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DESIGN STUDY OF REPAIRABLE MAIN ROTOR BLADES

By

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July 1972

EUSTIS DIRECTORATE
U. S. ARMY AIR MOBILITY RESEARCH AND DEVELOPMENT LABORATORY
FORT EUSTIS, VIRGINIA

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KAMAN AEROSPACE CORPORATION
BLOOMFIELD, CONNECTICUT

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13. ABSTRACT

This report presents the results of a design study of repairable main rotor blades. The designs studied are applicable to the Army's UH-1H helicopter with semirigid teetering rotor system. The program included development of analysis methodology, including a model for rotor blade life cycle costs, establishment of design concepts, analysis of these concepts from both a technical and cost veiwpoint, and selection of a final recommended configuration for future development. As partial support for the concept of field repairability of rotor blades, an experimental evaluation of a major repair was conducted under simulated field conditions. The procedure used and the results of this evaluation are included as an appendix to this report.

The final selected design is shown in this report as Configuration V.

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This is one of a number of parallel studies examining various rotor blade design concepts emphasizing reliability and maintainability. Other concepts under study are sectionalized and expendable rotor blade designs. These design studies are aimed at achieving considerable improvement in rotor blade R&M characteristics, thereby reducing life cycle cost. To achieve comparability, all blade designs are required to match UH-1D/H characteristics, and life cycle cost is compared to that for the UH-1D/H.

This study concentrated on designing a main rotor blade that could receive the bulk of its repair at DS/GS level rather than requiring depot repair. Five design concepts were considered and subjected to a detailed R&M analysis, which included consideration of external damage rates experienced by the UH-1D/H fleet.

The best design featured a damage-resistant aluminum spar with an aluminum-honeycomb-filled trailing section with fiberglass skins. Repair kits were designed, including one to handle large damaged areas in the honeycomb-filled area. The organizational repairability was about 65%, the depot repairability was 17%, and the resulting life cycle cost was calculated to be about one-half that of the current UH-1D/H.

Due to limitations placed on the study, the analyses performed included only external damage. The cost results, although valid for comparative purposes, cannot be considered on an absolute scale.

The repair kits and procedures designed in this study must also be tested under operational conditions, as well as the structural integrity of the repaired blade. A further study to establish these points is currently being planned.

The program was conducted under the technical management of Philip J. Haselbauer, Structures Division, with engineering support from Joseph H. McGarvey, Reliability and Maintainability Division.

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Final Report

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SUMMARY

This report presents the results of a design study of repairable main rotor blades. The designs studied are applicable to the Army's UH-1H helicopter with semirigid teetering rotor system. The program included development of analysis methodology, including a model for rotor blade life cycle costs, establishment of design concepts, analysis of these concepts from both a technical and cost viewpoint, and selection of a final recommended configuration for future development. As partial support for the concept of field repairability of rotor blades, an experimental evaluation of a major repair was conducted under simulated field conditions. The procedure used and the results of this evaluation are included as an appendix to this report.

The final selected design is shown in this report as Configuration V.

FOREWORD

This design study of repairable main rotor blades was performed under Contract DAAJ02-70-C-0070 with the Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, Project IF162203A119, and was under the general technical cognizance of Mr. Philip Haselbauer of the structures division. The study of repairable rotor blades represents one means that is being investigated for the purpose of achieving lower overall rotor blade costs for the Army. Sectionalized and expendable blade concepts are being studied in separate efforts.

The authors acknowledge the contributions made to this program by Messrs. George Halversen, John Carroll, James Fitzpatrick, Frank Starses, Anthony Belbruno, and John Porterfield of the Kaman Aerospace technical staff.

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A	blade cross-sectional area, $in.^2$
AOT	allowable blade operating time due to fatigue criteria, blade hours
BTBD	blade time between damage, blade hours
C_A	attrition cost per aircraft life cycle
C_C	container cost, dollars
C_{DR}	depot level repair cost per aircraft life cycle
C_{DS}	depot level scrap costs per aircraft life cycle
C_E	cost of any GSE required per repair
CF	centrifugal force at the station considered, lb
C_m	organizational level labor rate
C_{mc}	depot civil labor rate
C_{nb}	cost of a new blade FOB
C_O	blade cost to outfit one aircraft
C_{ORL}	cost of organizational/intermediate level repair labor
C_{ORM}	cost of organizational/intermediate level repair material
C_p	cost of repair kit FOB
C_{pc}	shipping preparation charges, one way
C_{ps}	cost of spare parts at depot level
C_{rd}	average cost of blade repair at depot level
C_{RO}	organizational/intermediate level repair cost per aircraft life cycle
C_S	initial spares cost per aircraft life cycle

C_{sa} blade air shipping cost

C_{sb} cost of spare blades and containers at depot level

C_{sc} empty container shipping cost

C_{so} organizational level scrap costs per aircraft life cycle

C_{sp} shipping cost of repair parts as a fraction of cost

C_{ss} blade surface shipping cost to CONUS

C_x distance between the point on the blade cross section and the chordwise neutral axis measured parallel to the blade axis of symmetry (X-X Axis), in.

C_y perpendicular distance between the point on the blade cross section and the X-X neutral axis, in.

C_1 cost factor for user repair = 110.3
This factor includes repair labor, assuming a constant MTTR = 4.0 man-hours and "off A/C" repair of 78%, and spare materials. Average repair kit costs are used.

C_2 cost factor for used scrap = $(1.05C_{nb}+251.5)$
This factor includes a spares allowance but does not include fatigue retirement defined below.

C_3 cost factor for depot repair = $(.383\ C_{nb}+466.5)$
This factor assumes depot overhaul cost at one third of blade price and includes a spare allowance.

C_4 cost factor for depot scrap = $(1.05\ C_{nb}+402.5)$
This factor includes replacement blade costs and spares allowance.

C_5 cost factor for fatigue retirement = $(.0284\ C_{nb}+6.8)$
This factor assumes an average fatigue retirement rate of 2.7% of blade damage and includes a spares allowance.

$\overline{DT}$ mean maintenance down time, hours

EA span or axial stiffness of total blade cross section, lb

EI_{xx}	flatwise bending stiffness of total cross section, lb-in.^{2}
EI_{yy}	edgewise bending stiffness of total cross section, lb-in.^{2}
E_m	modulus of elasticity for the material, lb/in.^{2}
F_A	allowable vibratory stress, lb/in.^{2}
f_b	rotor blade combined fatigue stress, lb/in.^{2}
F_E	endurance limit, lb/in.^{2}
FMEA	failure mode and effect analysis
f_{st}	calculated steady stress, lb/in.^{2}
F_{tu}	ultimate tensile strength, lb/in.^{2}
K	attrition rate, blade sets per A/C life cycle
K_A	number of blades lost to attrition
K_{BF}	fraction of damaged blades fatigue retired
K_{BR}	overall fraction of blade damage repaired
K_{BRD}	fraction of blades repaired at depot level
K_{BRF}	fraction of damaged blades repaired at the intermediate level
K_{BRO}	fraction of damaged blades repaired at organizational level
K_{BS}	fraction of damaged blades scrapped
K_{BSD}	fraction of blades scrapped at depot level
K_{BSO}	fraction of blades scrapped at user level
K_{RD}	fraction of damaged blades repaired at depot level
K_{RU}	fraction of damaged blades repaired at user level
K_{SD}	fraction of damaged blades scrapped at depot level
K_{SU}	fraction of damaged blades scrapped at user level

L	aircraft life cycle, flight hours
M_{CF}	steady edgewise bending moment due to centrifugal force, in.-lb
MH/FH	maintenance hours per flight hour
M_i	MMH to inspect, disposition damage, remove and replace a blade
M_{max}	90th percentile repair time
MMH	maintenance man-hours
MRB	main rotor blade
MTTR	mean time to repair
M_x	steady and vibratory flatwise bending moment, in.-lb
M_y	steady and vibratory edgewise bending moment, in.-lb
M_z	MMH to inspect and disposition damage
M_1	MMH in addition to MTTR at Int. level, hours Basis: Inspect and Disposition = 1.5 hours Remove and install blade = 7.5 hours
M_2	MMH in addition to MTTR at Org. level, hours Basis: Inspect and Disposition = 1.5 hours
M_3	MMH to scrap blade at Org/Int. level, hours Basis: Remove and Install Blade = 7.5 hours Requisition replacement blade = 3.0 hours Obtain replacement blade = 3.0 hours Inspect and disposition = 1.5 hours
M_4	MMH at depot for receiving and inspection
M_5	MMH at depot to: Receive and inspect, scrap disposal
n	number of blades per aircraft
N_{bf}	number of blades damaged per aircraft life cycle

T_R mean field repair time, MMH

$\bar{X}$ mean of the logarithms of repair time

σ_x standard deviation of the logarithms of repair time

INTRODUCTION

A significant portion of the costs incurred in acquiring and maintaining a fleet of helicopters is associated with the main rotor blades. To keep the fleet supplied with serviceable blades may involve a substantial investment in spares and in facilities to overhaul and repair damaged blades. This study program investigated one means of achieving lower overall costs of rotor blades: devising new blade configurations which are designed to be more readily repairable. To be most cost effective, such repair should be accomplished in the field where the helicopters are used and preferably without removal of the blade from the helicopter. Several blade designs which showed promise of meeting these goals were studied from both the technical and cost points of view, and recommendations for the further development of the most promising configuration are presented.

To aid in the study of competitive blade designs, a cost model was established. This model included all the significant rotor blade costs that are incurred in support of a fleet of helicopters over a 10-year life cycle. Relative costs for all candidate blade designs were evaluated using this model, and selection of the most promising configuration was based primarily on the results of this analysis. The ability of each design to meet the technical requirements of the program was evaluated using standard techniques and existing computer programs. The significant results of all these studies are contained in this report.

DISCUSSION

All rotor blades currently in service have some level of repairability. The type, size and number of repairs that can be permitted are influenced by the type of rotor system, the loads or stress levels that must be endured, the basic materials to be repaired, the facilities and personnel skill levels necessary to successfully accomplish repair, and the overall cost of repairs. For the purposes of the present program, it was decided that the repairable blade configurations studied should be capable of flight evaluation on the Army's UH-1H helicopter with its teetering semirigid rotor system. Since this system experiences high loadings and requires relatively high stiffness, it was considered that a blade concept that was acceptable for this aircraft could be applied to most other present-day rotor systems.

Any new rotor blade concept must first meet all the basic technical requirements to be considered a candidate worthy of evaluation. These would include blade weight, strength, stiffness both in and out of plane, natural frequencies, mass balance, and aerodynamic characteristics. In this study program, the current UH-1H blade was used as a basis for comparison for most of the above parameters. The airfoil contour was not varied and, therefore, aerodynamic characteristics were not changed. In devising new rotor blade concepts, the minimum deviation from the present rotor blade properties was sought.

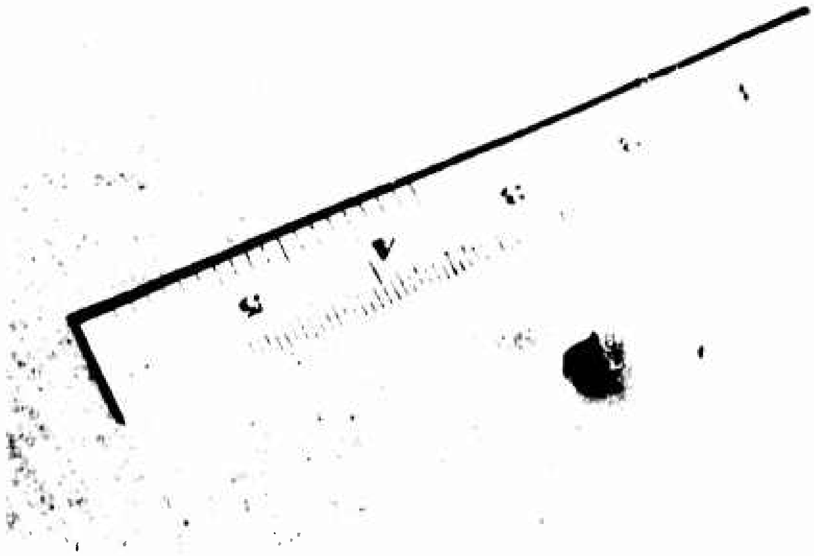
Service experience with fiberglass skins for helicopter main rotor blades has demonstrated that the general level of repairability that can be achieved with this material is significantly greater than that attainable with any metal skin. This experience specifically relates to a unitized blade structure with integral trailing edge. Therefore, the use of fiberglass skins is a basic part of each of the concepts that have been considered. Composite materials, using primarily glass filaments, have also been considered for most of the other elements of the blade. Other materials and processes have been considered for applications that showed promise.

Among the other considerations that have influenced the selection of blade configurations for study are the desire to standardize repair procedures, to minimize the number of repair kits required, and to simplify logistics and training by eliminating special tools and intricate operations. One approach that showed promise in this direction was the concept of a large insert repair for the aft structure which could be used for virtually any battle damage to this area. The insert would be coordinated with the airfoil contours and would contain provisions for making permanent structural repairs to skins and core material. With the availability of this repair, a bullet hole or other damage anywhere between spar and trailing edge spline could be removed and the local structure replaced in the field with one type of operation that support personnel would become accustomed to. The details of a preliminary trial of this operation are presented in Appendix V. Other simpler repair procedures could, of course, be accomplished for damage of a minor nature to a single skin; however, even these operations should be simplified and standardized to the maximum degree possible.

To accomplish any repairs in the field will mean the addition of at least a small amount of weight to the blade at the repair location. In order that the repaired blade will subsequently be acceptable for flight, it will be necessary to reestablish the blade span moment. This may be readily accomplished if the blade is provided with variable weights at the blade tip in positions forward and aft of the quarter chord. The standard repair kits provided to the field, which will introduce known weight increments, will also contain instructions as to how much tip weight of each type to remove depending upon size and location of the repair. If the removable weights are color-coded washers, a very simple procedure is envisioned. This process should restore first spanwise and chordwise moment and provide a repaired blade that is within the acceptable limits for balance. Second moment will deviate from that of a new blade; however, the degree of this deviation will be quite small and its effects imperceptible in the flying qualities of any present-day helicopter.

Based on actual combat experience with helicopters in Southeast Asia, four types of damage are of particular interest. These are battle damage, dent, puncture and tear. Typical examples of these different types of damage are shown in Figures 1 through 4.

Leading-edge damage can be repaired in the field if the blade is provided with a segmented replaceable leading-edge sheath. Damage to the leading edge from such incidents as tree strikes or contact with other solid objects will usually deform material backing the sheath as well as the sheath itself. In this case it would be essential to be able to repair the substrate material before replacing the sheath segment, and such repairs have been devised.



(a) Entry Hole.

(b) Exit Hole.

Figure 1. Battle Damage (Ballistic).

Figure 2. Dent Damage (Leading-Edge Impact).

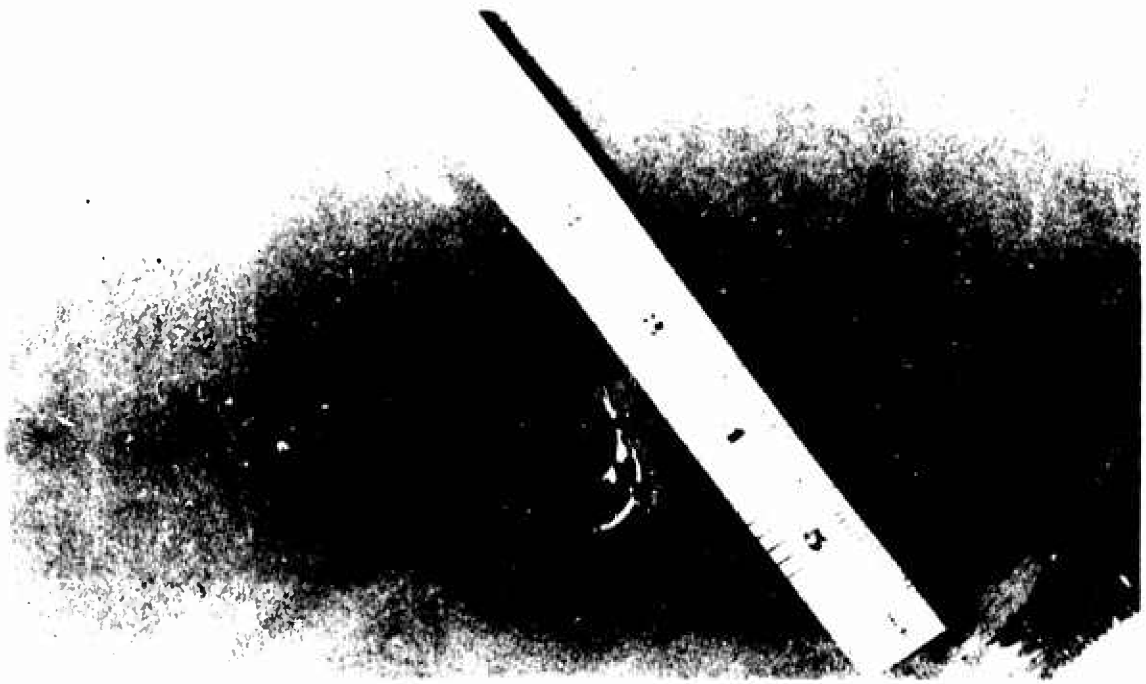


Figure 3. Puncture Damage.

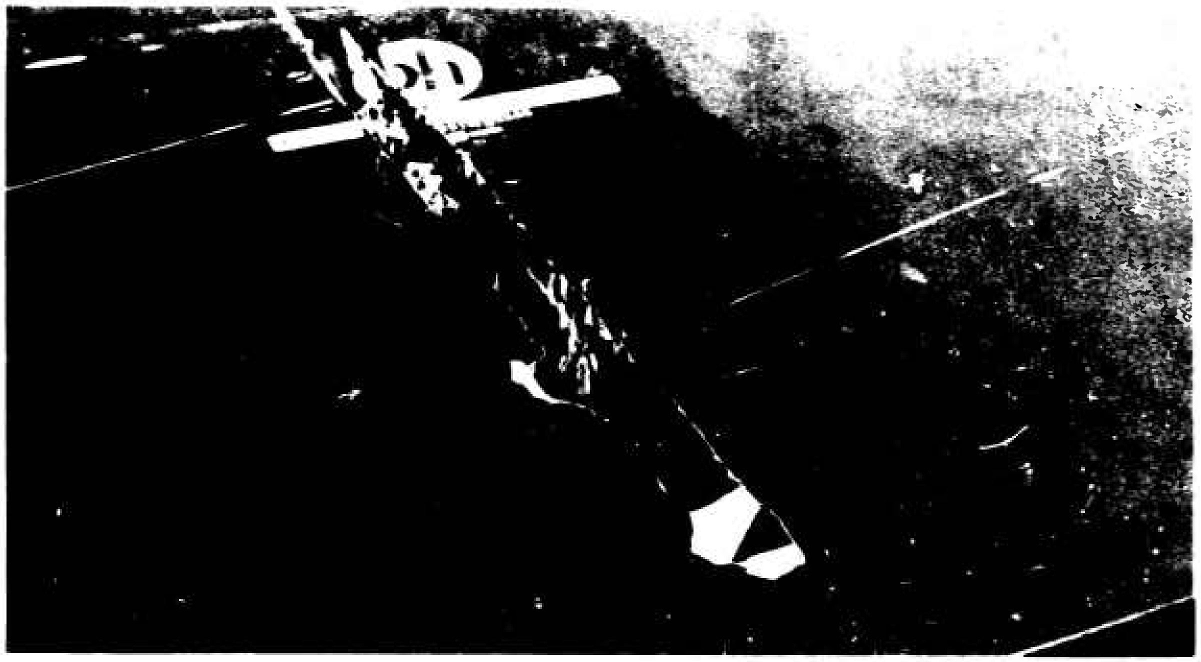


Figure 4. Tear Damage.

Battle damage to the main structural members, the spar, and the trailing-edge spline will generally not be repairable; however, it is important that these items provide a high level of damage tolerance so that the survival probability in any such incident will be as high as possible. Bullet holes through any spar could be blended and then buried under a substantial buildup of material; however, considerable structural development would be required to assure that no hidden crack propagation would occur, and it is also probable that objectionable flying qualities would result from so large a buildup. No repairs of this extent were assumed or undertaken in the present program. A severed trailing-edge spline in the outboard portion of the rotor, however, was considered to be repairable with a well developed external doubler system. Repairs of this nature have been successfully accomplished at overhaul facilities in the past.

With these general considerations in mind, a number of rotor blade design concepts were devised which were intended to be readily repairable in the field or at a depot facility. These concepts were subjected to technical and cost analyses before final selection of a preferred design concept was made.

ANALYSIS METHODOLOGY

Candidate design concepts were evaluated analytically with the aid of existing contractor computer programs and with a cost model that was specifically devised for this purpose. The computer programs were used to determine mass and stiffness properties, natural frequencies, airloads, bending moment distributions, and stresses. These programs are briefly described in the applicable sections of this report. The cost model was an important tool in the evaluation of competitive designs and provided the basis for selection of the preferred configuration. Details of this model are presented in this section of the report.

In addition to the cost analysis, the reliability and maintainability of each configuration were also studied. These analyses took the form of an objective review of each blade configuration and the current UH-1 blade so that direct comparisons could be drawn. The methodology employed in each of these studies is best described in conjunction with the analysis and, therefore, appears in a later section of the report.

Cost Model

The cost model used to develop repairable blade program costs is shown schematically in Figure 5. The model is arranged to

BASIC REPAIRABLE BLADE COST MODEL

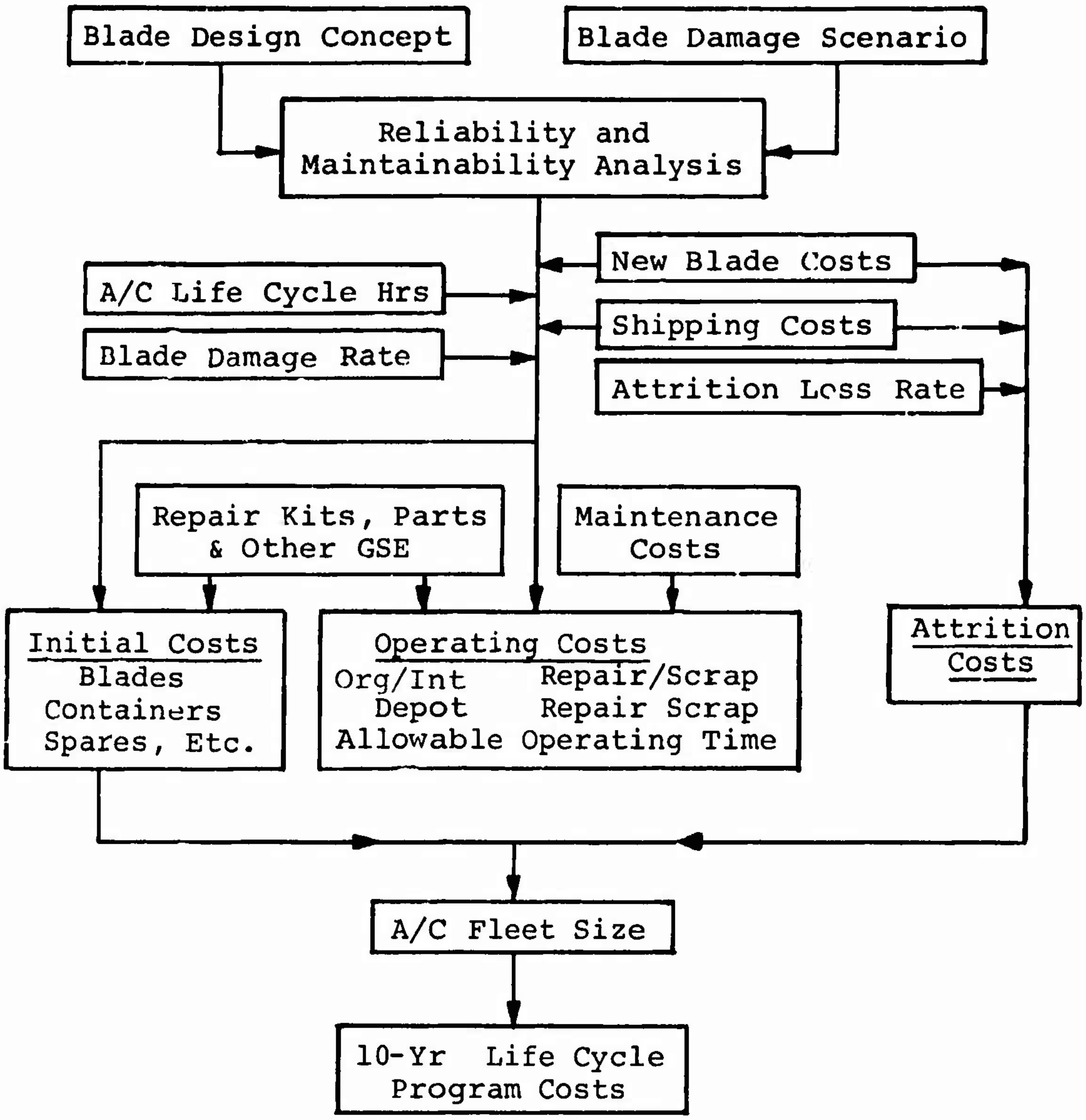


Figure 5. Cost Model, Rotor Blade Life-Cycle Costs.

generate costs per aircraft life cycle in the following three categories:

1. Initial Costs
2. Operating Costs
3. Attrition Costs

It should be noted here that attrition in this program is used to denote blades lost to other than blade damage events, and is included to provide a realistic appraisal of the total blade requirement during the program life cycle.

Input data for the cost model consists of a given repairable blade design concept and the scenario of blade damage events supplied by the Army (Appendix III). A reliability and maintainability analysis determines the fraction of blades that are either repaired or scrapped and at what maintenance level. In addition, the mean time to repair and repair kit contents are established and priced. Standardized blade cost model input values supplied by the Army (Appendix VI), including aircraft life, blade damage rate, shipping costs, maintenance, etc., are applied along with contractor-generated inputs such as new blade costs, repair criteria, kit costs, and repair man-hours.

<u>Model Input Data</u>

Cost factors that vary with repairable blade design concepts are defined as follows:

C_{nb} = Cost of a new blade FOB.

C_{rd} = Average cost of blade repair at depot level.

C_p = Cost of repair kit FOB.

C_E = Cost of any GSE required per repair.

T_R = Mean field repair time, MMH.

AOT = Allowable blade operating time due to fatigue criteria, blade hours.

K_{BRO} = Fraction of damaged blades repaired at organizational level.

K_{BRF} = Fraction of damaged blades repaired at intermediate level.

K_{BSO} = Fraction of blades scrapped at user level.

K_{BRD} = Fraction of blades repaired at depot level.

K_{BSD} = Fraction of blades scrapped at depot level.

Additional life-cycle cost elements common to all blade designs are incorporated into the following cost equations.

Aircraft Life-Cycle Blade Damage

$$N_{bf} = \left(\frac{nL}{BTBD} - n\right)$$

N_{bf} = Number of blades damaged per aircraft life cycle.

n = Number of blades per aircraft.

L = Aircraft life cycle, flight hours.

BTBD = Blade time between damage, blade hours.

1. Initial Costs

These consist of blade costs to equip production aircraft and provide spares.

a. Aircraft Outfitting

Only the FOB price of the new blades is considered here. Other costs such as preparation and installation are small compared to the new blade costs and are neglected since they occur only once in the aircraft life cycle.

$$C_o = n\ C_{nb}$$

where C_o = blade cost to outfit one aircraft.

b. Spares

Since the cost model is not time phased but considered as a single 10-year life-cycle analysis, initial spares costs are developed to reflect blade repairability during the aircraft life cycle as opposed to using a given percentage of installed blades. For this analysis, operating spares are accounted for by operating cost elements described later. The initial requirement for spares to fill the pipeline assumes that all blades scrapped and blades repaired at the depot level over a 6-month period must be procured to maintain the system. Since the aircraft life cycle is 120 months, a 6-month requirement is 1/20 of that for the aircraft life cycle and the initial spares cost is

$$C_s = N_{bf}/20 \left[(K_{BS}+K_{BRD}+K_{BF})(C_{nb}+C_c+C_{SA}) + (K_{BRO}+K_{BRF})(C_p C_{sp})\right] + C_E/20$$

where C_s = Initial spares cost per aircraft life cycle.

K_{BS} = Fraction of damaged blades scrapped.

K_{BF} = Fraction of damaged blades fatigue retired.

C_c = Container cost.

C_{sa} = Blade air shipping cost.

C_{sp} = Shipping cost of repair parts as a fraction of cost.

Combining the cost to outfit production aircraft with the initial spares cost yields

$$\text{Initial Cost} = C_o + C_s$$

2. Operating Costs

As shown in the cost model schematic, operating costs consist of:

Organizational/intermediate level cost of blade damage repair.

Organizational/intermediate level cost of blade damage scrap.

Depot level blade damage repair.

Depot level blade damage scrap.

When the 100 random blade damage criteria are applied to the repairable blade candidates, the fraction of blades damaged for each of the above categories is determined. Operating costs are then developed based on replacement parts cost, labor costs and shipping associated with each category as follows:

a. Organizational/Intermediate Repair Cost

$$C_{RO} = N_{bf} \left[C_m (M_i + T_R) K_{BRF} + C_m (M_z + T_R) K_{BRO} + (C_p + C_{sp})(K_{BRF} + K_{BRO}) \right] + C_E$$

where C_{RO} = Organizational/Intermediate level repair cost per aircraft life cycle.

C_m = Organizational level labor rate.

M_i = MMH to inspect, disposition, remove and replace a blade.

M_z = MMH to inspect and disposition damage.

The above expression allows costs to be determined for damage repair on the aircraft (K_{BRO}) and with blades removed (K_{BRF}).

b. Organizational/Intermediate Level Cost of Blade Scrap

The analysis assumes that every effort will be made to scrap at the user level both excessively damaged blades and those that have reached their fatigue life limit.

$$C_{so} = N_{bf} (K_{BSO} + K_{BF}) \left[C_{nb} + C_{sa} + C_{sc} + C_m (M_3) \right]$$

where C_{so} = Organizational field level scrap costs per aircraft life cycle.

*K_{BF} = Fraction of blade damage fatigue retired.

C_{SC} = Container shipping cost.

M_3 = MMH required to: Inspect and disposition damage.

Remove and replace blade.

Requisition and obtain replacement.

Assuming $K_{BF} = f\left(\frac{K_{BR}}{AOT}\right) = C(K_{BR})^{M_1}/(AOT)^{M_2}$ and

utilizing the data from above to resolve the constants,

$$K_{BF} \approx 27\ (K_{BR})^{1.395}\ /\ (AOT\times 10^{-2})^{1.835}$$

where K_{BR} = Overall fraction of blade damage repaired.

c. <u>Depot Level Cost of Blade Repair</u>

These costs consist of shipping the blade back to CONUS for repair. In addition, labor costs at the organizational and depot levels are included for items such as preparation, inspection, etc.

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*Estimate of fraction of blades fatigue retired - Data from Reference 1 shows that for the UH-1D/H, 1.06% of the damaged blade removals were due to reaching an allowable operating time of 2500 hours. For the AH-1G/UH-1C aircraft, 4.76% of the removals were due to reaching an AOT of 1100 hours. In addition, assume that when the average blade operating time per aircraft life cycle reaches the allowable operating time, scrap damage must be zero or, conversely, the blade is fully repairable. This provides a set of data with variations in both repairability and AOT.

$$C_{DR} = N_{bf} K_{BRD} \left[C_{rd}+C_m(M_3)+C_{sa}+C_{ss}+2C_{pc}+C_{mc}(M_4)\right]$$

where C_{DR} = Depot level repair per aircraft life cycle.

C_{ss} = Blade surface shipping cost to CONUS.

C_{pc} = Shipping preparation charges, one way.

C_{mc} = Depot civil labor rate.

M_4 = MMH at depot for receiving and inspection.

d. Depot Level Cost of Blade Scrap

As with depot level repair, depot scrap costs involve shipping and maintenance charges in addition to the replacement cost of a new blade.

$$C_{DS} = N_{bf} K_{BSD} \left[C_{nb}+C_m(M_3)+C_{sa}+C_{sc}+C_{pc}+C_{mc}(M_5)\right]$$

where C_{DS} = Depot level scrap costs per aircraft life cycle.

M_5 = MMH at depot to: Receive and inspect.

Scrap disposal.

3. Attrition Costs

These costs are considered in addition to program costs resulting from blade damage events as noted earlier. Since the blade may be used at the airframe origin, at the depot level, or in the field, the only attrition costs used here are for the new blade and assumed transportation.

$$C_A = K_A (C_{nb} + C_{sa})$$

where C_A = Attrition cost per aircraft life cycle.

K_A = Number of blades lost to attrition.

Summation of initial, operating and attrition costs provides a reasonable measure of blade program costs during the life cycle of the aircraft. There are other cost elements involved in the total program that are not included in this model because they are not readily available and because their effect is relatively minor. Some of these are:

Performance degradation due to repair.

Facilities and equipment not presently envisioned.

Shipping costs from one user location to another and depot to manufacturer and return.

Total program costs are readily generated knowing life-cycle cost per aircraft and applying it to the desired fleet size.

DESIGN CONCEPTS

Four basic design concepts were subjected to analysis and evaluation in the course of this program, and a fifth concept was formulated as the final recommended design. These five rotor blade designs are summarized in Table I.

TABLE I. MAIN ROTOR BLADE CONFIGURATIONS STUDIED

Configuration	Description
I	The basic structural components of the present UH-1H main rotor blade with fiberglass skins and spar doubler and segmented leading edge.
II	Minimum planform titanium spar and trailing-edge spline with modified root retention.
III	Heavy-wall aluminum spar with integral root retention machined from stepped extrusion. Leading edge bare in low-speed area.
IV	All-fiberglass blade using directed filaments for spar, trailing edge, and skins. Titanium root doubler plates integral in spar layup.
V	Final design selection incorporating features of Configurations I and III. Outboard sections of Configuration III are retained, but step extrusion is eliminated. Blade root utilizes laminated doubler buildup of Configuration I.

The basic designs employ a variety of structural materials in an attempt to identify advantages in repairability, planform area, reliability, maintainability and cost. Various detail design treatments are used in order to achieve a basic evaluation of each. The final selected design is based on an analysis of the four basic design concepts and an evaluation of 10-year life-cycle costs. After a thorough review of all factors involved in the selection process, the recommended concept, identified as Configuration V, was evolved. This preferred design utilizes variations of the basic design concepts that proved beneficial in meeting program goals. It is essentially a combination of the more desirable design features of Configurations I and III that provides a slight further reduction in total life-cycle cost.

A description of the five main rotor blade design concepts follows, beginning with Configuration V, the recommended repairable blade design.

Configuration V

The selected repairable rotor blade design is shown in Figure 6 as Configuration V. This recommended design incorporates features of the basic Configurations I and III discussed subsequently. The basic outboard sections of Configuration III have been retained, but the blade root utilizes the laminated doubler buildup of Configuration I. The step extrusion of Configuration III is eliminated, with the excess material that entails, as is the machining operation which is required to remove that material. In addition, an element of uncertainty is also eliminated. The step in extrusion cross section, which would occur in the neighborhood of Station 82, a highly loaded blade section, would introduce nonuniform grain flow to the spar at this station. This grain flow would not be parallel to the finished blade surface and would, therefore, contribute to a slight reduction of material properties locally. The influence of this disturbance on the fatigue performance of the basic spar material would require some detailed evaluation and would have to be considered a part of the development risk for Configuration III. The spar for Configuration V is a constant cross section with machining only where bonded attachments are made. Costs for blanking, forming and bonding the root doublers are incurred; however, a net saving in new blade cost is effected.

A life-cycle cost analysis for the Configuration V blade, based on data derived from Configurations I and III, indicates a net savings over a 10-year aircraft life cycle of 46%

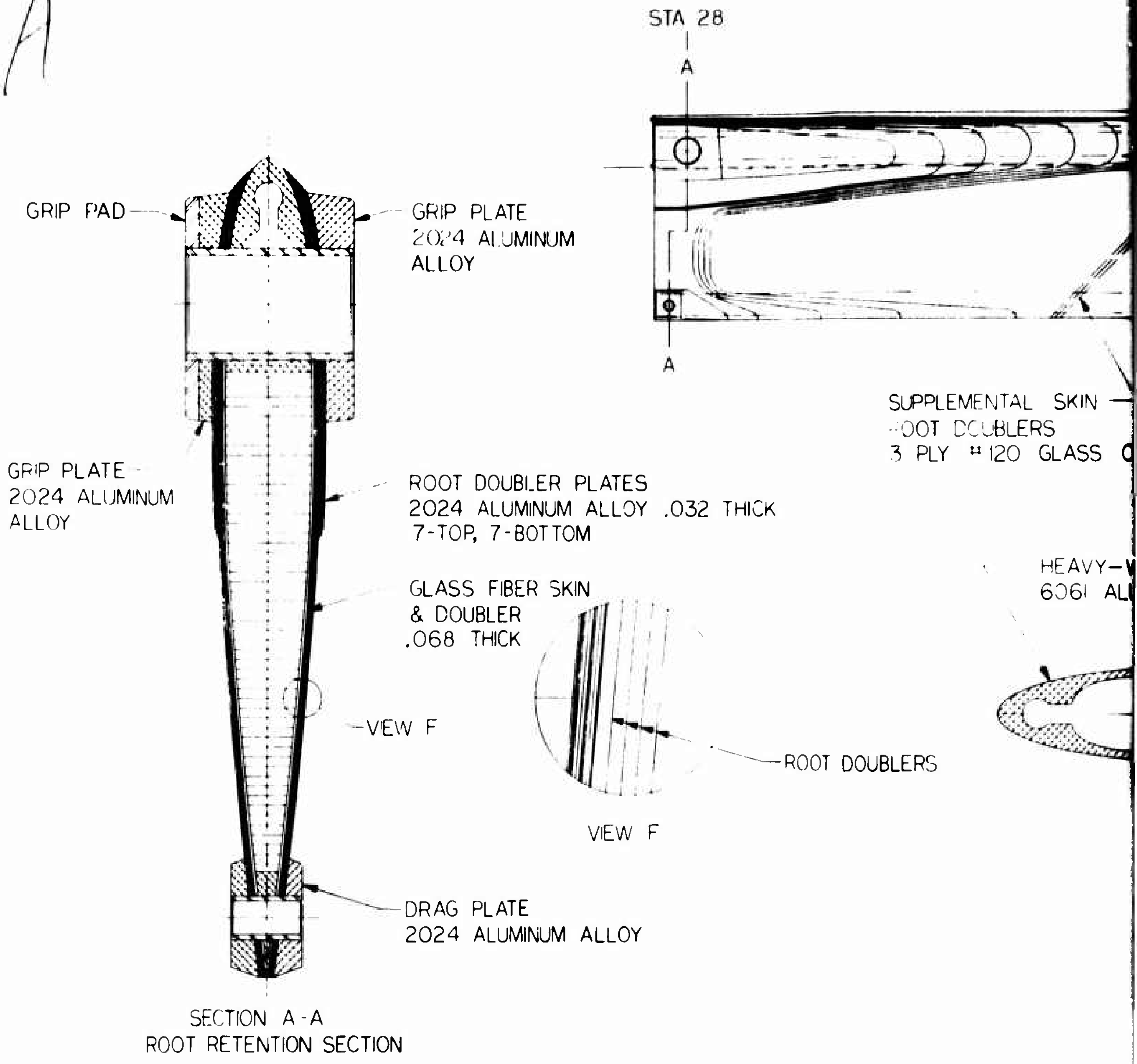
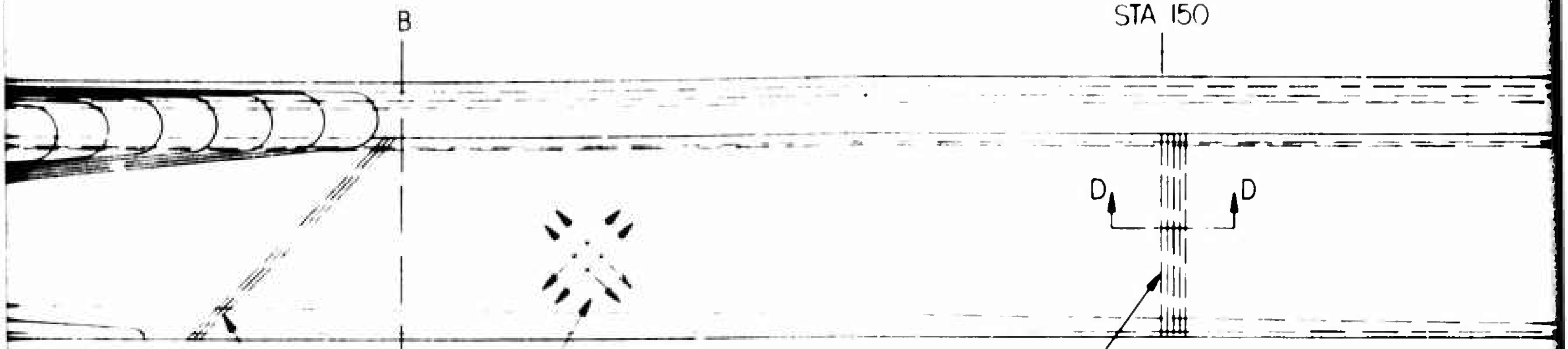
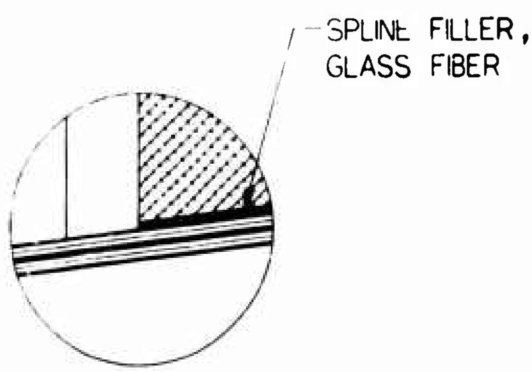


Figure 6. Configuration V, Selected Repairable Rotor Blade Design.

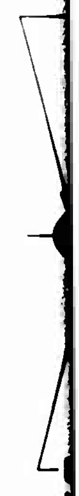


SECTION D-D

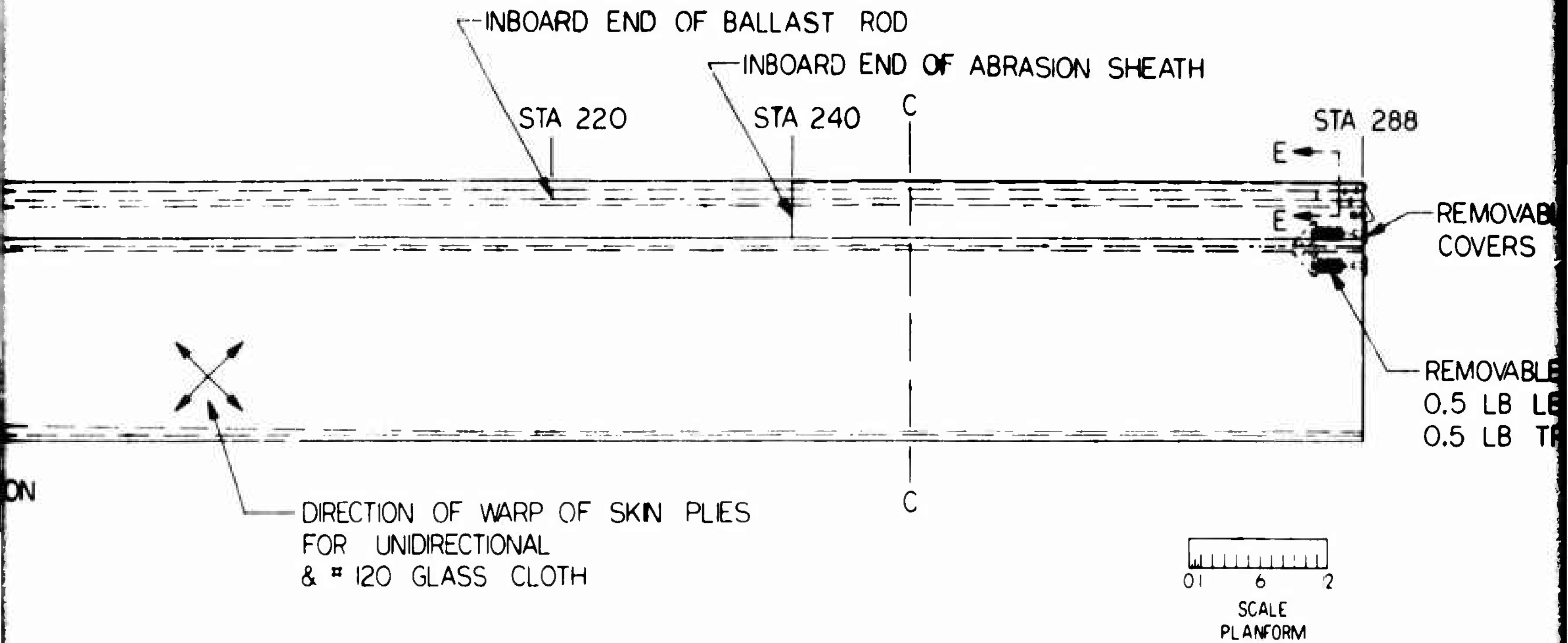
SECTION B-B
TYPICAL INBOARD SECTION

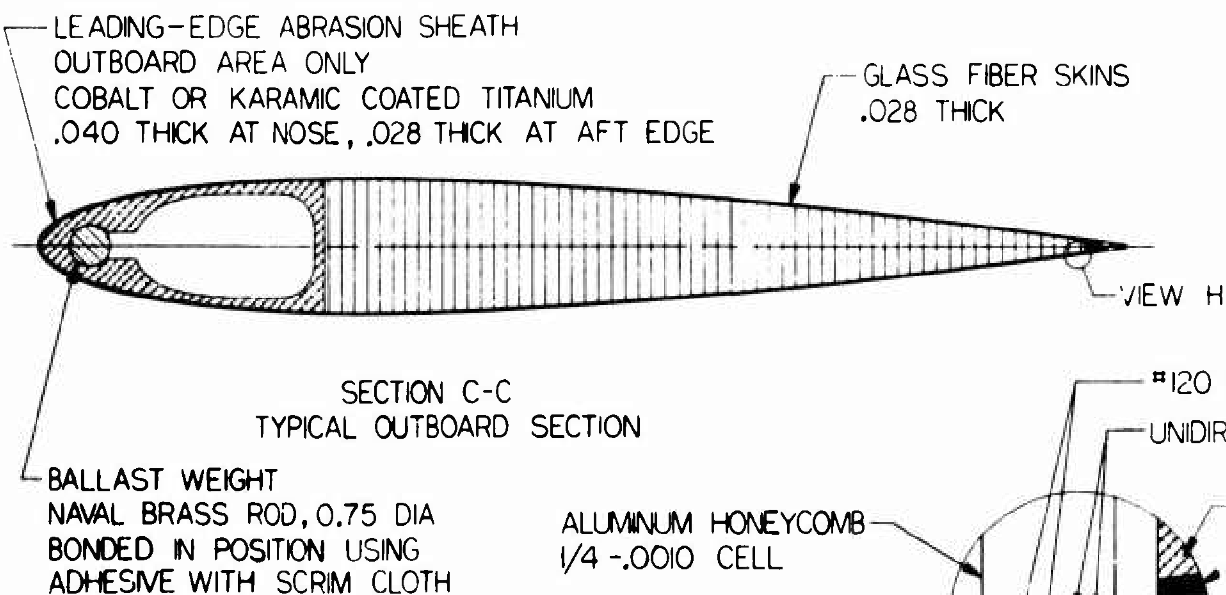


VIEW G

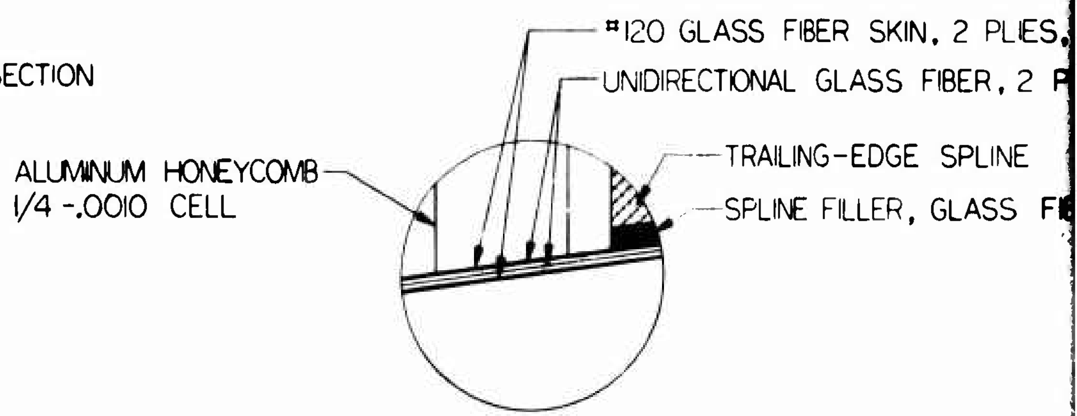


C

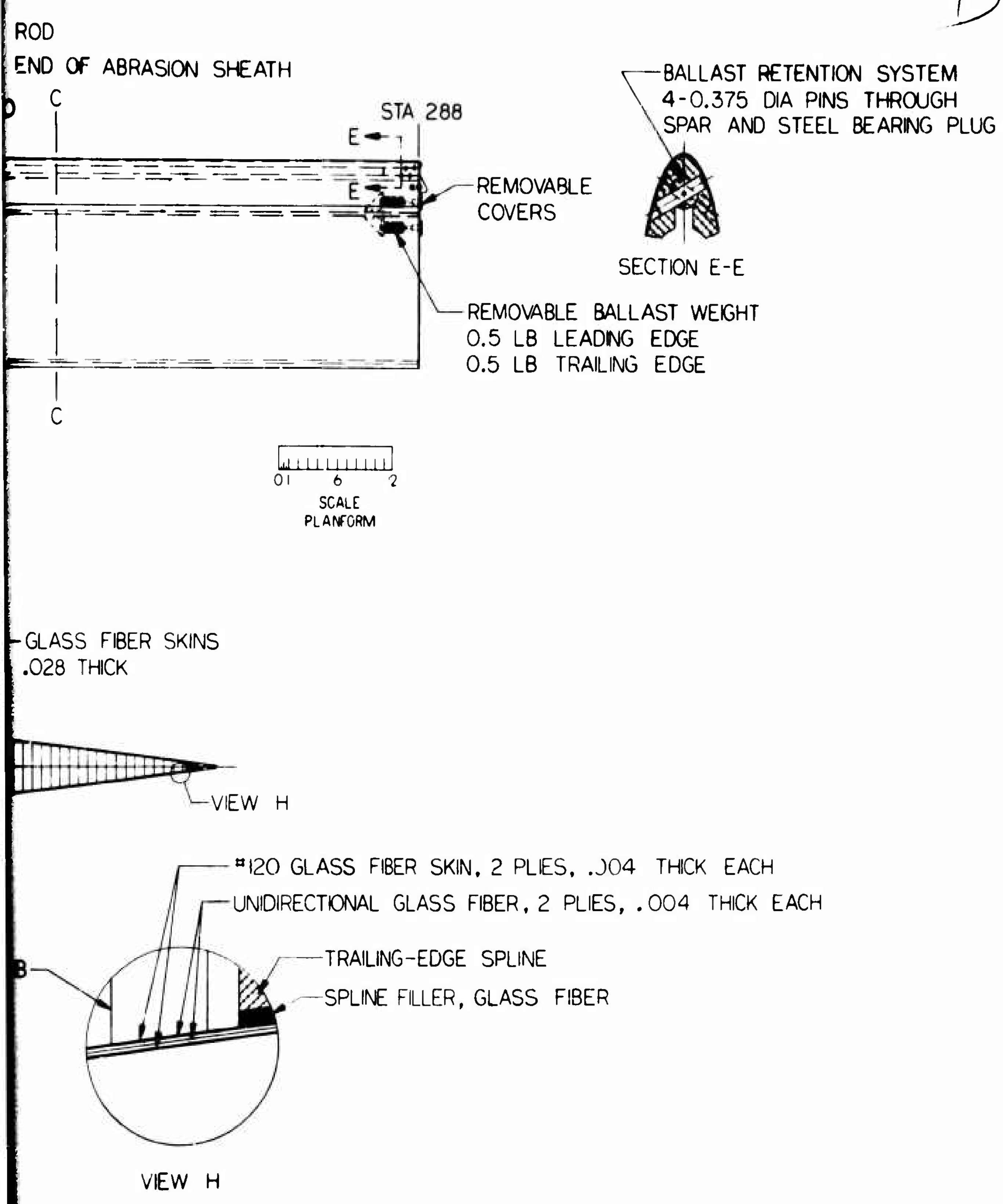




SECTION C-C
TYPICAL OUTBOARD SECTION



VIEW H


ROD
END OF ABRASION SHEATH
C
STA 288
E
E
REMOVABLE COVERS
BALLAST RETENTION SYSTEM 4-0.375 DIA PINS THROUGH SPAR AND STEEL BEARING PLUG
SECTION E-E
REMOVABLE BALLAST WEIGHT 0.5 LB LEADING EDGE 0.5 LB TRAILING EDGE
C
01 6 2
SCALE
PLANFORM
GLASS FIBER SKINS .028 THICK
VIEW H
#120 GLASS FIBER SKIN, 2 PLIES, .004 THICK EACH
UNIDIRECTIONAL GLASS FIBER, 2 PLIES, .004 THICK EACH
TRAILING-EDGE SPLINE
SPLINE FILLER, GLASS FIBER
VIEW H

compared to the present UH-1H blade. In addition to this cost advantage, Configuration V offers the simplest possible repair of leading-edge damage over most of the blade length and also contains fewer parts than the current UH-1H blade. The risks incurred in development of the Configuration V blade are minimal. Preliminary analysis has shown this design to meet all basic technical requirements.

