NASA Contractor Report 172126

DESIGN, FABRICATION, INSTALLATION AND FLIGHT SERVICE EVALUATION OF A COMPOSITE CARGO RAMP SKIN ON A MODEL CH-53 HELICOPTER

D.W. Lowry, and M.J.Rich

SIKORSKY AIRCRAFT
DIVISION OF UNITED TECHNOLOGIES CORPORATION
Stratford, Conn.

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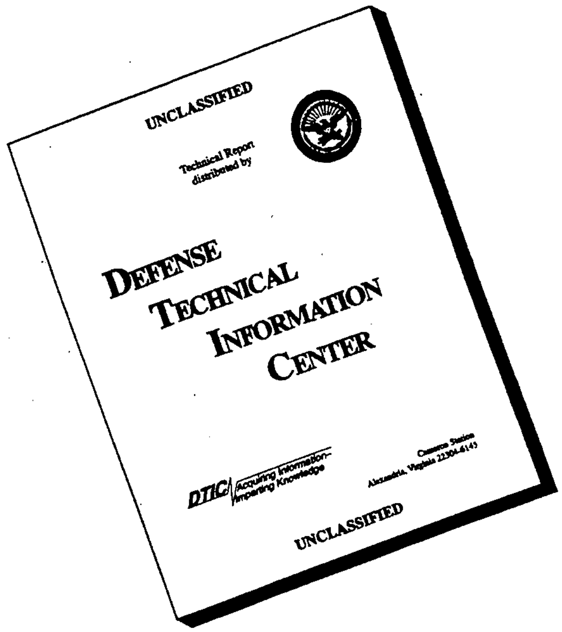

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April, 1983

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Stratford, Conn.

for

NASA

National Aeronautics and
Space Administration

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FOREWORD

This report was prepared by Sikorsky Aircraft, Division of United Technologies Corporation, under NASA Contract NAS1-14447 and covers the work performed during the period of June 1976 through December 1982. This program was jointly funded by the Materials Division of NASA-Langley Research Center and Structures Laboratory, U.S. Army Research and Technology Laboratory. The contract is monitored by Mr. Donald Baker of the Materials Processing and Applications Branch.

The authors wish to acknowledge the contributions of the following Sikorsky personnel: S. Ciardullo, analysis; J. Roberts, design; and G. Mardoian, coupon testing.

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F_{SU}	Ultimate shear strength, MPa (p.s.i.)
K	Statistical factor to account for sample size, non-dimensional
K/E	Kevlar/Epoxy
ℓ	Rivet pitch or spacing, mm (in.)
$\bar{P}$	Mean bearing strength, N (lbf.)
M.S.	Margin of safety, non-dimensional
P_B	"B" Allowable strength, N (lbf)
q	Shear flow, N/mm (lbf/in)
t	Thickness, mm (in.)
σv	Coefficient of Variation, Standard Deviation in Stress (or load) divided by mean strength (or load), non-dimensional

DESIGN, FABRICATION, INSTALLATION AND FLIGHT-SERVICE EVALUATION OF A COMPOSITE CARGO RAMP SKIN ON A MODEL CH-53 HELICOPTER*

By

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Division of United Technologies Corporation
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SUMMARY

This report presents the work performed for the installation of a composite skin panel on the cargo ramp of a Sikorsky CH-53D marine helicopter. The composite material is of Kevlar/Epoxy (K/E) which replaces aluminum outer skins on the aft two bays of the ramp. The cargo ramp aft region was selected as being a helicopter airframe surface subjected to possible significant field damage and would permit an evaluation of the long term durability of the composite skin panel.

A structural analysis was performed and the skin shears determined. Single lap joints of K/E riveted to aluminum were statically tested. The joint tests were used to determine bearing allowables and the required K/E skin gage. K/E skin panels riveted to aluminum edge members were tested in a shear fixture to confirm the allowable shear and bearing strengths.

Impact tests were conducted on aluminum skin panels to determine energy level and damage relationship. K/E skin panels of various ply orientations and laminate thicknesses were then impacted at similar energy levels.

The results of the analysis and tests were used to determine the required K/E skin gages in each of the end two bays of the ramp. The most aft K/E skin bay is 2.03 mm (.080 in.) thick which was determined from the impact tests. The other K/E skin bay is 1.015 mm (.040 in.) thick, which was determined from the strength criteria where bearing was the critical factor. The K/E skin panel replaces 7075-T6 aluminum skin of 1.27 mm (.050 in.) and 0.63 mm (.025 in.) thick, respectively. The weight of the modified ramp with the K/E skin panel installed did not change.

*The contract research effort which has led to the results in this report was financially supported by the Structures Laboratory, USARTL (AVRADCOM).

An epoxy mold was fabricated from an available stretch forming die used to form the production aluminum skins of the ramp. The K/E skin panel was laid up and cured in that mold. The panel and six (6) K/E coupons were shipped to the Naval Air Repair Facilities (NARF) at Pensacola, FL. A Sikorsky airframe mechanic and an airframe installer were sent to NARF to perform the skin and coupon installation. The ramp with the modified skin and coupons, were installed on a CH-53 marine helicopter, serial number 157741, on May 14, 1981. The helicopter was returned to its base of operation at New River, N.C., on September 8, 1981.

The first field inspection of the Kevlar skin panel was conducted in December of 1982. At that time, the Kevlar skin appeared to be in good condition. One Kevlar coupon was removed and sent to NASA Langley. At the end of each year, one (1) coupon will be removed and sent to NASA for testing.

SECTION 1.0 INTRODUCTION AND TECHNICAL BACKGROUND

1.1 INTRODUCTION

There is a need for flight service experience with woven K/E composite material under severe operating conditions. The cargo ramp of the CH-53 Marine helicopter was selected as the candidate structure to assess durability of woven K/E skins. As illustrated in Figure 1, the cargo ramp is located in the aft bottom region of the helicopter fuselage. The aft end of the ramp is subject to possible service damage when it is lowered to the ground for loading. The ramp may also be subjected to damage from ground surface debris.

The required tasks for this program are:

1. Conduct a stress analysis of the aft ramp section outer skin where K/E will replace the current aluminum skin.
2. Design, fabricate and test flat shear panels of K/E riveted to aluminum edge members.
3. Fabricate and test aluminum and K/E impact specimens.
4. Construct a mold and tooling to fabricate one K/E skin panel and twelve 177.8 mm (7 in.) x 177.8 mm (7 in.) coupons.
5. Specify a general repair procedure for the K/E skin panel.
6. Rework a CH-53 Cargo ramp furnished by the government, and install the K/E skin panel and six coupons. Send six additional coupons to NASA Langley.
7. Inspect the ramp with the K/E skin for a period of five years. At the end of each year, remove one coupon of K/E from the ramp and send to NASA Langley. One coupon is a spare.

FIGURE 1 CH-53D CARGO RAMP.

1.2 TECHNICAL BACKGROUND

The present CH-53 cargo ramp, as sketched in Figure 2, is constructed of aluminum beams, floor panels, and outer aluminum skins supported by stiffeners. The major portion of the skins are .63 mm (.025 in.) thick of 7075-T6 aluminum. The thickest skin panel is 1.27 mm (.050 in.) thick, under the aft end of the ramp from ramp bulkhead No. 6 to the canted closing bulkhead. The purpose of the thicker panel is to provide a wear/impact resistant/damage tolerant structure should the aft end of the ramp strike rough terrain. The .63 mm (.025 in.) thick skin panels provide torsional strength and rigidity should only one side of the ramp make contact with the ground when cargo or wheeled vehicles are being loaded or off loaded from the aircraft. The aluminum aft skin portion of the ramp, approximately 508 mm (20 in.) long by 2032 mm (80 in.) wide, is replaced with Kevlar/Epoxy.

