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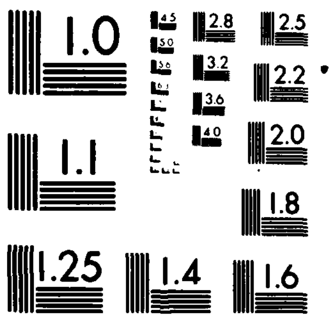

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(6) GLASS/PLASTIC TRANSPARENT ARMOR FOR HELICOPTERS

by

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(18) GIDEP (11) Apr 76
(14) E114-2513 (12) 17

ABSTRACT

This paper covers a program for the development of scaleup technology to produce contoured transparent glass/plastic armored glazings for the UH-1D helicopter. This work incorporated recent advances in high-performance glass/plastic composite transparent armor technology. Primary emphasis was placed on the design and scaleup required to add a significant level of such protection to a current inventory aircraft. The design and fabrication of direct replacement armored windshields duplicating the UH-1 contour and trim represented a significant advancement in the state-of-the-art. The program achievements clearly represent a milestone in aircrew protection and aircraft survivability. Findings apply to present aircraft, and provide the basis for the most efficient incorporation of transparent armor in the next generation of aircraft.

The work was performed by Goodyear Aerospace for the Army Materials and Mechanics Research Center, Watertown, Massachusetts (contract number DAAG-46-73-C-0075).

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6. ORIGINATOR'S DOCUMENT TITLE Glass/Plastic Transparent Armor for Helicopters		7. DOCUMENT TYPE ☒ GEN RPT ☐ NONSTD PART ☐ SPEC
8. ORIGINATOR'S DOCUMENT NUMBER ~~AFML-TR-76-54~~ AD32141	9. ORIGINATOR'S PART NAME/IDENTIFICATION N/A	
10. DOCUMENT (SUPERSEDES) (SUPPLEMENTS) ACCESS NO. None	11. ENVIRONMENTAL EXPOSURE CODES N/A	
12. MANUFACTURER N/A	13. MANUFACTURER PART NUMBER ----	14. INDUSTRY/GOVERNMENT STANDARD NUMBER

15. OUTLINE, TABLE OF CONTENTS, SUMMARY, OR EQUIVALENT DESCRIPTION

Covers the development of scaleup technology for contoured transparent glass/plastic armored glazings for the UH-1D helicopter, including recent advances in high-performance glass/plastic composite transparent armor technology. Emphasis was placed on the design and scaleup required to add a significant level of such protection to a current inventory aircraft. The design and fabrication of direct replacement armored windshields duplicating the UH-1 contour and trim represented a significant advancement in the state-of-the-art. Findings apply to present aircraft, and provide the basis for the most efficient incorporation of transparent armor in the next generation of aircraft.

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16. KEY WORDS FOR INDEXING
Aircraft; Windshield; Canopy; Transparencies; Interlayer; Armor; Helicopters (Doc Des--P)

17. GIDEP REPRESENTATIVE W. Tillman	18. PARTICIPANT ACTIVITY AND CODE Goodyear Aerospace Corp, Litchfield Park, AZ 85340 (GY)

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I. INTRODUCTION

The helicopter is playing an increasingly important role in modern warfare. Expanded combat area mission requirements such as search, rescue, attack, and other close proximity missions have exposed the helicopter to greater levels of hostile fire than previously experienced. Although opaque armor has been added to protect some vital components and crew seat assemblies, very little has been done to offer protection in the sizable transparent glazings. The standard glazings currently used have virtually no ballistic defeat capability and when penetrated often generate varying levels of injurious spall.

The best solution to maintaining high levels of visibility, while reducing ballistic vulnerability, is the incorporation of transparent armor. Recent advances in the state-of-the-art have made this practical. High-performance glass/plastic composites have been developed which provide ballistic protection at an areal density and thickness significantly lower than prior state-of-the-art laminated glass armor. The glass/plastic composite also eliminates the backside spalling of injurious particles upon ballistic impact. Although the performance of such armor was well documented by laboratory testing, no attempt had been made to design and replace the glazings with armor in an inventory aircraft.

