover without loss of forward speed capability. Spar fabricated by tape laying machinery, filament wound over skin.
Advanced Concept B-2, Composite Swept Tip Blade	**Fatigue Analysis**	408(a) 334(b)	32000 29300		7	7		6 6	5 5	6 6	5 5	
Similar in construction to B-1 except for swept tip. Designed for articulated or hingeless system.	All main blades & rotor heads are designed for no damage at maximum level-flight speed & at maximum gross weight. Designed for 5000-hour minimum life thru complete flight spectrum.											Increased forward speed, lower level noise, reduced control loads. Similar to B-1 construction.
Advanced Concept B-3, Composite Filament-Wound & Pultruded Blades		477(a,1)	41200					6		7	5	Simple construction using pultruded spar reduces cost significantly.
		477(a,2)	23300							6	5	
		435(a,3)	24600							7	5	
		435(a,4)	26300							6	5	
		390(b,1)	33900							7	5	
Composite filament-wound tubular spar, graphite and fiberglass material, outer skin, honeycomb sandwich core.		390(b,2)	33900							6	5	
		342(b,3)	29400							7	5	
		342(b,4)	22300		7	7		6	5	6	5	
		(See Table 15)										

NOTE: (a) = Hingeless (b) = Articulated

TABLE 14. (CONTINUED)

		PRIMARY						SECONDARY				
DESCRIPTION/CONCEPT	CRITERIA	WT, LB	COST,$	Δ$/ΔLB RATING	FAIL SAFETY	SAFETY	OVERALL RATING	DETECT.	CRASH WORTH	VUL.	R&M	REMARKS
<u>Main Rotor Head</u> Conventional titanium rotor head, articulated, elastomeric bearings. a) For cross beam rotor(hingeless) b) For articulated rotor(hinged)		449	30200									Fabricated by machining aluminum & titanium forgings.
<u>Advanced Concept B-4, Composite Cross-Beam Rotor Head</u> Integral composite plate type head with flex beams of graphite/epoxy & glass/epoxy.		347(a)	28600	See Table 15	7	7	See Table 15	5	5	6	4	Flex beam includes a portion of weight normally associated with blade weight (approx. 2 feet of blade spar). Eliminates all bearings for articulation. Automated process for composite layup.
<u>ADVANCED CONCEPT B-5, CLAMSHELL ROTOR HEAD</u> Molded graphite/epoxy upper & lower shells, mechanically fastened. Articulated system.		424(b)	31250		7	7		5	5	6	5	Automated flat lay-up of graphite/epoxy & fiberglass composite integrated with molded composite hard points for attachments.
<u>Advanced Concept B-6, Filament-Wound Rotor Hub</u> Tubular graphite/epoxy filament-wound hub for articulated system.		376(b)	28900		7	7		5	5	6	5	Filament wound and integrated with composite molded fittings.

NOTE: (a) = Hingeless (b) = Articulated

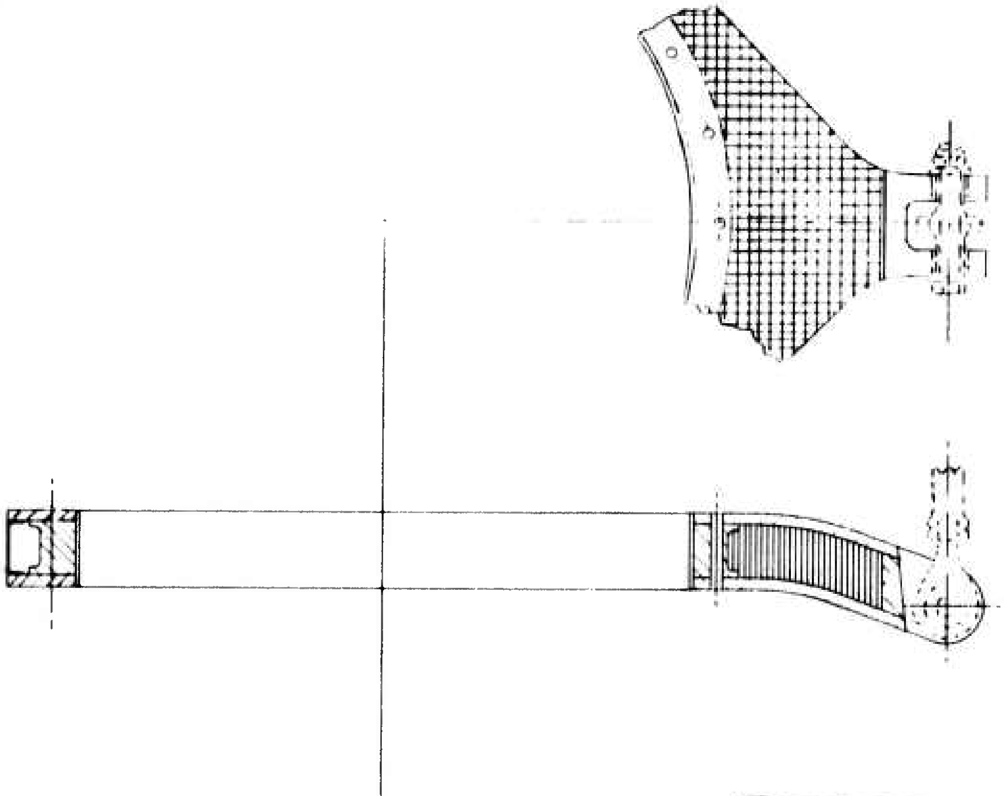
TABLE 14. (CONCLUDED)

			PRIMARY						SECONDARY			
DESCRIPTION/CONCEPT	CRITERIA	WT, LB	COST,$	Δ$/ΔLB RATING	FAIL SAFETY	SAFETY	OVERALL RATING	DETECT.	CRASH WORTH	VUL.	R&M	REMARKS
Advanced Concept B-7, Plate Type Rotor Hub		448	30400	6	6			5	5	5	4	
Flat, molded graphite/epoxy cross beam plates for articulated system.												Similar to B-5.
Rotor Blades, Tail Rotor		43	5030									
Conventional cross beam rotor, graphite/epoxy spar, fiberglass cover.	Design for maximum tail rotor thrust (yaw) in autorotation in a symmetrical dive & pullout.											Separate aluminum hub plates to retain cross beam rotor.
Advanced Concept B-8		44	5148	7	6		8.3	5	5	5	5	
Integral hub cross beam composite tail rotor.	Designed for natural frequency to be .2/rev removed from exciting frequency with an optimum of 1.5/rev.											

TABLE 15. ADVANCED MAIN ROTOR BLADES AND HUB CONCEPTS INTEGRATED, DATA SHEET

Structure	Rotor Blade		Rotor Hub		Totals Blade + Hub		Overall Rating
	W	R	W	$	W	$	
Base Line (Ref)	371	44,400	449	30,200	820	74,600	5
<u>Rotor Blades</u>							
B 1(a) Paddle Tip	408	32,000			755	60,600	
(b) Paddle Tip	334	29,300			710	58,200	
B 2(a) Swept Tip	408	32,000			755	60,600	
(b) Swept Tip	334	29,300			710	58,200	
B 3(a,1) Fiberglass, Filament Wound	477	41,200			824	69,800	
(a,2) Fiberglass, Pultruded	477	23,300			824	51,900	
(a,3) Graphite, Filament Wound	435	24,600			782	53,200	
(a,4) Graphite, Pultruded	435	26,300			782	54,900	
(b,1)	390	33,900			766	62,800	
(b,2) (Articulated)	390	33,900			766	62,800	
(b,3) Versions	342	29,400			718	58,300	
(b,4)	342	22,300			718	51,200	
<u>Rotor Hubs</u>							
B-4 Composite Hub (a)			347	28,600			
B-6 Composite Hub (b)			376	28,900			

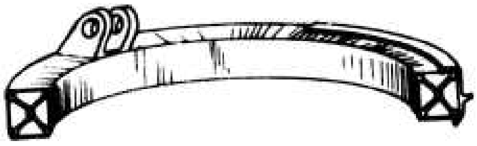
(a) Hingless
(b) Articulated



B-9 COMPOSITE
SWASH PLATE
WT - 85 LB
COST - $4,760

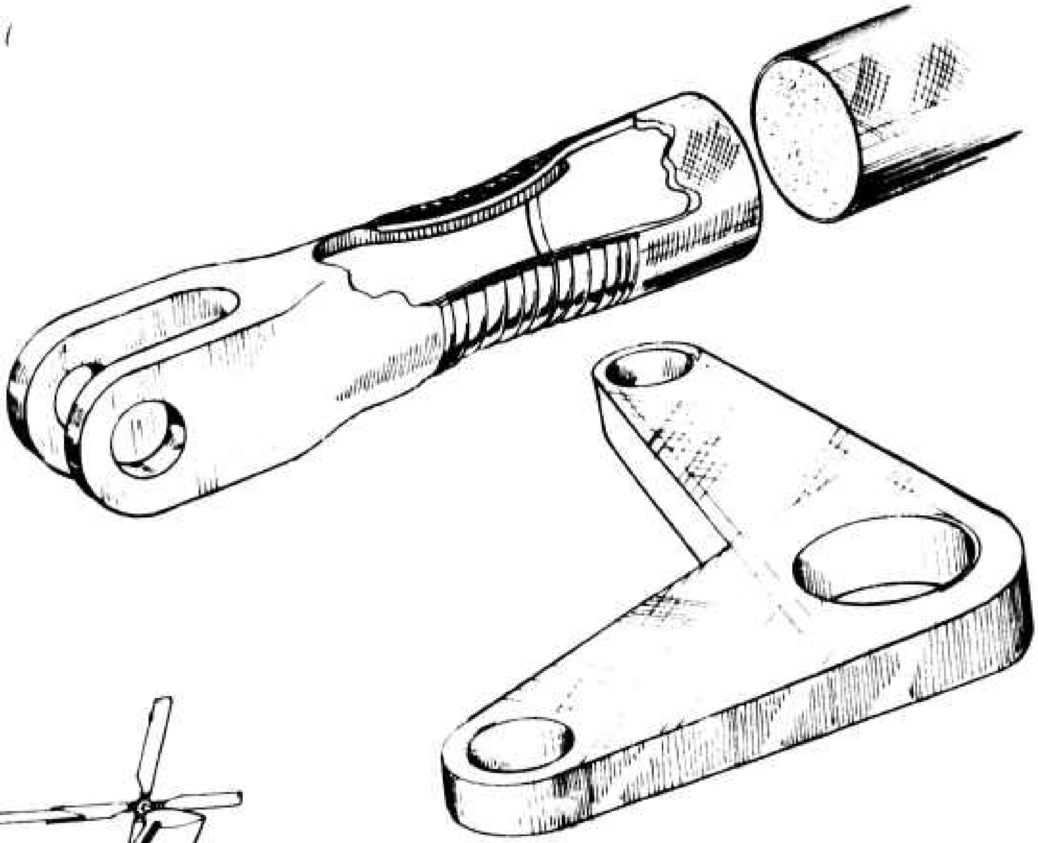
BASELINE
ROTOR HEAD CONTROLS
WT - 101 LB
COST - $6,224

BASELINE
CONTROL RODS, BELL CRANKS, ETC.
WT - 130 LB
COST - $15,210



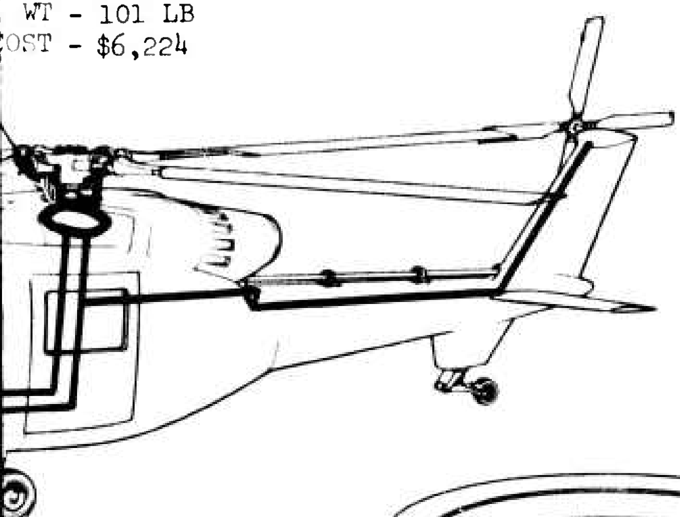
B-10 FILAMENT-WOUND COMPOSITE
SWASH PLATE
WT - 79 LB
COST - $4,740

FIGURE 12. ADVANCED CONTROL SYSTEM CONCEPTS.



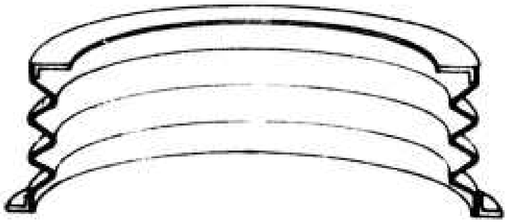
B-13 COMPOSITE FOAM STABILIZED CONTROL ROD S AND BELLCRANKS
WT - 123 LB
COST - $16,000

BASELINE
- ROTOR HEAD CONTROLS
WT - 101 LB
OST - $6,224



LL CRANKS, ETC.
LB
,210

B-12 ELASTOMERIC/SPRING COIL SCISSORS
WT - 10 LB
COST - $1300



B-11 CORRUGATED DIAPHRAM SCISSORS
WT - 9 LB
COST - $1200

TABLE 16. - ADVANCED CONTROL SYSTEM CONCEPT, DATA SHEET

DESCRIPTION/CONCEPT	CRITERIA	PRIMARY						SECONDARY				REMARKS
		WT, LB	COST,$	Δ$/ΔLB (RATING)	FAIL SAFETY	SAFETY	OVERALL RATING	DETECT	CRASH WORTH	VUL.	R&M	
ROTATING & STATIONARY SWASH PLATE		89	4784									
Conventional - aluminum forgings and assembly, spherical bearing.	Designed to provide cyclic & collective control to rotor blades. Designed to carry servo and control rod loads.											Fabricated by machining aluminum forgings.
ADVANCED CONCEPT B-9, COMPOSITE SWASH PLATE		85	4760	0	6	6	3	5	5	6	5	
Graphite fiberglass/epoxy, honeycomb sandwich construction.												Filament-wound graphite/epoxy fiberglass rings. Graphite/epoxy cover skins.
ADVANCED CONCEPT B-10, COMPOSITE TORQUE TUBE SWASH PLATE		79	4740	5.3	6	6	5.7	5	5	6	5	
Filament-wound composite around molded fiberglass "X" section.												Filament-wound internal members, outer wrap of graphite/epoxy skins.
ROTATING AND STATIONARY SCISSORS		12	1440									
Conventional - link type metal construction.	Stationary scissors designed to prevent rotating but to allow azimuthal positioning of stationary swash plate.											Machined steel & titanium forgings. Concentrated load at scissors.
ADVANCED CONCEPT B-11		9	1200	10	5	5	7.5	5	5	6	4	
Corrugated steel diaphragm (spring action).	Rotating scissors designed to drive and allow azimuthal positioning of rotating swash plate.											One-piece bellows-type steel cylinder distributes load uniformly.

TABLE 16. (CONCLUDED)

		PRIMARY						SECONDARY				
DESCRIPTION/CONCEPT	CRITERIA	WT, LB	COST,$	Δ$/ΔLB (RATING)	FAIL SAFETY	SAFETY	OVERALL RATING	DETECT	CRASH WORTH	VUL.	R&M	REMARKS
ADVANCED CONCEPT B-12		10	1300	10	5	5	7.5	5	5	7	4	
Elastomeric spring coil.												Matched metal mold process. Distributes load uniformly.
CONTROL RODS, BELL CRANKS, & SUPPORTS		130	15210									
Conventional - 2024T3 tubing for rods, forged 7075-T73 for bell cranks.												Fabricated by machining tubes & forgings.
ADVANCED CONCEPT B-13 COMPOSITE FOAM STABILIZED CONTROL RODS AND BELL CRANKS		123	16000	4	6	5	2.8	5	5	7	6	
Graphite/epoxy 0° with ± 45° for ballistic damage control. Lightweight polyurethane foam cure for control rods. Graphite/epoxy/Kevlar/epoxy bell cranks.												Automated filament-wound graphite/epoxy lay-ups for rods, tape application for bell cranks.

Transmission System

Figure 13 shows the advanced concepts for the main gearboxes, gearing, and tail rotor drive shafts of the transmission system.

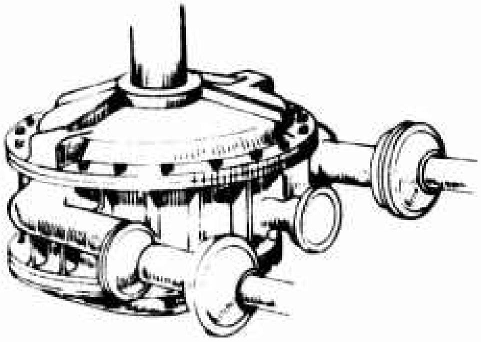
The baseline main gearbox employs machined magnesium castings reinforced by bearing linings. The composite gearbox, concept C-1, uses Kevlar as the surface material oriented ± 45 degrees for carrying shear loads. Graphite/epoxy is used in ribs to carry the axial loads arising from thrust and bending loads. Graphite/epoxy is also used in rings to accept the bearing liners that provide local reinforcement. The result is a very low weight gearbox compared with the conventional magnesium box. Costs are substantially higher, due mainly to the materials used and the added operations of lay-up.

C-2 and C-3 are advanced concepts for the main gearbox. C-2 is a fabricated build-up using stainless steel. C-3 is a stainless steel truss with stainless steel skins. For a gearbox of the design size, analysis indicated that the fabricated type weighs less and costs less than the truss type. The primary reason is that the low load intensity results in minimum gage steel tubes for the truss. As the gearbox increases in size for helicopters larger than the design helicopter, there could be a crossover in weight as the truss efficiency increases.

Weights, costs, and ratings for the main gearbox are summarized in Table 17.

C-4a, b, and c are the advanced concepts for the gearing. C-4a employs conformal gear teeth. C-4b employs high-contact-ratio gears. C-4c uses high-strength gear material. This material can be applied to all gears of conventional and advanced concepts to achieve a percentage reduction in weight and cost. Table 18 summarizes weights, costs, and ratings of the gearing.

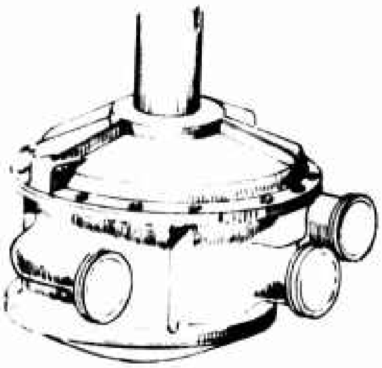
Three advanced concepts for tail rotor drive shafts are shown in Figure 13. All concepts are supercritical drive shafts. C-5 is an 2024-T3 aluminum shaft. C-6 is a graphite/epoxy Tetra-Core shaft. C-7 is a graphite/epoxy tube stabilized with a foam core and having integrally formed flanges. Table 19 summarizes weights, costs, and ratings of the tail drive shafts.



C-1 COMPOSITE
MAIN GEARBOX
WT - 82.6 LB
COST - $23,686

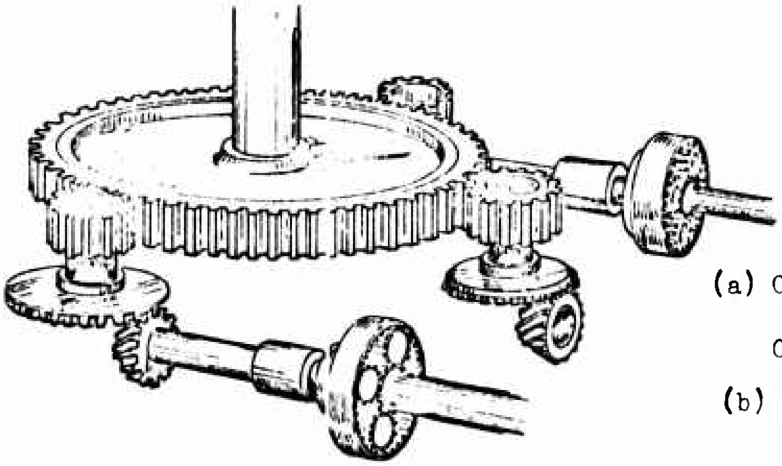
MAIN GEARBOX GEARING
WT - 129.3 LB
COST - $11,250

MAIN GEARBOX HOUSING
WT - 162.2 LB
COST - $8,770



C-2 FABRICATED
(SHEET METAL)
MAIN GEARBOX
WT - 128.2 LB
COST - $7,160

C-3 (TRUSS)
MAIN GEARBOX
WT - 155.5 LB
COST - $7,880



C-4 SIMPLIFIED BULL GEARING SYSTEM
(WITH VARIATION IN GEAR TOOTH FORMS)

(a) CONFORMAL GEAR TEETH
WT - 74.8 LB
COST - $10,701

(b) HIGH CONTACT RATIO GI
(2ND STAGE CONVENTIO
WT - 89.7 LB
COST - $7.802

(c) HIGH STRENGTH
WT - 107.9 LB
COST - $9,387

FIGURE 13. ADVANCED TRANSMISSION CONCEPTS.

(

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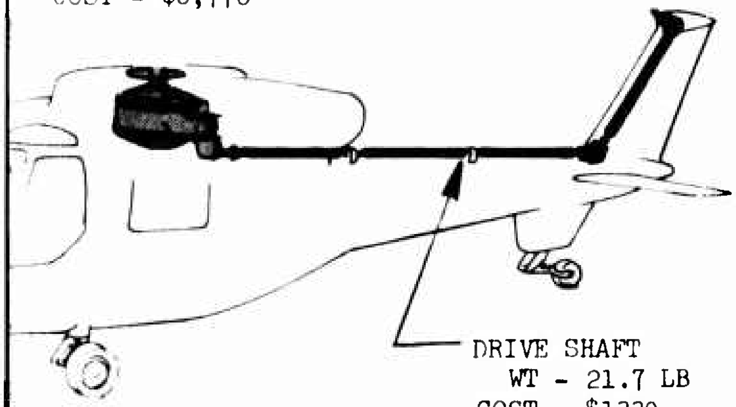
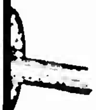
MAIN GEARBOX GEARING
WT - 129.3 LB
COST - $11,250

MAIN GEARBOX HOUSING
WT - 162.2 LB
COST - $8,770



DRIVE SHAFT
WT - 21.7 LB
COST - $1330



(a) CONFORMAL GEAR TEETH
WT - 74.8 LB
COST - $10,701

(b) HIGH CONTACT RATIO GEAR TEETH
(2ND STAGE CONVENTIONAL)
WT - 89.7 LB
COST - $7.802

(c) HIGH STRENGTH
WT - 107.9 LB
COST - $9,387

C-5 SUPERCRITICAL
ALUMINUM DRIVE SHAFT
WT - 17.7 LB
COST - $1080

C-6 SUPERCRITICAL
TETRA-CORE DRIVE SHAFT
WT - 14.2 LB
COST - $1,515

C-7 SUPERCRITICAL
COMPOSITE DRIVE SHAFT
WT - 10.9 LB
COST - $985

TABLE 17. ADVANCED TRANSMISSION CONCEPTS - MAIN GEARBOX HOUSING, DATA SHEET

		PRIMARY						SECONDARY				
DESCRIPTION/CONCEPT	CRITERIA	WT, LB	COST,$	Δ$/ΔLB RATING	FAIL SAFETY	SAFETY	OVERALL RATING	DETECT.	CRASH WORTH	VUL.	R&M	REMARKS
	Main Gearbox - react main rotor lift & thrust											
<u>Main Gearbox Housing</u>												
<u>Conventional</u>												
<u>Center Housing</u> - Magnesium casting machined to interface with upper, lower, & input housings, & to accept bearing liners.		72	3890									
<u>Upper Housing</u> - Magnesium casting machined to interface with center housing & to accept bearing liners.		32.5	1780									
<u>Sump</u> - Magnesium casting machined to interface with lower housing and to support oil pump.		22	1190									
<u>Input Housings (2)</u> - Magnesium castings machined to interface with center housing & to accept bearing liners.		27.5	1480									
<u>Tail Takeoff Housing</u> - Magnesium casting.		8.2	450									
	TOTAL	162.2	8770									

TABLE 17. (CONTINUED)

DESCRIPTION/CONCEPT	CRITERIA	PRIMARY WT, LB	 COST,$	 Δ$/ΔLB RATING	 FAIL SAFETY	 SAFETY	 OVERALL RATING	SECONDARY DETECT.	 CRASH WORTH	 VUL.	 R&M	REMARKS
C-1 Advanced Composite Gearbox												
Center Housing - 8-Ply (.080 thick) Kevlar 49 epoxy oriented $\pm 45^{\circ}$. 26 graphite/epoxy ribs @ .75 x .75 cross section oriented in 0° direction. Graphite/epoxy rings .50 to .75 thick to accept bearing liners.		40.7	12546									Hand lay-up of Kevlar 49 epoxy, graphite/epoxy ribs & support rings.
Upper Housing - 8-Ply (.080 thick) Kevlar 49 epoxy oriented $\pm 45^{\circ}$. Four graphite/epoxy ribs oriented in 0° direction. Graphite/epoxy rings to accept bearing liners.		15.8	4300									
Sump - 8-Ply (.080 thick) Kevlar 49 epoxy oriented $\pm 45^{\circ}$. Graphite/epoxy ribs oriented in 0° direction.		8.3	2150									
Input Housings (2) - 8-Ply (.080 thick) Kevlar 49 epoxy oriented $\pm 45^{\circ}$. Four graphite/epoxy ribs oriented in 0° direction.		14.3	3650									
Tail Takeoff Housing - 8-Ply (.080 thick) Kevlar 49 epoxy oriented $\pm 45^{\circ}$. Four graphite/epoxy ribs oriented 0° direction.		3.5	1040									
	TOTAL	82.6	23686	0	7	6	3.3	4	4	6	6	

TABLE 17. (CONTINUED)

		PRIMARY						SECONDARY				
DESCRIPTION/CONCEPT	CRITERIA	WT, LB	COST,$	Δ$/ΔLB RATING	FAIL SAFETY	SAFETY	OVERALL RATING	DETECT.	CRASH WORTH	VUL.	R&M	REMARKS
C-2 Advanced Fabricated Gearbox												
Fabricated Center Housing - Stainless steel structure .045 thick; stainless steel sheet welded to structure. Structure machined to interface with upper, lower, & input housings, & to accept bearing liners.		50.1	3050									
Upper Housing - Stainless steel structure .045 thick; stainless steel sheet welded to above structure. Machined to interface with center housing & to accept bearing liners.		22.2	1370									
Sump - Stainless steel structure .045 thick; stainless steel sheet welded to structure. Structure machined to interface with lower housing & to support oil pump.		17.9	960									
Input Housings (2) - Stainless steel structure .060 thick; stainless steel sheet welded to structure.		29.4	1390									
Tail Takeoff Housing - Similar to input housing.		8.6	390									
	TOTAL	128.2	7160	10	6	6	7	5	7	7	6	

TABLE 17. (CONCLUDED)

		PRIMARY						SECONDARY				
DESCRIPTION/CONCEPT	CRITERIA	WT, LB	COST,$	Δ$/ΔLB RATING	FAIL SAFETY	SAFETY	OVERALL RATING	DETECT.	CRASH WORTH	VUL.	R&M	REMARKS
<u>C-3 Advanced Truss Gearbox</u>												
<u>Center Housing</u> - Stainless steel structure consisting of .031 skin welded to .625 dia x .062 thick tube. Structure machined to interface with upper, lower & input housings & to accept bearing liners.		59.8	3330									
<u>Upper Housing</u> - Stainless steel structure consisting of .035 skin, 1.0 dia x .062 thick together machined to interface with center housing & to accept bearing liners.		23.3	1460									
<u>Sump</u> - Stainless steel structure consisting of .035 skin, .625 dia x .062 tube, & structure machined to interface with lower housing & to support oil pump.		26.6	1070									
<u>Input Housings (2)</u> - Stainless steel structure consisting of .031 skin, .50 dia x .06 thick tube, .062 thick gussets welded together		36.5	1580									
<u>Tail Takeoff Housing</u> - Similar to input housing.		9.3	440									
	TOTAL	155.5	7880	10	6	6	7	5	7	7	6	

