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WINDOW CONTOURED GLASS/PLASTIC TRANSPARENT ARMOR FOR THE UH-1D HELICOPTER

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Goodyear Aerospace Corporation

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WINDOW CONTOURED GLASS /PLASTIC TRANSPARENT ARMOR FOR THE UH-ID HELICOPTER

May 1975

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The objectives of this program relate to the design of a transparent armor installation for the UH-1D helicopter. This effort incorporated for the first time significant amounts of high performance glass/plastic laminate armor in an aircraft. Eight shipsets of armor were produced, one of which was installed and flight tested. Environmental testing was also conducted to define armor performance and characteristics.

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FOREWORD

This is the final technical report on a program to demonstrate the practicality of adding significant amounts of high-performance glass/plastic transparent armor protection into a current inventory Army helicopter. The program was performed by Goodyear Aerospace Corporation, Arizona Division, Litchfield Park, Arizona, under Contract Number DAAG46-73-C-0075.

The work was done for the Army Materials and Mechanics Research Center, Watertown, Massachusetts (AMXMR) under Project Number 1728032.

The Technical Supervisor for this contract is G.R. Parsons (AMXMR-ER).

Goodyear Aerospace has assigned GERA-2074 as a secondary number to this report.

R.A. Huyett is Project Engineer for Goodyear Aerospace. This report was submitted by the author in February 1975 for publication as a technical report. This report covers work conducted between 4 January 1973 and 20 January 1975.

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SUMMARY

This report 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 was basically 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).

The program achievements clearly represent a milestone in aircrew protection and aircraft survivability. Findings apply to present aircraft as well as providing the basis for the most efficient incorporation of transparent armor in next generation aircraft.

SECTION 1

INTRODUCTION

1. GENERAL

The helicopter has played an increasingly important role in modern warfare. Expanded combat area mission requirements have exposed the helicopter to greater levels of hostile fire. Helicopters used for search and rescue, attack, or other close proximity missions have been outfitted with high-performance opaque armor to reduce the vulnerability to such threats. This armor affords good protection to vital aircraft components and has also been built into aircrew seat assemblies. The sizable transparent glazings which afford excellent visibility to helicopter aircrews unfortunately also represent large areas of ballistic vulnerability. The standard glazings used on current inventory helicopters have virtually no ballistic defeat capability and when penetrated can generate varying levels of injurious spall particles. Limited quantities of opaque armor covering the vulnerable glazing areas can be tolerated without impairing flying visibility.

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 of transparent armor technology have made such an action practical. High-performance glass/plastic composite armor has been developed which provides ballistic protection at an areal density and thickness significantly lower than prior state-of-the-art laminated glass armor. The glass/plastic composite armor also eliminates the backside spalling of injurious particles upon ballistic impact. While the performance of such armor was well documented, no attempt had been made prior to the work performed on this contract to design and install the new armor in an aircraft.

2. PROGRAM SCOPE AND OBJECTIVES

The work effort accomplished and reported herein was directed toward demonstrating the practicability of incorporating significant amounts of such transparent armor in a current inventory helicopter.

Both the armor composite makeup and the use of the Army UH-1D helicopter as the test vehicle were specified by the contracting agency, AMMRC.

The complexity of the undertaking was great in that both flat and contoured armored glazings would be required to outfit the specified windshield, lower cabin window, and crew door areas. Innovative design was required to add the armor without compromising the aircrew function or necessitating major aircraft rework.

The fabrication of the contoured armor required close coordination of contours in glass bending and plastic sheet forming technology.

Environmental tests of both flat panels and contoured windshield articles were conducted to define the performance of the armor composite. Ballistic verification test panels were also fabricated and delivered to AMMRC for evaluation.

One shipset of configured armor panels was installed in a UH-1H helicopter for flight test evaluation. Four additional shipsets of configured armor panels were sent to the contracting agency, AMMRC. A cost analysis report and procurement specification were prepared for the transparent armor at the conclusion of the program.

SECTION 2

PHASE I - TRANSPARENT ARMOR DESIGN AND EVALUATION

1. GENERAL

The Phase I work 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 structural analysis were conducted concurrently in Phase I.

A mockup of the armor installation was 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 completing several changes, manufacturing drawings were prepared for the complete UH-1D transparent armor installation.

2. LAMINATE EFFECT STUDY (COMPOSITE VERIFICATION)

a. General

Flat panels of the armor composite were fabricated for testing to verify predicted ballistic and environmental performance levels. The composite makeup was as specified by AMMRC with the exception of the thickness of polyvinyl butyral (PVB) interlayer used to laminate the glass facing plies. It was necessary to increase the nominal thickness of this interlayer ply from 0.02 to 0.06 inch to laminate the contoured match ply P/N 3149000-009 windshield glass without breakage. The armor composite used in the UH-1D installation was 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 proprietary interlayer	0.100
Polycarbonate (ultraviolet stabilized) with Code 701 Goodyear Aerospace proprietary abrasion-resistant coating	0.125

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

1. Luminous transmittance - Federal Test Method Standard Number 406, Method 3022
2. Haze - Federal Test Method Standard Number 406, Method 3022
3. Optical Deviation - MIL-G-5485C, paragraph 4.5.2.1, (see Figures 1 and 2). The screen used by Goodyear Aerospace is modified by the incorporation of additional lines for increased reading range
4. Optical Distortion - MIL-G-5485C, paragraph 4.5.3 (double exposure photographs).

This data, together with average thickness and areal densities measured on the test panels, is shown in Table 1.

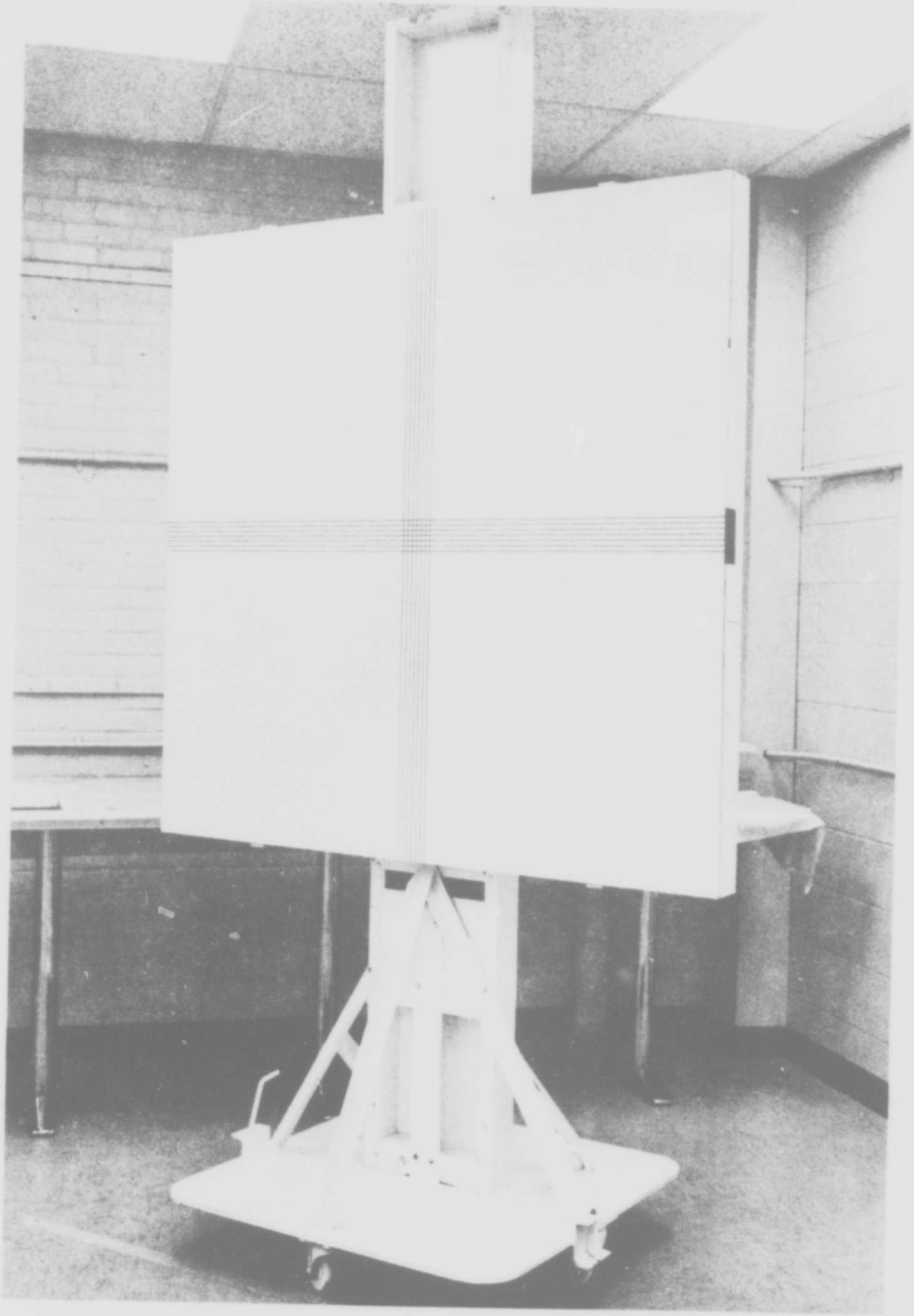

Figure 1. Goodyear Aerospace Optical Deviation Test Setup-Screen

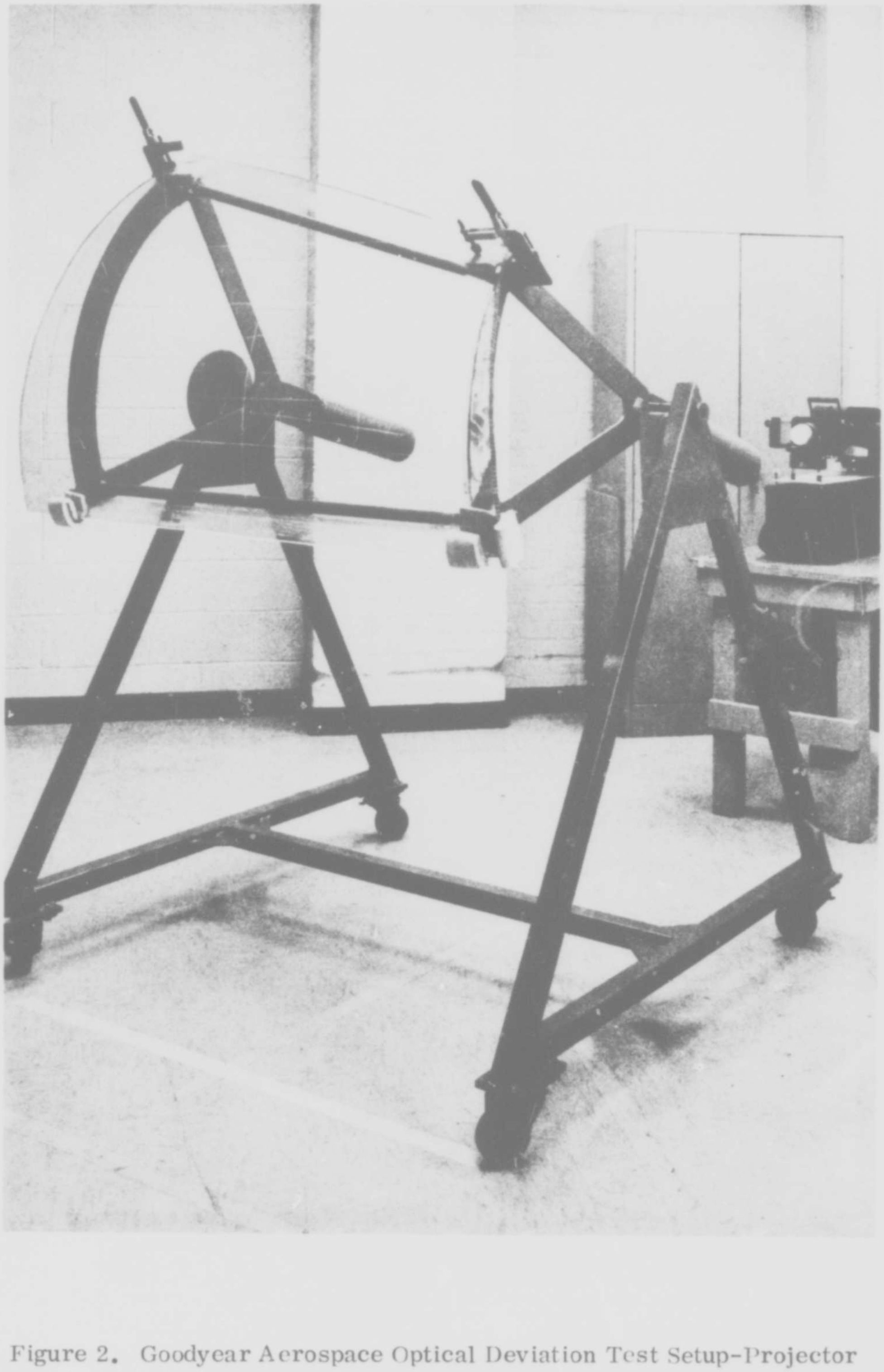

Figure 2. Goodyear Aerospace Optical Deviation Test Setup-Projector

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

Panel no.	Thickness (in., average)	Weight (lb/ft^2 average)	Luminous transmittance (percent, average)	Haze (percent, average)	Optical deviation (minutes)	Optical distortion (slope)
1	0.641	6.33	81.9	1.00	1.02	See note A
2	0.650	6.32	82.1	1.06	0.60	See note A
3	0.689	6.51	82.0	1.06	2.70	See note A
4	0.682	6.46	81.7	0.77	0.72	See note B
5	0.669	6.51	81.8	1.30	2.04	See note B
6	0.698	6.42	81.2	1.13	1.32	See note C
7	0.666	6.43	81.4	0.97	0.02	See note D
8	0.654	6.33	81.9	0.87	0.01	See note A
9	0.667	6.46	81.6	1.03	0.60	See note A
10	0.687	6.51	81.7	1.03	1.02	See note A

Notes:

A. No measurable distortion evident in entire panel.

B. Maximum distortion slope of 1 in 18 measured in panel corners within 3 inches of the edge. No measurable distortion in remainder of the panel.

C. Maximum distortion slope of 1 in 14 measured in panel corners within 3 inches of the edge. No measurable distortion in the remainder of the panel.

D. Maximum distortion slope of 1 in 14 measured within 3 inches of the panel edge. No measurable distortion in the remainder of the panel.

b. Environmental Testing

Following the completion of the optical tests, the panels underwent environmental testing in accordance with the following schedule:

1. High Temperature - MIL-STD-810B, Method 501, Procedure 1, Panels number 5 and 6
2. Low Temperature - MIL-STD-810B, Method 502, Procedure 1, Panels number 1 and 2
3. Thermal Shock - MIL-STD-810B, Method 503, Procedure 1, Panels number 7 and 8
4. Humidity - MIL-STD-810B, Method 507, Procedure 1, Panels number 9 and 10
5. Ultraviolet Stabilization - ASTM D1499-64 Procedure (240 exposure hours).

The results of these environmental tests are shown in Tables 2 and 3. Additional details of test procedures and observations of test panel performance during these environmental tests are as follows.

c. High Temperature

Panels number 5 and 6 completed the high-temperature test defined in MIL-STD-810B, Method 501 Procedure 1 (48 hours at 160 deg F) without cracking, clouding, delamination, or other visible signs of degradation.

d. Low Temperature

Panels number 1 and 2 underwent the low-temperature test defined in MIL-STD-810B, Method 502, Procedure 1 (48 hours at -65 deg F). Inspection following this exposure detected no visible degradation.