II. TECHNICAL APPROACH

1. GENERAL

Basically, this program was divided into three phases. Phase I included the design of the armor installation as well as ballistic and environmental testing to document performance. Manufacturing drawings and instructions for the armor installation were prepared. Phase II consisted of the fabrication of eight shipsets of the transparent armor and hardware in accordance with the drawings. Phase III effort included environmental testing of three shipsets of the full-scale parts produced during Phase II. One additional shipset of transparent armor was installed in a UH-1H helicopter to verify the design and installation procedures and to allow flight test evaluation. The remaining four shipsets of armor were delivered to the contracting agency, Army Materials and Mechanics Research Center (AMMRC), Watertown, Massachusetts.

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2. PHASE I - TRANSPARENT ARMOR DESIGN AND EVALUATION

The Phase I effort included the fabrication of several sizes of flat armor composite test panels for verification of environmental and ballistic properties suited to the proposed usage.

The configuring of the armor installation and the structural analysis were conducted concurrently in Phase I.

A mockup of each armor panel was made and installed in one hand of a UH-1B helicopter fuselage to confirm the feasibility of the design, demonstrate functional features, and assess possible modifications required.

After incorporation of the necessary changes, manufacturing drawings were prepared for the complete UH-1D transparent armor installation.

a. Composite Verification

Flat panels of the armor were fabricated for testing to verify predicted ballistic and environmental performance levels. Ballistic performance is classified and is not discussed herein.

The composite makeup as specified by AMMRC is as follows:

Material	Thickness (in.)
Soda-lime annealed plate glass	0.250
Polyvinyl butyral (PVB) interlayer	0.060
Soda-lime annealed plate glass	0.125
Code F4X-1 cast-in-place (CIP) Goodyear Aerospace proprietary interlayer	0.100
Polycarbonate (ultraviolet stabilized) with Code 701 Goodyear Aerospace proprietary abrasion-resistant coating	0.125

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A total of 30 flat 12-inch × 12-inch test panels were fabricated and delivered to AMMRC for ballistic evaluation. Ten flat 36-inch × 36-inch test panels were fabricated for environmental testing. Five flat test panels of reduced size (3 inches × 8 inches) were fabricated to permit ultraviolet stabilization testing in the standard test cabinet. Prior to the environmental tests, the optical properties of each 36-inch × 36-inch panel were measured; results are shown in Table I.

After 240 hours of accelerated ultraviolet testing in accordance with ASTM D1499-64 and G23 procedures, the haze had increased only one percent, while the luminous transmittance remain unchanged.

During the thermal testing, there was no visible change in optics. However, it was discovered that all glass edges had to be reasonably well ground to eliminate edge defects if thermal breakage was to be eliminated. Basically, all panels were cycled to +160 deg F and -65 deg F for 48 hours. For the exact military specification, refer to Table I.

The only test that presented any real problem was the humidity test. During this test, some opacity developed in the panels. Testing to MIL-STD-810B calls for 240 hours of exposure with up to 95-percent relative humidity and 160-deg F temperatures. This cycle is known to be very hard on many plastics and coatings. The polycarbonate backing on the armor panels is a hygroscopic material which permits the passage of moisture. This in turn can affect interlayers, primer coatings, and abrasion-resistant coatings.

When the panels were subjected to a constant 160 deg F and 35-percent relative humidity, it was found that the haze remained low (approximately 2 percent) and the luminous transmittance stayed in the 85-percent range. Field testing to date has not disclosed any serious problems.

b. Structural Criteria Study

The structural criteria study included defining potential structural attachment areas, maximum loadings imposed on armor attachments and the fuselage structure, structural adequacy of attachments and structure, and the effect of added armor weight on basic aircraft weight and balance.