The use of 6061 aluminum alloy for the spar in a highly loaded semirigid rotor system could be considered to introduce an element of risk. While the ultimate strength of this material is lower than that attainable with other alloys, the fatigue strength of large manufactured parts is not correspondingly reduced. The spar employed here utilizes a heavy wall and nose section in order that it can sustain damage from external sources and continue in use with only minor repair necessary. The heavy wall design also results in comparatively low operating stress levels and is, therefore, compatible with the lower strength alloy. At the blade root where the high bending and centrifugal loads are reacted through the retention pin, a system of bonded external doublers and plates is used to transfer the load. This bonded assembly may be made from the same high-strength alloy presently used on the UH-1H blade and will, therefore, provide essentially the same strength.

Configuration I

This design, illustrated in Figure 7, makes maximum use of existing UH-1 blade structural components and yet provides a significant advance in repairability. The basic spar, trailing-edge spline, root end doublers, and leading-edge ballast are common to the current blade, while the skins, spar doubler, and leading-edge sheath are modified designs. Outboard of station 152, the skin consists of two layers of unidirectional glass fiber with a ±45-degree orientation with an inner and outer ply of 120 fiberglass cloth also with a 45-degree orientation. Inboard of this station, this skin is doubled in thickness; and again at the blade root, additional doubling plies are added. For inboard portions of the blade, the shear strength and stiffness exceed that of the current aluminum skin; while outboard, where the loads and the influence on natural frequencies are reduced, the skin properties are less than the current aluminum skin.

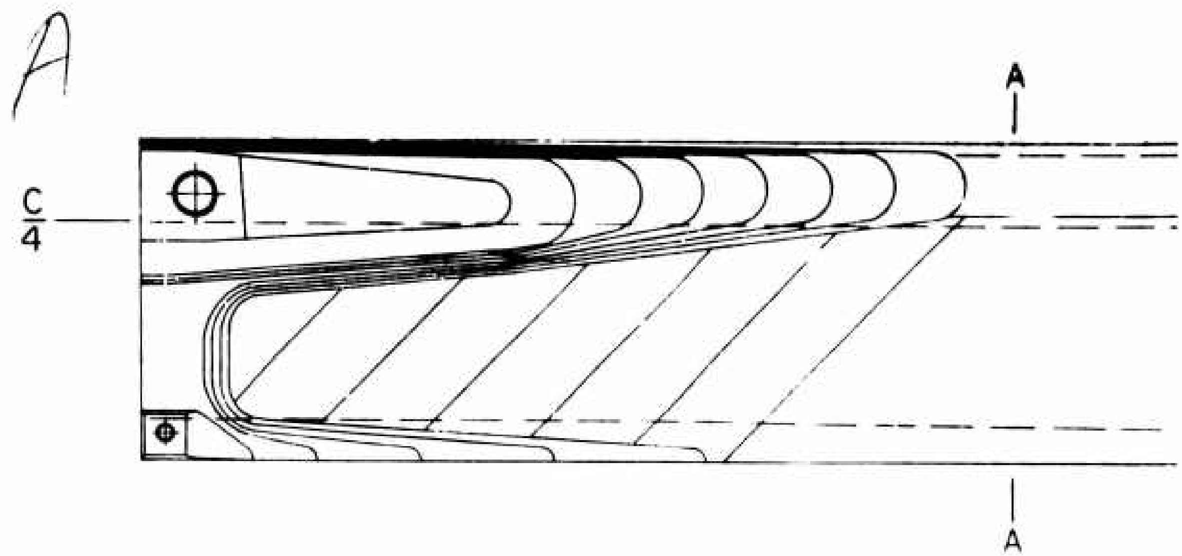
The leading edge abrasion sheath employed for this design is segmented in order to facilitate repair and replacement of locally damaged area. The tip segment could remain the present cobalt material if no acceptable substitute is found; however, inboard segments could be manufactured from a variety of materials, including stainless steel, nickel, or other possible base and coating combinations. One recent development that may provide excellent erosion protection consists of a very hard and dense coating applied to a titanium substrate. In high volume the process could be done inexpensively. The composite material would then be bonded to the blade leading edge. Thickness of leading-edge segments would be selected to coordinate with skin thickness at the appropriate stations, thereby eliminating any steps or undulations in airfoil contour. Removal and replacement of damaged leading-edge segments can be done in a manner similar to that presently employed by overhaul facilities; however, field replacement is also possible using the same technique as was demonstrated for aft structure and is illustrated in Appendix V.

Damage which penetrates the leading edge and damages or deforms the nose ballast block beneath the protective sheath can also be repaired in the field. In this case the affected sheath segment is removed, and the damaged area of the ballast weight is filed to a smooth clean depression. The standard repair kit contains a mixture of epoxy and lead filings which, when fully cured, has the same density as the ballast weight. An excess of this material is applied to the depression and cured. The original contour is then restored by filing, and a new segment of leading-edge sheath is installed. It is assumed here that damage of this nature normally occurs in the outer portions of the blade where stiffness requirements are low. Reasonably smooth blending of the original damage will aid in attachment of the lead/epoxy filler and minimize notch effects.

As one further improvement in repairability, the outboard box beam doubler of Configuration I is made from unidirectional fiberglass. In the case of a tear or gash which penetrates the leading-edge sheath and causes a chordwise damage pattern extending aft of the ballast block, the box beam doubler would be affected. Here, again, modest damage could be blended out and repaired in the field. Repair of more extensive damage requiring scarfed insertion of a complete segment of the doubler could be accomplished at a depot facility where higher skill levels and tooling are available. As long as the basic box beam spar is undamaged, repairs of this nature may be considered on an economic basis.

Configuration II

One of the goals of Configuration II shown in Figure 8 was to provide a minimum planform spar and to eliminate as much of the nonrepairable area of the blade as possible. To do this



DESIGN CONSIDERATIONS

1. MINIMUM CHANGE FROM CURRENT UH-1 BLADE.
2. FIBERGLASS SKINS PROVIDE SIGNIFICANT INCREASE IN REPAIRABILITY.
3. MINIMUM RESUBSTANTIATION REQUIRED.
4. UTILIZES EXISTING RETENTION.
5. SEGMENTED STEEL LEADING-EDGE SHEATH.
6. FIBERGLASS SPAR DOUBLER OUTBOARD.

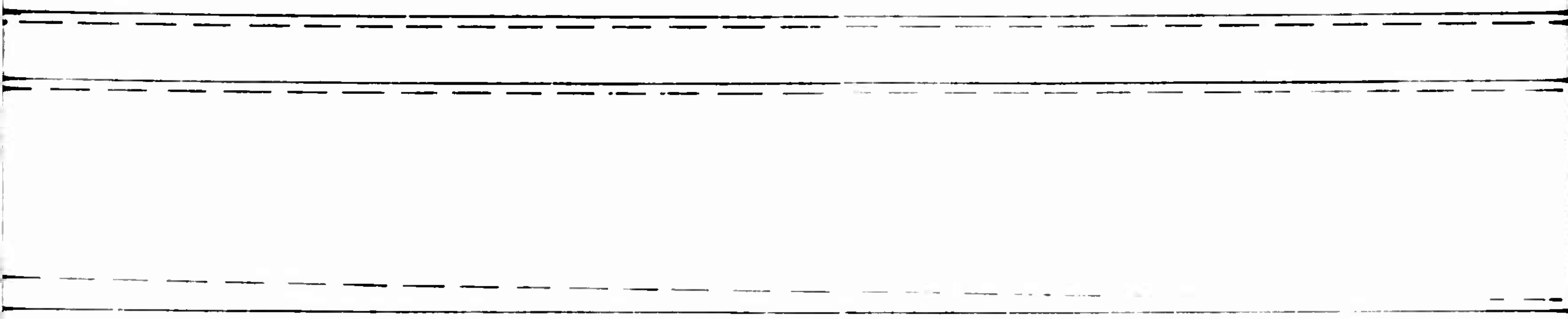
FABRICATION

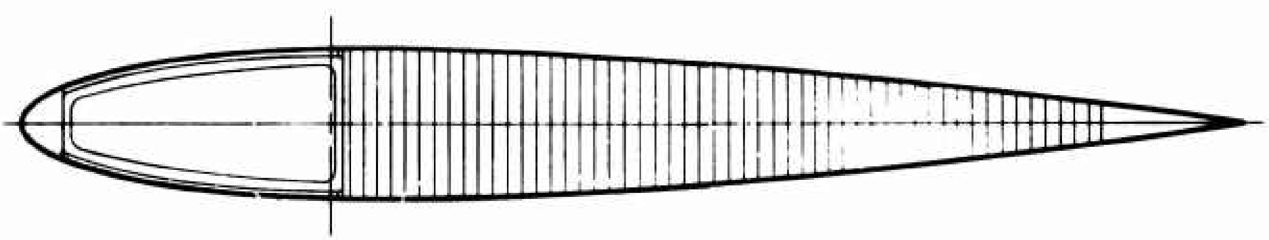
1. PROCESSING SIMILAR TO PRESENT UH-1 BLADE.
2. FIBERGLASS SKINS AND DOUBLERS PRECURED AS A UNIT AND BONDED INTO BLADE IN SUBSEQUENT OPERATION.

REPAIRABILITY

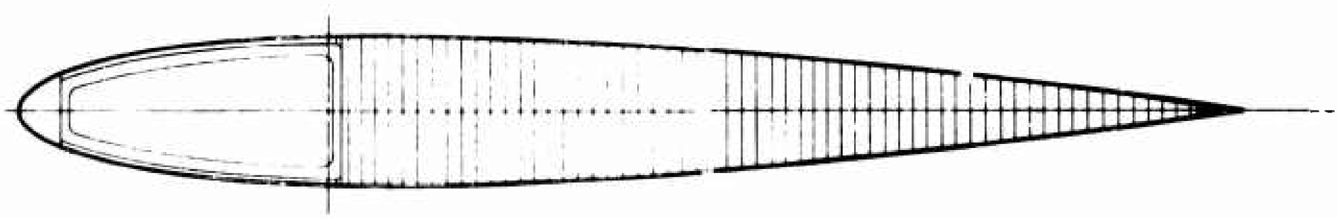
1. AFT STRUCTURE HIGHLY REPAIRABLE WITH PROPERLY DESIGNED KIT.
2. SPAR REPAIRABILITY IMPROVED.
3. SEGMENTED LEADING-EDGE FIELD REPLACEABLE.

Figure 7. Configuration I, Repairable Rotor Blade Using UH-1 Structural Components.

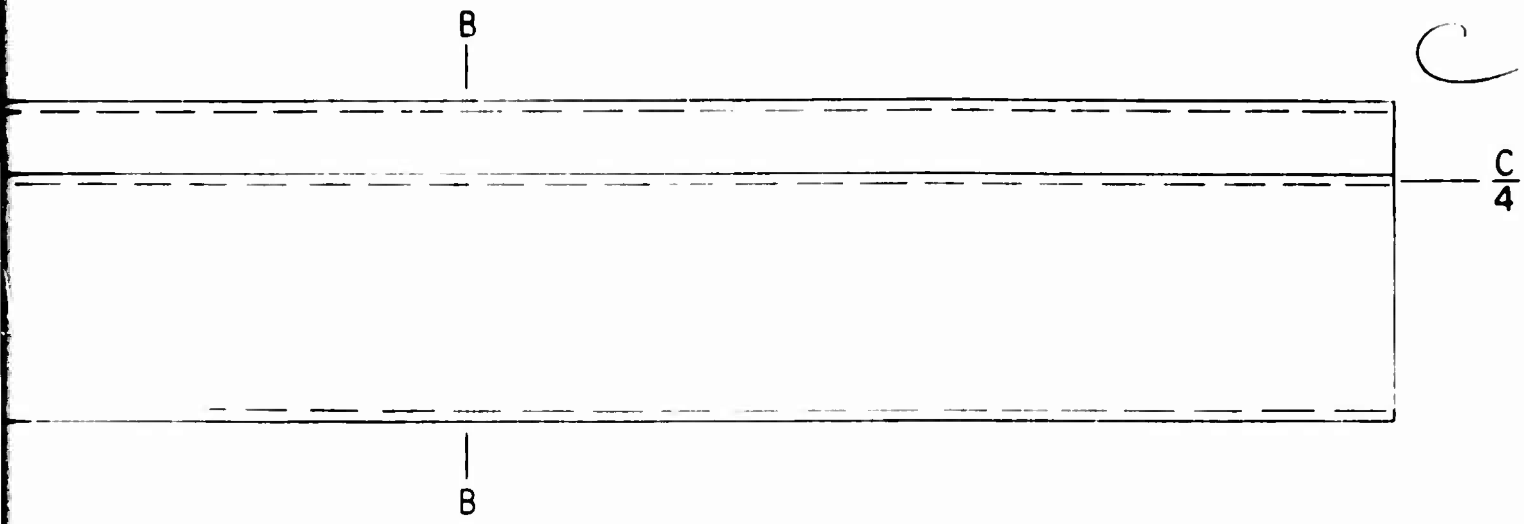




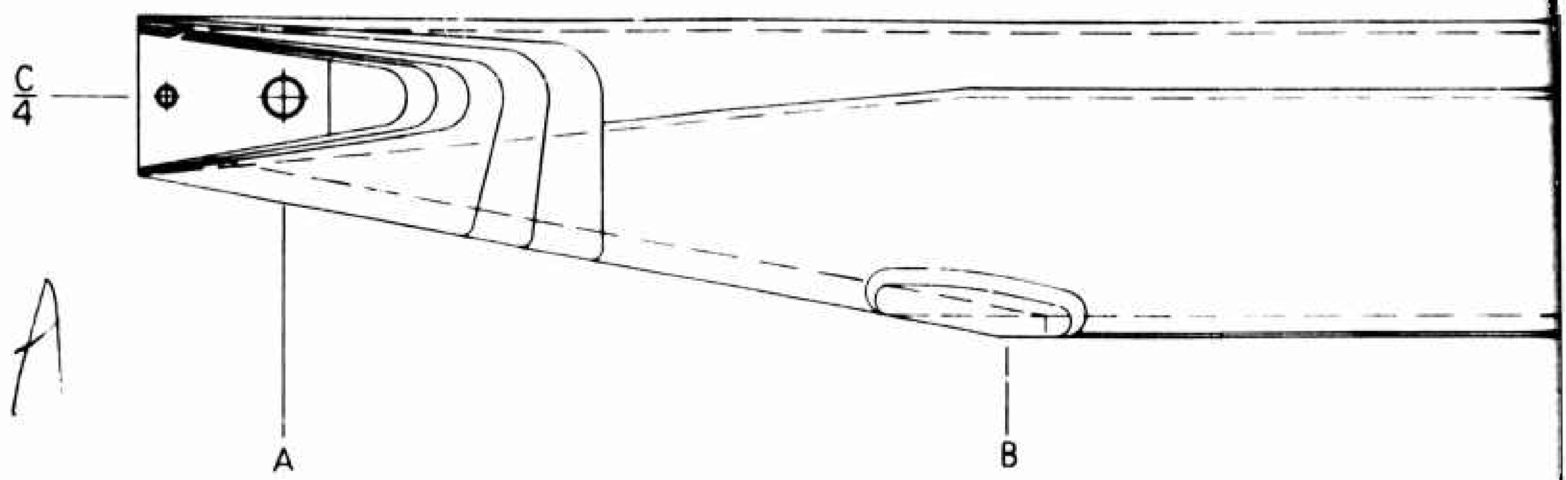
SECTION A



SECTION B



C
B
C
4
B



DESIGN CONSIDERATIONS

1. REDUCED BLADE PLANFORM - LOWER VULNERABILITY, LESS NONREPAIRABLE AREA.
2. TAPERED TITANIUM SPAR - DIFFUSION BONDED SHEET MATERIAL.
3. FIBERGLASS SKINS.
4. LEADING-EDGE BALLAST WEIGHT -
   HIGH MODULUS INBOARD FOR STIFFNESS -
   HIGH DENSITY OUTBOARD FOR CHORD BALANCE.

FABRICATION

1. SPAR FABRICATION REQUIRES DEVELOPMENT.
2. BONDING OPERATIONS SIMILAR TO PRESENT BLADE.

REPAIRABILITY

1. REDUCED VULNERABILITY
2. AFT STRUCTURE READILY REPAIRABLE WITH PROPERLY DESIGNED KIT.

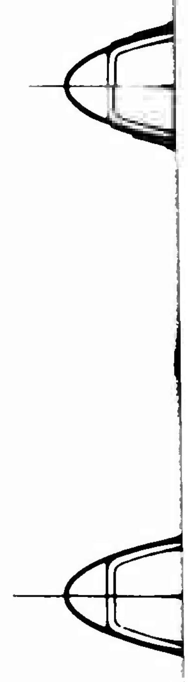
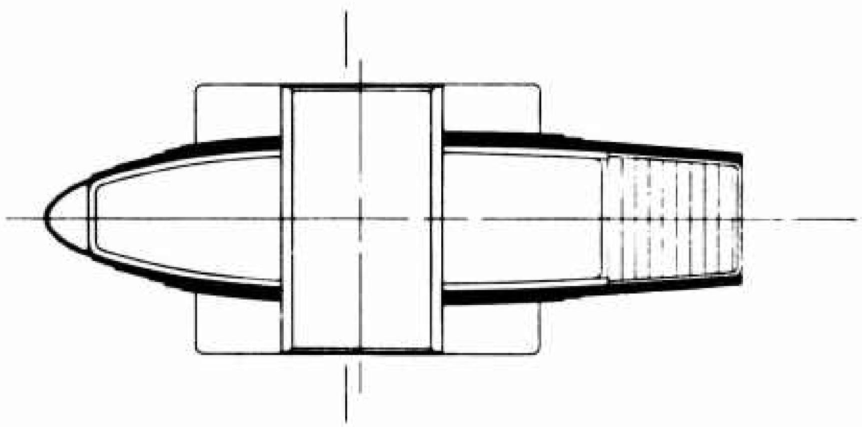
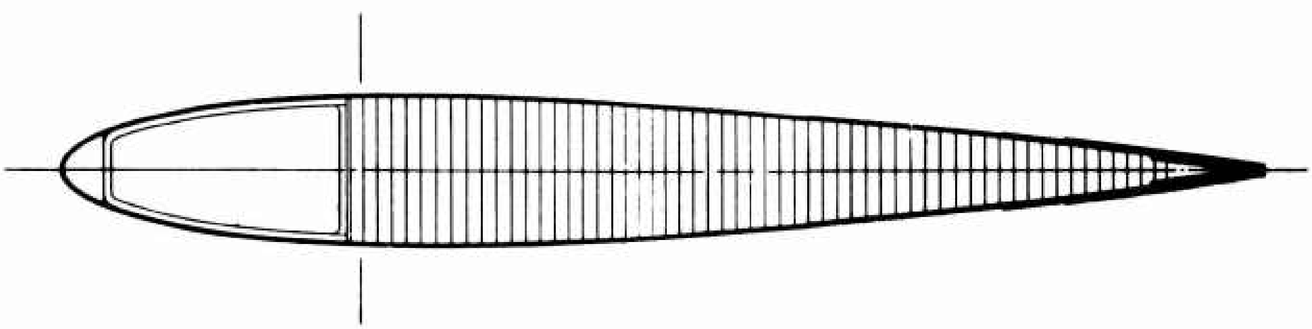


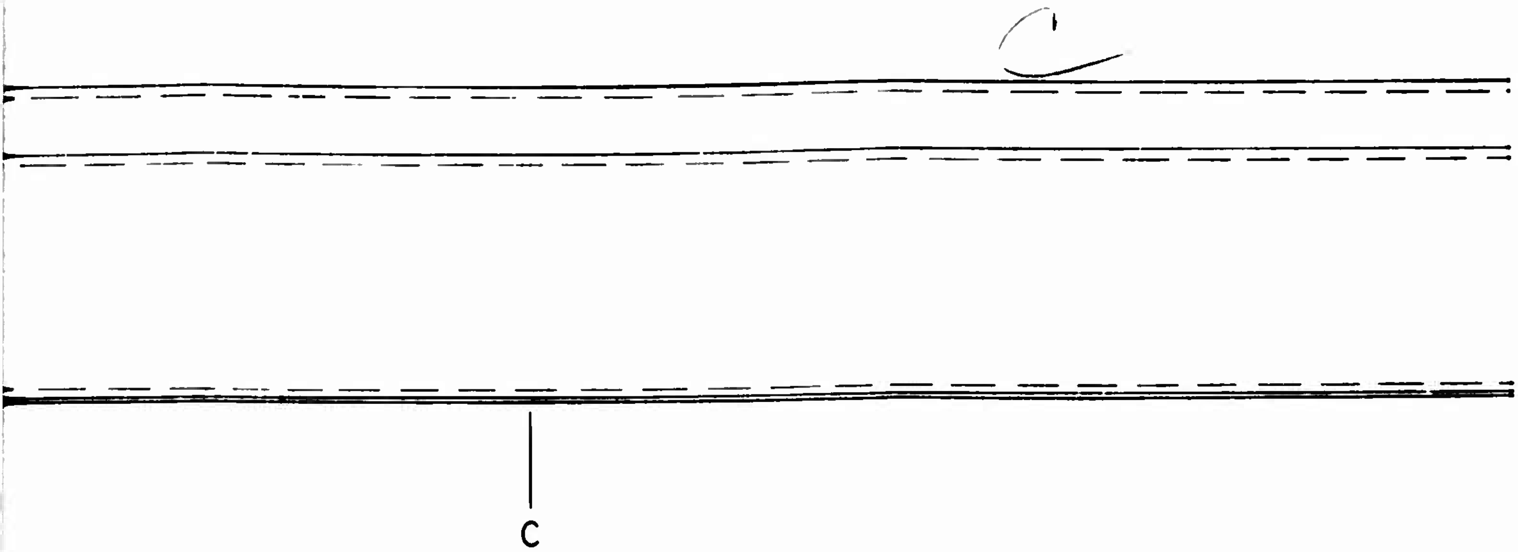
Figure 8. Configuration II, Repairable Rotor Blade Using Minimum Planform Titanium Spar.

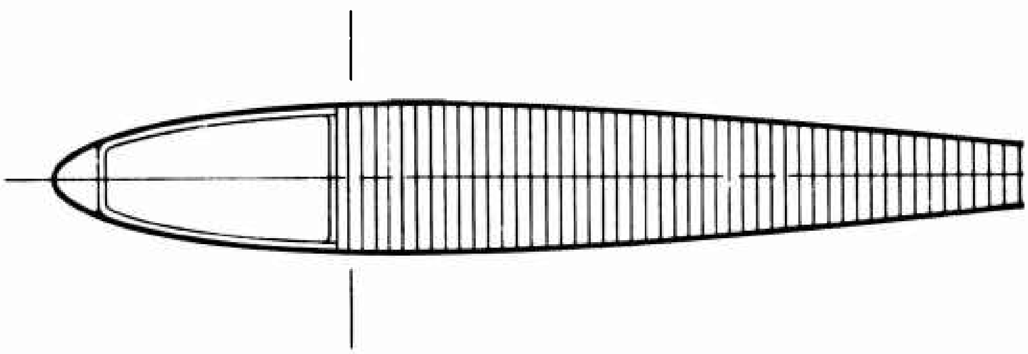


SECTION A
MAIN RETENTION PIN AREA

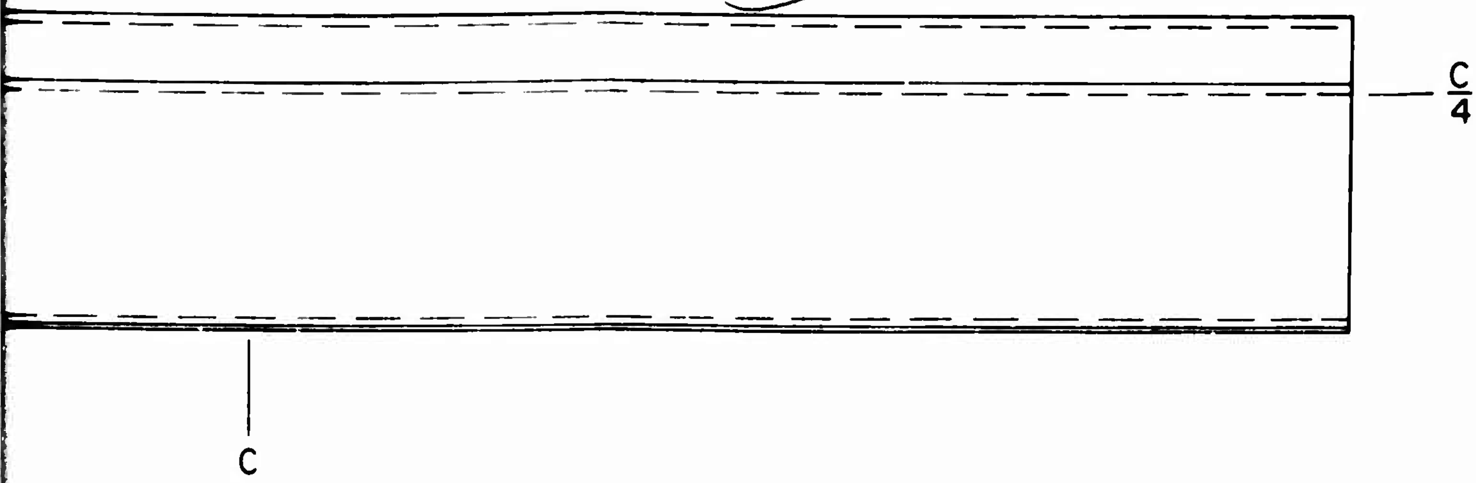


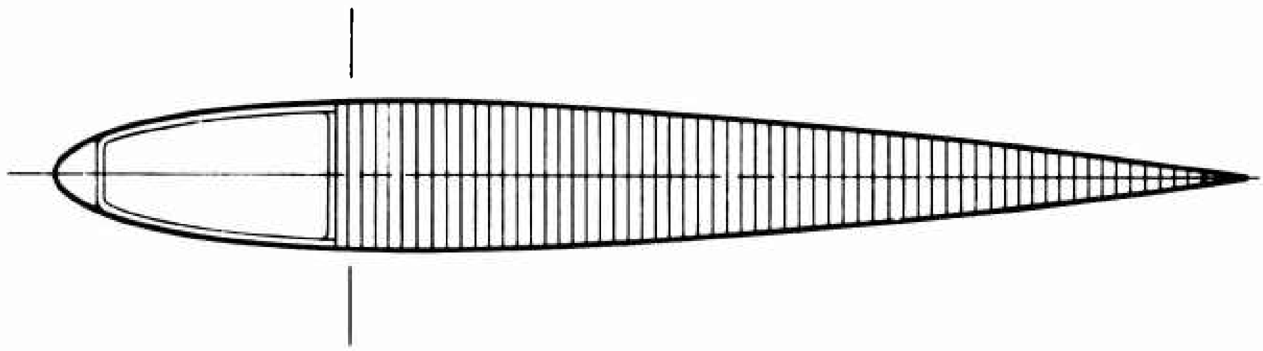
SECTION B
TRAILING EDGE SPLICE AREA





SECTION C
TYPICAL OUTBOARD AREA





SECTION C
TYPICAL OUTBOARD AREA

it was necessary to use a spar material with high strength and modulus of elasticity; titanium alloy Ti-6AL-4V was chosen. The configuration employs a modified retention scheme with two pins oriented spanwise, both piercing the main spar. The drag brace and some heavy root end structure are thereby eliminated, as is some of the vulnerable trailing-edge buildup. The main spar could have been formed from separate pieces and adhesively bonded; however, it appeared that higher integrity and reliability could be achieved by use of diffusion bonding. Preliminary evaluations of this process have shown the ability to produce excellent material properties for rotor blade applications. The process also lends itself to the fabrication of a tapered spar, which is necessary in approaching the minimum planform desired.

The trailing-edge spline and root end doublers are also of titanium. The nose block inboard is titanium and contributes significantly to edgewise stiffness. Outboard, the ballast block is brass for mass balance reasons. A titanium root end closing channel is incorporated to structurally connect the spline to the main spar in the retention pin area. Doublers outside the skin serve to reinforce attachment of the closing channel to spline and spar. Aft skins and honeycomb are identical to Configuration I, as is the segmented leading edge. No spar doublers are included in this design due to the higher strength and stiffness of the basic spar material. In addition to meeting stiffness requirements, this material contributes to improved damage resistance and should therefore have less need of repair for a given damage incident involving the spar. Battle damage or bullet holes, however, are expected to penetrate the spar wall as in the present blade.

Configuration III

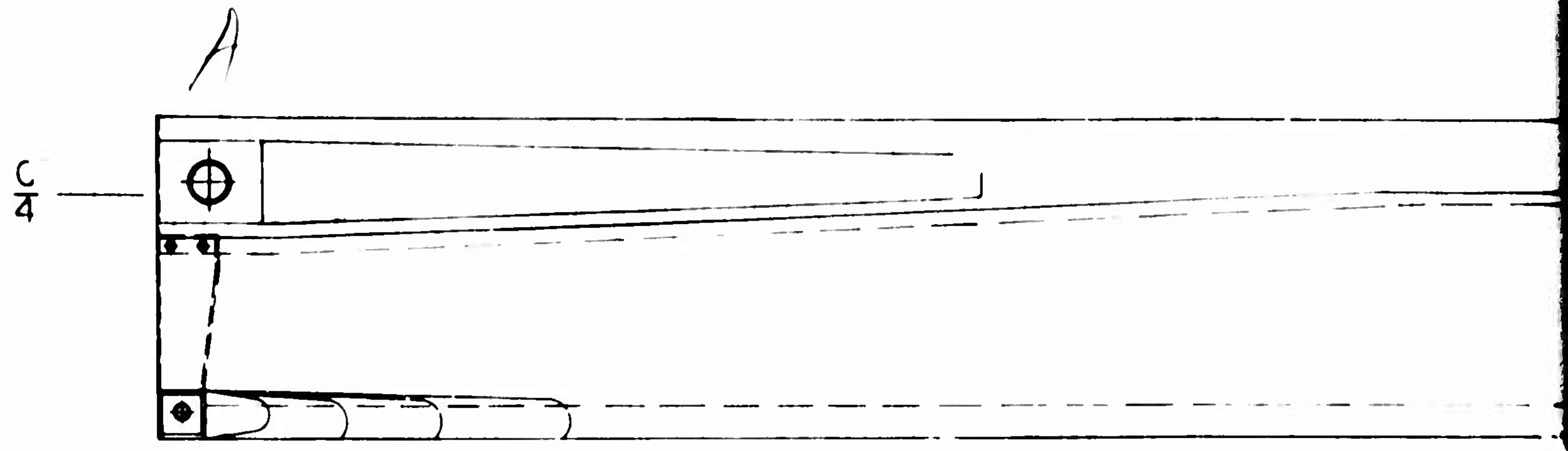
This design, based on a heavy-wall, stepped-extrusion main spar, is illustrated in Figure 9. The intent of this configuration is to supply a rugged spar which can withstand damage from external sources and continue in operation with only minor blendings, as is done with many propeller blades. No separate erosion protection is normally required; however, for a severe erosion environment, special protection may be provided for the tip area. The stepped extrusion reduces the possibility for inherent damage by making the buildup at the main retention pin an integral part of the spar.

With this design, a special root end fitting is required to connect the drag brace pin to the main retention pin. The trailing-edge spline is a combination of aluminum and unidirectional glass fiber, with the latter material protecting the aluminum and providing improved repairability for this element. The trailing edge is strengthened at the root with external doublers which provide structural connection to the root end fitting. The aft structure, skin, and honeycomb core are the same as those described for Configuration I with the same level of repairability. A brass ballast weight is contained in the leading-edge spar cavity. It is restrained at the tip with a multiple pin connection.

Configuration IV

This design, illustrated in Figure 10, uses unidirectional glass fiber as the primary structural material for main spar and trailing-edge spline. A relatively heavy wall spar is required with a layup schedule that will provide the integral root end buildup along with adequate bending and torsional stiffness. At the root of the spar, titanium doubler plates are incorporated into the layup to provide improved bearing strength and resistance to splitting. Edges of the doubler plates are beveled to minimize disturbance of filament load path. Titanium grip plates are also provided at the retention and drag pin holes, top and bottom surface. Leading-edge ballast is bonded to the front of the "D" shaped spar and encapsulated by the protective sheath. Ballast weight is brass outboard but is replaced with unidirectional fiberglass inboard, which contributes significantly to edgewise stiffness. The leading-edge erosion protection is provided by a segmented sheath and has the same material options described for Configuration I.

At the blade root, a machined fitting connects the main retention pin and drag brace pin. External skin doublers also provide connection as well as improving local skin shear strength. The trailing-edge spline is made up of a "V" of fiberglass cloth which houses a wedge of unidirectional material. The aft segment of the wedge is glass fiber and runs from root to tip, while the forward segment uses carbon filaments which run from the root and taper out at station 140. Carbon is used also for inboard spar doublers, which are replaced by glass doublers outboard of station 120. This limited use of advanced composite material is significant in attainment of the desired natural frequencies at minimal increase in weight and cost of the blade. Blade skins and honeycomb are similar to those used in Configuration I but incorporate a more extensive doubler system in the basic skin layup at the blade root.



<u>DESIGN CONSIDERATIONS</u>

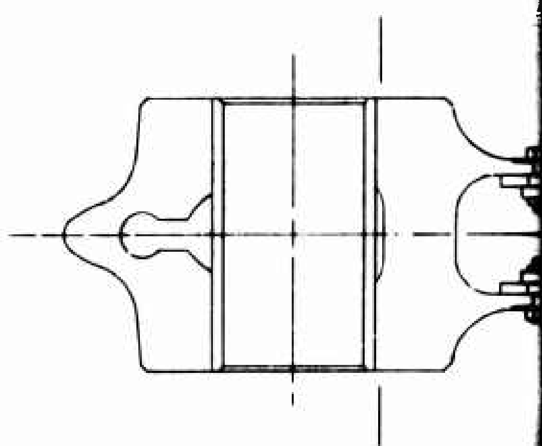
1. HEAVY-WALL ALUMINUM SPAR FOR EASY BLENDING OF DAMAGE.
2. INTEGRAL ROOT END STRUCTURE, STEP EXTRUSION.
3. GLASS FIBER SKINS AND TRAILING EDGE.

<u>FABRICATION</u>

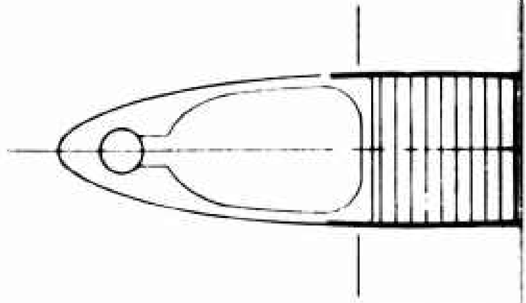
1. SPAR MACHINED FROM STEP EXTRUSION TO MINIMIZE MACHINING AND MATERIAL WASTE.
2. BONDING OF AFT STRUCTURE SIMILAR TO CURRENT BLADE, NO MAJOR DOUBLER BUILDUP REQUIRED.

<u>REPAIRABILITY</u>

1. LEADING EDGE READILY BLENDED TO REMOVE DAMAGE.
2. GLASS FIBER AFT STRUCTURE READILY REPAIRED WITH PROPERLY DESIGNED KIT.



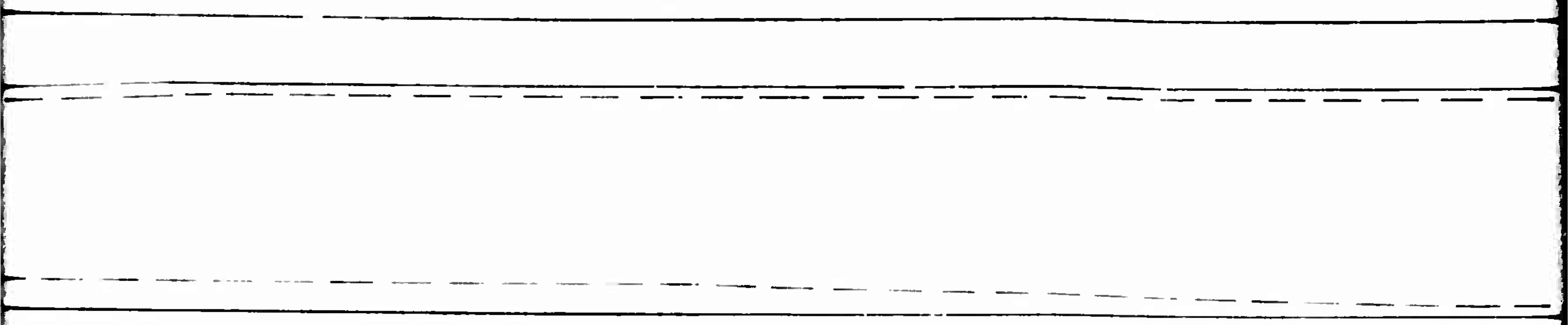
SECTION AT ROOT

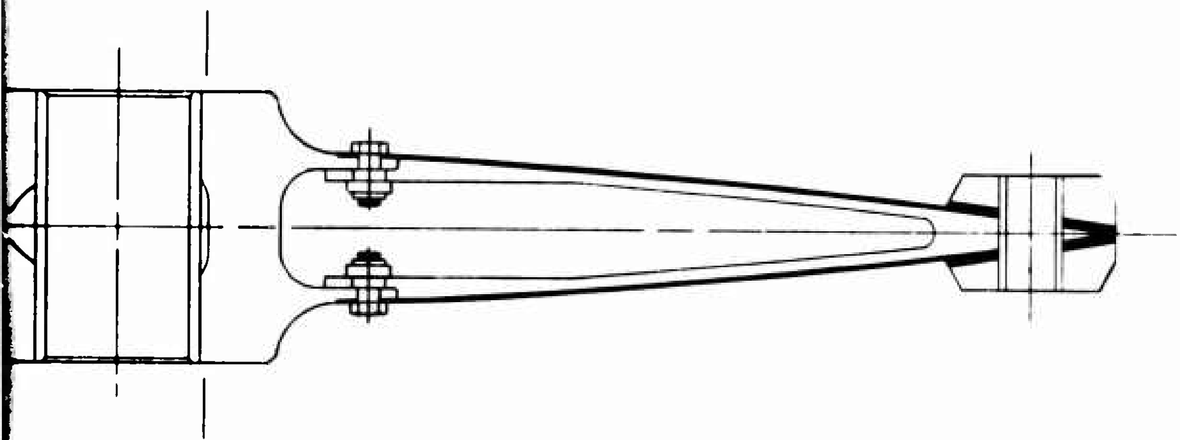


OUTBOARD SECTION

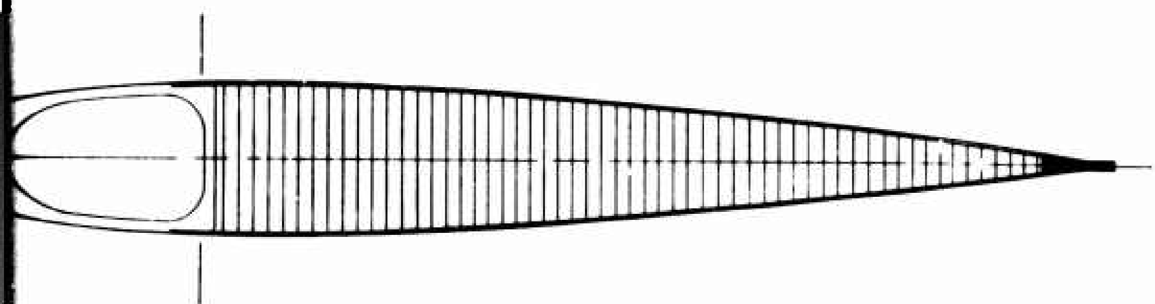
Figure 9. Configuration III, Repairable Rotor Blade Using Heavy Wall Aluminum Spar.

D

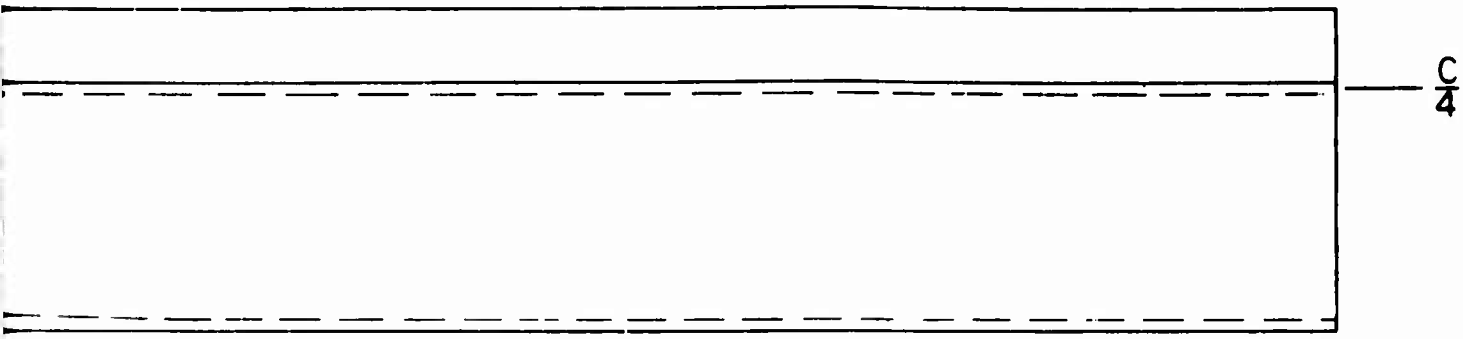




SECTION AT ROOT END



OUTBOARD SECTION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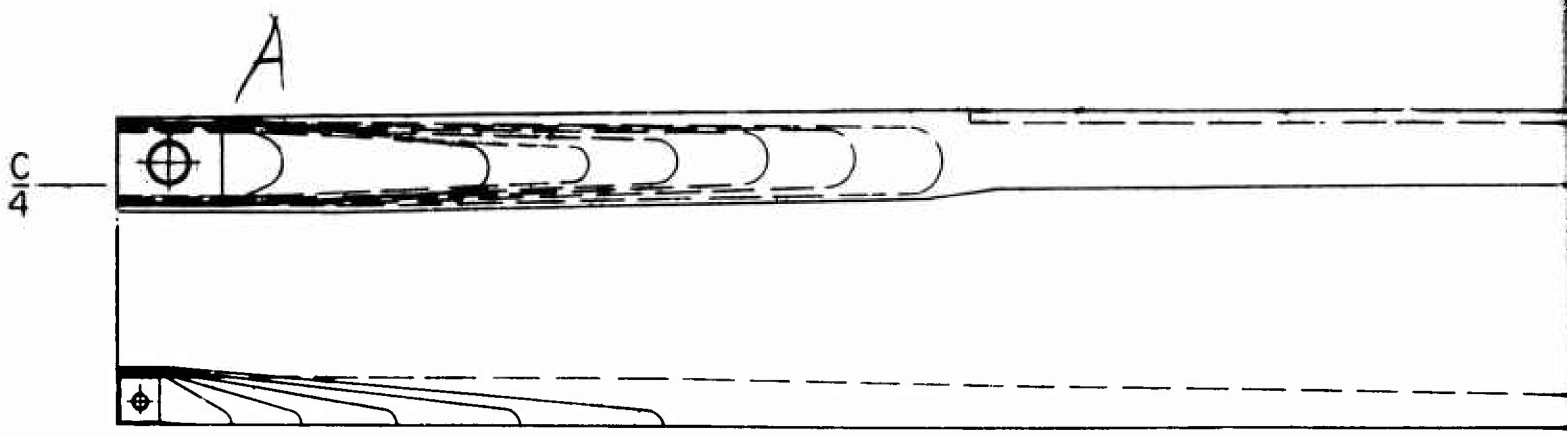
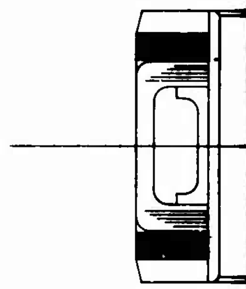
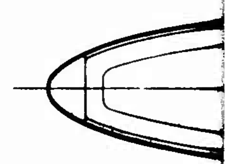






DESIGN CONSIDERATIONS

1. BASIC BLADE STRUCTURE MADE ENTIRELY OF DIRECTED GLASS FILAMENTS FOR IMPROVED REPAIRABILITY.
2. ROOT END RETENTION AND DOUBLERS REINFORCED WITH TITANIUM PLATES.
3. INTRODUCTION OF AIRFOIL VARIATIONS POSSIBLE.
4. TORSIONAL STIFFNESS DIFFICULT TO ACHIEVE.