TABLE 18. ADVANCED TRANSMISSION CONCEPTS - GEARING, DATA SHEET

		PRIMARY						SECONDARY				
DESCRIPTION/CONCEPT	CRITERIA	WT, LB	COST,$	Δ$/ΔLB RATING	FAIL SAFETY	SAFETY	OVERALL RATING	DETECT.	CRASH WORTH	VUL.	R&M	REMARKS
<u>CONVENTIONAL TOOTH FORMS OUTPUT GEARS</u> - Involute spur gear and pinion, $22\frac{1}{2}^\circ$ pressure angle, 4.4 in. face width, reduction ratio 6.58. Pinion Gear Pitch Dia. 4.00 13.12 RPM 2300 350 Face Width 4.44 4.44	Transmit torque from input bevel gears to main rotor shaft	85.8	7465									Weight of spur gear rims only - one gear and two pinions
<u>INPUT BEVEL GEARS</u> - Spiral bevel gear teeth reduction ratio 2.36 Pinion Gear Pitch Dia. 4.40 10.40 RPM 5420 2300	Transmit torque from input planetaries to output gears	36.0	3130									Weight of bevel gear teeth only - two gear sets
<u>ADVANCED TOOTH FORMS OUTPUT GEARS</u> C-4	Transmit torque from input bevel gears to main rotor shaft											Weight of spur gear rims only - one gear and two pinions
<u>CONFORMAL GEAR TEETH</u> C-4a 30° pressure angle, 15° helix angle, 2.35 in. face width, reduction ratio 9.11.												
(conventional mat'l)		48.2	8387	5.7	5	5	5.3	5	5	6	5	
(high strength mat'l)		39.6	6950	5.7	5	5	5.3	5	5	6	5	

TABLE 18. (CONTINUED)

		PRIMARY						SECONDARY				
DESCRIPTION/CONCEPT	CRITERIA	WT, LB	COST,$	Δ$/ΔLB RATING	FAIL SAFETY	SAFETY	OVERALL RATING	DETECT.	CRASH WORTH	VUL.	R&M	REMARKS
Pinion Gear Pitch Dia 1.50 13.66 RPM 3180 350 Face Width 2.35 2.35 Increased reduction ratio from 6.58 for involute gear teeth to 9.11 for conformal gear teeth allows for decreased reduction ratio in bevel gear set from 2.36 to 1.70												
INPUT BEVEL GEARS C-4a Spiral bevel gear teeth - reduction ratio - 1.70 Pinion Gear Pitch Dia 4.40 7.50 RPM 5420 3180	Transmit torque from input planetaries to output gears											Weight of bevel gear teeth only - two gear sets
(conventional mat'l)		26.6	2314	10	5	5	7.5	5	5	6	5	
(high strengtn mat'l)		22.0	1926	10	5	5	7.5	5	5	6	5	
OUTPUT GEARS, HIGH-CONTACT-RATIO GEAR TEETH C-4b 20° pressure angle 2.5 in. face width reduction ratio - 6.58 Pinion Gear Pitch Dia 4.00 13.12 RPM 2300 350	Transmit torque from input bevel gears to main rotor shaft	53.7	4672	10	5	5	7.5	5	5	6	5	Weight of spur gear rims only - one gear & two pinions

TABLE 18. (CONCLUDED)

		PRIMARY						SECONDARY				
DESCRIPTION/CONCEPT	CRITERIA	WT, LB	COST,$	Δ$/ΔLB RATING	FAIL SAFETY	SAFETY	OVERALL RATING	DETECT.	CRASH WORTH	VUL.	R&M	REMARKS
HIGH STRENGTH GEAR MATERIALS				10	5	5	7.5	5	5	5	5	Weight of spur gear rims only
Conventional												Based on available data, bending allowables of high-strength materials are 20% higher than conventional materials. This results in 17% reduction in face width of the gears in the system.
Output spur gear		67.8	5899									
output spur pinions(2)		18.0	1566									
bevel gears (2)		25.3	2201									
bevel pinions (2)		10.7	931									
input planetaries (2)		7.5	653									
		129.3	11250									
High Strength C-4c												
Output spur gear		56.6	4924									High-strength gear material will reduce weight further when applied to advanced tooth form gears outlined above.
output spur pinions(2)		15.0	1305									
bevel gear (2)		21.1	1836									
bevel pinion (2)		8.9	774									
input planetaries (2)		6.3	548									
		107.9	9387									

TABLE 19. ADVANCED TRANSMISSION CONCEPTS - TAIL DRIVE SHAFTS, DATA SHEET

		PRIMARY						SECONDARY				
DESCRIPTION/ CONCEPT	CRITERIA	WT, LB	COST, $	Δ$/ΔLB RATING	FAIL SAFETY	SAFETY	OVERALL RATING	DETECT	CRASH WORTH	VUL	R&M	REMARKS
Conventional Tail Drive Shafts, Aluminum Drive Shaft 2024 Aluminum, 3.00 dia, .049 in. wall thickness, three supports required. Designed to operate in subcritical speed range.		21.7	1330									Drive shaft weights include weights of bearings & supports. Conventional drive shaft operates in subcritical speed range. Design critical speed is 125% of operating speed.
Proposed Aluminum Drive Shaft Designed to operate above 1st critical speed of system. .049 in. wall thickness, two supports required.	C-5	17.7	1080	10	5	5	7.5	5	5	5	5	Supercritical shaft requires 33% fewer supports than subcritical shaft. Design critical speed is 80% of operating speed.
Tetra-Core Drive Shaft 3.00 in. shaft dia, graphite/epoxy filaments spirally wound & oriented to form tetrahedrons ±45°, filaments to take shear. 0° graphite epoxy filaments for bending stiffness. Two supports required. Shaft designed to operate above 1st critical speed.	C-6	14.2	1515	8	10	8	7.5	5	5	7	5	Fabricated by numerically controlled machinery.
Foam-Filled Composite Drive Shaft 3.00 in. shaft dia, graphite/epoxy laminate oriented ±45° to take shear & 0° for bending stiffness. Shaft filled with 3.0 LB/FT³ polyurethane foam to resist buckling failure. Integrally formed flanges. Shaft designed to operate above 1st critical speed.	C-7	10.9	985	10	5	5	7.5	5	5	6	5	Fabricated by numerically controlled tape lay-up. Foam injected automatically.

Propulsion System

Two advance concepts, D-1 and D-2, for the propulsion system are shown in Figure 14. D-1 is an infrared (IR) suppressor integrated with the airframe structure. The exhaust is discharged in a thin film, and rotor and free-stream airflow dilute the heat flux. The slotted geometry shown reduces the visible exhaust areas. The structure for IR suppression is of stainless steel and requires a fiberglass fairing for streamlining. Since no engine power is used, an additional benefit is an estimated 90 hp reduction in power required.

D-2 is an integrated fuel pump rod filter system to reduce cost and weight.

A summary of weights, costs, and ratings is contained in Table 20.

TABLE 20. ADVANCED PROPULSION SYSTEM CONCEPTS, DATA SHEET

		PRIMARY						SECONDARY				
DESCRIPTION/ CONCEPT	CRITERIA	WT, LB	COST,$	Δ$/ΔLB (RATING)	FAIL SAFETY	SAFETY	OVERALL RATING	DETECT.	CRASH WORTH	VUL.	R&M	REMARKS
<u>IR SUPPRESION</u>												
Conventional - Blower & ejector. Pumped cooling air dilutes plume & cools visible areas. Center plug blocks line of sight into turbine.	Hot metal & plume suppression equivalent to requirements for IR detection.	297	46,956									Requires 90 hp for operation.
<u>ADVANCED CONCEPT D-1</u>												
Exhaust is discharged in a thin film that is diluted externally by rotor downwash & free-stream air. Exhaust stream pumps ejector for film/ convection cooling of visible exhaust areas. Slot geometry blocks internal views.		151	11,480	10	5	6	7.8	6	6	7	5	No engine power required for operation. May increase drag and complicates airframe aft end structure. Preliminary studies indicate improvment against detection
<u>FUEL SYSTEM COMPONENTS</u>												
Conventional - Suction engine fuel feed systems require boost pump assistance at extreme altitude & temperatures. Boost pumps and fuel filters must have bypass provisions.	Simplication of system.	11.5	1,740									
<u>ADVANCED CONCEPT D-2</u>												
Integration of functions into a combined fuel pump/filter system.		8.3	1,350	10	6	6	8	5	7	5	5	

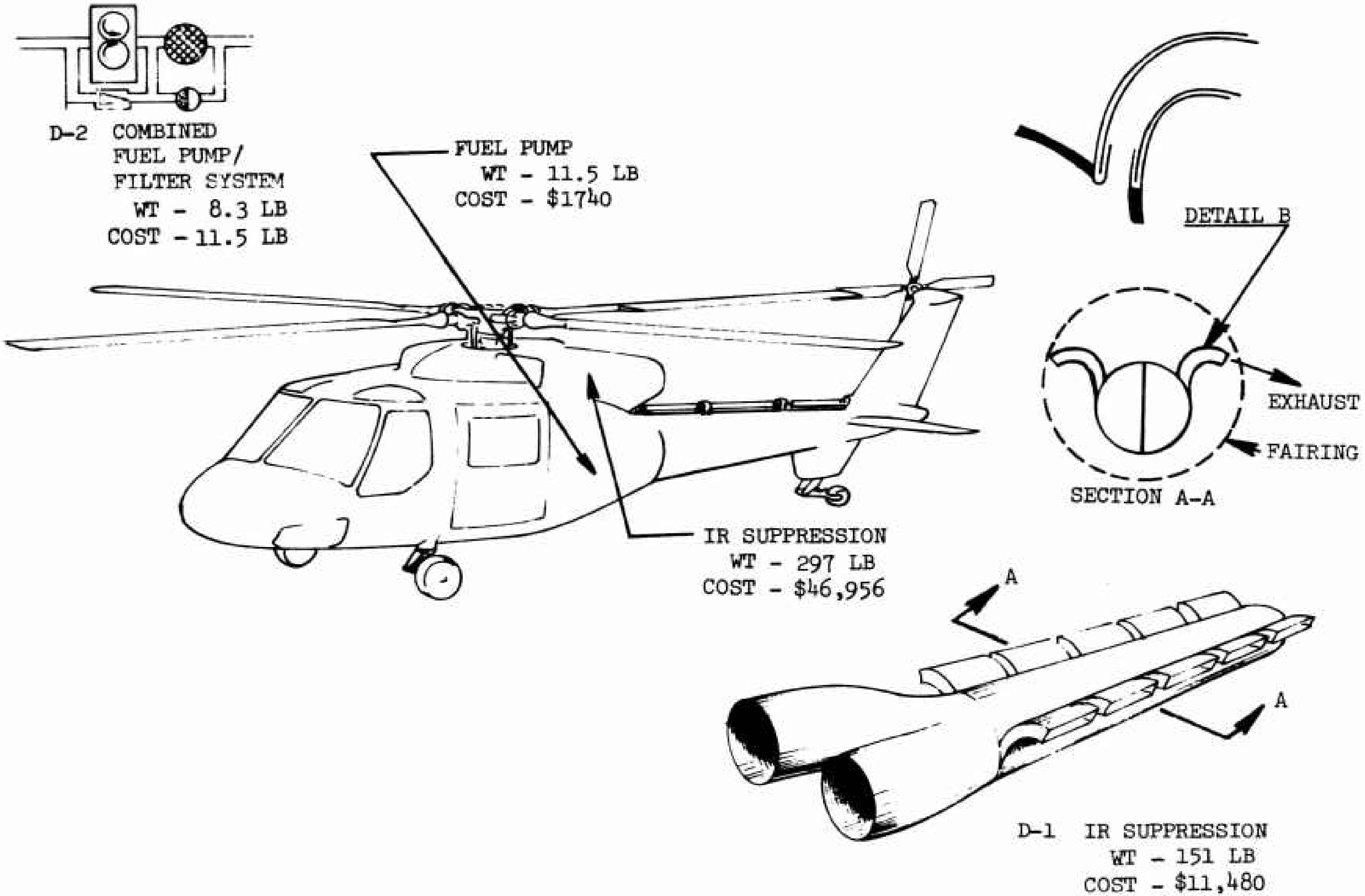


FIGURE 14. ADVANCED PROPULSION CONCEPTS.

Selection of Advanced Concepts

The advanced concepts presented in Figures 6 through 14 and the data tabulated in Tables 9 through 20 were evaluated for assessment of reduction in total weight empty (payload increase) at the same aircraft gross weight.

Three groupings of advanced concepts were considered: a lower cost group, a lower weight group, and a recommended selection for use in the final aircraft configuration. In these evaluations, the IR suppression concept D-1 was omitted. Although the concept shows promise in reducing weight and cost, it was rejected in this study because of anticipated difficulties in integrating other subsystems, such as controls, tail rotor drive, and tail wheel. Further detailed investigation of concept D-1 is recommended for future Army studies.

Initial comparisons of the advanced concepts with the baseline aircraft considered only the affected components of subsystem weight, and costs. The effect on the total system structure, weight, and cost was then assessed.

Detail weight and cost analysis substantiation is contained in Appendix B for affected structure of the recommended advanced concepts.

Lower Cost Grouping

The lower cost group emphasizes concepts that meet the rating requirements, where cost saving dominates.

A number of the airframe concepts in this group employs spot-welded bonded construction, taking advantage of the moderate weight saving and significant cost reduction. In some areas, however, composites show both a weight and cost saving and are included in this grouping. The conventional landing gear is used in this group, since it is the lowest cost structure at this time without a weight penalty.

Composites dominate the rotor group. The materials lend themselves to producing high aerodynamic performance at reduced cost. The cost saving is primarily due to the reduction in labor to produce the complex shapes that are excessive to achieve in conventional materials, such as titanium.

Only limited opportunities are apparent within the drive system for the lower cost group. The transmission appears to be a fruitful area for weight and cost reduction through the use of a fabricated gearbox, conformal gearing, and higher strength materials. The only propulsion system concept is the combined fuel pump/filler (concept D-2).

Table 21 summarizes the lower cost group of advanced concepts. Comparison is made with the affected baseline structural weights and costs.

TABLE 21. ADVANCED CONCEPTS, LOWER COST GROUPING

STRUCTURE	BASELINE DESIGN (REF.)		ADVANCED LOWER COST GROUP		
	W* LB	$*	CONCEPTS	ΔW	Δ$
Airframe, Including Pylon and Stabilizer	1132	117415	A-4, A-5C, A-9, A-10, A-11C A-14, A-15, A-19, A-20	-212	-23988
Landing Gear	219	8200	Use Conventional	0	0
Main Rotor (Blades & Hub)	820	74600	B-3 (a,2) and B-4	+4	-22216
Tail Rotor	47	5720	B-8	-3	-365
Controls	231	21434	B-11	-3	-240
Transmission	313.2	21350	C-2, C-4(b), C-4(c), C-7	-86.2	-5269
Fuel System	11.5	1740	D-2	-3.2	-390
Totals	2773.7	250069		-303.4	-52468

*Affected Weight & Costs Only

TABLE 22. ADVANCED CONCEPTS, LOWER WEIGHT GROUPING

STRUCTURE	BASELINE DESIGN (REF.)		ADVANCED LOWER WEIGHT GROUPING		
	W* LB	$*	CONCEPTS	ΔW	Δ$
Airframe, Including Pylon & Stabilizer	1132	117415	A-1, A-3, A-5B, A-6, A-8, A-10, A-11B, A-13, A-16, A-18, A-20	-412	-10143
Landing Gear	219	8200	A-21	-56	+2600
Main Rotor (Blades & Hub)	820	74210	B-3 (b,4),B-6	-102	-23017
Tail Rotor	47	5720	B-8	-3	-365
Controls	231	21434	B-10, B-11, B-13	-20	+506
Transmission	313.2	21350	C-1, C-4a, C-4C, C-7	-151.4	+12745
Fuel System	11.5	1740	D-2	-3.2	-390
Totals	2773.7	250069		-746.6	-18064

*Affected Weight & Cost Only

Lower Weight Grouping

The payoff in using many of the advanced concepts stems from the great potential for weight reduction, provided that the overall rating meets the criteria established for the baseline aircraft. Thus, whereas manufacturing cost per unit weight may increase significantly, the weight reduction for that component yields an overall reduction in cost. The effects of weight savings on reducing total aircraft cost are further emphasized when the design is resized to the same payload requirement.

Table 22 summarizes the advanced concepts for the lower weight group and their relationship to the baseline design.

The airframe concepts selected are those for built-up Kevlar and graphite/epoxy construction. The composite landing gear shows an appreciable weight saving, but at increased cost. The pultruded graphite/epoxy blade spar with a composite hub for an articulated (hinged) system was selected. The same tail rotor concept previously selected is used to realize its weight and cost benefits.

The transmission system now includes a composite gearbox, conformal gearing, high-strength materials for gears, and composite tail rotor shaft. The propulsion system includes only the fuel system, since the IR suppressor was dropped from consideration at this time.

The overall effect is a significant weight saving, but somewhat reduced cost saving. The important factor to be noted is that an overall weight and cost saving is projected.

Detailed Summary

(Recommended Selected Advanced Concepts)

The final recommendations for selection of the advanced concepts were screened between the two groups of Tables 21 and 22 and a further review of the weights, costs, and ratings of Tables 9 through 22.

Selection of advanced concepts also considered an aircraft design with the same payload but lighter gross weight. Considering that 1 pound saved in the study may have a value of 2 in a final design, there should be a cutoff factor in comparing the advanced concepts. A value of Δ \$100/Δ lb is used for the cutoff in final selection and recommendations.

Table 23 summarizes the recommended selected advanced concepts to be integrated into a final advanced medium-size utility helicopter. The results show an appreciable weight saving and a moderate cost reduction. Table 24 summarizes the effects on weight, cost, and payload. The most dramatic effect is the 70% increase in payload.

The selected advanced concepts for the airframe and landing gear are shown in Figure 15.

After calculation of manufacturing costs per unit weight for the advanced medium-size utility designs, and adjustment of weight trending equation coefficients to reflect the weight savings discussed above, HDM was exercised to resize each of the three advanced solutions to the same payload requirement as the baseline. The results are summarized in Table 25. The recommended design, previously judged to represent concepts providing weight savings at acceptable costs per unit weight, shows a 14% reduction in flyaway cost from the baseline.

Detailed "M.U.T." weight comparisons and summary weight statements are provided in Tables 26 through 30. Life cycle cost summaries are presented in Tables 31 through 33.

TABLE 23. RECOMMENDED SELECTED ADVANCED CONCEPTS SUMMARY

STRUCUTRE	BASELINE DESIGN (REF)		RECOMMENDED SELECTED CONCEPTS			REMARKS
	W*	$*	CONCEPT	ΔW LB	Δ$	
Airframe	1132	117415	A-1, A-3, A5B, A-6 A-8, A-10, A-11B, A-13, A-16, A-18, A-20	-412	-10143	Lower Weight Group selected; Δ$/ΔLB is $65/lb between groupings.
Landing Gear	219	8200	A-21	-55	+2600	Low Weight Group selected, since difference is $36/lb.
Main Rotor (Blades & Hub)	820	74600	B-3 (b,4), B-6	-102	-23017	Low Weight Group difference is $15/lb.
Tail Rotor	47	5720	B-8	-3	-365	Low Weight Group selected. Cost is $45/lb.
Controls	231	21434	B-10, B-11	-13	-200	Saves weight and cost.
Transmission	313.2	21350	C-2, C-4(b), C-4(c), C-7	-86.2	-5269	Composite gearbox dropped (C-1) due to $126 delta. Lower cost gearing (C-4b) selected due to $250 delta.
Fuel System	11.5	1740	D-2	-3.2	-390	Saves cost and weight.
Totals	2773.7	250069		-674.4	-36784	

*Affected Weights & Costs Only

TABLE 24. COMPARISON OF BASELINE AND ADVANCED AIRCRAFT WEIGHT/COSTS FOR SAME GROSS WEIGHT

CONFIGURATION	GROSS WEIGHT (LB)	WEIGHT(1) EMPTY (LB)	COST (2) ($)	PAYLOAD (LB)
BASELINE DESIGN	9471	5670	529,534	960
LOWER COST GROUP	9471	5367	477,066	1263 (+32%)
LOWER WEIGHT GROUP	9471	4923	511,470	1707 (+78%)
RECOMMENDED WT/COST GROUP	9471	4996	492,750	1634 (+70%)

NOTE (1) WEIGHT EMPTY LESS ENGINES, AVIONICS AND CONTINGENCY

(2) COST OF W.E. IN 1974 DOLLARS, 500 A/C PRODUCTION

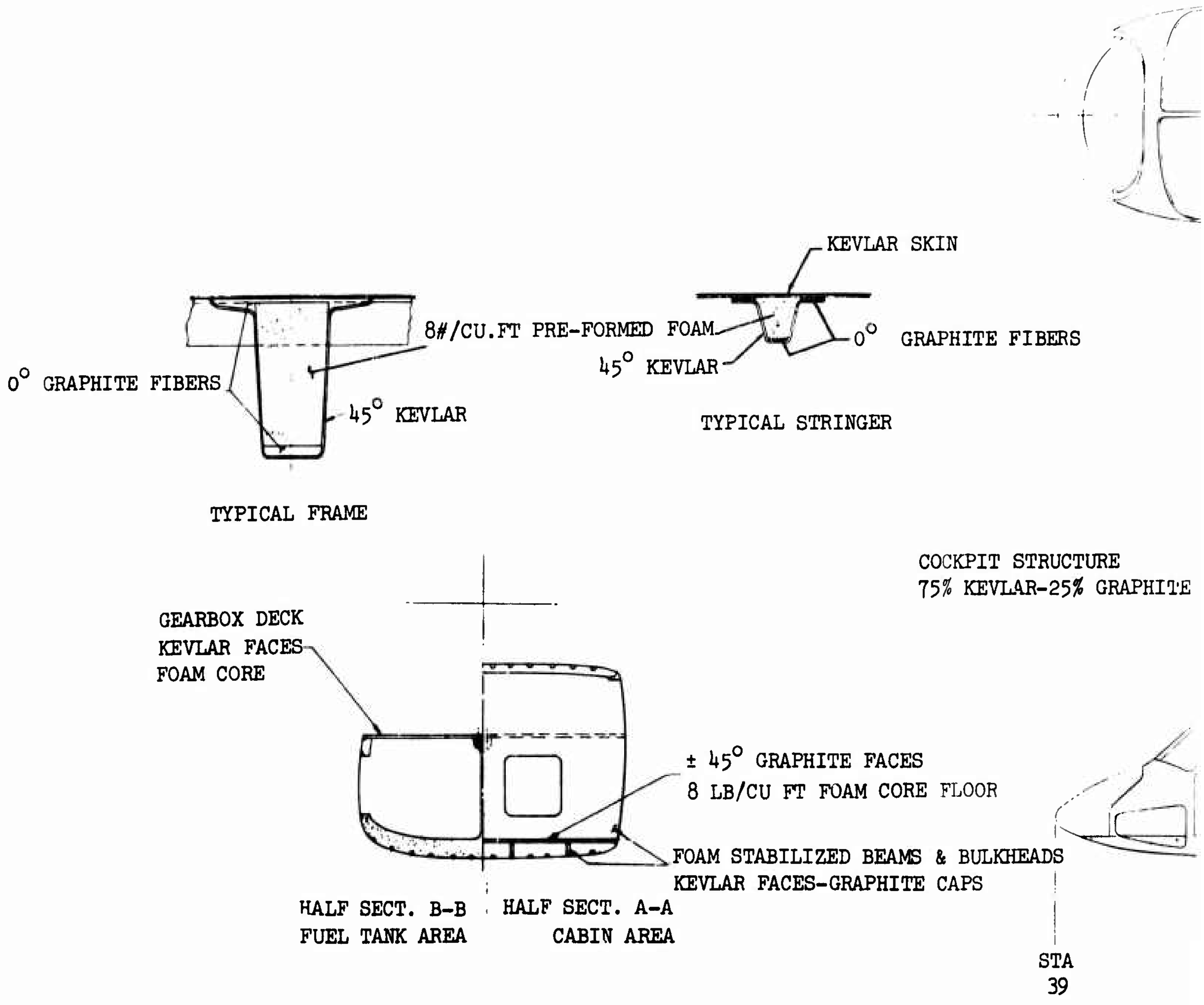


FIGURE 15. M.U.T. COMPOSITE STRUCTURE.