In general, this investigation indicated that the armor attachments and fuselage structure were adequate for the intended use.

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TABLE I - ENVIRONMENTAL TEST DATA, UH-1D GLASS/PLASTIC 36-INCH × 36-INCH FLAT COMPOSITE VERIFICATION PANELS

Panel no.	Test type	MIL-STD-810B		Luminous transmittance (percent average)		Haze (percent average)		Optical deviation (minutes)	
		Method no.	Procedure no.	Original	After test	Original	After test	Original	After test
1	Low temperature	502	1	81.9	82.0	1.00	0.90	1.02	0.90
2	Low temperature	502	1	82.1	82.1	1.06	0.90	0.60	0.60
5	High temperature	501	1	81.8	81.5	1.30	1.10	2.04	1.98
6	High temperature	501	1	81.2	81.9	1.13	0.90	1.32	1.74
7	Thermal shock	503	1	81.4	81.7	0.97	1.00	0.02	-
8	Thermal shock	503	1	81.9	81.9	0.98	1.00	0.01	-
9	Humidity	507	1	81.6	74.8[a]	1.03	42.50[a]	0.60	-
10	Humidity	507	1	81.7	76.3[b]	1.03	46.40[b]	1.02	-

[a]Values measured after drying 16 hours at 120 deg F were as follows: luminous transmittance, 81.8 percent; haze, 2.5 percent.

[b]Values measured after drying approximately 30 days at ambient temperature were as follows: luminous transmittance, 81.6 percent; haze, 2.4 percent.

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Running concurrently with this effort was the design of armor panels configured to provide the maximum protection possible within the limitations of operational constraints, mission profile, and added weight.

The windshield and crew door armor protection was accomplished with composite panels of the same shape and size as the standard UH-1D glazings. The highly double-contoured shape of the standard lower cabin window does not lend itself to duplication with the laminated armor construction.

Several combinations of internally mounted flat and single curvature panels were evaluated to add protection in this area. The major considerations which influenced the fitting of armor panels in the lower cabin windows included:

1. Optics - Visibility through the lower cabin windows is particularly important during landing operations. To maintain the best possible optics, plane surfaces and low-angle-of-incidence viewing were sought for the armor panel installation. Minimization of distracting framing or attachments encroaching upon the viewing area was also important.

2. Every effort was made to maximize the use of flat armor panels and thus provide the lowest-cost armor installation possible.

3. Operational clearances - Provision had to be made for adequate clearance between the armor panels and the various aircraft components extending into the lower cabin window area. Specific components requiring attention were as follows:

   a. Lower cabin window glazing
   b. Rudder pedal assembly
   c. Foot rests
   d. Communicator
   e. Electrical cables
   f. Instrument air lines.

4. Operational maintenance - Several aspects of operational maintenance had to be considered when adding the armor installation in the lower cabin window area. One aspect related to the routine maintenance, adjustments, and replacement actions required on the

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components of the unmodified UH-1D aircraft. Consideration was also required for similar functions applicable to the armor installation.

It became apparent that a removable armor panel would be needed on each of these left- and right-hand lower window installations. Access is necessary for periodic cleaning of the standard glazing interior surface and the transparent armor, as well as for routine maintenance of aircraft components located in the lower cabin window area. Access is likewise necessary to daily install and remove sensitive gear when operating in a combat area.

c. Fabrication of Mockup Windows

Upon completion of the initial design, a mockup of all armor panels and installation hardware was prepared for one hand of the aircraft. The mockup was used to confirm the feasibility of the armor addition, demonstrate functional features, and provide means for assessing possible modifications. Several changes were incorporated as a result of working with the mockup installation.

d. Ballistic Verification Tests

A series of physical tests was conducted on typical configurations with bonded armor attachments. The results of these tests using tension, peel, and torsional loading modes were used to support the analysis effort in the structural criteria study.