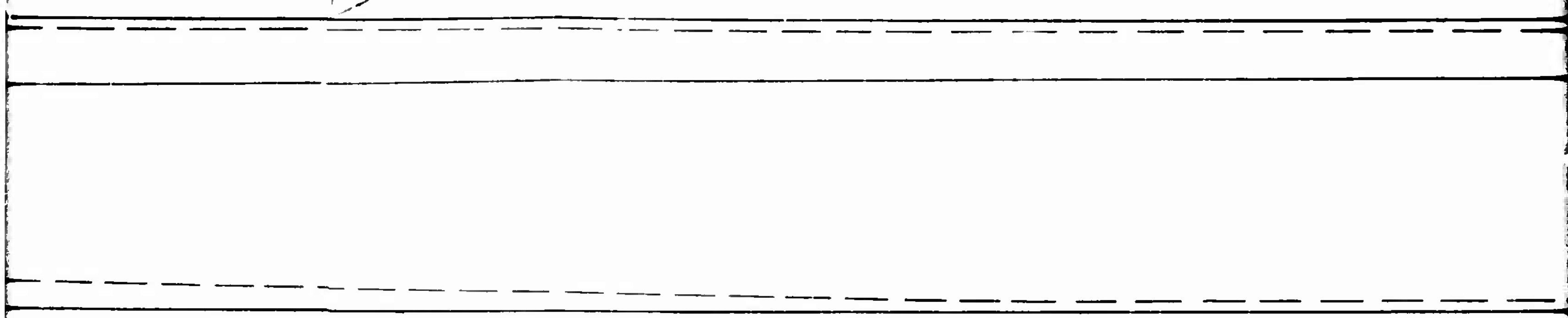
FABRICATION

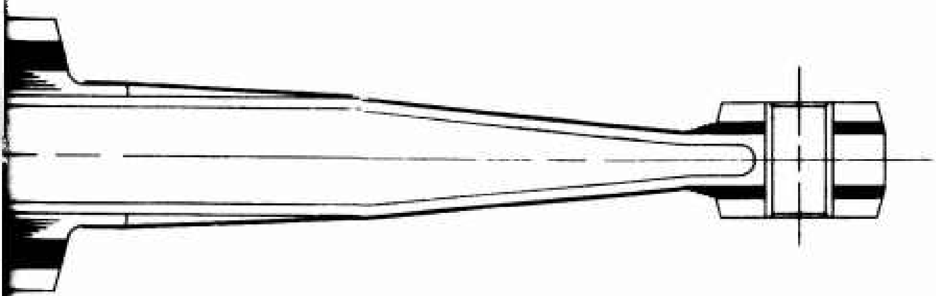
1. SPAR AND TRAILING EDGE LAYED UP AND CURED SEPARATELY.
2. FINAL BONDING SIMILAR TO CURRENT BLADE.

REPAIRABILITY

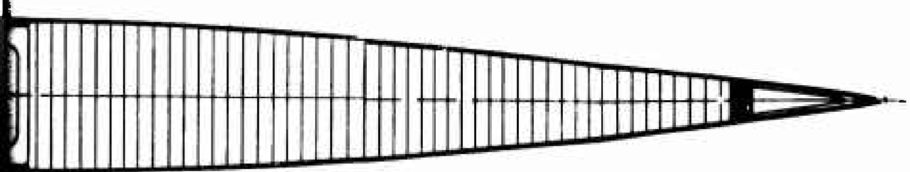
1. OVERALL REPAIRABILITY GOOD.
2. SPAR REPAIRABILITY FOR GOUGES AND DENTS IMPROVED OVER METAL SPAR.
3. AFT STRUCTURE HIGHLY REPAIRABLE WITH PROPERLY DESIGNED KIT.

Figure 10. Configuration IV, Repairable Rotor Blade Using Composite Material Spar.

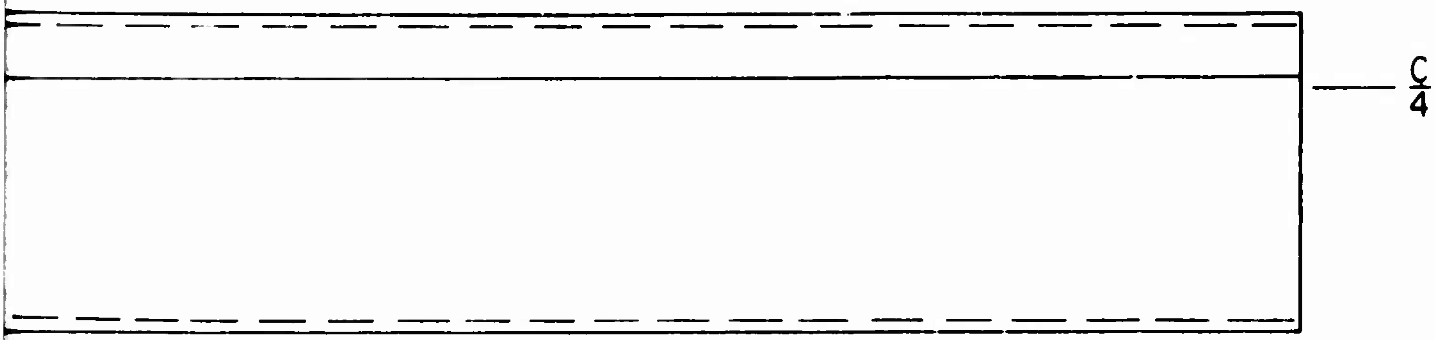




ROOT END



SECTION



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PRELIMINARY DESIGN ANALYSIS

The four rotor blade configurations previously described were subjected to preliminary analyses of their ability to meet technical requirements and also their potential impact on reliability, maintainability and cost factors. To simplify this phase of the work, the technical aspects were limited to weight, stiffness and mass balance considerations and were compared to the current blade as a base. Exact duplication of properties was not sought; however, reasonable approximation was taken as adequate satisfaction of technical requirements for this phase of the study. The resulting designs were then subjected to reliability, maintainability and cost analyses in an attempt to identify undesirable factors or designs that did not contribute to direct attainment of program goals. Details of these analyses follow.

RELIABILITY

Reliability engineering tasks were executed with the objective that the final blade design reflect at least current reliability and safety principles in addition to meeting the repairability requirements of this program.

The blade concepts were reviewed in regard to the survivability of the helicopter after occurrence of either part or external damage. Consideration was given to combinations of materials and detail construction which would have slow crack propagation rates. Equipment that could detect blade failures before they could progress to the point of damaging other portions of the helicopter also were considered. A method for detecting loss of pressure in the spar after flight due to a crack or bond failure was selected as the best suited to a fleet of medium-sized aircraft already in service. Improved methods of inspecting completed blades in both the depot and the field were studied with the goal of reducing in-service failures and reducing the shipping of unrepairable blades to depots.

Attention during the concept design stage was given to alternate construction details to reduce the probability of the blade's becoming corroded or contaminated in the interval between damage (or failure) and start of repair. The reliability review of the concepts included checks on the degree of blade repairability after failures due to inherent causes. The overall design concepts evaluation model was reviewed to assure that the reliability parameter was properly integrated and that effective reliability techniques were used.

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Reliability Analysis of Preliminary Designs

Based on Army-supplied data on UH-1H rotor blade design cost comparisons, all analyses considered external causes only, as the percentage of inherent damage was given as zero.

A failure mode and effect analysis (FMEA) to the detail part level was prepared for each blade concept and the configuration in current use. Parts were omitted whose modification, it any is needed, from the current UH-1H blade design will not affect repairability or reliability. The source for the failure modes of the fiberglass skins and the resultant mission effects was Kaman experience on the UH-2, adjusted to the Southeast Asia environment. Reference 1 data was used for parts similar to the current UH-1H blade and on modes of failure relatively independent of blade configuration; e.g., RPM over maximum allowed to be repaired.

The effects of bullet holes in spars of either fiberglass or aluminum were based on 30-06 ball ammunition fired in the laboratory into spars under centrifugal force, vibratory torsion, and vibratory flatwise bending.

Some of the additional sources of data for specific concepts are as follows:

Configuration I

Assumptions on the effectivity of the unidirectional fiberglass box beam doubler outward of station 105 are based on data of Reference 2.

Configuration II

The failure modes and effects for any titanium spar blade are more hypothetical than for the other concepts since only limited experience with blades of this material is available. Confidence in the Configuration II design is based on good aircraft industry experience with Ti-6-Al-4V and successful development work in diffusion bonding similar shapes.

A titanium-spar blade theoretically would provide more survivability than most blades flying today. Analyses of fatigue test data performed in the helicopter industry indicate that a titanium spar of equal weight to steel would have a slower crack propagation rate. Reference 3 indicates that diffusion welding of titanium alloys has been successful.

Configuration III

The failure modes and effects in regard to scratches on the step-extruded 6061 aluminum alloy spar are based on industry practice in maintaining solid aluminum aircraft propeller blades. Crack propagation time from start of indication to fracture in a 6061 spar is assumed to be 9 flight hours based on whirl test results on full-sized blades.

Configuration IV

Some of the failure modes and effects were based on Reference 4, Kaman's developmental fiberglass tail rotor blade for UH-1, and on development of an all fiberglass MRB for the H-43B. No service failure reports were available on fiberglass spar MRB's installed on helicopters, but the following experience during research tests was considered:

1. Reference 5 describes a whirl test fatigue failure at 300% of design load at 10^6 cycles on an experimental blade.

2. Full-sized root ends of the blade for the BO-105 failed in laboratory fatigue tests at .0847 to 13.24 million cycles as reported in Reference 6.

Current UH-1H Design

Criteria for the effects of failures were taken from manuals on structural repair of UH-1's rather than from Reference 1. Thus, the analysis of the current UH-1H design is comparable to that for the other four candidate designs.

A reliability (apportionment) report to the detail part level, including estimated repair facility, scrap, or crash disposition, was prepared for each preliminary design and the current UH-1H blade and is presented in Appendix II. The externally caused failure modes of each were apportioned into 1000 incidences/10^6 blade hours rather than the blade time between damage of 425 hours. This latter figure includes those from inherent causes as well as external damage.

Accident tabulations do not include a high rate of major accidents caused by MRB's of the types being apportioned in this study. An Armed Forces tabulation of UH-1 accidents/incidents indicates that no crashes between 1960 and 1970 were diagnosed to have been caused by failures of MRB's. Similarly, a tabulation of UH-2 major accidents from 1962 to the present indicates that no crashes were diagnosed to have been caused by failure of its blades which use figerglass skins.

General Reliability Problems Investigated

If more UH-1 MRB's are to be repaired at all levels, and consequently flown more hours before eventual scrap, it becomes economical to perform nondestructive testing in the field to verify the integrity of the basic blade structure before money is spent for local repair or shipping. Safety would be enhanced by a repeat of the test after repair to assure that successful repair was accomplished. Eddy-current testers similar to those already used by the Army for periodic inspection of rotor blades represent one means of accomplishing such an inspection. Based on discussion with equipment suppliers, the method is expected to be sufficiently accurate for all blade concepts except that penetration of external doublers is limited to a distance equivalent to .12 inch of laminated steel. It was concluded that eddy-current testing would be economically feasible for factory or depot testing of MRB's ready for shipment to assure that no cracks or discontinuities have been caused by handling or processing; however, its use in the field is not practical.

As reported in Reference 7, fracture toughness testing has indicated that titanium alloy specimens exposed to room-temperature salt water fractured at 1/3 the stress level in 1/7 the exposure time as compared to specimens exposed to other fluids. A survey of industry failures and the conclusions of other testing groups indicated negligible risk at ambient temperature. The spar of Configuration II is an interior part. All the titanium parts which are exterior will be protected by an environmental paint scheme. Other testing in 1969 indicated that titanium alloys with an aluminum alloy content of 4% or less are not susceptible to stress corrosion while those with a higher percentage are. A literature survey made in connection with the Configuration II blade concept uncovered no details on this testing. Ti-6Al-4V alloy scored high in the testing of all titanium researchers covered. Since titanium alloy components have survived operational aircraft environments better than was predicted by laboratory tests on specimens, and since Ti-6Al-4V has a proven history, it is considered to be a reliable choice of material.

Investigation was made of the problem of core corrosion if blades with the skin ruptured are exposed to moist air without benefit of the preparations for storage as directed in the structural repair manuals. Reference 1 indicates that field inspection sorting of removed blades is done at infrequent intervals. Perforated aluminum honeycomb core will allow moisture to spread inside the core if the skin is damaged or peels and the environment is corrosive to aluminum. Nonperforated core can be used with a low volatile 250°F adhesive system. The final designs, therefore, include non-perforated cores and compatible adhesive systems.

Failure Mode and Effect Analysis

The overall design evaluation for the four preliminary configurations and the current UH-1H blade design incorporates a failure mode and effect analysis and a prediction (apportionment) report. All of the new design concepts include an after-flight, failure-detecting indicator. The design of a blade with a spar crack propagation time longer than the maximum mission is a necessary adjunct to this system. For the present, program design effort along these lines was limited to selection of materials and alloys and approximate operating spar stress levels to make incorporation of such a system feasible.

Configuration I

This configuration, reported in Table XVI of Appendix I, has the following reliability features:

1. The use of fiberglass skin and fiberglass for the first external doublers softens the notch effect, is more damage tolerant, and increases the fatigue life of damaged skin and doublers.

2. The use of unidirectional fiberglass outboard of Station 105 for the box beam doubler decreases the crack propagation rate and increases the fatigue life of the damaged spar.

3. Reliability of the trailing-edge spline may be improved by incorporation of a fiberglass cloth trailing-edge cap bonded to the trailing edge to cover the exposed spline and protect it and the spline-to-skin glue line from a corrosive environment. The use of 6061 for the trailing-edge spline instead of 2024 increases the resistance to corrosive atmosphere and decreases the crack propagation rate.

Configuration II

The FMEA and prediction report for the Configuration II concept are presented in Table XVII of Appendix I. This concept has the following reliability features:

1. The spar has less planform area; therefore, the blade is less vulnerable in regard to battle damage.

2. The Ti-6Al-4V trailing-edge spline is more corrosion resistant than the 2024 trailing-edge spline of the blade in current use.

Configuration III

The FMEA and prediction report for the Configuration III concept are presented in Table XVIII of Appendix I. This concept has the following reliability features:

1. The use of 6061 for the spar decreases the crack propagation rate.

2. The trailing-edge spline sandwich of aluminum plate between wedges of fiberglass has a slow propagation rate and all except one edge of the metal is protected by fiberglass skin.

3. The thick-walled spar allows a safe landing to be made with deeper damage in the spar area than other designs and the probability of blade scrappage is lower since much deeper damage can be repaired by blending.

Configuration IV

The FMEA and prediction report for the Configuration IV concept are presented in Table XIX of Appendix I. Confidence in the reliability of the Ti-6Al-4V laminates reinforcing the fiberglass spar is based on developmental work done by Kaman on various designs and also that reported in Reference 6. Configuration IV has the following reliability features:

1. The molded beam consisting of spar, spar doubler, and closing channel, all or oriented unidirectional fiberglass, has the lowest stress levels and the slowest crack propagation rate of any of the concepts. It can sustain more extensive damage than any of the other concepts and still allow a safe landing. The probability of blade scrappage is less since more liberal repairs can be allowed.

2. The trailing-edge spline is completely noncorrosive and has a slow crack propagation rate.

3. Fiberglass spar blades provide ease of visual inspection greater than metal spar blades, particularly before painting or after paint has been removed for repair. At those times, portions of an acceptable blade are translucent, so voids can be detected by opaqueness. Even after painting, internal failures or damage can be detected with more ease in a fiberglass spar blade than a metal spar blade by ripples, resin crazing, bulges, etc., in the exterior.

4. The beginning of fatigue failure (cracking, crazing, deformation, or delamination) on a fiberglass spar blade on a semirigid rotor may be detected by a shift in the natural frequency of one or more of the vibration modes of the system.

Current UH-1H Blade

The FMEA and prediction report for the blade now in use are presented as Table XX of Appendix I. This design has the following reliability feature:

> The damage resistance of the skin to some forms of external damage may be greater, and therefore fewer repairs may be necessary.

MAINTAINABILITY

A maintainability analysis of repairable rotor blade concepts must assess the relative repairability of the designs and the cost of repairs in materials and man-hours, determine what support equipment and facilities may be required, and evaluate the personnel skill levels and training that will be needed to do the work. There are several possible approaches to this analysis; however, the one that seemed most objective and could provide the best comparative results was a random assignment of damage type, size and location over the planform of the blade and the assessment of repairability and maintenance factors for each damage incident, making use of the failure mode and effects analysis for all blade concepts considered. Tabulation of the resulting repair time, material costs, aircraft down time, etc., would provide the necessary input information for an analysis of the impact of each concept on total life-cycle costs of rotor blades.

Assignment of Damages

Four candidate blade configurations plus the current UH-1 blade were analyzed for 100 potential damage incidents in order that respective repairability analyses could be made. Table XXVI in Appendix III defines the 100 incidents. All occur with a 30-inch chord by 300-inch span damage envelope and are illustrated in Figure 11.

The apportionment of damage type was based on actual combat experience with helicopters in Southeast Asia. The distribution used in the analysis was as follows:

Damage Type	Percent Occurrence
Battle Damage	23
Dent	37
Puncture	17
Tear	10
Foreign Object	13

The incident locations on the blade planform and their dimensional description as to span, chord, and depth were determined by a random number selection. Range for span locations was 0 to 300 inches; range for chord location was 0 to 30 inches; range for size and depth of damage was based on service experience for each type. This random number analysis was set up and conducted by the Army, and the results were provided to the contractor for use in this analysis. Complete definition of the 100 damage incidents is presented in Table XXVI of Appendix III. In general, this data was used as supplied; however, in some specific areas, the random analysis led to illogical results. This was particularly true in the case of dents, which occurred over the relatively stiff and strong spar. Based on general rotor experience and specific laboratory testing, the following modifications of the damage depth dimensions were employed:

a. All battle damages are considered to have penetrated through full blade thickness.

b. All punctures are considered to have penetrated through half the blade thickness.

c. Depths of dents, tears and foreign object damage which do not occur over spar or doubler area are as defined by the random analysis.

d. Depths of dents, tears and foreign object damage which occur in the relatively hard metal spar areas are reduced to 6/1000 of the dimensions given by the random analysis.

e. Depths of dents, tears and foreign object damage which occur in a fiberglass spar area are reduced to 24/1000 of the dimensions given by the random analysis.

A 1/4 scale planform drawing of each of the five blade configurations was prepared, as was a 1/4 scale layout of the 30-inch by 300-inch damage scenario. Composite overlays were then produced using pitch change axis centerlines and rotation centerlines as blade planform-to-damage layout alignment indices. The composite layouts were used to quickly determine which of the 100 potential damage incidents actually struck each blade configuration and which blade details were thereby affected. Damage incident strikes and lists of details affected are recorded in Tables XXVII through XXXI of Appendix III. Because of their reduced planforms, candidate blade Configurations II and IV suffered fewer damage strikes than the other configurations.

Scrap Versus Repair Decision

Each blade planform/damage layout was reviewed and scrap decisions regarding damages occurring on candidate blades were made with the aid of the failure mode and effect analysis, using the following guidelines:

a. Any damage penetrating or causing gross deformation of spar walls, grip doublers, drag link doublers, root fittings, root closing channels or inboard sections of trailing-edge splines was cause for scrap.

b. Any damage causing extensive delamination of grip doublers, drag link doublers or transition doublers was cause for scrap.

All blade details mentioned above are not necessarily included in each candidate blade design. For instance, a root closing channel and transition doublers exist only in the Configuration II design. Also, planform shapes and sizes of critical details such as spars and trailing-edge splines vary from configuration to configuration. For these reasons, it is possible for a given damage incident to cause repairable damage on one blade configuration and result in scrappage of another.

Scrap decisions regarding the current UH-1 blade were based on criteria published in maintenance manuals.

<u>Maintenance Levels Assigned To Accomplish Repairs</u>

Damages not resulting in scrappage were judged to be repairable, and each was assigned to the maintenance level best suited to accomplish repair. Assignments are indicated in Table XXVII through XXXI of Appendix III. Organizational and intermediate level actions are indicated by entry of a repair time estimate in the respective repair time columns. Depot level actions are so indicated in the repair scheme description column. The repair actions performed at the three levels of maintenance are summarized for all five blade configurations in Table II. Maintenance level assignments were made using the following guidelines:

<u>Organizational</u>

a. May be accomplished by mechanic who normally inspects and maintains the helicopter.

b. Removal of blade not required.

c. Pneumatic tools or electrical equipment, except those capable of operation on aircraft DC power, not required.

d. Relatively short aircraft down time.

TABLE II. BLADE REPAIR SUMMARY

Maintenance Level	Current Blade		Configuration I		Configuration II		Configuration III		Configuration IV	
	Actions	Percent	Actions	Percent	Actions	Percent	Actions	Percent	Actions	Percent
Organizational Repair	12	16.9	15	21.1	11	15.9	13	18.3	5	7.1
Intermediate Repair	10	14.1	36	50.7	40	58.0	36	50.7	45	64.3
Subtotal (Org & Int Repairs)	22	31.0	51	71.8	51	73.9	49	69.0	50	71.4
Depot Repair	10	14.1	6	8.5	6	8.7	9	12.7	8	11.4
Total (All Repairs)	32	45.1	57	80.3	57	82.6	58	81.7	58	82.8
Scrap	39	54.9	14	19.7	12	17.4	13	18.3	12	17.2
Grand Total (All Damage Incidents)	71	100.0	71	100.0	69	100.0	71	100.0	70	100.0

Intermediate

a. Requires mechanic trained in repair of rotor blades.

b. Removal of blade from helicopter significantly facilitates repair.

c. Availability of tools and power sources significantly facilitates repair.

d. Aircraft down time to replace blade generally less than down time to repair blade.

Depot

Damage not extensive enough to cause scrappage, but beyond the repair capabilities of lower levels of maintenance.

Repair Procedures

Eleven basic repair procedures were devised such that they could be used singly or in combination to accomplish repair of any damage incident previously judged repairable at organizational and intermediate maintenance levels. The procedures are included as Appendix IV. It should be noted that the procedures are general in nature and not intended as instructions to maintenance personnel. They were used by the analyst in estimating times to accomplish repairs and to assure that adequate consideration was given to repair materials and equipment requirements. Specific combinations of procedures used and active repair times for each are given in Tables XXVII through XXXI of Appendix III.

As an adjunct to analytical application of the eleven repair procedures, the contractor selected the one considered most innovative and conducted an actual field test. Appendix V describes accomplishment of a patch/plug repair of an extensively damaged skin and core area of a blade. The area repaired in the test is representative of the skin and core areas of all candidate blade configurations. The test results verified the feasibility of the patch/plug repair concept.

Repair Kits

Availability of standard repair kits significantly reduces administrative and supply delays. Six kits are defined in Table XXXII of Appendix III. Each is related to a particular type of repair, and in cases of extensive blade damage requiring a combination of repair procedures, more than one type of kit may be used. Kit requirements for all organizational and intermediate level repairs of candidate blades are listed in Tables XXVII through XXXI of Appendix III. A summary of kit use frequencies for each blade configuration is given in Table III of this report. All six kits have unlimited shelf life due to exclusion of adhesives and filler mixes. The adhesives must be stocked separately, and it is recommended that they be packaged in special two-compartment plastic pouches of a type already in use.

Equipment Requirements

Table XXXIII, Appendix III, lists six groups of equipment used to accomplish repairs below the depot level of maintenance. The groups of equipment are numbered 1 through 6 and are directly related to the special repair kits of the same number listed in Table XXXII of Appendix III. A total of 11 items of equipment are listed, and all are in the Army supply system or commercially available except item 2. Item 2 is a specially designed inflatable rubber bladder and strap assembly which would be wrapped around a blade section being repaired to create bond pressure. The bladder design is simple and the item is inexpensive. Photographs of the bladder in use are shown in Appendix V.

Skill Levels

Those repairs designated for organizational level maintenance are within the capabilities of "Helicopter Repairman - Single Rotor, Turbine Observation/Utility", MOS 67N20.

The repairs designated for intermediate level maintenance are within the capabilities of "Rotor and Propeller Repairman", MOS 68E20.

Blade Repairability

Table II of this report summarizes the repair analysis data compiled in Tables XXVII through XXXI of Appendix III. Listed for each blade configuration are the percentages of damage incident strikes which resulted in:

a. Repair at organizational level

b. Repair at intermediate level

c. Repair at organizational and intermediate level combined

d. Repair at depot level

TABLE III. REPAIR KIT USE FREQUENCIES

Kit No. and Type	Configuration I	Configuration II	Configuration III	Configuration IV
1. Exposed Metal Repair Kit	3	2	9	0
2. Abrasion Sheet Kit	1	1	1	13
3. Directed Glass Fiber Repair Kit	6	0	7	14
4. Skin Patch Kit	13	16	15	17
5. Plug/Patch Kit	22	23	20	20
6. Trailing-Edge Doubler Kit	9	8	7	7

e. Repair at any level of maintenance

f. Scrappage

Also listed for each blade are the percentages of repairable damages which were repaired at maintenance levels lower than depot.

The total repairability of candidate blade configurations ranges from 80.3% to 82.8%. This compares with 45.1% for the current UH-1 blade as determined by this analysis. On the basis of field/intermediate level repair, this analysis showed the current blade to have a 31% repairability versus 69% to 73.9% for the candidates. Actual field repairability of the current blade is substantially less than 31%, as shown by Reference 1 and Appendix VI. This apparent discrepancy will be fully accounted for in the final analysis.

Maintenance Times

Table IV is a tabulation of maintenance times for each of the five blade configurations. The methods used to calculate maintenance times are described below.

Mean Time to Repair (MTTR)

The mean time to repair is the arithmetic average of all repair times at each of the two maintenance levels. It is derived by summing the repair times and dividing by the number of repair actions. Only the actual blade repairs are included in the MTTR. The time for blade replacement in cases of scrap or higher level repair is omitted.

Maximum Repair Time (M_{max})

The maximum repair time is the 90th percentile repair time based on a lognormal distribution. The method used to define the repair time distribution function has been developed by Kaman as part of a maintainability prediction model for aircraft systems and equipment. Equations developed from regression analysis of helicopter repair time data are used to predict the mean and variance of the log repair times based on a known or calculated MTTR. The regression equation used to calculate the variance is

$$\sigma_x^2 = .0580 + .3030 \log_{10} \text{MTTR} \quad (\text{for MTTR} \geq 1.0)^*$$

*For MTTR < 1.0, $\sigma_x^2 = .0580$

where:

σ_x^2 = the variance of the logarithms of repair time

From the mean time to repair and the variance, the mean of the logarithms is calculated using

$$\bar{X} = \log_{10} \text{MTTR} - 1.1513\, \sigma_x^2$$

where:

$\bar{X}$ = the mean of the logarithms of repair time

The maximum repair time is then calculated from

$$M_{max} = \text{antilog}_{10} (\bar{X} + 1.282\, \sigma_x)$$

where:

M_{max} = the 90th percentile repair time

σ_x = the standard deviation of the logarithms of repair time

Mean Maintenance Down Time ($\overline{DT}$)

For organizational level repair actions, the helicopter will be down for the elapsed time required to effect the repair. Damage beyond repair or beyond organizational capability requires that the rotor blade be replaced and the damaged blade scrapped or sent to a higher level facility for repair. Aircraft down time in these cases is the elapsed time required for a blade replacement. Based on an average of 7.46 man-hours per replacement and an average crew of two men, the active maintenance down time for a main rotor blade replacement is estimated at 3.73 hours. The mean maintenance down time is then the arithmetic average of the organizational repair down times and the blade replacement down times. Down time is the time during which maintenance is actually being performed. In the case of on-aircraft blade repair, time is added to account for adhesive and paint curing time where applicable. No allowances are made for administrative or supply delays.

Maintenance Man-Hours per Flight Hour (MH/FH)

In keeping with the computation of maintenance down time, the man-hours at the organizational level are those required for on-aircraft blade repair or blade replacement when damage is beyond organizational capability. For both the organizational and intermediate level repair actions, man-hours are equivalent to repair time (one man per action). Unlike the downtime calculation, no time is allowed at organizational level for adhesive and paint curing, since no productive maintenance is performed during this time. An average of 7.46 man-hours is allocated for a blade replacement at organizational level.

The average man-hours per action is obtained by summing the man-hours for all actions and dividing by the number of actions. Man-hours per flight hour at the organizational level is obtained by dividing the average man-hours per action by 425 flight hours (the frequency specified for external damage incidents). Intermediate level man-hours per flight hour is derived in the same manner, using the flight hour interval at which intermediate repair actions occur.

Review of the results of the maintenance time analysis presented in Table IV reveals that the four candidate blade designs generally require higher repair times and man-hours than does the current UH-1 blade. This result is to be expected since each of the new designs is intended to provide a higher level of repairability and therefore more extensive and time-consuming repairs. This increased time is, of course, more than offset by the reduced scrap rate, and all of these factors are included and fully accounted for in the cost model and are reflected in the total life-cycle cost of each blade type.

TABLE IV. MAINTENANCE TIME SUMMARY

Time Consideration	Current UH-1 Blade	Configuration I	Configuration II	Configuration III	Configuration IV
Mean Time to Repair (MTTR)					
Organizational Level	.40	.64	.73	.68	1.36
Intermediate Level	1.60	4.50	3.98	4.29	4.95
Organizational & Intermediate Combined	.95	3.37	3.27	3.33	4.59
Maximum Repair Time (M_{max})					
Organizational Level	.70	1.11	1.28	1.19	2.66
Intermediate Level	3.24	10.17	8.95	9.66	11.21
Organizational & Intermediate Combined	1.66	7.49	7.26	7.42	10.36
Mean Maintenance Down Time ($\overline{DT}$)					
Organizational Repair Actions Only	2.30	1.98	2.91	3.10	5.20
All Organizational Actions	3.49	3.36	3.52	3.61	3.84
Maintenance Man-Hours/Flt-Hr (MH/FH)					
Organizational Level	.0148	.0142	.0150	.0160	.0165
Intermediate Level	.0005	.0054	.0052	.0051	.0073

COST

Utilizing the cost model described earlier, main rotor blade life-cycle costs were generated for current UH-1D/H blades and the four candidate repairable blade concepts. Cost elements generated in this study are described herein, and those supplied by the Army are identified here as well as being included in Appendix VI.

Price of New Blades

With a given concept defined physically, a cost estimate to produce the blade was made and the experience curve slope established as shown in Figure 12. The adjusted candidate blade costs, based on mid-1971 rates, are shown in Table V along with the production cost estimate of the UH-1D/H blade. To the production cost is added the nonrecurring cost amortized over 10,000 blades and profit. This price is considered the FOB price to the Government in the cost analysis. The nonrecurring costs include design and analysis along with static, fatigue, whirl, and flight testing. RDTE costs for the UH-1D/H blade are assumed to be the same as for Configuration I, since many of the blade components are common to the existing blade. The cost of producing the UH-1D/H blade was estimated in the same manner as the candidate blades. For the 10,000th unit, this blade price was less than the stated value of $3000, Appendix VI. The price of all blades was therefore adjusted so that the candidate blade prices are consistent with the given UH-1D/H blade price.

100 Random Hit Analysis

Details of the hit analysis have been described previously in the maintainability section, and the results as used in the cost analysis are presented in Table VI. The values shown in the table are corrected fractions of total life-cycle damage events as determined by the 100 random hit analysis. The results of the UH-1D/H blade damage analysis showed a user repair capability of 31% when applying manufacturer repair criteria to the random damage events. However, the Government-specified user repairability for this blade is 12%. It appears from the above discrepancy that actual user repair is substantially less than that derived by analytical applications of blade repair manual criteria. The linear correction shown in Figure 13 was therefore applied to bring the repairable blade candidate data in line with the specified repairability of the UH-1D/H blade.

Cost Curves, Nc Profit, No RDTE

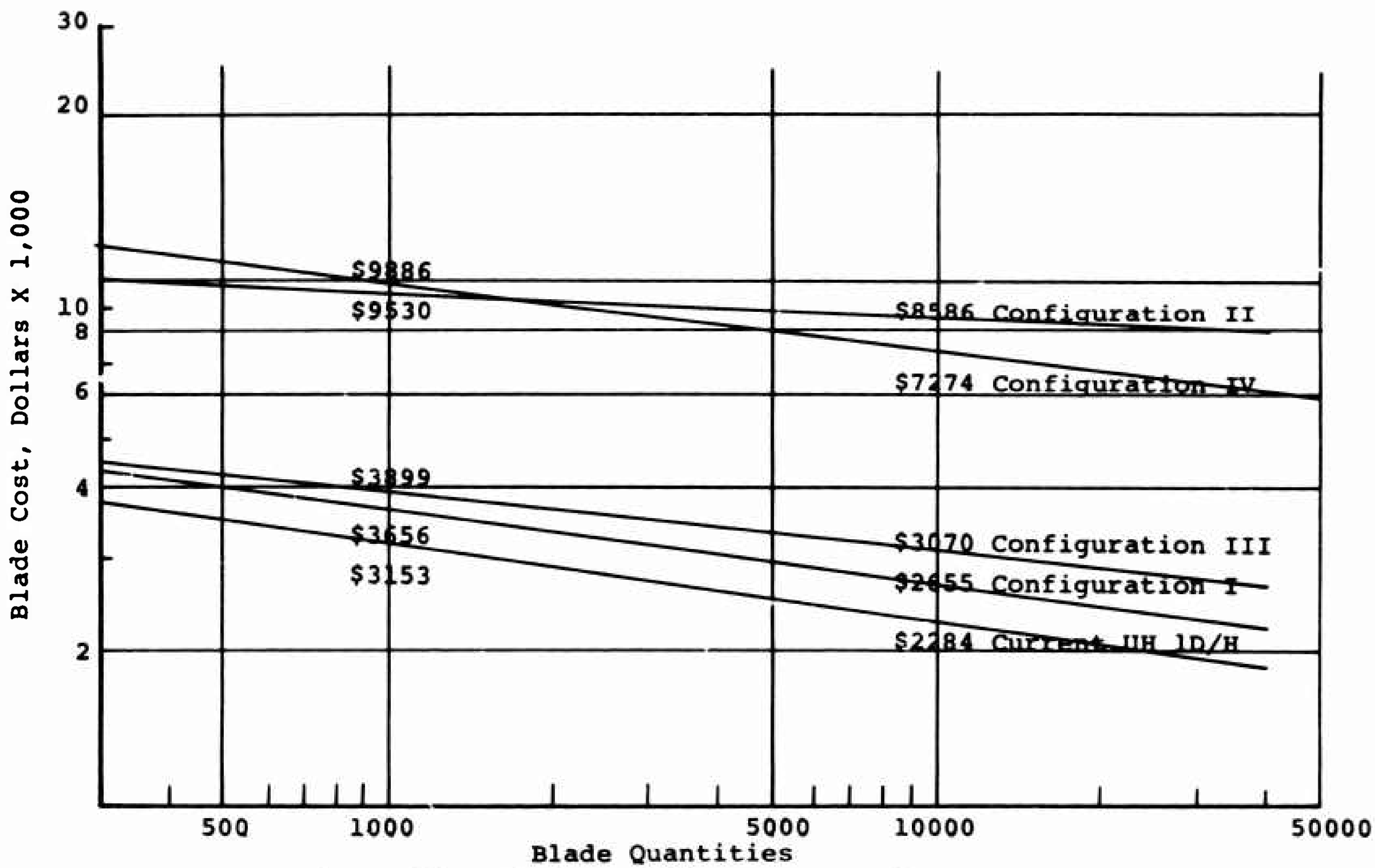


Figure 12. Blade Candidate Cost Estimates

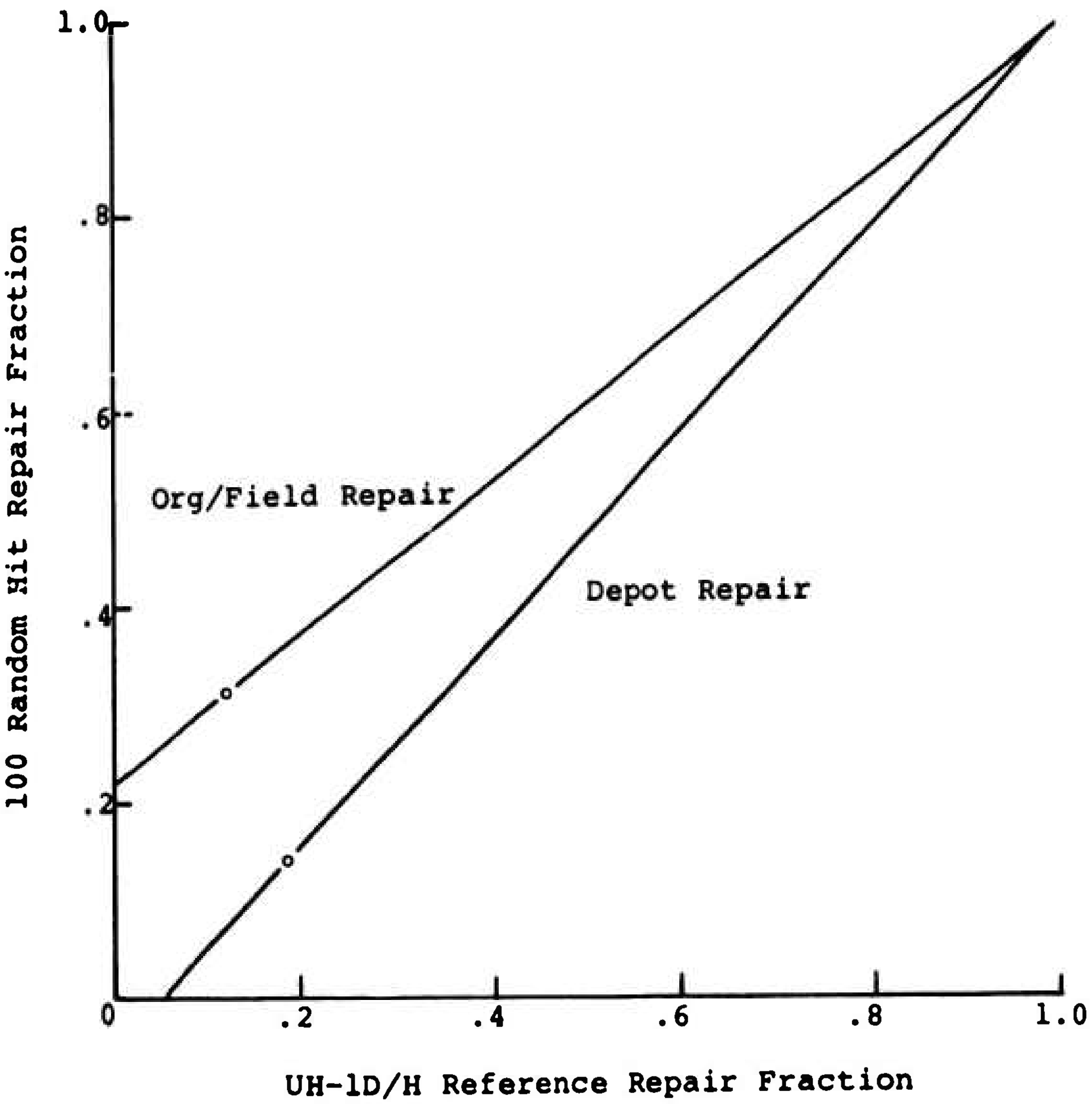


Figure 13. Blade Repair Analysis Adjustment.

The straight line relationships shown in Figure 13 are based on the assumption that any increase in the damage proportion that can be repaired will be accompanied by an improvement in ease of repair, so that proportionately more actual repairs will be performed. In the extreme, if a blade were 100% repairable (1.0 on the vertical scale), it would then be reasonable to expect that plans and procedures would take advantage of that characteristic, so that all repairs would be performed (1.0 on the horizontal scale). Considering the influence of human factors on the character of the variation shown in Figure 13, it is apparent that a large variety of curve shapes are possible. The linear variation used was found to be convenient but is not considered to be precise except in the neighborhood of the data points for the current blade.

TABLE V. COST OF NEW BLADES TO THE ARMY (FOB)

	Prod. Cost Est.*	RDTE Cost Per Unit	Profit	Blade Price To Army
UH-1D/H	$2593	$ 86	$ 321	$ 3,000.00
Config I	$2964	$ 86	$ 366	$ 3,416.00
Config II	$8895	$129	$1082	$10,106.00
Config III	$3379	$129	$ 421	$ 3,929.00
Config IV	$7583	$136	$ 926	$ 8,645.00

*Based on 10,000th unit of production and adjusted to agree with specified price of the current UH-1D/H blade.

TABLE VI. RESULTS OF 100 RANDOM HIT ANALYSIS

Symbols	Blade Damage Event Category	Current UH-1D/H	Configuration I	Configuration II	Configuration III	Configuration IV
	Fraction with no damage repair	0	0	.027	0	.018
K_{BRO}	Fraction repaired at org level (on A/C)	.066	.187	.145	.156	.062
K_{BRF}	Fraction repaired at int level (off A/C)	.054	.453	.508	.444	.560
K_{BRD}	Fraction repaired at depot level	.185	.130	.130	.175	.155
K_{BSO}	*Fraction scrapped at org/int level	.300	.172	.142	.169	.154
K_{BSD}	Fraction scrapped at depot level	.395	.058	.048	.056	.051
	Total disposition of 100 random hits	1.000	1.000	1.000	1.000	1.000
Fraction repaired at org/int level plus no damage		.120	.640	.680	.600	.640
Total fraction of blades repairable (K_{BR})		.305	.770	.810	.775	.795
Total fraction of blades scrapped (K_{BS})		.695	.230	.190	.225	.205

* The fraction of blades scrapped at the org/int level is estimated at 75% of total scrap for all the repairable blade candidates based on damage assessment of 100 random hit analysis.

Analysis of the candidate blades also showed that two of the planforms received fewer hits than the basic UH-1D/H blade planform, and this is shown in the table as the fraction of damage events with no damage repair.

Repair Costs

Repair of blades damaged by the 100 random hit criteria is resolved in the form of several repair kits applicable to all blades singly or in combination. For each repairable blade candidate configuration, the maintainability analysis identified the number and type of repair kit along with the mean time to repair (MTTR). Table VII defines the kits, kit price, quantities, etc., necessary to perform the cost analysis.

Support equipment required to repair blades using the designated repair kits is defined in the maintainability analysis in the previous section of this report. Equipment prices to support any or all of the kit repairs is estimated at $797.50, including transportation. Assuming that five sets of equipment will be required for a company of 25 aircraft, the cost per aircraft is approximately $160.

The material cost of repairing a UH-1D/H blade for which no repair kits are called out was assumed at $5.00 per repair. The blade damage analysis provides an estimated MTTR = .95 hour for this blade. It should be noted that all the repair costs include repair labor only and do not include other associated labor hours, such as inspection, removal, installation, etc., which are accounted for separately.

The allowable operating time (AOT) due to fatigue is assumed at 2500 hours for the UH-1D/H blade and the desired 3600 hours for the repairable blade candidates.

Program Cost Analysis

The contractor-determined cost elements described above along with cost elements supplied by the Government and presented in Appendix VI can now be incorporated into the cost model to determine program life-cycle costs. Configuration I will be used as an example, while costs for all blade configurations are tabulated in Table VIII.

TABLE VII. REPAIR KIT COSTS AND REPAIR TIMES

Kit Designation	Kit Price Dollars (FOB)	Kit Quantity Configuration I	II	III	IV
-1, Exposed Alum.	9.89	3	2	9	10
-2, Abrasion Sheath	53.29	1	1	1	13
-3, Undirectional glass fiber	26.29	6	0	7	14
-4, Skin Patch	32.37	13	16	15	17
-5, Plug Patch	99.51	22	23	20	20
-6, T.E. Doubler	38.43	9	8	7	7
Ave. repair kit price (FOB)		59.00	63.75	52.05	54.51
T_R = mean time to repair, hr		3.37	3.27	3.33	4.90

NOTE: An estimate of the -6 T.E. Doubler Kit in boron material has a price of $151.23 compared to the glass fiber price of $38.43 used above. The boron kit was not considered in the cost analysis, although its use may be required in some inboard-trailing edge repairs to retain a useable, structurally sound blade.

TABLE VIII. SUMMARY OF BLADE PROGRAM COSTS/AIRCRAFT LIFE CYCLE

	UH-1D/H	Configuration I	Configuration II	Configuration III	Configuration IV
1. <u>Initial Costs</u> - Dollars					
Outfitting Prod. A/C	6,000	6,832	20,212	7,858	17,290
Spare Blades and Containers	3,200	1,556	3,910	1,954	3,741
Spare Parts	0.7	54	53	45	48
2. <u>Operating Costs</u> - Dollars					
Org /Int Blade Repair Labor	60	561	596	536	705
Org /Int Blade Repair Parts	14	1,086	1,062	900	954
Org /Int Blade Scrap and Fatigue Retire	21,870	15,560	37,850	17,506	34,643
Depot Level Blade Repair	5,775	4,447	10,688	6,629	11,118
Depot Level Blade Scrap	28,796	4,747	10,843	5,202	9,916
3. <u>Attrition Costs</u> - Dollars					
Blade Replacements	9,390	10,638	30,709	12,175	26,325
Blade Program Cost/Aircraft Life Cycle - Dollars	75,106	45,481	115,923	52,805	104,740

Cost elements supplied by the Government and used in the various cost model equations are defined as follows:

n	=	Number of blades per aircraft	2
L	=	Aircraft life cycle, flt hours	5000
BTBD	=	Blade time between damage events, hours	425
C_c	=	Container cost, dollars	200
C_{sa}	=	Blade air shipping cost one way, dollars	130
C_m	=	Org level labor rate, dollars per hour	4.00
M_1	=	MMH in addition to MTTR at Int level, hours Basis: Inspect and disposition = 1.5 hours Remove and install blade = 7.5 hours	9.0
M_2	=	MMH in addition to MTTR at Org level, hours Basis: Inspect and disposition = 1.5 hours	1.5
M_3	=	MMH to scrap blade at Org/Int level, hours Basis: Remove and install blade = 7.5 hours Requisition replacement blade = 3.0 hours Obtain replacement blade = 3.0 hours Inspect and disposition = 1.5 hours	15.0
C_{ss}	=	Blade surface shipping cost one way, dollars	90.
C_{mc}	=	Depot level civilian labor rate, dollars	12.
M_4	=	MMH at depot level to receive and inspect, hours	2.5
C_{pc}	=	Shipping preparation charges one way, dollars	20.
C_{sc}	=	Container shipping cost one way, dollars	45.
M_5	=	MMH at depot to scrap blade, hours Basis: Scrap disposal = 0.5 hour Receive and inspect = 2.5 hours	3.0
K_A	=	Number of blades lost to attrition	3.0

Blade damage events per aircraft life cycle:

$$N_{bf} = \left(\frac{nL}{BTBD} - n\right) = \frac{2(5000)}{425} - 2 = 21.53$$

These blade damage events are assumed to be constant for all blade configurations.

Fraction of blade damage fatigue retired:

$$K_{BF} = 27\ (K_{BR})\ 1.395/(AOTx10^{-2})1.835$$

$$K_{BF} = 27\ (.77)\ 1.395/(36)\ 1.835 = .026 = 2.6\%$$

Other costs not identified above are:

C_{rd} = Ave. cost of depot blade repair - This cost is assumed at one-third of the new blade based on the UH-1D/H blade data and unofficial cost figures of other contractors

C_{sp} = Shipping cost of repair materials - This cost is conveniently assumed at 10% of the material cost.

1. Initial Costs

Blade Outfitting

$$C_o = n\ C_{nb} = 2\ (3416) = 6832$$

Spare Blades and Containers

$$C_{sb} = \frac{N_{bf}}{20}\left[(K_{BS} + K_{BRD} + K_{BF})\ (C_{nb} + C_c + C_{sa})\right] + \frac{C_E}{20}$$

$$= 21.53/20\ \left[(.23+.13+.026)(3416+200+130)\right] + \frac{160}{20} = 1156$$

Spare Parts

$$C_{ps} = \frac{N_{bf}}{20}\left[(K_{BRO} + K_{BRF})(C_p)(1+C_{sp})\right] + \frac{C_E}{20}$$

$$= 21.53/20\ \left[(.187+.453)(61.09)(1.10)\right] + \frac{160}{20} = 54$$

2. Operating Costs

Org/Int Level Repair Labor

$$C_{ORL} = N_{bf}\ [C_m(M_1+T_R)K_{BRF} + C_m(M_2+T_R)K_{BRO}]$$

$$= 21.53[4(9+3.37).453 + 4(1.5+3.37).187] = 561$$

Org/Int Level Repair Material

$$C_{ORM} = N_{bf}\ [(K_{BRF} + K_{BRO})\ (C_p)(1+C_{sp})] + C_E$$

$$= 21.53\ [.453+.187)(61.09)(1.10)] + 160 = 1086$$

Org/Int Level Scrap and Fatigue Retire

$$C_{so} = N_{bf}\ (K_{BSO} + K_{BF})\ [C_{nb} + C_{sa} + C_{cm}(M_3)]$$

$$= 21.53\ (.172+.026)\ [3416 + 130 + 4(15)] = 15560$$

Depot Level Repair

$$C_{DR} = N_{bf}\ K_{BRD}\ [C_{rd} + C_m(M_2) + C_{sa}+C_{ss}+2C_{sp}+C_{mc}(M_4)]$$

$$= 21.53\ (.130)[1139+4(15)+130+90+2(70)+12(2.5)]= 4447$$

Depot Level Scrap

$$C_{DS} = N_{bf}\ K_{BSD}[C_{nb}+C_m(M_2)\ +C_{sa}+C_{ss}+C_{sp}+C_{mc}(M_5)]$$

$$= 21.53\ (.058)[3416+4(15)+130+90+70+12(3)] = 4747$$

3. Attrition Costs

$$C_A = K_A\ (C_{nb} + C_{sa})$$

$$= 3.0\ (3416 + 130) = 10638$$

Total Program Cost per Aircraft Life Cycle = 45481

Discussion of Cost Analysis

Results of the maintainability analysis using the 100 random hit data supplied by the Government indicate that all four of the repairable blade candidates provide a similar overall level of repair on the order of 80% of damage incidents. This compares with an overall repairability goal of 95%. Repairability of the blade candidate at the user level on the order of 64% compares with a desired level of 75%. It is evident from this analysis that each of the blade candidates has a similar repair capability despite a wide range of materials employed for structural elements. This is probably due to the common aft section structure (honeycomb and fiberglass skins), which accounts for the majority of planform area vulnerable to damage.