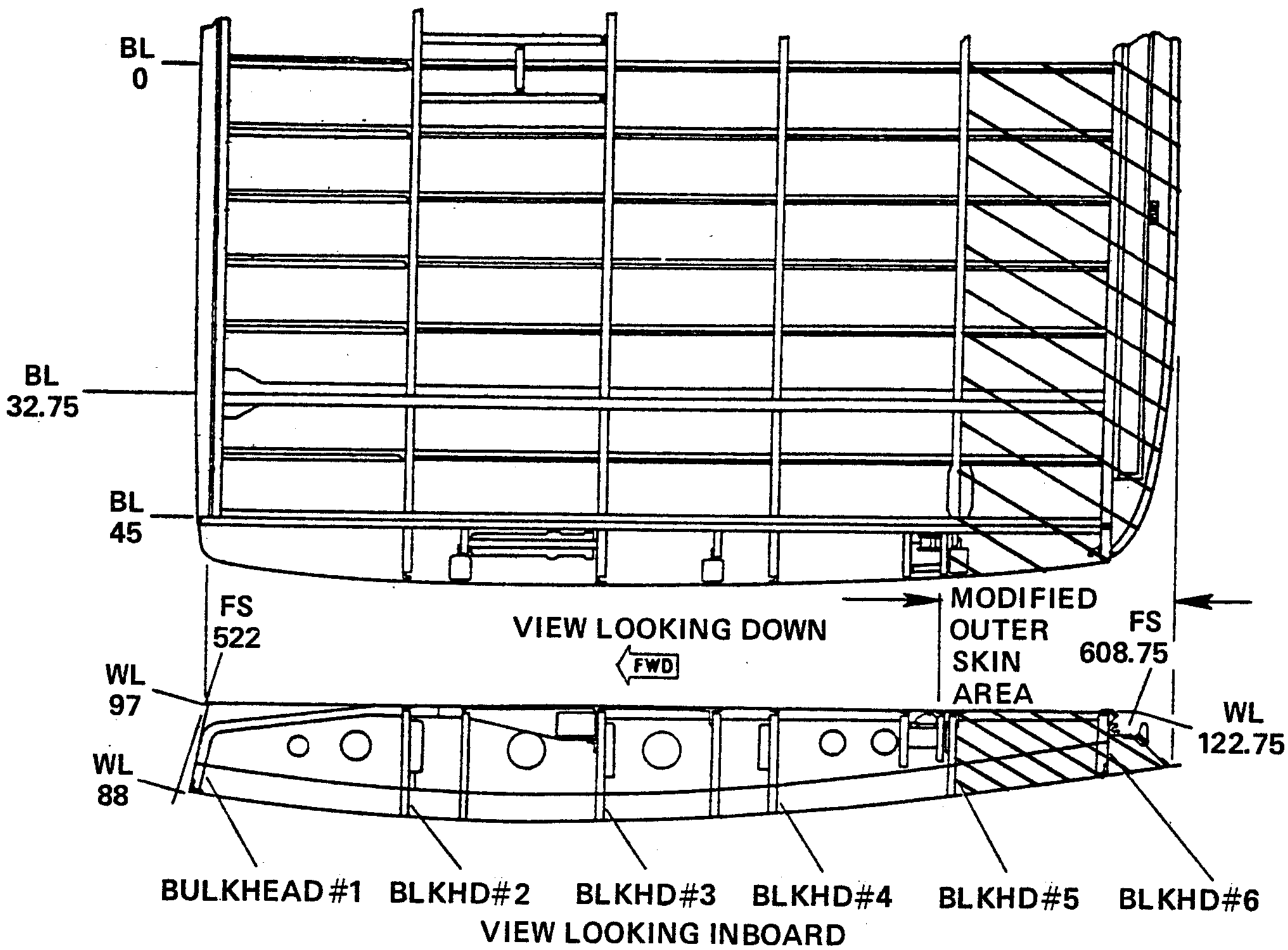

FIGURE 2 SKETCH OF RAMP STRUCTURE

SECTION 2.0 ANALYSIS AND DESIGN

2.1 RAMP DESIGN LOAD CRITERIA

The cargo ramp of the CH-53 helicopter, hinged at fuselage station 522 is designed to the loads criteria of Reference (1). The design condition for the ramp outer skin is the ramp extended to the ground with one aft corner supported and the opposite corner 76.2 mm (3.0 in.) off the ground. A wheeled vehicle is symmetrically placed such that an axle weight of 2.33 Mg (5150 lbm) is at the aft end of the ramp at a limit load factor of 1.5 g's. This condition produces a twisting of the ramp which causes maximum shears on the outer skin.

2.2 DESIGN SKIN LOAD

A Sikorsky shear and bending analysis computer program was used to determine the maximum skin shear flow for the K/E skin panel. The maximum ultimate shear flow is 70.0 N/mm (400 lbf/inch).

2.3 DESIGN ALLOWABLES

The K/E skin is constructed with DuPont Kevlar-49 fiber, 285 style fabric prepregged with a 176.6°C (350°F) cure 5143 DuPont epoxy resin and laid up at ±45° for maximum shear strength. The typical shear strength of this material is reported as being 165 MPa (24,000 psi) (Reference 2). A reduction factor of 25 percent is used for a design ultimate stress of 124 MPa (18,000 psi).

The minimum permissable skin gage, t, is determined from:

$$t_{REQ'D} = \frac{q}{F_{SU}} = \frac{70.0}{124} = .564 \text{ mm } (0.022 \text{ in.})$$

Using a nominal K/E ply thickness as .254 mm (.010 in.) thick, a minimum of 3 plies would be required for the shear condition.

The next stress requirement is bearing of the K/E skin with the existing fastener pattern of the aluminum skins. The fasteners were 3.175 mm (.125 in.) diameter*, at 20.32 mm (.8 in.) spacing. However, it became apparent that upon removing the aluminum skins, the rivet hole size would be increased. Therefore, it was decided that 3.96 mm (.156 in.)** fasteners would be required and all tests for rivet bearing allowables were conducted using the 3.96 mm diameter fastener.

*Protruding head aluminum rivets
**Diameter protruding head aluminum rivets

The final evaluation for the bearing allowable is to be determined by shear panel tests. However, to determine a realistic, statistical design ("B") value single lap bearing tests were conducted.

The test coupon shown in Figure 3 is almost representative of the K/E skin installation, i.e., single over lap, same aluminum gage, four ply K/E skin and 3.96 mm diameter fasteners. However, this test method induces bending which may not be present in a total shear panel. The K/E bearing tests were conducted with two different drill sizes.

A standard size drill (4.06 mm (0.160 in.) diameter) caused "fuzzing" in the hole. A larger drill (4.21 mm (0.166 in.) diameter) was used since the fuzzing caused some hole diameter contraction. The final check showed that the nominal drill hole size resulted in a better bearing strength although the rivet was a tight fit when inserted into the hole.