Ballistically induced loads imposed on the bonded attachments are complex and difficult to calculate. It was therefore necessary to verify the ballistic performance by test firing armor panels supported by typical bonded brackets and clips. A similar situation existed in the retention of the sliding crew door armor panel under ballistic impact. This panel is supported along both vertical edges by engagement of the outboard 1/4-inch-thick ply of glass in a U-channel structure.

The armor composite used in these panels duplicated the ply configuration of the UH-1D requirement. The bonded attachment ballistic test panels were mounted by bolting each attachment to rigid structure. The panels simulating the sliding crew door were mounted for test firing by full length engagement in a supported U-channel along both vertically oriented sides.

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Each test panel was subjected to from one to four impacts of caliber .30 ball M2 projectiles. Maximum energy transfer was thus imparted to the test panels and attachments.

These tests indicate that both the bonded attachments and glass engagement of the U-channel on the sliding crew door armor panel should withstand ballistic impact loads at the design threat level. Projectile strikes within 1-3/4 inches of the center of bonded attachments did not disrupt the bond to the panel. The glass fracture resulted in a softening of the local support; however, the other three attachments were unaffected. Panel retention after withstanding such close-proximity hits at three of the four attachments remained secure.

Projectile strikes within two inches of the unsupported edges of the sliding crew door panels resulted in local fracture of the glass ply engaging the channel. The fractured glass was retained in place and continued to support the panel. Much of this glass was lost after the panel was removed from the support channels. Test panel number 4 withstood three impacts, one in the center and two near one edge, without leaving the support. The actual crew door sliding windows have 27.0 inches of vertical edge support. This is nearly twice that of the ballistic test articles and provides additional undamaged glass in the channels for support.

e. Drawings

After completion of the mockup review and incorporation of the design modifications, manufacturing drawings were prepared in accordance with MIL-D-1000, Category A.

f. Installation Instructions

Detailed instructions were written for the transparent armor installation. These instructions, when used in conjunction with the installation drawings, supplied the information needed to modify the UH-1D aircraft and to install the armor panels.

3. PHASE II - PROTOTYPE GLASS/PLASTIC LAMINATE FABRICATION

a. General

The Phase II effort encompassed the fabrication of eight shipsets of transparent armor for the UH-1D aircraft. The armor manufactured in accordance with the drawings prepared in Phase I was complete with all framing and attachments necessary for installation. One shipset of armor is shown in Figure 1.

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Good tooling is required to form the plastic backing ply and support the glass and plastic components during the interlayer processing. Very little variance in glass contour can be accommodated by the forming and casting tools when flyable optics are required in the composite windshield. The degree of reproducibility attainable in the glass contour thus significantly affects the economic feasibility of quantity production by dictating the tooling requirements.

Dimensional variations in the windshield glass required the fabrication of special tools for each piece of glass to ensure that all components were properly matched.

With quantity production and improvement in the glass forming processing, good part-to-part contour control can be achieved.

The flat panels were processed in the usual manner without difficulty.

b. Mar Resistance

The glass/plastic composite armor used in the UH-1D program incorporates a polycarbonate plastic backing ply. The unique toughness and ductility exhibited by polycarbonate significantly contribute to the ballistic efficiency and nonspalling characteristics of the armor system.

Unfortunately, polycarbonate has a number of adverse characteristics, including low abrasion and chemical resistance. An abrasion-resistant coating was applied to the exposed backside surface of the material to protect the polycarbonate in the rigorous and potentially degrading environment of military helicopters.