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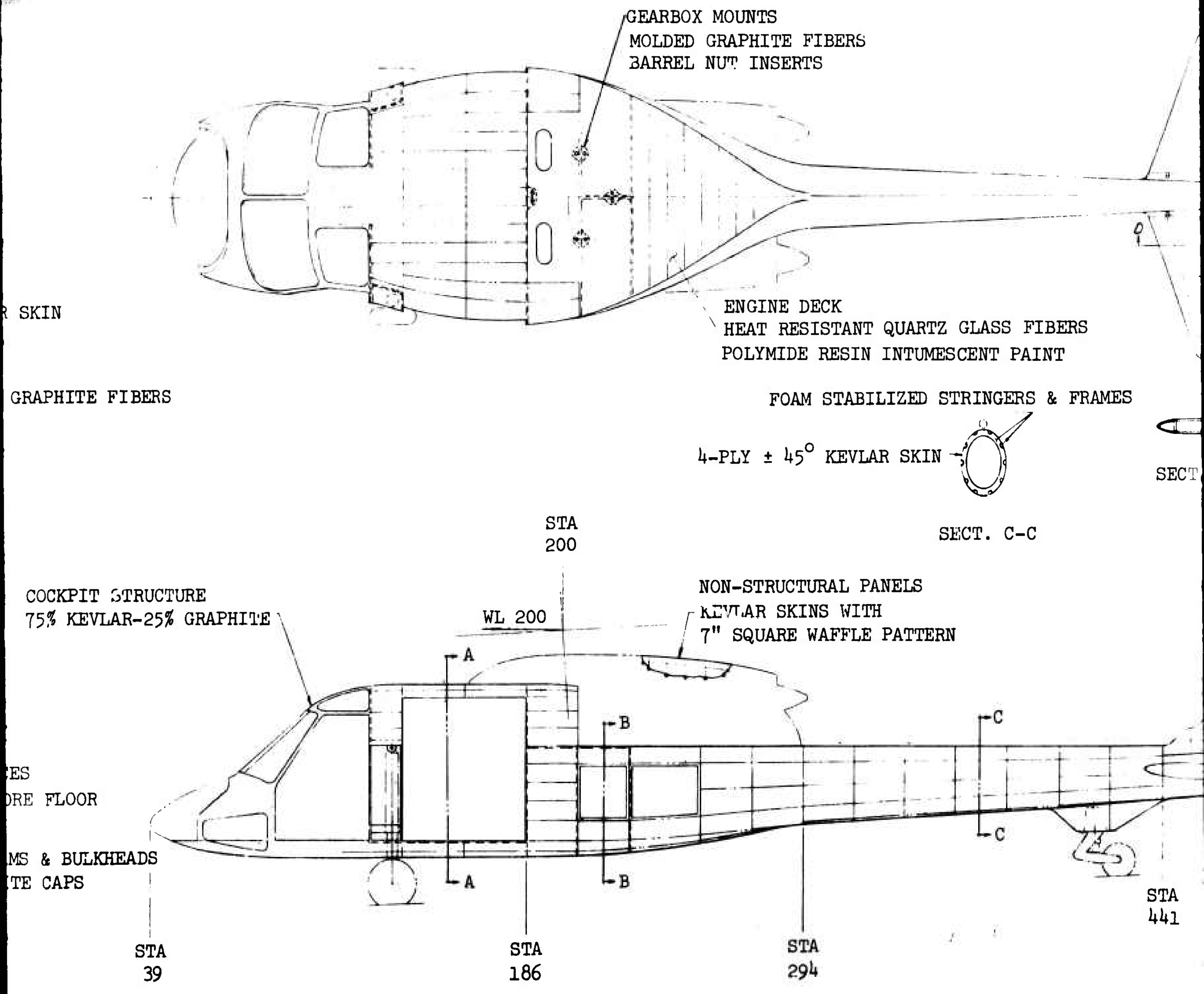

GEARBOX MOUNTS
MOLDED GRAPHITE FIBERS
BARREL NUT INSERTS
R SKIN
ENGINE DECK
HEAT RESISTANT QUARTZ GLASS FIBERS
POLYMIDE RESIN INTUMESCENT PAINT
GRAPHITE FIBERS
FOAM STABILIZED STRINGERS & FRAMES
4-PLY ± 45° KEVLAR SKIN
SECT
SECT. C-C
STA 200
COCKPIT STRUCTURE
75% KEVLAR-25% GRAPHITE
WL 200
NON-STRUCTURAL PANELS
KEVLAR SKINS WITH
7" SQUARE WAFFLE PATTERN
A
B
C
ES
ORE FLOOR
MS & BULKHEADS
TE CAPS
A
B
C
STA 441
STA 39
STA 186
STA 294

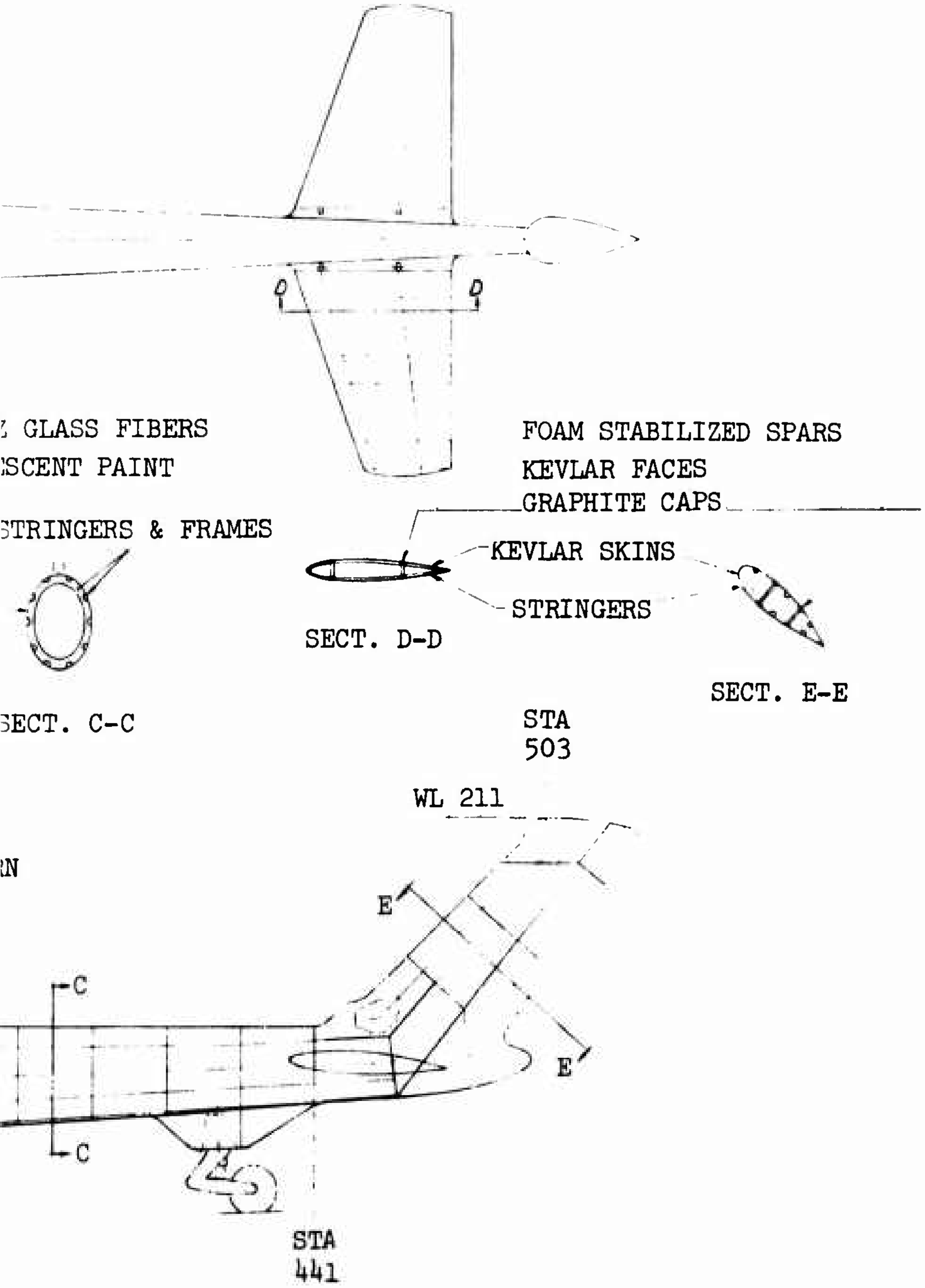
D
D
GLASS FIBERS
SCENT PAINT
STRINGERS & FRAMES
SECT. C-C
FOAM STABILIZED SPARS
KEVLAR FACES
GRAPHITE CAPS
KEVLAR SKINS
STRINGERS
SECT. D-D
SECT. E-E
STA
503
WL 211
N
E
E
C
C
STA
441

TABLE 25. COMPARISON OF BASELINE AND ADVANCED AIRCRAFT WEIGHT/COSTS FOR SAME PAYLOAD

CONFIGURATION	GROSS WEIGHT (lb)	WEIGHT EMPTY (lb)(1)	COST ($)(2)	PAYLOAD (lb)
Baseline Design	9471	5670	529,534	960
Lower Cost Group	8812	5104	467,391	960
Lower Weight Group	8081	4476	470,553	960
Recommended Weight Cost Group	8163	4549	457,023(3)	960

NOTE: (1) Weight empty less engines, avionics, and contingency

(2) Cost of W.E. in 1974 Dollars, 500 A/C.

(3) Mean $/lb higher than for Lower Cost Group, but solution Cost lower because of weight savings for same mission requirements

TABLE 26. M.U.T. WEIGHT COMPARISONS

Group	Baseline Design	Advance Design (Same G.W)	Advance Design Same Payload
Main Rotor	820	718	619
Tail Group	152	111	94
Body Group	1055	755	712
Alighting Gear	380	311	276
Flight Controls	638	622	546
Engine Section	100	87	87
Propulsion Group	1907	1781	1575
Instruments	135	135	135
Electrical Group	247	243	243
Avionics	460	457	457
Armament Group	53	51	51
Furnishings	422	421	421
Air Cond. and Anti-Ice	48	48	48
Aux. - Gear	60	56	56
Vibration Suppression	76	76	65
Contingency	66	59	54
Weight Empty	6618	5931	5439
Fixed Useful Load	504	504	504
Payload	960	1611	960
Fuel-Usable	1389	1389	1260
Gross Weight	9471	9471	8163

TABLE 27. M.U.T. DESIGN COMPARISONS.

	Baseline Conventional Design	Advance Design (Same G.W)	Advance Design (Same Payload)
Design Gross Weight, Lb	9471	9471	8163
Payload, Lb	960	1648	960
Weight Empty, Lb	6618	5931	5439
Fuel, Lb	1389	1389	1260
Main Rotor			
Radius, Ft.	20.5	20.5	19.03
Chord, Ft.	1.322	1.322	1.227
No. Blades	4	4	4
Tail Rotor			
Radius, Ft.	4.40	4.40	4.09
Chord, Ft.	.535	.535	.495
No. Blades	4	4	4
Main Gear Box Design, H.P.	1564	1564	1354
Hover Power (SHP.)	1178	1178	1020
Hover & Climb H.P.	1261	1261	1092

TABLE 28. SUMMARY WEIGHT STATEMENT

M.I.T. BASELINE

GROUP	WEIGHT		% GW
MAIN ROTOR GROUP		820.	8.65
WING GROUP		0.	.00
TAIL GROUP		152.	1.60
TAIL ROTOR/FAN	47.		.49
TAIL SURFACES	105.		1.11
BODY GROUP		1055.	11.14
ALIGHTING GEAR		380.	4.01
FLIGHT CONTROLS		638.	6.74
ENGINE SECTION		100.	1.06
PROPULSION GROUP		1907.	20.14
ENGINES	422.		4.46
AIR INDUCTION	40.		.42
EXHAUST SYSTEM	297.		3.13
LUBRICATING SYSTEM	0.		.00
FUEL SYSTEM	269.		2.84
ENGINE CONTROLS	25.		.26
STARTING SYSTEM	19.		.20
AUXILIARY PROPULSION PROPELLERS	0.		.00
DRIVE SYSTEM	835.		8.82
AUXILIARY POWER UNIT		0.	.00
INSTRUMENTS		135.	1.43
HYDRAULICS		0.	.00
ELECTRICAL GROUP		247.	2.61
AVIONICS		460.	4.86
ARMAMENT GROUP		53.	.56
FURNISHINGS		422.	4.46
AIR CONDITIONING AND ANTI-ICE		48.	.51
AUXILIARY GEAR		60.	.63
VIBRATION SUPPRESSION		76.	.80
TECHNOLOGY SAVINGS		0.	.00
CONTINGENCY		66.	.70
WEIGHT EMPTY		6618.	69.88
FIXED USEFUL LOAD		504.	5.32
PILOT	235.		
CO-PILOT	235.		
OIL-ENGINE	14.		
-TRAPPED	6.		
FUEL TRAPPED	14.		
MISSION EQUIPMENT	0.		
OTHER FUL.	0.		
PAYLOAD		960.	10.14
FUEL-USABLE		1389.	14.66
GROSS WEIGHT		9471.	

TABLE 29. SUMMARY WEIGHT STATEMENT

M.U.T. ADVANCED DESIGN (SAME G.W.)

GROUP	WEIGHT		%-GW
MAIN ROTOR GROUP		718.	7.58
WING GROUP		0.	.00
TAIL GROUP		111.	1.17
TAIL ROTOR/FAN	44.		.49
TAIL SURFACES	67.		.70
BODY GROUP		755.	7.97
ALIGHTING GEAR		311.	3.28
FLIGHT CONTROLS		622.	6.57
ENGINE SECTION		87.	.92
PROPULSION GROUP		1781.	18.80
ENGINES	422.		4.46
AIR INDUCTION	40.		.42
EXHAUST SYSTEM	297.		3.13
LUBRICATING SYSTEM	0.		.00
FUEL SYSTEM	243.		2.57
ENGINE CONTROLS	25.		.26
STARTING SYSTEM	17.		.18
AUXILIARY PROPULSION PROPELLERS	0.		.00
DRIVE SYSTEM	736.		7.77
AUXILIARY POWER UNIT		0.	.00
INSTRUMENTS		135.	1.43
HYDRAULICS		0.	.00
ELECTRICAL GROUP		243.	2.57
AVIONICS		457.	4.83
ARMAMENT GROUP		51.	.54
FURNISHINGS		421.	4.45
AIR CONDITIONING AND ANTI-ICE		48.	.51
AUXILIARY GEAR		56.	.59
VIBRATION SUPPRESSION		76.	.80
TECHNOLOGY SAVINGS		0.	.00
CONTINGENCY		59.	.63
WEIGHT EMPTY		5931.	62.62
FIXED USEFUL LOAD		504.	5.32
PILOT	235.		
CO-PILOT	235.		
OIL-ENGINE	14.		
-TRAPPED	6.		
FUEL TRAPPED	14.		
MISSION EQUIPMENT	0.		
OTHER FUL.	0.		
PAYLOAD		1611.	17.40
FUEL-USABLE		1389.	14.66
GROSS WEIGHT		9471.	

TABLE 30. SUMMARY WEIGHT STATEMENT

M.U.T. ADVANCED DESIGN (SAME PAYLOAD)

GROUP	WEIGHT		% GW
MAIN ROTOR GROUP		619.	7.59
WING GROUP		0.	.00
TAIL GROUP		94.	1.15
TAIL ROTOR/FAN	36.		.44
TAIL SURFACES	57.		.70
BODY GROUP		712.	8.72
ALIGHTING GEAR		276.	3.38
FLIGHT CONTROLS		546.	6.69
ENGINE SECTION		87.	1.07
PROPULSION GROUP		1575.	19.29
ENGINES	422.		4.65
AIR INDUCTION	40.		.49
EXHAUST SYSTEM	297.		3.40
LUBRICATING SYSTEM	0.		.00
FUEL SYSTEM	269.		2.71
ENGINE CONTROLS	25.		.31
STARTING SYSTEM	19.		.19
AUXILIARY PROPULSION PROPELLERS	0.		.00
DRIVE SYSTEM	503.		6.16
AUXILIARY POWER UNIT		0.	.00
INSTRUMENTS		135.	1.65
HYDRAULICS		0.	
ELECTRICAL GROUP		243.	2.98
AVIONICS		467.	5.60
ARMAMENT GROUP		51.	.62
FURNISHINGS		421.	5.16
AIR CONDITIONING AND ANTI-ICE		48.	.59
AUXILIARY GEAR		56.	.69
VIBRATION SUPPRESSION		65.	.80
TECHNOLOGY SAVINGS		0.	.00
CONTINGENCY		54.	.67
WEIGHT EMPTY		5439.	66.63
FIXED USEFUL LOAD		504.	6.17
PILOT	235.		
CO-PILOT	235.		
OIL-ENGINE	14.		
-TRAPPED	6.		
FUEL TRAPPED	14.		
MISSION EQUIPMENT	0.		
OTHER FUL.	0.		
PAYLOAD		960.	11.76
FUEL-USABLE		1260.	15.44
GROSS WEIGHT		8163.	

TABLE 31. LIFE CYCLE COST SUMMARY.

M.U.T. BASELINE		DOLLARS *******
DEVELOPMENT COST PER AIRCRAFT		88959.
PROTOTYPE COST PER PRODUCTION AIRCRAFT		22291.
RECURRING PRODUCTION COST	529160.	
GFE AVIONICS	40000.	
ENGINE COST	89378.	
(FLYAWAY COST)	(658539.)	
INITIAL SPARES	206147.	
GROUND SUPPORT EQUIPMENT	39512.	
INIT.TRAINING AND TRAVEL	52601.	
ACQUISITION COST		956800.
FLIGHT CREW	457200.	
FUEL + OIL	298324.	
REPLENISHMENT SPARES	893368.	
ORG+D/S+G/S MAINT	369534.	
DEPOT MAINTENANCE	322775.	
RECURRING TRAINING	274509.	
MAINTENANCE OF GSE	20769.	
OPERATING COST		2636479.
LIFE CYCLE COST		3704529.
PRODUCTIVITY		.01088
FLEET LIFE CYCLE COST		1852264512.

TABLE 32. LIFE CYCLE COST SUMMARY.

M.U.T. ADVANCED DESIGN (SAME G.W.)		DOLLARS *******
DEVELOPMENT COST PER AIRCRAFT		84004.
PROTOTYPE COST PER PRODUCTION AIRCRAFT		21213.
RECURRING PRODUCTION COST	497332	
GFE AVIONICS	40000.	
ENGINE COST	89378.	
(FLYAWAY COST)	(626708.)	
INITIAL SPARES	198825.	
GROUND SUPPORT EQUIPMENT	37602.	
INIT.TRAINING AND TRAVEL	52017.	
ACQUISITION COST		915153.
FLIGHT CREW	457200.	
FUEL + OIL	298318.	
REPLENISHMENT SPARES	812636.	
ORG+D/S+G/S MAINT	344377.	
DEPOT MAINTENANCE	292003.	
RECURRING TRAINING	271107.	
MAINTENANCE OF GSE	19019.	
OPERATING COST		2494732.
LIFE CYCLE COST		3515102.
PRODUCTIVITY		.02084
FLEET LIFE CYCLE COST		1757550784.

TABLE 33. LIFE CYCLE COST SUMMARY.

M.U.T. ADVANCED DESIGN (SAME PAYLOAD)		DOLLARS *******
DEVELOPMENT COST PER AIRCRAFT		80391.
PROTOTYPE COST PER PRODUCTION AIRCRAFT	-	19521.
RECURRING PRODUCTION COST	457023.	
GFE AVIONICS	40000.	
ENGINE COST	79677.	
(FLYAWAY COST)	(576700.)	
INITIAL SPARES	180825.	
GROUND SUPPORT EQUIPMENT	84602.	
INIT.TRAINING AND TRAVEL	51599.	
ACQUISITION COST		843725.
FLIGHT CREW	457200.	
FUEL + OIL	269893.	
REPLENISHMENT SPARES	754927.	
ORG+D/S+G/S MAINT	326394.	
DEPOT MAINTENANCE	270006.	
RECURRING TRAINING	268675.	
MAINTENANCE OF GSE	17892.	
OPERATING COST		2364987.
LIFE CYCLE COST		3308625.
PRODUCTIVITY		.01324
FLEET LIFE CYCLE COST		1654312416.

Risk and Feasibility

The recommended advanced concepts for each group of structures were reviewed for potential problem areas and assessed with respect to risk and feasibility. Based on the list of problem areas, further review was made in regard to the need for research and development required for risk reduction.

For airframe and landing structures, the major problem areas listed in Table 34 consist mainly of the need for detail design data and the ability to fabricate large, complex structures. While there is considerable data available from composite rotor blade work, the complexity and number of parts in an airframe will require considerable specimen testing and attention to detail part design. (See Table 38). Overall risk and feasibility are medium.

Rotor system and control system problem areas shown in Tables 35 and 36 consist mainly of fabrication processes. While considerable risk reduction is needed (see Table 39), overall risk appears low and feasibility is high. This conclusion was reached since the experience level is higher in R&D efforts to date (Ref. 11).

Transmission structures, as listed in Table 37, appear to be in the low- to medium-risk range, and feasibility is high. Table 40 lists the associated R&D efforts recommended.

TABLE 34. AIRFRAME AND LANDING GEAR STRUCTURES PROBLEM AREAS

STRUCTURAL CONCEPTS	POTENTIAL PROBLEM AREAS	RISK	FEASIBILITY
A-1: Cockpit Canopy Framework Hybrid Composite Closed Sections	. Cocure of Graphite/Epoxy and Kevlar/Epoxy System . Strength Properties of Hybrid Composite . Mechanical Attachment of Windshield to Framework	Low	High
A-3, A-5B, A-B, A-11B A-13: Main Cabin Area and Tail Cone - Molded Foam Stabilized Stringers/Frames (Graphite/Epoxy/Kevlar), with Kevlar Skins.	. Cocure of Graphite/Epoxy and Kevlar/Epoxy System . One-Stage Cocure of Large Built-Up Structures . Post-Buckled Static and Fatigue Strength of Kevlar Skins . Interaction Strength of Composite Skin/Stringer Panels . Crippling Strength of Composite Flanges . Effective Stiffness (Shear) of Post-Buckled Kevlar Skins . Local Mechanical Attachments for Equipment . Effect of Local Stress Concentration in Primary Structure for Routing of Equipment, Initial Design and Retrofit . Mechanical Attachments of Major Sections . Crashworthiness	Medium	High
A-16, A-18: Horizontal Stabilizer and Pylon - Same as Above, but Small Closed Structures	. Cocure of Graphite, etc. . One-Stage Cocure of Smaller Closed Sections . Interaction Strength of Skin/Stringer Panels . Crippling Strength of Composite Flanges . Local Mechanical Attachments for Equipment . Effect of Local Stress Concentrations, etc. . Durability of Surfaces for Walking Loads . Blind Mechanical Attachments . Mechanical Attachments	High	Medium
A-6: Cargo Floor - Graphite/Epoxy/Kevlar Faced Sandwich	. Cocure of Graphite, etc. . Local Mechanical Attachments for Equipment . Durability, Wear and Local Damage	Medium	High
A-10 Transition Section, Internal Structure - Graphite/Epoxy/Kevlar Faced Sandwich	. Cocure, etc. . Mechanical Attachments, etc. . Crippling Strength, etc. . Fireproofing . Crashworthiness . Local Stress Concentrations	High	Medium
A-20: Fairings - Waffle Type Graphite/Epoxy/Kevlar Construction	. Cocure . Strength Drop of Hybrid Composite . Forming of Waffle Pattern . Mechanical Attachments . Durability for Walking Loads	Low	High
General	. Lightning Protection . Static Discharge	Medium	Medium
	. Automated Fabrication of Molded Composite Construction	High	Medium

TABLE 35. ROTOR SYSTEM PROBLEM AREAS

CONCEPT	POTENTIAL PROBLEM AREAS	RISK	FEASIBILITY
B-3 (b, 4)			
Main Rotor Blade – Pultruded Spar, Filament-Wound Outer Skin, Nomex Honeycomb Core	. Development of pultrusion process . Methods to fabricate spar with fiber mixture and orientation . Obtain physical properties of mixture of unidirection and ± 45° fiber orientation	Medium	High
	. Mechanical attachment at root end, consisting of alternate laminated metal and composite lay-up, will require minor development	Low	
B-6 Main Rotor Head – Filament-Wound Hub With Composite Molded Fittings	. Development of filament winding hub in multiaxis directions required . Small-scale trial samples with integrated fittings to minimize risk and cost and to expedite learning would be first approach	Low but requires extensive development	High
B-8 Tail Rotor – Integral Hubs, Cross Beam Composite Structure	. Blade attachment , Hub integration Both require development of . Alternate layers and lay-up of composite and metal laminated build-up	Low	High

TABLE 36. CONTROL SYSTEM PROBLEM AREAS

CONCEPT	POTENTIAL PROBLEM AREAS	RISK	FEASIBILITY
B-10 Swash Plate - Filament-Wound	• Combination of filament winding and tape lay-up in match metal molds for split-half outer members will require development. Mechanical attachment of hard points and liners for control rods and bearings can be structurally bonded and will require minor development.	Low	High
B-11 Bellows Diaphragm Scissors - Filament-Wound Fiberglass Tape Laying Graphite Structure	• Development is needed to determine proportions of graphite at ± 45° and unidirectional fiberglass filament 90° to axis to carry combined cylindrical torsional stiffness (graphite) and axial softness (fiberglass) to allow for tilting and up/down motions about cylinder axis. Mechanical attachment of metal rings by structural bond will require minor development.	Low	High
B-12 Diaphragm Flex Scissors - Elastomer and Boron/Steel Composite Structure	• Development problems similar to B-11.	Low	High

TABLE 36. (CONCLUDED)

CONCEPT		POTENTIAL PROBLEM AREAS	RISK	FEASIBILITY
B-13 Bellcranks and Rods - Composite Foam Stabilized Structures	.	Unidirectional and ±45° wraps of high-modulus composite around metal inserts of the bellcranks and foam filled for stability.	Low	High
	.	Metal fitting filament wound and structurally bonded. Development required to integrate metal hard points (bearings and bushings to composite foam).		

TABLE 37. TRANSMISSION PROBLEM AREAS

CONCEPT	POTENTIAL PROBLEM AREAS	RISK	FEASIBILITY
<u>C-2</u> Fabricated Shaft Metal Housings	. Welding . Static and Fatigue Strength Properties of Welded Joints . Heat Transfer Characteristics of Housing . Rigidity of Structure	Low	High
<u>C-4b</u> High-Contact-Ratio Gear Teeth	. Strength Properties . Torque Capacity . Sensitivity to Machining Tolerances	Low	High
	. Scoring Tendency . Establishment of Fatigue Properties . Consistency of Fatigue Properties from Lot to Lot	Medium	High
<u>C-7</u> Foam-Filled Composite Drive Shaft	. Joint Attachments . Low-Cost Manufacturing Capability . Ballistic Vulnerability	Medium	High

TABLE 38. AIRFRAME STRUCTURES R&D REQUIREMENTS

POTENTIAL PROBLEM AREAS	RECOMMENDED R&D INVESTIGATIONS
DESIGN	
. Strength Properties of Hybrid Composite	Small specimen testing to determine mechanical properties for design.
. Post-Buckled Strength of Kevlar Skin Panels	Static tests for initial shear buckling and ultimate shear strength. Fatigue testing (for post-buckled state) for ground-air-ground cycling. Reduction of shear stiffness in post-buckled state. Effect of panel curvature on strength and stiffness properties
. Interaction Strength	Combined load tests of stringer skin panels to develop interaction strength data for design of flat and curved panels. Develop semiempirical analysis for crippling.
. Mechanical Attachments . Local Stress Concentrations	Small specimen testing, static and fracture, for rivet and bolt attachments in various ply orientations of composites. Develop finite-element/laminate analysis for predicting local loads and stress concentration in mechanical attachments.
. Crashworthiness	Conduct prototype tests of selected sections of molded hybrid composite construction to derive energy absorption capabilities.
. Durability	Conduct wear tests on representative composite construction for walking loads.
. Fireproofing	Conduct flame tests on affected areas. Decrease residual strength capabilities.
. Repair	Conduct tests on repaired portions of structure. Develop a design guide for repair.
. Lightning/Discharge	Determine requirements for composite airframes. Conduct tests.

TABLE 38. (CONCLUDED)

POTENTIAL PROBLEM AREAS	RECOMMENDED R&D INVESTIGATIONS
DESIGN	
. Cocure of Hybrid Composites	Select composite resin system for graphite and Kevlar. Conduct specimen tests to determine optimum system for structure and fabrication.
. One Stage Cocure of Hybrid Composite	Develop tooling concept for one-stage cocure of hybrid molded composite structure.

TABLE 39. ROTOR SYSTEMS AND CONTROLS R&D REQUIREMENTS

POTENTIAL PROBLEM AREAS	RECOMMENDED R&D INVESTIGATIONS
· Physical properties of various oriented fibers of composite structures for all selected designs	Laboratory test small specimens having required fiber orientation to ascertain physical properties for all designs.
· Development of process for pultruding cross-ply and unidirectional composite simultaneously (Blade Spar)	Evaluate scaled-down dies and mandrels and pultrude hybrid composite similar to full-scale design.
· Development of filament winding multiaxis directions (Hub)	Develop winding process and determine methods of integrating metal attachments.

TABLE 40. TRANSMISSION R&D REQUIREMENTS

POTENTIAL PROBLEM AREAS	RECOMMENDED R&D INVESTIGATIONS
• Housing-Fatigue Properties of Joints	Small specimen fatigue testing to determine design properties of weld.
• Static Properties of Joints & Rigidity of Structure	Full-scale load and deflection testing to determine static design requirements of housings.
• Heat Transfer Characteristics	Thermal mapping of gearbox required.
• High-Contact-Ratio Gear Teeth	Dynamic tests of high-contact-ratio tooth form required.
• High-Strength Gear Materials	Small specimen fatigue tests required. Testing at room temperature and at high temperature required to determine relative static and fatigue properties.
• Composite Drive Shafts - Joint Analysis	Develop analytical tool for joint analysis under combined loads.
• Ballistics	Develop fracture mechanics model to enable prediction of residual strength and life for small-arms fire damage.
• Fabrication	Develop low-cost manufacturing capability.

CONCLUSIONS

1. The application of advanced concepts and advanced materials can reduce both weight and cost of a medium size utility transport helicopter.

2. The application of advanced concepts and advanced materials can reduce cost and increase payload for a medium size utility transport of the same gross weight.

3. The concepts for the airframe and landing gear are reasonably feasible. Future research and development programs are recommended with medium risk.

4. The concepts for the rotor system and control system are very feasible and a low risk research and development program is recommended.

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Appendix A - System Design Modeling

Introduction

The Sikorsky Helicopter Design Model (HDM) is a rapid, efficient tool for design iteration and evaluation of an air vehicle at the system level. It was useful in evaluating the baseline helicopter and the advanced concept helicopter of this study.

Preliminary design of an aircraft is an iterative procedure involving configuration, weights, and performance. An initial configuration is developed from such design constraints as payload, volume, number of crew, number of engines, limit on rotor size, and mission equipment. This configuration is used to generate drag and wetted area estimates for HDM (Ref. 12). Other inputs to HDM are derived entirely from the system design specifications.

HDM is a digital computer program directed at specification, under design constraints, of rotor geometry, component weight breakdown, mission analysis, engine and gearbox sizing, speed capability, and cost. These outputs provide the designer with the refinements needed for the next configuration interation. A closed solution is achieved when the configuration, performance, weights, mission requirements, and system design specifications are consistent. Thus, HDM plays an important part in closing the design loop and furnishes insight into design sensitivities at the preliminary level never previously realizable. Aside from the derivation of the design point aircraft, the extensive trade-off and optimization capability of HDM has yielded a new phase of preliminary design, that of trending away from the baseline configuration.