In addition, tests were conducted using the same thickness of fiberglass to assess their comparative strengths with K/E.

The test results are tabulated in Table I. The data shows that (a) nominal drill (4.06 mm (0.160 in.) diameter) provides higher allowables for K/E and (b) the static bearing strength of the K/E is comparable with the fiberglass. The "B" allowables shown in Table I, are determined using the statistical tables of Reference 3.

$$P_B = \bar{P} \quad 1 - \frac{K\sigma v}{100}$$

Where

$\bar{P}$ = mean bearing strength

σv = coefficient of variation, standard deviation/mean strength

K = factor for number of test specimens (Ref. 3)

TABLE I

Single Lap Test Results of Kevlar/Epoxy and Fiberglass/Epoxy Riveted to Aluminum.

Specimen Type	N Number of Specimens	$\bar{P}$ Mean Bearing Load N, (lbf)	σv Coefficient of Variation (Percent)	"B" Allowable N, (lbf)
Kevlar-Epoxy (With 4.06 mm (.160) Drill)	5	2366 (532)	6.41	1850 (416)
Kevlar-Epoxy (With 4.21 mm (1.66) Drill)	5	2058 (463)	7.41	1538 (346)
Fiberglass-Epoxy (With 4.06 mm (.160) Drill)	5	2186 (491)	2.3	2015 (453)

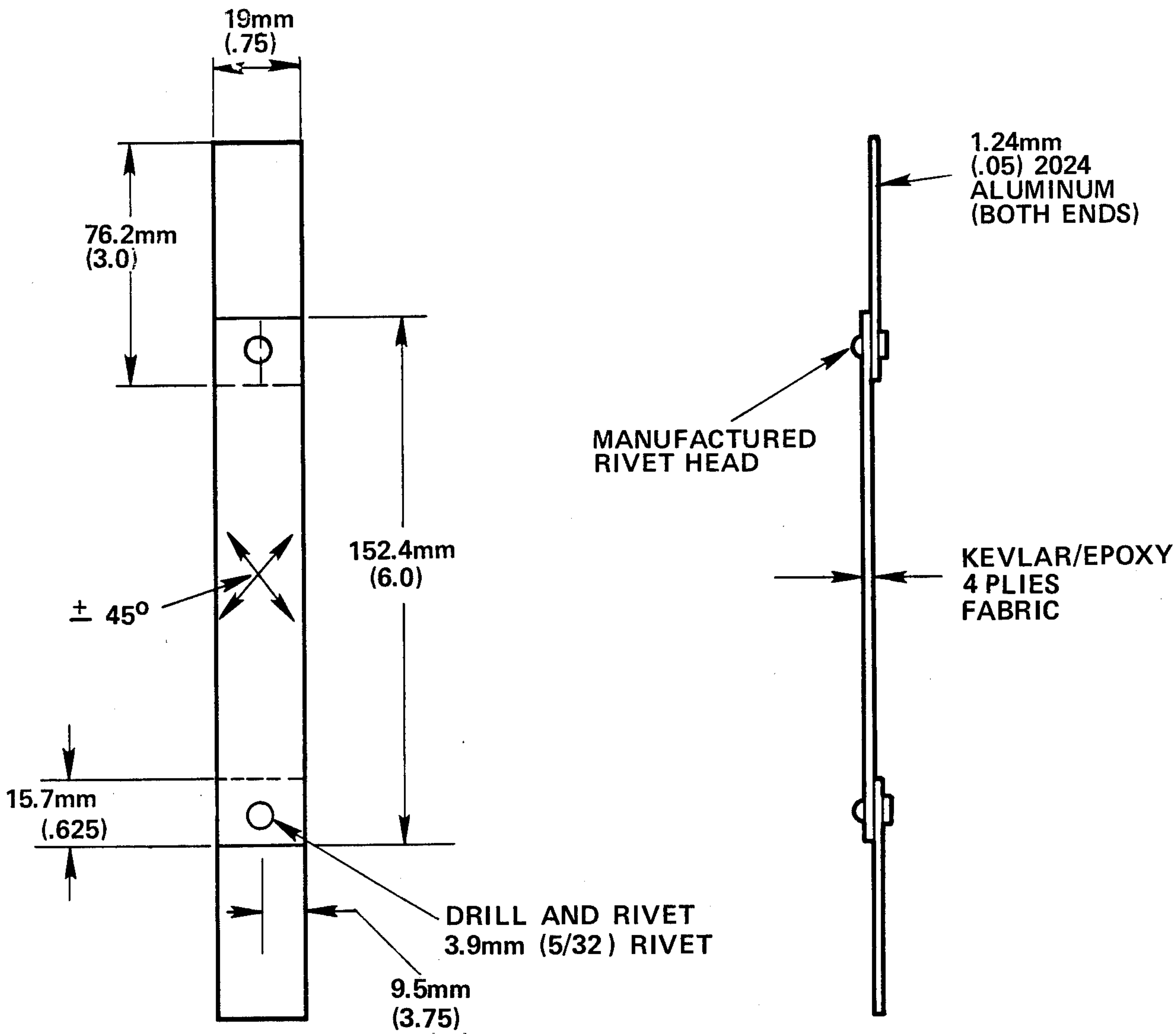

FIGURE 3 KEVLAR/EPOXY–ALUMINUM RIVETED TEST SPECIMEN

2.4 STRENGTH ANALYSIS

A 3 ply K/E skin is required for an ultimate shear flow of 70.0 N/mm (400 lbf/in). However, the bearing strength of a riveted joint is more critical. The load per rivet is:

$$P = q\ell$$

where

q = shear flow N/mm
ℓ = rivet spacing (pitch), mm

$$P = 70.0 \times 20.32 = 1422\text{N (320 lbf)/Rivet}$$

The "B" allowable for K/E, 4 ply, is 1850 N/rivet (416 lbf/rivet), as given in Table 1. The margin of safety for the riveted K/E skin is:

$$\text{M.S.} = \frac{P_B}{P} - 1 = \frac{1850}{1422} - 1 = .30$$

In addition, three shear panel tests were conducted as shown in Figure 4. The K/E panels were four plies thick, oriented at ±45°. 7075-T6 aluminum edge members were attached to the Kevlar panels with 3.96 mm (.156 in.) diameter rivets at 20.32 mm (.8 in.) spacing.

The fracture mode for each test was bearing of the K/E with an applied load of 28.5 kN (6400 lbf), 30.6 kN (6880 lbf) and 29.0 kN (6520 lbf). The corresponding average shear load was 136. N/mm (778 lbf/in) which results in rivet load of 294.4 N/rivet (662 lbf/rivet). It should be noted that the panel mean test results are about seventeen (17) percent higher than the single lap values presented in Table 1 and confirm that the bearing allowables are conservative.