TABLE 2. ENVIRONMENTAL TEST DATA, UH-1D GLASS/PLASTIC 36 × 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	0.87	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]	1.05	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.

TABLE 3. ACCELERATED ULTRAVIOLET TEST DATA, UH-1D GLASS/PLASTIC COMPOSITE

Panel no.	Luminous transmittance (percent, average)		Haze (percent, average)	
	Original	After 240 hr	Original	After 240 hr
1	82.8	81.3	1.0	2.7
2	82.9	82.4	1.0	2.7
3	82.9	83.2	1.3	1.3
4	82.9	82.9	1.0	2.0
5	83.0	83.0	0.9	2.0

e. Thermal Shock

In accordance with MIL-STD-810B, Method 503, Procedure 1, panels number 7 and 8 were subjected to thermal shock testing. The exposure schedule and results of this testing are shown in Table 4. Panels 7 and 8 experienced glass breakage during thermal shock testing and were carefully examined. The laminated glass used to fabricate these panels was produced on an expedited basis, replacing parts broken in shipment. The edges of the laminated glass contained many small chips or fractures which were not completely removed during finishing.

Goodyear Aerospace attempted to minimize these edge irregularities by hand working with a stone. This repair offered minimal chances of success since the inner edge of each glass ply contacting the polyvinyl butyral bonding layer was not accessible to work.

It is felt that the fracture of both panel facings can be attributed to the stress risers created by the poor edge finish. Previous thermal shock testing of Goodyear Aerospace developmental composite X72-8 was

TABLE 4. THERMAL SHOCK TEST DATA, UH-1D GLASS/PLASTIC COMPOSITE

Panel no.	Test sequence	Exposure conditions[a]	Results
7	1	4 hr at 160 deg F	No visible change
8	1	4 hr at 160 deg F	No visible change
7	2	17 hr at -65 deg F	No visible change
8	2	17 hr at -65 deg F	No visible change
7	3	4 hr at 160 deg F	No visible change
8	3	4 hr at 160 deg F	No visible change
7	4	4 hr at 160 deg F	No visible change
8	4	4 hr at 160 deg F	No visible change
7	5	4 hr at -65 deg F	No visible change
8	5	4 hr at -65 deg F	Glass fracture, both plies
7	6	4 hr at 160 deg F	No visible change
8	6	4 hr at 160 deg F	No visible change
7	7	4 hr at -65 deg F[b]	Glass fracture, both plies
8	7	4 hr at -65 deg F[b]	Increased glass fracture

[a] Maximum transfer time between hot and cold test chambers was 5 minutes.

[b] Equipment malfunction experienced during the -65 deg F test sequence. Temperature rose to -40 deg F as repairs were made. During subsequent cool-down, temperature dropped to -70 deg F for approximately 45 minutes.

conducted without failure. The X72-8 S/N 1 prototype, a 25 × 30-inch contoured part, is shown in Figure 3. The construction is identical to that used in this UH-1D contract effort except that the 1/8- and 1/4-inch glass plies are reversed.

The X72-8 S/N 1 composite was subjected to the following thermal conditioning schedule without apparent degradation:

1. Eighteen hours at -20 deg F
2. Four hours at 140 deg F
3. Cooled to ambient and examined
4. Eighteen hours at -65 deg F
5. Transfer to 160 deg F within 5 minutes
6. Four hours at 160 deg F
7. Cooled to ambient and examined
8. Forty-eight hours at -65 deg F
9. Warmed to ambient and examined
10. Forty-eight hours at 160 deg F
11. Cooled to ambient and examined.

The edges of the laminated glass used on the X72-8 S/N 1 part were smoothly polished without apparent defects.

To resolve the problem with regard to the flat, 36-inch-square UH-1D composite panels, Goodyear Aerospace decided to attempt rework on the glass edges of panels number 1 and 2. These 36-inch-square panels had previously undergone low-temperature testing in accordance with MIL-STD-810B, Method 502, Procedure 1 without visible degradation. The edges of each glass ply on these panels were carefully worked with a grinder. This was followed by hand stoning of any remaining apparent defects. Subsequent thermal shock retesting of these two panels to

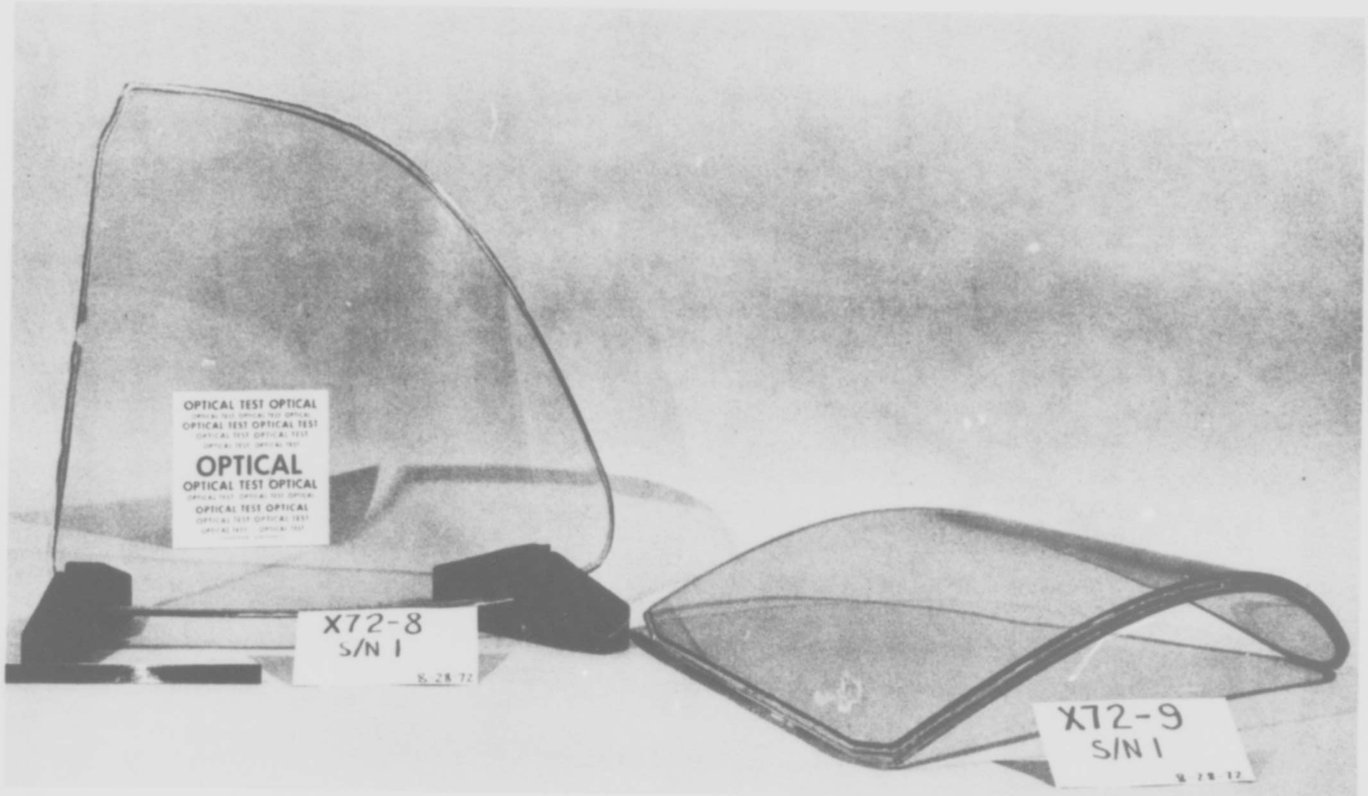

Figure 3. Composite X72-8 and X72-9 Test Articles

MIL-STD-810B, Method 503, Procedure 1, was completed without glass breakage or other signs of visible degradation. The results of this retesting substantiated the importance of glass edge finish in resisting breakage.

f. Humidity

Panels number 9 and 10 were subjected to humidity test exposure in accordance with MIL-STD-810B, Method 507, Procedure 1. Testing to this procedure consists of ten 24-hour cycles, with each cycle conducted as follows:

1. Starting at standard ambient temperature and uncontrolled humidity, gradually raise the temperature to 160 deg F and the relative humidity to 95 percent over a period of 2 hours
2. Maintain 160 deg F temperature and 95 percent relative humidity for not less than 6 hours
3. Maintain 85 percent, or greater, relative humidity and reduce the temperature in 16 hours to 82 deg F.

Inspection of the two test panels following the last (tenth) exposure cycle revealed opacity and delamination of the cast-in-place interlayer. The opacity appeared to be evenly distributed over both panels. The visible delamination of interlayer bond to the glass and polycarbonate substrates was spotted about each panel periphery. Most delaminations were within 3/4 inch of the edge with a maximum encroachment of 2-1/2 inches at one location.

Luminous transmittance and haze values were measured on both panels following the completion of the test. Panel number 9 was then conditioned in an oven at 120 deg F for 16 hours. This conditioning removed the opacity and more clearly defined the delaminated areas. Similar changes occurred more slowly on panel number 10 which had remained in the laboratory at standard atmospheric conditions. Test values for the humidity test panels are shown in Table 2.

Additional humidity testing was clearly needed to define the cause of panel degradation. The effect of other humidity conditions and the performance of a number of sealants and protective tapes for sealing panel edges were explored using Goodyear Aerospace research and development funds.

The additional humidity tests utilized during this effort were as follows:

1. MIL-STD-810B, Method 507, Procedure 1 (retest, see Page 14)
2. MIL-STD-810B, Method 507, Procedure 5
3. Exposure for 240 hours at 125 deg F, 95 percent relative humidity constant
4. Exposure for 240 hours at 160 deg F, 37 percent relative humidity constant.

The effect of these tests on the unmodified UH-1D armor composite is shown in Figure 4. Examination of the test data disclosed that all of the test exposures, excepting the constant 160 deg F, 37 percent relative humidity, resulted in serious degradation of the armor system. The opacity which developed was found to be in the F-4X-1 cast-in-place interlayer component ply. Moisture levels which caused a 6 percent haze at the conclusion of the MIL-STD-810B, Method 507, Procedure 5 were sufficient to destroy the interlayer bond. Procedure 5 consists of twenty 24-hour cycles with each cycle conducted as follows:

1. Starting at standard ambient temperature and humidity, gradually raise the temperature to 105 deg F and the relative humidity to 95 percent over a period of 2 hours

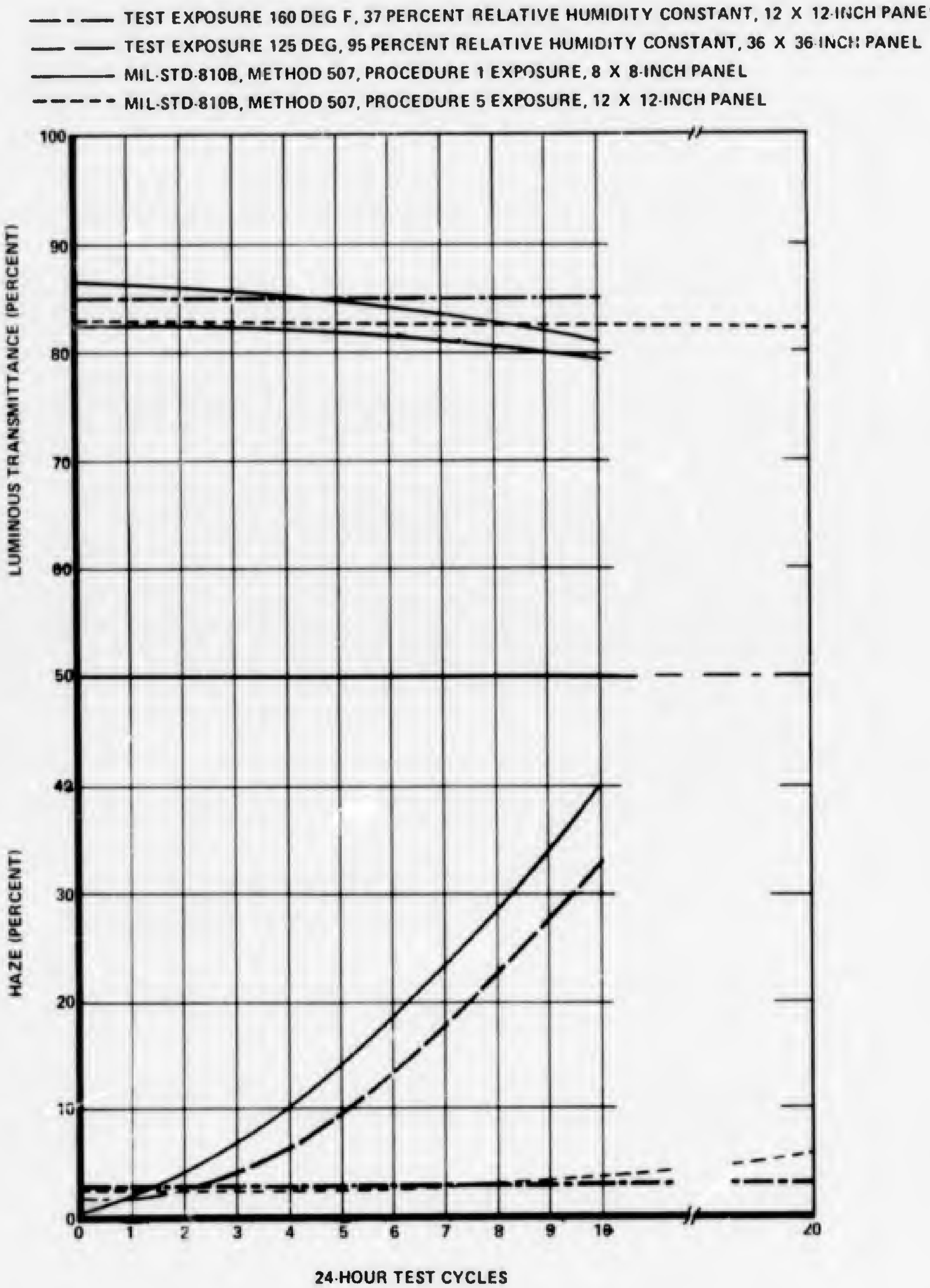

Figure 4. Humidity Test Data, UH-1D Glass/Plastic Composite

2. Maintain 105 deg F temperature and 90 percent relative humidity for 16 hours

3. Gradually decrease the temperature to 70 deg F and increase the relative humidity to 95 percent in 2 hours

4. Maintain 70 deg F temperature and 95 percent relative humidity for 4 hours.

The opacity developed uniformly throughout the entire test panel. It is believed that the moisture permeated the entire polycarbonate backing ply as well as the peripheral sealed edge. The polycarbonate is a hygroscopic material, and the abrasion resistant coating, which is approximately 1/2 mil or less in thickness, appears to permeate moisture. Substitute edge sealants of both injectable adhesive and tape types evaluated did not appear to measurably change the composite performance. Likewise, a number of surface coatings were evaluated for possible use as moisture barriers. These coatings, applied directly over the abrasion resistant coating on the polycarbonate backing ply, included the following:

1. REPCON rain repellant and surface conditioner[a]
2. TURTLE WAX, Stock No. T-123[b]
3. DARAN 220 polyvinylidene chloride emulsion[c]
4. Goodyear Tire & Rubber Co. Code F434 barrier coating.