4. PHASE III - ENVIRONMENTAL TESTING

During Phase III, one shipset of armor was installed in a UH-1H helicopter at the U.S. Army Proving Ground (YPG), Laguna Field, Yuma, Arizona. Environmental testing of full-scale armor panels was also repeated.

a. Windshield Installation

The standard windshields were removed intact and were suitable for reinstallation upon completion of the armor evaluation. Both the left- and right-hand armored windshields fit the structure contour well. No difficulty was encountered in marking,

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drilling, or trimming the windshields. The installation went as planned, and the only modification required was relocation of the free air temperature gauge and slight modification of the windshield wiper arms (see Figure 2).

b. Crew Door Installation

The doors were modified and the transparent armor panels installed at the Goodyear Aerospace plant in accordance with the installation instructions. The armor added to each door included a flat sliding window and a flat triangular fixed window as shown in Figure 3.

The modified crew doors were then easily installed on the test aircraft.

c. Lower Forward Installation

The installation of the transparent armor in the lower forward cabin window includes three flat panels, two fixed and one removable, on each side. These panels are mounted internally within the confines of the standard glazing, which is retained. The armor was installed in accordance with the installation instructions. The outboard rudder pedals were slightly modified by grinding a small amount of metal off one edge to permit proper clearance when the pedals were in the fully extended position. It was observed that some appreciable dimensional variations from ship to ship and model to model do exist which can somewhat slow the installation (see Figure 4).

After completion of the armor installation, the test aircraft was weighed to determine the new basic weight and center of gravity. The effect of the transparent armor installation on the test aircraft was calculated in accordance with the Army Aviation Maintenance Engineering Manual, Weight and Balance, TM55-405-9.

It was determined that the installation had increased the basic aircraft weight by 193 pounds (5428 pounds to 5621 pounds). The center of gravity (CG) of the basic aircraft was moved forward from station 144 to station 141. Allowable CG limits for takeoff are 134 to 144 and 131 to 144 for landing.

d. Flight Test Evaluation

The set of transparent armor installed and flown at the U. S. Army Proving Ground, Yuma, Arizona, was tested from December 1974 through June 1975. To minimize

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expense, the helicopter with the special glazings was used in support of other missions. The total flight time accumulated on the transparent armor was 44 hours, which included 5 hours of flight during inclement weather conditions at locations other than Yuma. Flights were made in light, medium, and heavy rain; and were made in daytime under instrument flight rules, including approaching through clouds to breakout. For each flight made, the pilot filled out an aircraft flight test and evaluation report on the glass/plastic armor. He was requested to comment on the glazings in level flight, hover, takeoff, and landing. Comments on operation of controls, aircraft flight characteristics, and maintainability were also made.

Since each pilot was requested to report critically on the armor installation, the comments varied considerably, as could be expected.

Nearly all agreed that the flight characteristics of the aircraft near the forward CG limit were undesirable. They suggested that the battery be moved aft to correct the problem. This is often done to compensate for other gear and did correct the nose-heavy effect.

Slight distortion around the outer edge of the windshield was commented on by most pilots but was not considered to be a serious problem in flight.

Some glare from the lower cabin panels during flight over water was reported.

The sliding window in the door broke once when the door was slammed shut. This problem was corrected by extending the window guides further down into the door.

Several pilots stated that when ice formed on the lower half of the windshield, the defrosters were not as effective as on the thinner acrylic windshield.

Nearly all pilots interviewed stated they would want the transparent armor on their aircraft in combat. The more each pilot flew the aircraft, the more complimentary he became.

III. SUMMARY

Glass/plastic transparent armor offers the unique combination of improved ballistic defeat characteristics and low areal density necessary for aircraft usage. The armor is capable of projectile or fragment defeat without backside spalling of injurious

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particles and can be manufactured for numerous threat levels at an areal density which permits a significant amount of coverage within allowable weight limits. This performance can be offered in direct replacement panels or parasitic panels placed behind existing glazings. The program achievements demonstrate how aircrew protection and aircraft survivability can be substantially increased.