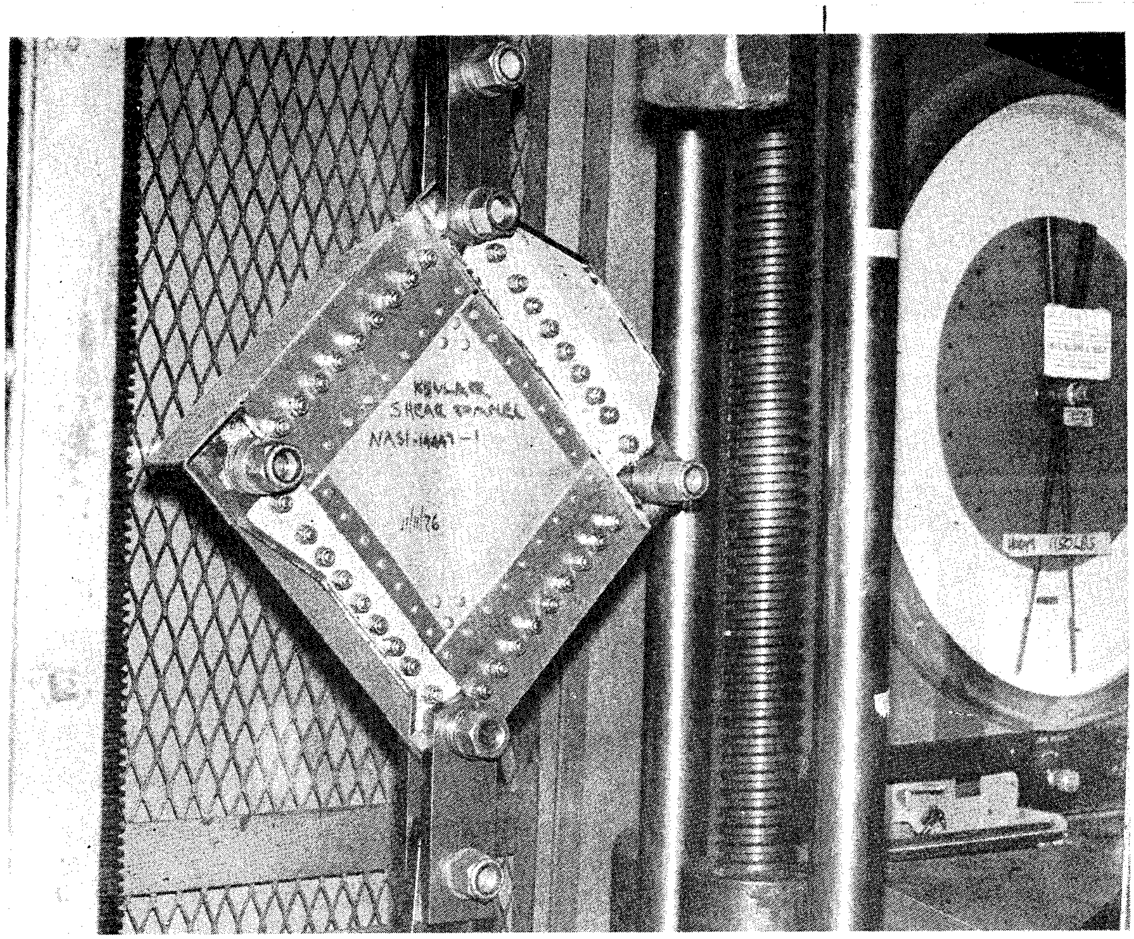

FIGURE 4 PICTURE FRAME SHEAR PANEL TEST SET UP.

SECTION 3.0 KEVLAR/EPOXY IMPACT DAMAGE TESTS

The most aft bay (bulkhead 6 aft) of the cargo ramp is constructed using a 1.27 mm (.050 in.) thick 7075-T6 aluminum skin. This 1.27 mm gage is twice that used in the other skin portions of the ramp. The increased gage was to provide greater damage tolerance for field conditions. The K/E skin panel, replacing the 1.27 mm aluminum skin, was sized by a damage criteria as follows:

1) The 1.27 mm aluminum skin panel was impacted by a 2.27 kg (5 lbm) steel rod (38.1 mm (1.5 in.) diameter), with a rounded end, at various drop heights as shown in Figure 5. The design impact energy was selected as 10.2 joules (7.5 ft-lb). That energy value corresponds to a 1.27 mm (.050 in.) dent (see Figure 6) in a flat panel. Impact energies greater than 10.2 joules caused the panels to "fold" even though through penetration did not occur.

2) The criteria for the K/E panel impact was that for the 10.2 joules energy level and no damage to the outer four ply structural skin to ensure full residual design load capability.

The aluminum and K/E panel impact tests are presented in Table II. Additional panels of 1.27 mm thick 2024-T3 aluminum were impacted to provide comparative data. The K/E data is not plotted in Figure 6 since the damage mode is not related to depth of dent, but delamination or fiber fracture.

The results of the tests were that an eight ply K/E skin would be used for the bay aft of bulkhead 6.

The minimum undamaged K/E skin was specified as four plies due to rivet bearing requirements, therfore, there appears to be no change in weight compared with the original aluminum skins. If the structure were of bonded components, some weight savings using K/E should be realized.