None of the coatings appeared to afford measurable improvement in the composite performance during the humidity exposures.

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[a]Trademark, Unelko Corporation, Chicago, Ill.

[b]Trademark, Turtle Wax, Inc., Chicago, Ill.

[c]Trademark, W.R. Grace and Co., Cambridge, Mass.

All of the humidity cycles except the constant 160 deg F, 37 percent relative humidity exposure also degraded the Goodyear Code 701 abrasion resistant coating on the polycarbonate backing ply. The higher humidity test environments resulted in reduced coating adhesion and spotting which could not be removed by conventional cleaning methods.

g. Ultraviolet Stabilization

Five 3 × 8 inch flat test coupons of the armor laminate were tested using accelerated ultraviolet radiant energy in accordance with the ASTM D1499-64 and G23 procedures. Luminous transmittance and haze values for each test coupon were determined prior to test exposure. The coupons were then subjected to 240 hours of exposure in an Atlas Model DMC Weather-Ometer which utilized twin enclosed violet carbon arc lamps, controlled temperature, and periodic water spray. Ten 24-hour cycles were used, with each cycle composed of the following exposure conditions.

Periods of 102 minutes of light only, followed by 18 minutes of light with spray, are repeated for a total of 18 hours. This is followed by 6 hours without light or spray. During the 18-hour period of light and spray, the black panel temperature, except when the specimen spray is on, was 145 ±9 deg F. During the 6-hour period of darkness without spray, the black panel temperature was 75 ±5 deg F.

Following the completion of the 240 hours of exposure, the test coupons were cleaned and examined. Luminous transmittance and haze values were again taken. The data for the ultraviolet stabilization test are shown in Table 3. No cracking, clouding, or delamination were visible on any of the five coupons. The Goodyear Aerospace Code 701 abrasion resistant coating on the polycarbonate backing ply was degraded by the test exposure. Varying degrees of coating disturbance were evidenced by loss of adhesion, reduced abrasion resistance, and spotting. The coating degradation resulted in the increased haze values recorded. The 2.7 percent maximum haze resulting from this test exposure can be compared with the 3.0 percent maximum allowed for MIL-P-25690A stretched acrylic which is a commonly used aircraft glazing material.

h. Disposition of Test Panels

A posttest assessment was made to determine the condition of the ten 36-inch-square test panels (Contract Item 001AC). All 10 panels were originally scheduled for delivery to AMMRC after the completion of environmental testing. Goodyear Aerospace felt that panels number 4 through 10 had been broken or were otherwise degraded beyond further use. Authorization was therefore requested to allow disposal of these panels and shipment of the remaining three panels to AMMRC. Such authorization was granted by AMMRC with disposal of the seven panels being made in accordance with existing regulations of the Property Administrator assigned by DCASR, Phoenix, Arizona.

3. 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.

The details of the structural analysis effort are documented in CLA-2168 (Structural Investigation of the UH-1D Transparent Armor Installation, P/N 3149000-001).

This investigation, in general, indicated that the armor attachments and fuselage structure should be adequate for the intended use.

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. Bending of the outer glass facing plies to such a contour is beyond the present state-of-the-art.

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 position were sought for the armor panel installation. Minimization of distracting framing or attachments encroaching upon the viewing area was also important

2. Cost - Transparent armor of the high-performance glass/plastic type is inherently expensive. Flat panels free of unusual trim configurations offer the best cost effective performance.

   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 to clearances were as follows:

   a. Lower cabin window glazing

   b. Rudder pedal assembly

   c. Foot rests

d. KY-28 discreet communicator

e. Electrical cables

f. Instrument air lines

4. Operational Maintenance - Several aspects of operational maintenance had to be considered when adding of the armor installation in the lower cabin window area. One aspect related to the routine maintenance, adjustments, and replacement actions required on the 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 period 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 key the KY-28 discreet communicator when operating in a combat area.

A number of mockup panels were fitted and evaluated prior to finalizing the various configurations.

4. FABRICATION OF MOCKUP WINDOWS

Three flat panels were incorporated to protect each hand of the lower cabin window area. The side and lower panels are fixed, while the upper panel which features quick-detach fasteners, is readily removable. 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. The mockup armor panels installed in the UH-1D structure are shown in Figures 5, 6, and 7.

Figure 5. UH-1D Windshield and Cabin Door Transparent Armor Mockup Installation

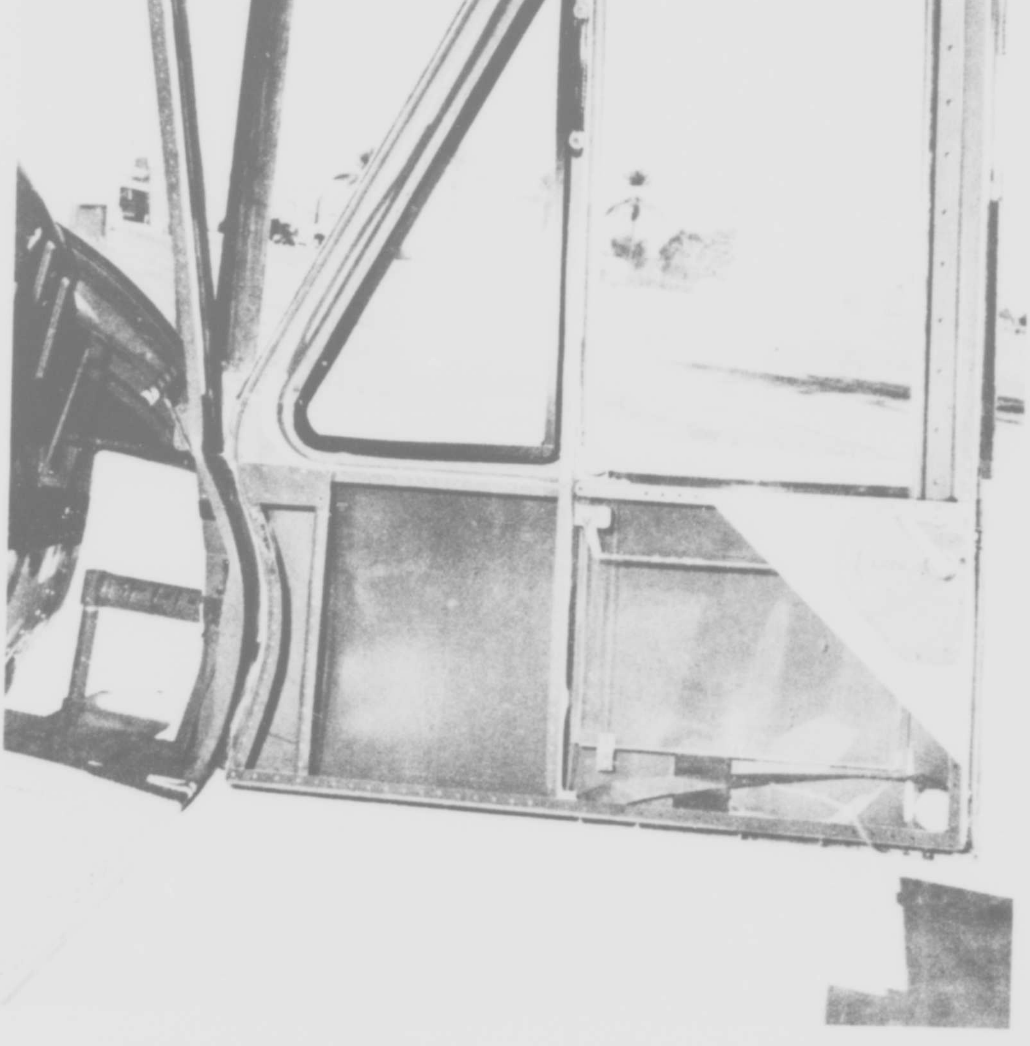


Figure 6. UH-1D Cabin Door Transparent Armor Mockup Installation

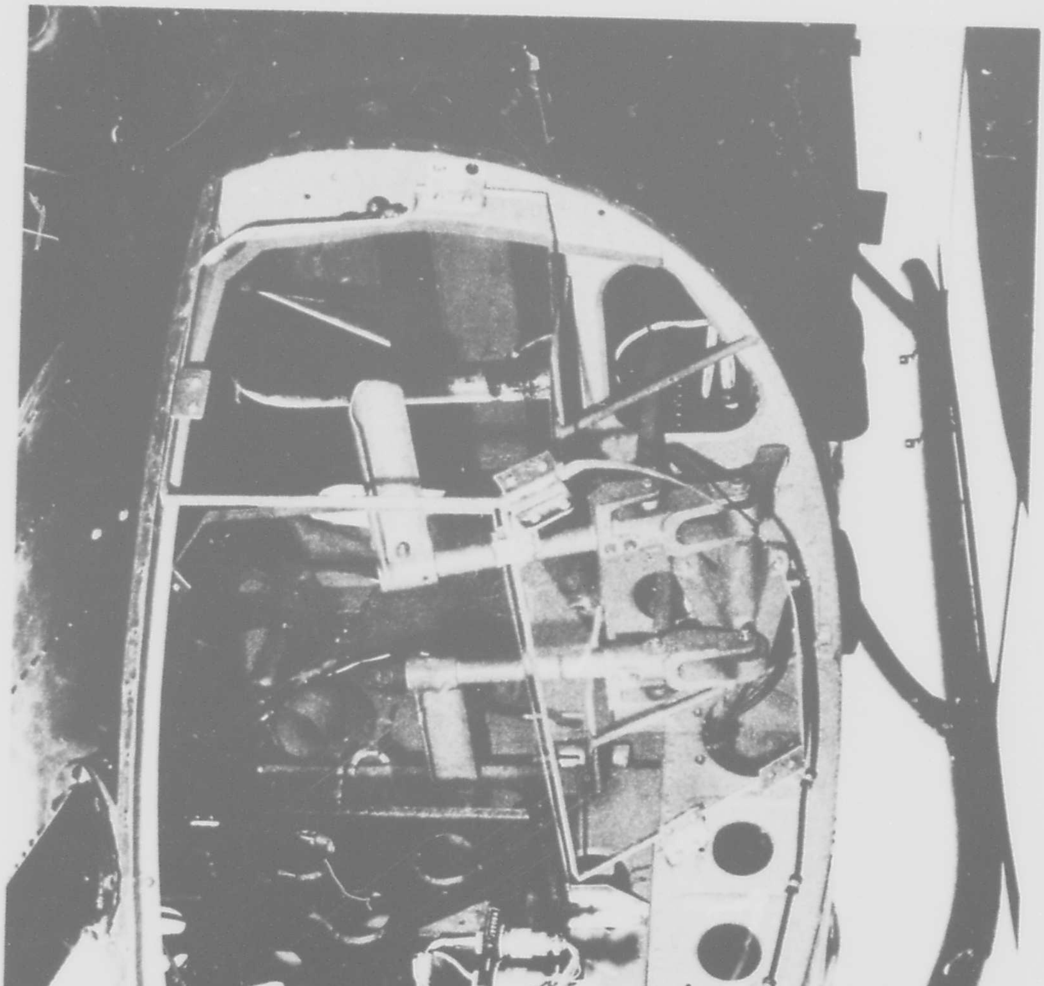


Figure 7. UH-1D Lower Cabin Window Transparent Armor Mockup Installation

5. BALLISTIC VERIFICATION TESTS

A series of physical tests were conducted on typical configurations of RTV-102 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 P/N 3149000-004 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.

Fourteen-inch-square test panels were fabricated which incorporated bonded brackets representative of the UH-1D armor installation. Additional test panels of this size were prepared which had an edge configuration duplicating the sliding crew door panel.

The armor composite used in these panels duplicated the ply configuration of the UH-1D requirement. The mounting of the bonded attachment ballistic test panels was accomplished 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.

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

The expended panels for the bonded attachment and crew door ballistic verification tests are shown in Figure 8 and 9, respectively. These tests indicate that both the bonded attachments and glass engagement of the U-channel on the

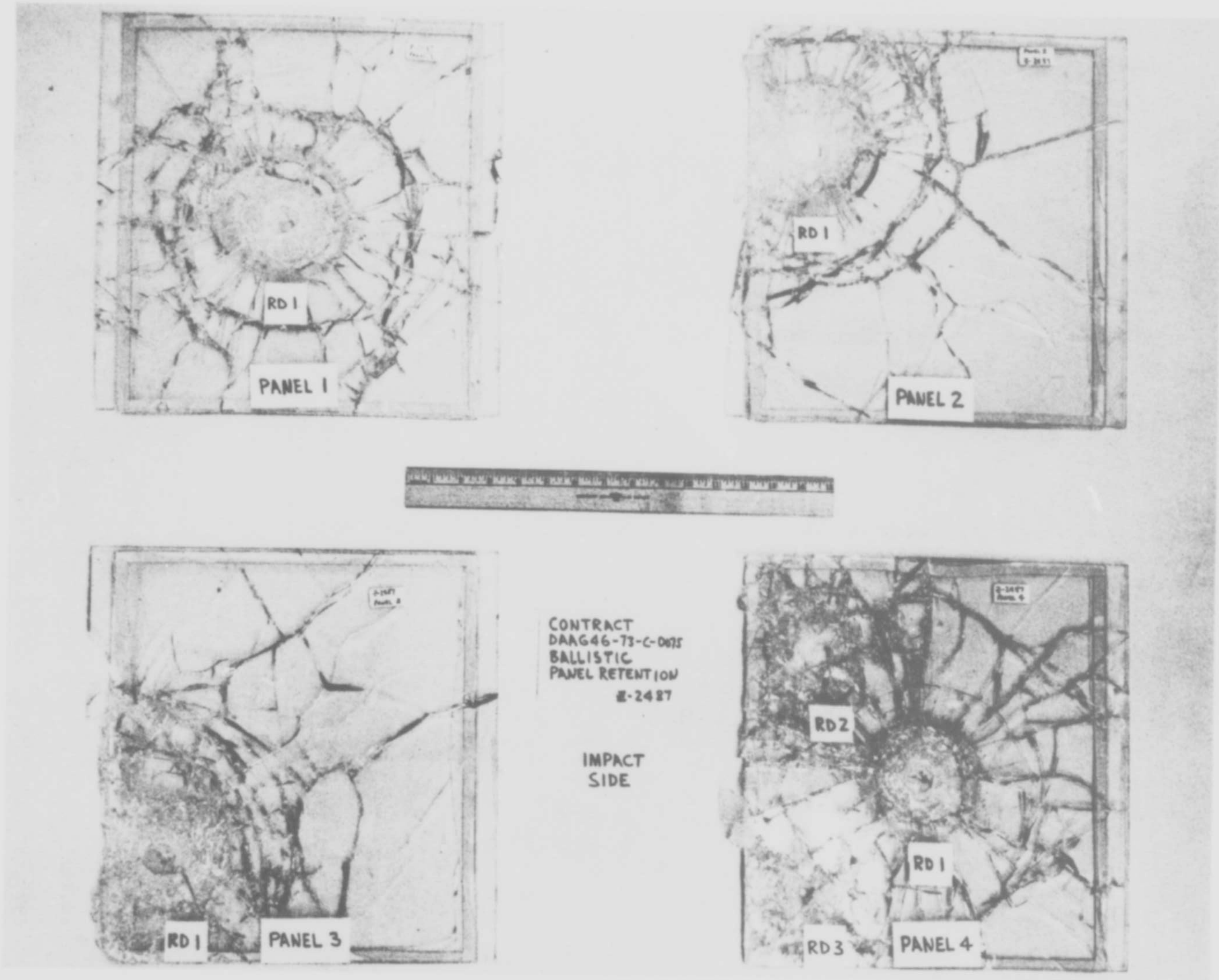


Figure 8. UH-1D Armor Panel, Sliding Crew Door Ballistic Verification Test Articles