Since the candidates' blade repair capabilities are similar, the effect of blade costs becomes significant. The least costly repairable blade candidate is Configuration I, which is a modification of the existing UH-1D/H blade. Program costs for Configuration I are reduced 40% from the UH-1D/H blade costs on a comparable basis using the cost guidelines established for the study. A note of caution is suggested at this point, however, because the analysis is based on a fixed blade damage rate of 425 hours. Typically, a metal skin blade would be expected to be less susceptible to damage, primarily of the nuisance variety, than a fiberglass skin blade, although no definitive data is presently available. As such, further study would be in order to adequately define the relationship between fiberglass skin's potentially higher vulnerability to damage versus its repairability advantages. Brief laboratory testing has indicated that a fiberglass skin is more readily damaged under a fixed load but is more damage resistant for impact loadings. Referring to Figure 9, the Configuration I blade will lose its cost advantage when the blade time between damage is reduced to 220 hours, assuming that the UH-1D/H blade remains at 425 hours. No reduction of this magnitude is anticipated.

Figure 14 also shows that the cost advantage of the repairable blade decreases with increasing blade time between damage so that in a peacetime environment, the repairable blade loses some of its cost effectiveness. Conversely, in a severe war-time environment, the cost advantages of a repairable blade increase significantly.

Table IX compares 10-year life-cycle costs of all blade candidates and the UH-1D/H for fleet sizes of 500, 1,000 and 2,000 aircraft. For a fleet size of 2000 aircraft, a potential savings of 6 million dollars a year can be realized

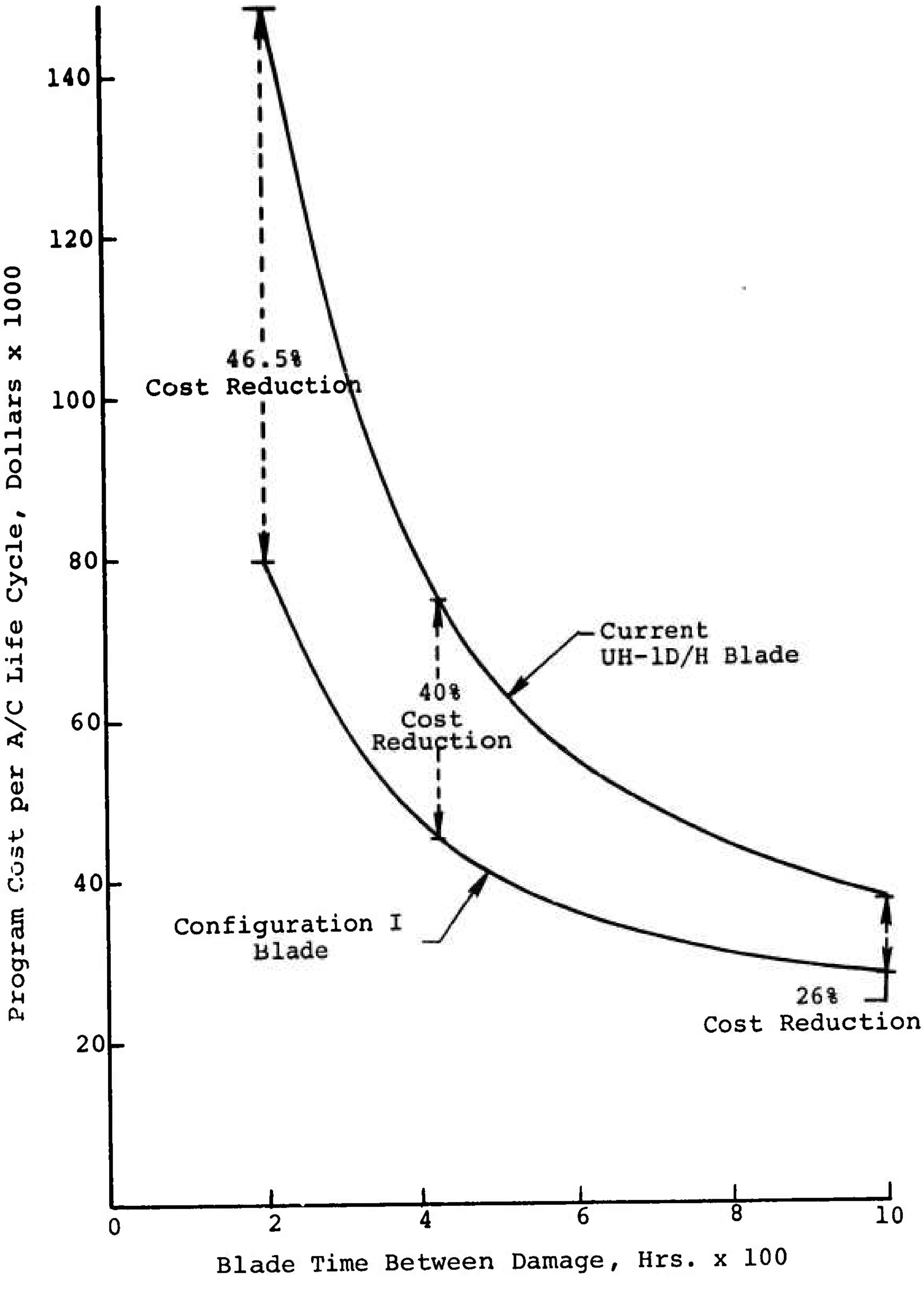


Figure 14. Program Cost With Varying Blade Time Between Damage.

TABLE IX. COMPARISON OF LIFE-CYCLE BLADE PROGRAM COSTS VERSUS FLEET SIZE

	(Costs shown in millions of dollars) Fleet Size			Percent of UH-1D/H
	500 A/C	1000 A/C	2000 A/C	
UH-1D/H	37.55	75.10	150.20	100.00
Configuration I	22.74	45.48	90.96	60.55
Configuration II	57.96	115.92	231.84	154.34
Configuration III	26.40	52.80	105.60	70.31
Configuration IV	52.37	104.74	209.48	139.45

using the Configuration I repairable blade design concept compared to the present UH-1D/H blade.

SENSITIVITY ANALYSIS

A variation in the critical cost factors that make up life cycle program costs provides an assessment of the risks involved if the repairable blade concept is incorporated. Sensitivity of the following cost elements is considered:

1. Blade price
2. Blade damage rate
3. User repair labor and materials
4. Blade repair and scrap fraction of damage
5. Blade set attrition

Since the four blade candidates studied have similar repair capabilities, a generalized program cost equation is defined which is typical of the repairable blade concept. The following equation combines the various cost elements, both Government and contractor generated, that are common to all blades:

$$\text{Prog. Cost} = n[C_{nb}(1+k)+130K]+\left(\frac{nL}{BTBD}-n\right)[K_{RU}C_1+K_{SU}C_2+K_{RD}C_3$$

$$+K_{SD}C_4+C_5] + 168$$

where:

Prog. Cost = Cost per aircraft life cycle, dollars

n = Number of blades per aircraft

C_{nb} = Blade price FOB, dollars

K = Attrition rate, blade sets per aircraft life cycle

L = Aircraft life, flt hours

BTBD = Blade time between damages, blade hours

K_{RU} = Fraction of blade damage repaired at user level

K_{SU} = Fraction of blade damage scrapped at user level

K_{RD} = Fraction of blade damage repaired at depot level

K_{SD} = Fraction of blade damage scrapped at depot level

C_1 = Cost factor for user repair = 110.3. This factor includes repair labor assuming a constant MTTR = 4.0 man-hours and "off A/C" repair of 78%, and includes spare materials. Average repair kit costs are used.

C_2 = Cost factor for user scrap = $(1.05C_{nb}+251.5)$. This factor includes a spares allowance but does not include fatigue retirement defined below.

C_3 = Cost factor for depot repair = $(.383C_{nb}+466.5)$. This factor assumes depot overhaul cost at one-third of blade price and includes a spare allowance.

C_4 = Cost factor for depot scrap = $(1.05C_{nb}+402.5)$. This factor includes replacement blade costs and spares allowance.

C_5 = Cost factor for fatigue retirement = $(.0284C_{nb}+6.8)$. This factor assumes an average fatigue retirement rate of 2.7% of blade damage and includes a spares allowance.

Using Configuration I as an example, a ±10% variation in critical cost factors has an overall life cycle program cost impact as shown in Table X.

The sensitivity of the cost factors evaluated shows that the fraction of blade damage repaired has the strongest impact on program costs, while blade price is next, followed by damage rate. Note that the variation in user repair labor and materials has only a small impact on program costs. It appears, then, from this analysis that a blade easily repairable at the user level has the potential of significant blade program cost reductions, assuming that the price is right and the repaired blade is in fact reused.

The generalized program cost equation is further utilized to investigate other variations in blade repair characteristics and price. The following cases describe blade programs representing maximum, limited-repairable, typical-repairable and minimum program costs:

Case 1. Blade Not Repairable

Assume that maximum program costs occur when $K_{BR} = 0$ and $K_{BS} = 1.0$. Further, theoretical maximum costs will occur where $K_{SD} = 1.0$, or all the blades are scrapped at the depot

TABLE X. SENSITIVITY OF AIRCRAFT LIFE-CYCLE BLADE PROGRAM COST TO A ±10% VARIATION IN CRITICAL COST FACTORS

Cost Factor	Program Cost Variations
1. Blade Price FOB	± 9.0%
2. Blade Damage Rate	± 6.9%
3. User Repair Labor and Materials	± 0.48%
*4. Blade Repair/Scrap Fraction of Damage	± 12.75%
5. Blade Set Attrition per A/C Life Cycle	± 2.34%

*Total blade repairability was varied ±10% and consequently, so was the total scrap rate. The ratio of user repair to total repair was held constant as was the ratio of user scrap to total scrap. Similar ratios were also retained for depot repair and scrap.

level. However, with no depot repair, depot scrap would be meaningless; so maximum program costs are assumed to occur where no depot level exists and damaged blades are scrapped at the user level. This case then represents a situation where all blade damage results in user scrap.

Case 2. Blade Field Repair, No Depot Repair

Consider program costs similar to the repairable blade concept except that no blades are returned to depot for either repair or scrap. Damaged blades either will be repaired or will be scrapped at the user level. Therefore, blades requiring depot level repair are considered beyond the user repair capability and are scrapped at the user level as well as blades formerly sent to the depot and subsequently scrapped. This case then represents a situation similar to the expendable blade concept.

Case 3. Typical Repairable Blade, Both User and Depot Levels

Assume that program costs occur in a manner typical of the repairable blade concepts. The anticipated blade repairability resulting from the 100 random hit analysis is on the order of K_{BR} = .80 where the fraction repaired at the user level averages K_{RU} = .80 K_{BR}. Blade scrappage is estimated at K_{SU} = .75 K_{BS}, or 75% of scrap blades will be scrapped at the user level as determined from the 100 random kit analysis.

Case 4. Ideal Blade, 100% Field Repairable

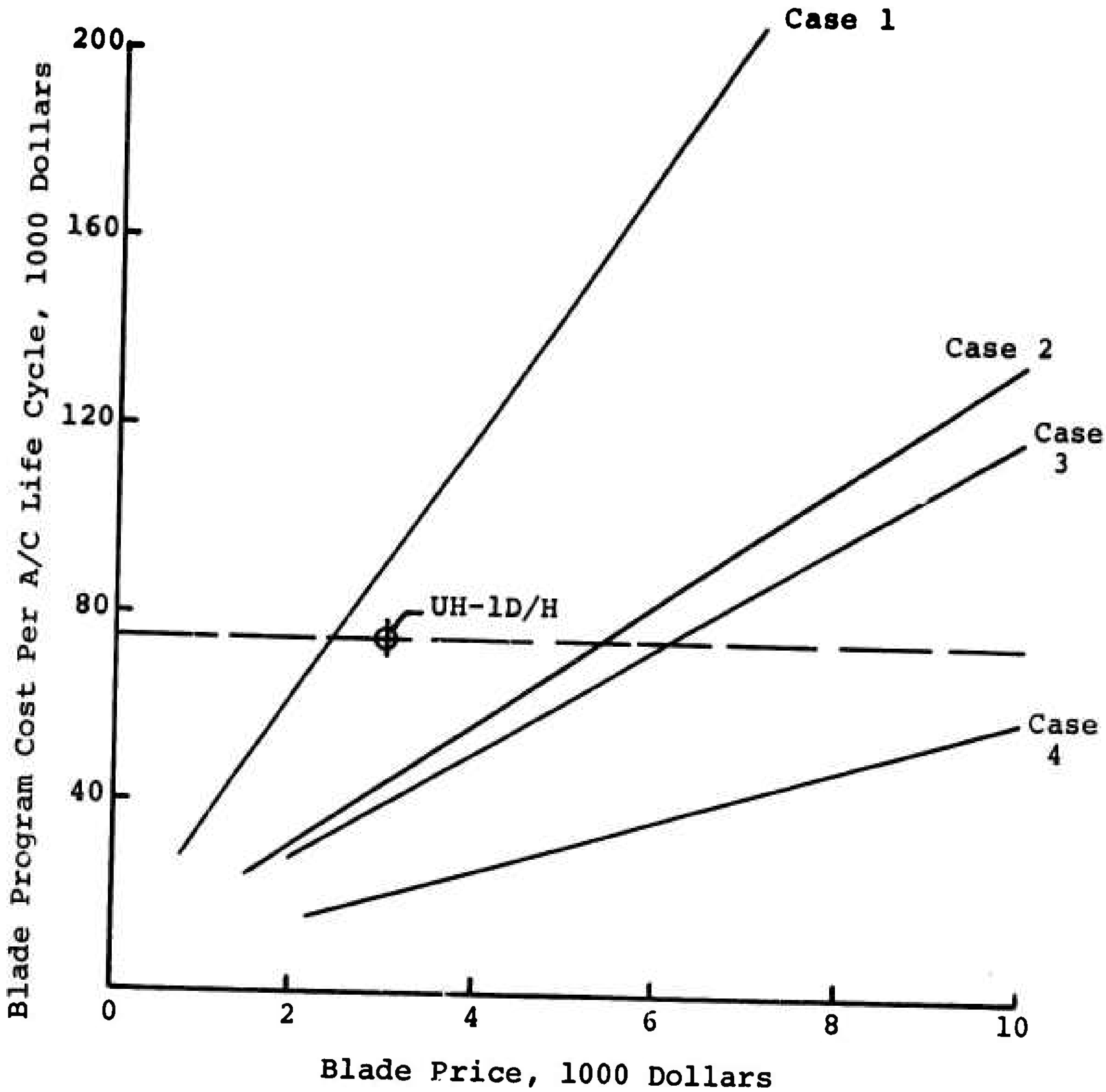
Assume that minimum program costs occur when K_{BR} = 1.0 and K_{BS} = 0. Further, theoretical minimum costs will occur when K_{RU} = 1.0 K_{BR}, or all the blades are repaired at the user level. Therefore, with no blades scrapped and all blades repaired at the user level, no depot level effort is required.

Table XI describes the fractions of blade damage either repaired or scrapped for the above cases. Applying these factors to the generalized program cost equation along with constraints defined for the study yields the relationship between blade price and program cost shown in Figure 15. Also shown is the blade program cost estimate for the current UH-1D/H of about $75,000 per aircraft life cycle. Assume that a 40% reduction ($45,000 program cost) is a desirable goal. The blade prices required to achieve this goal are as follows:

Case 1, Nonrepairable blade price = $1400
Case 2, Limited repairable blade price = $3100
Case 3, Typical repairable blade price = $3500

TABLE XI. EXAMPLE BLADE REPAIR DISTRIBUTIONS

Damage Disposition	Case 1	Case 2	Case 3	Case 4
Total Blade Repairability	0	.64	.80	1.0
Total Blade Scrappage	1.00	.36	.20	0
User Blade Repair, K_{RU}	0	.64	.64	1.0
User Blade Scrappage, K_{SU}	1.00	.36	.15	0
Depot Blade Repair, K_{RD}	0	0	.16	0
Depot Blade Scrappage, K_{SD}	0	0	.05	0
	1.00	1.00	1.00	1.00



Case 1 - Nonrepairable, all damage scrapped
Case 2 - Limited repair at user level only
Case 3 - Typical repairable blade from analysis
Case 4 - Ideal, fully repairable blade at user level

Figure 15. Generalized Blade Program Cost Versus Unit Cost for Selected Levels of Repairability.

Case 4, Ideal repairable blade price = $7500

The above blade prices represent the maximum that can be paid and still achieve the program cost reduction objective assumed. While Cases 1 and 4 are impractical, Cases 2 and 3 are practical and achievable based on the results of this study. Further analysis in the way of tradeoff studies between the fixed costs of maintaining a depot repair facility and the difference in program costs between the limited repairable blade (Case 2) and the typical repairable blade (Case 3) is recommended.

DETAIL DESIGN ANALYSIS

The main rotor blade design concepts studied in the preliminary analyses were also subjected to appropriate detailed analyses. These included calculation of natural frequencies, flight loads, stress analysis, and survivability analysis. Only those concepts which on the basis of all foregoing results showed promise of reaching program goals were carried through the complete analyses; however, since much of the detailed analysis was concurrent with the preliminary analyses, some results are presented for all four configurations. In conducting the detailed analyses, minor design changes were incorporated where indicated and the analyses were repeated until satisfactory results were obtained. In general, these analyses were concerned with the dynamic and structural properties of the basic rotor blade cross section and did not exhaustively investigate design of the heavy root end buildup and load transfer. All designs are capable of duplicating the structural properties of the present blade root for the blade configurations studied.

NATURAL FREQUENCIES

The natural frequencies of all candidate designs were calculated for comparison to the same frequencies calculated for the current UH-1H blade. Reasonable duplication of frequencies calculated by the same procedures for the same conditions was sufficient to warrant further study of a particular configuration. The natural frequencies and modes are obtained using matrix iteration on the response matrices for the zeroth harmonic. This procedure, which has been separately programmed for the computer, was used to calculate the natural frequencies and modes for the several configurations as a function of rotational speed. For these calculations, the pitch at the three-quarter radius was taken to be +5 degrees. The representative end conditions were cantilever out-of-plane bending, cantilever in-plane bending, and pin-ended out-of-plane bending. By this means, the proximity to resonance in the operating range could be checked for any configuration. The natural frequencies are presented in terms of "fan" plots of natural frequency versus rotational speed for three or four harmonics at the three end conditions for the current UH-1H blade and for each of the candidate designs. These plots are presented in Figures 16 through 20. A review of these results indicates that the candidate designs closely duplicate the frequencies of the current blade for the modes calculated and that this favorable comparison indicates that further study of all designs is justified.

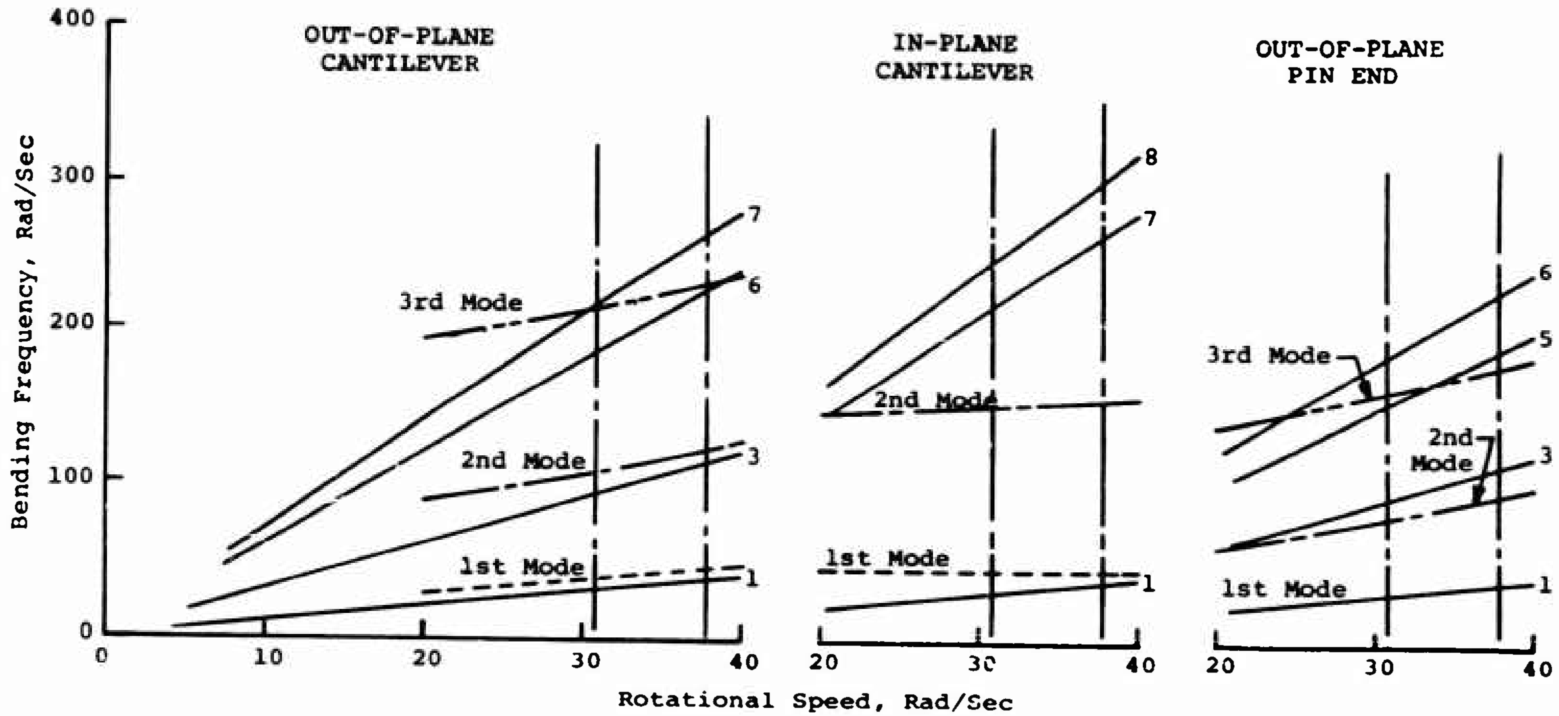


Figure 16. Natural Frequencies of Current UH-1H Blade.

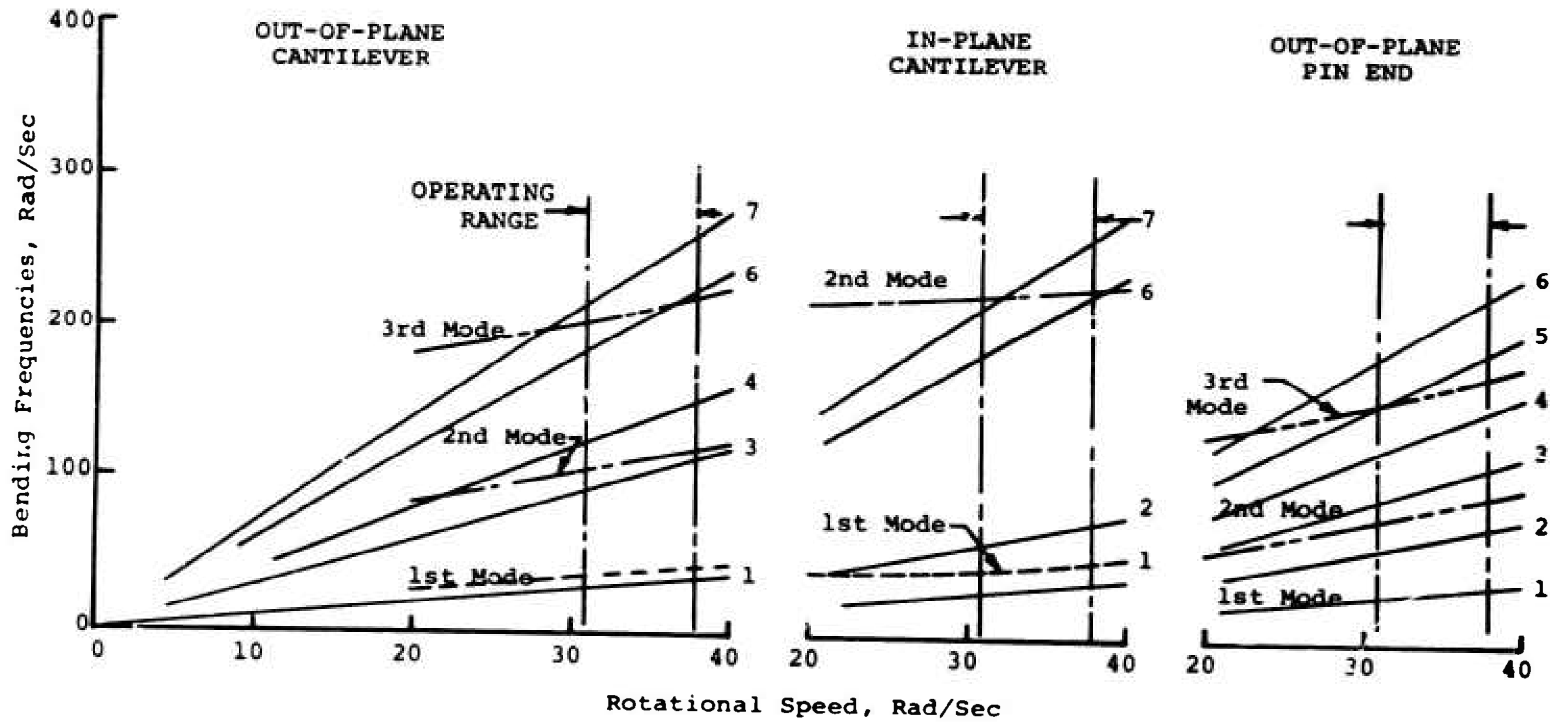


Figure 17. Natural Frequencies of Configuration I.

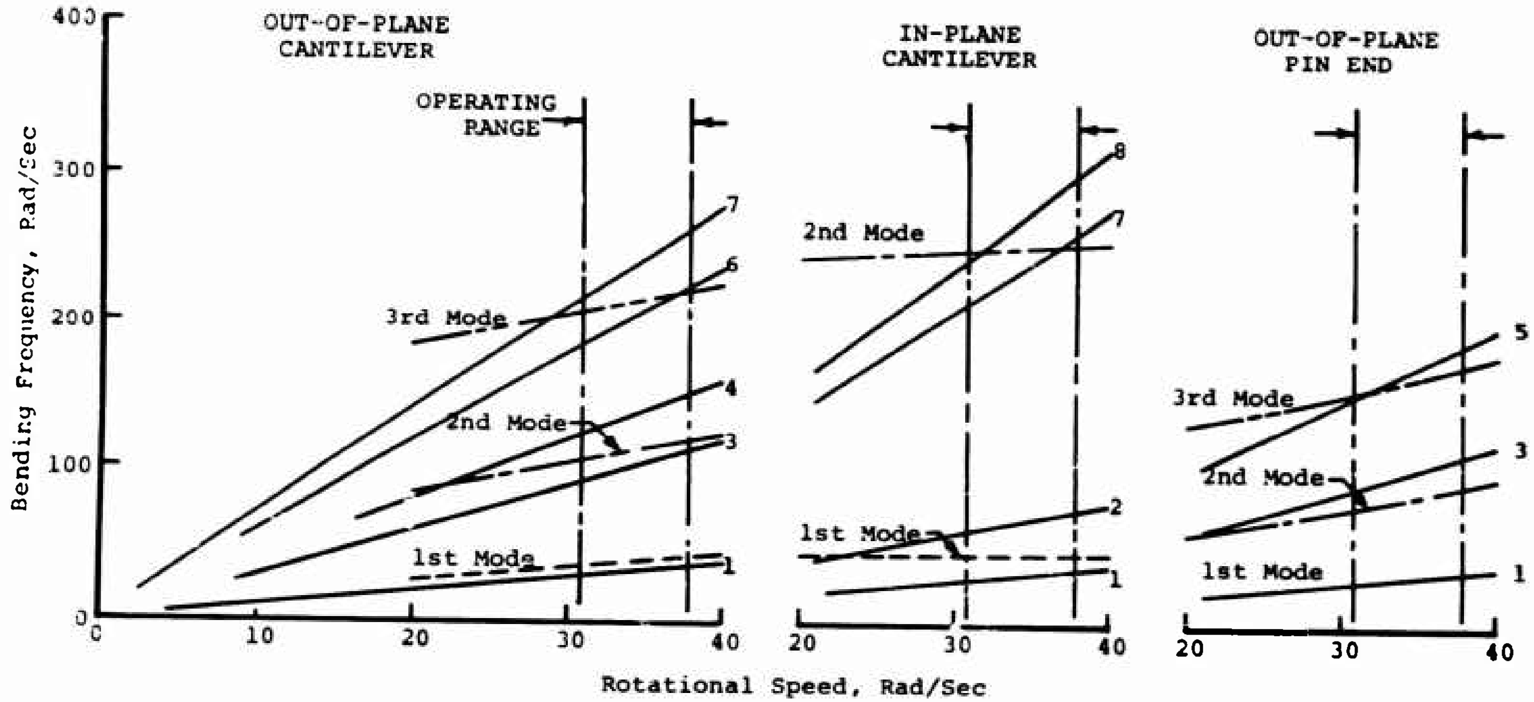


Figure 18. Natural Frequencies of Configuration II.

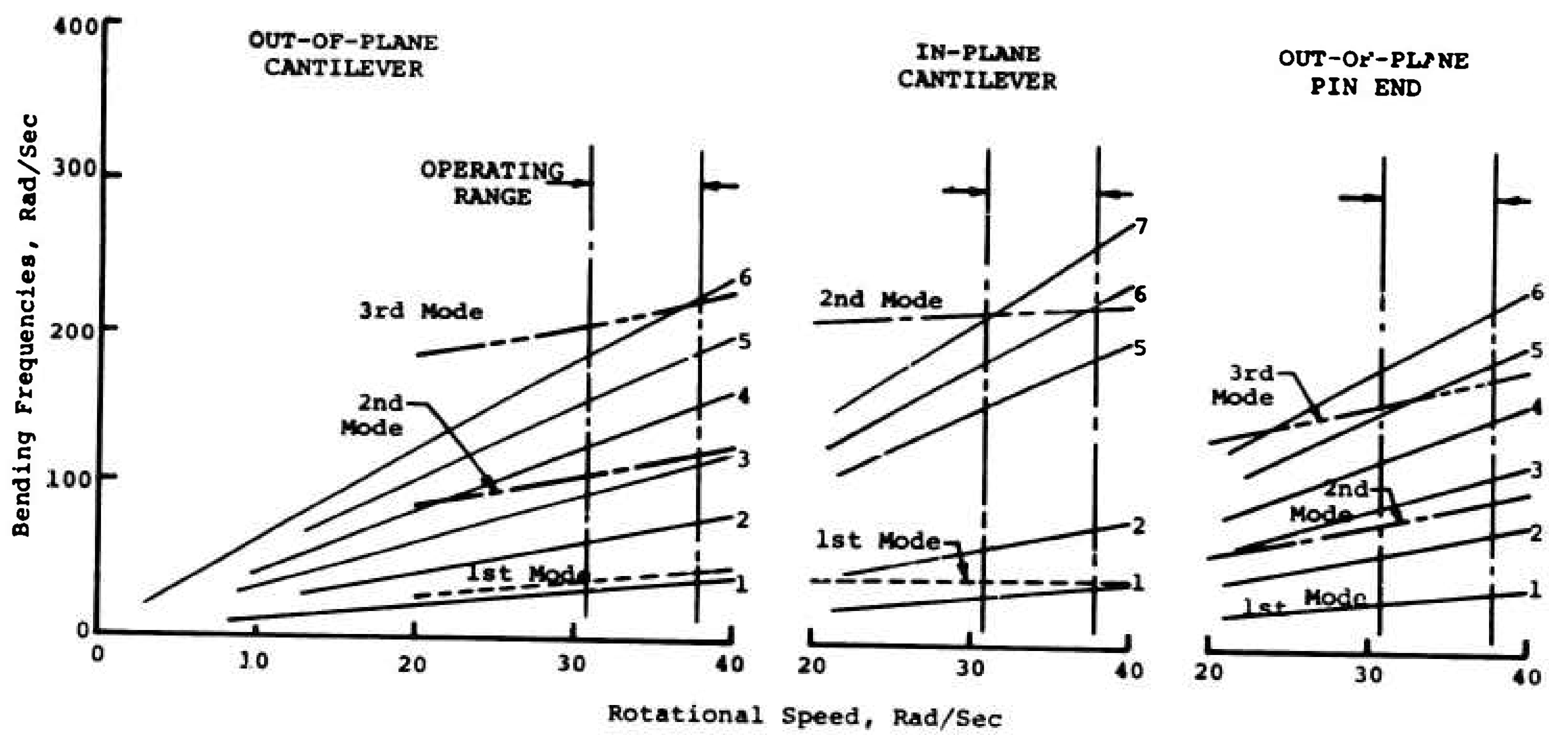


Figure 19. Natural Frequencies of Configuration III.

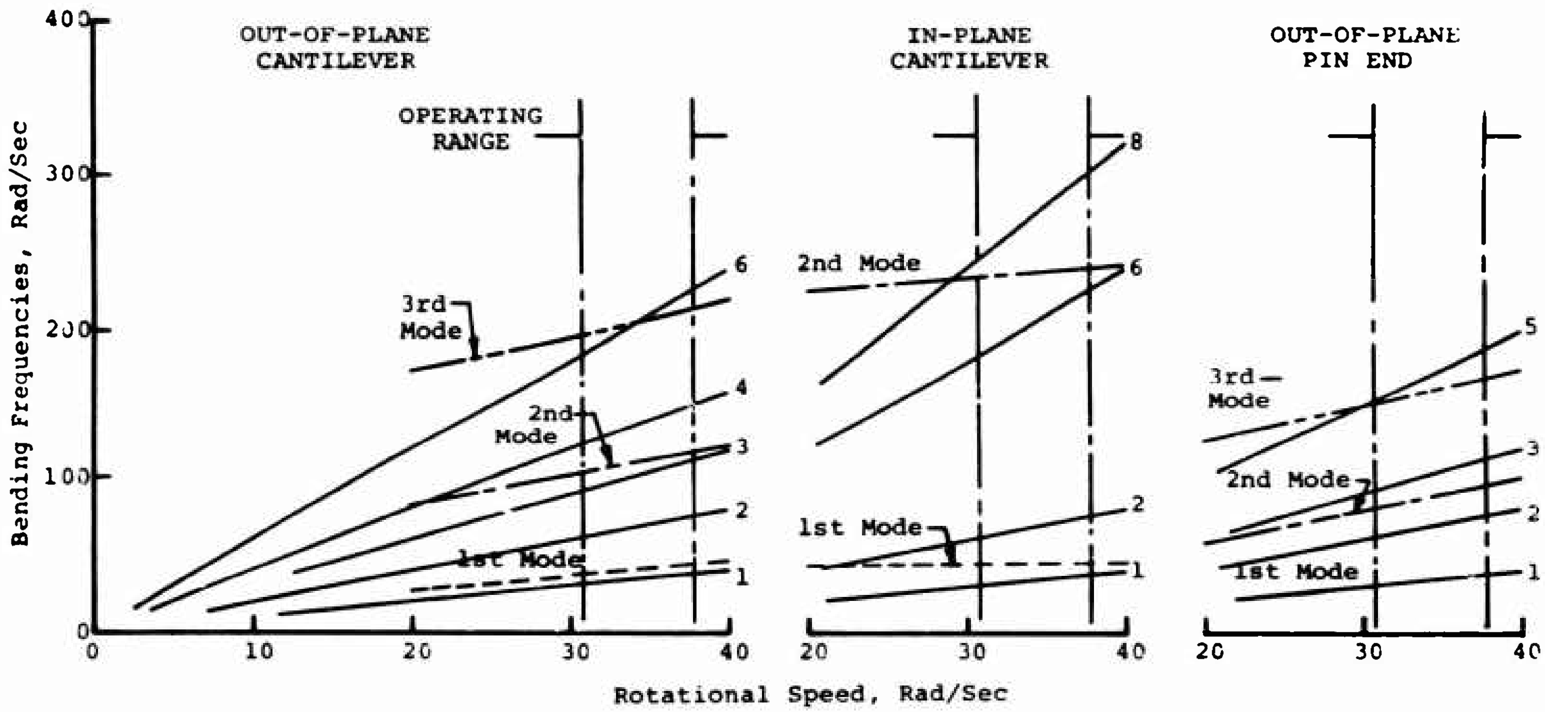


Figure 20. Natural Frequencies of Configuration IV.

FLIGHT LOADS

As a part of the evaluation of the suitability of candidate blade designs for service on the UH-1H, it is necessary to estimate the flight loadings that these blades would encounter and compare them to the ability of the design to withstand these loadings. While the total spectrum of loadings is quite broad and structural requirements vary, experience has shown that one of the most important criteria in determining the acceptability of a particular blade design is that it not accrue significant amounts of fatigue damage in any steady-state level flight condition. Flight conditions that cannot be sustained or which are encountered very infrequently, such as lateral flight at maximum velocity or forward flight at limit airspeed in a dive, may be excluded from this consideration if total exposure is small. For the present program, the flight condition selected for evaluation is high-speed level flight at 107 knots, a condition which produces high vibratory loadings and which is rarely exceeded. The basic evaluation consists of the calculation of all flight loadings for the current UH-1H blade and all candidate designs for this condition and a comparison of the resulting stresses to the calculated endurance limit for each. Positive fatigue margins indicate that the design is operating below the endurance limit and, therefore, is not accruing fatigue damage in this decisive flight condition. The performance of candidate designs is evaluated on an absolute basis and also on the basis of a comparison to the present UH-1H blade, which has an assigned life of 2500 hours,and the ability of each to meet this goal is evaluated.

Reference 8 presents a method of developing air loads by an iterative numerical procedure for solving the blade flapping equation of motion of an articulated rotor. It is essentially that used,but several improvements have been incorporated. Because the actual equation of motion is solved, there is no restriction on advance ratio, inflow ratio, or forward speed and there are no small-angle assumptions. It incorporates actual two-dimensional airfoil data which includes both stall and Mach number effects. The equation also provides for the insertion of arbitrary pitching and rolling velocities. The differential equation of motion about the flapping hinge, which expresses the equilibrium of the centrifugal, gyroscopic and aerodynamic moments with the inertia moment, is set up and solved numerically.

This procedure, which is programmed for the computer, was adapted to a teetering rotor by considering each blade separately but connected by a center blade-to-blade spring to restrict independent flapping. This spring rate was chosen to simulate the bending frequency of the actual UH-1H hub.

The equations of static equilibrium for any helicopter or compound have been written and programmed and are standard contractor analyses. Therefore, the UH-1H was trimmed in 1g level flight at 107 knots, and the air loads were determined for this condition.

The blade bending moments were calculated by the method developed from Reference 9 using the air loads determined as above. This method consists of calculating the blade response to any arbitrary loading by post multiplying the appropriate response matrix by a column matrix representing the rigid blade load distribution. The response matrices for each harmonic are calculated directly by a matrix integration method.

The results of these analyses are the steady and vibratory flight bending moment distributions presented in Figures 21 through 25 for the current UH-1H blade and the four candidate designs.

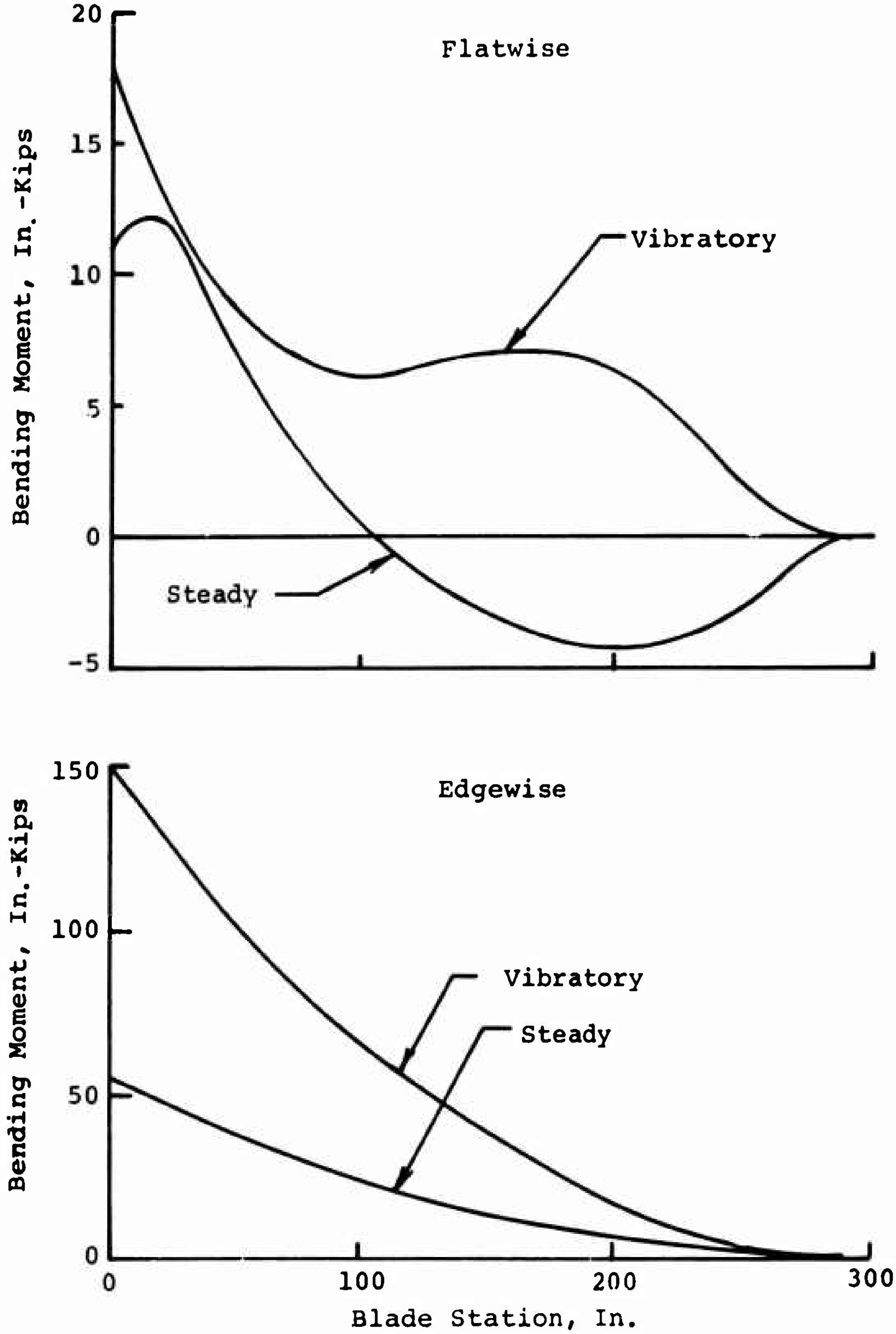


Figure 21. Flatwise and Edgewise Flight Loading for the Current UH-1H Blade.

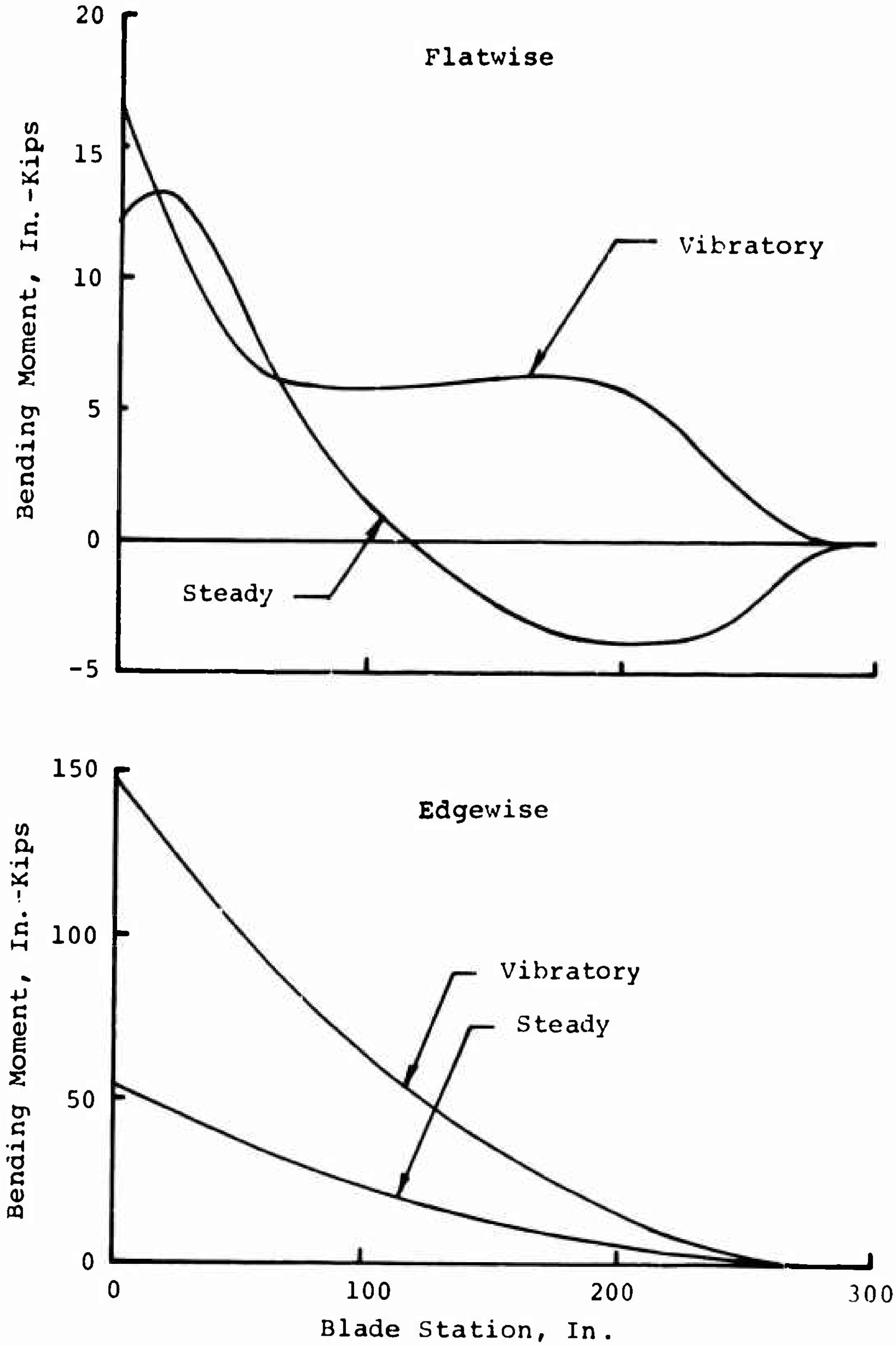


Figure 22. Flatwise and Edgewise Flight Loading for the Configuration I Blade.

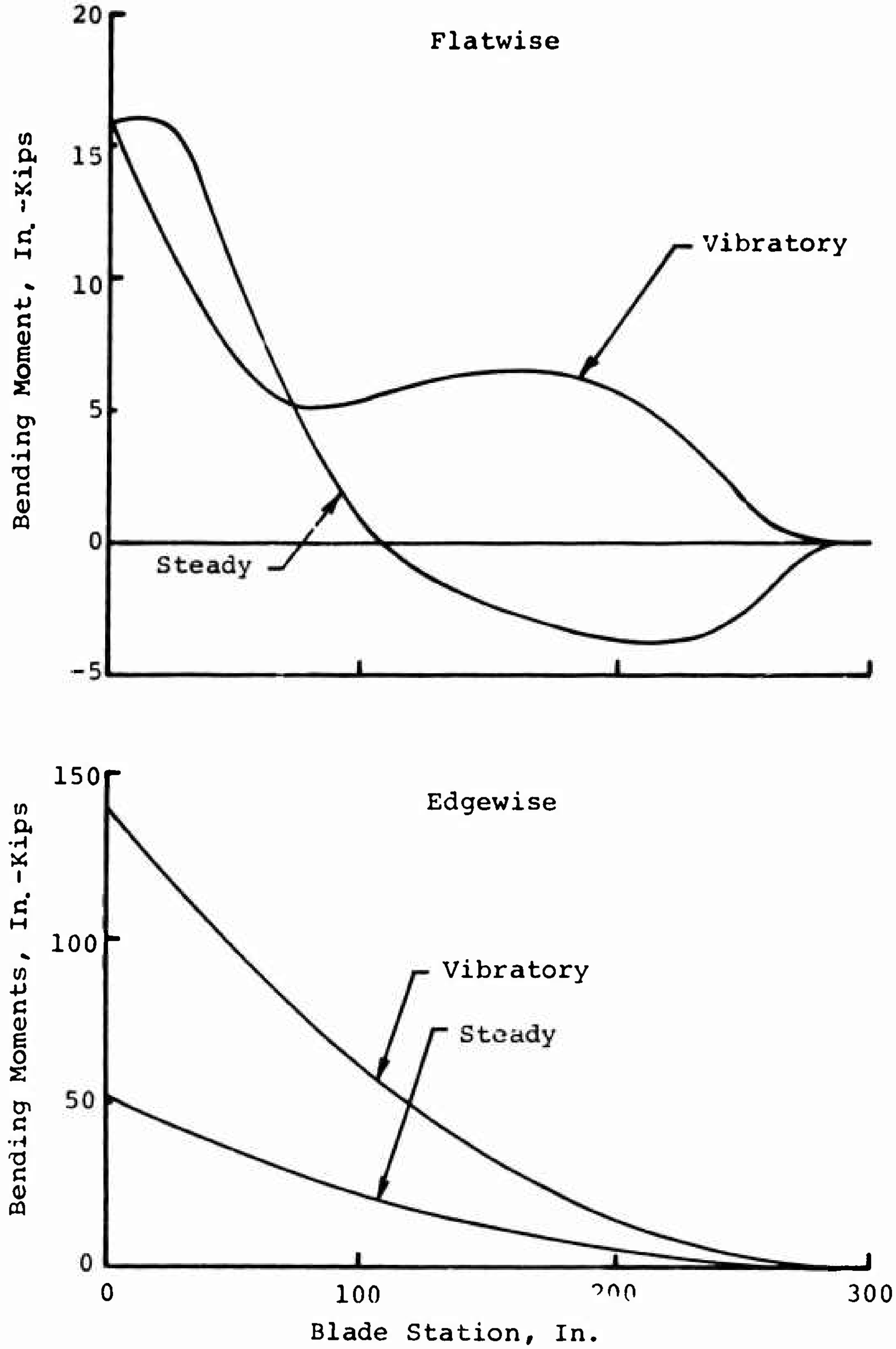


Figure 23 Flatwise and Edgewise Flight Loading for Configuration II Blade.