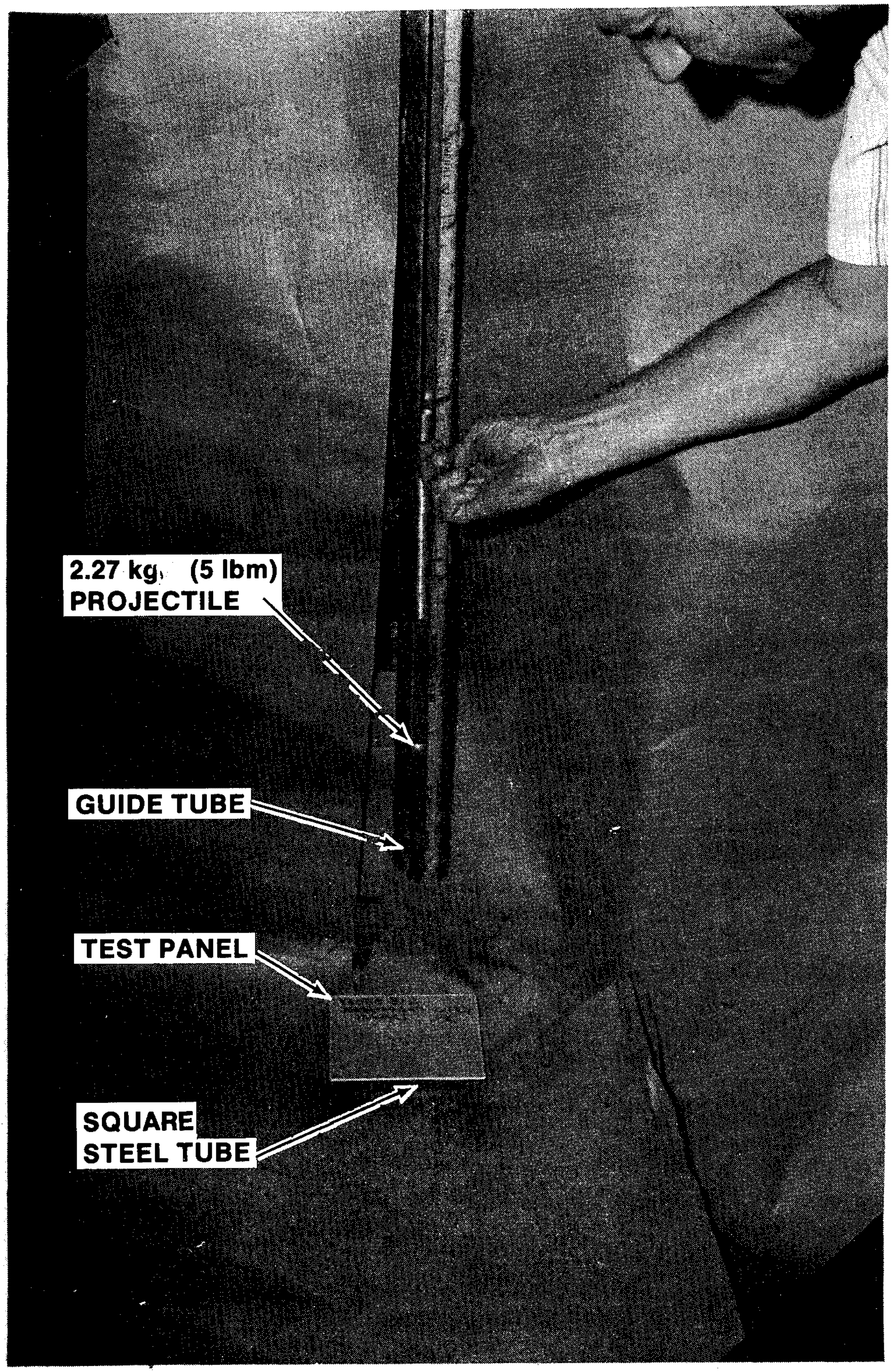

FIGURE 5 PANEL IMPACT TEST SET UP.

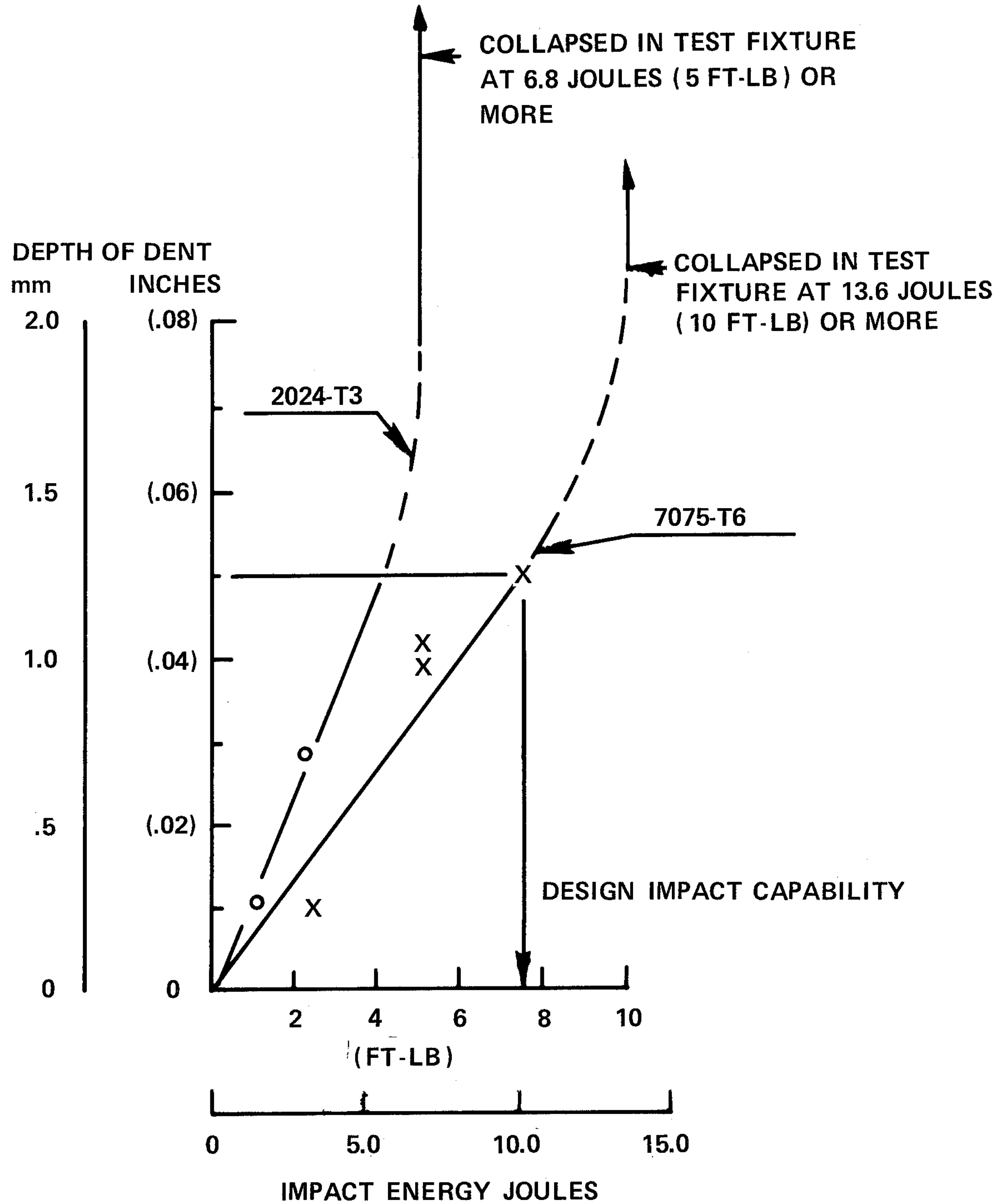

FIGURE 6 IMPACT ENERGY AS A FUNCTION OF DEPTH OF DENT FOR 2024-T3 AND 7075-T6 ALUMINUM PANELS

TABLE II IMPACT STRENGTH COMPARISON
OF ALUMINUM AND KEVLAR SKIN PANELS - TEST RESULTS

SPECIMEN		IMPACT ENERGY JOULES (FT LB)	RESULTS	
7075-T6 Alum. 1.27 mm (.050)			Depth of Dent	
	-1	40.7 (30.0)		Severe Damage
	-2	13.5 (10.0)		Severe Damage
	-3	6.7 (5.0)	.98 mm (.039)	Dent
	-4	6.7 (5.0)	1.06 mm (.042)	Dent
	-5	10.2 (7.5)	1.27 mm (.050)	Dent
	-6	3.4 (2.5)	.25 mm (.010)	Dent
2024-T3 Alum. 1.27 mm (.050)				
	-1	10.2 (7.5)		Severe Damage
	-2	10.2 (7.5)		Severe Damage
	-3	6.7 (5.0)		Severe Damage
	-4	3.4 (2.5)	.71 (.028)	Dent
	-5	1.7 (1.25)	.27 (.011)	Dent
Kevlar-49	6 Ply			
± 45°	-1	13.5 (10.0)	Damaged 3 Back Plies	
	-2	6.7 (5.0)	Damaged Outer Back Ply	
	-3	3.4 (2.5)	Damaged Outer Back Ply	
± 45°	8 Ply			
	-1	13.5 (10.0)	Damaged Front & Back Ply	
	-2	10.2 (7.5)	Damaged 2 Back Plies	
	-3	6.7 (5.0)	Damaged Back Ply	
	-4	3.4 (2.5)	No Damage	
± 45°	10 Ply			
	-1	13.5 (10.0)	Damaged Back Ply	
	-2	10.2 (7.5)	Damaged Back Ply	
	-3	6.7 (5.0)	Damaged Back Ply	
	-4	3.4 (2.5)	No Damage	
4 Ply ± 45° 2 Ply 0°				
	-1	13.5 (10.0)	Damaged 3 Back Plies	
	-2	10.2 (7.5)	Damaged 3 Back Plies	
	-3	6.7 (5.0)	Damaged 3 Back Plies	
	-4	3.4 (2.5)	Damaged Back Ply	
4 Ply ± 45° 4 Ply 0°				
	-1	13.5 (10.0)	Damaged All Plies	
	-2	10.2 (7.5)	Damaged 4 Back Plies	
	-3	6.7 (5.0)	Damaged 2 Back Plies	
	-4	3.4 (2.5)	Damaged Back Ply	

SECTION 4.0 TOOLING AND KEVLAR/EPOXY SKIN FABRICATION

4.1 TOOL FABRICATION

An epoxy mold, female type, was constructed to the outboard mold lines of the ramp skin. The mold was constructed from a plaster mockup of the CH-53 ramp that has been used to develop stretch forming dies for the aluminum skins. A wax build up was applied to the plaster mockup to simulate the Kevlar skin thickness. Epoxy was applied over the wax and a base was constructed to provide support for the epoxy. Trim lines were then scribed into the mold. The mold extended approximately 100 mm (4) beyond the trim lines. The epoxy mold is shown in Figure 7.