The program is available on the UNIVAC 1110 facility at Sikorsky's corporate research laboratories in Hartford, Connecticut. HDM is sufficiently versatile to handle articulated and hingeless lifting systems. The program has been the primary preliminary design tool for the following contracts and proposals:

U.S. Army Advanced Antitorque Study
U.S. Army HLH Proposal
U.S. Army UTTAS Proposal
NASA/Army Rotor Systems Research Aircraft Predesign Study
U.S. Army Structural Armor Fuselage Study
U.S. Army ABC Operational Configuration Study
U.S. Navy VTOL Escort Study
U.S. Army AAH Proposal

For the present study, HDM was modified to suit the design constraints for a medium-size utility helicopter and to obtain the desired level of detail in weights equations, engine and gearbox sizing criteria, and aerodynamic performance. This fine tuning of the program was used throughout definition of the baseline helicopter during Task I, the advanced concept helicopter design of Task II, and comparison of the two designs in Task III.

Program Operation

HDM has four basic loops (L0, L1, L2, L3) as shown in Figure A-1. L0 is the loop used to derive the gross weight needed to achieve the required payload. If gross weight is specified, payload is calculated. The calculations within this loop form the nucleus of the program. The remaining three loops enable trending, for a single set of input data, of what are considered the three primary design constraints: blade loading (C_T/σ), disc loading (DL), and percentage of power (PCTPR) provided at the engine shaft output that will be available for the antitorque device. Elements of the drive system may be sized on the basis of a design performance requirement, such as percentage overrating above the design hover input power. Knowledge of rotor power and PCTPR defines total power required from the engines, thus enabling selection of engine type and size. If required rotor geometry (radius and chord) is specified, CTSIG and DL are calculated. If a particular tail rotor geometry is specified, PCTPR is calculated. CTSIG, DL, and PCTPR may be selected as single inputs or as a required range (initial, final, and incremental values), so that repeated passes are made around the appropriate loop (L1, L2 or L3) to create a matrix of design points. For each range of any of these three variables, the interpolated value needed to produce the aircraft is selected, based on user preference for minimum weight, minimum cost, maximum productivity, etc. Thus, if ranges of values are desired for CTSIG, DL, and PCTPR, the program will identify the combination of values needed to optimize the helicopter design. The user may request printouts at various levels of definition and at varying frequency through the calculation. For example, he may request a complete detailed weight breakdown for every pass around loop L0, or a summary weight statement on completion of the optimization.

Generally, loop L0 is entered with rotor CT/σ, disc loading, and number of blades specified. A gross weight has been assumed. A given rotor geometry may be assumed, but the general case was considered in this study. The main rotor of a conventional helicopter is usually designed to two design criteria: a hover point at given altitude and temperature, and a cruise speed goal possibly at some other altitude and temperature.

At the design hover condition, the power required is computed by the figure of merit method. At this stage, accessory and mechanical power losses are known, and power consumed at the tail rotor has been assumed. Hence, total shaft power at the engines can be calculated, as well as the power at the input and at other stations through the drive system. (Certain helicopter configurations, such as the Heavy Lift Helicopter (HLH), required an alternate hover condition at an increased gross weight, but less stringent altitude and temperature environment. HLH powers were determined at the alternate hover point.) Where a cruise speed goal is set, power required at that speed is computed by the Sikorsky

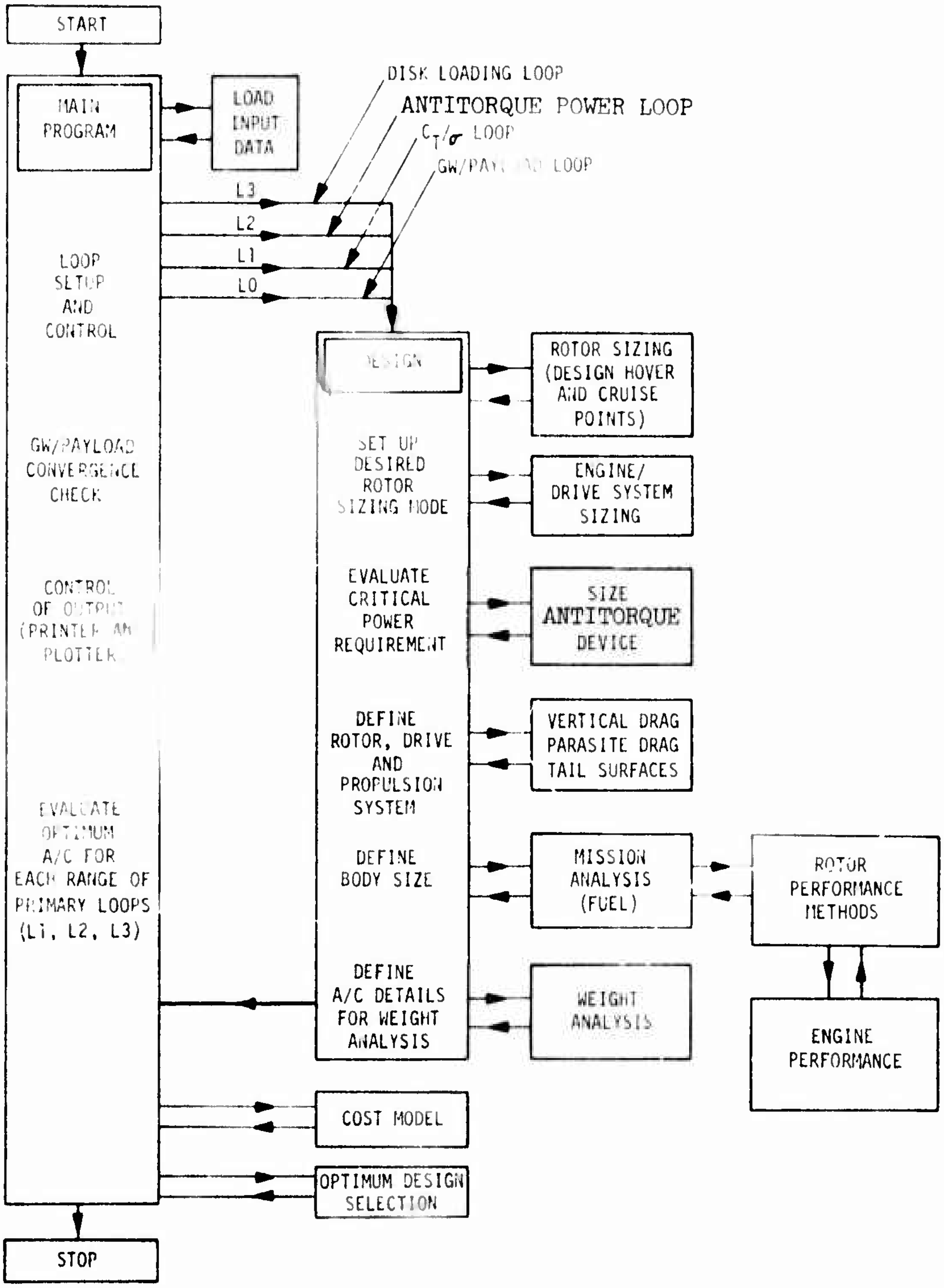


FIGURE A-1. HELICOPTER DESIGN MODEL FLOW CHART.

Nondimensional Rotor Performance (NDRP) method (Ref. 13). Engine size and transmission rating may now be selected from one of the following options:

1. Specified engine
2. Sufficient for the design hover point
3. Sufficient for the alternate hover point
4. Sufficient for the design cruise point
5. Greater of 2 and 3
6. Greatest of 2, 3, and 4

Engine powers are reduced to sea level standard equivalents for purposes of comparison. Where applicable, the tail rotor is evaluated. Subroutine ANTORK is entered with knowledge of the hover torques at the main rotor; constraints on the antitorque device such as number of blades maximum C_T/σ,maximum disc loading, etc.; and allowable amount of power to be consumed in steady-state hover. An initial tail rotor radius is assumed from which is calculated thrust, hence power required, in steady-state hover at alternate gross weight. Iteration of radius continues until a power match is obtained.

The maximum thrust requirement needed to satisfy the MIL-H-8501A specification for yaw control is calculated. This gives the maximum sustained power to be transmitted through the tail drive shafts and gearboxes. Power consumption at design steady-state hover is also evaluated, from which overall system hover efficiency is computed: main rotor power ÷ engine shaft power. This value is compared with the value assumed at the commencement of the design evaluation. Iteration proceeds until a power consumption match is reached. Tail surface areas and parasite drag are taken from input values or are computed from empirical data, depending on user preference. A simple acoustic model calculates perceived noise level in terms of gross weight, tip speed, and blade loading.

The mission analysis routine provides sufficient flexibility for division of a mission into discrete elements at the required altitude, temperature, and speeds. The mission profile may contain as many as 50 segments. Alternatively many missions may be stacked to a total of 50 segments to be processed sequentially. Speed may be specified in knots, or coded as the speed required to produce maximum range, maximum endurance, rotor stall threshold; or the speed required to match a gearbox design power or some engine rating. In addition, the analysis accounts for such aircraft limitations as stall speed and engine torque limit. Fuel burn-off and changes in aircraft configuration are accounted for that may result from payload expenditure or pickup of passengers. Performance calculations are based on the NDRP method for forward flight and the figure of merit method for hover. Engine performance is represented as curve data of specific fuel consumption versus shaft horsepower normalized to one line by altitude and temperature effects. The data sheets of Tables A-1, A-2, and A-3 illustrate HDM summary output for the baseline and advanced helicopters.

The weights subroutine accounts for each helicopter subsystem, providing a sufficient degree of component identification to accurately reflect each subsystem weight. Component weights are evaluated by a set of statistical weight equations. To some degree, these equations are tailor-made to suit a specific helicopter type. Rotor group weight estimates take proper account of blade aspect ratio, design dive speed, and hinge offset effects. The drive system is broken down into individual shaft lengths and gearboxes, and weight estimates reflect the transmitted horsepower and rotational speeds of each component. Empennage configuration may be selected as low-T, high T, V, inverted V, or single asymmetric. Landing gear type may be selected as tricycle, tail wheel, quadricycle, retractable or fixed, or skids. The weight statement output is available either as a detailed breakdown by subsystem component, or as a summary by major group (rotor, body, etc). The medium-size utility helicopter summary weight statement is shown in Table 28. The three-view drawing of Figure 15 illustrates the resulting design of the helicopter.

Life-cycle cost of a military helicopter is a summation of the costs of development, production, ground support equipment, crew training, maintenance, spares, and fuel. The composition of each of these items depends on the particular project under study. Development and production costs for the baseline helicopter were statistically trended and were in general a function of the component weights already calculated. Outputs from this subroutine are production cost, flyaway cost, and life-cycle cost. Cost modeling was limited to flyaway cost for the purpose of this study. Flyaway cost was based on production of 500 aircraft and is stated in 1974 dollars. Baseline helicopter costs are presented in Table 31.

TABLE A-1. M.U.T. BASELINE DESIGN ATTRIBUTES

GENERAL	
DESIGN G.W. (LB)	9471.
PAYLOAD (LB)	960.
WEIGHT EMPTY (LB)	6618.
FUEL (LB)	1389.
HOVER POWER (SHP)	1178.
HOVER & CLIMP HP	1261.
MAIN ROTOR DESIGN HP	1048.
TAIL ROTOR CANT (DEG)	20.00
M.R. DISC LOADING (PSF)	7.00
MAIN G.B. DESIGN HP	1564.
MAIN ROTOR	
RADIUS (FT)	20.50
CHORD (FT)	1.322
NO. OF BLADES	4.0
ROTOR SOLIDITY	.0819
TIP SPEED (FPS)	730.0
ASPECT RATIO	15.511
CT/SIGMA	.0850
MAIN ROTOR LIFT	9239.4
FIGURE OF MERIT	.7555
BLADE AREA (SQ.FT)	108.4
TAIL ROTOR/FAN	
RADIUS (FT)	4.40
CHORD (FT)	.535
NO. OF BLADES	4.0
ROTOR SLDTY/AF	.1547
TIP SPEED (FPS)	700.0
ASPECT RATIO	8.231
CT/SIGMA	.1089
TAIL ROTOR LIFT	231.9
FIGURE OF MERIT	.7147
BLADE AREA (SQ.FT)	9.4

TABLE A-2. ADVANCED DESIGN (SAME G.W.)
DESIGN ATTRIBUTES

GENERAL	
DESIGN G.W. (LB)	9471.
PAYLOAD (LB)	1700.
WEIGHT EMPTY (LB)	5878.
FUEL (LB)	1389.
HOVER POWER (SHP)	1178.
HOVER & CLIMB HP	1261.
MAIN ROTOR DESIGN HP	1048.
TAIL ROTOR CANT (DEG)	20.00
M.R. DISC LOADING (PSF)	7.00
MAIN G.B. DESIGN HP	1564.
MAIN ROTOR	
RADIUS (FT)	20.50
CHORD (FT)	1.322
NO. OF BLADES	4.0
ROTOR SOLIDITY	.0819
TIP SPEED (FPS)	730.0
ASPECT RATIO	15.511
CT/SIGMA	.0850
MAIN ROTOR LIFT	9239.1
FIGURE OF MERIT	.7555
BLADE AREA (SQ.FT)	108.4
TAIL ROTOR/FAN	
RADIUS (FT)	4.40
CHORD (FT)	.535
NO. OF BLADES	4.0
ROTOR SLDTY/AF	.1547
TIP SPEED (FPS)	700.
ASPECT RATIO	8.231
CT/SIGMA	.1089
TAIL ROTOR LIFT	231.9
FIGURE OF MERIT	.7147
BLADE AREA (SQ. FT)	9.4

TABLE A-3. ADVANCED DESIGN (SAME PAYLOAD)
DESIGN ATTRIBUTES

GENERAL	
DESIGN G.W. (LB)	8081.
PAYLOAD (LB)	960.
WEIGHT EMPTY (LB)	5364.
FUEL (LB)	1252.
HOVER POWER (SHP)	1011.
HOVER & CLIMB HP	1082.
MAIN ROTOR DESIGN HP	894.
TAIL ROTOR CANT (DEG)	20.00
M.R. DISC LOADING (PSF)	7.00
MAIN G.B. DESIGN HP	1241.
MAIN ROTOR	
RADIUS (FT)	18.94
CHORD (FT)	1.221
NO. OF BLADES	4.0
ROTOR SOLIDITY	.0819
TIP SPEED (FPS)	7300.
ASPECT RATIO	15.511
CT/SIGMA	.0850
MAIN ROTOR LIFT	7883.1
FIGURE OF MERIT	.7555
BLADE AREA (SQ.FT)	92.5
TAIL ROTOR/FAN	
RADIUS (FT)	4.07
CHORD (FT)	.492
NO. OF BLADES	4.0
ROTOR SLDTY/AF	.1539
TIP SPEED (FPS)	700.0
ASPECT RATIO	8.274
CT/SIGMA	.1067
TAIL ROTOR LIFT	197.5
FIGURE OF MERIT	.715
BLADE AREA (SQ.FT)	8.0

Appendix B - Weight and Cost Substantiation

Details including criteria for design, samples of structural analysis, and weight and cost breakdown are presented for the affected structural weight of the selected concepts. A brief description is also given for other concepts considered in this study.

Composite Airframe

Cockpit Canopy

The cockpit canopy is designed by airloads at dive speed. The airloads are used to develop the thickness of the glazing material. The framework supporting the glazing material is designed primarily for stiffness.

At present, fiberglass/epoxy is used in the construction of the canopy framework for such helicopters as the CH-53A and the UTTAS. These canopies are molded as a single cure. An advanced canopy framework is concept A-1, Kevlar and graphite/epoxy.

It is estimated that 75 percent Kevlar and 25 percent graphite/epoxy is used for the framework of concept A-1. The weight saving is:

$$\frac{.05\ (.75) + .055\ (.25) -1 = 22\%}{.065}$$

where .05 is the density of Kevlar/epoxy
.055 is the density of graphite/epoxy
.065 is the density of fiberglass

Table B-1 compares the affected weight for the conventional structure and concept A-1.

TABLE B-1. WEIGHT OF CONVENTIONAL COCKPIT CANOPY AND CONCEPT A-1

Item	Conventional Affected Weight	Concept 2A-1
Primary Structure	(14.1)	(8.0)
Frames & Bulkheads*	12.4	7.1
Joining	1.7	.9
Secondary Structure	(28.5)	(22.2)
Framing	28.1	22.0
Joining		.2
Equipment Support Steps**	(4.1)	(3.1)
	(46.7)	(33.3)

*Aluminum bulkhead 42% saving as composite

**Use wheel as step

The material weight is as follows :

Graphite/Epoxy	7.7
Kevlar	25.0
Misc.	.6
	33.3

The cost of cockpit canopy concept A-1 is estimated as follows:

Labor Hours for Layup, etc. Same as
the Conventional Fiberglass Layup

Material:			
Graphite/Epoxy	7.7 lb x 1.2 x $20/lb	=	$184
Kevlar	25 lb x 1.2 x $10/lb	=	$300
Misc.	.6 lb x $ 3/lb	=	$ 2
			$486
Conventional Fiberglass	28.5 lb x 1.2 x $2.35/lb	=	-$80
			$406

Estimated Cost Increase:

1.35*(406) = $550

*Factor, see page 16

<u>Cockpit Tub, Upper and Lower Cabin, and Transition Sections</u>

The cockpit tub, upper and lower cabin, and transition sections are constructed mainly of heavy frames, beams, and bulkheads to react concentrated loads for seats, equipment, landing gear, etc. The critical condition for these components is the crash condition for high mass items. Conventional construction is of formed aluminum skin and stringers, built-up or forged aluminum beams, frames, and longerons. Bulkheads are of aluminum sheet and stiffeners.

The advanced concepts for these components are as follows:

Cockpit Tub	A-3
Upper Cabin	A-5b
Lower Cabin	A-8
Transition Section	
Outer Shell	A-11

These four advanced concepts are of the same basic construction as the conventional: molded composite skins with foam-stabilized stringers, frames, and beams.

The internal structure for the transition section is concept A-10, composite sandwich bulkheads.

Weight savings using the advanced concepts for the cockpit tub, cabin, and outer shell of the transition section are based on the data of Ref. 11. A preliminary analysis of the bulkheads in the transition section was performed for crash loads in the fuel cell.

The average skin gage is .032 2024-T3 aluminum for conventional construction. A minimum of 4-ply ± 45° Kevlar is used for advanced composite skins. The weight saving is:

$$\left(1 - \frac{.040(.050)}{.032(.1)}\right)/\ 100 = 38\%$$

The average stringer compression load is 3000 pounds. From Figure 17 of Ref. 7, the conventional stringer weight is .00725 lb/in. of length. The weight of a foam-stabilized stringer is .0057 lb/in. length. The weight saving is:

$$\left(1 - \frac{.0057}{.00725}\right)/\ 100 = 22\%$$

The average bending moment for highly loaded frames and beams is approximately 100,000 in.-lb. From Figure 20 of Ref. 7, a conventional frame weighs 1.3 lb/ft.A foam-stabilized frame is .75 lb/ft. The weight saving is:

$$\left(1 - \frac{.75}{1.3}\right)/\ 100 = 42\%$$

Bulkheads in the transition section are designed for fuel pressures during a crash. A conventional bulkhead is constructed of .020 in. aluminum webs supported by 2 in. x 3/4 in. aluminum channels .050 in. thick spaced at 6 in. An advanced concept for a fuel bulkhead is constructed of graphite/epoxy and Kevlar skins over a foam core. A composite bulkhead under the engine is constructed of skins of quartz glass in a polyimide matrix. The bulkhead is coated with intumescent paint. This type of construction provides a fire retardant structure up to 2000°F. The composite bulkheads are designed to match the bending strength of the aluminum bulkheads.

The bending capability of a conventional bulkhead is

$$M = \underline{F_{cc}I} = \underline{50000\ (.108)} = 5400 \text{ in.-lb.}$$

for 6 in. space

$$= 900 \text{ in.-lb/in.}$$

Composite bulkhead is 3/8 in. thick. For a 1-in.-wide strip,

$P_T = P_c = 900/.375 = 2400$ lb

$F_c = 160{,}000$ psi graphite/epoxy (Ref. Table 7).

$t = 2400/160{,}000 = .015$ in. for the compression face.

$F_T = 189{,}000$ psi Kevlar (Ref. Table 7).

$t = 2400/189{,}000 = .0127$ in. for the tension face.

The conventional bulkhead weight is computed as follows:

$$\begin{array}{lll} \text{Web} & 144 \times .020 \times .1 = & .286 \\ \text{Stiff} & 2(12)\ (3.5 \times .050).1 = & \underline{.42} \\ & & .706\ \text{lb/ft}^2 \end{array}$$

Concept A-10

$$\text{Core} \quad \frac{144 \times .375(8)}{1728} = .240$$

Graphite/Epoxy 3-ply 0°

$$144 \times .015\ (.055) = .119$$

Kevlar 2-ply 0° 2-ply 90°

$$\begin{array}{r} 144 \times .040\ (.050) = \underline{.285} \\ .544\ \text{lb/ft}^2 \end{array}$$

The weight saving is

$$(.544/.706) - 1 = 23\%$$

Fittings and joints of such composites as graphite/epoxy are assumed to be proportional in weight to the joint strength-to-density ratio. The weight saving is then

$$\left(1 - \frac{F_{tu}\ \text{aluminum}}{\rho\ \text{aluminum}} \Big/ \frac{F_{tu}\ \text{composite}}{\rho\ \text{composite}}\right) / \ 100 = \left(1 - \frac{70000}{.1} \Big/ \frac{80000^*}{.066}\right) / \ 100 = 50\%$$

*Approximate mechanical joint allowable with 60% 0° graphite/epoxy and 40% $\pm 45^\circ$ graphite/epoxy .

Tables B-2 through B-6 compare the affected weights of the conventional structures and the selected concepts.

TABLE B-2. WEIGHT OF CONVENTIONAL COCKPIT TUB AND CONCEPT A-3

Item	Conventional Affected Weight	Concept A-3
Primary Structure	(63.4)	(39.1)
Frames & Bulkheads	8.4	5.1
Joining	1.1	.6
Skins/Stringers (64/36)	14.8	10.0
Joining	1.2	.6
Beam Install	3.6	1.8
*Floor	8.3	6.2
Panel Breaker	1.0	.5
Longerons	.7	.4
Crash Beams	16.0	9.2
Joining	1.9	1.0
Seat Beams	6.4	3.7
	63.4 lb	39.1 lb

*2-Ply Kevlar ± 45° is substituted for .025-in. aluminum.

The material weight for concept A-3 is:

Graphite/Epoxy	16.0
Kevlar	12.6
Foam	8.5
Misc.	2.0
	39.1 lb

TABLE B-3. WEIGHT OF CONVENTIONAL UPPER CABIN AND CONCEPT A-5b

Item	Conventional Affected Weight	Concept A-5b
Primary Structure	(104.7)	(61.7)
Frames & Bulkheads	48.3	27.5
Joining	2.7	1.3
Skins	18.3	11.8
Joining	1.2	.6
Stringers	3.0	2.3
Joinings	0.5	0.3
Longerons	13.9	8.2
Transmission Beam	16.8	9.7
Secondary Structure	(11.6)	(6.4)
	116.3 lb.	68.1 lb.

The material weight of concept A-5b is:

Graphite/Epoxy	24.0
Kevlar	16.3
Foam	23.2
Misc.	4.6
	68.1 lb

TABLE B-4. WEIGHT OF CONVENTIONAL CABIN TUB AND CONCEPT A-8

Item	Conventional Affected Weight	Concept A-8
Primary Structure	(51.9)	(29.1)
Frames & Bulkheads	15.9	9.1
Joining	1.5	0.8
Skins	11.6	7.2
Joining	1.0	0.5
Stringers	2.1	1.6
Longerons	4.1	2.3
Floor Beams	14.7	7.1
Misc.	1.0	0.5
Alighting Gear Supports	(18.1)	(9.8)
Skins	2.8	1.8
Beams	3.4	2.0
Fittings	11.9	6.0
Equipment Fittings	(9.8)	(5.9)
	79.8 lb	44.8 lb

The material weight of concept A-8 is:

Graphite/Epoxy	20.5
Kevlar	9.4
Foam	12.5
Misc.	2.4
	44.8 lb

TABLE B-5. WEIGHT OF CONVENTIONAL TRANSITION SHELL AND CONCEPT A-11B

Item	Conventional Affected Weight	Concept A-11B
Primary Structure	(167.9)	(112.6)
Skin	110.4	68.0
Stringers	50.2	39.2
Intercostals	6.9	5.4
Secondary Structure	(8.7)	(4.6)
Supports	(2.0)	(1.0)
	178.6 lb	118.2 lb

The material weight of concept A-11B is:

Graphite/Epoxy	35.4
Kevlar	60.8
Foam	12.0
Misc.	10.0
	118.2 lb

TABLE B-6. WEIGHT OF CONVENTIONAL TRANSITION INTERNAL STRUCTURE AND CONCEPT A-10

Item	Conventional Affected Weight	Concept A-10
Primary Structure	(165.1)	(94.2)
Frame & Bulkheads	132.9	77.0
Joining	16.1	8.0
Beams	16.1	9.2
Secondary Structure	(56.4)	(38.2)
Tank Support	45.4	27.2
Foam	11.0	11.0
System Supports	(13.2)	(6.5)
	234.7 lb	138.9 lb

The material weight of concept A-10 is:

Graphite/Epoxy	32.8
Kevlar	29.2
Foam	53.8
Misc.	23.1
	138.9 lb

The cost for the selected concepts is based on the baseline upper and lower cabin costs derived from cost studies of a cabin of a current helicopter now being manufactured.

Baseline Weight (affected)

Upper Cabin	100	(TABLE B-3)
Cabin Tub	73	(TABLE B-4)
	173 lb	

Material Cost (Aluminum)

173 x \$1.20/lb. = \$207

Labor

Detail Fabrication	330 hr
Assembly	235 hr
Installation	365 hr
	930 hr

Cost 930 x \$22.50/hr = \$21,000

Estimated Cost

\$21,000 + 1.35(\$207) = \$21,280

Upper Cabin Cost

$$\frac{\text{Upper Cabin Wt}}{\text{Cabin Wt}} \times \$21{,}280 = \$12{,}600$$

Cabin Tub Cost

\$21,280 - \$12,600 = \$8,680

Costs of the selected concepts are a result of total lower labor hours but higher material costs (Ref. 7 and page 145 of this report.) From page 145 the labor hours for the conventional cone are 310. Labor hours for the advanced concept are 265. The ratio of concept hours to conventional hours is:

265/310 = .86

Reference 7, pages 110-111, shows that the ratio varies from .87 to .96 for prototype and production labor costs.

The ratio of .86 is applied to the baseline labor costs to develop the labor cost for the selected concepts.

Table B-7 is a summary of the estimated costs of the cockpit tub, upper cabin, cabin tub, and transition section.

TABLE B-7. ESTIMATED COST OF SELECTED CONCEPTS (AIRFRAME)

Section	Concept	Labor Cost	Material	Cost *
Cockpit Tub	A-3	$ 5513	$ 763	$ 6903
Upper Cabin	A-5B	$ 10463	$1150	$ 1277
Cabin Tub	A-8	$ 6863	$ 890	$ 8328
Transition Shell	A-11B	$ 17438	$2220	$21655
Internal	A-10	$ 15750	$1810	$19316

Concept	Graphite/Epoxy ($20/lb)	Kevlar ($10/lb)	Foam ($3/lb)	Misc. ($1/lb)	Total Cost
A-3	16.0 lb	12.6 lb	8.5 lb	2.0 lb	$ 763
A-5B	24 lb	163 lb	23.2 lb	4.6 lb	$1150
A-8	20.5 lb	9.4 lb	12.5 lb	2.4 lb	$ 890
A-11B	35.4 lb	60.8 lb	12.0 lb	10.0 lb	$2220
A-10	32.8 lb	29.2 lb	53.8 lb	23.1 lb	$1810

* Total cost includes 10% for installation.

** Total material cost includes 20% wastage and 35% overhead.

Other advanced concepts considered for the cockpit tub, upper and lower cabin, and transition shell are given in Table B-8. Table B-8 also lists the estimated weight and cost.

TABLE B-8. OTHER ADVANCED CONCEPTS

SECTION	CONCEPT		WEIGHT	COST
Cockpit Tub	A-2	Molded Foam Filled	65 lb	\$94,000
	A-4	Spot Bonded Aluminum	57 lb	\$ 5,896
Upper Cabin	A-5A	Sandwich Skins Foam Stabilized Frames	85 lb	\$14,500
	A-5C	Spot Bonded Aluminum	105 lb	\$95,000
Cabin Tub	A-7	Molded Foam Filled	70 lb	\$11,950
	A-9	Spot Bonded Aluminum	72 lb	\$ 6,500
Transition Shell	A-11A	Composite Sandwich Shell	170 lb	\$25,600
	A-11C	Spot Bonded Aluminum	161 lb	\$18,612

<u>Cargo Floor</u>

The cargo floor is designed for 300 lb/ft^2 at maximum vertical load factor. A conventional floor is constructed of .012 titanium sheet, 3/4 inch thick 6 lb/ft^3 aluminum honeycomb, and 2-ply 0°/90° fiberglass/epoxy at a total weight of 1.06 lb/ft^2.