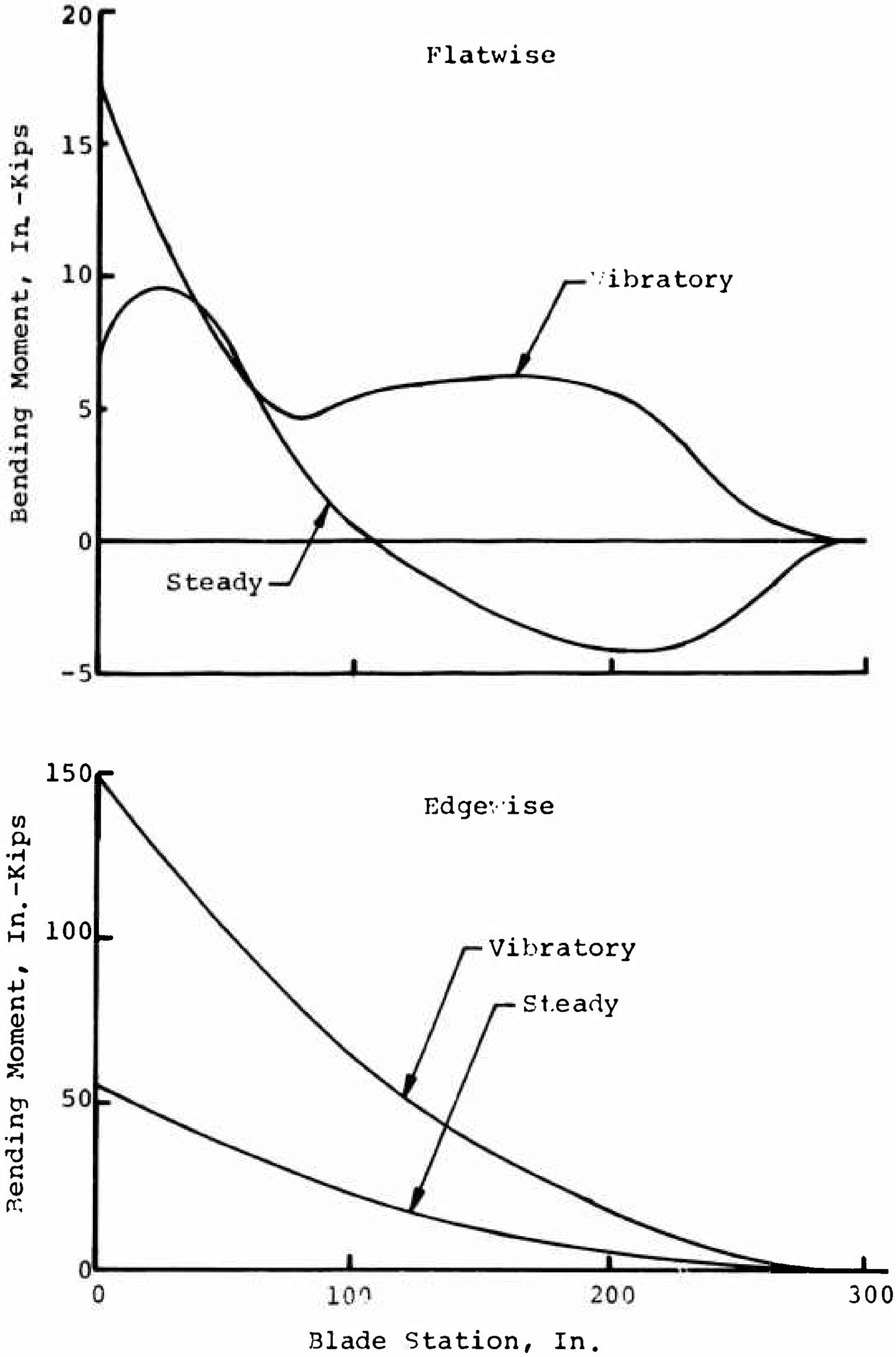


Figure 24. Flatwise and Edgewise Flight Loading for Configuration III Blade.

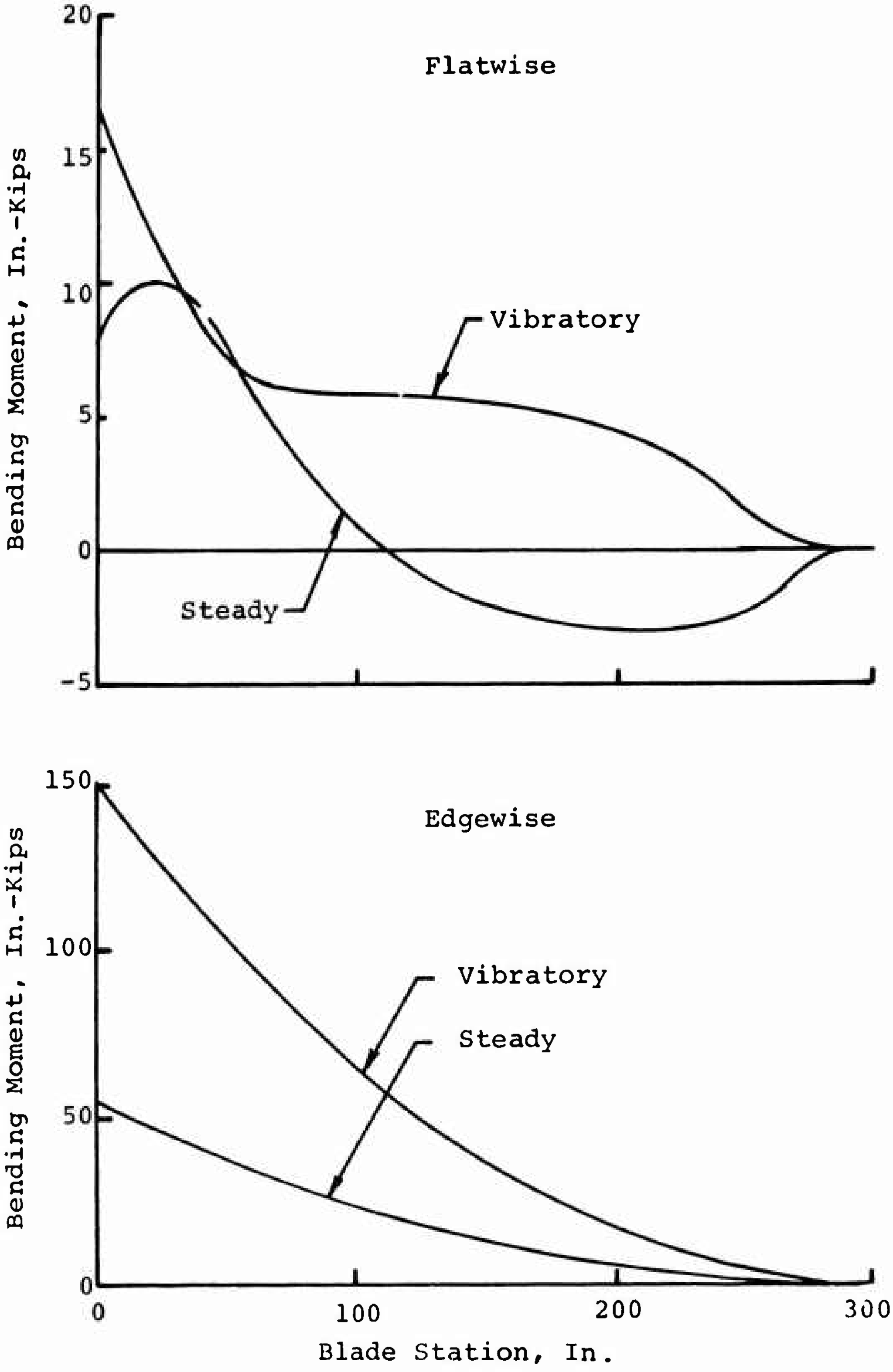


Figure 25. Flatwise and Edgewise Flight Loading for Configuration IV Blade.

STRESS ANALYSIS

Stress analyses for the UH-1H main rotor blade and for the candidate blades, Configurations I through IV, were performed for the purpose of comparing the blades structurally as well as for determining the effects of possible service-connected damage that might be encountered during their lifetime.

The fatigue strength of the basic UH-1H blade and the four candidate configurations were calculated at significant structural blade stations. Station 82 is in the zone of the inboard doubler to clean blade transition, and Station 210 is at the outboard end of the trailing-edge spline taper. Configurations I and III were studied in more detail, and additional analyses were made at Stations 150 and 152, the skin transition. Configuration III was also analyzed at Station 220, the ballast weight transition area for this blade configuration.

Stiffness and mass properties for the above stations were calculated for Configurations I through IV by means of a computer program and compared to the current UH-1H blade. Figures 26, 27, and 28 show the results of these calculations compared to those for the current blade. In general, a fairly close agreement between the section properties developed for the four configurations and those for the UH-1H is shown.

The material properties used in establishing the stiffness and strengths of the individual components are found in Table XII.

The blade loads considered in the basic stress analysis were derived for a rotor speed of 315 rpm and a forward velocity of 107 knots, a normal operating condition for the UH-1H helicopter. Steady and vibratory flatwise (out-of-plane) moments and edgewise (in-plane) moments were calculated for this flight condition as previously described. The axial loads due to centrifugal force and the steady edgewise bending moments due to centrifugal force were calculated for each of the significant stations considered. A typical result of these calculations is shown in Figure 29 for the current UH-1H rotor blade.

Fatigue stresses were obtained for several points on the blade cross section at each blade station considered using the following general expression for combined stress:

TABLE XII. MATERIAL PROPERTIES*

Material	Modulus of Elasticity $E \times 10^{-6}$ ($Lb/In.^2$)	Modulus of Rigidity $G \times 10^{-6}$ ($Lb/In.^2$)	Density ($Lb/In.^3$)	Ultimate Tensile Strength F_{tu} ($Lb/In.^2$)	Endurance Limit F_E ($Lb/In.^2$)
2024-T3 Aluminum	10.5	4.0	.101	65,000	6,000
6061-T6 Aluminum	10.0	3.8	.100	38,000	6,000
AISI 301 Stainless Steel	27.0	12.0	.286	125,000	18,000
6AL-4V Titanium	16.0	6.2	.160	160,000	12,000
Naval Brass	15.0	5.8	.308	75,000	6,000
2 Plies of 120 Fiberglass at ±45° and 2 Plies of Unidirectional Fiberglass at ±45°	3.863	1.56	.064	13,000	4,000
Unidirectional Fiberglass at 0°	5.70	.40	.064	75,000	4,000
Carbon Graphite	18.5	1.3	.059	75,000	8,000

* Material properties were obtained from References 10 and 11 and suppliers' literature. Reference 12 was used to derive lamination properties at orientations other than 0° and 90°.

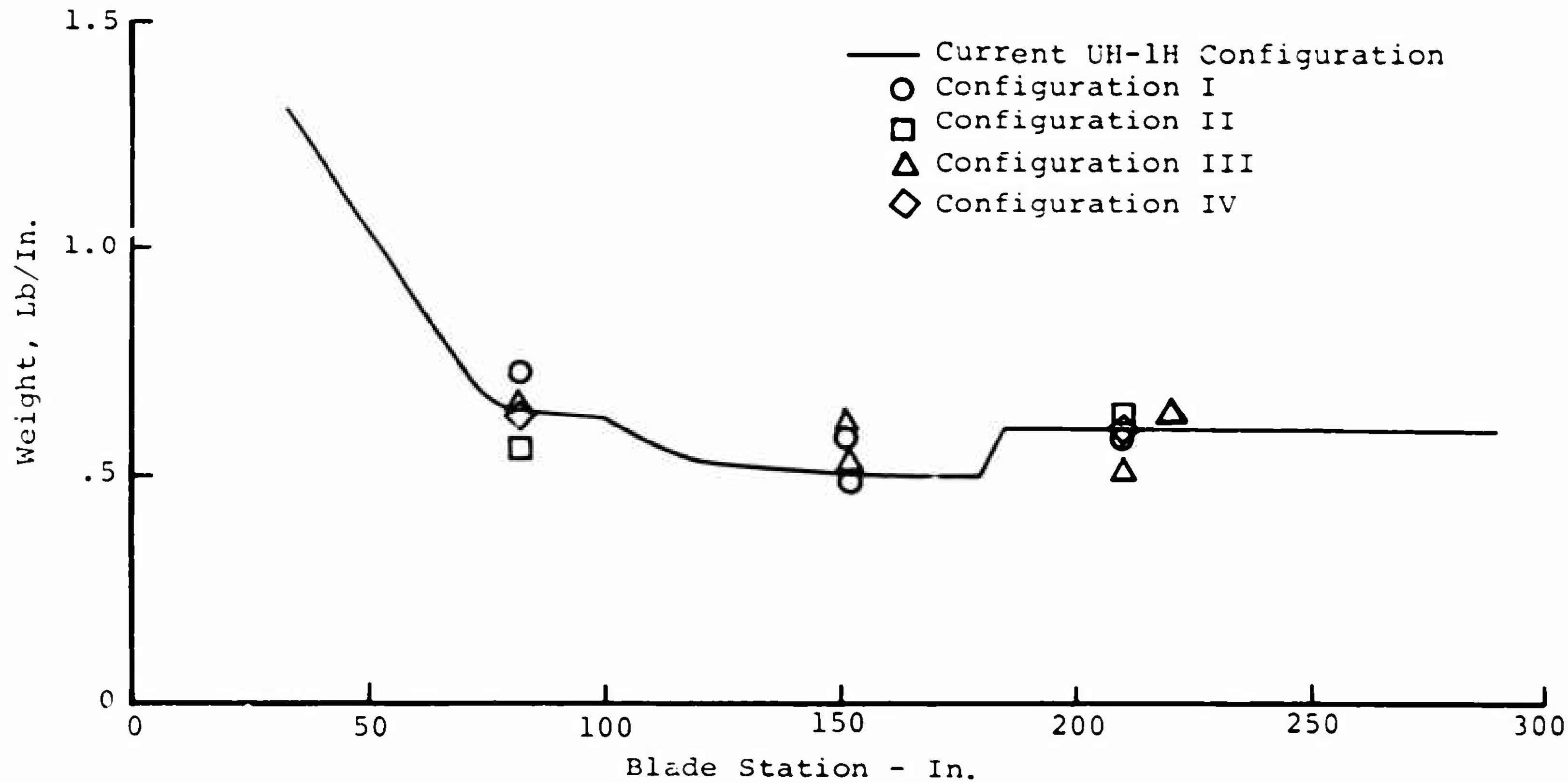


Figure 26. Blade Spanwise Weight Distribution.

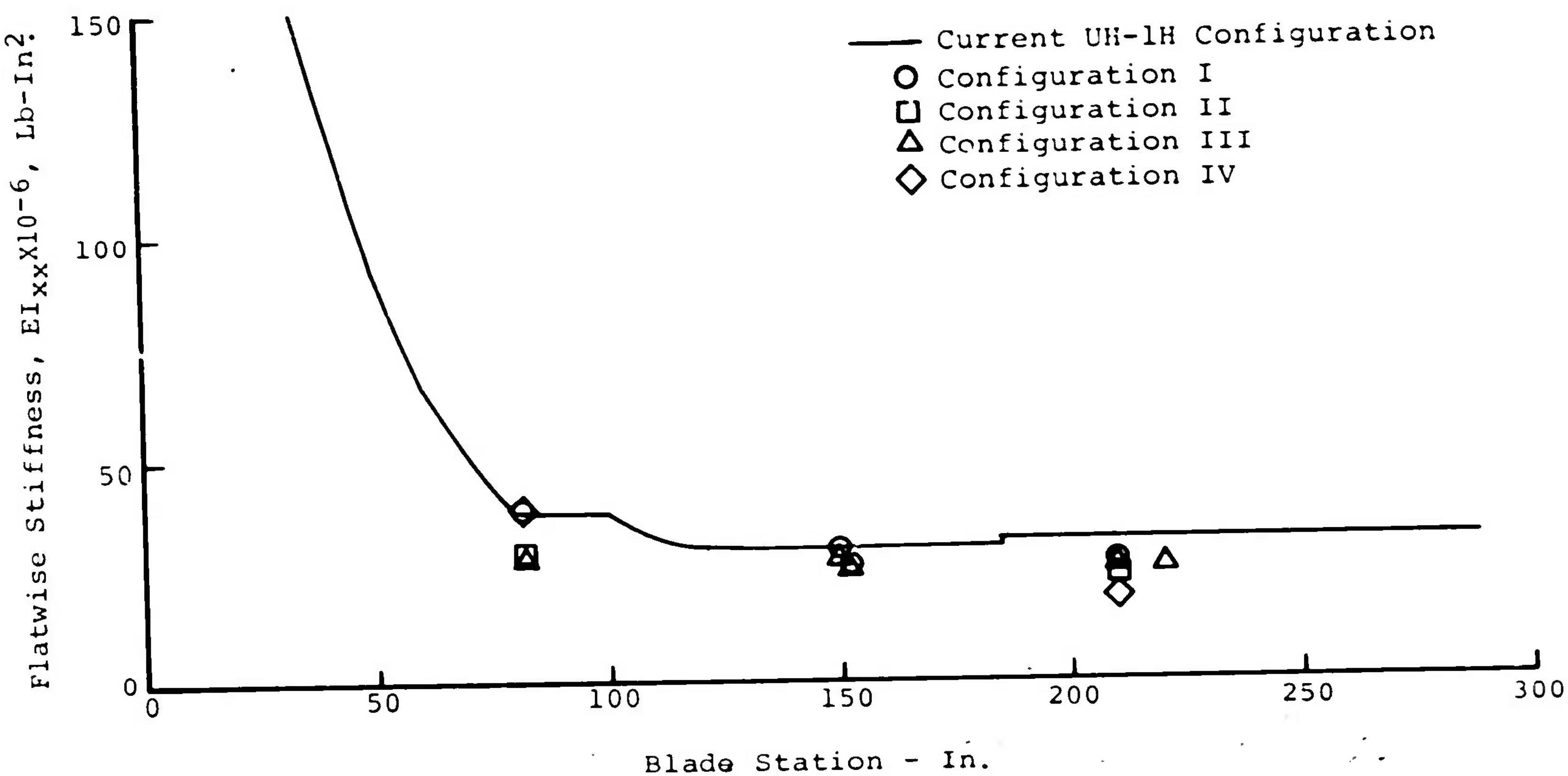


Figure 27. Flatwise Stiffness Distribution.

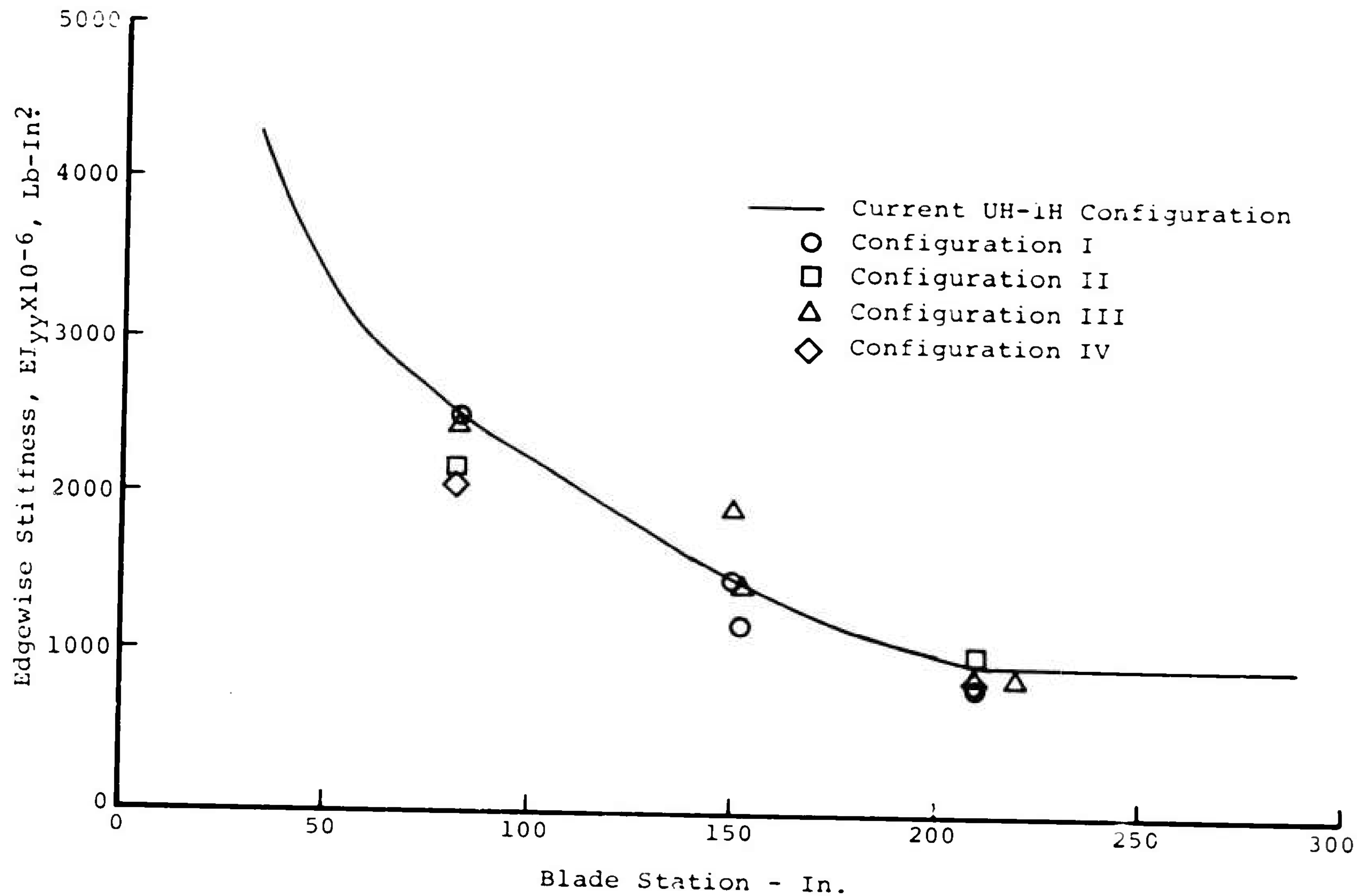
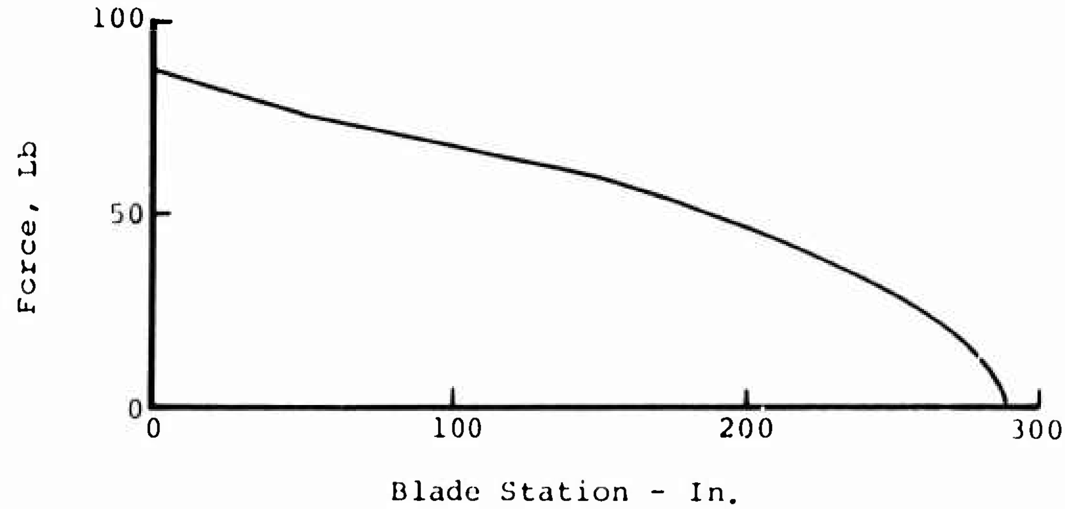
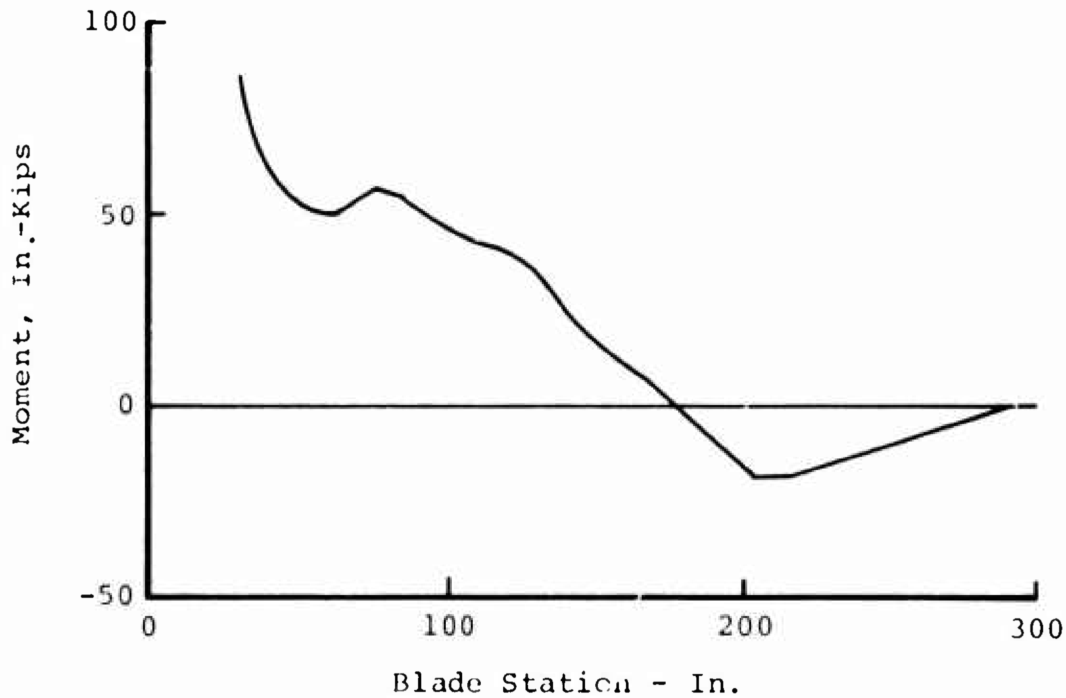


Figure 28. Edgewise Stiffness Distribution.



(a) Centrifugal Force at a Rotor Speed of 315 rpm for the UH-1H Blade.



(b) Steady Edgewise Moment Due to Centrifugal Force at a Rotor Speed of 315 rpm for the UH-1H Blade.

Figure 29. Rotor Blade Centrifugal Loading.

$$f_b = \frac{CF(E_m)}{EA} + \frac{M_{CF}C_xE_m}{EI_{yy}} + \frac{M_yC_xE_m}{EI_{yy}} + \frac{M_xC_yE_m}{EI_{xx}}$$

where:

CF = Centrifugal force at the station considered, lb

E_m = Modulus of elasticity for the material, lb/in.^{2}

M_{CF} = Steady edgewise bending moment due to centrifugal force, in.-lb

M_y = Steady and vibratory edgewise bending moment, in.-lb

M_x = Steady and vibratory flatwise bending moment, in.-lb

EA = Span or axial stiffness of total blade cross section, lb

EI_{yy} = Edgewise bending stiffness of total cross section, lb-in.^{2}

EI_{xx} = Flatwise bending stiffness of total cross section, lb-in.^{2}

C_x = Distance between the point on the blade cross section and the chordwise neutral axis measured parallel to the blade axis of symmetry (X-X Axis), in.

C_y = Perpendicular distance between the point on the blade cross section and the X-X neutral axis, in.

The sign convention used in this analysis is:

Edgewise bending moment - Positive denotes tension on the leading edge of the blade.

Flatwise bending moment - Positive denotes tension on the lower side of the blade.

Axial load - Positive denotes tension.

Calculated steady and vibratory stresses obtained for the fatigue condition were compared to the allowable vibratory stress by means of the modified Goodman diagram which can be expressed as:

$$F_A = F_E \left[1 - \frac{f_{st}}{F_{tu}} \right]$$

where: F_A = Allowable vibratory stress, lb/in.^{2}

F_E = Endurance limit, lb/in.^{2}

F_{tu} = Ultimate tensile strength, lb/in.^{2}

f_{st} = Calculated steady stress, lb/in.^{2}

Results of the foregoing analyses are found in Table XIII. Fatigue stresses and margins of safety are presented for each significant point or component of the blades. In all cases, a positive margin of safety was obtained for the critical components of each configuration.

As previously described, the significance of a positive margin of safety in this calculation is that the component under consideration will operate at stresses below its calculated endurance limit and will, therefore, accrue little or no fatigue damage throughout the entire forward flight spectrum. It may, therefore, be concluded that all of the designs analyzed will have high fatigue lives. The current UH-1H blade, which is also included in the stress summary, is assigned a 2500-hour fatigue retirement life as presently used in the Army environment. A comparison of the margins calculated for this blade to those calculated for the candidate designs by the same procedures shows that the margins are, in fact, very similar. Minor variations exist; however, the basic conclusion that can be drawn is that the candidate blades would enjoy fatigue lives of the same order as that now assigned to the current UH-1H blade. Since a thorough and complete assessment of the fatigue life of a new rotor blade can be made with confidence only when adequate experimental data are available for the fatigue strength, the flight loads and the frequency of occurrence of loads, no further detailed calculations are undertaken at this time.

TABLE XIII. BASIC STRESS ANALYSIS SUMMARY

Configuration	Station	Component	Coordinates X^1	Coordinates Y^2	Fatigue Stress (Lb/In.^{2})	Margin of Safety
UH-1H	82	Spline	21.000	.027	7,385 ± 4,771	.114
		Skin	20.690	.070	7,521 ± 4,761	.114
		Spar	.677	.542	14,948 ± 2,759	.674
		Nose Weight	.020	0	14,786 ± 1,925	1.409
		Abrasion Strip	0	0	38,039 ± 4,966	1.523
	210	Spline	21.000	.027	12,507 ± 2,673	.814
		Skin	6.300	1.260	12,177 ± 2,862	.704
		Spar	.677	.542	10,332 ± 1,603	2.148
		Nose Weight	.020	0	13,506 ± 809	4.528
		Abrasion Strip	0	0	24,304 ± 1,611	8.006
I	82	Spline	21.000	.027	7,110 ± 4,863	.099
		Skin	20.690	.098	2,674 ± 1,773	.790
		Spar	.677	.542	13,654 ± 2,592	.831
		Nose Weight	.020	0	13,382 ± 1,945	1.449
		Abrasion Strip	0	0	34,429 ± 5,019	1.600
	152	Spline	21.000	.027	11,107 ± 4,847	.026
		Skin	20.690	.070	4,120 ± 1,788	.528
		Spar	.677	.542	14,591 ± 2,911	.599
		Nose Weight	.020	0	14,123 ± 1,727	1.720
		Abrasion Strip	0	0	36,324 ± 4,458	1.567
	210	Spline	21.000	.027	12,323 ± 3,036	.601
		Skin	20.690	1.070	4,526 ± 1,132	1.304
		Spar	.677	.542	9,138 ± 1,677	2.073
		Nose Weight	.020	0	11,729 ± 913	4.546
		Abrasion Strip	0	0	21,325 ± 1,452	9.277

TABLE XIII - Continued

Configuration	Station	Component	Coordinates X^1	Coordinates Y^2	Fatigue Stress (Lb/In.^{2})	Margin of Safety
II	82	Spline	21.000	.027	12,121 ± 8,215	.350
		Skin	20.464	.100	3,028 ± 1,965	.575
		Spar	.677	.542	24,178 ± 4,485	1.272
		Nose Weight	.020	0	23,491 ± 3,130	2.270
		Abrasion Strip	0	0	39,659 ± 5,301	1.319
	210	Spline	21.000	.027	17,319 ± 3,651	1.932
		Skin	6.300	1.260	4,142 ± 1,203	1.260
		Spar	.677	.592	14,364 ± 2,562	3.262
		Nose Weight	.020	0	11,669 ± 751	5.743
		Abrasion Strip	0	0	20,997 ± 1,358	10.028
III	82	Spline	21.000	.020	7,724 ± 4,982	.061
		Skin	21.000	.076	4,175 ± 1,870	.452
		Spar	0	0	14,845 ± 2,080	.757
	152	Spline	21.000	.020	10,167 ± 4,431	.143
		Skin	21.000	.048	3,751 ± 1,656	.720
		Spar	0	0	11,987 ± 1,226	3.352
	210	Spline	21.000	.020	10,643 ± 2,986	.680
		Skin	21.000	.048	3,935 ± 1,119	1.495
		Spar	0	0	8,222 ± 642	6.327
	220	Spline	21.000	.020	10,694 ± 2,604	.926
		Skin	6.300	1.260	3,864 ± 984	1.858
		Spar	0	0	7,301 ± 559	7.673

TABLE XIII - Continued

Configuration	Station	Component	Coordinates X^1	Coordinates Y^1	Fatigue Stress (Lb/In.^{2})	Margin of Safety
IV	82	Spline	18.713	.241	11,275 ± 9,416	.083
		Skin	21.000	.056	1,901 ± 2,193	.558
		Spar	.677	.502	6,878 ± 1,336	1.961
		Nose Weight	.020	0	8,155 ± 1,306	1.729
		Abrasion Strip	0	0	38,657 ± 6,208	1.004
	210	Spline	20.787	0	2,882 ± 849	2.665
		Skin	21.000	.028	3,171 ± 953	2.173
		Spar	.677	.502	6,984 ± 882	3.032
		Abrasion Strip	0	0	37,626 ± 2,198	4.724

1. X is measured from the leading edge parallel to the chord.
2. Y is measured from the chord plane.

SURVIVABILITY ANALYSIS

In addition to the stress analysis conducted for the basic configurations, Configurations I and III were further analyzed to determine the structural deterioration caused by three types of assumed damage: (1) a bullet hole through the spar, (2) the loss of both upper and lower skins, and (3) the loss of both skins as well as the trailing-edge spline.

Condition 1 was selected to simulate the effects of a loss of structural material equivalent to that which would be caused by a 50-caliber bullet passing through the spar just aft of the nose ballast weight. The change in cross section properties at each station analyzed, although relatively small (7 to 10% for flatwise bending stiffness and 8 to 16% for edgewise bending stiffness), as shown in Table XIV, could be significant due to the local stress condition surrounding the damaged area. Stress concentrations of varying magnitudes could increase the vibratory stresses over those shown in Table XIII by a significant factor.

Condition 2, the loss of both upper and lower skins, considers in-flight damage to the aft structure due to projectiles, debris, foreign objects, etc., that would result in tears or punctures to both skins of such a magnitude to prevent them from performing any load-carrying function. As such, the flatwise bending loads would be resisted primarily by the spar, while edgewise bending and axial loads would be resisted by the spar and, to some extent, the trailing-edge spline. Reductions in section properties are noted for both flatwise and edgewise bending stiffness amounting to approximately 15 to 20% for both configurations.

Condition 3, the loss of both skins and the trailing-edge spline, could include damage that would result in the loss of portions of the complete aft structure for several inches as well as those instances where the spline receives sufficient damage to cause separation. Usually, failure of the spline is accompanied by failure of both skins as well. In this condition the remaining forward structure, such as the spar, spar doublers, abrasion strip, and possibly the nose ballast weight, would be required to resist all of the flight-induced loads. Loss in section properties is largest for the three conditions studied, amounting to approximately 15 to 20% for flatwise bending stiffness and 95 to 96% for edgewise bending stiffness.

TABLE XIV. SURVIVABILITY ANALYSIS SUMMARY

Configuration	Survivability Condition	Station (In.)	Section Properties: Flatwise Bending Stiffness $EI_{xx} X10^{-6}$ (Lb/In^2)	Section Properties: Edgewise Bending Stiffness $EI_{yy} X10^{-6}$ (Lb/In^2)	Section Properties: Neutral Axis Location $\bar{X}_{NA}$ (In.)	Critical Component	Fatigue Condition: Stress (Lb/In^2)	Fatigue Condition: Margin of Safety*	Static Condition: Stress (Lb/In^2)	Static Condition: Margin of Safety
I	Basic	82	39.410	2509.000	6.053	Spline	7,110 ± 4863	.10	11,973	4.42
		152	26.265	1182.609	4.568	Spline	11 107 ± 4847	.03	15,554	3.07
		210	26.422	803.401	3.723	Spline	12,323 ± 3036	.60	15,359	3.23
	Bullet Hole in Spar	82	35.632	2470.109	6.261	Spline	7,882 ± 4874	.08	12,756	4.09
		152	23.400	1180.192	4.692	Spline	11,980 ± 5171	LL	17,151	2.79
		210	23.556	801.410	3.782	Spline	12,970 ± 3042	.57	16,012	3.05
	Loss of Both Skins	82	33.398	2016.370	5.183	Spline	7,218 ± 6397	LL	13,615	3.77
		152	23.332	855.460	3.824	Spline	11,150 ± 7392	LL	18,541	2.50
		210	23.489	425.035	2.916	Spline	16,354 ± 5948	LL	22,302	1.91
	Loss of Both Skins and Spline	82	33.279	121.[illegible]95	2.674	Doubler	High	LL	164,204	-.23
		152	23.319	103.500	2.593	Spar	High	LL	54,300	.19
		210	23.487	113.988	2.456	Spar	High	LL	34,265	.89
III	Basic	82	27.836	2461.856	6.218	Spline	7,724 ± 4982	.06	12,706	4.11
		152	25.656	1441.140	4.593	Spline	10,167 ± 4431	.14	14,598	3.45
		210	25.635	860.153	3.756	Spline	10,643 ± 2986	.68	13,629	3.76
		220	25.635	860.153	3.756	Spline	10,694 ± 2604	.93	12,758	4.09
	Bullet Hole in Spar	82	25.844	2439.806	6.342	Spline	8,023 ± 4987	.05	13,010	3.99
		152	23.664	1435.470	4.665	Spline	10,676 ± 4433	.13	15,109	3.30
		210	23.643	856.738	3.794	Spline	11,046 ± 2988	.68	14,034	3.63
		220	23.643	858.738	3.794	Spline	11,061 ± 2607	.89	13,668	3.75

TABLE XIV - Continued

Configuration	Survivability Condition	Station (In.)	Section Properties: Flatwise Bending Stiffness $EI_{xx} \times 10^{-6}$ (Lb/In.²)	Section Properties: Edgewise Bending Stiffness $EI_{yy} \times 10^{-6}$ (Lb/In.²)	Section Properties: Neutral Axis Location $\bar{X}_{NA}$ (In.)	Critical Component	Fatigue Condition: Stress (Lb/In.²)	Fatigue Condition: Margin of Safety*	Static Condition: Stress (Lb/In.²)	Static Condition: Margin of Safety
III	Loss of Both Skins	82	22.251	1949.206	5.227	Spar	7,875 ± 6711	LL	18,752	1.02
		152	22.785	1103.193	3.924	Spar	13,808 ± 4035	LL	17,843	1.13
		210	22.764	465.405	2.974	Spar	13,213 ± 5738	LL	16,023	1.37
		220	22.764	465.405	2.974	Spar	13,945 ± 5003	LL	15,058	1.52
	Loss of Both Skins and Spline	82	22.130	110.897	2.452	Spar	High	LL	83,695	-.54
		152	22.764	114.030	2.481	Spar	High	LL	54,733	-.30
		210	22.762	114.035	2.481	Spar	High	LL	34,809	.09
		220	22.762	114.035	2.481	Spar	High	LL	31,930	.19

*LL denotes Life Limited.

Flatwise and edgewise bending moments were reevaluated for the blades, assuming local damage of Condition 3 type. When compared to the moments obtained for the basic stress analysis, insignificant change was noted. Therefore, the steady and vibratory flatwise and edgewise moments derived for the basic configurations were used for the survivability analysis. The steady edgewise bending moment due to centrifugal force, however, changed drastically, particularly for the Condition 3 damage situation. Due to the loss of the complete aft structure, the neutral axis at Station 82 shifts forward 3.38 inches for Configuration I and 3.68 inches for Configuration III. The neutral axis shift at other stations, although not as extreme, is still substantial. Therefore, the steady edgewise bending moment due to centrifugal force for Condition 3 was recalculated and is reflected in the stresses and margins of safety reported in Table XIV.

Table XIV presents the survivability analysis summary for blade Configurations I and III. Section properties for several significant stations of the basic blade as well as those resulting from the three damage conditions are shown. Both fatigue and static stresses as well as their respective margins of safety are presented for the critical blade components. Fatigue margin of safety is based on analysis of steady and vibratory stresses and a comparison to the appropriate material allowables. Static margin of safety in this analysis is based upon calculated stresses from all steady load sources plus stress amplitude resulting from vibratory loads. The resulting peak stress is compared directly to the material ultimate strength to ascertain whether blade separation is imminent. In all cases the very high stress concentration that would exist at the tip of a crack or tear is assumed to be blunted by local yielding. Such yielding, which will generally be present, will in fact be beneficial in many cases because of the state of residual compression induced. A positive fatigue margin of safety is usually associated with a high static margin and indicates that the damage is of minor consequence and does not require immediate action. Negative fatigue margins designated as LL in Table XIV denote components that are life limited after damage. If they are associated with a relatively high static margin, the component may survive for a limited time before corrective action is mandatory. If, however, a life-limited component has a relatively low static margin, the expected life of the component could be very short and immediate corrective procedures should be initiated. Negative static margins of safety for a component are evidence that the component cannot survive the extent of damage considered at that station.

Bullet hole damage at Station 152 of Configuration I causes life-limiting fatigue damage but is less damaging at other stations. This condition does not appear to present any immediate safety of flight problem as all static margins are relatively high.

All Configuration I blade stations are life limited for damage Conditions 2 and 3. Condition 2 static margins are relatively high, indicating that there is a good probability of its surviving for a sufficient time to complete the flight or at least to make a successful landing. Static margins for Condition 3 reveal that Station 82 of Configuration III could not sustain this type of damage without experiencing a failure. The low static margins for stations outboard of Station 82 indicate a low probability of being able to sustain flight for any appreciable length of time. A safe landing could probably be made, particularly if the damage occurred outboard of Station 210.

Configuration III appears to be slightly less sensitive to Condition 1 bullet hole damage than is Configuration I, notably at Station 152. The Configuration III blade exhibits positive fatigue margins of safety for the full length of the blade. These margins are not, however, very high, and any increase in the vibratory level caused by stress concentrations could result in a life-limited blade, particularly inboard of Station 152.

Configuration III blades exposed to damage Condition 2, the loss of both skins, is life limited for the full blade length. The static margins indicate less ability to sustain continued flight than does the Configuration I blade but, in all probability, are sufficiently high to permit a safe landing.

Static margins for the Configuration III blade subjected to Condition 3 damage, the loss of both skins and trailing-edge spline, indicate that the blade could not sustain this extensive amount of damage inboard of approximately Station 200. The probability of a successful landing increases as the damage location moves outboard from Station 200.

FINAL DESIGN SELECTION

A review of the results of all the foregoing analyses reveals that all candidate blade designs have merit and that no single design is the outstanding obvious selection. A sufficient number of design and analysis iterations were conducted for each configuration so that in the final evaluation all four candidates fully met the technical requirements. Blade natural frequencies, flight loadings and stress margins were all within acceptable limits. Evaluation of the basic fatigue margins of safety indicated that all configurations would enjoy a high fatigue life in service on the UH-1H. The reliability evaluation of each configuration revealed no major differences, though newer and more novel materials or processes must, of course, leave questions as to their final reliability in service. Major gains in repairability and maintainability have been made for all configurations by the incorporation of fiberglass skins for the aft structure. Development of the ability to do major repairs to this area of the blade at the field level provides a substantial improvement in repairability over a comparable metal skin blade. Due to the importance of this area in determining overall blade repairability, all four candidate designs fell in the narrow range of 80 to 83% repairability.

Evaluation of the 10-year life-cycle costs of the candidate blades did, however, reveal significant differences. Configurations I and III showed promise of a substantial reduction in life-cycle costs when compared to the present UH-1H blade or to Configurations II and IV. Savings on the order of 40% of the cost of an overall rotor blade program could be realized by the incorporation of one of these designs. Since the initial cost of both of these blades is slightly higher than current UH-1H blades estimated on the same basis, the savings accrue from the improvement in repairability and the resulting increased time in service. To further evaluate differences between blade configurations I and III, details of the cost analysis were examined for the purpose of identifying elements which might provide further reduction in total life-cycle cost. As a result of this review and a general evaluation of all factors involved in the selection of a preferred design, the final recommended Configuration V design was evolved. This design uses a combination of the features of Configurations I and III in such a way as to provide a slight further reduction in total life-cycle cost.

Table XV presents the results of a life-cycle cost analysis for the Configuration V blade. This analysis used relia-

TABLE XV. CONFIGURATION V LIFE-CYCLE COST SUMMARY	
Cost of New Blade (FOB) - Dollars	
Blade Production Cost Estimate *	2715
RDTE Cost per Unit	107
Profit	339
Blade Price to Army	3161
100 Random Hit Blade Damage Analysis	
K_{BRO} Fraction Repaired at Org Level (on A/C)	.187
K_{BRF} Fraction Repaired at Int Level (off A/C)	.454
K_{BRD} Fraction Repaired at Depot Level	.175
K_{BSO} Fraction Scrapped at Org/Int Level**	.138
K_{BSD} Fraction Scrapped at Depot Level	.046
Total Dispostion of 100 Random Hits	1.000
Average Repair Kit Price (FOB), dollars	52.05
Mean Time to Repair, T_R, MMH	3.33
Blade Program Cost/Aircraft Life Cycle - Dollars	
Initial Costs	
Outfitting Production Aircraft	6321
Spare Blades and Containers	1454
Spare Parts	48
Operating Costs	
Org /Int Blade Repair Labor	560
Org /Int Blade Repair Parts	950
Org /Int Blade Scrap & Fatigue Retire	12,110
Depot Level Blade Repair	5,670
Depot Level Blade Scrap	3,510
Attrition	
Blade Replacement	9,872
Blade Program Cost/Aircraft Life Cycle - Dollars	40,495

*Based on 10,000th unit of production and adjusted to agree with specified price of the current UH-1D/H blade.

**Fraction of blades scrapped at the Org/Int Level is estimated at 75% of total scrap for all repairable blade candidates, based on damage assessment of 100 random hit analysis.

ability, maintainability and cost data derived for Configurations I and III, as applicable. The resulting blade program cost represents a net savings over a 10-year aircraft life cycle of 46% compared to the present UH-1H blade. This represents slightly greater savings than are offered by any of the other candidate blade designs.

Attainment of stiffness and natural frequency requirements is predicted on a shear modulus, which was calculated for the laminated glass fiber skins, using standard theory developed for this purpose. The properties can be influenced by the conditions of cure of the laminate and may be expected to vary from theoretical prediction. In the event that the shear modulus is too low, the required shear stiffness could be attained with the simple addition of more skin plies. Such a design change will directly affect blade weight, but it is not expected to significantly affect mass balance, since the stiffness requirement is primarily associated with the inboard blade stations and root end.

The survivability characteristics of this design will be the same as those defined for Configuration III, where, for major areas of the blade, excellent damage tolerance has been demonstrated. Damage type 3, the case of the severed trailing-edge spline, in which the skins are also considered to be failed and only the spar structure remains, is survivable only for outer portions of the blade. An improvement in the survivability for this case could be provided at an increase in basic blade cost. This would involve an increased thickness for the aft web on the "D" spar for inboard sections, which is machined to present thickness for outboard sections. Although it appears that such a change would be desirable from an aircraft/systems approach, it is not warranted on the basis of rotor blade costs alone.

CONCLUSIONS

Based on work performed in this program, the following conclusions can be drawn:

1. An increase in repairability can provide a significant decrease in total program costs for main rotor blades, even at a slight increase in unit cost.

2. A rotor blade that offers repairability on the order of 80% has been designed for the UH-1H and in that application offers potential savings of more than 40% of total program costs.

3. The rotor blade designed for the UH-1H meets the technical requirements of that application and will have a high fatigue life. The same concept is applicable to other rotor systems, particularly those where the stiffness and strength requirements are less stringent.

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APPENDIX I

FAILURE MODE AND EFFECT ANALYSIS

TABLE XVI. CONFIGURATION I

Item Name	Assumed Failure	Possible Cause	Effect	Method or Failure Detection	Compensating Provisions
Box Beam, Al., 2024, & Box Beam Doubler. Doubler is 18.8 CRES to Sta. #105, F.G. outward	a) Splits, blade separates.	a) Overstress - hard landing.	a) Unbalance may cause extensive aircraft damage and personnel injury.	None.	-
	b) Splits, blade separates.	b) Gash or crack over 3" long & all the way through, propagates.	b) Will cause strike.	None.	-
	c) Splits, blade separates.	c) Sudden stoppages.	c) Likely to crash.	None.	-
	d) Cut or strike by F.O	d) Gash or crack less than 3" long or not all the way through doubler.	d) No mission effect. Repairable at depot.	Visual during next preflight if gash.	-
	e) Cut or strike by F.O.	e) Gash or crack of any length but less than .031" depth. Dent.	e) No mission effect. Repair in field shop.		-
	f) Battle Damage.	1) 30 cal. or .50 cal.	1) Would not propagate enough to cause separation of blade. Abort mission.	Visual.	-
		2) Warhead fragment.	2) Ability of doubler to retard propagation for a safe forced landing depends on size of warhead fragment.		-
Abrasive Strip, segmented. CRES, K-ramic coated Ti for outward 3'	a) Torn, cracked, scratched through or punctured.	a) Bullets, tree strikes, F.O.'s in air, handling damage.	No mission effect. Causes blade to be removed for field repair.	Visual at next preflight.	Only one segment damaged at one time, normally.