4.2 KEVLAR/EPOXY SKIN AND COUPON FABRICATION

K/E Fabric Style 285 was laid up in the mold per drawing requirements. The style 285 fabric was used because of the good draping characteristics of the fabric.

Twelve coupons of the same material as the skin panel were fabricated. Six coupons (each 17.8 cm (7 in.) x 17.8 cm (7 in.) x 1.02 mm (.040 in.) were sent to NASA. The other six were installed on the ramp.

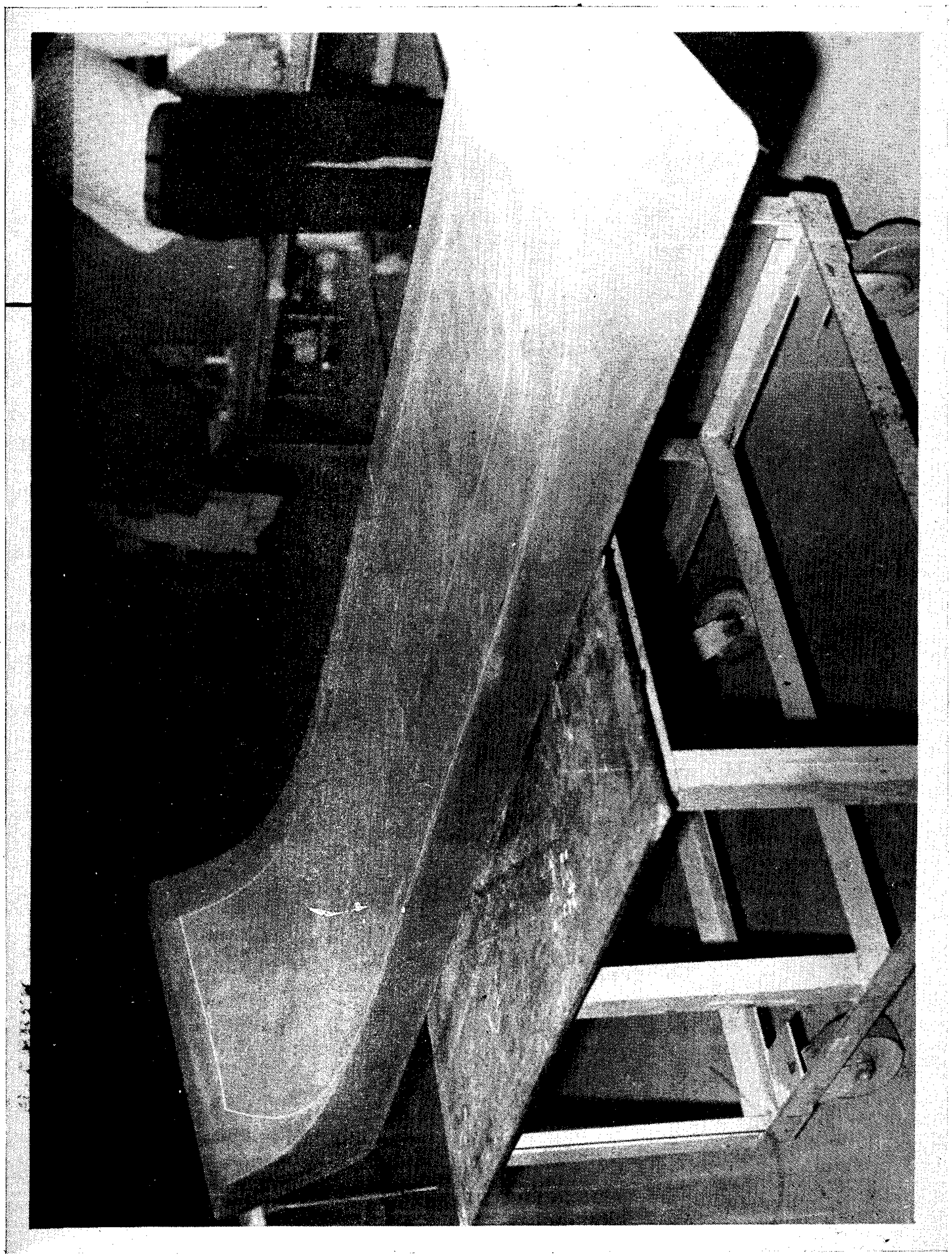

FIGURE 7 EPOXY MOLD FOR KEVLAR SKIN

SECTION 5.0 RAMP INSTALLATION AND INSPECTION

5.1 SKIN/COUPON INSTALLATION

A Kevlar skin panel and six (6) Kevlar coupons were shipped to the Naval Air Repair Facilities (NARF) at Pensacola, FL. A Sikorksy airframe mechanic and an airframe installer were sent to NARF to perform the skin and coupon installation. The ramp with the modified skin and coupon, shown in Figure 8, were installed on a CH-53 marine helicopter, serial number 157741, on May 14, 1981. The helicopter was returned to its base of operation at New River, N.C., on September 8, 1981. The weight of the modified ramp with the K/E skin panel did not change compared to the weight before the modification.

5.2 INSPECTION

The first field inspection of the Kevlar skin panel was conducted in December of 1982. At that time, the Kevlar skin appeared to be in good condition. One Kevlar coupon was removed and sent to NASA Langley. At the end of each year, one (1) coupon will be removed and sent to NASA for testing. Total flight time of the aircraft with the modified ramp installed was 382.9 hours.