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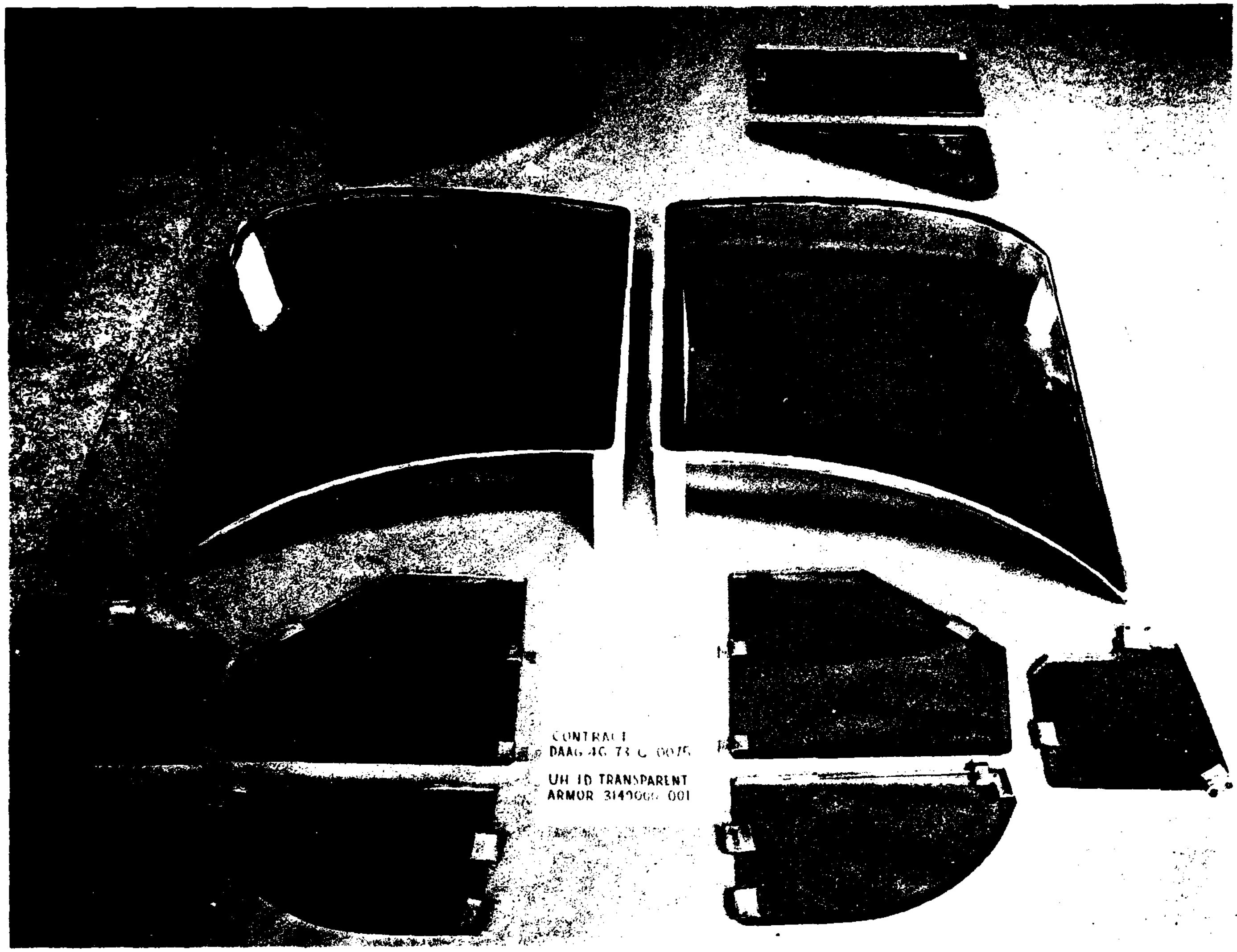