TABLE XVI - Continued

Item Name	Assumed Failure	Possible Cause	Effect	Method of Failure Detection	Compensating Provisions
Abrasive Strip, (continued)	b) Dented, nicked or scratched less than all the way through.	b) Bullets, tree strikes, F.O.'s in air, handling damage.	No mission effect. Repair on aircraft.	Daily inspection.	-
Core, honeycomb	a) Punctured, bent, cut, dented, or portions pulled loose from beam, spline, or skin.	a) Battle or tree strikes, F.O.D., tool damage, or handling damage.	a) Decrease in stiffness of core and/or decrease in area bonded to other blade parts past some point will cause part of aft blade section to separate. Less movement will degrade performance, but allow forced abort. Repairable in depot if beam not overstressed.	None.	Extensive damage, even missile hits, will not cause normal loads to structurally fail rest of blade. Increased vibration etc. may however, before a landing can be made.
	b) Same as above but within limits for field shop repair.	b) Battle or tree strikes, F.O.D., tool damage, or handling damage.	b) Slight degradation of performance, but mission will be completed.	Visual at preflight inspection.	-
Skin, fiberglass	a) Punctured, cut, torn, scratched, or dented with skin fractures, but all within limits for ORG repair.	a) Bullet or tree strikes, handling damage, tool damage, F.O.D.	a) Slight degradation in performance. Schedule repair on aircraft.	Visual inspection.	-

TABLE XVI - Continued

Item Name	Assumed Failure	Possible Cause	Effect	Method of Failure Detection	Compensating Provisions
Skin, fiberglass (continued)	b) Same but requires field shop repair.	b) Bullet or tree strikes, handling damage, tool damage, F.O.D.	b) Complete mission with slight degradation in rotor performance. Schedule blade repair.	Visual inspection.	-
	c) Same but beyond limits for field shop repair.	c) Tree strikes, handling damage, F.O.D.	c) Degraded rotor performance. Abort mission.	Visual inspection.	-
Spline, 2024	a) Shears.	a) Battle damage, handling damage, sudden stoppage, hard landing.	a) Note 3, Table XX.	Note 4, Table XX.	Note 5, Table XX.
	b) Punctures.	b) Bullets, tool damage.	b) Note 3, Table XX.	Note 4, Table XX.	Note 5, Table XX.
	c) Bends, chips cuts, or dents.	c) F.O.D., handling damage, tree strike.	c) Degradation of performance but mission will be completed.	Visual if occurs on ground.	-
Doublers for Grip Pad and Drag Plate	a) Ruptures.	a) Sudden stoppage, overstress due to hard landing.	a) Beam will be overloaded and split.	Note 4, Table XX.	-
	b) Punctured.	b) Battle hits, F.O.D.	b) Damage may propagate under load & cause blade to separate. Strike.	Note 4, Table XX.	-
	c) Cut, torn, dented, softened.	c) Tool damage, handling damage, F.O.D., solvents.	c) Damage may propagate under load & cause blade to separate. Strike.	c) At daily inspection.	-
	d) Same as above but less extensive.	d) Tool damage, handling damage, F.O.D., solvents.	d) No mission effect. Repairable at Depot.	Visible at daily inspection.	-

TABLE XVI - Continued

Item Name	Assumed Failure	Possible Cause	Effect	Method of Failure Detection	Compensating Provisions
Grip Pad	a) Shears.	a) Sudden stoppages.	a) Will overload beam so blade will separate.	None.	-
	b) Cut, broken, gouged.	b) Enemy projectile.	b) Will split and allow blade to separate.	None.	-
	c) Chipped, cut, dented, nicked, or scratched.	c) F.O.D., bullets, tool damage.	c) Will reduce fatigue life. No mission effect if blade removed for field replacement.	Visual during daily inspection.	Bottom pad can withstand considerable abuse.
Drag Plate	a) Shears.	a) Sudden stop.	a) Note 2, Table XX.	None.	-
	b) Cut, broken, gouged.	b) Enemy projectile.	b) Note 2, Table XX.	None.	-
	c) Chipped, cut, dented, nicked, or scratched.	c) Bullets, F.O.D., tool damage.	c) Reduction in fatigue life. No mission effect if Drag Plate is replaced.	Visual during daily inspection.	-
Overall Blade	a) Reduction in fatigue life. Possible damage.	a) RPM above repairable limit.	a) In most cases mission can be completed or precautionary abort made without crash. Scrap all blades.	Air crew has gages and a red warning light, but air crew must notice gage or warning light.	-
	b) Burnt, overheated.	b) Fire.	b) Beam will be overloaded and may fail structurally. Likely to cause crash if occurs in flight.	b) Note 4.	-
	c) Blistered or scorched but not structurally damaged.	c) Fire.	c) No mission effect. Repairable at depot.	c) Visual at daily inspection.	-
	d) Out-of-track, vibration, or noise.	d) Bad patch, defective maintenance.	d) Forced abort. Repairable in field or at Depot.	-	-

TABLE XVII. CONFIGURATION II

Item Name	Assumed Failure	Possible Cause	Effect	Method of Failure Detection	Compensating Provisions
Spar, Ti-6Al-4V	a) Fractures so blade separates.	a) Overstress during hard landing.	a) Unbalance may cause extensive aircraft damage and personnel injury.	None.	-
	b) Gash or crack over 3" long and all the way through, propagates to blade separation.	b) Tree hit, glancing bullet, handling damage, F.O.D., hard landing.	b) Note 1, Table XX.	b) Vibration.	b) None of rest of helicopter would be in path of lost portion of rotor.
	c) Fractures so blade separates.	c) Sudden stoppage.	c) Note 1, Table XX.	c) Vibration.	c) None of rest of helicopter would be in path of lost portion of rotor.
	d) Gashed or cracked less than 3" long or not all the way through.	d) Tree hit, glancing bullet, handling damage, F.O.D., hard landing.	d) No mission effect.	d) Visual. Note 4, Table XX.	-
	e) Punctured.	e) Enemy projectile.	e) Except at grip attachment, a hole less than 2" diameter would not propagate to cause immediate crash. Vibration would abort mission for anything bigger than 30 cal. hole.	e) Indicator, vibration, visual.	e) Crack propagation is slow in Ti-6Al-4V.

TABLE XVII - Continued

Item Name	Assumed Failure	Possible Cause	Effect	Method of Failure Detection	Compensating Provisions
Abrasive Strip, KAramic coated Ti	a) Torn, cracked, scratched through or punctured. b) Dented, nicked or scratched.	a) Bullets, tree strikes, F.O.D., handling damage. b) Bullets, tree strikes, F.O.D., handling damage.	a) No mission effect. Causes blade to be removed for field repair. b) No mission effect. Repair on aircraft.	a) Visual at next preflight. b) Periodic Inspection.	- -
Core, Honeycomb	a) Punctured, bent, cut, crushed, or portions pulled loose from beam, spline, or skin.	a) Bullet or tree strikes, F.O.D., tool or handling damage.	a) Decrease in stiffness of core and/or change in aero contour may cause loss of control. Less movement will degrade performance, but allow forced abort. Repairable in depot if spar not overstressed.	None.	a) Extensive damage, even missile hits, will not cause normal loads to structurally fail rest of blade. Increased vibration, etc., may, however, before a landing can be made.
	b) Same as above but within limits for field shop repair.	b) Bullet or tree strikes, F.O., tool, or handling damage.	b) Degradation of performance, but mission will be completed.	b) Visual at preflight inspection.	-

TABLE XVII - Continued

Item Name	Assumed Failure	Possible Cause	Effect	Method of Failure Detection	Compensating Provisions
Skin, Fiberglass	a) Punctured, cut, torn, scratched, or dented with skin fractures, but all within limits for Org repair.	a) Bullet or tree strikes, handling damage, tool damage, F.O.D.	a) Slight degradation in performance. Schedule repair on aircraft.	a) Visual during preflight inspection.	-
	b) Same but beyond limits for field shop repair.	b) Bullet or tree strikes, handling damage, F.O.D.	b) Degraded rotor performance abort mission. Remove blade.	b) Vibration.	-
Spline, Inboard Ti-6Al-4V	a) Sheared, cut-through, punctured, cracked.	a) Bullet or tree hits.	a) Failure of spline may overload closing channel etc. to failure. Decrease in stiffness would cause a forced landing.	a) Vibration.	Note 5, Table XX.
	b) Bent, gashed, or cracked, but not ruptured.	b) Bullet or tree hits.	b) Degradation of performance but mission will be completed.	b) Visual if occurs on ground. Vibration.	-
	c) Bond to outboard spline fails.	c) Weaked by solvents during maintenance.	c) Note 6.	c) Vibration.	-
Spline, Outboard Ti-6Al-4V	a) Cracked, sheared, punctured.	a) Bullet or tree, F.O., handling, or tool damage.	a) Note 6, Table XX.	a) Vibration.	-
	b) Dented, gashed or cracked but not ruptu	b) Bullet or tree, F.O., handling, or tool damage.	b) Degradation of performance but mission will be completed.	b) Vibration.	-

TABLE XVII - Continued

Item Name	Assumed Failure	Possible Cause	Effect	Method of Failure Detection	Compensating Provisions
Inboard Doublers for Grip Pad, Ti-6Al-4V	a) Ruptured.	a) Sudden stop, hard landing.	a) Other retention parts may be overloaded and fail. Lead-lag and twist problems may cause loss of control.	a) Vibration.	-
	b) Punctured, cut, torn, dented.	b) Bullets, F.O.D., tool damage.	b) Damage may propagate under load and cause the effects of (a) above.	b) Vibration.	-
	c) Dented, nicked or scratched.	c) Tool, handling or F.O. damage.	c) No mission effect. Schedule repair.	c) Visual during daily inspection.	-
Transition T.E. Doublers, Ti-6Al-4V	a) Ruptured.	a) Sudden stop, hard landing.	a) Note 6, Table XX.	a) Vibration.	-
	b) Punctured, cut, torn, or dented.	b) Bullets, F.O.D., tool damage, tree strike.	b) Damage may propagate under load and cause the effects of (a) above.	b) Vibration.	-
	c) Dented, nicked, or scratched.	c) Tool, handling or F.O. damage; tree strike.	c) No mission effect. Schedule repair.	c) Visual during daily inspection.	-
Closing Channel, Ti-6Al-4V	a) Cracked, cut-through, sheared, or punctured.	a) Bullet or tree hits.	a) Failure of closing channel may overload spline etc. to failure. May cause forced landing. Failure on start up would damage rotor.	a) Vibration.	-
	b) Dented, gashed, or cracked, but not ruptured.	b) Tree, F.O., or handling damage.	b) Degradation of performance but mission will be completed.	b) Vibration.	-

TABLE XVII - Continued

Item Name	Assumed Failure	Possible Cause	Effect	Method of Failure Detection	Compensating Provisions
Grip & Drag Pad Ti-6Al-4	a) Sheared, or cracked and propagates.	a) Sudden stop.	a) Other retention parts may be overstressed causing the effects of Note 1, Table XX.	a) None.	-
	b) Cut, broken, gouged, dented, and splits.	b) Enemy projectile.	b) Other retention parts may be overstressed causing the effects of Note 1, Table XX.	b) None.	-
	c) Chipped, dented, nicked, or scratched.	c) F.O.D., bullets, tool damage.	c) Will reduce fatigue life. No mission effect if repaired.	c) Visual during daily inspection.	-
Doubler, Spar to Core, Al	a) Punctured or torn.	a) Bullet hits or tree strikes; F.O. tool, or handling damage.	a) Slight increase in vibration due to turbulence. No mission effect.	a) Visual at daily inspection, vibration.	-
	b) Gashed or scratched.	b) Tree strikes F.O., tool, or handling damage.	b) Slight increase in vibration due to turbulence. No mission effect.	b) None.	-
Retention Bushing S/S 17-4	a) Fatigue cracks.	a) Overstressed during maintenance action.	a) May cause stress concentration leading to premature fatigue of interfacing parts.	a) None.	-
Overall Blade	a) Reduction in fatigue life, possible damage.	a) RPM above repairable limit, overloaded.	a) In most cases mission can be completed or precautionary abort made without crash. Scrap blades.	a) Cockpit gage or warning light must be observed while RPM is still over spec.	-

TABLE XVII - Continued

Item Name	Assumed Failure	Possible Cause	Effect &	Method of Failure Detection	Compensating Provisions
Overall Blade (continued)	b) Burnt, over-heated.	b) Fire.	b) Loaded members may fail structurally. Likely to cause crash if occurs in flight.	b) Vibration.	-
	c) Blistered or scorched but no structural damage.	c) Fire.	c) No mission effect. Repairable at depot.	c) Visual at daily inspection.	-
	d) Out-of-track, vibration, or noise.	d) Bad patch, defective maintenance.	d) Forced abort. Repairable at Depot.	d) Vibration.	-

TABLE XVIII. CONFIGURATION III

Item Name	Assumed Failure	Possible Cause	Effect	Method of Failure Detection	Compensating Provisions
Spar, 6061, Al	a) Fractures so blade separates.	a) Overstress during hard landing.	a) Unbalance may cause extensive aircraft damage and personnel injury.	None.	-
	b) Gashed or cracked over 3" long and all the way through, propagates.	b) Tree hit, overspeed, overloaded, bullet hit.	b) Note 1, Table XX.	-	-
	c) Fractures so blade separates.	c) Sudden stop* due to tree hit or collision.	c) Note 1, Table XX.	None.	-
	d) Cut, gashed, dented, cracked less than 3" long or not all the way through, scratched.	d) Tree hit, glancing bullet, tool damage, handling damage, F.O.D.	d) No mission effect.	d) Indicator will detect any damage causing leak path. Visual during preflight.	-
	e) Punctured.	e) Enemy projectiles.	e) Except at grip attachment, a hole less than 2" diameter would not propagate to cause immediate crash. Vibration would abort mission for anything bigger than 30 cal. hole.	e) Indicator, vibration, visual.	e) Crack propagation is slow in 6061.

* Sudden stops refer to collisions of blade with immovable object.

TABLE XVIII - Continued

Item Name	Assumed Failure	Possible Cause	Effect	Method of Failure Detection	Compensating Provisions
Abrasive Strip, K-ramic Coated Ti	a) Torn, cracked, scratched through or punctured.	a) Bullets, tree strikes, F.O.D., handling damage.	a) No mission effect. Causes blade to be removed for field repair.	a) Visual at next preflight.	-
	b) Dented, nicked or scratched less than all the way through.	b) Bullets, tree strikes, F.O.D., handling damage.	b) No mission effect. Repair on aircraft.	b) Daily inspection.	-
Core, Honeycomb	a) Punctured, bent, cut, crushed, or portions pulled loose from beam, spline, or skin.	a) Battle or tree strikes, F.O.D., tool damage, or handling damage.	a) Decrease in stiffness of core and/or decrease in area bonded to other blade parts past some point will cause part of aft blade section to separate. See Note 1. Less movement will degrade performance, but allow forced abort. Repairable in depot if spar not overstressed.	a) None.	a) Extensive damage, even missile hits, will not cause normal loads to structurally fail rest of blade. Increased vibration etc. may however, before a landing can be made.
	b) Same as above but within limits for field shop repair	b) Battle or tree strikes, F.O.D., tool damage, or handling damage.	b) Slight degradation of performance, but mission will be completed.	b) Visual at preflight inspection.	-
Skin, Fiberglass	a) Punctured, cut, torn, scratched, or dented with skin fractures, but all within limits for field repair.	a) Bullet or tree strikes, handling damage, tool damage, F.O.D.	a) Slight degradation in performance. Schedule repair on aircraft.	a) Visual during preflight inspection.	-

TABLE XVIII - Continued

Item Name	Assumed Failure	Possible Cause	Effect	Method of Failure Detection	Compensating Provisions
Skin, Fiberglass (continued)	b) Same but requires field shop repair.	b) Bullet or tree strikes, handling damage, tool damage, F.O.D.	b) Complete mission with slight degradation in rotor performance.	b) Visual during preflight inspection.	-
	c) Same but beyond limits for field shop repair.	c) Bullet or tree strikes, handling damage, F.O.D.	c) Complete mission with slight degradation in rotor performance. Remove blade.	c) Visual during preflight inspection.	-
Spline, Al. in D.F.G. sandwich	a) Sheared, cut-through, punctured.	a) Battle damage, handling damage, sudden stop, hard landing, tree hit.	a) Note 3, Table XX.	a) Note 4, Table XX.	a) Note 5, Table XX.
	b) Bent, gashed, or	b) F.O.D., handling damage, tree strike.	b) Degradation of performance but mission will be completed.	b) Visual if occurs on ground.	-
External Doublers for Drag Plate, Al	a) Ruptured.	a) Sudden stop hard landing.	a) Note 6, Table XX.	-	-
	b) Punctured.	b) Enemy projectiles.	b) Note 6, Table XX.	b) None.	-
	c) Cut or gouged and propagates.	c) Tool damage, handling damage, F.O.D., bullet hit.	c) Note 6, Table XX.	c) At daily inspection if occurred on ground.	-
	d) Dented, nicked, scratched.	d) Tool damage, handling damage, F.O.D.	d) No mission effect. Blended on aircraft.	d) Visible at periodic inspection.	-

TABLE XVIII - Continued

Item Name	Assumed Failure	Possible Cause	Effect	Method of Failure Detection	Compensating Provisions
Grip Pad, Al	a) Shears.	a) Sudden stop.	a) Other retention parts may be overstressed causing the effects of Note 1, Table XX.	a) None.	-
	b) Cut, broken, gouged, dented and splits.	b) Enemy projectile.	b) Other retention parts may be overstressed causing the effects of Note 1, Table XX.	b) None.	-
	c) Chipped, cut, dented, nicked, or scratched.	c) F.O.D., bullets, tool damage.	c) Will reduce fatigue life. No mission effect if blade removed for repair.	c) Visual during daily inspection.	-
Drag Plate, Al	a) Sheared.	a) Sudden stop.	a) Other retention parts may be overstressed to fail point causing the effects of Note 2, Table XX.	a) Vibration.	-
	b) Broken or gouged and propagates.	b) Enemy projectile.	b) Other retention parts may be overstressed to fail point causing the effects of Note 2, Table XX.	b) Vibration.	-
	c) Chipped, cut, dented, nicked, or scratched.	c) Bullets, F.O.D., tool damage.	c) Reduction in fatigue life. No mission effect if Drag Plate is replaced.	c) Visual during daily inspection.	-
Doubler, Spar to Core, Al	a) Punctured or torn.	a) Bullet hits or tree strikes; F.O., tool or handling damage.	a) Slight increase in vibration due to turbulence. No mission effect.	a) Visual at daily inspection, vibration.	-
	b) Gashed or scratched.	b) Tree strikes, F.O.D., handling damage.	b) Slight increase in vibration due to turbulence. No mission effect.	b) None.	-

TABLE XVIII - Continued

Item Name	Assumed Failure	Possible Cause	Effect	Method of Failure Detection	Compensating Provisions
Bolt or Nut for Fitting	a) Sheared.	a) Overtorqued during maintenance, head hit by tool or bullet, sudden stop.	a) Stiffness of blade will decrease and control will degrade. Cause mission abort.	a) Vibration.	-
Retention Bushing, S/S	a) Fatigue cracks.	a) Overstressed during maintenance action.	a) May cause stress concentration leading to premature fatigue of interfacing parts.	a) None.	-
Fitting, Al	a) Cracks.	a) Sudden stops, hard landings.	a) Note 2, Table XX.	a) Vibration.	-
	b) Punctured, gouged.	b) Enemy projectiles.	b) Safe landing could probably be made after 30 Cal. hits. Larger damage areas would propagate and cause the effects of Note 2.	b) Vibration.	-
Overall Blade	a) Reduction in fatigue life, possible damage.	a) RPM above repairable limit, overloaded.	a) In most cases mission can be completed or precautionary abort made without crash. Scrap blades.	a) Cockpit gage or warning light must be observed while RPM is still over spec.	-
	b) Burnt, overheated.	b) Fire.	b) Loaded members will fail structurally. Likely to cause crash if occurs in flight.	b) Vibration.	-
	c) Blistered or scorched but not structurally damaged.	c) Fire.	c) No mission effect. Repairable at depot.	c) Visual at daily inspection.	-
	d) Out-of-track, vibration, or noise.	d) Bad patch, defective maintenance.	d) Forced abort. Repairable at Depot.	d) Vibration.	-

TABLE XIX. CONFIGURATION IV

Item Name	Assumed Failure	Possible Cause	Effect	Method of Failure Detection	Compensating Provisions
Spar, D.F.G.	a) Spar sheared or cut 3" or longer chordwise and most of thickness. Propagates and spars splits.	a) Battle Damage, sudden stop as blade hits tree, pole, or solid object.	a) Note 1, Table XX.	-	Safety margin is higher than in metal spar and transverse crack propagation is slower so F.O. must dent most of fibers on one side of spar to separate blade.
	b) Cut or dented.	b) Tree strike, in-air collision, glancing bullet.	b) A safe forced landing would result if damage was not more than 1/3 through spar. Spar likely to delaminate from root of damage. Propagation would allow twisting which could cause crash if landing spot was not close.	-	-
	c) Cracks spanwise.	c) Overspeed or overload.	c) Note 1, Table XX.	-	-
	d) Punctured or torn.	d) Enemy hits, tree strike, collision.	d) A 30 cal. bullet hole would cause precautionary abort while 50 cal. would cause forced abort. Larger gaps might cause loss of control depending on size and location in spar.	-	-

TABLE XIX - Continued

Item Name	Assumed Failure	Possible Cause	Effect	Method of Failure Detection	Compensating Provisions
Abrasive Strip	a) Torn, cracked, scratched through or punctured. b) Dented, nicked, or scratched less than all the way through.	a) Bullets, tree strikes, F.O.'s, handling damage. b) Bullets, tree strikes, F.O.'s, handling damage.	a) No mission effect. Causes Causes blade to be removed for field repair. b) Repair on aircraft.	a) Visual at next preflight. b) Visual during periodic inspection.	a) Only one segment at one time, normally. -
Core, Honeycomb	a) Punctured, cut, torn, dented, or portions pulled loose from beam, spline, or skin.	a) Battle or tree strikes, F.O.D., tool damage, or handling damage.	a) Note 5, Table XX.	a) None.	a) Extensive damage, even missile hits, will not cause normal loads to structurally fail rest of blade but increased vibration may.
	b) Same as above but less extensive.	b) Battle or tree strikes, F.O.D., tool damage, or handling damage.	b) Slight degradation of performance, but mission will be completed.	b) Visual at preflight inspection.	-
Skin, Fiberglass	a) Punctured, cut, torn, scratched, or dented with skin fractures, but all within limits for ORG repair.	a) Bullet or tree strikes, handling damage, tool damage, F.O.D.	a) Slight degradation in performance. Schedule repair on aircraft.	a) Visual inspection.	-

TABLE XIX - Continued

Item Name	Assumed Failure	Possible Cause	Effect	Method of Failure Detection	Compensating Provisions
Skin, Fiberglass (continued)	b) Same but requires field shop repair.	b) Bullet or tree strikes, handling damage, tool damage, F.O.D.	b) Complete mission with slight degradation in rotor performance. Schedule blade removal.	b) Visual inspection.	-
	c) Same but beyond limits for field shop repair.	c) Bullet or tree strikes, handling damage, F.O.D.	c) Degraded rotor performance. Abort mission. Replace blade.	c) Visual inspection.	-
T. E. Spline D.F.G.	a) Punctured or gashed.	a) Bullets, tree hits.	a) Local damage, even if spline is sheared through, will allow safe landing. More than 6" torn out of place by F.O. and air stream would cause loss of control. Repairable in depot.	a) Vibration.	-
	b) Dented, nicked, gashed.	b) F.O.D., tree hit, handling or tool damage, glancing bullet.	b) No mission effect. Field shop repair required for damage deeper than .030".	b) Visual at daily inspection.	-
T.E. Wrap Nondirectional Fiberglass	a) Punctured or torn.	a) Bullets, tree hits.	a) Local damage may cause mission abort. More than 18" torn off may cause loss of control. Field repair.	a) Vibration.	T.E. Wrap is not a primary load carrying member.
	b) Cut, warped, delaminated, dented, or torn.	b) Tree hit, F.O.D., handling damage.	b) Slight performance degradation due to increased turbulence and decreased stiffness. Schedule repair locally.	b) Visual at daily inspection.	T.E. Wrap is not a primary load carrying member.

TABLE XIX - Continued

Item Name	Assumed Failure	Possible Cause	Effect	Method of Failure Detection	Compensating Provisions
External Doublers for Grip Pad, Ti	a) Ruptures.	a) Sudden stoppage, hard landing.	a) Note 1, Table XX.	a) None.	-
	b) Punctured.	b) Battle hits.	b) Damage may propagate under load and cause other retention parts to be overloaded to fail point.	b) None.	-
	c) Cut, torn, dented.	c) Tool damage, handling damage, F.O.D., bullet hit.	c) Damage may propagate under load and cause other retention parts to be overloaded to fail point.	c) At daily inspection if occurred on ground.	-
	d) Same as above but less extensive.	d) Tool damage, handling damage, F.O.D., bullet hit.	d) No mission effect. Repairable at depot.	d) Visible at periodic inspection.	-
Grip Pad, Ti	a) Shears.	a) Sudden stoppage.	a) Note 1, Table XX.	a) Vibration.	-
	b) Gouged, broken.	b) Enemy projectiles.	b) Note 1, Table XX.	b) Vibration.	-
	c) Chipped, cut, dented, nicked, or scratched.	c) F.O.D., bullets, tool damage.	c) Will reduce fatigue life. No mission effect if blade removed for field replacement of Grip Pad.	c) Visual during daily inspection.	-
External Doublers for Drag Plate	a) Ruptures.	a) Sudden stoppage, hard landing.	a) Note 6, Table XX.	a) None.	-
	b) Punctured.	b) Enemy projectiles.	b) Note 6, Table XX.	b) None.	-
	c) Cut, torn, dented.	c) Tool damage, handling damage, F.O.D., bullet hit.	c) Note 6, Table XX.	c) At daily inspection if occurred on ground.	-

TABLE XIX - Continued

Item Name	Assumed Failure	Possible Cause	Effect	Method of Failure Detection	Compensating Provisions
External Doublers for Drag Plate (continued)	d) Same as above but less extensive.	d) Tool damage, handling damage, F.O.D., bullet hit.	d) No mission effect. Repair at depot.	d) Visible at periodic inspection.	-
Drag Plate, Ti	a) Shears.	a) Sudden stop, hard landing.	a) Note 2, Table XX.	a) None.	-
	b) Cut, broken, gouged.	b) Enemy projectile.	b) Note 2, Table XX.	b) None.	-
	c) Chipped, cut, dented, nicked, or scratched.	c) Bullets, F.O.D., tool damage.	c) Reduction in fatigue life. No mission effect if drag plate is replaced.	c) Visual during daily inspection.	-
Fitting, Al	a) Cracks.	a) Sudden stops, hard landings.	a) Reduction in fatigue life. No mission effect if drag plate is replaced.	a) Vibration.	-
	b) Punctured, gouged.	b) Enemy projectiles.	b) Safe forced landing could probably be made after 30 cal. hits. Larger damage areas would propagate and cause the root end and T.E. stiffness will decrease. Lead-lag and twist will cause out-of-track. Forced landing will be hazardous.	b) Vibration.	-
Retention Bushing Stainless Steel	a) Fatigue Cracks.	a) Overstressed during maintenance action.	a) May cause stress concentration leading to premature fatigue of interfacing parts.	-	-

TABLE XIX - Continued

Item Name	Assumed Failure	Possible Cause	Effect	Method of Failure Detection	Compensating Provisions
Doubler, Spar to Core, Al	a) Punctured or torn.	a) Bullet hits or tree strikes.	a) Slight increase in vibration due to turbulence. No mission effect.	a) Visual at daily inspection, vibration.	-
	b) Dented.	b) Tree strikes, F.O.D., handling.	b) Slight increase in vibration due to turbulence. No mission effect.	b) None.	-
Spar Doubler, D.F.G.	a) Punctured, cut-through, or torn.	a) Tree strikes, collisions, bullets.	a) A cut completely through doubler transversely would degrade performance, but would not abort mission.	a) Vibration.	-
	b) Dented or scratched.	b) Tree strikes, collisions, F.O.D., or glancing bullets.	b) No mission effect. Repair in field shop.	b) Visual during daily inspection.	-
Overall Blade	a) Reduction in fatigue life. Possible damage.	a) RPM above repairable limit, overloaded.	a) In mose cases mission can be completed or precautionary abort made without crash. Scrap all blades.	a) Air crew has gages and a red warning light, but air crew must notice gage or warning light.	-
	b) Burnt, overheated structural damage.	b) Fire.	b) Loaded members will fail structurally. Likely to cause crash if occurs in flight.	b) Vibration.	-
	c) Blistered or scorched but no structural damage.	c) Fire.	c) No mission effect. Repairable at depot.	c) Visual at daily inspection.	-
	d) Out-of-track, vibration, or noise.	d) Bad patch, defective maintenance.	d) Forced abort. Repairable.	d) Vibration.	-

TABLE XX. CURRENT UH-1H BLADE

Item Name	Assumed Failure	Possible Cause	Effect	Method of Failure Detection	Compensating Provisions
Box Beam, Al. 2024, and Box Beam Doubler. Doubler is 18-8 CRES to Sta. 105, Al. outward	a) Splits so blade separates.	a) Overstress - hard landing.	a) Unbalance may cause extensive aircraft damage and personnel injury.	a) None.	-
	b) Ruptured; gashed or cracked over 3" long and all the way through beam inward of Sta. 105 (or 2" outward) and propagates.	b) Tree hit, glancing bullet, handling damage, F.O.D., hard landing.	b) Note 1, Table XX.	b) Vibration.	b) None of rest of helicopter would be in path of lost portion of rotor.
	c) Beam punctured.	c) Enemy projectiles.	c) 30 caliber bullet hits would cause safe forced landing. Larger projectiles would cause the effects of Note 1 if inward of Sta. 105.	c) Vibration.	-
	d) Doubler gashed, or cracked.	d) Collision with F.O.	d) Cracks or gashes all the way through doubler and more than 3" long may propagate and cause a forced landing. Less damage will cause no mission effect.	d) Vibration, visual during next preflight if a gash.	-
	e) Dented, or scratched.	e) Collision with F.O.	e) No mission effect. Remove blade.	-	-

TABLE XX - Continued

Item Name	Assumed Failure	Possible Cause	Effect	Method of Failure Detection	Compensating Provisions
Abrasive Strip, 18-8 CRES except for last 4' which is Cobalt	a) Torn, cracked, punctured, scratched or dented deeper than .012".	a) Bullets, tree strikes, F.O., or handling damage.	a) No mission effect. Ship to depot.	a) Visual at next preflight.	-
	b) Dented, nicked or scratched less than .012" deep.	b) Bullets, tree strikes, F.O., or handling damage.	b) No mission effect. Repair on aircraft.	b) Periodic inspection.	-
Core, Honeycomb	a) Punctured, bent, cut, dented, or portions pulled loose from beam, spline, or skin.	a) Battle or tree strikes, F.O., tool or handling damage.	a) Decrease in stiffness of core and/or change in aero contour may cause loss of control. Less movement will degrade performance, but allow forced abort.	a) Vibration, visual inspection.	Extensive damage, even missile hits, will not cause normal loads to structurally fail rest of blade. Increased vibration, etc., may, however, before a landing can be made.
	b) Less extensive damage than above.	b) Battle or tree strikes, F.O., tool or handling damage.	b) Slight degradation of performance, but mission will be completed.	b) Visual at preflight inspection.	-

TABLE XX - Continued

Item Name	Assumed Failure	Possible Cause	Effect	Method of Failure Detection	Compensating Provisions
Skin, Al	a) Punctured, cut, torn, scratched, or dented so area after cleanup would be larger than 2" in diameter or 1" by 4".	a) Bullet or tree strikes, handling damage, tool damage, F.O.D.	a) Slight degradation in performance. Scrap blade. Also scrap if water has entered core or oblong patch would not be within ± 15° of span axis.	a) Vibration visual.	-
	b) Same as above but within repairable limits.	b) Bullet or tree strikes, handling damage, tool damage, F.O.D.	b) Slight degradation in performance. Complete mission. Repair at depot.	b) Vibration, visual.	-
Spline, 2024	a) Sheared or punctured.	a) Battle damage, handling damage, collision.	a) Spline rupture in first one-third of span would propagate across chord and cause beam to split. Crack near tip would allow return to base. Cracks through intermediate span locations would cause forced landings.	-	-
	b) Bent, cut, nicked, dented, or scratched.	b) Handling damage, tree strikes, F.O.D.	b) Slight increase in turbulence but mission will be completed. Return to depot.	b) Vibration.	-

TABLE XX - Continued

Item Name	Assumed Failure	Possible Cause	Effect	Method of Failure Detection	Compensating Provisions
External Doublers, Al	a) Ruptured.	a) Collision, hard landing.	a) Other blade parts may be overstressed to fail point. Reduced blade stiffness may cause vibration and out-of-track to point of loss of control.	a) Vibration.	-
	b) Punctured, gashed, nicked, cracked and propagates.	b) Battle hits, F.O.D., handling damage.	b) Other blade parts may be overstressed to fail point. Reduced blade stiffness may cause vibration and out-of-track to point of loss of control.	b) Vibration.	-
	c) Same as above but not extensive enough to propagate.	c) Battle hits, F.O.D , handling damage.	c) No mission effect if detected before fatigue failure.	c) Visual.	-
Grip Pad	a) Shears.	a) F.O. or hard landing.	a) Will overload beam so it may fail and allow blade to separate.	None.	-
	b) Gashed, punctured.	b) Enemy projectile.	b) May split and allow blade to separate.	None.	-
	c) Chipped, cut, dented, nicked, or scratched.	c) F.O.D., bullets, tool damage.	c) Will reduce fatigue life. No mission effect if blade removed for repair.	c) Visual during daily inspection.	Bottom pad can withstand considerable abuse.

TABLE XX - Continued

Item Name	Assumed Failure	Possible Cause	Effect	Method of Failure Detection	Compensating Provisions
Drag Plate, Al	a) Shears.	a) Collision.	a) Note 2.	a) Vibration.	-
	b) Punctured or gouged and propagates.	b) Enemy projectile.	b) Note 2.	b) Vibration.	-
	c) Chipped, cut, dented, nicked, or scratched.	c) Bullets, F.O.D., tool damage.	c) Reduction in fatigue life. No mission effect if drag plate is replaced.	c) Visual during daily inspection.	-
Overall Blade	a) Reduction in fatigue life. Possible damage.	a) RPM above repairable limit.	a) In most cases mission can be complete or precautionary abort made without crash. Scrap all blades.	a) Cockpit gage or warning light must be observed while RPM is still over spec.	-
	b) Burnt, overheated to cause structural damage.	b) Fire.	b) Beam will be overloaded and fail structurally. Likely to cause crash if occurs in flight.	-	-
	c) Blistered or scorched but no structural damage.	c) Fire.	c) No mission effect. Repairable at depot.	c) Visual at daily inspection.	-
	d) Out-of-track, vibration, or noise.	d) Bad patch, defective maintenance.	d) Forced abort. Repairable.	-	-

TABLE XX - Continued

Item Name	Assumed Failure	Possible Cause	Effect	Method of Failure Detection	Compensating Provisions

NOTES:

1. Primary effects of separate part of span are rotor unbalance and loss of lift. Secondary effects are loss of lift and excessive coning, flapping, or out-of-track. Probability of crash decreased from 1.0 at root to slightly less near tip.

2. Connection to drag strut will be lost. Shutdown destruction of blades probable.

3. Crack in first one-third of span would propagate across chord and cause blade separation. Crack near tip would allow return to base.

4. Crack can be visually detected after flight.

5. Blade is repairable at depot if beam is not overstressed.

6. T.E. stiffness will decrease. Vibration and out-of-track may cause landing.

TABLE XXI. CONFIGURATION I

Item Name	Cause of Failure	Maint. Actions 10^6 BL Hr	Repair Level
Box Beam & Doubler	a(1) Overstressed by hard landing.	.60	Strike
	2) Gash or crack longer than 3 inches and all the way through. Propagates.	.26	Strike
	3) Split by sudden stoppage.	.60	Strike
	4) Less than 3 inches long or not all the way through doubler.	2.32	Depot
	5) Any length but less than .031 inches deep.	2.00	Field
	b(1) 30 or 50 caliber bullet hole through	76.00	Scrap
	2) Warhead fragments.	.17	Strike
Abrasive Strip	a) Torn, cracked, scratched through, or punctured.	8.00	Field
	b) Dented, nicked, scratched, or chipped less than all the way through.	40.00	Org.
Core, Honeycomb	a) 1. Punctured, bend, cut, dented, etc.	.05	Strike
	2. Punctured, bend, cut, dented, etc.	24.00	Depot
	b) Punctured, etc., but within limits for field shop repair.	72.00	Field
Skin, Fiberglass	a) Punctured, cut, torn, scratched.	192.00	Org.
	b) Punctured, cut, torn, scratched.	342.00	Field
	c) Punctured, cut, torn, scratched.	122.00	Depot
Spline	a) 1. Shears through 1st 14 inches.	.53	Strike
	2. Shears farther outward.	9.60	Depot
	b) 1. Punctures in 1st 14 inches.	.05	Strike
	2. Punctures farther outward.	9.50	Depot
	c) 1. Bends, chips, cuts, or dents beyond capabilities of field shop.	32.40	Depot
	2. Chips, nicks, or dents within ability to repair in field shop.	11.50	Field
Doublers for Grip Pad & Drag Plate	a) Ruptures from sudden stoppage or overstress from hard landing.	.52	Strike
	b) Punctured and propagates.	.08	Strike
	c) Cut, torn, etc., & propagates.	1.06	Strike
	d) Same as above but less extensive.	3.50	Depot

TABLE XXI - Continued

Item Name	Cause of Failure	Maint. Actions 10^6 BL Hr	Repair Level
Grips Pads	a) Shears from sudden stop.	.80	Strike
	b) Punctured or broken.	.05	Strike
	c) Chipped, cut, dented, nicked.	.86	Field
Drag Plate	a) Shears from sudden stop.	1.00	Scrap
	b) Cut, broken, gouged by projectile.	1.00	Scrap
	c) Chipped, cut, dented, etc.	5.00	Field
Overall Blade	a) RPM, over repairable limit.	33.07	Scrap
	b) Burnt, overheated past yield point.	.05	Strike
	c) Blistered or scorched but not overheated past yield point.	.40	Depot
	d) Bad patch - out-of-track, etc.	7.76	Depot
Total incidences per 10^6 BL Hr for Ext. Causes - 1,000		MAINT ACT./10^6 BL HR	

TABLE XXII. CONFIGURATION II

Part Name	Mode of Failure	Maint. Actions 10^6 BL Hr	Repair Level
Spar	(a) Fractured by hard landing.	.20	Strike
	(b) Gashed, or cracked longer than 3 inches and all the way through, propagates.	.58	Strike
	(c) Fractured by sudden stop due to tree hit etc.	.60	Strike
	(d) Gashed or cracked less than 3 inches long or not all the way through.	24.50	Scrap
	(e) Punctured.	57.00	Scrap
Abrasive Strip	(a) Torn, cracked, scratched-through, or punctured.	61.50	Field
	(b) Dented, nicked, scratched, or chipped.	23.00	Org
Core, Honeycomb	(a) Punctured, bent, cut, crushed, or loosened.	.20	Strike
	(b) Punctured, bent, cut, crushed, or loosened.	77.00	Depot
	(c) Punctured, etc., but within limits for field shop repair.	298.44	Field
Skin	(a) Punctured, cut, torn, scratched.	71.00	Org
	(b) Punctured, cut, torn, scratched.	266.00	Field
	(c) Punctured, cut, torn, scratched.	20.00	Depot
Spline, Inboard	(a) Sheared, cracked, punctured, or cut-through.	1.40	Depot
	(b) Bent, gashed, or cracked.	.10	Depot
	(c) Bond to outboard spline fails.	1.00	Depot
Spline, Outboard	(a) Cracked, sheared, punctured.	7.00	Depot
	(b) Dented, gashed, or cracked.	14.50	Depot

TABLE XXII - Continued

Part Name	Mode of Failure	Maint. Actions 10^6 BL Hr	Repair Level
Inboard Doublers for Grip Pad	(a) Ruptured from sudden stop or hard landing.	.10	Strike
	(b) Punctured, cut, or torn and propagates.	.10	Strike
	(c) Dented, nicked, or scratched.	1.70	Field
Transition, T.E. Doublers, Ti-6Al-4	(a) Ruptured by sudden stop, hard landing.	.50	Field
	(b) Punctured, cut, torn, or dented.	5.00	Field
	(c) Dented, nicked, or scratched.	.60	Org
Closing Channel	(a) Cracked, cut-through, sheared, or punctured.	2.40	Depot
	(b) 1. Dented, gashed, or cracked but not ruptured.	.70	Depot
	2. Dented, nicked, scratched.	.30	Field
Grip & Drag Pad	(a) Sheared, or cracked and propagates.	.12	Strike
	(b) Broken, gouged, dented, and splits.	.06	Strike
	(c) Chipped, dented, nicked, or scratched.	1.40	Org
Doubler, Spar to Core	(a) Punctured or torn.	11.17	Field
	(b) Gashed or scratched.	5.00	Org
Retention Bushings	(a) Cracks from overstress during maintenance.	.02	Strike
Overall Blade	(a) RPM above repairable limit.	33.07	Scrap
	(b) Overheated past yield point.	.04	Strike
	(c) Blistered or scorched but not overheated past yield point.	3.70	Depot
	(d) Bad patch - Out-of-track, etc.	10.00	Depot
* From mean time between externally caused damage incident of 1,000 hr of Annex B of Army Statement of Work.	* Total =	1,000.00	Maint. Actions per 10^6 BL Hr

TABLE XXIII. CONFIGURATION III

Part Name	Mode of Failure	Maint. Actions 10^6 BL Hr	Repair Level
Spar	(a) Fractured by hard landing.	.30	Strike
	(b) Gash or crack longer than 3 inches and all the way through propagates.	1.25	Strike
	(c) Fractured by sudden stop due to tree hit etc.	.45	Strike
	(d) Gashed or cracked less than 3 inches long or not all the way through.	25.50	Scrap
	(e) Punctured.	70.00	Scrap
	(f) Scratched, dented, or cut less than 1/8 inch deep on outward 25% of span or less than 1/16 inch deep on inward 75%.	72.00	Crg
Abrasive Strip	(a) Torn, cracked, scratched-through, or punctured.	30.50	Field
	(b) Dented, nicked, scratched, or chipped less than all the way through.	17.50	Org
Core, Honeycomb	(a) Punctured, bent, cut, crushed, etc.	.20	Strike
	(b) Punctured, bent, cut, crushed, etc.	20.00	Depot
	(c) Punctured, etc., but within limits for field shop repair.	235.00	Field
Skin	(a) Punctured, cut, torn, [illegible]	50.00	Org
	(b) Punctured, cut, torn, [illegible]	271.00	Field
	(c) Punctured, cut, torn [illegible]atched.	27.00	Depot
Spline	(a) 1. Shears or punctures through first 14 inches.	.25	Strike
	2. Shears or punctures farther outward.	21.00	Depot
	(b) 1. Bent, gashed, or cracked beyond capabilities of field shop.	10.00	Depot
	2. Bent, gashed, cracked, or dented.	10.00	Field

TABLE XXIII - Continued

Part Name	Mode of Failure	Maint. Actions 10^6 BL Hr	Repair Level
External Doublers for Drag Plate	(a) Ruptured from sudden stop or overstress from hard landing.	.53	Scrap
	(b) Punctured and propagates.	2.00	Scrap
	(c) Cut or gouged and propagates.	5.70	Scrap
	(d) Dented, nicked, or scratched.	.80	Field
Grip Pad	(a) Shears from sudden stop.	.15	Strike
	(b) Broken, or gouged and propagates.	.10	Strike
	(c) Chipped, cut, dented, nicked.	10.00	Field
Drag Plate	(a) Shears from sudden stop.	.50	Scrap
	(b) Broken or gouged and propagates.	1.00	Scrap
	(c) Chipped, cut, dented, or scratched.	3.40	Field
Doubler, Spar to Core	(a) Punctured or torn.	37.75	Field
	(b) Gashed or scratched.	29.00	Org
Bolt or Nut for Fitting	(a) Shears from overtorque or sudden stop.	2.00	Scrap
Retention Bushings	(a) Cracks from overstress during maintenance.	.05	Strike
Fitting	(a) Cracks due to sudden stop.	1.50	Scrap
	(b) Punctured by 30 Cal. bullet.	3.00	Depot
	(c) Punctured by 50 Cal. bullet.	1.00	Scrap
Overall Blade	(a) RPM above repairable limit.	33.07	Scrap
	(b) Overheated past yield point.	.10	Strike
	(c) Blistered or scorched but not overheated past yield point.	.40	Depot
	(d) Bad patch - out-of-track, etc.	6.00	Depot
	* Total =	1,000.00	Maint. Actions per 10^6 BL Hr

* From mean time between externally caused damage incident of 1,000 hr of Annex B of Army Statement of Work.