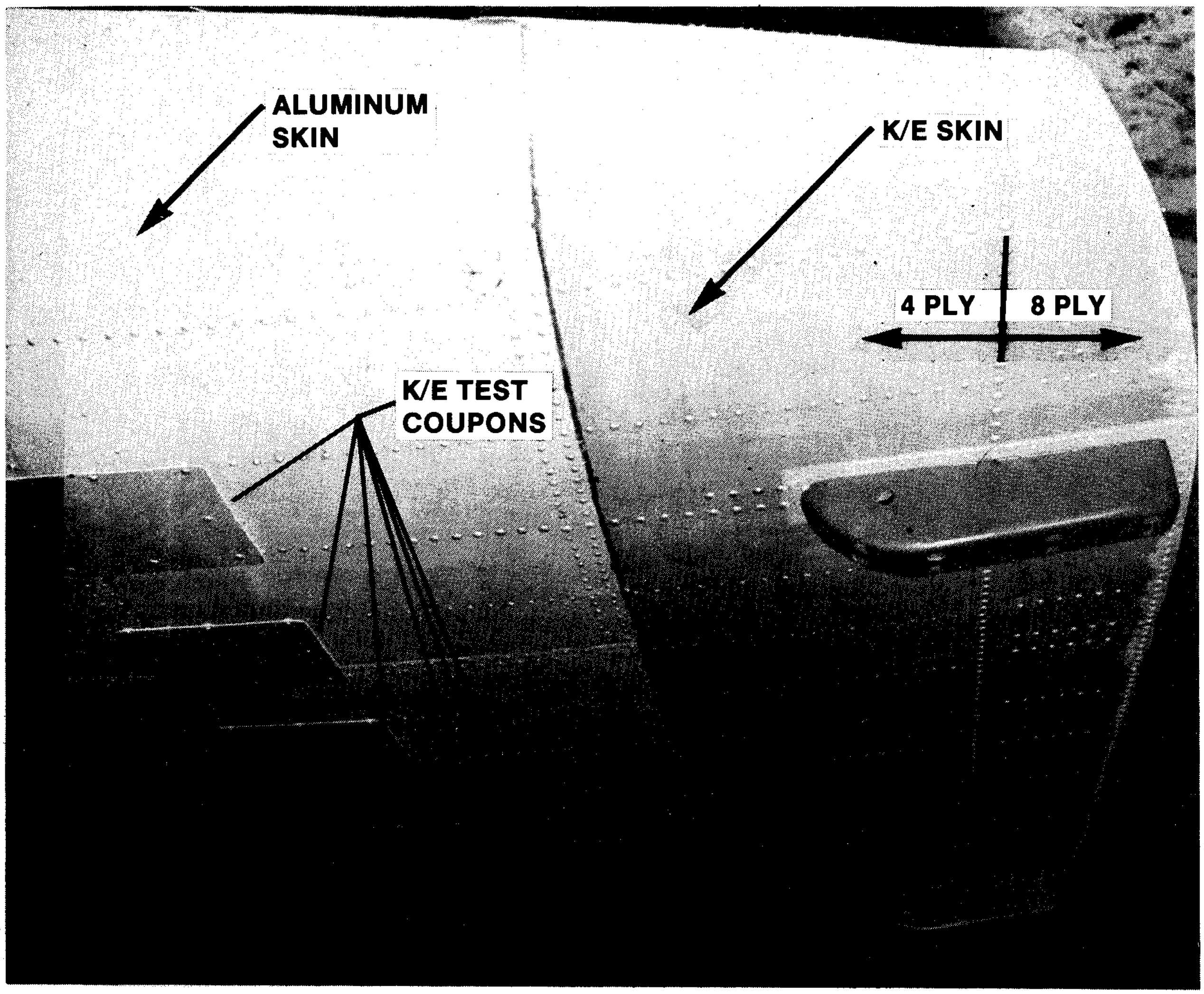

FIGURE 8 COMPLETED RAMP WITH KEVLAR/EPOXY SKIN PANEL AND TEST COUPONS INSTALLED. (PHOTO COURTESY OF U.S. NAVY)

SECTION 6.0 REPAIR OF KEVLAR/EPOXY SKIN

The following is a general guide for the repair of the Kevlar/ Epoxy skin panel on the cargo ramp.

6.1 REQUIRED MATERIALS

1) Dry Fiberglass, Fabric, Type 7781 (Burlington Industrial Fabrics, Rockleight, NJ) or equivalent.

2) Epon 828, Type I Resin Base and DTA Curing Agent (Shell Plastics, Houston, TX) or equivalent.

6.2 REQUIRED TOOLS AND EQUIPMENT

1) Rotary File

2) Motor-Driven Diamond Wheel 25 mm (1.0) diameter

3) Disk Sander

4) Vacuum Bag, Seal and Pump

5) Composite Material Layup Tools

6) Portable Vacuum Cleaner

7) Heat Gun

6.3 REPAIR PROCEDURE

STEP 1 - DAMAGE INSPECTION AND CLEANUP

(a) Remove all loose and splintered material. Inspect the structure, note all defects, and mark the damaged area to be cut away.

(b) Remove the damaged structure with a diamond wheel. Vacuum away all residue. Make a final inspection to be sure that all damage has been removed.

STEP 2 - CUT WOVEN MATERIALS

(a) Use tracing paper or thin mylar to trace the cutout in the skin. Use the tracing to cut four or eight plies of fiber-glass fabric to fill the cutout. Make all plies uniform in size and larger than the cutout by approximately 12.5 mm (.5 in.) all around.

(b) Cut three plies of fiberglass fabric to cover the skin filler piece. Make the smallest ply a minimum of 12.5 mm (.5 in.) larger than the cutout all around. Cut the two remaining plies larger than the first by 25 mm (1.0 in.) and 50 mm (2.0 in.) respectively.

(c) Cut four plies of fiberglass fabric to form the exterior skin patch. Cut the smallest ply to overlap the cutout by a minimum of 12.5 mm all around. Cut the remaining three plies to create successive 6 mm (.25) overlaps.

STEP 3 - MIXING RESIN

(a) Do not mix resin in extreme temperature conditions (hot or cold).

(b) Mix a quantity of resin sufficient to lay up the repair. For large repairs, mix approximately one-half the required amount at one time to avoid exceeding the pot life.

(c) Make certain that the resin and curing agent are thoroughly mixed. Handle with care to avoid contamination.

(d) Always use mixed resin promptly. Discard mixed resin that has been allowed to stand for more than 10 minutes.

STEP 4 - LAY UP AND CURE SKIN FILLER PIECE

(a) Sand the surfaces of the structure surrounding the cutout and thoroughly clean the structure with MEK. Use a heat gun to thoroughly dry the structure in the repair area.

(b) Lay up one ply of material at a time.

(c) Saturate the material with resin using a flat brush. Make certain that the material is thoroughly saturated, but avoid oversaturation.

(d) Make certain that each ply is accurately located as it is laid up. Use a flat brush, spatula or tongue depressor to align and press the material flat. Use the brush to distribute the resin and draw off excess resin. Make certain that there are no voids or wrinkles in the material.

(e) Use spray adhesive to tack a clean sheet of bagging film on a flat surface. Lay up the four or eight fiberglass plies for the skin filler patch on the surface covered by the bagging film. Make certain that the plies are laid up in the correct orientation. Cover the patch with peel ply and apply pressure with a weight. Allow the patch to cure sufficiently to be handled.

(f) Hold the semi-cured fiberglass patch against the aircraft skin and accurately trace the cutout on the patch. Cut and fit the patch to the cutout and tape it in position. See Figure 9. Use a liberal amount of tape on the exterior skin side to be sure that the patch is securely held. Use spray adhesive and bagging film to seal the exterior surface over the patch.

(g) Remove the tape from the interior side of the skin filler patch. Lay up the three fiberglass patch plies over the skin filler piece. Start with the largest of the three plies, centering it over the skin cutout. Lay up the two remaining plies to create 12.5 mm (.5 in.) steps as shown in Figure 12.

(h) Vacuum bag and cure the repair.