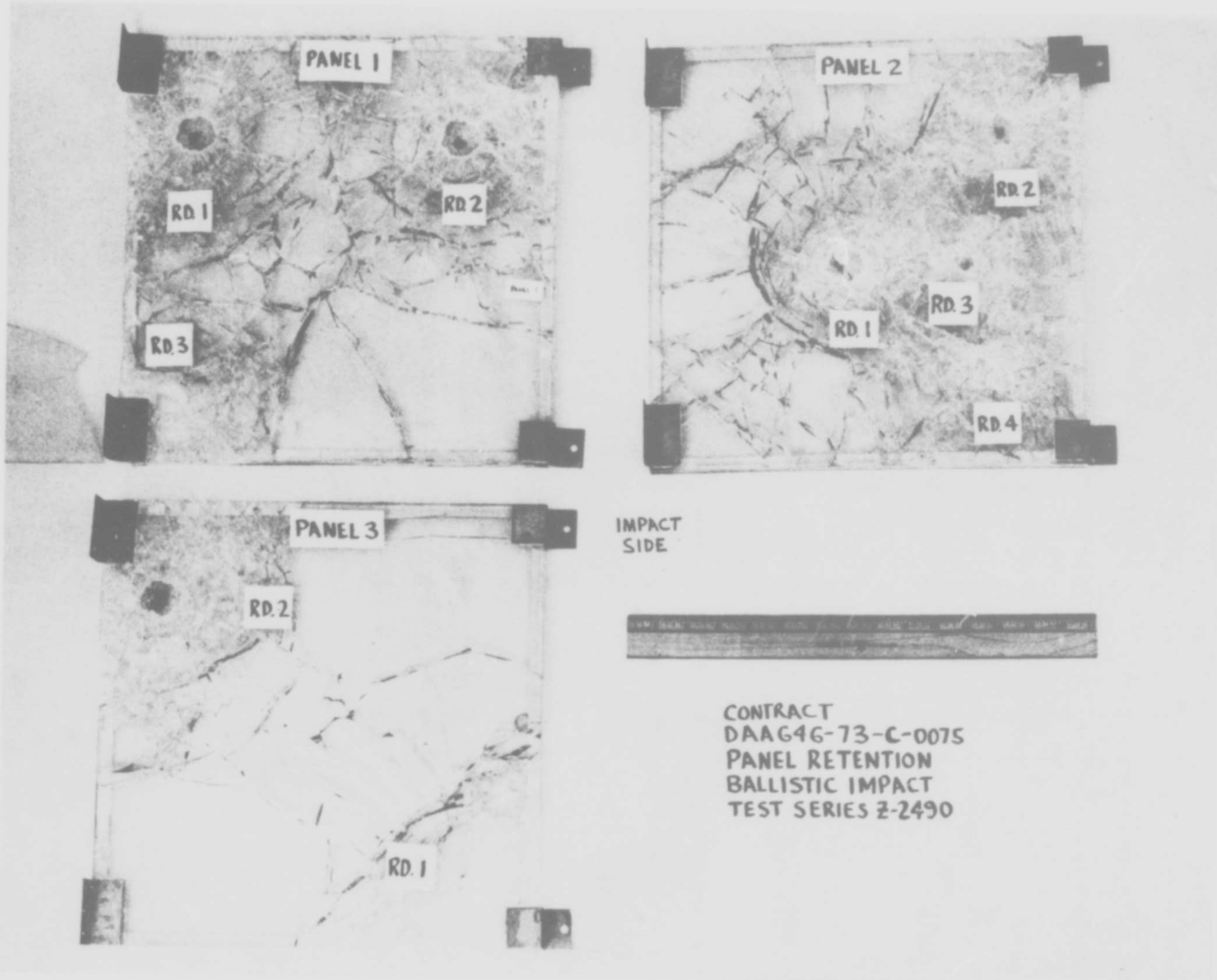


Figure 9. UH-1D Armor Panel Bonded Attachment Ballistic Verification Test Articles

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 2 inches of the supported 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 once the panel was removed from the support channels and is thus not apparent in the photograph. Test panel number 4 withstood three impacts, one in the center and two near one edge, without leaving the support. The actual P/N 3149000-004 crew door sliding windows have 27.0 inches of vertical edge support. This is nearly twice that of the ballistic test articles and should provide additional undamaged glass in the channels for support.

6. DRAWINGS

After completion of the mockup review and incorporation of the design modifications, manufacturing drawings were prepared. An assembly breakdown of the UH-1D transparent armor installation drawings is shown in Table 5. All drawings were prepared in accordance with MIL-D-1000, Category A.

7. INSTALLATION INSTRUCTIONS

Detailed instructions were prepared for the transparent armor installation. This document, CLA-13874, Rev A, when used in conjunction with the installation drawings, supplied the information needed to modify the UH-1D aircraft and install the armor panels.

TABLE 5. UH-1D TRANSPARENT ARMOR INSTALLATION DRAWINGS

Assembly breakdown										
0	1	2	3	4	5	6	7	8	9	Nomenclature
	3149000-001									Transparent armor installation
		3149000-002								Windshield assembly and installation
			3149000-009							Panel - glass windshield
		3149000-003								Armor installation - crew door
			3149000-004							Panel assembly - crew door sliding
				3149000-010						Panel - glass - door - sliding
		3149000-005								Panel assembly - crew door - fixed
			3149000-011							Panel - glass - door - fixed
		3149000-006								Armor installation - lower forward
			3149000-007							Panel assembly, lower forward - lower
				3149000-014						Panel - glass, lower forward - lower
			3149000-008							Panel assembly, lower forward - side
				3149000-013						Panel - glass, lower forward - side
			3149000-012							Panel assembly, lower forward - upper
				3149000-015						Panel - glass, lower forward - upper

SECTION 3

PHASE II - PROTOTYPE GLASS/PLASTIC LAMINATE FABRICATION

1. GENERAL

The Phase II work effort encompassed the fabrication of eight shipsets of P/N 3149000-001 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 this armor is shown in Figure 10.

2. GLASS TECHNOLOGY

Fabrication of the transparent armor panels for the UH-1D P/N 3149000-001 installation required both flat and contoured laminated glass facings. The procurement of the five separate configurations of laminated flat glass did not pose a problem. The contoured glass for the windshields, however, required special processing techniques to produce. Traditionally, glass bent for automotive or aircraft windshields has been processed with reasonably close control of peripheral variance from the nominal contour.

Restraint and sealing mechanisms designed to accommodate variance within the producible limits have minimized installation difficulties and in-service breakage.

The gravity bending of glass generally results in appreciable part-to-part contour variance over the unsupported central area. Liberal crossbend (sag) tolerances have been common and generally do not seriously affect optics if abrupt contour change is avoided.

The successful processing of glass/plastic composite armor with flyable optics requires close matching of the component ply contours.

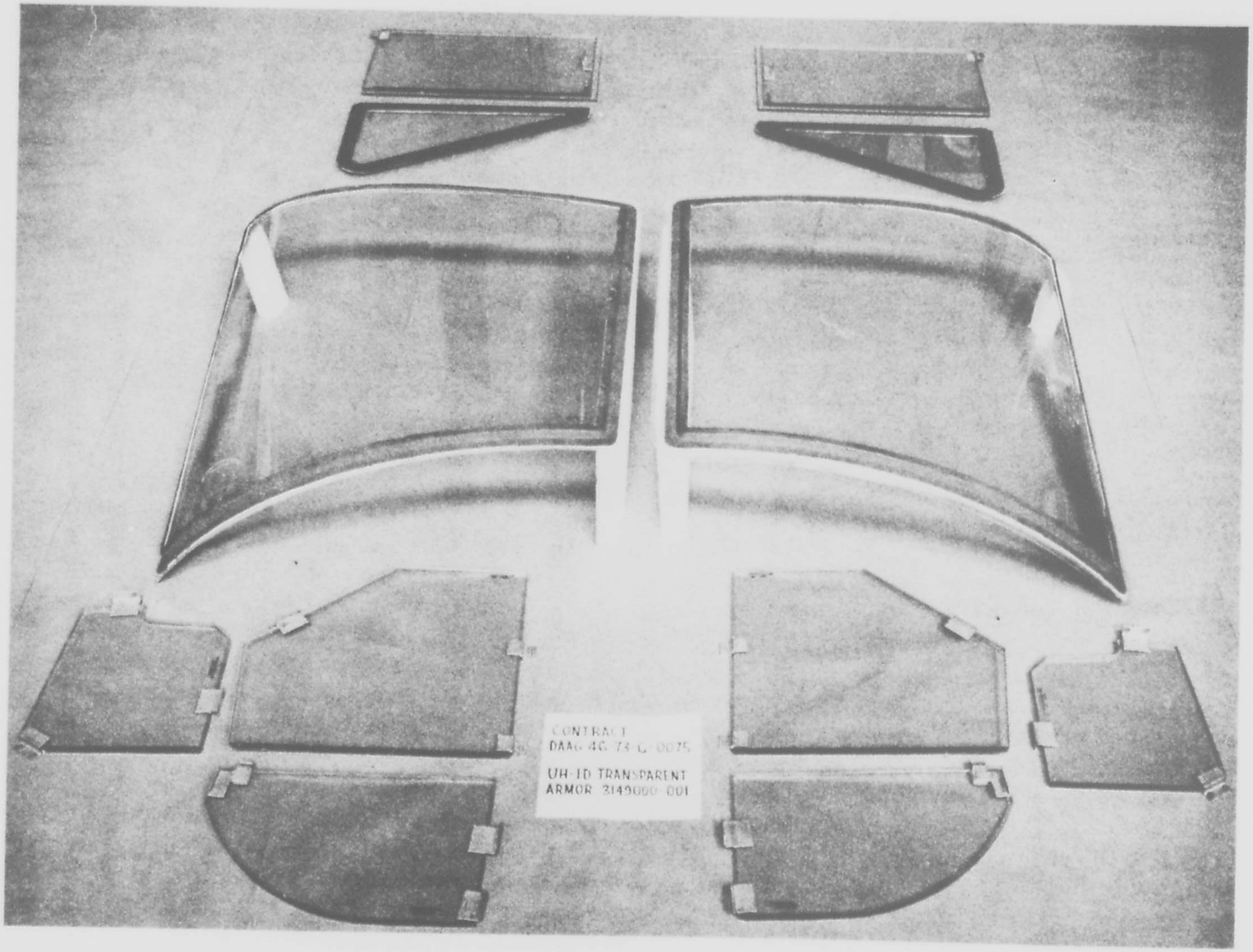


Figure 10. Display of UH-1D Transparent Armor, P/N 3149000-001

Good tooling is required to form the plastic backing ply and support the glass and plastic components during the cast-in-place 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.

The Libbey-Owens-Ford Company (LOF) was selected to produce P/N 3149000-009 windshield glass articles. LOF has been a major producer of large contoured laminated glass automobile and specialty aircraft windshields. Measurements of peripheral off-form variance and crossbend made on each of the 12 shipsets of windshield glass including four shipsets of spares are shown in Table 6. Crossbend is deviation of the windshield straight line elements caused by sag during gravity forming of the glass on a peripheral support tool. Such tooling with an unsupported center is used to prevent markoff. Off-form variance is the departure from the nominal contour measured about the periphery of the article. Each glass was positioned on a nominal male check fixture for measurement. The location of individual measuring positions is shown in Figure 11.

Variation was subsequently found in the contour and trim configuration of these parts which prevented proper fit to the ship. This necessitated retooling and the manufacture of glass for five additional shipsets of windshields. The measurements of peripheral off-form variance and crossbend taken on these five shipsets of reconfigured glass including three shipsets of spares are shown in Table 7.

The data contained in Tables 6 and 7 reflect an insignificant difference in the control of peripheral off-form and crossbend attained during the two separate glass bending runs.

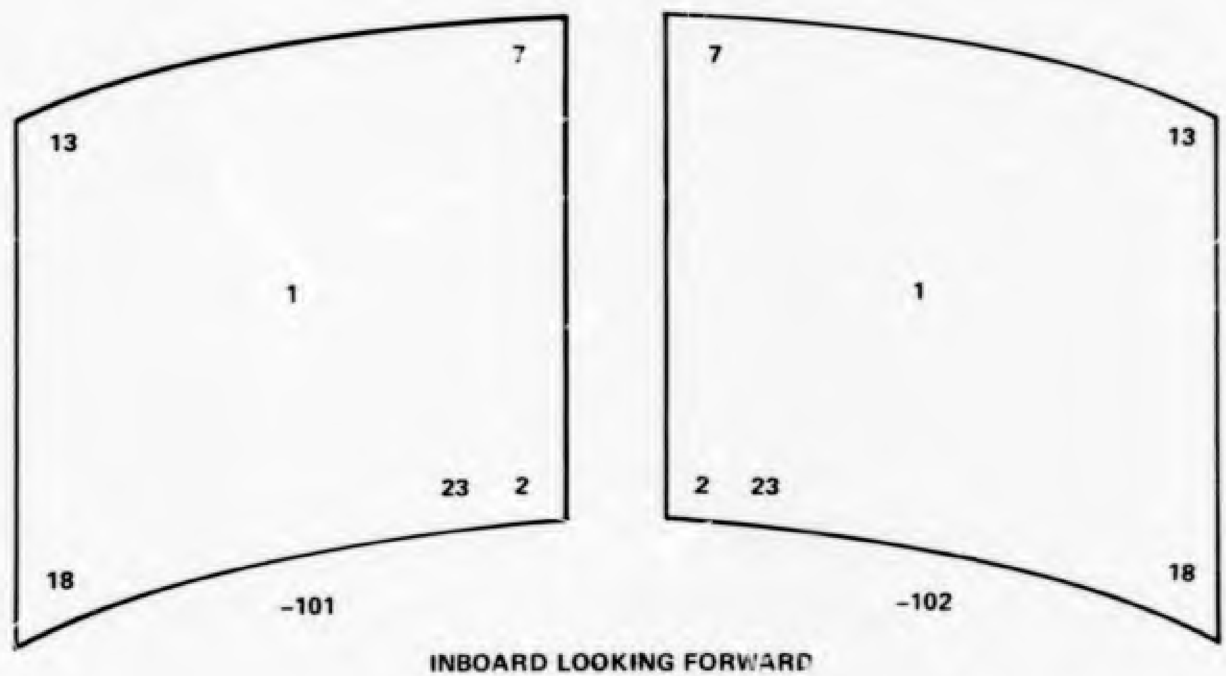
3. MAR RESISTANCE

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 contributes to the ballistic efficiency and nonspalling characteristics of the armor system.