Figure 1 - Display of UH-1D Transparent Armor

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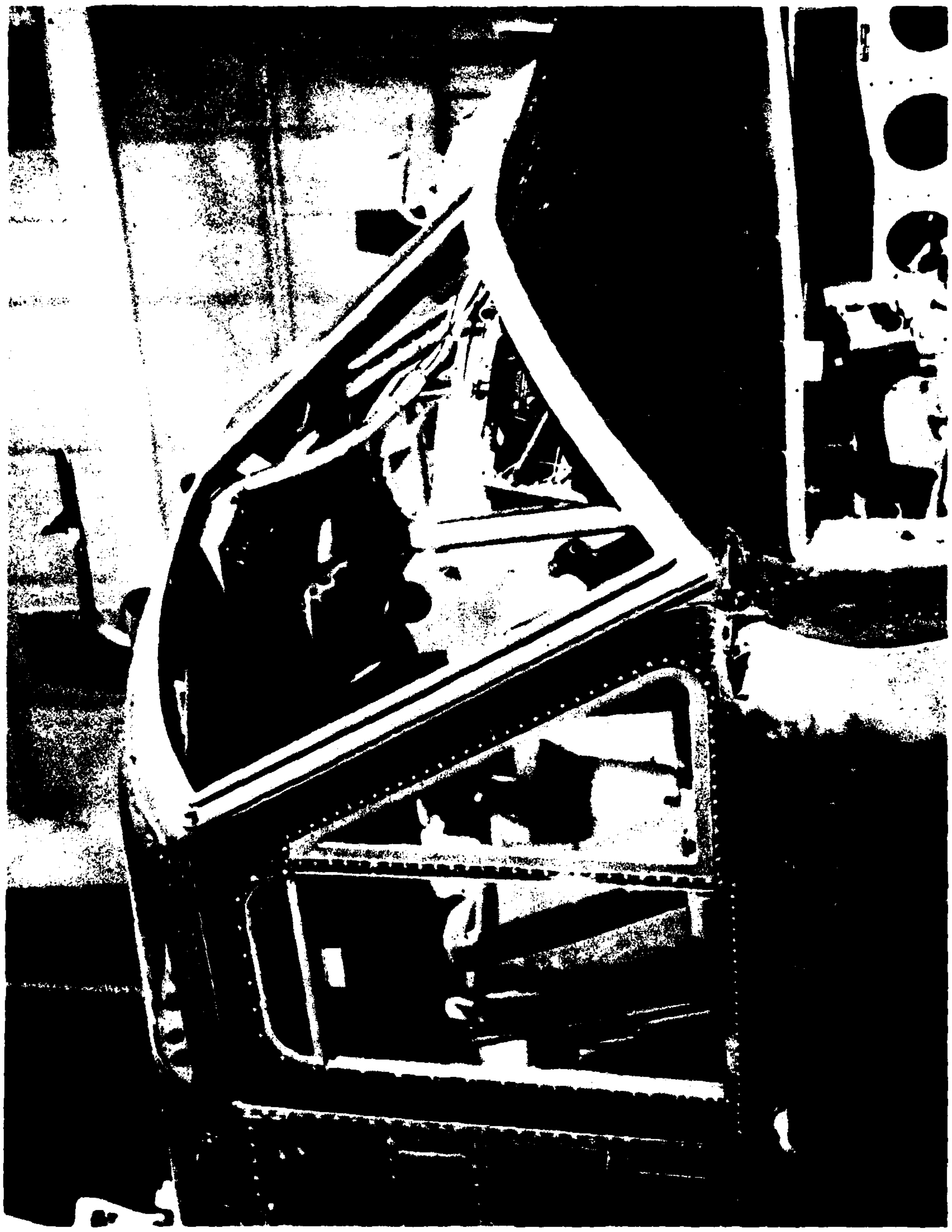

Figure 2 - UH-1D Windshield and Cabin Door

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Figure 3 - UH-1D Cabin Door Transparent Armor