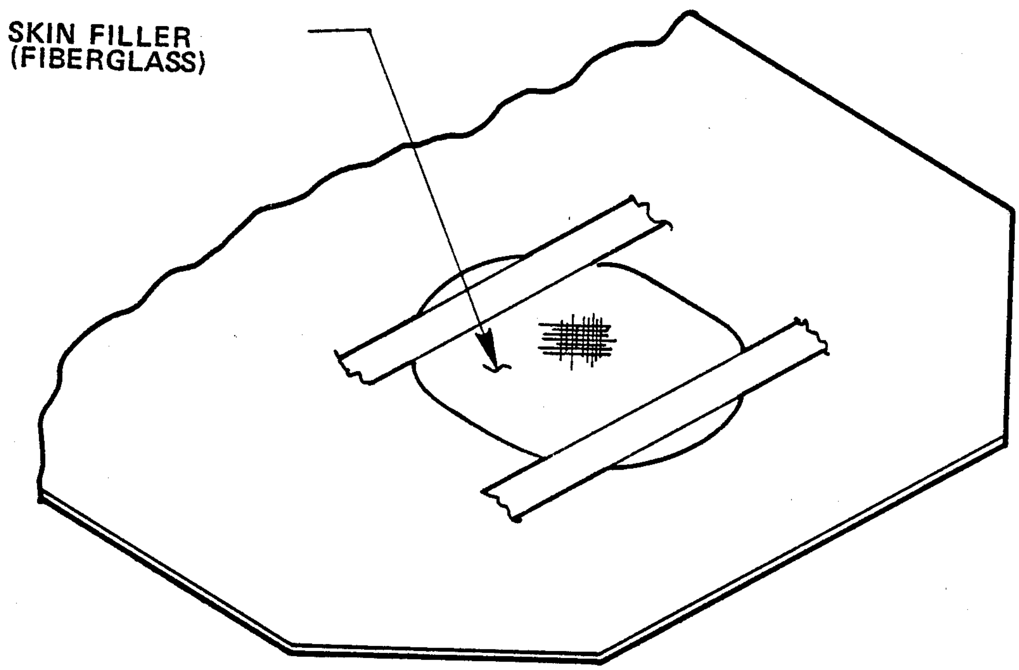

FIGURE 9 SKIN FILLER PATCH LAID UP, FITTED TO CUTOUT, AND TAPED IN PLACE

STEP 4 - LAY UP AND CURE EXTERIOR SKIN PATCH

(a) Remove the bagging film and tape from the exterior side of the skin filler patch. Lay up the four ply exterior skin patch. Start with the second largest ply, centering it over the skin filler patch. Lay up the next two smaller plies to create 6 mm (.25 in.) overlaps as shown in Figure 10. Apply the largest ply last.

(b) Vacuum bag and cure the repair.

(c) Clean up and visually inspect the repair.

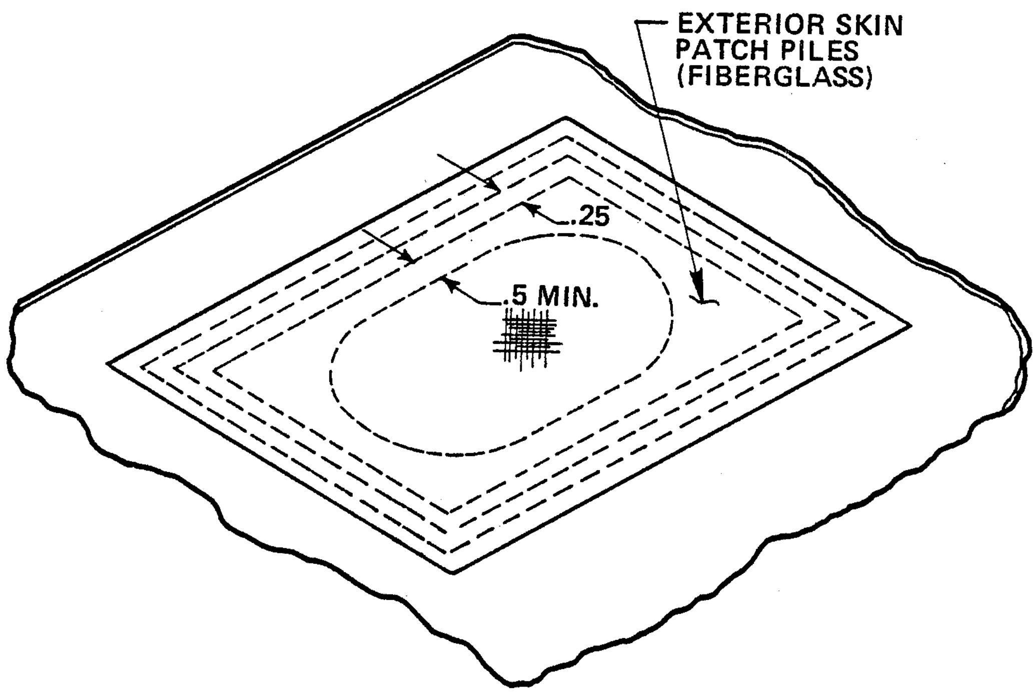

FIGURE 10 EXTERIOR SKIN PATCH LAID UP.

SECTION 7.0 CONCLUSIONS

1) The four ply portion of the K/E skin panel is sized by the rivet bearing requirements. The mean bearing strength, as determined by panel shear tests, is almost twice that required for design.

2) The bearing strength margin is expected to be more than adequate to account for material strength scatter and environmental effects. Service experience, however, is needed to substantiate this assessment.

3) The impact damage criteria, that requires at least four undamaged plies of the eight ply portion of K/E skin, meets the 1.27 mm (.050 in.) thick 7075-T6 aluminum capabilities per the test procedure. Service experience is required to substantiate this assessment.

4) After fifteen (15) months of service use, the flight time on the modified ramp was 382.9 hours and the Kevlar skin panel was in good condition.

SECTION 8.0 REFERENCES

1) Milton, A. "Miscellaneous Loads and Conditions," Sikorsky Aircraft, Division of United Technologies Corporation, SER-65018, 11/26/72. Prepared under Contract NOw63-0150f.

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16. Abstract

This report presents the work performed for the installation of a composite skin panel on the cargo ramp of a Sikorsky CH-53D marine helicopter. The composite material is of Kevlar/Epoxy (K/E) which replaces aluminum outer skins on the aft two bays of the ramp. The cargo ramp aft region was selected as being a helicopter airframe surface subjected to possible significant field damage and would permit an evaluation of the long term durability of the composite skin panel. A structural analysis was performed and the skin shears determined. Single lap joints of K/E riveted to aluminum were statically tested. The joint tests were used to determine bearing allowables and the required K/E skin gage. K/E skin panels riveted to aluminum edge members were tested in a shear fixture to confirm the allowable shear and bearing strengths.

Impact tests were conducted on aluminum skin panels to determine energy level and damage relationship. K/E skin panels of various ply orientations and laminate thicknesses were then impacted at similar energy levels.

The results of the analysis and tests were used to determine the required K/E skin gages in each of the end two bays of the ramp. The most aft K/E skin bay is 2.03mm (.080 in.) thick which was determined from the impact tests. The other K/E skin bay is 1.015mm (.040 in.) thick, which was determined from the strength criteria where bearing was the critical factor. The K/E skin panel replaces 7075-T6 aluminum skin of 1.27mm (.050 in.) and 0.63mm (.025 in.) thick respectively.

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