TABLE 6. OFF-FORM DATA FOR P/N 3149000-009 WINDSHIELD GLASS (ORIGINAL PROCUREMENT)

Glass no.	Off-form measurement (inches) measuring position[a]																						
-101	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1	0.300	0.043	0.046	0.060	0.070	0.084	0.120	0.040	0.000	0.000	0.014	0.050	0.070	0.037	0.018	0.000	0.040	0.100	0.040	0.006	0.002	0.000	0.000
2	0.320	0.056	0.046	0.047	0.044	0.045	0.093	0.026	0.014	0.000	0.016	0.038	0.048	0.023	0.008	0.000	0.047	0.094	0.028	0.000	0.004	0.012	0.012
3	0.310	0.030	0.028	0.028	0.028	0.032	0.067	0.023	0.012	0.000	0.016	0.045	0.093	0.060	0.033	0.012	0.030	0.071	0.036	0.000	0.004	0.006	0.000
4	0.330	0.050	0.027	0.018	0.016	0.016	0.072	0.018	0.016	0.014	0.013	0.003	0.000	0.045	0.052	0.037	0.032	0.035	0.018	0.000	0.016	0.020	0.000
5	0.290	0.031	0.019	0.021	0.022	0.028	0.055	0.000	0.000	0.000	0.005	0.000	0.000	0.040	0.048	0.035	0.032	0.078	0.030	0.000	0.000	0.000	0.000
6	0.390	0.080	0.055	0.042	0.020	0.016	0.062	0.006	0.018	0.008	0.010	0.004	0.000	0.034	0.034	0.012	0.010	0.006	0.014	0.002	0.020	0.028	0.014
7	0.310	0.079	0.038	0.025	0.020	0.015	0.052	0.000	0.000	0.000	0.000	0.000	0.000	0.025	0.042	0.042	0.045	0.025	0.015	0.000	0.015	0.028	0.031
8	No measurements taken																						
9	No measurements taken																						
10	0.225	0.037	0.033	0.050	0.057	0.062	0.080	0.018	0.000	0.000	0.007	0.042	0.045	0.024	0.016	0.014	0.043	0.062	0.026	0.003	0.002	0.000	0.000
11	No measurements taken																						
12	0.300	0.041	0.035	0.035	0.020	0.012	0.018	0.003	0.002	0.002	0.010	0.018	0.016	0.000	0.018	0.048	0.058	0.062	0.018	0.000	0.004	0.019	0.027
-102																							
1	0.480	0.048	0.012	0.022	0.008	0.030	0.118	0.025	0.013	0.004	0.000	0.020	0.018	0.000	0.003	0.012	0.034	0.050	0.010	0.000	0.000	0.000	0.002
2	0.500	0.035	0.025	0.022	0.020	0.020	0.088	0.014	0.016	0.023	0.016	0.022	0.024	0.053	0.073	0.080	0.053	0.056	0.032	0.000	0.000	0.000	0.003
3	0.340	0.045	0.030	0.030	0.018	0.000	0.035	0.011	0.027	0.028	0.000	0.000	0.006	0.030	0.040	0.040	0.040	0.065	0.033	0.000	0.000	0.000	0.008
4	0.460	0.041	0.032	0.028	0.019	0.018	0.055	0.020	0.004	0.014	0.000	0.000	0.000	0.012	0.045	0.070	0.082	0.075	0.028	0.000	0.000	0.000	0.000
5	0.450	0.068	0.048	0.040	0.022	0.000	0.030	0.003	0.000	0.003	0.000	0.005	0.003	0.006	0.035	0.057	0.048	0.036	0.013	0.000	0.004	0.004	0.026
6	0.460	0.060	0.040	0.032	0.019	0.019	0.058	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.005	0.030	0.037	0.040	0.000	0.000	0.000	0.000	0.000
7	0.437	0.063	0.062	0.054	0.032	0.028	0.060	0.015	0.000	0.000	0.000	0.035	0.000	0.000	0.000	0.000	0.015	0.010	0.000	0.000	0.000	0.000	0.030
8	0.450	0.045	0.029	0.035	0.020	0.011	0.035	0.006	0.000	0.004	0.000	0.010	0.035	0.032	0.030	0.025	0.055	0.074	0.028	0.000	0.000	0.000	0.020
9	0.425	0.029	0.023	0.029	0.017	0.014	0.060	0.007	0.002	0.004	0.000	0.010	0.004	0.004	0.015	0.019	0.037	0.090	0.030	0.000	0.000	0.000	0.008
10	0.470	0.080	0.056	0.043	0.026	0.000	0.040	0.004	0.000	0.014	0.000	0.004	0.000	0.027	0.038	0.052	0.050	0.042	0.015	0.000	0.000	0.000	0.030
11	0.450	0.045	0.041	0.040	0.020	0.020	0.070	0.020	0.015	0.000	0.000	0.000	0.032	0.028	0.044	0.080	0.084	0.065	0.022	0.000	0.000	0.000	0.000
12	0.450	0.070	0.036	0.029	0.020	0.022	0.066	0.039	0.025	0.018	0.004	0.000	0.006	0.010	0.022	0.038	0.050	0.095	0.024	0.000	0.000	0.000	0.004

[a]Measurement position 1 is center crossbend. Positions 2 through 23 are peripheral off-form measurements (see Figure 11).



NOTE: ALL SEQUENTIALLY NUMBERED POSITIONS NOT SHOWN WERE EQUALLY SPACED.

Figure 11. UH-1D Off-form Data Measuring Positions - P/N 3149000-009 Windshield Glass

TABLE 7. OFF-FORM DATA FOR P/N 3149000-009 WINDSHIELD GLASS (RECONFIGURED PROCUREMENT)

Glass no.	Off-form measurement (inches) measuring position[a]																						
-101	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
13	0.350	0.025	0.014	0.000	0.000	0.000	0.010	0.025	0.014	0.011	0.011	0.018	0.018	0.000	0.000	0.000	0.045	0.070	0.047	0.025	0.000	0.000	0.022
14	0.300	0.035	0.020	0.012	0.000	0.000	0.000	0.028	0.015	0.011	0.012	0.000	0.000	0.000	0.000	0.019	0.059	0.093	0.044	0.020	0.000	0.000	0.051
15	0.325	0.057	0.037	0.025	0.015	0.000	0.015	0.015	0.015	0.021	0.023	0.000	0.000	0.022	0.043	0.035	0.044	0.054	0.027	0.000	0.000	0.014	0.029
16	0.290	0.041	0.018	0.018	0.020	0.037	0.066	0.031	0.015	0.013	0.000	0.060	0.065	0.060	0.062	0.043	[illegible]	0.053	0.007	0.000	0.000	0.000	0.000
17	0.280	0.030	0.020	0.014	0.000	0.012	0.031	0.038	0.017	0.000	0.000	0.000	0.019	0.022	0.036	0.030	0.035	0.038	0.014	0.000	0.000	0.000	0.025
18	0.425	0.020	0.017	0.026	0.029	0.055	0.031	0.013	0.012	0.018	0.016	0.021	0.067	0.026	0.021	0.020	0.023	0.058	0.013	0.000	0.000	0.000	0.000
19	0.350	0.030	0.035	0.039	0.025	0.029	0.000	0.012	0.013	0.014	0.019	0.050	0.046	0.029	0.023	0.030	0.038	0.056	0.039	0.000	0.000	0.000	0.010
20	0.315	0.018	0.014	0.014	0.000	0.025	0.000	0.023	0.018	0.018	0.017	0.037	0.079	0.040	0.021	0.014	0.000	0.037	0.000	0.000	0.000	0.000	0.000
-102																							
13	0.370	0.069	0.059	0.052	0.037	0.015	0.020	0.037	0.013	0.014	0.000	0.000	0.028	0.048	0.015	0.000	0.000	0.042	0.039	0.020	0.014	0.040	0.093
14	0.320	0.082	0.080	0.060	0.072	0.060	0.085	0.057	0.015	0.000	0.000	0.014	0.030	0.042	0.025	0.030	0.045	0.077	0.042	0.020	0.000	0.034	0.092
15	0.380	0.074	0.075	0.081	0.083	0.080	0.093	0.053	0.018	0.016	0.000	0.000	0.027	0.045	0.021	0.000	0.020	0.057	0.024	0.000	0.000	0.021	0.053
16	0.410	0.093	0.089	0.090	0.085	0.073	0.093	0.034	0.014	0.015	0.000	0.000	0.020	0.056	0.035	0.023	0.000	0.070	0.000	0.002	0.004	0.029	0.070
17	0.320	0.071	0.063	0.065	0.060	0.051	0.071	0.044	0.013	0.012	0.000	0.023	0.023	0.020	0.015	0.039	0.070	0.055	0.053	0.000	0.000	0.031	0.070
18	0.440	0.083	0.068	0.058	0.040	0.022	0.030	0.027	0.016	0.025	0.034	0.043	0.049	0.054	0.020	0.000	0.050	0.065	0.039	0.017	0.012	0.027	0.071
19	0.390	0.093	0.066	0.048	0.026	0.000	0.020	0.023	0.017	0.025	0.025	0.016	0.000	0.035	0.017	0.000	0.034	0.050	0.033	0.012	0.013	0.046	0.093
20	0.310	0.093	0.069	0.062	0.045	0.030	0.046	0.025	0.017	0.028	0.031	0.028	0.035	0.042	0.012	0.000	0.038	0.065	0.038	0.000	0.000	0.030	0.075

[a]Measurement position 1 is center crossbend. Positions 2 through 23 are peripheral off-form measurements (see Figure 11).

Unfortunately, polycarbonate has a number of adverse characteristics which include low abrasion and chemical resistance. A coating applied to the exposed backside surface of the material is required to protect the polycarbonate in the rigorous and potentially degrading environment of military helicopters.

Goodyear Aerospace has conducted a company-funded research and development program for several years on abrasion resistant coatings for polycarbonate and other transparent plastic substrates. As a result of this effort, a definition of the properties and processing parameters for several of the best state-of-the-art abrasion resistant coatings existed at the start of the contract. After careful consideration of the specific requirements for the UH-1D transparent armor, Goodyear Code 701 abrasion resistant coating was selected. Goodyear Code 701 is a modified fluorocarbon/silicate copolymer solution coating system.

4. OPTIMIZED FABRICATION TECHNIQUES

The processing used to fabricate the UH-1D transparent armor was based on Goodyear Aerospace prior work accomplished during company-funded programs. The processing encompassed the best methods and procedures applicable to the many specialized operations necessary to produce glass/plastic transparent armor. The most important of these operations include:

1. Compounding and application of solution coatings
2. Compounding and injection of the cast-in-place interlayer system
3. Fabrication of tooling
4. Forming of polycarbonate
5. Cleaning of glass and polycarbonate
6. Assembly of the glass/plastic assembly.

All of the flat armor composites produced in both Phases I and II were made using the established processing. As was anticipated, modification of much of the processing was required to accomplish the more difficult task of producing acceptable windshields. The combined size and contour of the UH-1D windshield posed a task extending the present state-of-the-art into production in a glass/plastic composite.

The difficulty in processing the windshields was compounded by the large variance in the contours of the individual P/N 3149000-009 laminated glass facings produced by the glass vendor. The extent of this variance is documented in Tables 6 and 7.

The first three shipsets of windshields scheduled for use in the Phase III testing were produced using the first glass facings received.

A previously mentioned contour and trim error was found in these glass articles; however, it was not felt that this would affect the function of the finished composites as test articles.

It was decided that a single nominal contour tool would be employed to form the plastic backing ply for each hand of the three shipsets of test windshields. The effect of this factor on the resultant composite optical properties and environmental performance would have considerable impact on manufacturing economy. The lowest cost concept was thus employed for the initial fabrication effort. The added effort of producing a forming tool to the contour of each glass was a contingency to be considered only if the first method failed to produce acceptable windshields.

It was evident after reviewing the sizable crossbend and peripheral off-form variance of the individual glass articles (reference Table 6) that casting tooling for each glass would be necessary. Hard tooling is required to support the plastic and glass plies during the casting and cure of the interlayer.

A gross mismatch between the glass and plastic plies would have resulted, had any of the windshield glasses been assembled and cast to the polycarbonate ply on the nominal contour forming tool. The lack of ply parallelism resulting from such action would yield a windshield having unusable optical properties.

One tooling concept to match the glass contour was used to produce the S/N 1 and 2 shipsets of P/N 3149000-002 windshields. This concept consisted of making an individual "plug" to match each glass inner contour. Plaster was splined around the periphery of each plug to extend the contoured surface to a size large enough to support the polycarbonate ply. It was apparent that this concept was not producing parts with suitable optical properties. The failure of this tooling concept was traced to the secondary operation required to extend the contoured tool surface.

A second tooling concept was employed to produce the S/N 3 shipset of windshields. This tooling extended the glass contour more accurately and in a single operation. During the assembly of all three shipsets of windshields, the polycarbonate which had been formed to a nominal contour was moderately reshaped by vacuuming to conform to the individual casting tool.

The S/N 3 windshields produced in this manner had only marginally better optical properties. Neither article approached the level of flyable optics required. Further change in the tooling concept was clearly needed to improve the contour match of the glass and plastic component plies. Starting with the S/N 4 windshields, a fiberglass reinforced plastic laminate tool was produced to the concave surface of each windshield glass. This tool was then used for both the forming of the polycarbonate backing ply and as a support during the interlayer casting operation joining the glass and polycarbonate plies. This tooling concept and fabrication method produced composite windshields having greatly improved optical quality. This concept was used to fabricate the five deliverable shipsets of windshields, S/N 4 through 8, with one exception. An experiment to minimize the tooling requirement was made by grouping the windshield glass articles by center crossbend measurements. The forming and casting tool used to produce the P/N 3149000-002-101, S/N 4 windshield was reused to fabricate a second unit. The glass component of the P/N 3149000-002-101, S/N 5 windshield produced on this same tooling had a center crossbend matching that of S/N 4 within 0.010 inch. The resultant S/N 5 composite windshield had a considerable amount of distortion. The distortion pattern indicates that significant variance in overall contour existed between the two glass articles. Such variance in two pieces having nearly identical center crossbend indicates that controlled glass bending response was not achieved.

Double exposure photographs illustrating the optical quality achieved by the various tooling methods are presented in Figures 12, 13, 14, and 15. Figure 12 shows the right-hand S/N 3 windshield which was produced using the original tooling concept. Figure 13 shows the right-hand S/N 6 windshield made using the latest tooling and processing. It is the best optical quality windshield produced on the contract. Figure 14 is the left-hand S/N 7 windshield which is the worst optical quality article produced using the same basic tooling and processing as the right-hand S/N 6 unit. Figure 15 presents the left-hand S/N 5 windshield, the second article produced on the S/N 4 tooling. Some difficulty was encountered with several of the fiberglass reinforced plastic laminate tools changing contour during the high temperature polycarbonate forming cycle. This factor manifested in the optical quality of the composite windshields explains most of the difference between the windshields shown in Figures 13 and 14.