An advanced floor concept is concept A-6, which is constructed of 1-ply 0° graphite/epoxy, 1-ply 90° Kevlar coated with Shipsgrip for the top face, 6 lb/ft^2 1/2-inch foam core, and a lower face of 1-ply 0° graphite/epoxy and 1-ply 90° Kevlar. The basic structural weight of concept A-6 is:

Graphite/Epoxy	.080 lb/ft^2
Kevlar	.073 lb/ft^2
Core	.250 lb/ft^2
Adhesive	.200 lb/ft^2
Grip	.076 lb/ft^2
Misc.	.067
	.746 lb/ft^2

Weight savings: $\frac{.747}{1.06} - 1 = 29\%$

The cost is:

$$\begin{aligned}\text{Labor/ft}^2 &= \quad .40 \times 22.50 = \$\quad 9.00\\ \text{Material/ft}^2 &= 11.34 \times \ 1.35 = \underline{\$\quad 15.30}\\ & \qquad\qquad\qquad\quad \$\quad 24.30/\text{ft}^2\\ \text{10\% Installation} &= \underline{\$\quad\ \ 2.40}\\ & \qquad\qquad\qquad\quad \$\quad 26.70\end{aligned}$$

Cost of the conventional floor is $\$24/\text{ft}^2$.

The cost increase for the advanced concept is (26.70/24.00) -1 = 10%.

The cost of a conventional cargo floor is based on the cost per pound for the body group at \$129/lb. This cost/lb was used, since the Helicopter Design Model (HDM) does not break down aircraft weight and cost into individual components. Cost of the conventional floor, therefore, is

$$28\ \text{ft}^2 \times 1.06\ \text{lb/ft}^2 \times \$129/\text{lb} = \$3{,}820$$

Advanced concept A-6 is estimated to cost 1.10 x \$3820 = \$4202.

Tail Cone

The tail cone is a lightly loaded structure, compared with the cabin section. It is designed for two conditions: rolling pullout left and hard landing.

The rolling pullout induces maximum shear for the skin panels. The hard landing induces maximum bending.

For the average cross section of the tail cone (Station 329), the skin shear flow is

$$q_{max} = 220\ \text{lb/in. (ultimate)}$$

The tail cone skins are nonbuckling at 1g steady flight, so the critical buckling shear flow is calculated to be

$$q_{CR} = 220/6.5 = 34\ \text{lb/in.}$$

The required skin thickness for 2024 skins of the baseline aircraft is .032 in. (a = 6 in., Ref. 14).

The advanced tail cone is concept A-13, constructed of ± 45° Kevlar skins over foam-stabilized graphite/epoxy stringers. Minimum skin thickness is assumed to be 4-plies. Based on the shear buckling curves for graphite/epoxy of Ref. (11) for tp = .0022 and $E_{graphite/epoxy\ 0^{\circ}} = 17.0 \times 10^{6}$, the shear buckling for .040-inch Kevlar is estimated to be

$$q_{CR_K} = q_{CR_{graphite/epoxy}} \times \frac{E_{KEV\ 0^{\circ}}}{E_{graphite/epoxy\ 0^{\circ}}} = 57 \times \frac{10.8}{17} = 37 \text{ lb/in.}$$

The ultimate shear stress for .040 Kevlar skin due to the rolling pull out condition is:

$$f_s = 220/.040 = 5500 \text{ psi}$$

$$F_{s_u} = 27{,}000 \text{ psi (Ref. Table 7)}$$

Maximum bending moment is M_y = -180000 in.lb (ULT) from the hard landing (Ref. Figure 2) at Station 329. The maximum stringer compression load is 2400 lb (ULT). Due to buckling of the Kevlar skins, an additional load will be acting on the stringer. Assume a total load of 3000 lb (ULT). From Ref. (3), Figure 17, at 3000 lb an aluminum stringer would weigh .0072 lb/in. A foam stabilized stringer would weight .0056 lb/in.

Tail cone frames provide stability for stringers and maintain geometry. A typical aluminum frame would be a bent-up .032 in. channel 2-1/2 inches deep. A foam-stabilized frame must match the stiffness of an aluminum frame.

$$EI_{aluminum} = 1.2 \times 10^{6} \text{ lb in.}^{2}$$

$$EI_{foam\ stab.} = .75 \times 10^{6} \text{ lb in.}^{2}$$

Weight for aluminum frame = .0128 lb/in.

Weight for stabilized frame of graphite/epoxy, Kevlar & foam = .0115 lb/in.

Tail cone bulkheads are used to introduce large concentrated loads, such as landing gear loads, into the structure. Bulkhead structure is similar to that of large frames and beams, which can be constructed of composite sandwich. From the data of Ref. (7), Figure 20, a 42% weight saving is possible for bulkheads.

The weight saving for the tail cone concept A-13 is

Skins $\left(1 - \frac{.040(.050)}{.032(.1)}\right) / \ 100 = 38\%$

Stringers $\left(1 - \frac{.0056}{.0072}\right) / \ 100 = 22\%$

Frames $\left(1 - \frac{.0115}{.0128}\right) / \ 100 = 10\%$

Bulkheads $= 42\%$

Fittings and joints are assumed to be graphite/epoxy. The weight saving is then 50%, as shown on page 131.

Table B-9 compares the affected weights for the conventional structure and concept A-13.

TABLE B-9. WEIGHT OF CONVENTIONAL TAIL CONE AND CONCEPT A-13

Item	Conventional Affected Weight	Concept A-13
Primary Structure	(91.7)	(62.9)
*Frames & Bulkheads	16.5	11.3
Joining	2.3	1.6
Skins & Stringers	60.5	42.5
Shear Deck	3.9	2.8
Joining	6.8	3.8
Longeron	1.7	.9
Fittings - Aircraft	(2.3)	(1.2)
Fold	.7	.4
Jacking	.3	.1
Blade Stowage	.6	.3
Tiedown	.7	.4
Fittings - Components	(7.1)	(3.6)
Landing Gear	4.1	2.1
Tail Drive Shaft	1.3	0.7
Flight Controls	.6	.3
Lights	1.1	.5
TOTAL TAIL CONE	101.1 lb	67.7 lb

*Frames	5.5 lb
Bulkheads	12.1 lb

The material weight is:

Graphite/Epoxy	16.1
Kevlar	39.0
Foam	9.2
Misc.	3.4
	67.7 lb

The labor hours for the construction of the tail cone concept A-13 is outlined as follows:

Skin Layup (1/2 Cone Section) L.H. Side	Labor, Hr
Set up N.C. Tape Laying Machine	
Lay down + 45° Orientation	
13.50 lb Kevlar (Pro-49)	
Flat Pattern on Mylar	
Dink Flat Pattern into	
T60 Female Mold	38.70
Foam Stringer Fabrication	
Prepare Matched Metal Stringer	
Molds (Mirror Finish on Molds)	
Pour Foam Mix into Automatic	
Dispenser (2.5 lb Mix)	
Dispense Foam into Matched Molds	
Cure Cycle	
Remove Stringer Parts from Mold	
Clean Flash	
Place Stringer Assy into T60 Mold	
Common to Skin Layup	3.50
Skin Stringer Layup	
Set up N.C. Tape Laying Machine	
Lay down 1 40° Orientation	
3.60 lb Graphite/Epoxy 2.90 lb Kevlar	
Flat Pattern on Mylar	
Dink Flat Pattern Common to	
Molded Foam Stringer Assy	26.30
Cure 1/2 Cone Section	
Apply One Layer of Peel-Ply	
Oven Entire Layup	
Attach Caul Plates and Necessary	
Fittings to T60 Mold	
Vacuum Bag	
Autoclave Cure	
Remove from Autoclave	
Strip 1/2 Cone Section from Mold	
Trim as Required	11.50

(1/2 Cone Section) R. H. Side	Labor, Hr
Similar to Operations for (1/2 Cone Section) L.H. Side	80.00
Frames (8 Required)	
Molded Foam Fabrication (2.2 lb) N.C. Skin Layup Graphite/Epoxy 2.2 lb Kevlar 3.8 lb Dink Skin over Molded Foam in a Common Assy with Stringers	24.00
Bulkheads (2 Required)	
Molded Foam Fabrication (2.5 lb) N.C. Tape Layup Graphite/Epoxy 2.5 lb Kevlar 4.2 lb Cocure Molded Foam and Graphite/Epoxy - Kevlar Layup - Autoclave Strip from Mold Trim as Required	29.00
Composite Fitting (4 Required)	
N. C. Tape Layup Dink on Mold (Matched - Metal) Cure (Press) Clean Flash	6.00
Tail Cone Bonded Assembly	
Install 2 Tail Cone Sections into T018 Bonding Fixture Apply Bonding Adhesives and Foam Adhesives to All Assembly Joining Points Install 2 Bulkheads and 4 Fittings Secure Bonding Fixture for Cure Cycle - Oven Cure After Oven Cure Remove Assy from T018 Bonding Fixture Clean and Add Mechanical Joints as Required	46.00
Total Balanced Hr per Assy	265.00

The cost of the conventional tail cone is:

Labor

Detail Fabrication	135 hr
Assembly	63 hr
Installation	112 hr
	310 Labor Hours

310 x $22.50 = $7000

Material

101 x $1.20 = $122

Estimated Cost

$7000 + (1.35* x $122) = $7165

* 35% overhead

The cost of the tail cone concept A-13 is:

265 Labor Hours @ $22.50	=	$6000	
16.8 lb Graphite/Epoxy x 1.2*@ $20/lb			$400
40.8 lb Kevlar x 1.2 @ $10.lb			$494
9.7 lb Foam x 1.2 @ $3/lb			$ 35
		$6000	$929

* 20% wastage

Estimated Cost is:

1.10* ($6000 + 1.35** x $929) = $7942

* Factor for miscellaneous attachments and details.

**35% Overhead

Other advanced concepts considered for the tail cone are A-12, a sandwich construction, and A-14, an aluminum spot-welded bonded tail cone.

Concept A-12 is constructed of 1/4-inch-thick 6 lb/ft^3 foam core between two face skins of ± 45° 2-ply Kevlar for shear. Bending capability is provided by unidirectional graphite/epoxy strips molded into the sandwich skins. Foam stabilized frames are used for stringer stability. This concept is 25 percent heavier than selected concept A-13.

The sandwich construction is estimated to cost $9224.

Concept A-14 is similar to conventional construction except that structural members are spot-welded bonded (adhesive bond, spot-welding for clamping). Preliminary tests conducted by Sikorsky showed an increase in load capability of approximately 12 percent, due to an increase in effective web area or compression members. The weight saving with spot bonding is estimated to be 10 percent.

The cost of a spot-welded bonded structure is 10% less than conventional construction due to a larger spot spacing of approximately 1-1/2 inches compared with automatic riveting at 3/4 inch spacing.

<u>Horizontal Stabilizer</u>

The horizontal stabilizers are of a symmetrical airfoil designed to the maximum anticipated flight loads or local walking loads. Conventional construction is of .020- to .025-inch beaded aluminum skins with formed ribs and built-up spars. The advanced concept for a stabilizer is A-18, which if of molded Kevlar, graphite/epoxy beaded skins with composite sandwich spars.

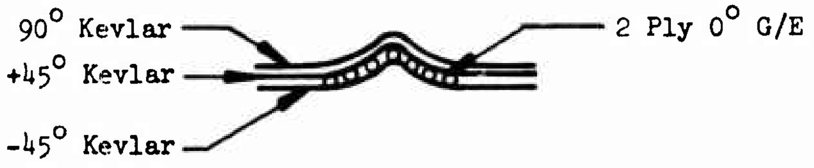
The trailing-edge beaded skins are .020-inch 2024 aluminum.

For the bead, the stiffness is

$$I = .000413 \text{ in.}^4$$

$$EI = .0043 \times 10^6 \text{ lb-in.}^2$$

The composite skin is three plies of Kevlar (90, ± 45°) with 0° graphite/epoxy sandwiched between at the beads, as sketched below.



$$I_{\substack{\text{composite}\\ \text{bead}}} = \frac{.0043 \times 10^6}{17 \times 10^6} = .00025 \text{ in.}^4$$

Two-ply 0° graphite/epoxy provides the required bead stiffness.

Composite skin weight =

$$.030 \times 144 \times .050 + 3 \times 12 \times 1.2 \times .010 \ (055)$$

$$= .215 + .002 = .217 \ \mathrm{lb/ft}^2$$

Beaded aluminum skin weight =

$$.020 \times 144 \times .1 + 3 \times 12 \times 1.2 \times .020 \ (.1)$$

$$= .285 + .085 = .370 \ \mathrm{lb/ft}^2$$

Weight saving $= (.217/.37) - 1.0 = 30\%$

The ribs and spars are similar in design to beams. Composite sandwich ribs and spars are used for concept A-18. The weight saving is estimated to be 42% based upon the data of Ref. (7), Figure 20.

Table B-10 compares the affected weight for the conventional structure and concept A-18.

TABLE B-10. WEIGHT OF CONVENTIONAL STABILIZER AND CONCEPT A-18

Item	Conventional Affected Weight	Concept A-18
Primary Structure	(36.0)	(22.5)
Skin	7.0	4.8
Spars	9.0	5.2
Ribs	3.2	1.9
L. E. Skin	5.1	3.5
L. E. Rib	1.4	.8
T. E. Skin	6.0	4.2
Attachment Fittings	4.3	2.1
	36.0 lb	22.5 lb

The material weight is:

Graphite/Epoxy	2.9
Kevlar	13.4
Foam	6.2
	22.5 lb

The cost of concept A-18 for the stabilizer is:

110 Labor Hours @ $22.50 = $2480
2.9 lb Graphite/Epoxy x 1.2* @ $20/lb = $ 70
13.4 lb Kevlar x 1.2 @ $90/lb = $160
6.2 lb Foam x 1.2 @ $3/lb = $ 22
$2480 $252

* 20% wastage

Estimated cost is:

1.10* ($2480 + 1.35 ** x $252) = $3102

* Factor for miscellaneous attachments and details
** 35% overhead

Pylon

The pylon is an airfoil section designed to the maximum thrust of the tail rotor. The construction of the pylon is similar to that of the stabilizers.

TABLE B-11. WEIGHT OF CONVENTIONAL PYLON AND CONCEPT A-16

Item	Conventional Affected Weight	Concept A-16
Primary Structure	(41.9)	(26.6)
Skin-Torque Box	9.4	6.6
Spars	12.5	7.4
Shear Decks	6.8	4.6
Frames & Bulkheads	11.6	6.6
Stringers	1.6	1.4
Secondary Structure	(5.5)	(2.7)
	47.4 lb	29.3 lb

The material weight for concept A-16 is:

Graphite/Epoxy	2.6
Kevlar	16.6
Foam	7.5
Misc.	2.6
	29.3 lb

The cost of concept A-16 is:

180 Labor Hours @ $22.50 = $4050
2.6 lb Graphite/Epoxy x 1.20* x $20 = $ 62.
16.6 lb Kevlar x 1.20 x $10 = $200
7.5 lb Foam x 1.20 x $3 = $ 27
2.3 lb Misc. x $1 = $ 2.3
$291.3

Estimated cost is:

1.10*($4050 +(1.35**x $291) = $4888
* 20% wastage
**35% overhead

Fairings

Fairings include doors and cowlings and are secondary structures designed to local airloads. The fairings are mostly honeycomb sandwich with Kevlar faces. A typical panel is built of 3-ply Kevlar outer face, 1/2-inch-thick 3 lb/ft^3 honeycomb, and 2-ply Kevlar inner face. Weight is approximately 0.475 lb/ft^2.

An advanced concept for fairings is concept A-20. The concept is of a waffle pattern design of Kevlar skins with stiffening members of Kevlar and graphite/epoxy.

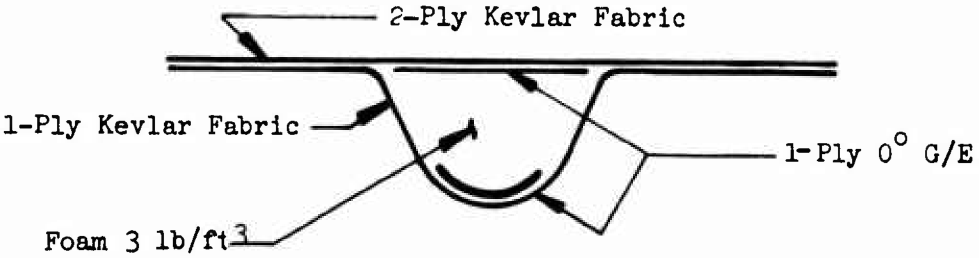
For the conventional fairing, the stiffness per inch width is

$$EI = .0132 \text{ lb-in.}^2 \times 10^6$$

For concept A-20, the airload is carried as membrane loads on the Kevlar skins, which are supported on a 8" x 8" grid framework. Stiffness of the grid is

$$EI_{grid} = 7 \times .0132 \times 10^6 = .0924 \text{ lb- in.}^2 \times 10^6$$

A grid stiffener is sketched below.



The weight of a waffle design panel is 0.27 lb/ft^2

Weight saving is $\left(1 - \frac{.27}{.47}\right) / 100 = 43\%$.

TABLE B-12. WEIGHT OF CONVENTIONAL FAIRINGS AND CONCEPT A-20

Item	Conventional Affected Weight	Concept A-20
Main Rotor Pylon	(32.0)	(18.1)
Frames & Bulkheads	1.9	1.1
Beams	.8	.4
Shell	28.6	16.2
Fittings	.7	.4
Antenna Cover	(4.4)	(2.5)
Cockpit Doors	30.5	(24.5)
Structure	30.5	24.5
Nose Door	(20.2)	(12.6)
Structure	20.2	12.6
Avionics Shelf	(5.6)	(3.7)
Cargo Door	(34.9)	(26.7)
Structure	28.3	22.4
Fairings	6.1	4.0
Joining	.5	.3
Engine Cowling	(46.2)	(33.6)
Frames	3.9	2.1
Shell	41.3	31.0
Fittings	1.0	.5
Other Fairings	(24.4)	(13.9)
	198.2 lb	135.6 lb

The cost of concept A-20 is estimated as follows:

Labor Hours = .57 hr/ft^2
Material Cost = \$6.84/ft^2
Weight = .27 lb/ft^2

$$\text{Labor} = \frac{.57}{.27} = 2.1 \text{ hr/lb}$$

2.1 x 22.50 = \$47 labor/lb

Material

$$1.2 \times \frac{6.84}{.27} = \$30/\text{lb}$$

Estimated Cost

1.10 (\$47 + 1.35 x \$30) x 135.6 lb = \$13,100

Landing Gear

The landing gears are designed primarily for two conditions:

1) 3-point 15-ft/sec sink speed, 2 g lateral.

2) 2-point crash landing.

Estimated loads for the two conditions are:

	V (Shear) (lb)	D (Drag) (lb)	S (Side) (lb)
1)	11,100		± 7,650
2)	42,000	-	-

A conventional gear consists of an upper cylinder of forged aluminum, housing an aluminum honeycomb core and a piston/cylinder of high-heat-treat steel. The piston/cylinder contains oil and a lower piston of steel. Attached to the lower piston is a steel axle supporting wheel brakes and a forged aluminum wheel.

The lower piston and oil cylinder act as an oleo strut for landings up to 15 ft/sec. During a crash landing, the lower piston bottoms, pins are sheared, and the oleo assembly crushes the honeycomb core in the upper cylinder. (See Figure B-1).

Bearings and seals are used to reduce sliding friction and to contain the oil. Torque scissors are used between the lower piston and the piston/cylinder to prevent pivoting of the wheels.

An advanced concept for a landing gear is concept A-21. This concept uses graphite/epoxy and Kevlar for all landing gear components except the axle. Bearings are not required. Preliminary tests show that graphite/epoxy sliding on graphite/epoxy is self lubricating (Ref. 15) The cylinders and pistons are of 0° polar-wound graphite/epoxy for axial load and bending, ± 45° graphite/epoxy for shear, and Kevlar at 90° for hoop tension caused by pressure on the oil during landings.

Design loads for the main gear cylinders and pistons are as follows:

Axial load = 11,100 lb (ULT)
Shear = 8,400 lb (ULT) (MAX)
Bending = 303,750 lb (ULT) (MAX)

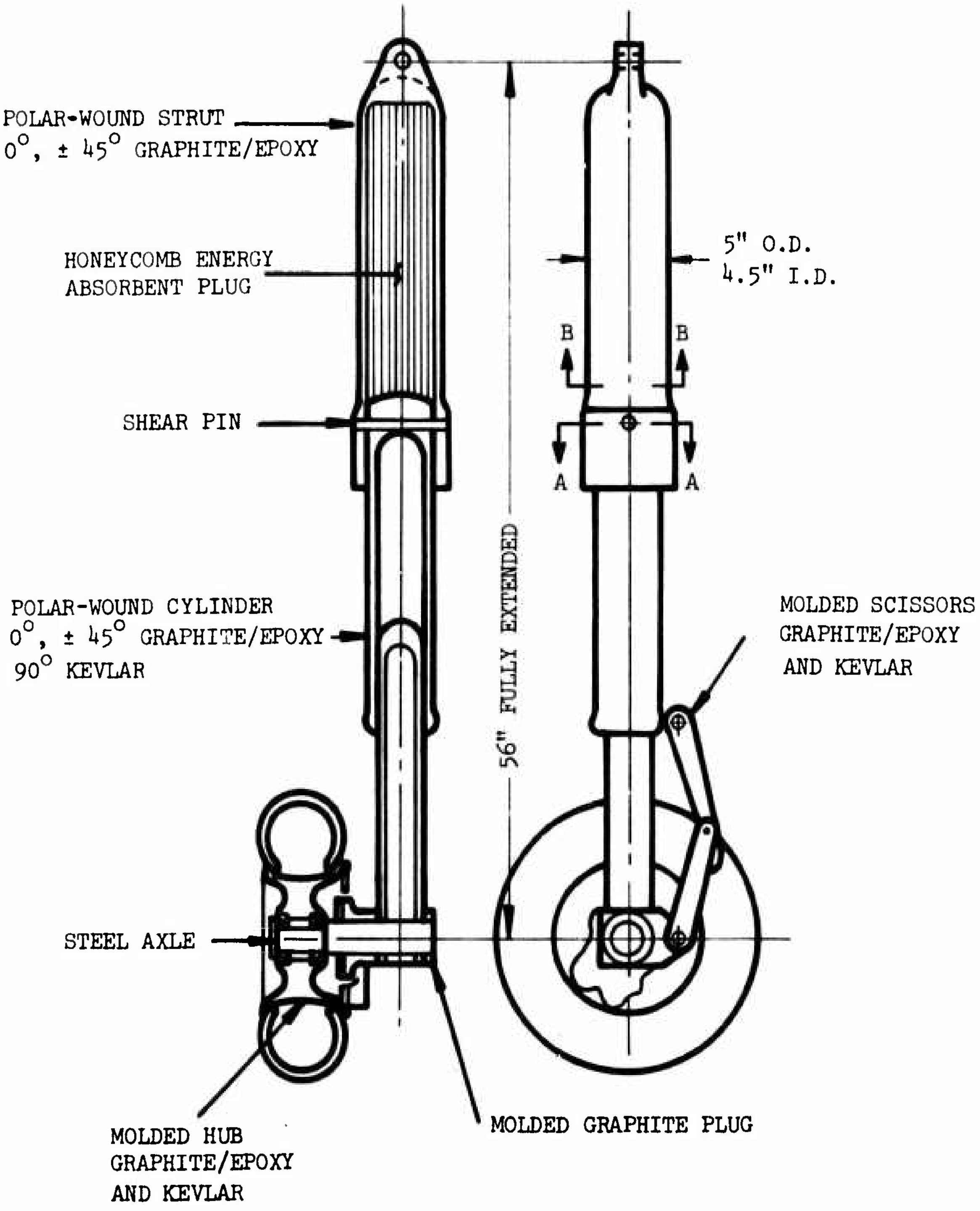


FIGURE B-1. **COMPOSITE LANDING GEAR.**

Upper cylinder (conventional) (Sect A-A)

I.D. = 4.50 in., t- .35 in., D/t = 12.7

Material 7075-T73 forging

$$fc = P/A + Mc/1 = \frac{11100}{T1(2.60^2 - 2.25^2} + \frac{303750\ (2.60)}{.25\ T1\ (2.60^4 - 2.25^4}$$

$$= 2050 + 48500 = 50550 \text{ psi}$$

$$Fs = 8400/8.5 = 980 \text{ psi}$$

$$Fcy = 51000 \text{ psi (Ref}$$

$$Wt = \pi\ (4.85)\ .35\ (.1) = .53 \text{ lb/in.length}$$

$$Wt = .53\ (26) = 13.8 \text{ lb}$$

The upper cylinder of graphite/epoxy and Kevlar is critical for the loads on the shear pin in a crash condition. The load required to shear the pin is 11,100 lb. A 5/16-in.-diameter shear pin is required. A reasonable joint allowable is approximately 30,000 psi.

Joint load = 11,100/2 = 5500 lb

$$t_{req} = \frac{5500}{.3125\text{x}30000} = .585 \text{ in.}$$

At section B-B the upper cylinder is critical for the bending loads.

I.D. = 4.5, t = .188 in., 0° graphite/epoxy

$$fc = \frac{11100}{(2.43^2 - 2.25^2} + \frac{303750\ (2.43)}{.25\ (2.43^4 - 2.25}$$

$$= 5000 + 105000 = 110{,}000 \text{ psi}$$

2-Ply $\pm 45^{\circ}$ graphite/epoxy is used for shear.
2-Ply 90° Kevlar is used for protection.

The weight is estimated to be:

$$Wt = 9\ (5.67 \times .6) + 27\ (4.9 \times .218)\ \ .055$$

$$= 10 \text{ lb + dome, caused by polar winding} = 10.5 \text{ lb}$$

$$\text{Wt saving is } \left(1 - \frac{10.5}{13.8}\right) / 100 = 25\%$$

TABLE D-13. WEIGHT OF CONVENTIONAL LANDING GEAR AND CONCEPT A-21

Item	Conventional Affected Weight	Concept A-21
Main Landing Gear	(170.1)	(127.0)
Wheels	22.9	17.0
Shock Struts	147.2	110.0
Tail Landing Gear	(48.9)	(36.7)
Wheel	4.6	3.4
Shock Strut	12.7	9.6
Fork	11.4	8.4
Trunnion	20.2	15.3
Alighting Gear	219.0 lb	163.7 lb

The material weight is:

	Total	Main	Tail
Graphite/Epoxy	(129)	97	32
Kevlar	(22)	15.4	6.6
Misc.	(13)	8.0	5.0
	164 lb	120.4 lb	43.6 lb

The cost for a composite landing gear, concept A-21, is estimated as follows:

Main Gear

Component	Labor Hours
Upper Cylinders	61.7
Piston/Cylinders	50.1
Pistons	36.6
Fittings	14.6
Wheels	32.4
Misc.	8.4
	203.8 hr

Labor Cost = 203.8 x 22.50 = $4575

Material Cost

Graphite/Epoxy 97 x $20 = $1940
Kevlar 15.4 x $10 = $ 154
Misc. 8.0 x $ 1 = $2102 x 1.2 = $2520

Cost is estimated as

$4575 + 1.35 ($2520) = $8000

Cost/lb = 8000/120.4 = $66.02/lb

Total cost, main & tail:

66.02 x 164 = $10,800

TABLE B-14. AFFECTED WEIGHT AND COST SUMMARY (AIRFRAME AND LANDING GEAR)

	Baseline		Advanced	
Item	Wt	Cost	Wt	Cost
Cockpit	47	4512	33	5062
Cockpit Tub	63	6510	39	6903
Upper Cabin	116	12693	68	12774
Cabin Tub	80	8735	45	8328
Transition				
Shell	179	20680	118	21655
Interior	224	18480	139	19316
Floor	30	3820	22	4202
Tail Cone	101	7165	68	7942
Horiz. Stab.	37	4300	23	3102
Pylon	48	5550	29	4888
Fairings	199	24000	136	13100
	1124	$116445	720	$107272
	$103.60/lb		$148.98/lb	
Land Gear	219	8200	164	10827
	$37.44/lb		$66.02/lb	

ROTOR BLADES AND MAIN ROTOR HEAD

All main blades and rotor heads are statically designed for an ultimate flatwise static load factor of 4.0.