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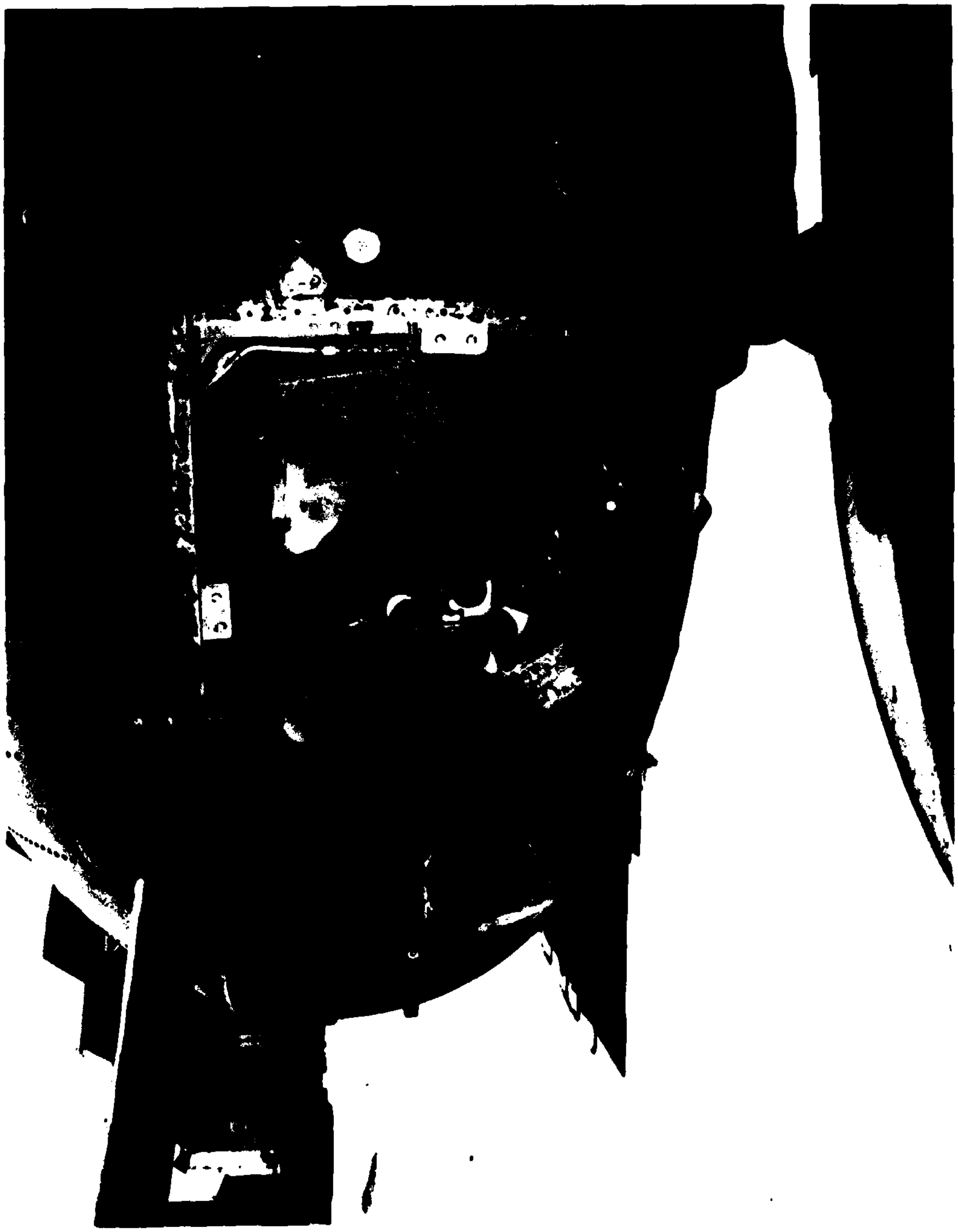

Figure 4 - UH-1D Lower Cabin Window

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