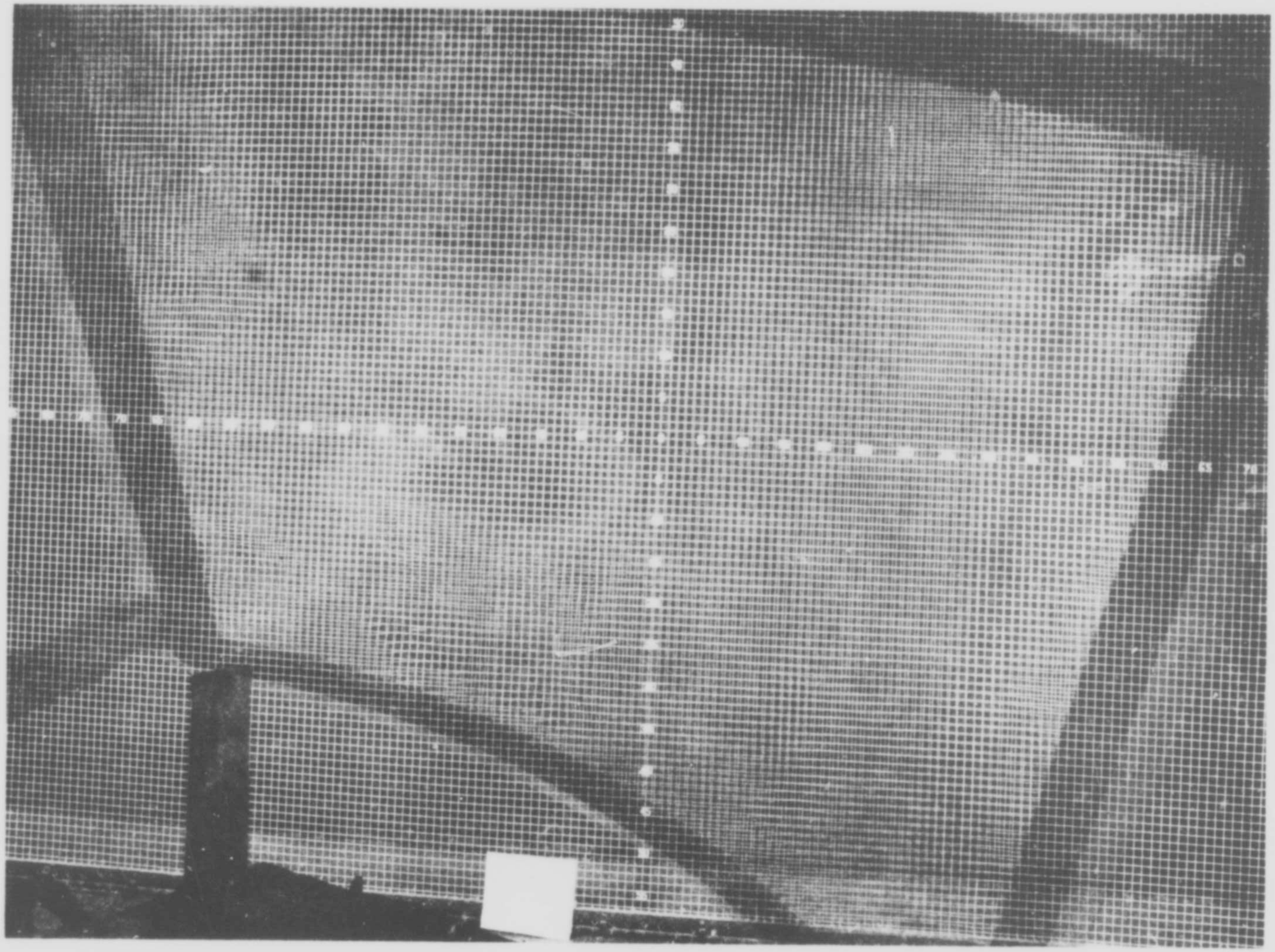


Figure 12. UH-1D Windshield Double Exposure Distortion, Original Tooling Concept

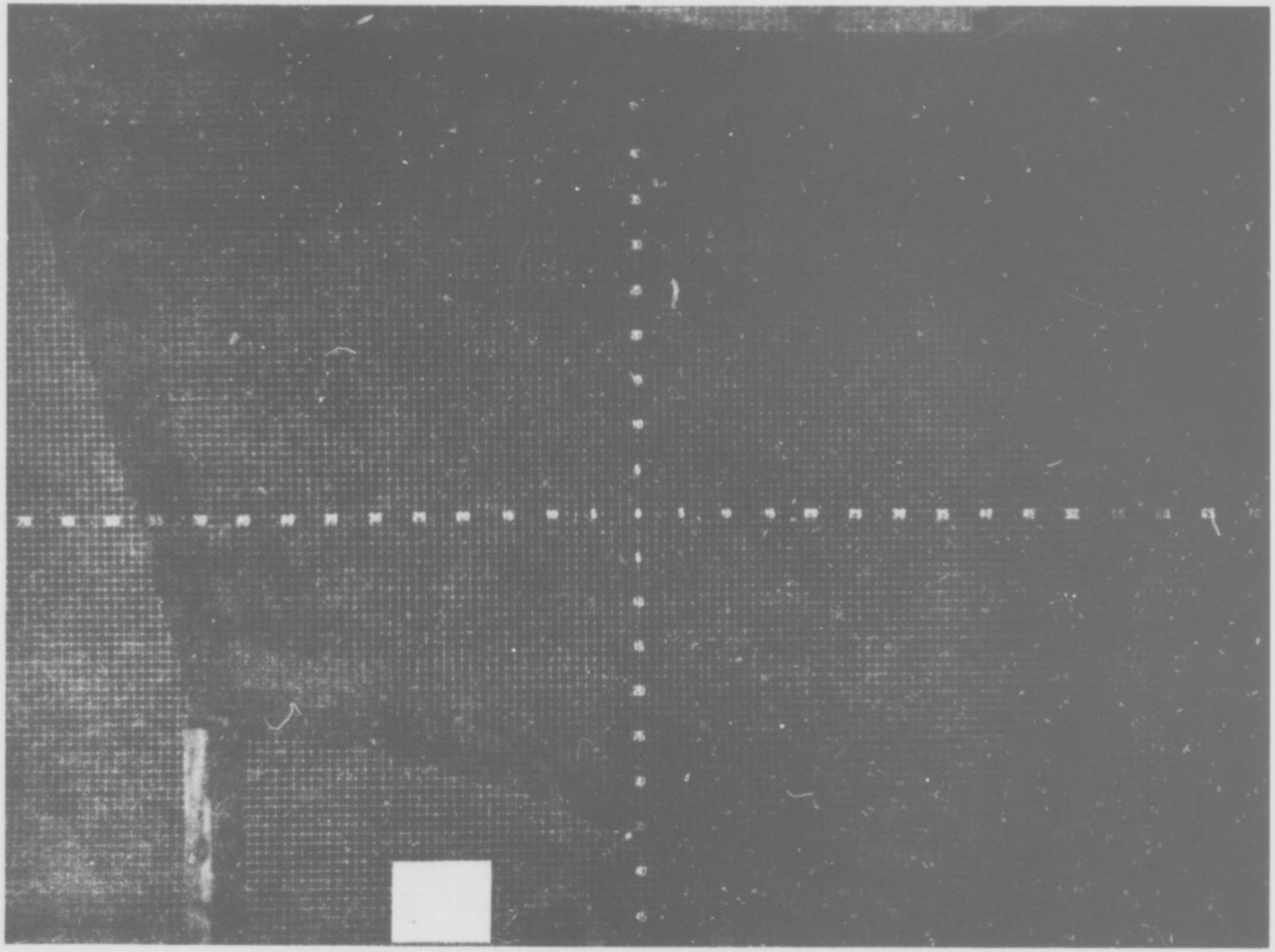


Figure 13. UH-1D Windshield Double Exposure Distortion, Latest Tooling Concept, Best Optical Unit

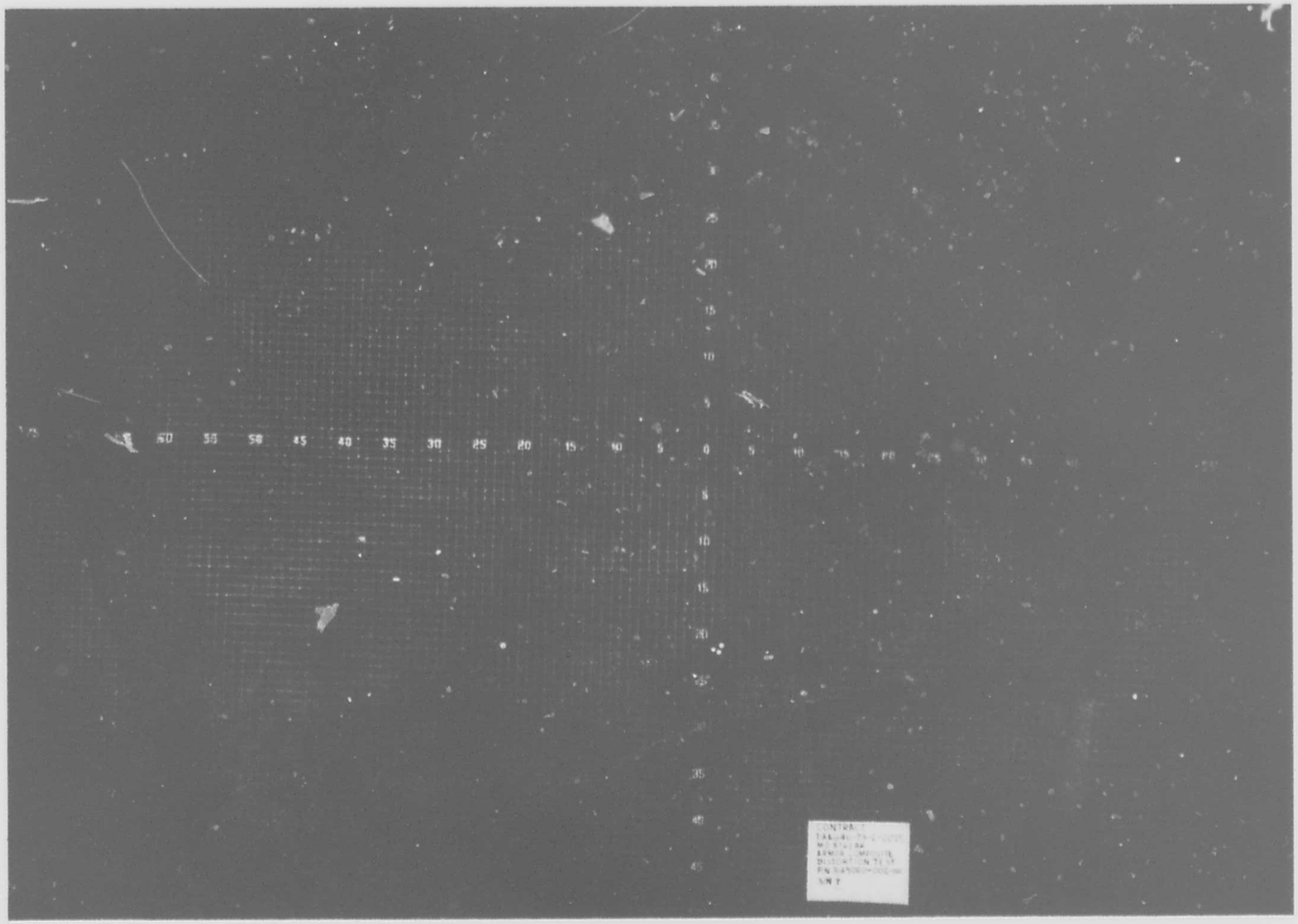


Figure 14. UH-1D Windshield, Double Exposure Distortion, Latest Tooling Concept, Worst Optical Unit

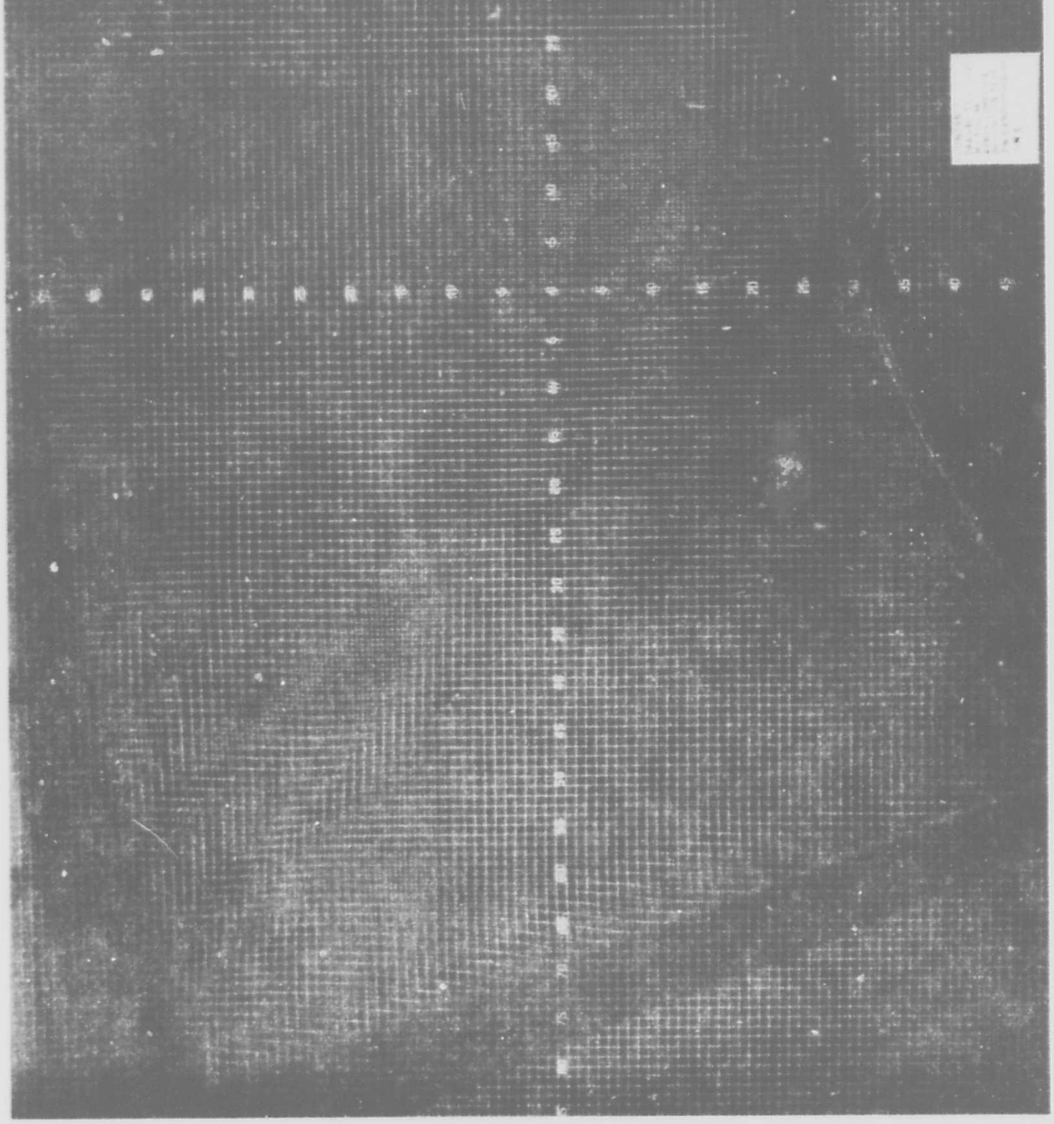


Figure 15. UH-1D Windshield, Double Exposure Distortion, Tooling Reuse Concept

SECTION 4

PHASE III - PROTOTYPE INSTALLATION

1. GENERAL

During Phase III, three shipsets of the transparent armor fabricated in Phase II were to be installed in UH-1D helicopters at the Goodyear Aerospace facility. This effort would provide a means of verifying the universality of the design, and the suitability of the modification and installation instructions. Flight testing and evaluation of the three modified aircraft by Army personnel were also scheduled.