TABLE XXIV. CONFIGURATION IV

Item Name	Assumed Failure & Cause	Maint. Actions 10^6 BL Hr	Repair Level
Spar	(a) Sheared by collision with tree, pole, aircraft, or bird.	.07	Strike
	(b) Cut or dented by tree strike, aircraft collision or glancing bullet.	9.10	Scrap
	(c) Cracks spanwise due to overspeed or overload.	.10	Strike
	(d) Punctured or torn by bullets, trees or other collisions. (Not over 50 cal. size damage.)	42.20	Depot
Abrasive Strip	(a) Torn, cracked, scratched-through, or punctured.	41.67	Field
	(b) Dented, nicked, scratched, or chipped less than all the way through.	43.17	Org
Core	(a) Punctured, cut, dented, or loose.	.01	Strike
	(b) Punctured, cut, dented, or loose.	33.30	Depot
	(c) Punctured, cut, dented, or loose.	165.77	Field
Skin	(a) Punctured, cut, torn, scratched by bullets.	125.77	Org
	(b) Punctured, cut, torn, scratched by bullets.	243.72	Field
	(c) Punctured, cut, torn, scratched by bullets.	48.90	Depot
T.E. Spline	(a) Punctured or gashed by bullets, trees.	12.68	Depot
	(b) Dented, nicked, cut by F.O., tree.	6.34	Depot
	(c) Same but less than .030 inch deep.	6.47	Field
T.E. Wrap	(a) Punctured or torn by bullets, trees.	43.89	Field
	(b) Cut, warped, delaminated, dented.	26.61	Field
	(c) Cut, warped, delaminated, dented.	9.17	Org

TABLE XXIV - Continued

Item Name		Assumed Failure & Cause	Maint. Actions 10^6 BL Hr	Repair Level
Doublers for Grip Pad	(a)	Ruptures from sudden stoppage or hard land.	.20	Strike
	(b)	Punctured and propagates, overloads spar.	.10	Strike
	(c)	Cut, torn, dented, etc. and propagates.	.10	Strike
	(d)	Same as above but less extensive.	12.39	Field
Grip Pads	(a)	Shears from sudden stoppages or hard land.	.05	Strike
	(b)	Punctured or broken by bullets.	.01	Strike
	(c)	Chipped, cut, dented, nicked, scratched.	6.57	Field
External Doublers for Drag Plate	(a)	Ruptures from sudden stoppage or hard land.	.49	Scrap
	(b)	Punctured and propagates so T.E. separates.	1.25	Scrap
	(c)	Cut, torn, dented, etc. and propagates.	1.70	Scrap
	(d)	Same as above but less extensive.	5.32	Field
Drag Plate	(a)	Shears from sudden stoppage or hard land.	.49	Scrap
	(b)	Cut, broken, gouged by enemy projectile.	.25	Scrap
	(c)	Chipped, cut, dented, scratched.	5.92	Field
Retention Bushings	(a)	Cracks due to overstress in maintenance.	.01	Strike
Fitting	(a)	Cracks due to sudden stop.	.76	Scrap
	(b)	Punctured by 30 cal. bullet.	.50	Depot
	(c)	Punctured by 50 cal. bullet, etc.	.50	Scrap
Doubler, Spar to Core	(a)	Punctured or torn by bullets or trees.	15.17	Field
	(b)	Dented by tree strikes, F.O., handling.	8.07	Org
Spar, Doubler	(a)	Punctured, cut-through, or torn.	23.40	Depot
	(b)	Dented or scratched.	17.07	Field

TABLE XXIV - Continued

Item Name	Assumed Failure & Cause	Maint. Actions 10^6 BL Hr	Repair Level
Overall Blade	(a) RPM high or disk overloaded.	33.07	Scrap
	(b) Burnt, overheated past yield point.	.01	Strike
	(c) Blistered or scorched but not overheated past yield point.	.40	Depot
	(d) Bad Patch - out-of-track, etc.	7.27	Depot

Total incidences per 10^6 BL Hr for ext. causes = 1,000 MAINT.ACT./10^6 BL Hr

TABLE XXV. CURRENT UH-1 BLADE

Item Name	Cause of Failure	Maint. Actions per 10^6 BL Hr	Repair Level
Box Beam & Doublers	(a) Overstressed by hard landing, splits, etc.	1.70	Strike
	(b) 1. Ruptured, gashed, or cracked longer than 3 inches and all the way through beam inward of Sta. 105 (or 2 inches outward) and propagates.	1.20	Strike
	2. Beam penetration more than .008 inch in depth but enough less extensive than above so does not propagate to crash.	9.50	Scrap
	3. Same as above but beam penetration less than .008 inch deep.	3.50	Depot
	(c) Punctured by bullets.	32.00	Scrap
	(d) Doublers gashed, cracked, dented, or scratched deeper than .012 inch.	25.60	Depot
	(e) Doubler dented or scratched less than .012 inch. Polish out.	16.60	Depot
Abrasive Strip	(a) Torn, cracked, punctured, scratched or dented deeper than .012 inch.	49.00	Depot
	(b) Dented, nicked, or scratched less than .012 inch deep.	62.90	Org
Core, Honeycomb	(a) Punctured, bent, cut, dented, loosened, etc.	.05	Strike
	(b) 1. Same as above but repairable (voids not over allowable, no water in core, and skin patch within structural repair manual limits.)	50.00	Field
	2. Damaged less than (a) so safe landing is made but past repairable limits of manual.	136.00	Scrap

TABLE XXV - Continued

Item Name	Cause of Failure	Maint. Actions per 10^6 BL Hr	Repair Level
Skin	(a) Punctured, cut, torn, scratched, or dented so area after cleanup would be larger than 2 inches in diameter of 1 inch by 4 inches.	280.00	Scrap
	(b) Less extensive than above and oriented ± 15° to spanwise (if oblong) and not on same chord as previous repair.	198.00	Field
Spline	(a) 1. Sheared or punctured through first 28 inches of span.	.80	Strike
	2. Sheared or punctured outward of 28 inches; cracks, nicks, and scratches extending forward more than .120 inch; and dents deeper than .040 inch, or bent.	26.00	Scrap
	(b) Cut, cracked, nicked, scratched, or dented less extensive than above.	22.00	Field
External Doublers	(a) Ruptured by foreign object or hard landing.	.20	Strike
	(b) Punctured, gashed, nicked, cracked, and propagates.	.10	Strike
	(c) 1. Damaged more than .012 inch deep but does not propagate.	11.20	Depot
	2. Nicked, dented, or scratched less than .012 inch deep.	18.00	Org
Grip Pads	(a) Sheared by F.O. or hard landing.	.10	Strike
	(b) Punctured or gashed and propagates.	.10	Strike
	(c) 1. Punctured; chipped, gashed, or dented deeper than .012 inch but does not propagate.	4.00	Field
	2. Scratched, dented, or nicked less than .012 inch deep.	4.00	Org

TABLE XXV - Continued

Item Name	Cause of Failure	Maint. Actions per 10^6 BL Hr	Repair Level
Drag Plate	(a) Sheared by collision.	.07	Scrap
	(b) Punctured, gashed, nicked, cracked, and propagates.	.60	Scrap
	(c) 1. Damaged more than .012 inch deep but does not propagate.	1.00	Field
	2. Nicked, dented, or scratched less than .012 inch deep.	2.00	Org
Overall Blade	(a) RPM, over repairable limit.	33.07	Scrap
	(b) Burnt, overheated past yield point.	.06	Strike
	(c) Blistered or scorched but not overheated past yield point.	.40	Scrap
	(d) Bad patch - out-of-track, etc.	10.45	Scrap
	Total incidences per 10^6 BL Hr for ext. causes = 1,000 Maint. Act./10^6 BL Hr		

TABLE XXVI. RANDOM DAMAGE INCIDENT DESCRIPTIONS

Damage		Location		Dimensional Description					
						Depth			
No.	Type	Radius	Chord	Span	Chord	I	II	III	IV
1	Dent	146.4	16.5	.544	4.407	.234	.234	.234	.234
2	Dent	236.4	17.1	1.432	8.633	.403	.403	.403	.403
3	Puncture	129.9	3.6	.684	.899	1/2 Thru	1/2 Thru	1/2 Thru	1/2 Thru
4	Dent	7.2	3.3	2.969	6.036	-	-	-	-
5	Puncture	267.6	24.9	.113	.843	-	-	-	-
6	Tear	121.8	27.3	.761	3.108				
7	Battle Damage	117.6	22.2	.730	1.164	Thru	Thru	Thru	Thru
8	Dent	26.7	12.9	3.340	.762	.532	.532	.532	.532
9	Dent	168.9	0.0	1.053	7.703	.003	.003	.003	.013
10	Dent	5.1	20.4	3.655	10.765	-	-	-	-
11	Dent	270.0	21.6	3.044	2.134	.412	.412	.412	.412
12	Battle Damage	15.9	10.2	.616	1.316	-	-	-	-
13	Foreign Object	151.8	6.0	1.164	1.832	.003	.003	.003	.013
14	Foreign Object	267.9	0.3	1.089	2.562	-	-	-	-
15	Dent	104.4	23.1	2.393	3.986	.612	-	.612	.612
16	Battle Damage	203.7	21.3	.413	.626	Thru	Thru	Thru	Thru
17	Dent	81.0	27.9	1.501	2.628	-	-	-	-
18	Battle Damage	242.1	3.6	1.077	.621	Thru	Thru	Thru	Thru
19	Dent	45.3	9.9	2.277	3.540	.200	.002/.200	.002/.200	.005/.200

TABLE XXVI - Continued

Damage		Location		Dimensional Description					
						Depth			
No.	Type	Radius	Chord	Span	Chord	I	II	III	IV
20	Battle Damage	148.2	12.9	1.149	1.215	Thru	Thru	Thru	Thru
21	Puncture	99.6	13.8	.341	.601	1/2 Thru	1/2 Thru	1/2 Thru	1/2 Thru
22	Dent	60.9	8.7	3.135	2.130	1.163	.007	.007/1.163	.028/.163
23	Dent	178.5	29.7	1.890	6.598	-	-	-	-
24	Foreign Object	36.0	1.8	1.401	1.998	.004	.004	.004	.016
25	Dent	197.4	22.5	1.779	10.023	.984	.984	.984	.984
26	Battle Damage	127.5	26.1	.718	.186	-	-	-	-
27	Puncture	111.9	16.5	.583	.862	1/2 Thru	1/2 Thru	1/2 Thru	1/2 Thru
28	Dent	45.3	14.4	.686	11.086	.022	.022	.022	.022
29	Puncture	137.1	4.2	.376	.764	1/2 Thru	1/2 Thru	1/2 Thru	1/2 Thru
30	Battle Damage	3.0	0.0	.908	1.815	-	-	-	-
31	Foreign Object	242.4	21.3	1.314	2.325	.146	.146	.146	.146
32	Dent	182.7	10.5	.793	8.681	.003/.418	.003/.418	.003/.418	.010/.418
33	Puncture	38.1	16.2	.562	.488	1/2 Thru	1/2 Thru	1/2 Thru	1/2 Thru
34	Dent	14.1	8.4	.947	12.092	-	-	-	-
35	Dent	228.9	10.5	1.614	8.616	.005/.895	.005/.895	.005/.895	.022/.895
36	Puncture	286.5	13.5	.663	.774	1/2 Thru	1/2 Thru	1/2 Thru	1/2 Thru
37	Foreign Object	114.3	9.3	.958	1.877	.334	.334	.002/.334	.334
38	Tear	176.4	9.6	.929	10.050	.006/.971	.006/.971	.006/.971	.023/.971
39	Dent	71.7	14.1	1.332	.625	.222	.222	.222	.222
40	Dent	197.7	28.2	2.722	12.223	.671	.671	.671	.671
41	Battle Damage	168.6	23.4	1.051	1.789	Thru	Thru	Thru	Thru

TABLE XXVI - Continued

Damage		Location		Dimensional Description					
						Depth			
No.	Type	Radius	Chord	Span	Chord	I	II	III	IV
42	Puncture	40.8	5.7	.589	.877	1/2 Thru	1/2 Thru	1/2 Thru	1/2 Thru
43	Dent	197.4	22.8	1.503	2.055	.367	.367	.367	.367
44	Puncture	102.3	12.6	.762	.585	1/2 Thru	1/2 Thru	1/2 Thru	1/2 Thru
45	Dent	44.7	9.3	.824	4.610	.004	.004	.004/.712	.017/.712
46	Dent	54.6	18.9	1.720	10.788	.146	.146	.146	.146
47	Battle Damage	251.4	23.1	.162	2.088	Thru	Thru	Thru	Thru
48	Battle Damage	141.3	28.2	1.642	.922	-	-	-	-
49	Dent	134.7	3.6	2.849	2.126	.004	.004	.004	.014
50	Dent	244.5	8.4	.609	4.133	.005/.807	.807	.005/.807	.019/.807
51	Dent	195.9	21.0	.322	.773	.489	.489	.489	.489
52	Foreign Object	187.8	24.6	2.534	2.361	-	-	-	-
53	Dent	142.5	16.2	1.519	1.764	.782	.782	.782	.782
54	Dent	115.5	21.0	1.193	10.349	.180	.180	.180	.180
55	Tear	114.0	25.5	1.240	1.669	-	-	-	-
56	Tear	95.4	12.9	.479	5.071	.558	.558	.558	.558
57	Puncture	3.0	3.9	.915	.911				
58	Battle Damage	72.0	8.4	.148	1.021	Thru	Thru	Thru	Thru
59	Battle Damage	219.9	20.1	1.520	1.142	Thru	Thru	Thru	Thru
60	Dent	113.4	21.9	1.498	14.081	.328	.328	.328	.328
61	Dent	259.2	5.4	3.712	2.969	.004	.004/.700	.004	.017
62	Tear	153.9	0.9	1.825	5.888	.005	.005	.005	.021
63	Foreign Object	176.4	12.9	.717	2.047	.329	.329	.329	.329

TABLE XXVI - Continued

Damage		Location		Dimensional Description					
						Depth			
No.	Type	Radius	Chord	Span	Chord	I	II	III	IV
64	Puncture	272.7	23.1	.380	.842	1/2 Thru	1/2 Thru	1/2 Thru	1/2 Thru
65	Puncture	95.1	0.9	.152	.936	-	-	-	-
66	Battle Damage	294.3	6.9	1.063	1.310	-	-	-	-
67	Puncture	117.6	15.9	.396	.709	1/2 Thru	1/2 Thru	1/2 Thru	1/2 Thru
68	Tear	238.2	2.1	1.637	5.711	.003	.003	.003	.010
69	Puncture	222.3	27.9	.229	.750	-	-	-	-
70	Puncture	294.0	0.0	.230	.385	-	-	-	-
71	Battle Damage	78.3	13.2	1.349	.863	Thru	Thru	Thru	Thru
72	Battle Damage	231.6	23.4	1.094	.423	Thru	Thru	Thru	Thru
73	Foreign Object	127.5	14.7	.980	1.150	.746	.746	.746	.746
74	Dent	116.7	21.3	2.659	6.899	.751	.751	.751	.751
75	Foreign Object	228.9	6.9	1.580	2.141	.003/.531	.003/.531	.003	.013/.531
76	Dent	22.5	26.4	3.599	1.109	-	-	-	-
77	Dent	171.6	24.6	1.210	2.465	-	-	-	-
78	Tear	201.3	6.3	.964	.571	.009	.009/1.443	.009	.035
79	Battle Damage	118.	23.7	1.830	.073	-	-	-	-
80	Puncture	188.1	1.2	.463	.702	-	-	-	-
81	Battle Damage	148.5	8.7	.945	.793	Thru	Thru	Thru	Thru
82	Foreign Object	293.4	3.0	1.345	2.847	-	-	-	-
83	Tear	221.7	17.7	1.093	8.853	1.446	1.446	1.446	1.446

TABLE XXVI - Continued

Damage		Location		Dimensional Description					
						Depth			
No.	Type	Radius	Chord	Span	Chord	I	II	III	IV
84	Battle Damage	241.2	17.4	.700	1.999	Thru	Thru	Thru	Thru
85	Tear	297.9	26.4	.766	4.219	-	-	-	-
86	Dent	96.0	20.1	2.172	11.351	.091	.091	.091	.091
87	Foreign Object	93.6	3.9	1.225	1.787	.003	.003	.003	.014
88	Dent	227.7	3.3	2.270	5.283	.004	.004	.004	.017
89	Dent	275.4	5.1	2.150	11.375	.003/.455	.003/.455	.003/.455	.011/.455
90	Foreign Object	238.5	26.1	1.109	1.935	-	-	-	-
91	Battle Damage	30.3	0.3	.423	1.301	-	-	-	-
92	Battle Damage	93.6	6.0	1.463	.620	Thru	Thru	Thru	Thru
93	Battle Damage	279.0	28.8	1.836	1.618	-	-	-	-
94	Puncture	265.2	2.1	.928	.574	1/2 Thru	1/2 Thru	1/2 Thru	1/2 Thru
95	Battle Damage	234.9	17.7	1.542	2.299	Thru	Thru	Thru	Thru
96	Dent	118.5	24.3	1.755	2.219	.181	.181	.181	.181
97	Foreign Object	131.7	15.3	.701	2.192	.492	.492	.492	.492
98	Dent	240.0	22.8	4.368	9.100	.646	.646	.646	.646
99	Battle Damage	192.0	8.1	.954	.816	Thru	Thru	Thru	Thru
100	Tear	19.5	19.2	.901	10.020	-	-	-	-

TABLE XXVII. REPAIRS, CONFIGURATION I

Damage Incident No.	Blade Details Affected	Repair Scheme		A/C Down Time	Org Repair Time	Int Repair Time	Kits
		No.	Description				
8	Skin Grip Doublers Root Fitting Skin Doublers	-	Scrap	3.73	-	-	-
33	Skin Core Skin Doublers	-	Depot Repair	3.73	-	-	-
24	Abrasion Sheath Grip Doublers	1	Blend	2.3	.4	-	1
45	Grip Doublers Skin Doublers	-	Scrap	3.73	-	-	-
42	Spar Doubler Spar Grip Doublers Skin Doublers	-	Scrap	3.73	-	-	-
28	Skin Core Grip Doublers Skin Doublers	-	Scrap	3.73	-	-	-
19	Skin Core Grip Doublers Skin Doublers	-	Scrap	3.73	-	-	-

TABLE XXVII - Continued

Damage Incident No.	Blade Details Affected	Repair Scheme		A/C Down Time	Org Repair Time	Int Repair Time	Kits
		No.	Description				
46	Skin Core Spline Link Doublers Skin Doublers	-	Scrap	3.73	-	-	-
22	Skin Core Grip Doublers Skin Doublers	-	Scrap	3.73	-	-	-
39	Skin Core Skin Doublers	4 10	Patch small skin area Fill small core area	3.73	-	3.0	4
58	Skin Core Grip Doublers Skin Doublers	-	Depot repair	3.73	-	-	-
71	Skin Core	7	Install patch/plug	3.73	-	4.5	5
15	Skin Spline	-	Scrap	3.73	-	-	-
87	Abrasion Sheath	1	Blend	.4	.4	-	-

TABLE XXVII - Continued

Damage Incident No.	Blade Details Affected	Repair Scheme No.	Repair Scheme Description	A/C Down Time	Org Repair Time	Int Repair Time	Kits
92	Abrasion Sheath Spar Doubler Spar	-	Scrap	3.73	-	-	-
56	Skin Core	5 11	Patch large skin area Fill large core area	3.73	-	4.4	4
86	Skin Core Spline	1 5 8 11	Blend Patch large skin area Install trailing edge doubler Fill large core area	3.73	-	5.3	4 6
21	Skin Core	7	Install patch/plug	3.73	-	4.5	5
44	Skin Core	7	Install patch/plug	3.73	-	4.5	5
27	Skin Core	7	Install patch/plug	3.73	-	4.5	5
60	Skin Core Spline	-	Scrap	3.73	-	-	-
37	Skin Core Doubler Core	1 4 10	Blend Patch small skin area Fill small core area	3.73	-	2.1	4

TABLE XXVII - Continued

Damage Incident No.	Blade Details Affected	Repair Scheme		A/C Down Time	Org Repair Time	Int Repair Time	Kits
		No.	Description				
67	Skin Core	7	Install patch/plug	3.73	-	4.5	5
96	Spline	1	Blend	2.3	.4	-	1
54	Skin Core Spline	-	Depot repair	3.73	-	-	-
74	Skin Core Spline	-	Scrap	3.73	-	-	-
7	Skin Spline	-	Depot repair	3.73	-	-	-
73	Skin Core	7	Install patch/plug	3.73	-	4.5	5
3	Abrasion Sheath Spar Doubler Spar	-	Scrap	3.73	-	-	-
97	Skin Core	4 10	Patch small skin area	6.4	1.6	-	4
49	Abrasion sheath	1	Blend	.4	.4	-	-

TABLE XXVII - Continued

Damage Incident No.	Blade Details Affected	Repair Scheme		A/C Down Time	Org Repair Time	Int Repair Time	Kits
		No.	Description				
29	Abrasion Sheath Spar Doubler Spar	-	Scrap	3.73	-	-	-
53	Skin Core	7	Install patch/plug	3.73	-	4.5	5
1	Skin Core Spline	1 5 8 11	Blend Patch large skin area Install T.E. doubler Fill large core area	3.73	-	5.3	4 6
81	Skin Core Doubler Core	1 7	Blend Install patch/plug	3.73	-	4.9	5
20	Skin Core	7	Install patch/plug	3.73	-	4.5	5
13	Abrasion Sheath	1	Blend	.4	.4	-	-
62	Abrasion Sheath	1	Blend	.4	.4	-	-
41	Skin Spline	1 8	Blend Install T.E. Doubler	3.73	-	1.8	6
9	Abrasion Sheath	1	Blend	.4	.4	-	-

TABLE XXVII - Continued

Damage Incident No.	Blade Details Affected	Repair Scheme No.	Repair Scheme Description	A/C Down Time	Org Repair Time	Int Repair Time	Kits
38	Abrasion Sheath Spar Doubler Skin Core Doubler Core	1 7 9	Blend Install patch/plug Splice glass doubler	3.73	-	6.4	3 5
63	Skin Core	4 10	Patch small skin area Fill small core area	6.4	1.6	-	4
32	Abrasion Sheath Spar Doubler Skin Core Doubler Core	1 5 9 11	Blend Patch large skin area Splice glass doubler Fill large core area	3.73	-	6.3	3 4
25	Skin Core Spline	-	Depot repair	3.73	-	-	-
51	Skin Core	4 10	Patch small skin area Fill small core area	6.4	1.6	-	4
99	Skin Core Doubler Core	1 7	Blend Install patch/plug	3.73	-	4.9	5
78	Abrasion Sheath	1	Blend	.4	.4	-	-

TABLE XXVII - Continued

Damage Incident No.	Blade Details Affected	Repair Scheme		A/C Down Time	Org Repair Time	Int Repair Time	Kits
		No.	Description				
43	Skin Core Spline	-	Depot repair	3.73	-	-	-
40	Skin Core Spline	1 8 10	Blend Install T.E. doubler Fill small core area	3.73	-	2.0	6
16	Skin Core	7	Install patch/plug	3.73	-	4.5	5
59	Skin Core	7	Install patch/plug	3.73	-	4.5	5
83	Skin Core	7	Install patch/plug	3.73	-	4.5	5
88	Abrasion Sheath	1	Blend	.4	.4	-	-
72	Spline	1	Blend	2.3	.4	-	1
95	Skin Core	7	Install patch/plug	3.73	-	4.5	5
35	Abrasion Sheath Spar Doubler Skin Core Doubler Core	1 7 9	Blend Install patch/plug Splice glass doubler	3.73	-	6.4	3 5

TABLE XXVII - Continued

Damage Incident No.	Blade Details Affected	Repair Scheme		A/C Down Time	Org Repair Time	Int Repair Time	Kits
		No.	Description				
75	Abrasion Sheath Spar Doubler Skin Core Doubler Core	1 4 9 10	Blend Patch small skin area Splice glass doubler Fill small core area	3.73	-	3.7	3 4
2	Skin Core	5 11	Patch large skin area Fill large core area	3.73	-	4.4	4
68	Abrasion Sheath	1	Blend	.4	.4	-	-
84	Skin Core	7	Install patch/plug	3.73	-	4.5	5
18	Abrasion Sheath Spar Doubler Spar	-	Scrap	3.73	-	-	-
50	Abrasion Sheath Spar Doubler Skin Core Doubler Core	1 7 9	Blend Install patch/plug Splice glass doubler	3.73	-	6.4	3 5
98	Skin Core Spline	1 7 8	Blend Install patch/plug Install T.E. doubler	3.73	-	5.4	5 6

TABLE XXVII - Continued

Damage Incident No.	Blade Details Affected	Repair Scheme		A/C Down Time	Org Repair Time	Int Repair Time	Kits
		No.	Description				
31	Skin	1	Blend	3.73	-	2.8	4
	Core	4	Patch small skin area				
	Spline	8	Install T.E. doubler				
		10	Fill small core area				
47	Skin	1	Blend	3.73	-	5.4	5
	Core	7	Install patch/plug				6
	Spline	8	Install T.E. doubler				
61	Abrasion Sheath	1	Blend	.4	.4	-	-
94	Abrasion Sheath	2	Blend and fill	3.73	-	4.8	2
	Nose Block	3	Replace sheath				
11	Skin	1	Blend	3.73	-	5.4	5
	Core	7	Install patch/plug				6
	Spline	8	Install T.E. doubler				
64	Skin	1	Blend	3.73	-	1.8	6
	Spline	8	Install T.E. doubler				
89	Abrasion Sheath	1	Blend	3.73	-	6.3	3
	Spar Doubler	5	Patch large skin area				4
	Skin	9	Splice glass doubler				
	Core Doubler	11	Fill large core area				
	Core						
36	Skin	7	Install patch/plug	3.73	-	4.5	5
	Core						

TABLE XXVIII. REPAIRS, CONFIGURATION II

Damage Incident No.	Blade Details Affected	Repair Scheme		A/C Down Time	Org Repair Time	Int Repair Time	Kits
		No.	Description				
8	Skin Skin Doublers Grip Doublers Root Fitting Closing Channel	-	Scrap	3.73	-	-	-
33	No Damage Inflicted on Blade	-	-	-	-	-	-
24	Abrasion Sheath	1	Blend	.4	.4	-	-
45	Core Doubler Skin Doublers Grip Doublers	-	Depot repair	3.73	-	-	-
42	Abrasion Sheath Spar Skin Doublers Grip Doublers	-	Scrap	3.73	-	-	-
28	Skin Doublers Grip Doublers Closing Channel	-	Scrap	3.73	-	-	-

TABLE XXVIII - Continued

Damage Incident No.	Blade Details Affected	Repair Scheme		A/C Down Time	Org Repair Time	Int Repair Time	Kits
		No.	Description				
19	Skin Core Doubler Core Skin Doublers Grip Doublers	-	Depot repair	3.73	-	-	-
46	Skin Skin Doublers Closing Channel	-	Scrap	3.73	-	-	-
22	Abrasion Sheath Skin Core Doubler	1 4	Blend Patch small skin area	3.73	-	2.2	4
39	Skin Core	4 10	Patch small skin area Fill small core area	3.73	-	1.9	4
58	Abrasion Sheath Spar	-	Scrap	3.73	-	-	-
71	Skin Core	7	Install patch/plug	3.73	-	4.5	5
15	No Damage Inflicted on Blade	-	-	-	-	-	-
87	Abrasion Sheath	1	Blend	.4	.4	-	-

TABLE XXVIII - Continued

Damage Incident No.	Blade Details Affected	Repair Scheme		A/C Down Time	Org Repair Time	Int Repair Time	Kits
		No.	Description				
92	Abrasion Sheath Spar	-	Scrap	3.73	-	-	-
56	Skin Core	5 11	Patch large skin area Fill large core area	3.73	-	4.4	4
36	Skin Core Spline Closing Channel Transition Doubler	-	Scrap	3.73	-	-	-
21	Skin Core	7	Install patch/plug	3.73	-	4.5	5
44	Skin Core	7	Install patch/plug	3.73	-	4.5	5
27	Skin Core	7	Install patch/plug	3.73	-	4.5	5
60	Skin Core Spline	-	Scrap	3.73	-	-	-
37	Skin Core	4 10	Patch small core area Fill small core area	3.73	-	1.9	4

TABLE XXVIII - Continued

Damage Incident No.	Blade Details Affected	Repair Scheme		A/C Down Time	Org Repair Time	Int Repair Time	Kits
		No.	Description				
67	Skin Core	7	Install patch/plug	3.73	-	4.5	5
96	Spline	1	Blend	2.3	.4	-	1
54	Skin Core Spline	-	Depot repair	3.73	-	-	-
74	Skin Core Spline	-	Scrap	3.73	-	-	-
7	Skin Spline	-	Depot repair	3.73	-	-	-
73	Skin Core	7	Install patch/plug	3.73	-	4.5	5
3	Abrasion Sheath Spar	-	Scrap	3.73	-	-	-
97	Skin Core	4 10	Patch small skin area Fill small core area	6.4	1.6	-	4
49	Abrasion Sheath	1	Blend	.4	.4	-	-
29	Abrasion Sheath Spar	-	Scrap	3.73	-	-	-

TABLE XXVIII - Continued

Damage Incident No.	Blade Details Affected	Repair Scheme		A/C Down Time	Org Repair Time	Int Repair Time	Kits
		No.	Description				
53	Skin Core	7	Install patch/plug	3.73	-	4.5	5
1	Skin Core Spline	1 5 8 11	Blend Patch large skin area Install T.E. doubler Fill large core area	3.73	-	5.2	4 6
81	Skin Core	7	Install patch/plug	3.73	-	4.5	5
20	Skin Core	7	Install patch/plug	3.73	-	4.5	5
13	Abrasion Sheath Skin Core Doubler	1 4	Blend Patch small skin area	3.73	-	2.2	4
62	Abrasion Sheath	1	Blend	.4	.4	-	-
41	Skin Spline	1 8	Blend Install T.E. doubler	3.73	-	1.7	6
9	Abrasion Sheath	1	Blend	.4	.4	-	-
38	Abrasion Sheath Skin Core Doubler Core	1 7	Blend Install patch/plug	3.73	-	5.1	5

TABLE XXVIII - Continued

Damage Incident No.	Blade Details Affected	Repair Scheme No.	Repair Scheme Description	A/C Down Time	Org Repair Time	Int Repair Time	Kits
63	Skin	4	Patch small skin area	6.4	1.6	-	4
	Core	10	Fill small core area				
32	Skin	1	Blend	3.73	-	4.7	4
	Core Doubler	5	Patch large skin area				
	Core	11	Fill large core area				
25	Skin	-	Depot repair	3.73	-	-	-
	Core						
	Spline						
51	Skin	4	Patch small skin area	6.4	1.6	-	4
	Core	10					
99	Skin	7	Install patch/plug	3.73	-	4.5	5
	Core						
78	Skin	1	Blend	3.73	-	4.8	5
	Core Doubler	7	Install patch/plug				
	Core						
43	Skin	-	Depot repair	3.73	-	-	-
	Core						
	Spline						
40	Skin	1	Blend	3.73	-	1.9	6
	Core	8	Install T.E. doubler				
	Spline	10	Fill small core area				

TABLE XXVIII - Continued

Damage Incident No.	Blade Details Affected	Repair Scheme		A/C Down Time	Org Repair Time	Int Repair Time	Kits
		No.	Description				
16	Skin Core	7	Install patch/plug	3.73	-	4.5	5
59	Skin Core	7	Install patch/plug	3.73	-	4.5	5
83	Skin Core Spline	1 7	Blend Install patch/plug	3.73	-	4.7	5
88	Abrasion Sheath Skin Core Doubler	1 4	Blend Patch small skin area	3.73	-	2.2	4
72	Spline	1	Blend	2.3	.4	-	1
95	Skin Core	7	Install patch/plug	3.73	-	4.5	5
35	Skin Core Doubler Core	1 7	Blend Install patch/plug	3.73	-	4.8	5
75	Skin Core Doubler Core	1 4 10	Blend Patch small skin area Fill small core area	3.73	-	2.1	4
2	Skin Core	5 11	Patch large skin area Fill large core area	3.73	-	4.4	4

TABLE XXVIII - Continued

Damage Incident No.	Blade Details Affected	Repair Scheme		A/C Down Time	Org Repair Time	Int Repair Time	Kits
		No.	Description				
68	Abrasion Sheath	1	Blend	.4	.4	-	-
84	Skin Core	7	Install patch/plug	3.73	-	4.5	5
18	Abrasion Sheath Spar	-	Scrap	3.73	-	-	-
50	Skin Core Doubler Core	1 7	Blend Install patch/plug	3.73	-	4.8	5
98	Skin Core Spline	1 7 8	Blend Install patch/plug Install T.E. doubler	3.73	-	5.3	5 6
31	Skin Core Spline	1 4 8 10	Blend Patch small skin area Install T.E. doubler Fill small core area	3.73	-	2.7	4 6
47	Skin Core Spline	1 7 8	Blend Install patch/plug Install T.E. doubler	3.73	-	5.3	5 6
61	Abrasion Sheath Skin Core Doubler Core	1 4 10	Blend Patch small skin area Fill small core area	3.73	-	2.4	4

TABLE XXVIII - Continued

Damage Incident No.	Blade Details Affected	Repair Scheme		A/C Down Time	Org Repair Time	Int Repair Time	Kits
		No.	Description				
94	Abrasion Sheath Nose Block	2 3	Blend and fill Replace sheath	3.73	-	4.8	2
11	Skin Core Spline	1 7 8	Blend Install patch/plug Install T.E. doubler	3.73	-	5.3	5 6
64	Skin Spline	1 8	Blend Install T.E. doubler	3.73	-	1.7	6
89	Abrasion Sheath Skin Core Doubler Core	1 5 11	Blend Patch large skin area Fill large core area	3.73	-	5.0	4
36	Skin Core	7	Install patch/plug	3.73	-	4.5	5

TABLE XXIX. REPAIRS, CONFIGURATION III

Damage Incident No.	Blade Details Affected	Repair Scheme		A/C Down Time	Org Repair Time	Int Repair Time	Kits
		No.	Description				
8	Skin Root Fitting	-	Scrap	3.73	-	-	-
33	Skin Core	-	Depot repair	3.73	-	-	-
24	Spar	1	Blend	2.3	.4	-	1
45	Spar Skin Core Doubler Core	-	Depot repair	3.73	-	-	-
42	Spar	-	Scrap	3.73	-	-	-
28	Skin Core Doubler Core	-	Depot repair	3.73	-	-	-
19	Spar Skin Core Doubler Core	-	Depot repair	3.73	-	-	-
46	Skin Core Spline Doubler Spline	-	Scrap	3.73	-	-	-

TABLE XXIX - Continued

Damage Incident No.	Blade Details Affected	Repair Scheme		A/C Down Time	Org Repair Time	Int Repair Time	Kits
		No.	Description				
22	Spar Skin Core Doubler Core	-	Depot repair	3.73	-	-	-
39	Skin Core	4 10	Patch small skin area Fill small core area	3.73	-	1.9	4
58	Spar Skin Core Doubler Core	-	Scrap	3.73	-	-	-
71	Skin Core	7	Install patch/plug	3.73	-	4.5	5
15	Skin Spline Doubler Spline	-	Scrap	3.73	-	-	-
87	Spar	1	Blend	2.3	.4	-	1
92	Spar	-	Scrap	3.73	-	-	-
56	Skin Core	5 11	Patch large skin area Fill large core area	3.73	-	4.4	4

TABLE XXIX - Continued

Damage Incident No.	Blade Details Affected	Repair Scheme		A/C Down Time	Org Repair Time	Int Repair Time	Kits
		No.	Description				
86	Skin Core Spline Doubler Spline	1 5 8 11	Blend Patch large skin area Install T.E. doubler Fill large core area	3.73	-	6.5	3 4 6
21	Skin Core	7	Install patch/plug	3.73	-	4.5	5
44	Skin Core	7	Install patch/plug	3.73	-	4.5	5
27	Skin Core	7	Install patch/plug	3.73	-	4.5	5
60	Skin Core Spline Doubler Spline	-	Scrap	3.73	-	-	-
37	Spar Skin Core Doubler Core	1 4 10	Blend Patch small skin area Fill small core area	3.73	-	2.2	4
67	Skin Core	7	Install patch/plug	3.73	-	4.5	5

TABLE XXIX - Continued

Damage Incident No.	Blade Details Affected	Repair Scheme		A/C Down Time	Org Repair Time	Int Repair Time	Kits
		No.	Description				
96	Skin Spline Doubler Spline	1 4	Blend Patch small skin area	3.73	-	2.0	4
54	Skin Core Spline Doubler Spline	-	Depot repair	3.73	-	-	-
74	Skin Core Spline Doubler Spline	-	Scrap	3.73	-	-	-
7	Skin Spline Doubler Spline	-	Depot repair	3.73	-	-	-
73	Skin Core	7	Install patch/plug	3.73	-	4.5	5
3	Spar	-	Scrap	3.73	-	-	-
97	Skin Core	4 10	Patch small skin area Fill small core area	6.4	1.6	-	4
49	Spar	1	Blend	2.3	.4	-	1
29	Spar	-	Scrap	3.73	-	-	-

TABLE XXIX - Continued

Damage Incident No.	Blade Details Affected	Repair Scheme No.	Repair Scheme Description	A/C Down Time	Org Repair Time	Int Repair Time	Kits
53	Skin Core	7	Install patch/plug	3.73	-	4.5	5
1	Skin Core Spline Doubler Spline	1 5 8 11	Blend Patch large skin area Install T.E. doubler Fill large core area	3.73	-	6.5	3 4 6
81	Spar Skin Core Doubler Core	-	Scrap	3.73	-	-	-
20	Skin Core	7	Install patch/plug	3.73	-	4.5	5
13	Spar	1	Blend	2.3	.4	-	1
62	Spar	1	Blend	2.3	.4	-	1
41	Skin Spline Doubler Spline	1 8 9	Blend Install T.E. doubler Splice glass doubler	3.73	-	4.2	3 6
9	Spar	1	Blend	2.3	.4	-	1

TABLE XXIX - Continued

Damage Incident No.	Blade Details Affected	Repair Scheme		A/C Down Time	Org Repair Time	Int Repair Time	Kits
		No.	Description				
38	Spar Skin Core Doubler Core	1 7	Blend Install patch/plug	3.73	-	5.0	5
63	Skin Core	4 10	Patch small skin area Fill small core area	6.4	1.6	-	4
32	Spar Skin Core Doubler Core	1 5 11	Blend Patch large skin area Fill large core area	3.73	-	4.8	4
25	Skin Core Spline Doubler Spline	-	Depot repair	3.73	-	-	-
51	Skin Core	4 10	Patch small skin area Fill small core area	6.4	1.6	-	4
99	Spar Skin Core Doubler	-	Scrap	3.73	-	-	-
78	Spar	1	Blend	2.3	.4	-	1

TABLE XXIX - Continued

Damage Incident No.	Blade Details Affected	Repair Scheme		A/C Down Time	Org Repair Time	Int Repair Time	Kits
		No.	Description				
43	Skin Core Spline Doubler Spline	-	Depot repair	3.73	-	-	-
40	Skin Core Spline Doubler Spline	1 8 9 10	Blend Install T.E. doubler Splice glass doubler Fill small core area	3.73	-	3.2	3 6
16	Skin Core	7	Install patch/plug	3.73	-	4.5	5
59	Skin Core	7	Install patch/plug	3.73	-	4.5	5
83	Skin Core	7	Install patch/plug	3.73	-	4.5	5
88	Spar	1	Blend	2.3	.4	-	1
72	Skin Spline Doubler Spline	1 4	Blend Patch small skin area	3.73	-	2.0	4
95	Skin Core	7	Install patch/plug	3.73	-	4.5	5

TABLE XXIX - Continued

Damage Incident No.	Blade Details Affected	Repair Scheme		A/C Down Time	Org Repair Time	Int Repair Time	Kits
		No.	Description				
35	Spar Skin Core Doubler Core	1 7	Blend Install patch/plug	3.73	-	5.0	5
75	Spar Skin	1 4	Blend Patch small skin area	3.73	-	2.0	4
2	Skin Core	5 11	Patch large skin area Fill large core area	3.73	-	4.4	4
68	Spar	1	Blend	2.3	.4	-	1
84	Skin Core	7	Install patch/plug	3.73	-	4.5	5
18	Spar	-	Scrap	3.73	-	-	-
50	Spar Skin Core Doubler Core	1 7	Blend Install patch/plug	3.73	-	5.0	5
98	Skin Core Spline Doubler Spline	1 7 8 9	Blend Install patch/plug Install T.E. doubler Splice glass doubler	3.73	-	7.8	3 5 6

TABLE XXIX - Continued

Damage Incident No.	Blade Details Affected	Repair Scheme No.	Repair Scheme Description	A/C Down Time	Org Repair Time	Int Repair Time	Kits
31	Skin Core	4 10	Patch small skin area Fill small core area	3.73	-	1.9	4
47	Skin Core Spline Doubler Spline	1 7 8 9	Blend Install patch/plug Install T.E. doubler Splice glass doubler	3.73	-	7.8	3 5 6
61	Abrasion Sheath	1	Blend	.4	.4	-	-
94	Abrasion Sheath Spar	2 3	Blend & fill Replace sheath	3.73	-	4.7	2
11	Skin Core	7	Install patch/plug	3.73	-	4.5	5
64	Skin Core Spline Doubler Spline	1 8 9 10	Blend Install T.E. doubler Splice glass doubler Fill small core area	3.73	-	3.2	3 6
89	Abrasion Sheath Skin Core Doubler Core	1 4 10	Blend Patch small skin area Fill small core area	3.73	-	2.3	4
36	Skin Core	7	Install patch/plug	3.73	-	4.5	5

TABLE XXX. REPAIRS, CONFIGURATION IV

Damage Incident No.	Blade Details Affected	Repair Scheme		A/C Down Time	Org Repair Time	Int Repair Time	Kits
		No.	Description				
8	Skin Root Fitting	-	Scrap	3.73	-	-	-
33	Skin Core	-	Depot repair	3.73	-	-	-
24	No Damage Inflicted on Blade	-	-	-	-	-	-
45	Skin Core Grip Doublers	-	Scrap	3.73	-	-	-
42	Spar Grip Doublers	-	Scrap	3.73	-	-	-
28	Skin Core Grip Doublers	-	Depot repair	3.73	-	-	-
19	Skin Core Grip Doublers	-	Scrap	3.73	-	-	-
46	Skin Core Link Doublers	-	Scrap	3.73	-	-	-

TABLE XXX - Continued

Damage Incident No.	Blade Details Affected	Repair Scheme		A/C Down Time	Org Repair Time	Int Repair Time	Kits
		No.	Description				
22	Skin Core Grip Doublers	-	Depot repair	3.73	-	-	-
39	Skin Core	4 10	Patch small skin area Fill small core area	3.73	-	1.9	4
58	Spar Spar Doubler Skin Core Doubler Core	-	Scrap	3.73	-	-	-
71	Skin Core	7	Install patch/plug	3.73	-	4.5	5
15	Skin Spline Wrap Spline	-	Scrap	3.73	-	-	-
87	Abrasion Sheath	3	Replace sheath	3.73	-	4.3	2
92	Abrasion Sheath Spar Doubler Spar	-	Scrap	3.73	-	-	-
56	Skin Core	5 11	Patch large skin area Fill large core area	3.73	-	4.4	4

TABLE XXX - Continued

Damage Incident No.	Blade Details Affected	Repair Scheme		A/C Down Time	Org Repair Time	Int Repair Time	Kits
		No.	Description				
86	Skin Core Spline Wrap Spline	2 5 8 9 11	Blend & fill Patch large skin area Install T.E. doubler Splice glass doubler Fill large core area	3.73	-	6.5	3 4 6
21	Skin Core	7	Install patch/plug	3.73	-	4.5	5
44	Skin Core	7	Install patch/plug	3.73	-	4.5	5
27	Skin Core	7	Install patch/plug	3.73	-	4.5	5
60	Skin Core Spline Wrap Spline	-	Depot repair	3.73	-	-	-
37	Skin Core Doubler Core	1 4 10	Blend Patch small skin area Fill small core area	3.73	-	2.1	4
67	Skin Core	7	Install patch/plug	3.73	-	4.5	5
96	Skin Spline Wrap	1 4	Blend Patch small skin area	3.73	-	1.8	4

TABLE XXX - Continued

Damage Incident No.	Blade Details Affected	Repair Scheme		A/C Down Time	Org Repair Time	Int Repair Time	Kits
		No.	Description				
54	Skin Core Spline Wrap Spline	-	Depot repair	3.73	-	-	-
74	Skin Core Spline Wrap Spline	-	Scrap	3.73	-	-	-
7	Skin Spline Wrap Spline	-	Depot repair	3.73	-	-	-
73	Skin Core	7	Install patch/plug	3.73	-	4.5	5
3	Abrasion Sheath Spar Doubler Spar	-	Scrap	3.73	-	-	-
97	Skin Core	4 10	Patch small skin area Fill small core area	6.4	1.6	-	4
49	Abrasion Sheath	3	Replace sheath	3.73	-	4.3	2
29	Abrasion Sheath Spar Doubler Spar	-	Scrap	3.73	-	-	-

TABLE XXX - Continued

Damage Incident No.	Blade Details Affected	Repair Scheme		A/C Down Time	Org Repair Time	Int Repair Time	Kits
		No.	Description				
53	Skin Core	7	Install patch/plug	3.73	-	4.5	5
1	Skin Core Spline Wrap Spline	2 5 8 9 11	Blend & fill Patch large skin area Install T.E. doubler Splice glass doubler Fill large core area	3.73	-	6.5	3 4 6
81	Skin Core Doubler Core	1 7	Blend Install patch/plug	3.73	-	4.9	5
20	Skin Core	7	Install patch/plug	3.73	-	4.5	5
13	Abrasion Sheath	3	Replace sheath	3.73	-	4.3	2
62	Abrasion Sheath Nose Block Spar Doubler	2 3	Blend & fill Replace sheath	3.73	-	4.7	2
41	Skin Spline Wrap Spline	8 9	Install T.E. doubler Splice glass doubler	3.73	-	5.0	3 6
9	Abrasion Sheath	3	Replace sheath	3.73	-	4.3	2

TABLE XXX - Continued

Damage Incident No.	Blade Details Affected	Repair Scheme		A/C Down Time	Org Repair Time	Int Repair Time	Kits
		No.	Description				
38	Abrasion Sheath	1	Blend	3.73	-	9.9	2
	Spar Doubler	3	Replace sheath				3
	Skin	7	Install patch/plug				5
	Core Doubler	9	Splice glass doubler				
	Core						
63	Skin	4	Patch small skin area	6.4	1.6	-	4
	Core	10	Fill small core area				
32	Abrasion Sheath	1	Blend	3.73	-	6.3	3
	Spar Doubler	5	Patch large skin area				4
	Skin	9	Splice glass doubler				
	Core Doubler	11	Fill large core area				
	Core						
25	Skin	-	Depot repair	3.73	-	-	-
	Core						
	Spline Wrap						
	Spline						
51	Skin	4	Patch small skin area	6.4	1.6	-	4
	Core	10	Fill small core area				
99	Skin	1	Blend	3.73	-	4.9	5
	Core Doubler	7	Install patch/plug				
	Core						
78	Abrasion Sheath	3	Replace sheath	3.73	-	5.7	2
	Spar Doubler	9	Splice glass doubler				3

TABLE XXX - Continued

Damage Incident No.	Blade Details Affected	Repair Scheme No.	Repair Scheme Description	A/C Down Time	Org Repair Time	Int Repair Time	Kits
43	Skin Core Spline Wrap Spline	-	Depot repair	3.73	-	-	-
40	Skin Spline Wrap Spline	8 9	Install T.E. doubler Splice glass doubler	3.73	-	2.7	3 6
16	Skin Core	7	Install patch/plug	3.73	-	4.5	5
59	Skin Core	7	Install patch/plug	3.73	-	4.5	5
83	Skin Core	7	Install patch/plug	3.73	-	4.5	5
88	Abrasion Sheath	3	Replace sheath	3.73	-	4.3	2
72	Skin Spline Wrap	1 4	Blend Patch small skin area	3.73	-	1.8	4
95	Skin Core	7	Install patch/plug	3.73	-	4.5	5

TABLE XXX - Continued

Damage Incident No.	Blade Details Affected	Repair Scheme No.	Repair Scheme Description	A/C Down Time	Org Repair Time	Int Repair Time	Kits
35	Abrasion Sheath	1	Blend	3.73	-	9.9	2
	Spar Doubler	3	Replace sheath				3
	Skin	7	Install patch/plug				5
	Core Doubler	9	Splice glass doubler				
	Core						
75	Abrasion Sheath	1	Blend	3.73	-	7.8	2
	Spar Doubler	3	Replace sheath				3
	Skin	4	Patch small skin area				4
	Core Doubler	9	Splice glass doubler				
	Core	10	Fill small core area				
2	Skin	5	Patch large skin area	3.73	-	4.4	4
	Core	11	Fill large core area				
68	Abrasion Sheath	1	Blend	.4	.4	-	-
84	Skin	7	Install patch/plug	3.73	-	4.5	5
	Core						
18	Abrasion Sheath	-	Scrap	3.73	-	-	-
	Spar Doubler						
	Spar						
50	Abrasion Sheath	1	Blend	3.73	-	9.9	2
	Spar Doubler	3	Replace sheath				3
	Skin	7	Install patch/plug				5
	Core Doubler	9	Splice glass doubler				
	Core						

TABLE XXX - Continued

Damage Incident No.	Blade Details Affected	Repair Scheme No.	Repair Scheme Description	A/C Down Time	Org Repair Time	Int Repair Time	Kits
98	Skin Core Spline Wrap Spline	2 5 8 9 11	Blend & fill Patch large skin area Install T.E. doubler Splice glass doubler Fill large core area	3.73	-	6.5	3 4 6
31	Skin Core	4 10	Patch small skin area Fill small core area	6.4	1.6	-	4
47	Skin Core Spline Wrap Spline	4 8 9 10	Patch small skin area Install T.E. doubler Splice glass doubler Fill small core area	3.73	-	6.9	3 4 6
61	Abrasion Sheath	3	Replace sheath	3.73	-	4.3	2
94	Abrasion Sheath Nose Block	2 3	Blend & fill Replace sheath	3.73	-	4.8	2
11	Skin Core	7	Install patch/plug	3.73	-	4.5	5
64	Skin Spline Wrap Spline	8 9	Install T.E. doubler Splice glass doubler	3.73	-	3.8	3 6

TABLE XXX - Continued

Damage Incident No.	Blade Details Affected	Repair Scheme		A/C Down Time	Org Repair Time	Int Repair Time	Kits
		No.	Description				
89	Abrasion Sheath	1	Blend	3.73	-	6.3	3
	Spar Doubler	5	Patch large skin area				4
	Skin	9	Splice glass doubler				
	Core Doubler	11	Fill large core area				
	Core						
36	Skin	7	Install patch/plug	3.73	-	4.5	5
	Core						

TABLE XXXI. REPAIRS, CURRENT UH-1 BLADE

Damage Incident No.	Blade Details Affected	Repair Scheme		A/C Down Time	Org Repair Time	Int Repair Time	Kits
		No.	Description				
8	Skin Grip Doublers Root Fitting	-	Scrap	3.73	-	-	-
33	Skin Core	-	Depot repair	3.73	-	-	-
24	Abrasion Sheath Grip Doublers	1	Blend	2.3	.4	-	-
45	Skin Grip Doublers	-	Scrap	3.73	-	-	-
42	Spar Doubler Spar Grip Doublers	-	Scrap	3.73	-	-	-
28	Skin Core Grip Doublers	-	Scrap	3.73	-	-	-
19	Skin Core Grip Doublers	-	Scrap	3.73	-	-	-
46	Skin Core Spline Link	-	Scrap	3.73	-	-	-

TABLE XXXI - Continued

Damage Incident No.	Blade Details Affected	Repair Scheme		A/C Down Time	Org Repair Time	Int Repair Time	Kits
		No.	Description				
22	Skin Core Grip Doublers	-	Scrap	3.73	-	-	-
39	Skin Core	6	Patch small skin area	3.73	-	1.6	-
58	Skin Core Grip Doublers	-	Scrap	3.73	-	-	-
71	Skin Core	-	Depot repair	3.73	-	-	-
15	Skin Spline	-	Scrap	3.73	-	-	-
87	Abrasion Sheath	1	Blend	2.3	.4	-	-
92	Abrasion Sheath Spar Doubler Spar	-	Scrap	3.73	-	-	-
56	Skin Core	-	Scrap	3.73	-	-	-
86	Skin Core Spline	-	Scrap	3.73	-	-	-

TABLE XXXI - Continued

Damage Incident No.	Blade Details Affected	Repair Scheme No.	Repair Scheme Description	A/C Down Time	Org Repair Time	Int Repair Time	Kits
21	Skin Core	6	Patch small skin area	3.73	-	1.6	-
44	Skin Core	6	Patch small skin area	3.73	-	1.6	-
27	Skin Core	6	Patch small skin area	3.73	-	1.6	-
60	Skin Core Spline	-	Scrap	3.73	-	-	-
37	Skin Core	6	Patch small skin area	3.73	-	1.6	-
67	Skin Core	6	Patch small skin area	3.73	-	1.6	-
96	Spline	1	Blend	2.3	.4	-	-
54	Skin Core Spline	-	Scrap	3.73	-	-	-
74	Skin Core Spline	-	Scrap	3.73	-	-	-

TABLE XXXI - Continued

Damage Incident No.	Blade Details Affected	Repair Scheme		A/C Down Time	Org Repair Time	Int Repair Time	Kits
		No.	Description				
7	Skin Spline	-	Scrap	3.73	-	-	-
73	Skin Core	6	Patch small skin area	3.73	-	1.6	-
3	Abrasion Sheath Spar Doubler Spar	-	Scrap	3.73	-	-	-
97	Skin Core	-	Scrap	3.73	-	-	-
49	Abrasion Sheath	1	Blend	2.3	.4	-	-
29	Abrasion Sheath Spar Doubler Spar	-	Scrap	3.73	-	-	-
53	Skin Core	6	Patch small skin area	3.73	-	1.6	-
1	Skin Core Spline	-	Scrap	3.73	-	-	-
81	Skin Core	-	Depot repair	3.73	-	-	-

TABLE XXXI - Continued

Damage Incident No.	Blade Details Affected	Repair Scheme		A/C Down Time	Org Repair Time	Int Repair Time	Kits
		No.	Description				
20	Skin Core	-	Depot repair	3.73	-	-	-
13	Abrasion Sheath	1	Blend	2.3	.4	-	-
62	Abrasion Sheath	1	Blend	2.3	.4	-	-
41	Skin Spline	-	Scrap	3.73	-	-	-
9	Abrasion Sheath	1	Blend	2.3	.4	-	-
38	Abrasion Sheath Spar Doubler Skin Core	-	Scrap	3.73	-	-	-
63	Skin Core	-	Scrap	3.73	-	-	-
32	Abrasion Sheath Spar Doubler Skin Core	-	Scrap	3.73	-	-	-
25	Skin Core Spline	-	Scrap	3.73	-	-	-

TABLE XXXI - Continued

Damage Incident No.	Blade Details Affected	Repair Scheme		A/C Down Time	Org Repair Time	Int Repair Time	Kits
		No.	Description				
51	Skin Core	6	Patch small skin area	3.73	-	1.6	-
99	Skin Core	-	Depot repair	3.73	-	-	-
78	Abrasion Sheath	1	Blend	2.3	.4	-	-
43	Skin Spline	-	Scrap	3.73	-	-	-
40	Skin Spline	-	Scrap	3.73	-	-	-
16	Skin Core	-	Depot repair	3.73	-	-	-
59	Skin Core	-	Depot repair	3.73	-	-	-
83	Skin Core	-	Scrap	3.73	-	-	-
88	Abrasion Sheath	1	Blend	2.3	.4	-	-
72	Spline	1	Blend	2.3	.4	-	-
95	Skin Core	-	Scrap	3.73	-	-	-

TABLE XXXI - Continued

Damage Incident No.	Blade Details Affected	Repair Scheme		A/C Down Time	Org Repair Time	Int Repair Time	Kits
		No.	Description				
35	Abrasion Sheath Spar Doubler Skin Core	-	Scrap	3.73	-	-	-
75	Abrasion Sheath Spar Doubler Skin Core	-	Scrap	3.73	-	-	-
2	Skin Core	-	Scrap	3.73	-	-	-
68	Abrasion Sheath	1	Blend	2.3	.4	-	-
84	Skin Core	-	Depot repair	3.73	-	-	-
18	Abrasion Sheath Spar Doubler Spar	-	Scrap	3.73	-	-	-
50	Abrasion Sheath Spar Doubler Skin Core	-	Scrap	3.73	-	-	-

TABLE XXXI - Continued

Damage Incident No.	Blade Details Affected	Repair Scheme		A/C Down Time	Org Repair Time	Int Repair Time	Kits
		No.	Description				
98	Skin Core Spline	-	Scrap	3.73	-	-	-
31	Skin Core Spline	-	Scrap	3.73	-	-	-
47	Skin Core Spline	-	Scrap	3.73	-	-	-
61	Abrasion Sheath	1	Blend	2.3	.4	-	-
94	Abrasion Sheath Nose Block	-	Depot repair	3.73	-	-	-
11	Skin Core Spline	-	Depot repair	3.73	-	-	-
64	Skin Spline	-	Scrap	3.73	-	-	-
89	Abrasion Sheath Spar Doubler Skin Core	-	Scrap	3.73	-	-	-

TABLE XXXI - Continued

Damage Incident No.	Blade Details Affected	Repair Scheme		A/C Down Time	Org Repair Time	Int Repair Time	Kits
		No.	Description				
36	Skin Core	6	Patch small skin area	3.73	-	1.6	-

TABLE XXXII. REPAIR KIT CONTENTS

ITEM NO.	ITEM	DESCRIPTION	-1- EXPOSED METAL KIT	-2- ABRASION SHEATH KIT	-3- DIRECTED GLASSFIBER KIT	-4- SKIN PATCH KIT	-5- PLUG/ PATCH KIT	-6- T.E. DOUBLER KIT
1	Sand Paper	Sheet, 9 in. sq., 180 grit	2	4	4	2	2	2
2	Sand Paper	Sheet, 9 in. sq., 240 grit	2	4	4	8	4	8
3	Sanding Disc	1 1/2 in. dia., (used with air meter)	-	2	4	2	2	2
4	Cheese Cloth	18 in. wide, (qty. indicated in ft.)	10	20	8	16	20	18
5	MEK Solvent	Pint can	1	1	1	1	1	1
6	Adhesive Stripper	Pint can	-	1	-	-	-	-
7	Cotton Gloves	Pair, light weight	-	1	1	1	1	1
8	Rubber Gloves	Pair, chemical resistant	-	1	-	-	-	-
9	Mixing Cup	Quart size, paper	2	4	2	3	2	1
10	Wooden Spatula	Tongue depressor	1	2	1	2	1	2
11	Serrated Spreader	Contractor made	-	1	1	1	1	-
12	Masking Tape	Roll, 1 in. wide	1	1	1	1	1	1
13	Hi-Temp. Mylar Tape	2 in. wide, (qty. indicated in ft.)	-	10	5	5	10	5
14	Aluminum Tape	1 in. wide, (qty. indicated in ft.)	-	15	-	-	-	-
15	Teflon Film	Sheet, transparent, .0005x20x40 in.	-	2	1	1	2	1
16	Aluminum Sheet	Sheet, .010 x 20 in. square	-	-	1	1	2	1
17	Brush	1/4 in. wide	1	1	1	1	1	1
18	Brush	2 in. wide	-	1	-	-	-	-
19	Alodine, Brushable	1 oz. bottle	1	2	1	1	1	1
20	Zinc Chromate Primer	3 oz. aerosol can	1	-	-	-	-	1
21	Paint, Brown	3 oz. aerosol can	1	1	-	1	1	1
22	Paint, Black	3 oz. aerosol can	1	1	-	1	1	1
23	Wrap-Around Template	Contractor made	-	-	-	-	1	-
24	Preimpregnated Skin	Sheet, 4 ply, 120 cloth, 8 x 16 in.	-	-	-	1	-	-
25	Plug/Patch & Frame Doubler	Contractor made	-	-	-	-	1	-
26	Trailing-Edge Doubler	Contractor made	-	-	-	-	-	1
27	Abrasion Sheath Segment	Contractor made	-	1	-	-	-	-
28	Directed Glass Fiber Material	Sheet, 1/8 thick x 8 wide x 4 in. long	-	-	1	-	-	-
	Adhesive EC 2216	Special 2 section plastic package	[illegible]	2	1	1	2	1
	Corfil 615	Special 2 section plastic package		-	-	1	-	1
	Lead/Epoxy Filler	Special 2 section plastic package	-	1	-	-	-	-

Note: The last three items are required as indicated, but not included in kits due to limited shelf life.