Edgewise stiffness is governed by a starting torque of two times military rated power delivered to the rotor. The blades and heads are also designed for an overspeed condition of centrifugal force caused by 1.25 x normal rpm. For fatigue analysis, all blades and rotor heads are designed for no damage at maximum level-flight speed and maximum gross weight. These components are designed for 5000-hour minimum life through the complete flight spectrum. The conventional main blade has a titanium main structural member. It is rolled, formed, and contoured oval in shape to fit just below outer wrappings of fiberglass/graphite/epoxy plies, which are applied later. The spar forms approximately 30% of the chord width. The trailing edge has nomex honeycomb formed to the airfoil configuration. A leading-edge molded counterweight is formed to the leading edge of the blade. The entire structure is then covered with layers of fiberglass and graphite/epoxy tapes and structurally bonded in matched metal molds to conform to the exact aerodynamic contour.

GRAPHITE/EPOXY PULTRUDED SPAR, MAIN ROTOR BLADE

Total advanced concept blade weight is 342 lb, or 85.5 lb per blade. Each blade is essentially all composite. The main structural member is a pultruded graphite/epoxy spar extending the length of the blade. The fibers are oriented at ± 45° and unidirectional to withstand centrifugal and bending loads from the blade mass, pitch flapping, and lead/lag motions. The outer skin is a filament-wound wraparound formed in a mold while in wet layup to the blade aerodynamic configuration. The fiber orientation is mainly ± 45° to take most of the blade torsional loads. The blade inboard end thickens, as shown in Figure 18, to absorb root end edgewise, flapwise, and torsional bending loads. The blade is bolted to a plate cuff as shown in Figure B-2. All other blade components are secondary, or nonstructural, members. These include the molded counterweight, foam, and honeycomb core. The breakdown of component material is graphite/epoxy 35 lb, fiberglass 35 lb, molded counterweight 10 lb, and foam, bolts, honeycomb and adhesive filler 5 lb.

The conventional main rotor head is essentially all metal: titanium hub, aluminum and steel dampers, steel pitch control rods, and aluminum pitch horn. Elastomeric bearings are used mounted on steel spindles. All items of the rotor head were analyzed. Only the hub was found to be a candidate for change of material to improve structure and reduce weight. All other components were considered, but the same types of materials were retained for the following reasons:

a) The horn is already aluminum and already fairly lightweight and economical.

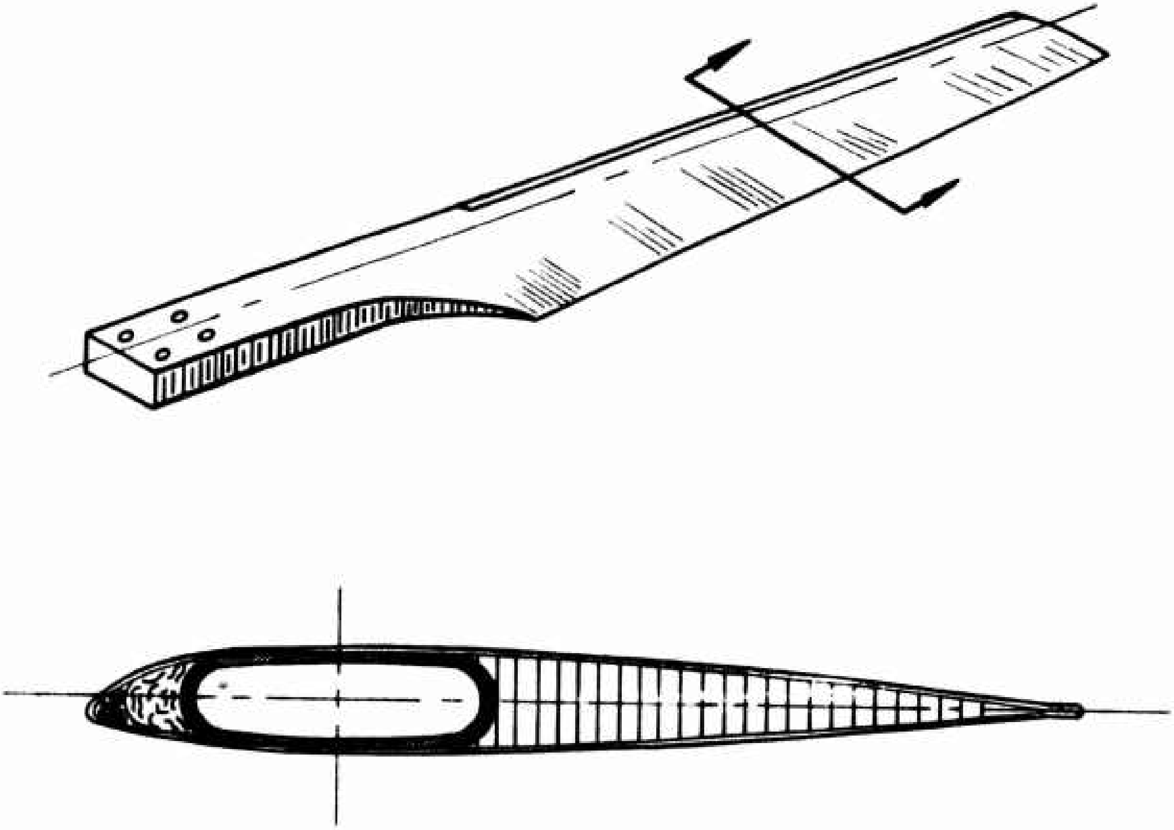


FIGURE B-2. GRAPHITE/EPOXY PULTRUDED SPAR - MAIN ROTOR BLADE.

b) The damper contains high cycle damping motions, which produce high hoop stresses in the cylinder and high compression and tensile loads on the steel piston/rod.

c) The elastomeric bearing supports the spindles and is also highly stressed in bending torsionally and centrifugally.

Even if these items were fabricated of composites, they would still require steel end bearings and fittings, which would later add back the weight saved in going to composites. Even though these conventional steel and aluminum parts are retained, the low weight of the advanced concept blades saves in total weight of the main rotor because of their lower centrifugal loads to the hub. The elastomeric bearings are reduced in size for the same reason. Finally, weight was saved by fabricating the conventional hub of composites.

FILAMENT-WOUND COMPOSITE ROTOR HUB

The advanced concept rotor hub is shown in FIGURE B-3. It is an all-composite, filament-wound hub of fiberglass and graphite/epoxy. The composite filaments in the hub arms are wound $\pm 45^{\circ}$ for torsional stiffness and unidirectionally for blade edgewise and flatwise root bending moments. Integrated metal inserts are woven into the structure during the winding operation. Each lug retains one end of each damper, which extends between the hub and an attachment on the blade cuff. Elastomeric bearings are inserted into each hub arm and bolted. Metal inserts are provided in the ends of the hub arms to retain these bolts, which extend through the elastomeric bearing assembly flange into the hub. Each elastomeric assembly has a spherical bearing that controls flapping and lead/lag motions and a thrust bearing that allows blade pitch and absorbs blade centrifugal loads. The use of a composite hub, plus lowered blade weight, accounts for a 73 lb weight saving in the rotor head assembly.

BLADE AND HEAD SAVINGS

The application of composites and advanced methods of fabrication result in rotor system components that are lighter and less costly than conventional components. The conventional blades and rotor head weigh 371 and 449 lb, respectively, and cost $44,400 and $30,200, respectively. The advanced structures for blades and rotor head result in weights of 342 and 403 lb and costs of $22,300 and $28,900, respectively. Total saving is 75 lb and $23,400.

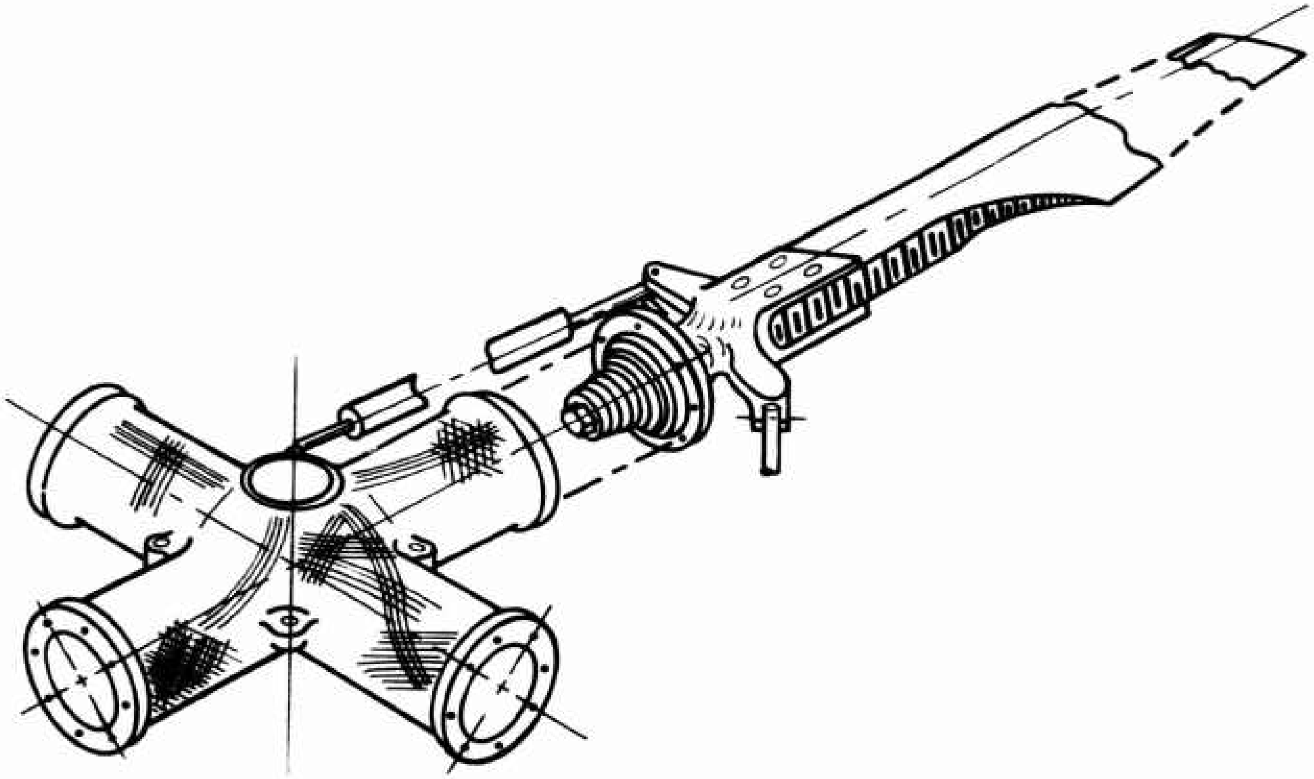


FIGURE B-3. FILAMENT-WOUND COMPOSITE ROTOR HUB.

COST FOR FABRICATION OF MAIN BLADE

Costs presented in Table B-15 assume experience obtained in fabrication of 2000 to 3000 blades.

TABLE B-15. SAMPLE COST OF FABRICATION OF BLADE CONCEPT B-3 (b, 4)

Material	
Graphite 35 lb @ $20/lb	$ 700
Fiberglass 40 lb @ $2.35/lb	$ 94
Adhesive	$ 50
Honeycomb (fabricated)	$ 160
Molded Counterweight	$ 75
Miscellaneous	$ 50
Abrasion Strip (fabricated)	$ 100
TOTAL MATERIAL	$1229
Labor	174 hr
Estimated Cost	Labor Cost + 1.35 Material Cost = 174 hr x $22.5/hr + (1229) (1.35) 3915 + 1659
Blade Cost	$5575

COST FOR FABRICATION OF MAIN ROTOR HEAD

Concept B-6

All components for both the baseline and advanced rotor head are the same except for the hubs. The baseline is titanium and the advanced hub is fiberglass and graphite. The difference in costs of these materials is the difference in the rotor head costs. The advanced rotor head cost is based on the following calculations:

Baseline titanium hub cost = (150 lb)($16/lb) = $2400

Advanced composite hub cost =
graphite (48 lb)($20/lb) = 960
fiberglass (56 lb)($2.35/lb) = 132
-$1092

Material cost savings = $1308

Cost of Advanced Rotor Head = Baseline Cost-Material Cost Savings

$30,200-$1308 = $28,892 or $28,900

CONVENTIONAL CROSS-BEAM COMPOSITE TAIL ROTOR

The conventional cross beam composite tail rotor is already a simplified rotor. Thrust and pitch bearings are not needed because of the flex action of the spar beam. The tail rotor consists of two unidirectional graphite/epoxy beams, each extending through the hub for full diameter length. All blade pitching and flapping are accomplished by the flexible blade spar. The spars are clamped to two aluminum hub plates fastened to the tail rotor shaft. The outer skin covering the outboard portion of the spar is cross-ply composite and forms the airfoil contour taking all the blade torsional loads. The leading edge of the blade is covered with a formed steel/nickel-plated abrasion strip structurally bonded to the leading edge of the blade. Nomex honeycomb is encapsulated between the spar and the outer skin and is also structurally bonded in a match-metal mold. A molded counterweight, to maintain mass balance about the pitch axis, is incorporated in the leading edge of the outboard portion of the blade.

The torque tube provides means of pitching the blade. It is torsionally stiff, sufficiently rigid to transfer torque from the pitch horn to the end of the torque tube and eventually pitch the blade portion of the cross beam assembly.

ADVANCED CROSS-BEAM COMPOSITE TAIL ROTOR

In the advanced concepts study, further improvements were made to the existing cross-beam composite tail rotor. Design and analytic studies were performed to demonstrate that the two aluminum hub plates could be integrated into a one-piece hub/spar subassembly (Figure 8-4). The integrated assembly consists of alternate layers of laminated titanium and composite materials to form a hub strong enough to withstand torsional and bending loads. With this advanced design, plates are not needed to fasten the cross beams to the tail rotor shaft. The result is lower weight and a more compact profile, producing less drag and smoother aerodynamic flow.

Another improvement is a separate blade attachment for each cross beam. This facilitates manufacture and reduces cost. The separate blade attachment also increases the maintainability of each cross beam. After damage to a blade sufficient to cause scrappage, a replacement blade can be installed without removing and scrapping an entire cross-beam member. This would reduce the cost for the member of spare cross beams required in the field.

The outboard portion of the advanced blade consists of a combination of graphite/epoxy and fiberglass filaments. Filament winding and forming in match-metal molds can be accomplished as with the outer skin of the main blade. Fiber orientation is similar to that in the main blade: $\pm 45^{\circ}$ and unidirectional to provide optimum strength lay-ups. The internal structure is nomex honeycomb and a molded leading-edge counterweight for blade balance, both structurally bonded to the skin. The inboard end of the blade is made thicker at the bolt attachment to obtain smooth

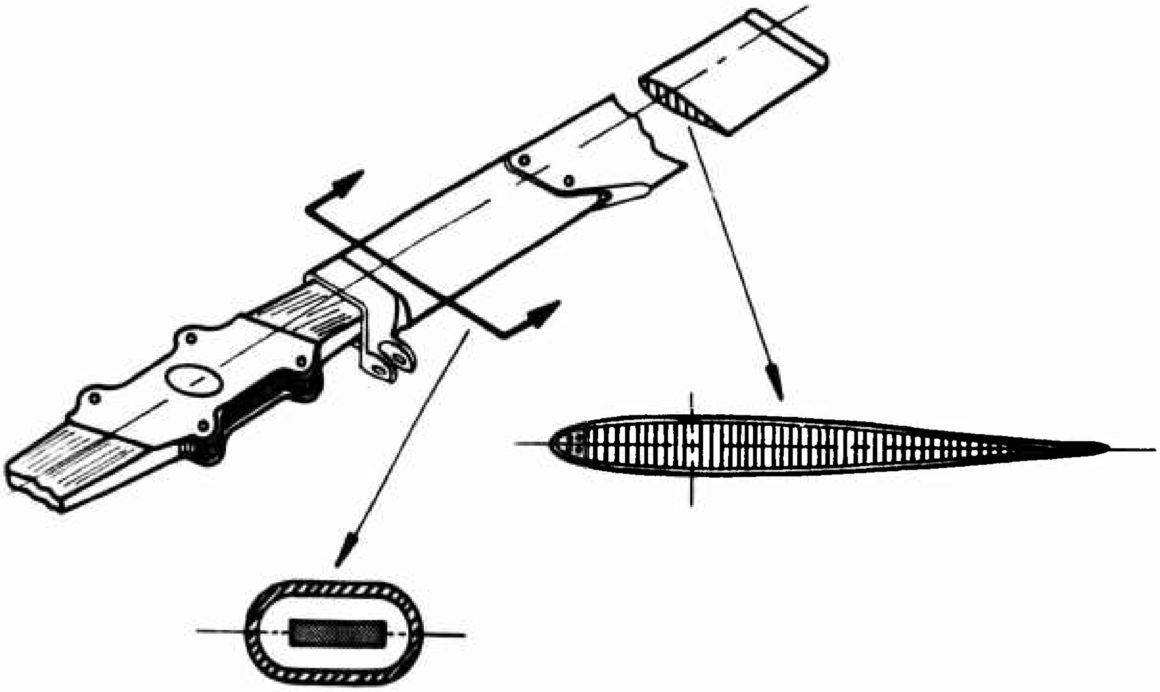


FIGURE B-4. ADVANCED CROSS-BEAM COMPOSITE TAIL ROTOR.

transfer of loads from the blade to the flex beam.

The tail rotor design criterion is for maximum tail rotor thrust (yaw) in autorotation during severe symmetrical dive and pullout. The tail rotor is designed for a natural frequency .2/rev removed from the exciting frequency. The optimum would be 1.5/rev.

COST FOR FABRICATION OF CROSS-BEAM TAIL ROTOR ASSEMBLY - CONCEPT B-8

The conventional tail rotor assembly weighs 47 lb and costs $5,500. By integrating the hub plates with the tail rotor cross-beams, 3 pounds can be saved. Three pounds less weight results in ($5,500/47 lb) (3 lb) = $351.00 savings. Therefore, the advanced cross-beam tail rotor cost is: 5,500 - 351 = $5,149.00 or $5,150.00.

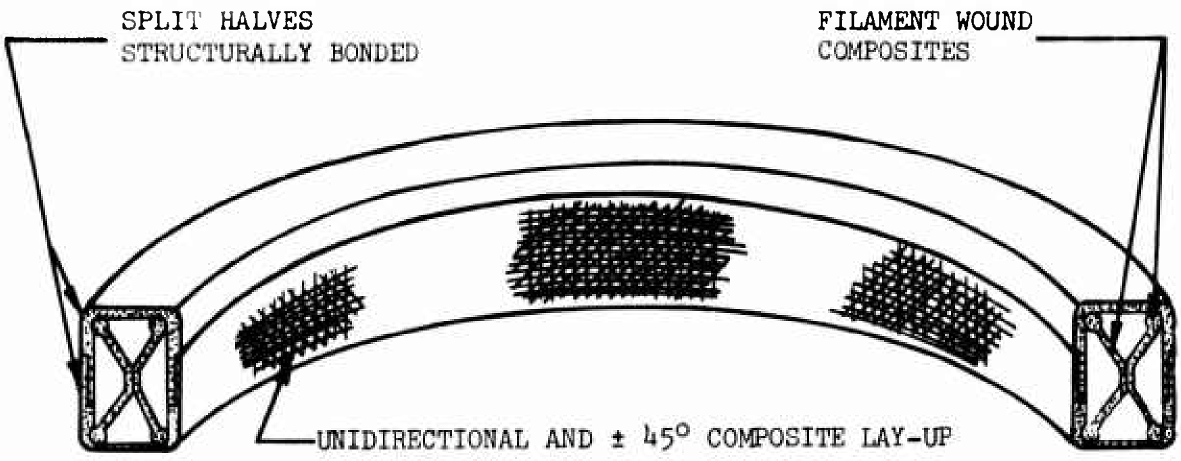
ROTATING AND STATIONARY CONTROLS

The conventional swash plate and scissors assemblies are made of metal. The stationary and rotating swash plates and scissors are aluminum and steel forgings machined to reduce weight and to obtain close fits with mating parts. Fittings are provided for servo control rods and stationary scissors to be attached to the stationary swash plate. The rotating swash plate has mounting provisions for the blade pitch control rods and rotating scissors. A standpipe is bolted to the main gearbox, and the stationary scissors are attached between the standpipe and the stationary swash plate.

The advanced concept rotating and stationary swash plates are similar in design, as shown in Figure B-5. The heavy forgings have been replaced by filament-wound and tape laid-up composites. The only metal is found in the bearings and the hard points required for servo and pitch control rod attachments. The interior of the swash plates consists of two cylindrical members that form a cross. The individual members of the cross have high-modulus filament-wound fiberglass and graphite/epoxy to carry the swash-plate bending and shear loads. The exterior half shells are in two split halves. These halves are filament-wound composites that are formed in match-metal molds while still in the wet lay-up. The two halves are then structurally bonded over the interior cross member, as shown in Figure B-4.

The entire structure can sustain torsional, shear, and bending loads induced by the servo and pitch control rods. Metal bearing liners and lugs for control rods are structurally bonded as required. This process eliminates forgings and machining and requires a minimum of tools.

The swash plate design criteria call for the individual components to carry vibratory shear, bending, and torsional loads resulting from simultaneous reactions of the servo and pitch control rods. The components are designed for a safety factor above the allowable combined working stresses.



TYPICAL FILAMENT-WOUND COMPOSITE SWASH PLATE

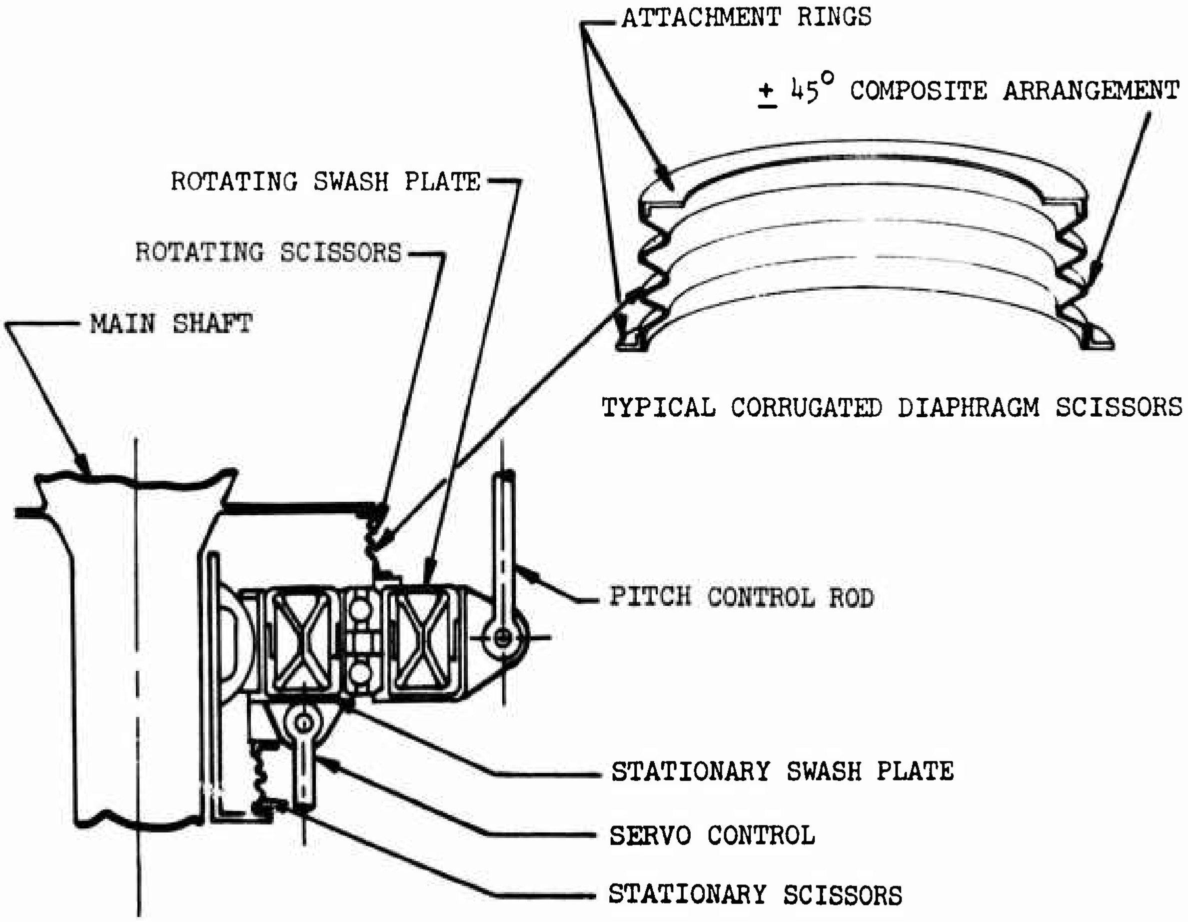


FIGURE B-5. ROTATING AND STATIONARY CONTROLS.

Each of the conventional rotating/stationary scissors is attached at one point on the rotor system assembly. The advanced scissors are circumferential. The torsional load path of the bellows-type scissors uniformly distributes the load in contrast with the conventional scissors, which develop a less desirable concentrated load. The advanced bellows scissors are of fiberglass for flexibility and graphite/epoxy for stiffness. The stationary and rotating members of the bellows diaphragm are convoluted conical structures. The fiberglass materials of the scissors permit vertical and tilt motion of the swash plate for collective and cyclic motions. The graphite/epoxy at ± 45° orientation maintains torsional rigidity. The diaphragm has the flexibility to extend, contract, or tilt to duplicate scissors actions, but the addition of the graphite fibers provides the torque requirements to prevent rotation or elbow turning. This process eliminates the need for heavy links and machining, resulting in lower weight and cost.

An alternative design to the bellows diaphragm scissors of Concept B-11 is B-12, a diaphragm flex scissors (Figure B-6). This component has the same flexibility of motions as the bellows diaphragm scissors. It can translate axially up or down for collective motion and can be combined with tilt to produce cyclic motions. It has another feature: inherent lateral stability without the spherical bearing required with the bellows diaphragm scissors.

The construction is typical of a stationary or rotating swash plate. A flexible elastomer membrane provides the cyclic and collective motions to the scissors needed to move the blade pitch rods for helicopter control. To prevent lateral movement, either steel or boron reinforcement is cylindrically positioned 90° to the vertical axis. The steel or boron acts like a coil spring, permitting axial or tilt motions but preventing side-to-side movement from the vertical axis.

COST FOR FABRICATION OF COMPOSITE TORQUE TUBE SWASH PLATE - CONCEPT B-10

The conventional swash plate weighs 89 lb and costs $4,800. The estimated labor savings fabricating by filament winding is 22 hours or 22 hr x $22.5/hr = $495. The cost of the aluminum for the conventional swash plates is 55 lb x 1.20 = $66. The cost of the graphite and fiberglass for the advanced swash plates is:

graphite, 25 lb x $20/lb = $500
fiberglass, 20 lb x $2.35/lb = $ 47
$547

The cost of the advanced swash plate is: $4,800 - $495 - $66 + $547 = $4,786 or $4,800.