It was subsequently determined by AVSCOM that three helicopters were not available for this purpose. It was also determined that the aircraft modification, armor installation, and flight testing would have to be accomplished at a government facility charged with such responsibilities. A change in the contract work scope was made by AMMRC to accommodate these findings. In accordance with this change, Goodyear Aerospace personnel installed one shipset of transparent armor in a UH-1H helicopter at the U.S. Army Proving Ground (YPG), Laguna Field, Yuma, Arizona. Environmental testing of configured transparent armor was also conducted during Phase III.

2. PROTOTYPE INSTALLATION

a. General

One shipset of P/N 3149000-001 transparent armor was installed in a UH-1H helicopter, S/N 68-16301. The test aircraft was undergoing a routine 100-hour maintenance and inspection procedure at the time that installation of the armor was initiated. The UH-1H helicopter is basically a UH-1D which has been upgraded by the installation of a more powerful turbine engine.

The installation was broken down into three separate areas:

1. P/N 3149000-002-100 Windshield installation
2. P/N 3149000-003-100 Crew door installation
3. P/N 3149000-006-100 Lower forward installation.

The findings of the personnel installing the armor in these three areas are summarized as follows.

b. Windshield Installation

The P/N 3149000-002-101 left-hand and 3149000-002-102 right-hand windshield panels were installed in accordance with the Installation Instructions, CLA-13874. 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, drilling, or trimming the windshields. The installation calls for the reuse of the AN960PD10L flat washers and AN364D1032 nuts as used on the standard windshield. The windshields in the test aircraft were found to be fastened with thicker AN365D1032 nuts. No AN364D1032 nuts were available at the YPG Laguna Field facility. The MS27039DD1-08 screws supplied with the installation were of insufficient length to be used with the thicker nuts. Because either nut could apparently be encountered in the field, it was decided to change to longer MS27039DD1-10 screws. Similar length adjustments were made where MS27039DD1-10 and MS27039DD1-11 screws were called out. There are several areas where these longer screws fasten a clip or bracket as well as the windshield.

It was found that the standard windshield wiper stop brackets would not fit the armored windshield. Modification or redesign is required for this piece. Windshield wiper operation is seldom required in the Yuma test area; however, it was agreed that the wiper arms would be modified and installed by Yuma personnel. The free air temperature gage was relocated from the pilot's windshield to the cabin roof in accordance with the installation drawing.

c. Crew Door Installation

The crew doors were removed from the fuselage which had been supplied to Goodyear Aerospace during Phase I for use in the design and mockup effort. These 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. Several washer and spacer changes were incorporated during this work. A rivet head clearance problem between the door post and a retainer was likewise resolved. Changes in the manufacturing drawings and installation instructions were effected to reflect these items.

The modified crew doors were installed on the test aircraft without difficulty. The aircraft features a pull-type quick-disconnect linkage which frees both door hinges for emergency egress. After changing the doors, minor adjustments were required in the latch mechanism.

d. 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. Modified pilot's and copilot's outboard rudder pedals from the mockup fuselage were substituted on the test aircraft.

The standard right-hand glazing was removed, and the positions of the fixed side and lower armor panels were measured and marked. The panels were clamped in place for trial fitting. This disclosed a small amount of interference between the side panel lower forward attachment bracket and the standard glazing which was handheld in place for this check. The panel positioning was adjusted as much as possible to minimize this interference prior to the drilling of the attachment holes. After the panels were securely attached, the clearance was rechecked. It was necessary to file as much material as possible from the lower corner of the bracket. This action corrected the interference, but better than a zero clearance condition could not be readily achieved.

The mounting bracket and clip were installed on the upper removable panel with the proper quick-release fasteners. This assembly was then trial fit to the aircraft in the premeasured location. It was found that the assembly was too long to fit correctly between the fixed side panel and the interior bulkhead. The measurement of the correct upper panel positioning also disclosed a problem relating to the location of the mounting bracket attachment holes. The UH-1H aircraft interior bulkhead in this area differed from that of the UH-1B structure used for the design of the armor installation. Specifically, the size and location of lightening and access holes in the structure were different. This was contrary to information supplied Goodyear Aerospace when a UH-1B structure was provided for use in designing the armor for the UH-1D aircraft. The change resulted in several of the planned attachment holes in the bracket being negated by matchup with the larger holes in the structure. A mismatch of the upper outboard attachment clip to the appropriate structure was also noted. The dimensional fit problems encountered were of sufficient number and complexity to indicate that appreciable dimensional variation of basic structure can be anticipated from ship to ship for this type aircraft. This variation cannot be accommodated by the present attachment design. A redesign of the lower forward armor installation is needed to provide more positive clearance between the side panel corner and the standard glazing as well as to provide added adjustability in the panel attachments to the aircraft structure. The inner attachment bracket was modified to facilitate installation of the upper armor panel in the test aircraft for this evaluation. This bracket was narrowed, and the receptacles for the quick-release fasteners were moved inboard. New locations were determined for the fasteners to hold the bracket to the aircraft structure. The upper outboard attachment clip was moved aft to match the aircraft structure properly. It was then drilled and secured with fasteners. These modifications allowed the upper panel to be securely mounted and retained the quick-release feature. The upper outboard edge of the panel was located approximately one-half inch aft of the proper position matching the side panel.

On the left-hand installation, similar conditions were encountered with the exception of the side panel which cleared the standard glazing by approximately one-eighth inch. The same hardware modifications were made to permit the installation of the left-hand lower forward armor panels.

The completed armor installation in the test aircraft is shown in Figures 16, 17, 18, and 19.

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.

Figure 16. Windshield and Crew Door Transparent Armor Installation in Test Aircraft

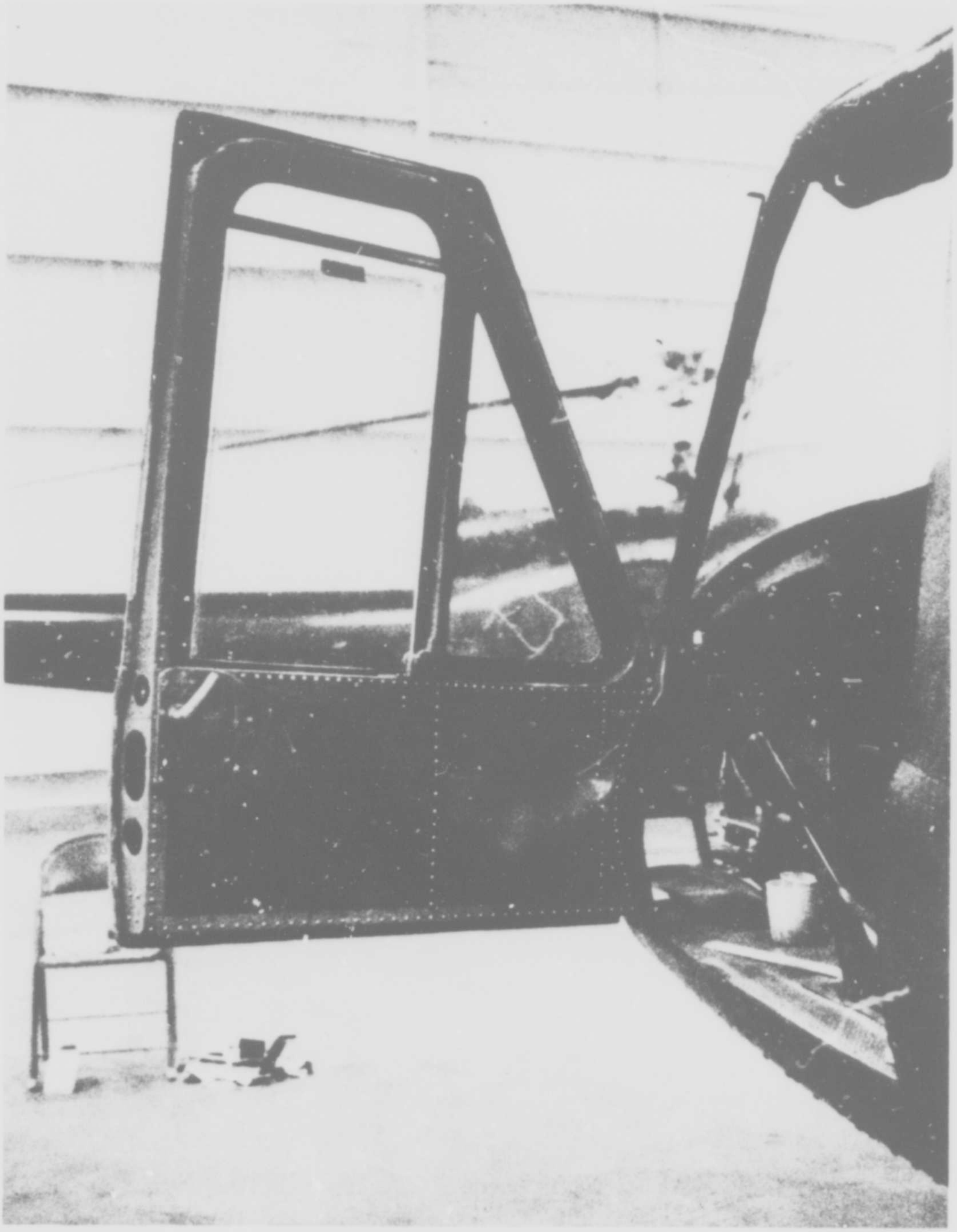


Figure 17. Crew Door Transparent Armor Installation in Test Aircraft

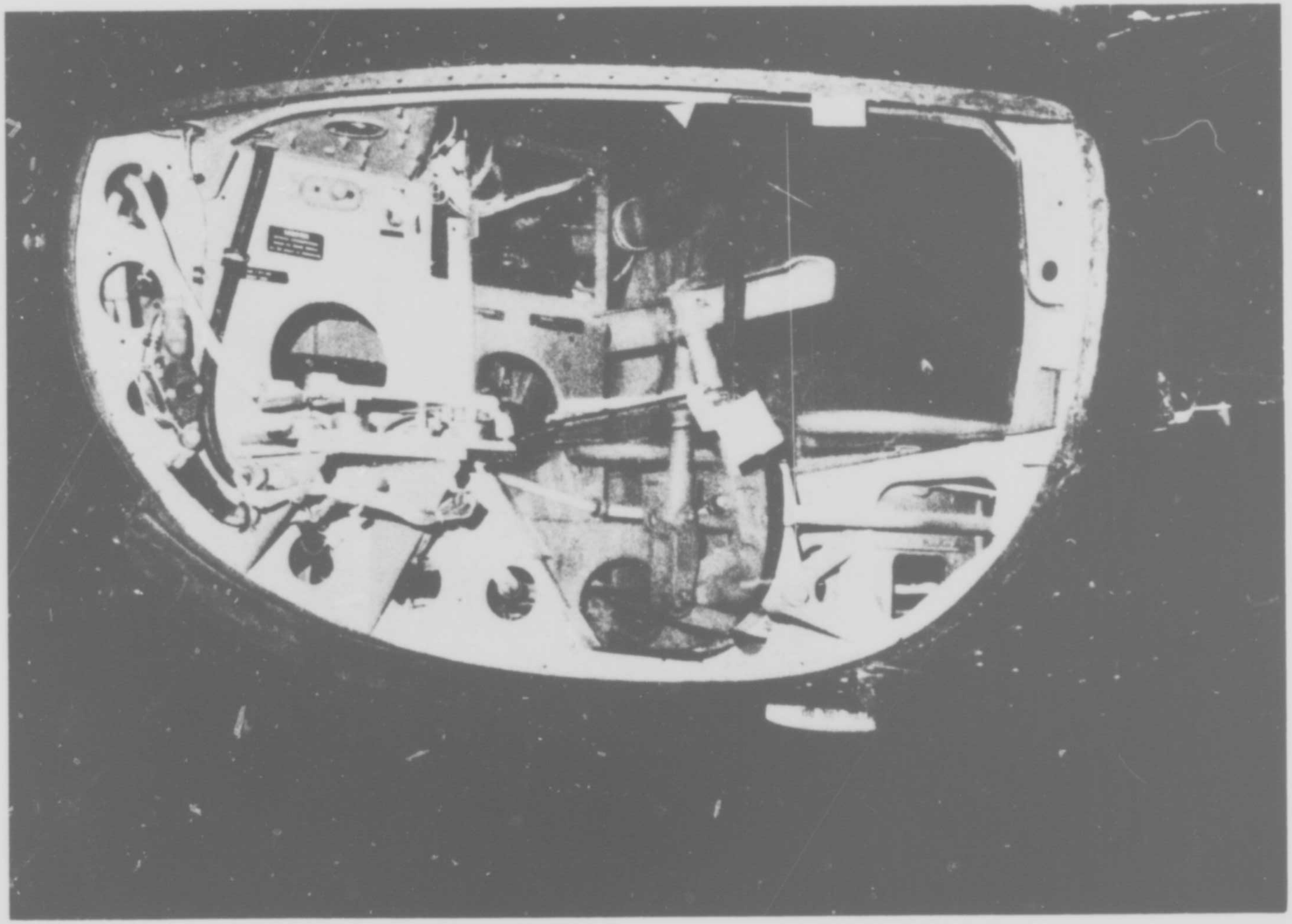


Figure 18. Lower Forward Transparent Armor Installation in Test Aircraft

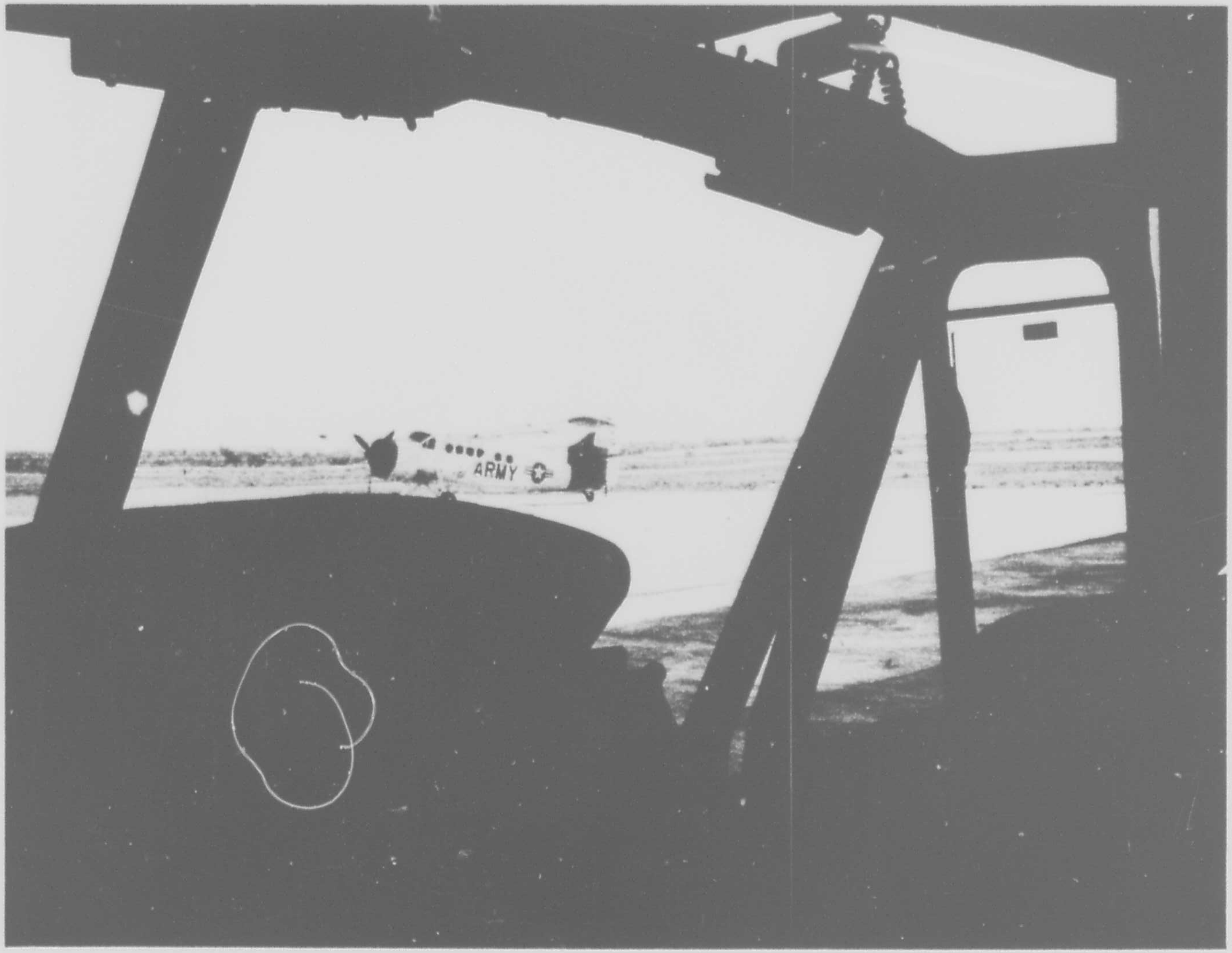


Figure 19. View Through Pilot's Transparent Armor Windshield and Crew Door in Test Aircraft

It was determined that the installation had increased the basic aircraft weight by 193 pounds (5428 pounds to 5621 pounds). The center of gravity of the basic aircraft was moved forward from station 144.3 to station 141.0. An analysis of the modified aircraft gross weight and center of gravity was calculated for several missions. This data is presented in Table 8. The test aircraft was redesignated as JUH-1H to indicate modified status.