TABLE XXXIII. EQUIPMENT LIST

ITEM NO.	DESCRIPTION	EQUIPMENT REQUIREMENTS -1- EXPOSED METAL REPAIR	-2- ABRASION SHEATH REPAIR	-3- DIRECTED GLASS FIBER	-4- SKIN PATCH REPAIR	-5- PLUG PATCH REPAIR	-6- T.E. DOUBLER REPAIR
1	Heating Blanket (12 in. x 12 in.)	-	3	1	1	2	1
2	Inflatable Bladder with Straps	-	3	1	1	1	1
3	Tire Hand Pump (or compressed air)	-	1	1	1	1	1
4	Tire Pressure Gage	-	1	1	1	1	1
5	Scissors	-	-	-	1	-	-
6	28-Volt D.C. Power Source	-	1	1	1	1	1
7	Scraping Knife	-	1	-	1	1	1
8	Die File	1	-	-	-	-	-
9	Electric Heat Gun	-	1	-	-	-	-
10	Hack Saw	-	-	1	-	-	-
11	4-In.-Long Knife	-	-	-	-	1	-

APPENDIX IV

STANDARD REPAIR PROCEDURES

INDEX

1. Blend repair not requiring restoration of profile.
2. Blend repair requiring restoration of profile.
3. Replacement of abrasion sheath segment.
4. Patch repair of small fiberglass skin area.
5. Patch repair of large fiberglass skin area.
6. Patch repair of small aluminum skin area.
7. Patch/plug repair of core area.
8. "V" doubler repair at blade trailing edge.
9. Insertion repair of directed glass fiber doubler.
10. Core-fill of small area.
11. Core-fill of large area.

NOTE: A combination of two or more of the above procedures may be required to accomplish repair needed because of a single damage incident.

REPAIR PROCEDURE NO. 1

1. Blend scratch, nick, gouge, chip, etc., using die file and abrasive paper.

2. Using suitable means, measure depth of rework. Continue with step 3 below only if depth of rework is within allowable limits and is shallow enough not to require restoration of original profile. If profile must be restored, accomplish Repair Procedure No. 2.

3. Clean reworked area using MEK solvent and cheesecloth.

4. Apply brushable alodine or cadmium, respectively, to reworked aluminum or steel. Omit this step if material being reworked is stainless steel, titanium or fiberglass.

5. Touch up repair area using aerosol cans of zinc chromate primer, black paint and brown paint, as required. Omit this step if material being reworked does not comprise part of blade exterior.

REPAIR PROCEDURE NO. 2

1. Blend scratch, nick, gouge, chip, etc., using die, file and abrasive paper.

2. Using suitable means, measure depth of rework. Continue with step 3 below only if depth of rework is within allowable limits.

3. Clean reworked area using MEK solvent and cheesecloth.

4. Apply brushable alodine or cadmium, respectively, to reworked aluminum or steel. Omit this step if material being reworked is stainless steel, titanium or fiberglass.

5. Mask area to be filled.

6. Mix 2-part filler and apply to damaged area using wooden spatula.

   Note: Special lead/epoxy filler to be used in restoration of nose block weights.

7. Allow filler to cure for time specified. Heat may be used to accelerate cure. Place heat lamp in a manner that heat rays are directed on rework area and temperature at surface is within prescribed range.

   Note: Heat blankets placed over the repair area with a Teflon film sandwiched between may also be used as a heat source to speed curing of filler.

8. Contour reworked area to restore original profile using hand file and abrasive paper.

9. Touch up repair area using aerosol cans of zinc chromate primer, black paint and brown paint, as required. Omit this step if material being reworked does not comprise part of blade exterior.

REPAIR PROCEDURE NO. 3

1. File or grind through sheath at leading edge using power tools as available.

   Note: Contingent upon availability of air motor, an electric motor or sanding discs may be used.

2. Apply heat locally and peel sheath off.

3. Apply aluminum adhesive tape to blade around area from which old sheath was removed.

4. Remove old adhesive using chemical stripper.

5. Clean areas to be bonded using solvent and cheesecloth.

6. Mask area to be bonded.

7. Mix 2-part adhesive and apply to spar and new sheath using serrated spreader.

8. Install new sheath section and retain in place with hi-temp Mylar tape.

9. Cover with Teflon film and retain film with Mylar tape.

10. Cover with heating blankets and retain with Mylar tape.

11. Wrap with inflatable bladder and secure with web straps.

12. Inflate bladder to 5-10 psi using compressed air or hand-operated tire pump.

13. Provide electric power to heating blankets using auxiliary power unit (APU) or other 28-volt D.C. power source. Allow adhesive to cure, maintaining prescribed cure conditions for time specified.

14. Remove bladder, Teflon film, etc., and sand smooth excess adhesive at sheath edges.

15. Touch up repair area using aerosol cans of zinc chromate primer, black paint and brown paint, as required.

REPAIR PROCEDURE NO. 4

Note: This repair may be utilized for damaged areas up to 3 inches in diameter.

1. File or grind away damaged skin using power tools as available. Scarf edges of reworked skin using abrasive paper.

   Note: In cases where compressed air supply is not available, a specially ground, hand-held scraper may be used to remove damaged skin.

2. Remove paint from area surrounding scarfed edges using solvent and cheesecloth.

   Note: If applicable, Repair Procedure No. 10, "core-fill of small area", should now be accomplished.

3. Cut and scarf fiberglass skin patch to fit repair area.

4. Clean areas to be bonded using solvent and cheesecloth.

5. Mask area to be bonded.

6. Mix 2-part adhesive and apply to patch and reworked area using serrated spreader.

7. Install patch and retain in place with hi-temp Mylar tape.

8. Cover with Teflon film and retain film with Mylar tape.

9. Cover with thin aluminum sheet and retain with Mylar tape.

10. Cover with heating blanket and retain with Mylar tape.

11. Wrap with inflatable bladder and secure with web straps.

12. Inflate bladder to 5-10 psi using compressed air or hand-operated tire pump.

Note: An alternate means of creating bond pressure may be employed by using a sand bag weight over the patch area. In cases where the repair is performed on the underside of a blade still installed on the helicopter, the sand bag may be supported by a piece of plywood propped up from the ground by a wooden strut.

13. Provide electric power to heating blankets using auxiliary power unit (APU) or other 28-volt D.C. power source. Allow adhesive to cure, maintaining prescribed cure conditions for time specified.

14. Remove bladder, aluminum sheet, etc., and sand smooth excess adhesive at patch edges.

15. Touch up repair area using aerosol cans of black paint and brown paint, as required.

16. Refer to repair versus blade balance chart. Remove specified number of balance washers from either or both blade tip locations, as indicated.

REPAIR PROCEDURE NO. 5

Note: This procedure is same as Procedure No. 4 except that repair area is greater, accounting for longer average time to accomplish.

This repair may be utilized for damaged areas up to 8 inches by 16 inches.

REPAIR PROCEDURE NO. 6

Note: This repair may be utilized for damaged areas up to 2-1/2 inches in diameter or oblong areas 1 inch by 4 inches.

1. Draw a circle around the damaged area just large enough to encompass the damage.

2. Remove skin just inside the circled area, disturbing the honeycomb core as little as possible. It is desirable to heat the cut-out disk to 200°F (max.) and lift out the disk of skin while heated.

3. Deburr edges of hole, making sure skin is free of scratches and nicks.

4. Remove paint from repair area with cleaner. Dry with a clean cloth. Do not allow cleaner to enter the blade.

5. Prepare a patch to cover the hole that will overlap by 0.75 inch. Patch may be fabricated from 2024 T3 aluminum 0.020 inch thick and large enough to overlap the hole at least 0.75 inch all around the perimeter. Deburr and blend out edges. Sand the bond area of the patch and blade with 400 grit paper.

6. Clean bond area on patch and blade with cleaner. Dry with a clean cloth.

7. Apply adhesive to patch area around hole and patch. Apply patch to blade, moving patch slightly under pressure, to make sure voids in bond are expelled. Blend out excess adhesive.

8. Patch may be held in place while curing with rubber bands made from inner tube or other mechanical means. Allow Metalset A4 to cure at 70 to 90 degrees for 24 hours, or 145 to 155 degrees for 30 minutes, until completely firm. Allow Epon 934 to cure at 75 degrees minimum for 5 days or at 180 degrees for 60 minutes. (Adhesive will resist fingernail penetration.)

9. Refinish patch and adjoining area.

REPAIR PROCEDURE NO. 7

1. Secure wrap-around template to blade in damage area using masking tape.

2. Using 4-inch knife and hacksaw type blade, cut hole through blade, working alternately from top and bottom sides of blade.

3. Remove paint from areas surrounding cutout on top and bottom of blade using solvent and cheesecloth.

4. Abrade surfaces to be bonded using abrasive paper.

5. Clean areas to be bonded using solvent and cheesecloth.

6. Mask areas to be bonded.

7. Mix 2-part adhesive and apply to areas to be bonded on top surface of blade, flange of patch/plug and core surfaces of blade and patch/plug. Use serrated spreader to apply.

8. Install patch/plug through top side of blade and retain in place with hi-temp Mylar tape.

9. Cover with Teflon film and retain film with Mylar tape.

10. Cover with thin aluminum sheet and retain with Mylar tape.

11. Cover with heating blanket and retain with Mylar tape.

12. Turn blade over and apply adhesive to areas to be bonded on bottom surface of blade and patch/plug and on picture frame doubler.

13. Install picture frame doubler and retain in place with hi-temp Mylar tape.

14. Repeat steps 9 through 12.

15. Wrap with inflatable bladder and secure with web straps.

16. Inflate bladder to 5-10 psi using compressed air or hand-operated tire pump.

17. Provide electric power to heating blankets using auxiliary power unit (APU) or other 28-volt D.C. power source. Allow adhesive to cure, maintaining prescribed temperature range for time specified.

18. Remove bladder, aluminum sheets, etc., and sand smooth excess adhesive at patch/plug and picture frame doubler edges.

19. Touch up repair area using aerosol cans of black paint and brown paint.

REPAIR PROCEDURE NO. 8

1. File or grind away damaged skin using power tools and sanding disks, as available. Scarf edges of reworked skin using abrasive paper.

   Note: In cases where compressed air supply is not available, a specially ground, hand-held scraper may be used to remove damaged skin.

2. Remove paint from both sides of blade in areas that will be covered by "V" doubler.

   Note: Damaged trailing-edge blade sections which underlie skin removed in step 1 above should be repaired now in accordance with applicable procedures 1, 2 or 9.

3. Clean areas to be bonded using solvent and cheesecloth.

4. Mask area to be bonded.

5. Mix 2-part adhesive and apply to "V" doubler and reworked area using serrated spreader.

6. Install "V" doubler and retain in place with hi-temp Mylar tape.

7. Cover with Teflon film and retain film with Mylar tape.

8. Cover with thin aluminum sheet and retain with Mylar tape.

9. Cover with heating blanket and retain with Mylar tape.

10. Wrap with inflatable bladder and secure with web straps.

11. Inflate bladder to 5-10 psi using hand tire pump or compressed air.

    Note: Mechanical means, such as "C" clamps over contoured wooden blocks, may be used as an alternate method of creating bond pressure.

12. Provide electric power to heating blankets using auxiliary power unit (APU) or other 28-volt D.C. power source. Allow adhesive to cure, maintaining prescribed temperature range for time specified.

13. Remove bladder, aluminum sheet, etc., and sand smooth excess adhesive at "V" doubler edges.

14. Touch up repair area using aerosol cans of zinc chromate primer, black paint and brown paint, as required.

15. Refer to repair versus blade balance chart. Remove specified number of balance washers from either or both blade tip locations, as indicated.

REPAIR PROCEDURE NO. 9

1. File or grind away damaged directed glass fiber doubler using power tools and sanding disks, as available. Scarf inboard and outboard ends of repair area.

2. Cut and scarf directed glass fiber patch to fit repair area. Direction of glass fibers must be from root to tip of blade.

3. Clean area to be bonded using solvent and cheesecloth.

4. Mask area to be bonded.

5. Mix 2-part adhesive and apply to patch and reworked area using serrated spreader.

6. Install patch and retain in place with hi-temp Mylar tape.

7. Cover with Teflon film and retain film with Mylar tape.

8. Cover with thin aluminum sheet and retain with Mylar tape.

9. Cover with heating blanket and retain with Mylar tape.

10. Wrap with inflatable bladder and secure with web straps.

11. Inflate bladder to 5-10 psi using compressed air or hand-operated tire pump.

    Note: Mechanical means, such as "C" clamps over contoured wooden blocks, may be used as an alternate method of creating bond pressure.

12. Provide electric power to heating blankets using auxiliary power unit (APU) or other 28-volt D.C. power source. Allow adhesive to cure, maintaining prescribed cure conditions for time specified.

13. Remove bladder, aluminum sheet, etc., and sand smooth excess adhesive at patch edges.

REPAIR PROCEDURE NO. 10

Note: This repair supplements Repair Procedure No. 4, when required.

1. To the extent practicable, remove damaged honeycomb using knife and scissors.

2. Mix 2-part adhesive and apply to reworked core area using wooden spatula.

3. Place heat source in a manner that heat is directed on rework area and temperature at surface is within prescribed range. Allow adhesive to cure for time specified.

4. Contour reworked area to restore original profile using abrasive paper.

REPAIR PROCEDURE NO. 11

Note: This procedure is same as Repair Procedure No. 10 except that repair area is greater, accounting for longer average time to accomplish.

This repair supplements Repair Procedure No. 5, when required.

APPENDIX V

EVALUATION OF MAJOR REPAIR PROCEDURE

To provide a preliminary evaluation of the repair procedure proposed, a trial repair was made of an existing rotor blade section with fiberglass skins. The repair was made under simulated field conditions, and the results generally demonstrated the feasibility of this approach.

This trial repair was made using Minnesota Mining's EC 2216 paste epoxy, which is a high-peel-strength adhesive that will cure at the moderate temperatures attainable with heating blankets using a 28-volt APU unit for a power source. (EC 2216 is also listed by Federal Stock No. 8040-788-2839). This adhesive was used throughout for bonding core to core and fiberglass patch to fiberglass skin. Other paste epoxy adhesives such as AEX 2007-N made by Adhesive Engineering Company and ADX 372/87 made by Dexter-Hysol, both of California, are also suitable for this purpose.

A variation of this repair which would simplify operations and yield better weight control would be to use the paste epoxy for the core bonds but to have a low-temperature-curing adhesive film that bonds with low pressures for the fiberglass to fiberglass bonds. This film would be pre-applied to the bonding surface of the patch and covered with a protective peel ply that would not be removed until just before bonding. Any such film would obviously need long-term storage properties at room temperature. One newly developed adhesive material that might serve the purpose is Loktac, Type S J 8001X, made by Minnesota Mining Industrial Special Products Department.

Heating pads used for this project were 12 inches square and rated at 5 watts per square foot. It is noted that temperatures recorded by the thermocouples during the repair reached 200°F, and they would have gone higher if not controlled. At the start of the repair, the temperatures attainable with this 28-volt APU unit arrangement were mostly conjectured. Ambient temperature at the time was 62°F.

A description of the complete procedure follows.

MATERIALS AND EQUIPMENT REQUIRED

1. Honeycomb core plug, prefabricated
2. Picture frame doubler of fiberglass, prefabricated
3. EC 2216 epoxy adhesive - paste
   105 grams base (white)
   150 grams accelerator (grey)
4. Two electric heating pads, 12" x 12"
5. Inflatable bladder with straps
6. Tire hand pump
7. Two thin aluminum plates, .010" x 12" x 12"
8. Serrated adhesive spreader
9. Wood tongue depressors for mixing adhesive
10. Disposable cups
11. One container methyl ethyl ketone (MEK)
12. Clean cheesecloth
13. One roll green Mylar tape, 2" wide
14. Teflon film, transparent, .0005" thick
15. Emery paper, #240
16. Scissors

NOTE: The above items would be supplied in the field kit, which would also include a wrap-around template to mark the cutout on both surfaces of the blade, plus a special hacksaw type blade and a long-bladed knife for cutting through the fiberglass skins and the core.

PROCESS FOR REPLACEMENT OF AFT STRUCTURE IN LARGE CUTOUT IN ROTOR BLADE

1. Position template to encompass complete damage area.

2. Use knife to sever skins and cut through core, top and bottom. Remove plug and even edges with hacksaw blade.

3. After cutting the hole to proper size, solvent wipe around periphery with MEK to remove all paint from surfaces to be bonded.

4. Mask off area approximately 1/8 inch beyond perimeter of patch, both surfaces (Figure 30).

Figure 30. Masking Blade Repair Area.

5. Lightly abrade bonding surfaces on both sides with #240 emery paper to remove gloss from skins but not to cut through the fibers of the fabric.

6. Solvent wipe abraded surfaces with MEK and clean cheesecloth. Wipe dry before solvent evaporates.

7. Mix 255 grams of EC 2216 paste epoxy adhesive.

8. Apply EC 2216 to exposed core edges, 4 sides, using the spatula and on the bonding surface around the hole using the finely serrated adhesive spreader (Figure 31).

Figure 31. Spreading Adhesive.

9. Remove protective peel ply from the flange of the insert (Figure 32).

Figure 32. Removing Peel Ply From Insert.

10. Spread adhesive on the bonding surface of the flange using the serrated spreader and on the exposed core edges on 4 sides using a spatula.

11. Position repair section into hole in blade and tape in place with 2-inch-wide green Mylar tape, straddling the joint edge along 4 sides (Figure 33).

Figure 33. Inserting Repair Section.

12. Position the thin Teflon film over the area and the .010-inch aluminum sheet on top of it, directly over the patch, and tape in place.

13. Turn the blade over and remove the protective peel ply from the bottom surface of the insert. Spread adhesive on the bonding surface of the plug and blade skins using the serrated spreader.

    <u>NOTE</u>: Bottom skin of plug had already been masked off to protect against squeeze-out of the adhesive during bonding.

14. Remove the protective peel ply from the bonding surface of the picture frame doubler and spread adhesive with the serrated spreader (Figure 34).

Figure 34. Removing Peel Ply From Doubler.

15. Position the doubler over the core plug joint and tape in place by 2-inch-wide green Mylar tape straddling the joint on all edges (Figure 35).

Figure 35. Positioning Doubler.

16. Position the thin Teflon film over the area and the .010-inch aluminum sheet on top of it, directly over the doubler, and tape in place.

17. Position the heating blanket and tape in place with the green Mylar tape.

18. Turn blade over and position 3 thermocouple wires, one at the center of the plug, one at the inboard edge and one at the trailing edge over the aluminum spline (test instrumentation only).

19. Position the heating blanket and tape in place with green Mylar tape.

20. Wrap inflatable bladder around the blade repair area, starting at the trailing edge. Apply the 4 straps and inflate to 10-15 psi (Figures 36 and 37).

Figure 36. Positioning Bladder.

Figure 37. Inflating Bladder.

21. Apply heat using 28 volts from APU source and cure for 2 hours minimum (Figure 38).

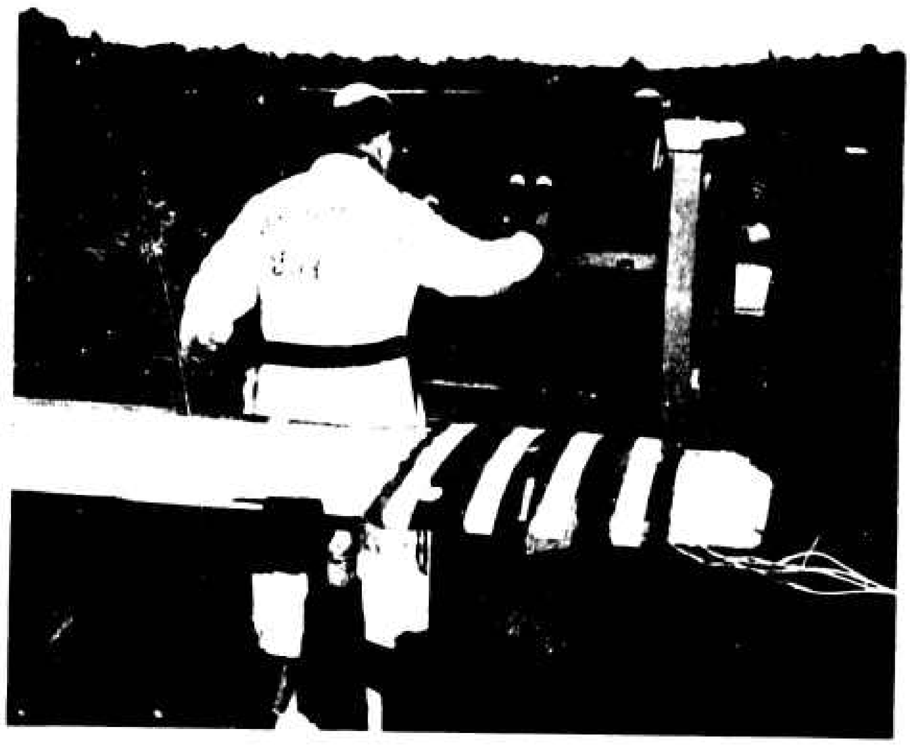
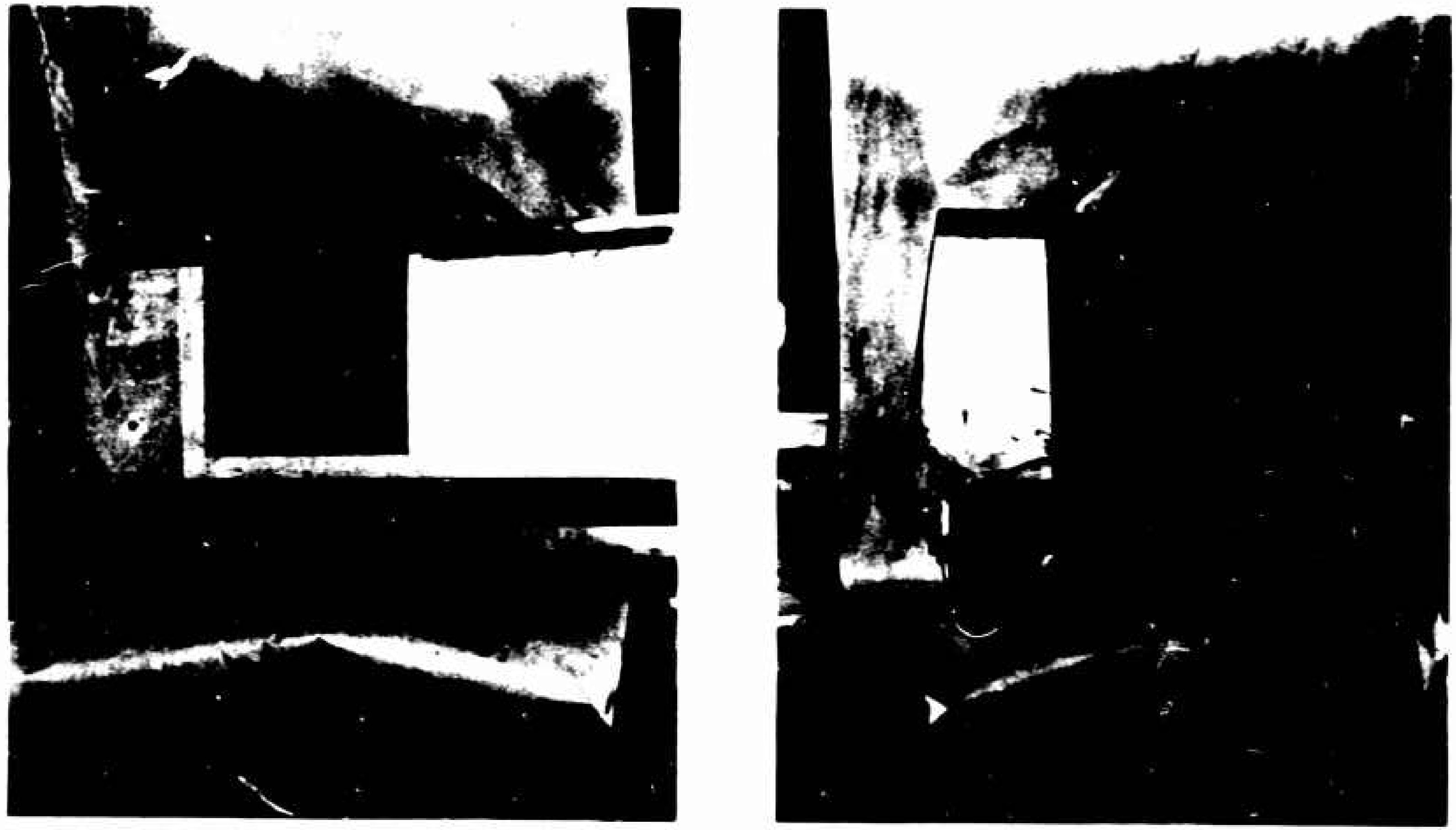


Figure 38. Starting Power Source To Heat Bond.

The completed repair is shown in Figure 39 prior to cleanup and painting. The surfaces of the doublers are out of contour and will slightly disturb the airflow; however, the precured doubler with stepped positioning of successive edges minimizes this effect. The number of steps and separate items used in this trial repair may be significantly reduced by use of an integrated repair kit designed specifically for this purpose in which an absolute minimum of materials and skill is required. The use of film adhesives and pressure bladder with integral heating blanket would make significant contributions to this goal.



(a) Upper Surface (b) Lower Surface

Figure 39. Completed Repair.

APPENDIX VI

UH-1 ROTOR BLADE DESIGN COST COMPARISONS

The following cost model values are being supplied by the Government to standardize the various rotor blade comparisons. The current UH-1 rotor blade values are listed together with values of the candidate blade that are considered relatively insensitive to variations in design. Where values of the candidate blade are not supplied, they are to be developed by the Contractor for use after approval by the Government Contracting Officer.

	Current UH-1	Candidate
Blade Life Hours	2500	-
Aircraft Life Hours	5000	Same
Aircraft Fleet Size	500-1000-2000	Same
Aircraft Attrition	Zero	Same
Blade Set Attrition	.0003/Flight Hr	Same
Time of Blade Initiation	Original Production	Same
Cost of One Blade	$3000.00	-
Experience Curve Position	10,000 Blades	Same
Blade Spares Inventory	30% of Installed	-
% Inherent Damage	Zero	Same
% External Damage	100%	Same
Blade Time Between Damage	425 Hours	Same
Repair Performance Degradation	Zero	Same
Cost Field, Org Mil Labor/Hr	4.00	Same
% Military Labor, Field	100%	Same
Field Overhead & Support Cost	Zero	Same
MMH Each Blade Removal	3.75	Same
MMH Disposition, Inspect	1.5	Same
MMH Repair, Field	-	-
Parts Materiel Cost/Repair (Fld)	$5.00	-
GSE, Tooling Cost/Repair(Fld)	Zero	-
MMH Obtain Replacement Blade	3.0	Same
MMH Ops, Inventory, Requisition	3.0	Same
MMH Blade Installation	3.75	Same
% Field Repairs Require Removal	100%	-
% Removed Blades Scrapped,Org	30%	-
% Removed Blades, Repaired, Org	12%	-
% Removed Blades to Depot Repair	58%	-

	Current UH-1	Candidate
% Depot Received Blades Scrapped	68%	-
% Depot Received Blades Overhauled	32%	-
Shipping, 8000 Mi, Surface, Blade	$90	Same
Shipping, 8000 Mi, Surface, M-T Container	$45	Same
Rotor Blade Container, Reuseable	200.00	Same
Preparation for Shipping, Field	70.00	Same
% Surface Shipping to CONUS	100%	Same
% Mil Air Shipping from CONUS	100%	Same
8000 Mi Mil Air Shipping	$130	Same
% Civilian Labor, Depot	100%	Same
Composite Civilian Labor Cost, Hr	$12	Same
Blade Overhaul Cost, Depot	$925	-
Depot Overhaul & Support Cost	Zero	Same
MMH Receive, Unpack, Depot	1.0	Same
MMH Inspect (100% of Rec'd), Depot	1.5	Same
MMH to Dispose of Scrap, Depot	.5	Same
Preparation for Shipping, Depot	$70	Same
Shipping Containers Required	30% of Installed	-

NOTES:

a. Develop R&D, prototype and production candidate blade costs, determine learning curve equation, assume previous production of 10,000 units and establish cost at 10,000 unit for use in cost model and comp rison with current UH-1 blade.

b. Conduct 3 separate cost runs for each fleet size, 500 - 1000 - 2000.

c. Aircraft utilization is 500 hours/year for 10 years, 5000 hour life.

d. Zero aircraft attrition permits the fleet size to remain constant throughout the analyses, replacing the blade sets at a rate of .0003/flight hour accounts for the new set of blades required as a result of attrition.

e. A complete scenario of damage events has been supplied: Type of damage, cause, location center, size, penetration, current blade repairability, scrappage or shipment to overhaul and repair time in MMH. A similar analysis will be made for each candidate blade following the same scenario sequence.

APPENDIX VII

DEVELOPMENT PLAN FOR REPAIRABLE MAIN ROTOR BLADES

SUMMARY

This appendix presents the plan for development of the recommended Repairable Main Rotor Blade concept. The proposed plan includes sufficient test substantiation to justify preliminary service trials of the blade on a quantity of H-1 helicopters in simulated field conditions. Service trial would include intentional damage and subsequent repair using the service kits and techniques developed in the course of the program for this purpose. It is intended that this program will provide sufficient background and experience in the application and use of repairable rotor blades that this general concept may be made a requirement on future Army procurements involving large quantities of rotor blades.

DISCUSSION

The following development plan is presented for the purpose of demonstrating in service the principles of the repairable main rotor blade and the savings that are attainable with this concept. The plan provides for sufficient test and substantiation of the blade to permit flying of a quantity of blades by service pilots for the purpose of obtaining an evaluation of the design under field conditions. The complete plan evaluates all aspects of the application of repairable blades to a fleet of helicopters including virtually all of the economic influences.

DEVELOPMENT PLAN

The plan includes six basic phases: Design and Analysis, Tooling, Bench Test, Whirl Test, Flight Test, and Service Evaluation. A detailed description of each of these phases follows.

Design and Analysis

The Design and Analysis phase makes maximum utilization of the work completed on the present program. Detailed design and complete analytical support however will require further effort to provide complete definition. Detailed drawings of all components, dynamic analysis of all significant flight conditions and flight loadings, stress analysis for all critical conditions and detailed design of repair kits are included in this phase. The analysis must define static strength requirements for limit load conditions and also fatigue strength requirements for all steady-state flight conditions.

Tooling

The tooling designed for this program should be permanent tooling capable of producing a quantity of blades at a low rate. Automation of processing is not jusitifiable at this time. The approach should anticipate a significant amount of skilled hand labor and should therefore minimize the number and complexity of tools. Following fabrication the tools should be evaluated in terms of the quality of the product they produce by destructive test of a sufficient quantity of blades or components to demonstrate a high level of consistent quality. Destructive test of at least four samples of each bond joint is anticipated. Tooling developed here should provide an excellent basis for the design of hard production tools on a subsequent program.

Bench Test

This phase of the program provides for static and fatigue test substantiation of the blade design both as new and as repaired. Static test includes one sample of the blade root, transition and a short length of basic airfoil section. Static test plan would include application of limit loads to the new specimen followed by unloadings, damage of the specimen in a representative manner, and loading to steady-state level flight loads. The specimen would then be repaired utilizing the repair kits and techniques designed for this purpose and the specimen subsequently static tested to ultimate load and then to failure under a complete set of flight loads. As a minimum the test should include centrifugal force, flatwise bending and edgewise bending. The repaired specimen should be capable of surpassing ultimate load requirements.

Fatigue test of a minimum of three blade root specimen and two outboard specimens is anticipated. The blade root specimen would include the transition area and a length of basic air-foil section. Two specimens would be tested in the new condition, one at high vibratory load levels to failure and the other at levels representative of high speed level flight. Root end fatigue testing should apply steady centrifugal force, flatwise bending and edgewise bending and would superimpose vibratory flatwise and edgewise bending. One blade root specimen containing representative repairs should be run at the high load level to failure for a direct comparison of the failure mode and cycles to failure to that of the new specimen.

Two outboard blade panels should be fatigue tested in flatwise bending, one specimen tested in the new condition and the other containing the maximum number of repairs permitted for that area. Test level should be high enough to produce failure for direct comparison of failure mode and cycles to failure.

Whirl Test

A pair of new rotor blades should be whirl tested for 150 hours with representative cyclic and collective control inputs. Following completion of this test a demonstration of the survivability of the design should be undertaken. This would include inflicting damage to the blade while rotating and evaluation of the resulting unbalance, out-of-track, or other behavior. The result of this behavior on a flight vehicle should be estimated.

The blades should then be repaired using the kits and techniques designed for this purpose and the blades subsequently whirled for a minimum of 100 hours or sufficient time to demonstrate the integrity of the repairs.

Flight Test

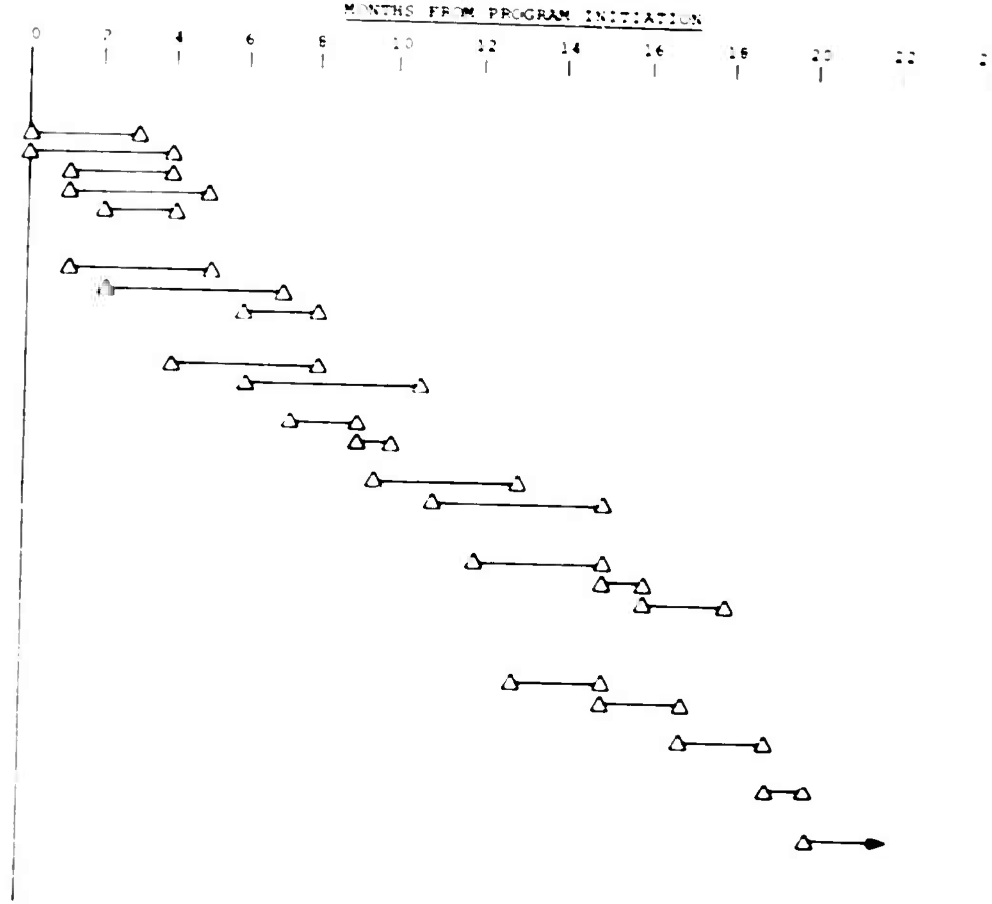
Flight test of the Repairable Main Rotor Blade concept should include a strain survey, limited structural demonstration, flying qualities and performance evaluation. These program elements should be conducted for new blades and the critical portions repeated after the blades have been intentionally damaged and repaired. The strain survey should cover all portions of the flight envelope that are important to an assessment of the fatigue life of the rotor blade including the maneuver spectrum. Structural demonstration should be flown in such a way as to demonstrate only the approved load factor-airspeed flight envelope of UH-1 helicopter with adequate build-up to insure that blade loads and stresses are within the strength capabilities of the blade. General flying qualities, vibration and performance should be compared to published data for the present UH-1 blade. These comparisons should be drawn for both the new and repaired configurations of the Repairable Main Rotor Blade.

At the end of the flight test program, a Data Review and Analysis phase is included. This phase is to review data from all phases of the program and evaluate the suitability of the Repairable Main Rotor Blade for flight by service pilots in an accelerated service evaluation. One of the key elements in this evaluation will be a calculation of the fatigue life of the blade for the UH-1 flight spectrum. Any deviations from this spectrum anticipated in the accelerated service trials shall also be investigated. A final report with recommendations for future effort shall be produced as a result of this phase.

Service Evaluation

The service evaluation of the Repairable Main Rotor Blade concept should be conducted by Army personnel at a facility selected by the Army. The contractor will supply five ship sets of rotor blades with spares and also a sufficient quantity of repair kits and materials. Technical advice and assistance shall be provided by the contractor at least at the outset of the service evaluation. The details and duration of the evaluation should be jointly agreed to by the contractor and the Army. Final results and conclusions to be drawn from the service evaluation shall be the responsibility of the cognizant Army technical personnel.

DEVELOPMENT SCHEDULE - REPAIRABLE MAIN ROTOR BLADE



TASK

1. DESIGN & ANALYSIS
   - DETAILED DESIGN
   - DYNAMIC ANALYSIS
   - CALCULATE FLIGHT LOADING
   - STRESS ANALYSIS
   - DETAILED REPAIR KIT DESIGN
2. TOOLING
   - TOOL DESIGN
   - TOOL FABRICATION
   - TOOL TRYOUT
3. BENCH TEST
   - TEST RIG DESIGN & FABRICATION
   - TEST SPECIMEN FABRICATION
   - STATIC TESTS
     - BASIC DESIGN
     - DAMAGE TOLERANCE
   - FATIGUE TESTS
     - BASIC DESIGN
     - REPAIRS
4. WHIRL TEST
   - BASIC SUBSTANTIATION
   - SURVIVABILITY DEMONSTRATION
   - REPAIRS
5. FLIGHT TEST
   - FLIGHT TEST (NEW BLADE)
     - STRAIN SURVEY, STRUCTURAL DEM.
     - FLYING QUALITIES, PERFORMANCE
   - FLIGHT TEST (REPAIRED BLADE)
     - COMPARATIVE STRAINS, PERFORMANCE, VIBRATION & FLYING QUALITIES
   - DATA REVIEW & ANALYSIS
6. SERVICE EVALUATION
   - 5 SHIP SETS OF BLADES AND REPAIR KITS DELIVERED TO ARMY ACTIVITY FOR EVALUATION BY MAINTENANCE PERSONNEL UNDER SIMULATED FIELD CONDITIONS

ESTIMATED MAN-HOUR DISTRIBUTION REPAIRABLE MAIN ROTOR BLADE

MONTHS FROM PROGRAM INITIATION

TASK	0		2		4		6		8		10		12		14		16		18	20	TOTALS
1. DESIGN AND ANALYSIS																					
DETAILED DESIGN	960	960	960																		2880
DYNAMIC ANALYSIS	160	160	160	160																	640
CALCULATE FLIGHT LOADING		160	160	160																	480
STRESS ANALYSIS		160	160	160	320																800
DETAILED REPAIR KIT DESIGN			640	640																	1280
2. TOOLING																					
TOOL DESIGN		320	320	320	320																1280
TOOL FABRICATION			1600	1600	1600	1600	1600														8000
TOOL TRYOUT							800	800													1600
3. BENCH TEST																					
TEST RIG DESIGN AND FABRICATION					480	480	480	480													1920
TEST SPECIMEN FABRICATION							1700	1700	160	160	160										3880
STATIC TESTS:																					
BASIC DESIGN								640	640												1280
DAMAGE TOLERANCE										640											640
FATIGUE TESTS:																					
BASIC DESIGN										640	640	640	640								2560
REPAIRS											480	480	480	480	480						2400
4. WHIRL TEST																					
BLADE AND REPAIR KIT FABRICATION									1700												1700
BASIC SUBSTANTIATION													640	640	640						1920
SURVIVABILITY DEMONSTRATION																640					640
REPAIRS																	640	640			1280
5. FLIGHT TEST																					
BLADE AND KIT FABRICATION										1700	1700										3400
NEW BLADES TEST														2240	2240	2240	2240				8960
REPAIRED BLADES TEST																		2240	2240		4480
DATA REDUCTION																				2240	2240
6. SERVICE EVALUATION																					
BLADE AND KIT FABRICATION												1700	1700	1700	1700	1700					8500
DELIVERY																				40	40
TOTALS	1120	1760	4000	3040	2720	2080	4580	3620	2500	3140	2980	2820	3460	5060	5060	4580	2880	2880	2240	2280	62,800

DEVELOPMENT COSTS

REPAIRABLE MAIN ROTOR BLADE

TASK	ESTIMATED COST
1. DESIGN AND ANALYSIS	$ 128,000
2. TOOLING	277,000
3. BENCH TEST	213,000
4. WHIRL TEST	87,000
5. FLIGHT TEST	345,000
6. SERVICE EVALUATION	142,000
TOTAL	$1,192,000

RECOMMENDATIONS

It is recommended that the development plan defined here be undertaken for the purpose of demonstrating the feasibility, practicality and cost effectiveness of the Repairable Main Rotor Blade concept. As a result of conducting this program, it will be possible for the Army to specify with confidence the characteristics that are attainable in future repairable rotor blades and the benefits that will be derived through this approach.

San Antonio Air Materiel Area	1
Air Force Aero Propulsion Laboratory	1
Air Force Materials Laboratory	4
Air Force Flight Dynamics Laboratory	5
Aeronautical Systems Division, AFSC	2
Air Force Avionics Laboratory	1
Naval Air Systems Command	13
Chief of Naval Research	3
Naval Research Laboratory	1
Naval Safety Center	2
Naval Air Rework Facility	1
Naval Air Test Center	1
Naval Air Development Center	3
Naval Weapons Laboratory	1
Naval Ship Research & Development Center	3
Marine Corps Liaison Officer, Army Transportation School	1
U.S. Coast Guard	1
Transportation Systems Center	1
NASA Headquarters	1
Ames Research Center, NASA	2
Langley Research Center, NASA	1
Manned Spacecraft Center, NASA	1
Scientific & Technical Information Facility, NASA	2
Department of Transportation Library	1
Eastern Region Library, FAA	1
Federal Aviation Administration, Washington	3
Civil Aeromedical Institute, FAA	1
Bureau of Aviation Safety, National Transportation Safety Board	1
Government Printing Office	1
Defense Documentation Center	2