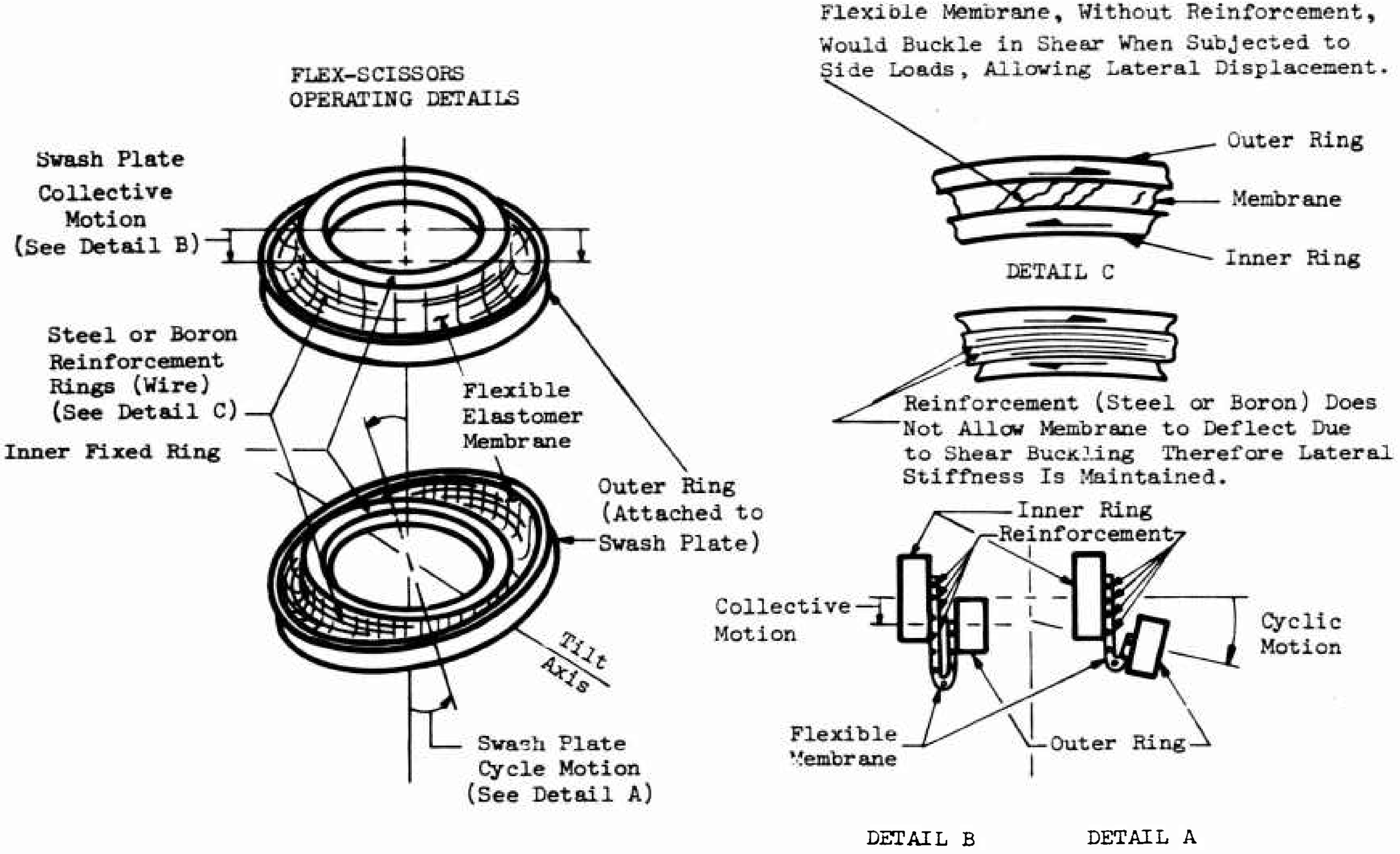


FIGURE B-6. ALTERNATE FLEX-SCISSORS.

COST FOR FABRICATION OF COMPOSITE BELLOWS DIAPHRAGM

CONCEPT B-11

The conventional scissors weigh 12 pounds and are estimated to cost $1440. The advanced bellows diaphragms are reduced to 9 pounds by substituting lightweight graphite and fiberglass for titanium and steel forgings. Overall savings in materials and labor reduces cost to $1200 as follows:

Conventional

Material

Titanium 8 lb x $16/lb = $128
Steel 4 lb x $1/lb = $ 4
$132

Labor 56 hrs

Cost 56 hr x $22.5/hr + (132)(1.35) = $1438 or $1440.

Advanced

Material

Graphite = 2 lb x $20/lb = $ 40.00
Fiberglass = 4 lb x $2.35 = $ 9.40
Steel = 3 lb x $1.00 = $ 3.00
$ 52.40

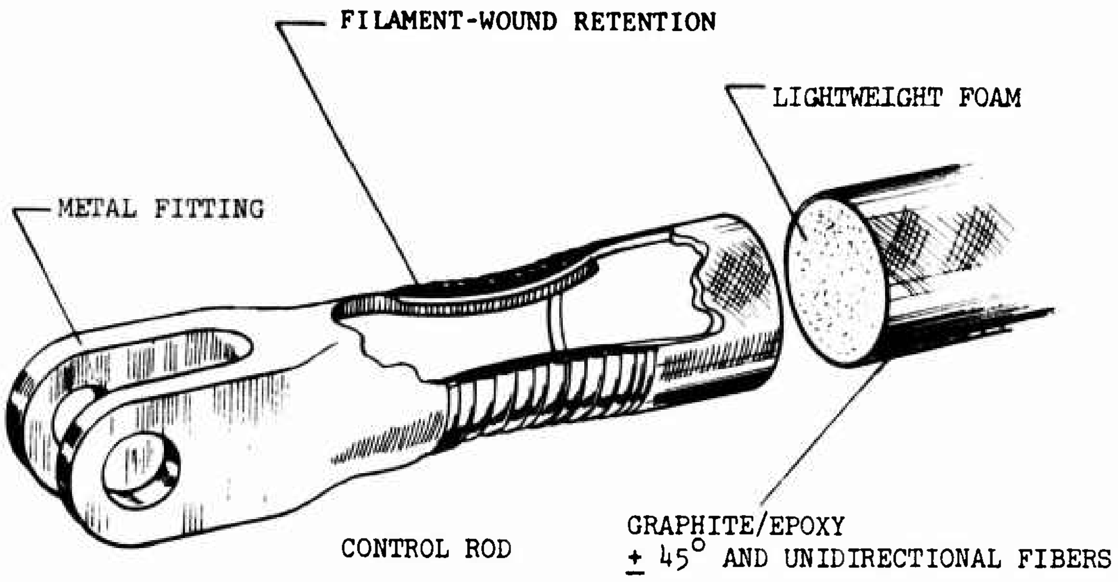
Labor 50 hrs

Cost 50 x $22.5/hr + (52.4)(1.35) = $1195 or $1200

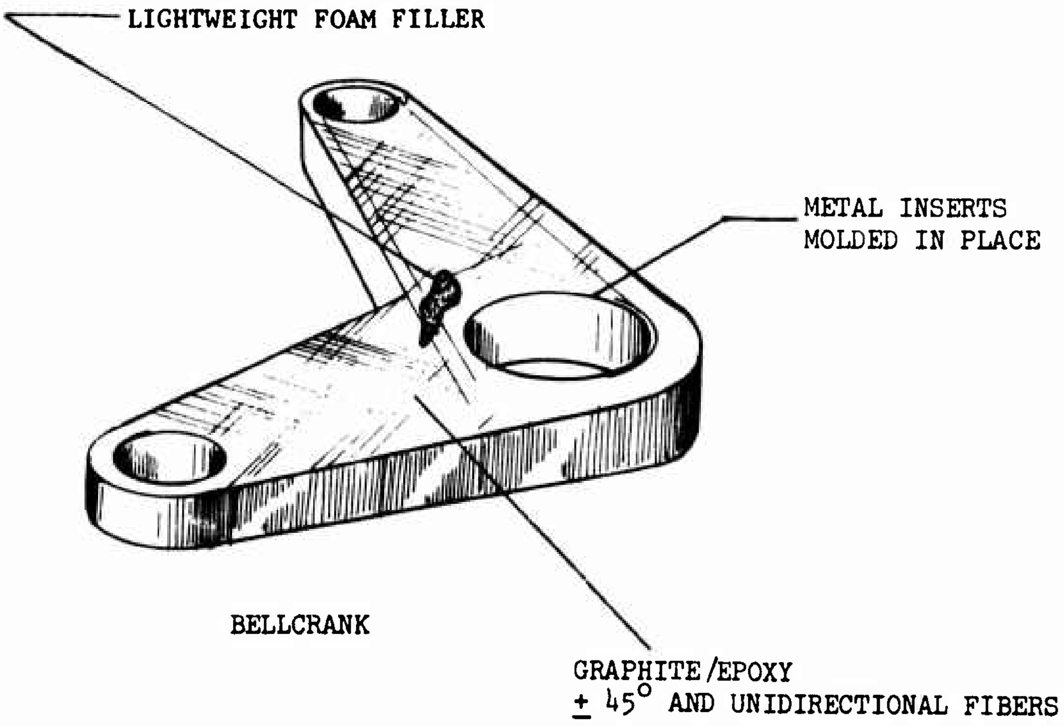
CONTROL RODS AND BELLCRANKS

Conventional control rods are made from aluminum and steel tubings. Bellcranks and attachment fittings are made from steel and aluminum forgings. The control rods have steel spherical ball bearings and fork-ended fittings, which are attached to the tubular control rods. The bellcranks are machined and assembled with press-fitted bearings to eliminate friction during motion of control rods and bellcranks. Because of the spherical bearing attachments, the control rods are loaded axially (tension or compression). The concept depends on the loading.

The advanced concept control rods, (Figure B-7) consist mostly of unidirectional graphite/epoxy fibers with a wrap of ± 45° graphite/epoxy to retain the unidirectional fibers. The tubular structure of the rod makes this a good application for the filament-winding process. A metal fitting



CONTROL ROD



BELLCRANK

FIGURE B-7. CONTROL RODS AND BELLCRANKS.

is attached by filament winding at 90° to the tube axis around an area where the tube and fitting are necked down in the familiar coke bottle design. The interior of the tube is filled with a lightweight foam to prevent crushing or collapsing of the fibers under compressive load.

The advanced concept bellcranks are essentially loaded in bending, with the main stress load at the pivot point. The bellcranks contain mostly unidirectional fibers so wrapped as to encompass the pivot bearing and control rod end bearings. Layers of ± 45° graphite/epoxy tape are applied over the unidirection fibers to retain the assembly intact. A lightweight foam is inserted in the bellcranks for stability.

The selection of amounts and fabrication costs for materials for control rods and bellcranks depends on the modulus, density, allowable bending, compressive and tensile stresses, and labor costs. A reduction of seven pounds appears possible with a slight increase in cost over the conventional control rods and bellcranks.

COST FOR FABRICATION OF CONTROL RODS, BELLCRANKS AND SUPPORTS - CONCEPT B-12

The conventional control rods and bellcranks are fabricated from steel and aluminum tubing and forgings weighing 130 lb and costing $15,210. The advanced control rods and bellcranks are fabricated with lightweight graphite resulting in a savings of 7 lb. There is an increase in cost, however, due to the higher price of the graphite material.

Conventional

Steel and aluminum forgings and tubes approximately $1.20/lb. Therefore: (130 lb)($1.20/lb) = $156

Advanced

Graphite (42 lb)($20/lb)	=	$840
Steel/Aluminum Fittings (75 lb)(1.2)	=	$ 90
Foam	=	$ 15
		$945

The cost of the advanced control components equals 15,210 - 156 + 945 = $15,999 or $16,000.

ROTOR SYSTEM WEIGHTS

The weights of the baseline and advanced rotor system components were based on trending weight curves and empirical formulas developed by Sikorsky for helicopters of various sizes and gross weights. The baseline rotor system weights were scaled down from the Army/Sikorsky UTTAS 15,858-pound gross weight helicopter, using empirical formulas for similar components. A typical trending equation is shown below for the main rotor blade. The rotor blade weight equation is derived semianalytically from stress analysis with statistical indexing factors to correct for manufacturing technique and secondary weight items not covered by the analysis. The equation is indexed to the UTTAS improved rotor blade with its high-twist titanium spar. Major design parameters included in the equation are forward speed, blade area, aspect ratio, stress level, and tip speed.

$$Wb = K1\ (MS + 1)\ (R/10)^3\ (\ R/100)^2\ (1 +\ \ )^2 + K2\ RC\ 1 + K3\ (R/10C)^2$$

$$(\ R/100)^2\ 1 - K4\ (MS + 1)\ (\ R/100)^2$$

The advanced components were further modified by differences in physical properties between the baseline and the advanced concepts.

The final selection was an articulated rotor system. The advanced blade, 2B-3 (b,4), has a pultruded composite spar and filament-wound outer skin. The advanced rotor head has a filament-wound composite hub, B-6.

The main difference between the baseline and the advanced rotor systems is that the advanced blade spar material is graphite/epoxy and the baseline is titanium. The advanced blades weigh approximately 85 pounds each, 7 pounds lighter than the conventional blades. The weight of the advanced blade was estimated by comparing differences in moduli and densities of the spar material. The baseline spar is 50% of the blade weight, or (50)(92.7) = 46 pounds. Weight saved by using graphite/epoxy equals:

$$\text{Spar}_{\text{Advanced}} = \left(\text{Spar}_{b}\right)\left(\frac{E_b}{E_a}\right)\left(\frac{G_b}{G_a}\right)\left(\frac{{}_a}{{}_b}\right)$$

where Spar_b = titanium baseline weight = 42 lb

E_b = titanium baseline tensile modulus = 16 x 10^6 psi

G_b = titanium baseline shear modulus = 6.2 x 10^6 psi

${}_b$ = density baseline = .16 lb/in^3

$^*E_a$ = advanced tensile modulus = 12 x 10^6 psi

$^*G_a$ = advanced shear modulus = 3.75 x 10^6 psi

ρ_a = density (advanced) = .055 lb/in^3

*Combined fibers

Therefore,

$$\text{Spar}_{\text{Advanced}} = (46)(16/12)(6.2/3.75)(.055/.16) = 35\ \text{lb}$$

which reduces blade weight by 7 pounds.

The advanced main rotor head selected weighs 403 pounds before reduction in weight for the lighter blade, which reduces the head weight to 376 pounds. The principal differences are in the hubs. The baseline is titanium, and the advanced hub is of filament-wound combinations of fiberglass and graphite/epoxy filaments. The baseline hub was estimated to weigh 131 pounds, or 29% of the total baseline rotor head weight of 449 pounds.

The weight saving of the advanced rotor system was developed by:

$$\text{Hub}_{\text{Advanced}} = \left(\text{Hub}_b\right)\left(\frac{E_b}{E_a}\right)\left(\frac{G_b}{G_a}\right)\left(\frac{a}{b}\right)$$

where Hub_b = titanium baseline weight = 150 lb

E_b, G_b, and ${}_b$ (See Above)

$^*E_a$ = advanced tensile modulus = 14.25×10^6 psi

$^*G_a$ = advanced shear modulus = 3.75×10^6 psi

ρ_a = density (advanced) = .06 lb/in^3

*Combined fibers

Therefore,

$$\text{Hub}_{\text{Advanced}} = (150)(16/14.25)(6.2/3.75)(.06/16) = 104 \text{ lb}$$

which reduces the advanced rotor head weight by 46 pounds.

The selected cross beam composite tail rotor, B-8, has integrated laminated plates in the hub portion of the blade. It is estimated that three pounds can be saved by the laminated concept.

The advanced controls, consisting of rotating and stationary swash plates and scissors and bellcranks and control rods, also show small decreases in weight. These were based on physical property differences between the baseline and advanced concepts.

TRANSMISSION SYSTEM

Several advanced drive system concepts were reviewed and compared with existing designs used in the baseline aircraft. Concepts chosen for further study are listed in Table B-16.

TABLE B-16. TRANSMISSION CONCEPTS CHOSEN FOR STUDY

Item	Baseline	Advanced Concept
Housings	Magnesium Casting	C-2 Fabricated Sheet Metal Housing (Stainless Steel)
Output Gears	Conventional Spur Gears	C-4b High-Contact-Ratio Gears
Gear Materials	Conventional Gear Materials	C-4c High-Strength Gear Materials
Tail Drive Shafts	Subcritical Aluminum Drive Shafts	C-7 Supercritical Foam-Filled Composite Drive Shafts

Gearbox Housings

Gearbox housings (Figure B-8) are designed for two conditions:

1) Crash conditions (weight of rotor head and blades x appropriate factor)
2) Extreme maneuver conditions (aerodynamic blade loads transferred to the housing through the main rotor shaft).

Crash conditions generally result in higher loads on the housings and usually govern design. A shell analysis is done to determine basic wall thicknesses, and attached segments are analyzed as flat plates or cantilever beams.

Finite-element techniques are applicable to casting analysis, but because of long lead times required for procurement of castings, design usually must be finalized too quickly to use these technqiues. If a pre-processor were developed to define housing geometry, lead times could be cut substantially, and several more design options could be reviewed.

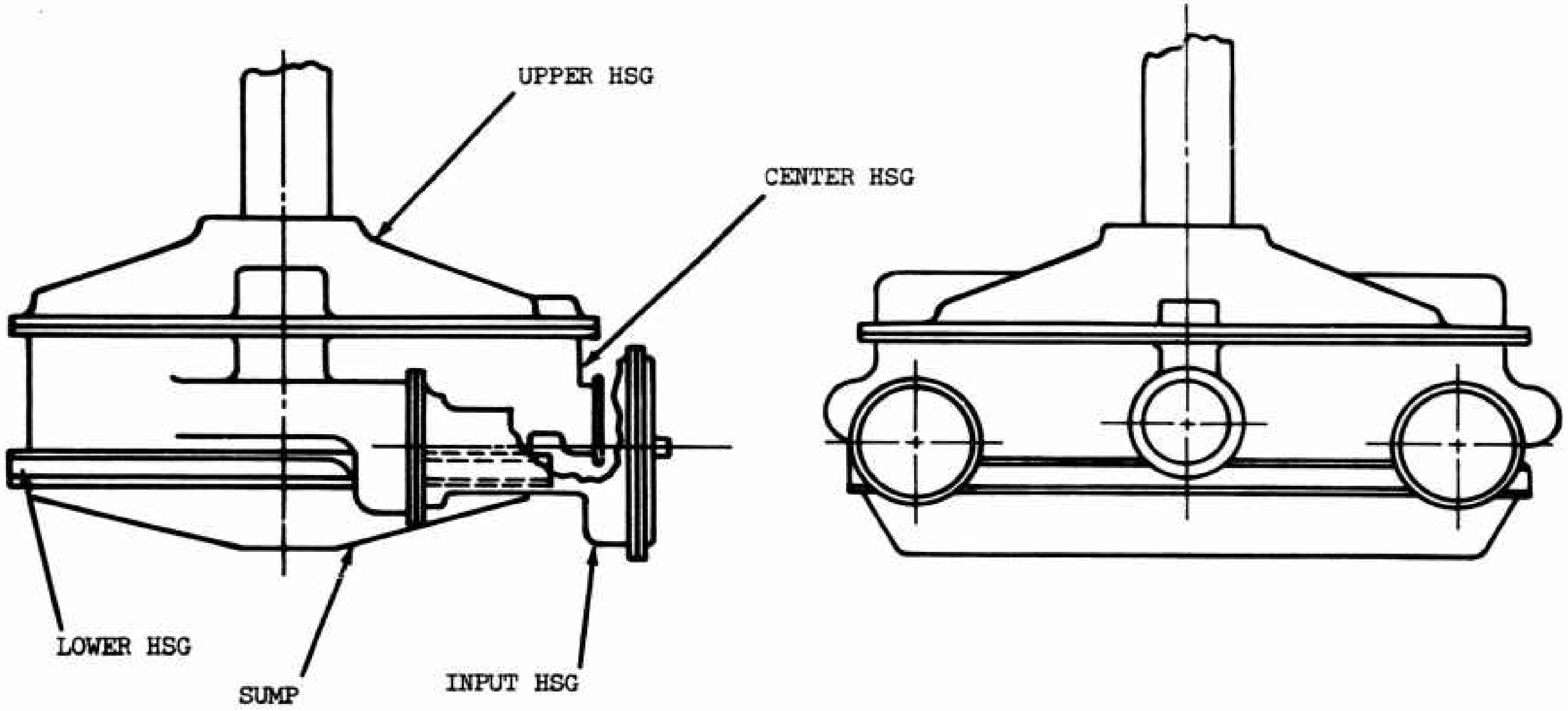


FIGURE B-8. BASELINE GEARBOX.

The design selected for comparison with the baseline magnesium castings is the concept C-2 fabricated stainless-steel sheet-metal design. Because the housings are loaded primarily in tension and compression, a strength comparison was made to size the fabricated housing:

$$(\text{Margin of Safety})\ \text{Magnesium} = (\text{Margin of Safety})\ \text{ST}$$

$$(F_{tu}\ A)\ \text{Magnesium} = (F_{tu}\ A)\ \text{ST}$$

$$F_{tu}\ \text{magnesium} = 17000\ \text{psi}$$

$$F_{tu}\ \text{ST} = 150{,}000\ \text{psi}$$

The cast and fabricated center housings are compared below. The baseline magnesium casting consists of a .38-in.-thick wall, .38-in.-thick flanges, and .75-in. x .38-in. cross-section ribs. The cross-sectional area and the perimeter of the casting are:

$$A = 49.4\ \text{in.}^2$$

$$P = 125\ \text{in.}$$

Using the same configuration for the fabricated center housing, (Figure B-9) the cross-sectional area and wall thickness become

$$A_{st} = \frac{17000 \times 49.4}{150000} = 5.6\ \text{in}^2$$

$$T_{st} = \frac{5.6}{125} = .045\ \text{in}$$

For bending, the flange thickness is a function of t^2:

$$(F_{tu}t^2)\ \text{Magnesium} = (F_{tu}t^2)\ \text{ST}$$

The fabricated housing flange thickness is

$$t_{fst} = T_{f_{mag}} \left(\frac{F_{tu}\ \text{mag}}{F_{tu}\ \text{st}}\right)^{1/2}$$

$$t_{fst} = .38 \left(\frac{17000}{150000}\right)^{1/2} = .125\ \text{in.}$$

The thickness of ribs .75 in. wide on the fabricated design is also t_{st} = .125 in.

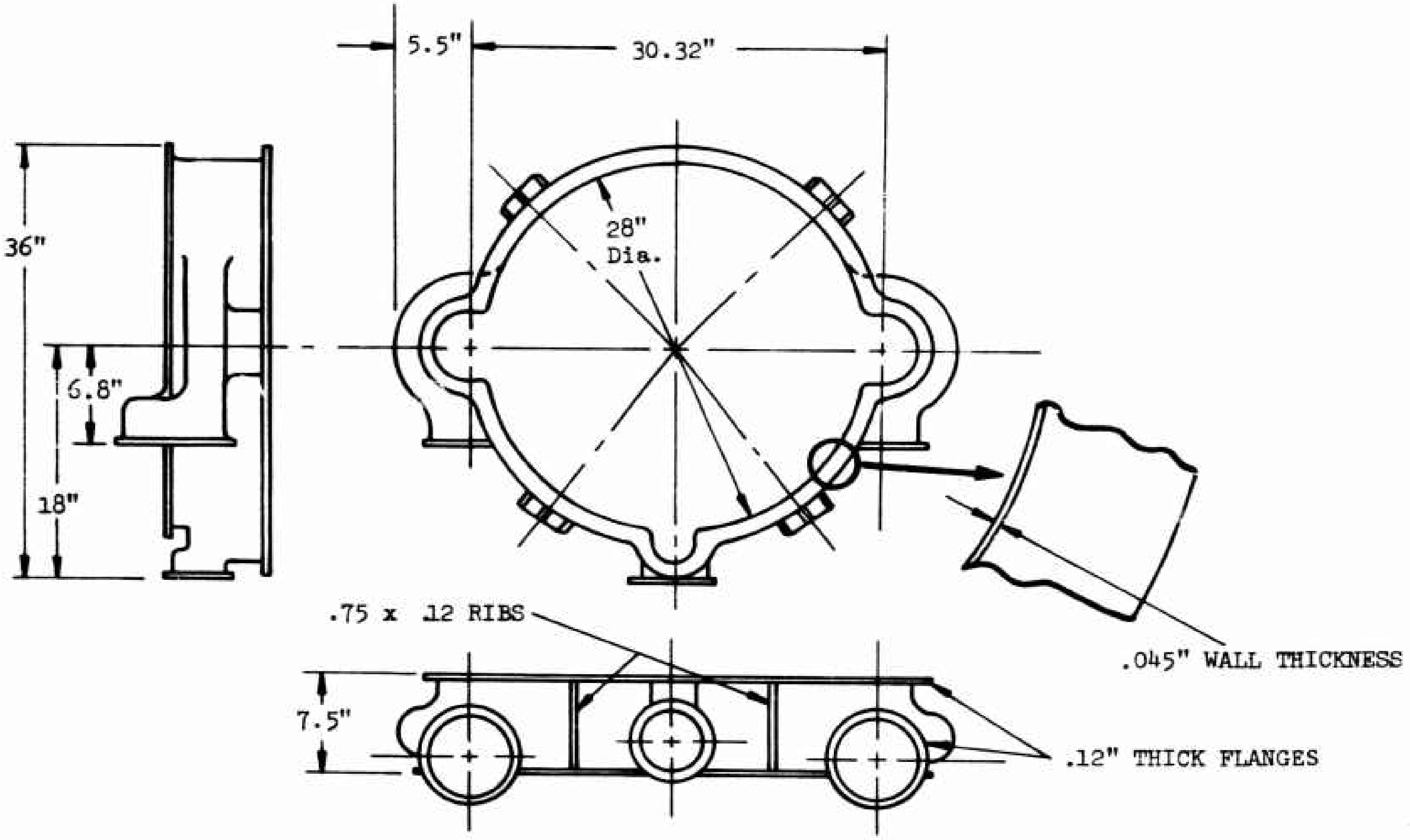


FIGURE B-9. FABRICATED CENTER HOUSING, STAINLESS STEEL.

The major weight savings in the center housing are:

Skins $\frac{19.9 - 10.3}{19.9}$ X = 48%

Accessory and Feet $\frac{40.0 - 26.0}{40.0}$ X = 35%

It is assumed that the addition of accessories, feet, and servo pads to the weight of other items is the same for both housings. This assumption results in a weight of 26.0 pounds for accessories and feet of the fabricated housing.

The baseline upper housing consists of a .38-in.-thick wall, .38-in.-thick flanges, and 1.5-in.x .38-in. cross-section ribs. The fabricated upper housing consists of .045-in.-thick skin, .125-in.-thick flange, and 1.0-in. x .12-in. cross-section ribs as shown in Figure B-10.

The major weight reductions in the upper housing are

Ribs $\frac{3.2 - 1.5}{3.2} \times 100 = 53\%$

Skin $\frac{18.3 - 10.0}{18.3} = 45\%$

Bearing Supports and Liners $\frac{7.6 - 5.0}{7.6} = 34\%$

The wall and flange thicknesses of the baseline sump are .25 in. Rib cross sections are .38 in. x 2.0 in. The wall thickness of the fabricated sump is .030 in. The flange thickness is .09 in., and rib cross sections are .09 in. x 2.0 in., as shown in Figure B-11. The major weight reduction is in the skins.

$$\frac{14.6 - 7.8}{14.6} \times 100 = 46\%$$

The baseline input housing consists of .188-in. wall thickness, .25-in.-thick flanges, and .188-in. x 2.0-in. cross-section ribs. The fabricated input housings consist of .030-in. wall thickness, .090-in.-thick flanges, and .060-in.-thick ribs. A slight increase in weight is seen, due to the smaller relative amount of skin material required in the input housings.

The weight of the tail takeoff housing is approximately 60% the weight of one input housing.

Affected costs of the conventional and fabricated housings are shown in Table B-17. Conventional housing cost is assumed to be $54/lb.

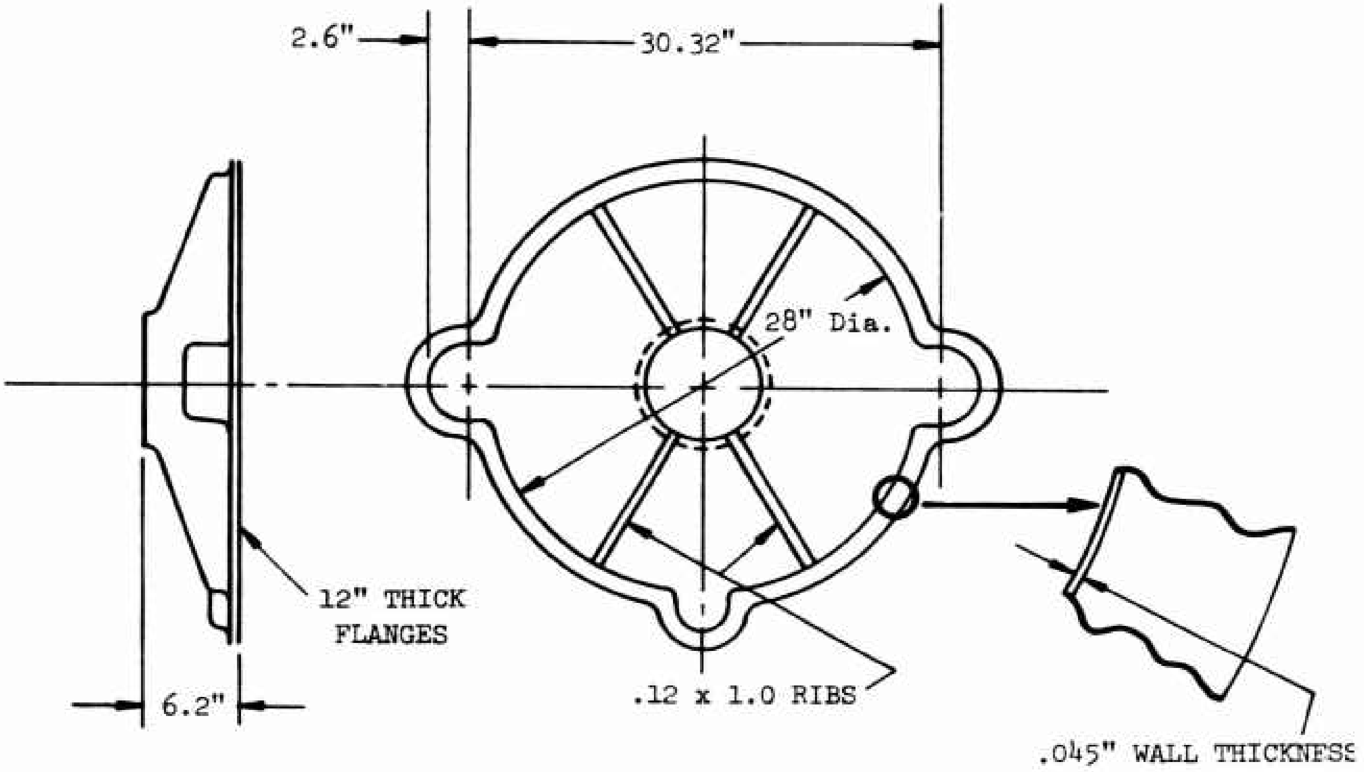


FIGURE B-10. FABRICATED UPPER HOUSING, STAINLESS STEEL.

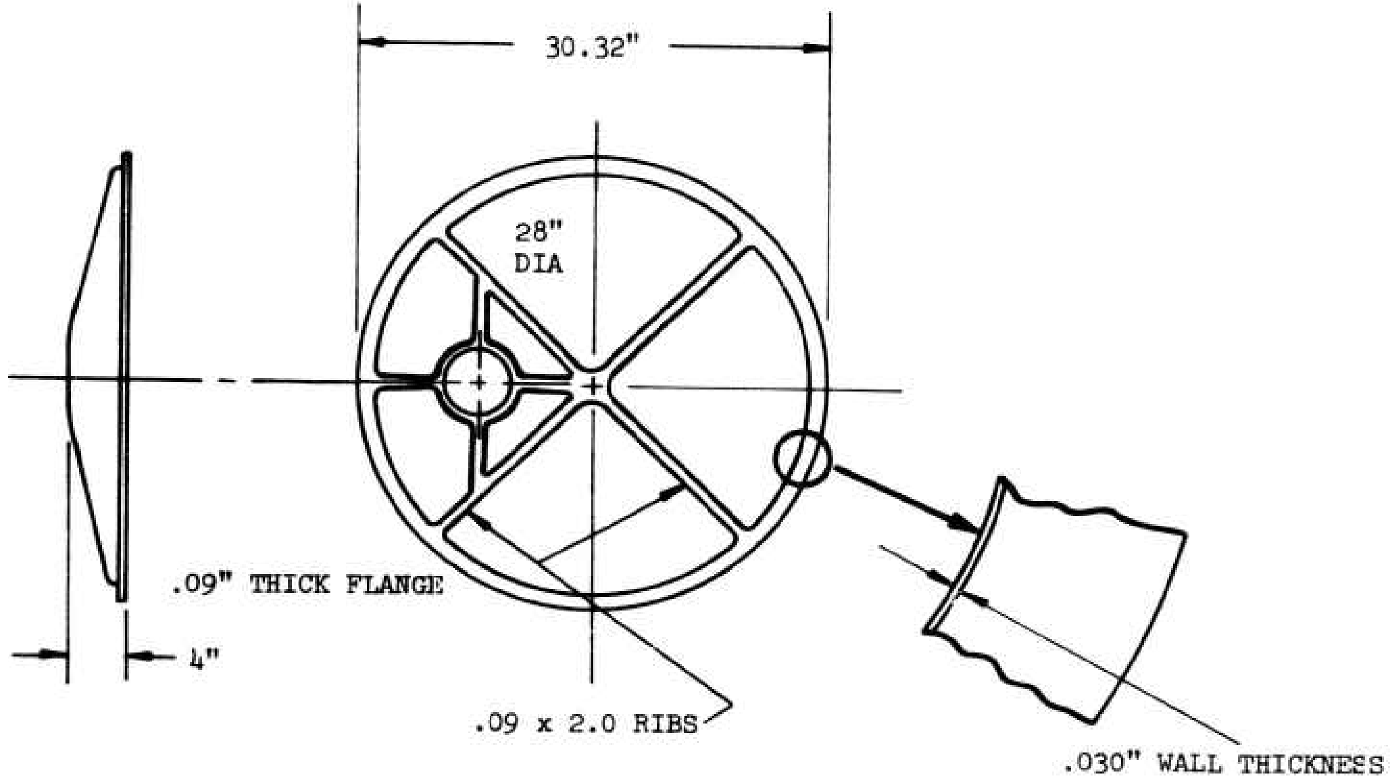


FIGURE B-11. FABRICATED SUMP, STAINLESS STEEL.

TABLE B-17. WEIGHT OF CONVENTIONAL HOUSING AND CONCEPT C-2

Item	Conventional Affected Wt	Concept C-2
Center Hsg.	(72.0)	(50.1)
Flanges	8.3	11.0
Ribs	1.0	1.5
Skin	19.9	10.3
Studs	2.8	.4
Welds	-	3.5
Acc.,Feet & Servo Pods	40.0	26.0
Upper Hsg.	(32.5)	(22.2)
Flanges	3.4	3.8
Ribs	3.2	1.5
Skin	18.3	10.0
Brg. Supts & Liners	7.6	5.0
Weld	-	1.9
Sump	(22.0)	(17.9)
Flanges	4.5	5.5
Ribs	2.9	3.1
Skin	14.6	7.8
Weld	-	1.5
Input Hsgs. (2)	(27.5)	(29.4)
Flanges, Brg. Supts & Liners	18.7	19.5
Ribs	2.4	2.1
Skins	6.4	5.3
Welds	-	2.5
Tail Takeoff Hsg.	(8.2)	(8.6)
Flanges, Brg. Supts & Liners	5.6	5.8
Ribs	.7	.6
Skins	1.9	1.6
Welds		.6
Total Wt.	(162.2) lb	(128.2) lb

TABLE B-18. COST OF CONVENTIONAL HOUSING AND CONCEPT C-2.

Item	Conventional Housing Cost	Concept C-2 Cost
Center Housing	$ 3890.00	$ 3050.00
Upper Housing	1760.00	1370.00
Sump	1190.00	960.00
Input Housings (2)	1480.00	1390.00
Tail Takeoff Housing	450.00	390.00
	($ 8770.00)	($ 7160.00)

For the conventional center housing:

Cost = $54/lb x 72/lb = $3890

Material and fabrication cost for the sheet metal housing is assumed to be $22/lb. It is also assumed that machining cost for the conventional housing is one-half the total cost. This does not change for the fabricated housing. For the advanced center housing:

Cost = $22/lb x 50.1 lb + 1/2 x 3890

Cost = $3050

Truss housing, Concept C-3, was investigated. The truss housings consist of stainless steel skins and flanges welded to stainless steel tubes. Weight and cost of Concept C-3 are listed below.

Item	Weight	Cost
Center Housing	59.8	$3330.00
Upper Housing	23.3	1460.00
Sump	26.6	1070.00
Input Housings (2)	36.5	1580.00
Tail Takeoff Housing	9.3	440.00
	(155.5) lb	($7880.00)

Composite housing, Concept C-1, was investigated. Composite housings investigated consist of Kevlar epoxy oriented in the ±45° direction to react shear loads, graphite ribs oriented in the 0° direction to react axial loads, and graphite rings to accept bearing liners. Weight and cost of Concept C-1 are listed below.

Item	Weight	Cost
Center Housing	40.7	$12,546.00
Upper Housing	15.8	4,300.00
Sump	8.3	2,150.00
Input Housings (2)	14.3	3,650.00
Tail Takeoff Housing	3.5	1,040.00
	(82.6) lb	($23,686.00)

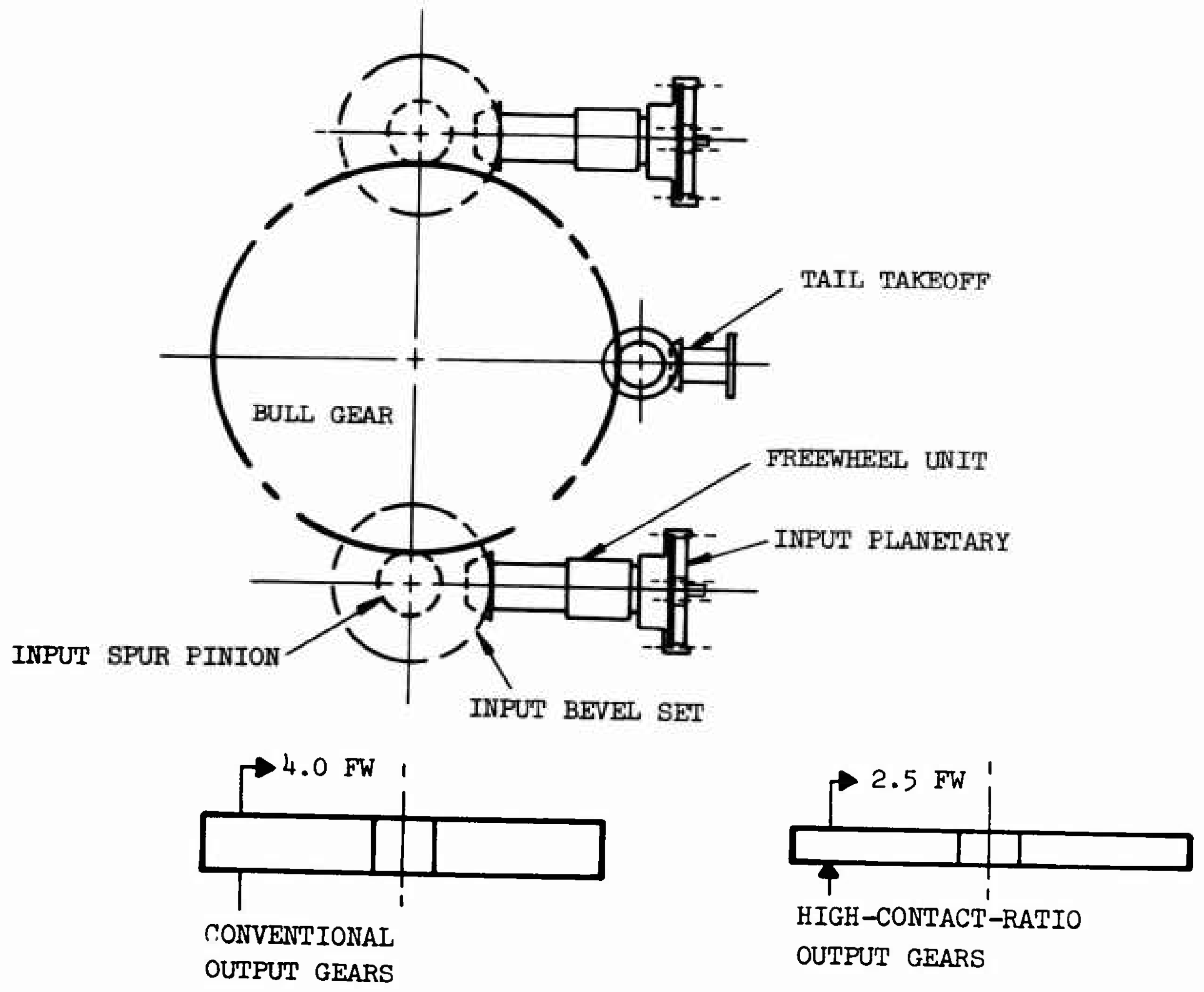


FIGURE B-12. GEAR FACE WIDTH COMPARISON.

Gear Tooth Forms

Gear teeth are designed by comparing gear tooth properties and stresses induced by limit horsepowers to the allowables for material, hardness, and surface finish of the selected material (9310 carburized steel).

The proposed baseline main transmission has three gear reductions (Figure B-12). A star planet with a reduction ratio of 5.55 is used for the first stage. A bevel gear set with a reduction ratio of 2.36 is used for the second stage. A spur gear set with a reduction ratio of 6.58 is used for the third stage.

Two gearing concepts were chosen for the advanced main transmission:

1. Concept C-4B

   High-Contact-Ratio Gearing

2. Concept C-4C

   High-Strength Gear Materials

Application of high-contact-ratio gearing to the third stage reduction yields the highest weight payoff, because the high torques and loads are transmitted by the output gears. Conventional spur gears are designed with a contact ratio of 1.4 - 1.6, so at least one tooth is in contact at all times. High-contact-ratio gear teeth are designed with a contact ratio of 2.1 - 2.6, so at least two teeth are in contact at all times. Load sharing between teeth reduces gear size and weight.

Table B-19 compares gear data for the baseline and the high-contact-ratio gearing. Sikorsky Computer Program No. E970 was used to size both sets of gears.

The conventional spur gear teeth are designed in bending (f_b = 65,000 psi), and the high-contact-ratio gear teeth are designed in compression (f_c = 146,000 psi).

Table B-19 also compares affected weights. The same reduction ratio and the same pitch diameters were used to size both sets of gears. This results in a reduction in face width from 4.44 in. for the baseline gear teeth to 2.775 in. for the high-contact-ratio gear teeth. Weight saving is $\frac{4.44 - 2.775}{4.44} = .37$ or 37%.

The baseline gears are fabricated of 9310 steel. By using steels with higher material properties, such as Vasco X2 or CBS 600, which have allowables 20% greater than 9310, gear weight can be reduced further. Let F_{HS} and f_{HS} be the face width and bending stress of the high-strength material gears.

TABLE B-19. GEAR DATA - CONVENTIONAL AND HIGH-CONTACT-RATIO GEAR TEETH (C-4B)

	Conventional Gear Teeth		High-Contact-Ratio Gear Teeth	
	Pinion	Gear	Pinion	Gear
HP	782	782	782	782
RPM	2300	350	2300	350
Pressure	$22\ ^1/_2{}^\circ$	$22\ ^1/_2{}^\circ$	20°	20°
Pitch Dia	4.00	13.12	4.00	13.12
Face Width	4.44	4.44	2.775	2.775
Weight of Two Pinions and One Gear (Rims Only)	85.8 lb		53.7 lb	
Cost @ $87/lb	$7465.0		$4670	
Contact Ratio	1.6		2.3	
f_b	65,000 psi		43,000 psi	
f_c	137,000 psi		146,000 psi	

TABLE B-20. WEIGHT OF CONVENTIONAL GEAR TEETH AND HIGH-STRENGTH MATERIAL GEAR TEETH (C-4C)

Item	Conventional Affected Wt	Concept C-4C
Output Spur Gear	67.8	56.6
Output Spur Pinions (2)	18.0	15.0
Bevel Gear (2)	25.3	21.1
Bevel Pinion (2)	10.7	8.9
Input Planetaries (2)	7.5	6.3
	(129.3 lb)	(107.9 lb)
Cost @ $87/lb	$11250.0	$9387.0

TABLE B-21. WEIGHT OF CONVENTIONAL OUTPUT GEAR SET AND COMBINED CONCEPTS C-4B, -4C

	Conventional Affected Wt	Concept C-4C
Output Spur Gear	85.8 lb	44.6 lb
and (2) Pinions	$7465.0	$3880.0

$_B$ and f_B be the face width and bending stress of the baseline al. Face width is inversely proportional to the bending stress material.

Since $f_{HS} = 1.2\ f_B$

$$F_{HS} = F_B \frac{f_B}{f_{HS}} = F_B \left(\frac{1}{1.2}\right)$$

$$F_{HS} = .83\ F_B$$

A 17% weight savings can be realized by using high strength gear materials.

Table B-20 compares baseline and high-strength material weights. The additional weight reduction of the spur gears is

.17 (53.7) = 9.1 lb.

The total weight reduction of the spur gears is

32.1 + 9.1 = 41.2 lb. or

$$\frac{85.8 - 44.6}{85.8} = 48\%$$

Conformal gearing, concept C-4A, was also investigated.

Conformal gear teeth in the output gears permit an increase in reduction ratio in the third stage from 6.58 to 9.11. The reduction ratio in the second-stage bevel gears can be reduced from 2.36 to 1.70.

TABLE B-22. BASELINE AND CONCEPT 2C-4 AFFECTED WEIGHT AND COST

Item			Baseline Gears			Concept 2C-4A
Third-Stage Gear						
Weight			85.8 lb			48.2 lb
Cost	@$87/lb	=	$7465.0	@$174/lb	=	$8387.0
Second-Stage Gears						
Weight			36.0 lb			26.6 lb
Cost	@$87/lb	=	$3130.0	@$87/lb	=	$2314.0

TAIL ROTOR DRIVE SHAFT

Three conditions are important in designing a conventional tail drive shaft:

1. The first bending natural frequency of the system must be 25% greater than the operating speed.

2. Torsional buckling of drive shafts must not occur.

3. Commercially available tubing is generally used to fabricate the drive shafts.

The baseline drive shaft is designed to conventional drive shaft standards. It is fabricated of 3.00-in.-dia 2024 AL tubing with .049-in. wall thickness. Three supports are required.

The advanced drive shaft is fabricated of graphite/epoxy laminate oriented ± 45° to react shear and 0° to react bending loads. See Figure B-13. Flanges are integrally formed, and the shaft is filled with 3.0 lb/ft^3 density polyurethane foam to resist buckling failure. The system is designed to operate above the first bending natural frequency and requires only two supports.

The drive shafts can be fabricated by numerically controlled tape lay-up and the foam injected automatically.

Tail takeoff speed is 3000 rpm. The first bending natural frequency for a simply supported beam is

$$\omega_n = \left(\pi^2/l^2\right)\sqrt{EIg/M} \times 60 \Big/ 2\pi \text{ rpm}$$

Based on experience, the actual system natural frequency is approximately two-thirds the calculated natural frequency for a simply supported beam.

If the first critical speed is to be 80% of the operating speed,

$$w_n = .8(3000) = 2400 \text{ rpm}$$

The design critical speed becomes

$$w_n = 1.5 \times 2400 = 3600 \text{ rpm}$$

For a 3.00-in.-dia shaft, with speed equal to 3000 rpm, power equal to 190 hp, and max f_s equal to 50,000 psi for ± 45° graphite/epoxy, the thickness of the material required is

t - .0057 in.

Presently, the minimum thickness of graphite/epoxy tape is approximately

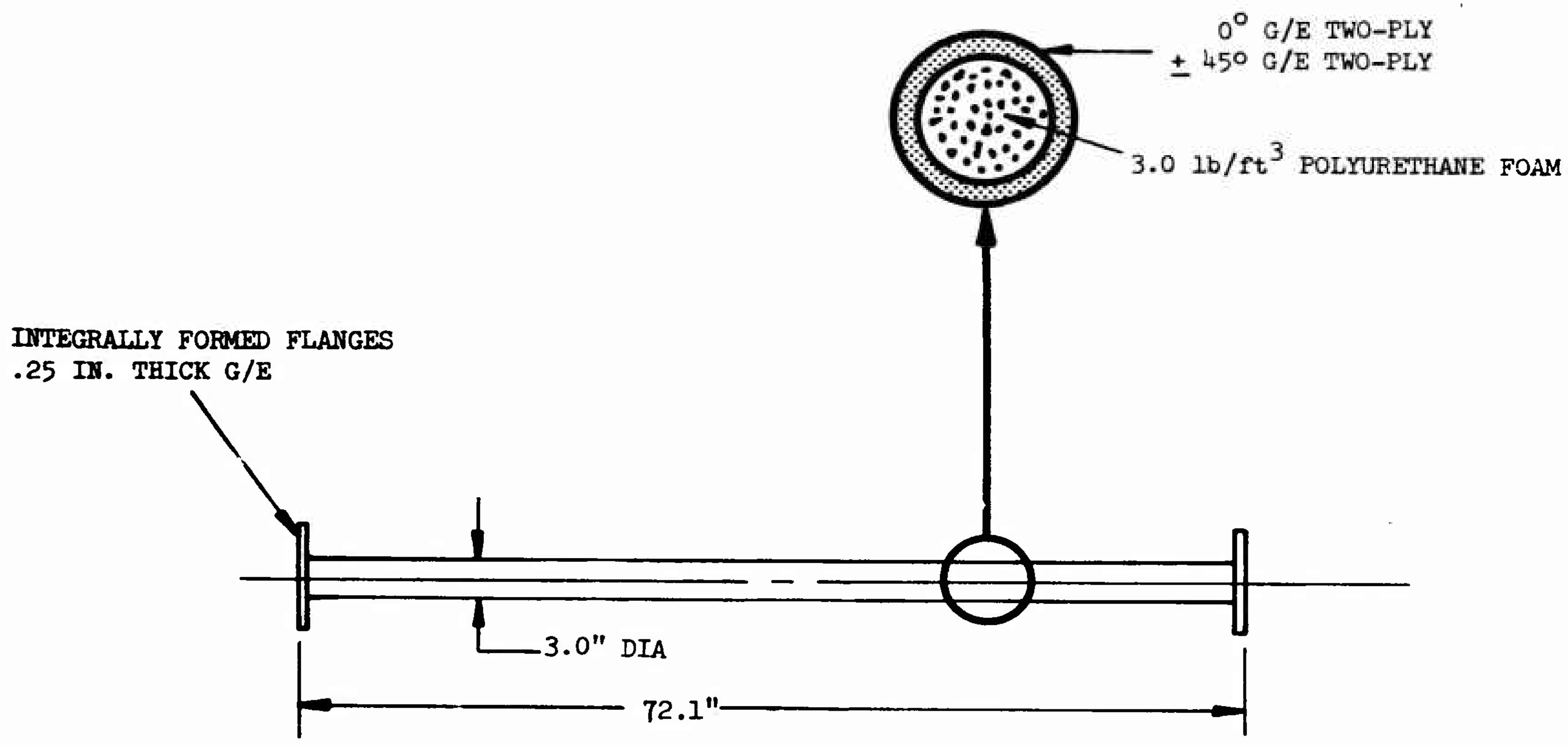


FIGURE B-13. TYPICAL FOAM-FILLED COMPOSITE TAIL DRIVE SHAFT.

.005 inch. The thickness of ± 45° graphite/epoxy must then be at least .010 inch.

For w_n = 3600 rpm, the equivalent thickness of 0° G/E required is:

$t = .014$ inch

$t_{total} = .010 + .014 = .024$ inch

The weight per unit length of graphite/epoxy is:

$W_t = \pi \times 3 \times .024 \times 1 \times .055 = .0125$ lb/in.

The weight per unit length of 3 lb/ft^3 foam is:

$W_t = .013 + .012 - .025$ lb/in.

The weight of the baseline aluminum driveshaft is

$W_t = .0454$ pound/in.

The drive shaft is 213 inches long. The baseline drive shaft requires three supports, including flanges, couplings, etc. Distance between supports must be 59.1 inches, and the drive shaft's first natural bending frequency is 3750 rpm. The foam-filled composite drive shaft requires two supports with flanges integral at each end of the shaft. Distance between supports must be 72.1 inches if the first natural bending frequency of the system is to be 2400 rpm. The affected weights of each system are:

Weight of baseline D/S - 21.7 lbs.

Weight of advanced D/S - 10.9 lbs.

This results in a weight saving of

$$\frac{21.7 - 10.9}{21.7} \times 100 = 50\%$$

TABLE B-23. WEIGHTS OF BASELINE DRIVE SHAFT AND CONCEPTS C-7, C-5 AND C-6

Item	Baseline Affected Wt	Concept C-7
Bearing and Damper Assy.	6.0	4.0
Flanges	4.5	.5
Thomas Couplings	1.5	1.0
Drive Shafts	9.7	5.4
Total	21.7 lbs	10.9 lbs

Estimated cost of the drive shaft concept C-7 is:

* 7.7 lb graphite/epoxy @ $20/lb	$155.00
23.4 hr labor @ $22.50/hr	525.
5.0 lb couplings and supports @ $61/lb	305.00
Total	$985.00

*Includes 30% extra material for scrap

Two other drive shaft concepts were investigated.

Concept C-5. Supercritical aluminum drive shaft.

Material	2024 AL tubing
Diameter	3.00 dia
Wall Thickness	.049
Number of Supports	2
Distance Between Supports	74.2 in.
Weight of Supports	8 lb
Weight of D/S	9.7 lb
Total Weight	17.7 lb
Cost @ $61/lb	$1080.00
System Natural Frequency	2400 rpm
Design Natural Frequency	3600 rpm

TABLE B-23. (CONCLUDED)

Concept C-6. Tetra-Core Drive Shaft	
Material	Graphite/Epoxy
Diameter	3.00 in.
Equivalent Wall Thickness	
0° Fibers	.0184 in.
± 45° Fibers	.0375 in.
Number of Supports	2
Distance Between Supports	74.2 in.
Weight of Supports	8.0 lb
Weight of D/S (graphite/epoxy fibers)	6.2 lb
Total Weight	14.2 lb
Cost of G/E \$20/lb x 1.3* (6.2)	160.00
Labor 38.4 hr @ \$22.50/hr	865.00
Cost of Supports @ \$61/lb	490.00
Total Cost	\$1515.00
System Natural Frequency	2400 rpm
Design Natural Frequency	3600 rpm

*Includes 30% wastage

IR Suppression

The IR suppression system is based on the following concept. Engine exhaust gasses are ducted to an exhaust manifold within the tail cone. The engine exhaust flow, by ejector action, pumps cooling air through the visible walls of the exhaust system, cooling the walls by convection and by film cooling. The visible walls form curved exhaust slots, which prevent view of the exhaust manifold that delivers exhaust gas to the slots. The curved exhaust slots discharge the exhaust gas in thin films. The exhaust gas is undiluted except for the wall cooling air. Rotor downwash effects quickly dissipate the thin film, thereby reducing its IR signature.

Advanced Concept Summary

Table B-24 is a summary of the recommended Advanced Concept for the affected weight and cost.

TABLE B-24. RECOMMENDED ADVANCED CONCEPT

Structure	Weight Affected	Cost	Cost/lb
Airframe	720	$107,272	148.98
Landing Gear	164	10,827	66.02
Main Rotor (Blades and Hub)	718	51,200	71.26
Tail Rotor	44	5,148	117.00
Controls	228	22,278	97.71
Transmission	227	16,081	70.84
Fuel System	8.3	1,350	162.65
	2109.3 lb	$214,156	

LIST OF SYMBOLS

"A"	Design strength allowable, value above which 99 percent of population of values expected to fall, with 95 percent confidence.
"B"	Design strength allowable, value above which 90 percent of population of values expected to fall, with 95 percent confidence.
b	Number of blades
C. F.	Centrifugal force, lb
e	Offset of flapping hinge, ft
$F_{( )}$	Force, lb, subscript, if applicable, denotes direction
F_{cu}	Ultimate design allowable in compression, psi
F_{su}	Ultimate design allowable in shear, psi
F_{tu}	Ultimate design allowable in tension, psi
$E_{(c)}$	Compression modulus, psi
$E_{(t)}$	Tension modulus, psi
G	Shear modulus, psi
K	Blade flapping constant, ft-lb/deg
$M_{( )}$	Moment, in-lb, subscript, if applicable, denotes axis
M_R	Hub moment
$N_{( )}$	Load factor, subscript denotes direction, X Forward, Y Lateral, Z Vertical, in aircraft coordinates
R	Rotor radius, ft
t_p	Total panel thickness, in.
V	Shear, lb
V_c	Cruise speed, knots
V_{max}	Maximum speed, knots
W	Design gross weight, or weight of structure, as applicable, lb
W_B	Blade weight, lb