TABLE 8. TEST AIRCRAFT WEIGHT AND BALANCE DATA

Aircraft condition	Aircraft gross weight (lb)				Aircraft center of gravity (in.)			
	Takeoff		Landing		Takeoff		Landing	
	Actual	Allowed	Actual	Allowed	Actual	Allowed	Actual	Allowed
1	7394	9500	6515	9500	139.0	130-144	135.6	130-144
2	9374	9500	8495	9500	134.8	134-144	131.8	130-144

Aircraft condition code:

1. Training mission includes 2-man crew, survival kit, 209 gallons of fuel, 1.5-hour flight time.
2. Maximum passenger mission includes 2-man crew, 11 passengers, survival kit, and 209 gallons of fuel.

General Notes:

1. Test aircraft JUH-1H, S/N 68-16301, with transparent armor installation.
2. Data based on an aircraft weighing record dated 12 December 1974, Laguna Army Airfield, Yuma Proving Ground, Arizona.

3. FLIGHT TEST EVALUATION

Flight testing of the armored aircraft has been scheduled as an add-on to its routine mission assignments. The test aircraft is assigned to the Laguna Army Airfield, Yuma Proving Ground, Arizona. The chief of the airfield facility is Lt. Col. H.T. Woodmansee. The Project Engineer assigned to monitor the armor installation and flight testing is J. F. LaFata. Mr. LaFata works under the direction of T.O. Ellison, Chief, Aviation Engineering Branch.

Goodyear Aerospace has prepared a flight test and evaluation report form which will be used to document this effort. A report will be prepared by each pilot and copilot after each flight. The report format includes identification of the aircraft, personnel, and flight conditions, as well as comments regarding visibility, operation of controls, effect on aircrew functioning, aircraft flight characteristics, and maintainability. The findings of the flight test evaluation will not be available in time to include in this report. The duration of flight testing which can be accomplished is presently 6 months.

4. ENVIRONMENTAL TESTING

a. General

Selected pieces from three shipsets of the configured armor manufactured during Phase II were subjected to environmental test exposures. All of the armor panels in the three shipsets were tested for luminous transmittance, haze, optical deviation, and optical distortion prior to any environmental testing. Each armor panel used for environmental testing was retested for these optical properties upon completion of such exposure.

A summary correlating the testing schedule and test articles is shown in Table 9.

TABLE 9. PHASE III ENVIRONMENTAL TEST SCHEDULE

Test	Specification	Test article (P/N)
High Temperature	MIL-STD-810B Method 501 Procedure 1	3149000-002-101 S/N 3 3149000-002-102 S/N 3 3149000-004-101 S/N 1 3149000-004-102 S/N 2
Low Temperature	MIL-STD-810B Method 502 Procedure 1	3149000-002-101 S/N 2 3149000-002-102 S/N 2 3149000-004-101 S/N 2 3149000-004-102 S/N 1
Temperature Shock	MIL-STD-810B Method 503 Procedure 1	3149000-002-101 S/N 1 3149000-002-102 S/N 1 3149000-004-101 S/N 3 3149000-004-102 S/N 3
Humidity	160 deg F, 37 percent relative humidity constant, 240 hr	3149000-002-101 S/N 3 3149000-002-102 S/N 3 3149000-004-101 S/N 1 3149000-004-102 S/N 1
Ultraviolet Stabilization	Federal Test Method Standard No. 406, Method 6024 (Goodyear Aerospace modified) - 1000 hr	3149000-005-101 S/N 1 3149000-005-102 S/N 1
Contam-ination	Goodyear Aerospace Test Method TT-S-735, Type III Fluid Vapor Exposure - 1 month	3149000-008-101 S/N 1

Optical test data measured on the three shipsets of armor are shown in Tables 10, 11, and 12. Details of the individual tests conducted on these armor panels are as follows.

b. High Temperature

Two each P/N 3149000-002 windshields and P/N 3149000-004 sliding door panels were subjected to high-temperature testing in accordance with MIL-STD-810B, Method 501, Procedure 1. The test articles were conditioned for the required 48 hours at 160 deg F and relative humidity not exceeding 15 percent. After returning to standard ambient conditions and stabilizing, each of the four test articles was visually inspected. No change in appearance or other visible sign of degradation was evident for any of the four test articles.

c. Low Temperature

Two each P/N 3149000-002 windshields and P/N 3149000-004 sliding door panels underwent low-temperature testing in accordance with MIL-STD-810B, Method 502, Procedure 1. The test articles were conditioned at -65 deg F for the required 48 hours and were then returned to ambient conditions and stabilized.

Both P/N 3149000-004 test articles showed no change in appearance or other visible signs of degradation. The P/N 3149000-002-101, S/N 2 windshield was delaminated in the upper left-hand corner following the low-temperature exposure. The delamination measured approximately 5 inches in length and extended 1-1/4 inches inward. The loss of adhesion was at the cast-in-place interlayer bond to the polycarbonate substrate. More extensive delamination was evident in the P/N 3149000-002-102, S/N 2 windshield after low-temperature exposure. Delamination extending nearly the full length of the outboard edge extended from 1/4 to 1-3/4 inches into the optical area.

TABLE 10. UH-1D TRANSPARENT ARMOR OPTICAL TEST DATA

Part no.	Serial no.	Optical deviation (minutes) Original Measuring position[a] 1	2	3	4	5	Optical deviation (minutes) Posttest	Optical distortion (slope) Original Viewing area[c] A	B	Optical distortion (slope) Posttest
3149000-002-101	1	18	10	6	2.5	15	Footnote b	1 in 10	1 in 4	Footnote b
	2	17	12	20	14	16	Footnote b	1 in 9	1 in 3	Footnote b
	3	6	3	4	6	4	Footnote b	1 in 15	1 in 7	Footnote b
3149000-002-102	1	3	5	14	16	1	Footnote b	1 in 10	1 in 4	Footnote b
	2	13	32	16	12	24	Footnote b	1 in 10	1 in 4	Footnote b
	3	2	5	9	5	4	Footnote b	1 in 6	1 in 5	Footnote b

[a] Location of measuring positions for optical deviation are shown in Figure 20.

[b] No measurable change in optical deviation or distortion was found after testing.

[c] Location of viewing areas for optical distortion are shown in Figure 21.

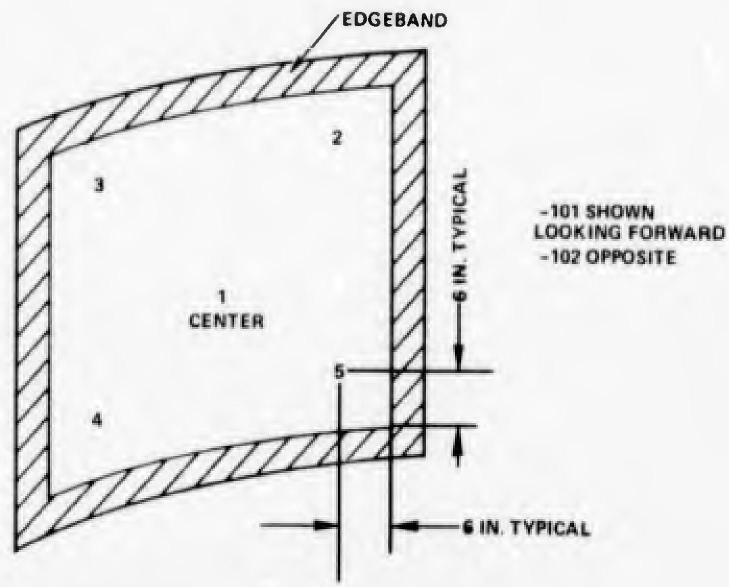


Figure 20. UH-1D Windshield, Location of Optical Deviation Measuring Positions

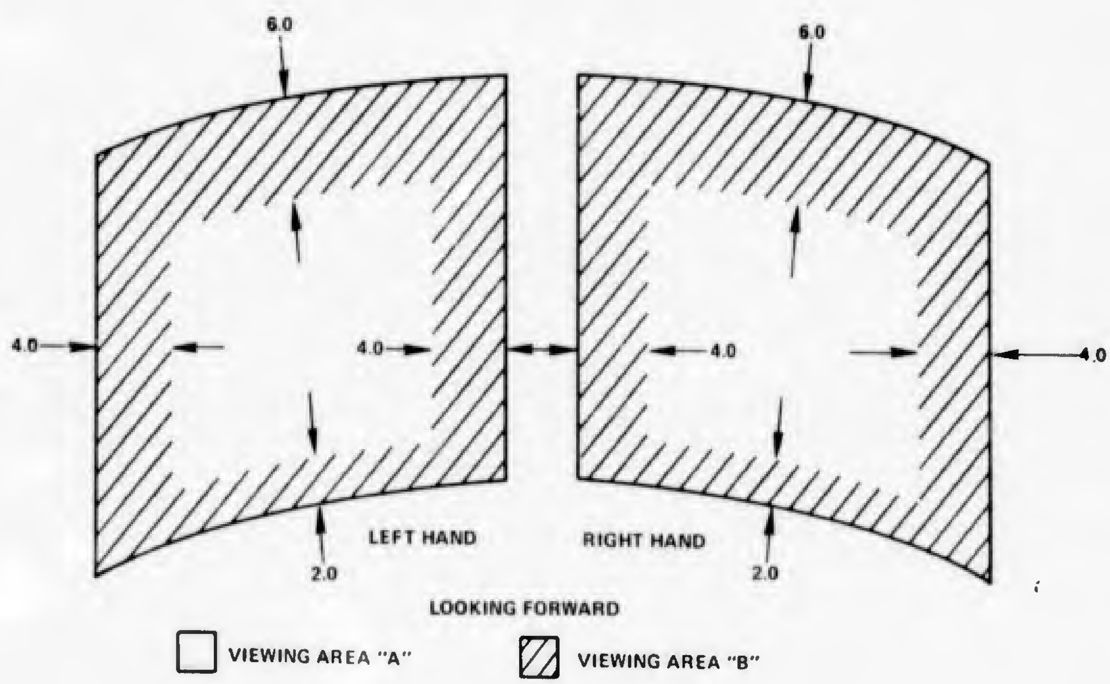


Figure 21. UH-1D Windshield, Optical Distortion Viewing Area

TABLE 11. UH-1D TRANSPARENT ARMOR OPTICAL TEST DATA

Part no.	Serial no.	Luminous transmittance (percent)										Haze (percent)									
		Original					Posttest					Original					Posttest				
		Measuring position[a]					Measuring position					Measuring position					Measuring position				
		1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
3149000-002-101	1	77.8	79.3	80.1	80.0	79.7	79.0	79.0	79.3	79.2	79.0	6.0	7.3	4.3	4.3	6.5	3.9	5.2	3.3	3.7	4.6
	2	80.1	80.1	81.0	80.1	80.2	80.7	80.4	81.0	81.0	80.5	4.3	7.1	2.8	2.0	5.0	4.1	6.1	2.8	1.7	4.9
	3	80.8	80.8	81.1	80.9	80.9	81.0	80.5	80.0	81.0	80.2	3.0	3.8	2.6	2.6	3.1	3.0	2.5	2.6	2.5	3.2
3149000-002-102	1	80.9	80.8	80.4	80.0	80.8	80.5	80.5	80.5	79.5	81.5	3.6	3.2	4.3	5.1	2.6	3.0	3.8	3.0	4.1	2.6
	2	80.4	79.9	80.6	80.2	80.1	81.8	79.8	80.0	81.0	80.0	2.9	6.8	3.8	5.1	6.7	2.1	4.0	2.6	3.0	3.9
	3	79.0	78.5	80.5	80.6	78.1	79.0	80.0	79.8	80.2	78.7	4.2	4.3	3.3	3.3	6.0	6.1	6.6	4.0	4.2	5.0

[a] Location of measuring positions for luminous transmittance and haze are shown in Figure 20.

TABLE 12. UH-1D TRANSPARENT ARMOR OPTICAL TEST DATA

Part no.	Serial no.	Optical deviation (minutes)			Optical distortion (slope)		Luminous transmittance (percent)		Haze (percent)	
		Original								
		Min	Max	Posttest	Original	Posttest	Original	Posttest	Original	Posttest
3149000-004-101	1	1.0	2.0	Note A	Note B	Note A	82.8	82.7	3.4	3.9
	2	1.0	1.0	Note A	Note C	Note A	83.0	82.9	3.4	3.3
	3	1.0	1.0	Note A	Note B	Note A	82.8	82.9	3.1	3.0
3149000-004-102	1	0.75	2.0	Note A	Note B	Note A	82.3	82.4	3.1	3.4
	2	0.25	0.75	Note A	Note B	Note A	83.0	82.8	3.4	3.2
	3	0.25	3.0	Note A	Note B	Note A	82.7	82.9	3.0	2.9
3149000-005-101	1	1.0	4.0	Note A	Note B	Note A	83.1	82.8	3.4	3.2
	2	1.0	2.0	-	Note C	-	82.6	-	3.3	-
	3	1.0	3.0	-	Note C	-	82.5	-	2.8	-
3149000-005-102	1	1.0	1.0	Note A	Note C	Note A	83.3	82.8	3.2	3.0
	2	0.25	1.0	-	Note B	-	83.0	-	3.1	-
	3	1.0	4.0	-	Note C	-	82.8	-	2.8	-
3149000-007-101	1	1.0	5.0	-	Note B	-	82.3	-	3.1	-
	2	0.50	1.5	-	Note C	-	82.6	-	3.1	-
	3	1.0	4.0	-	Note C	-	83.1	-	1.3	-

Notes: A. No measurable change in optical deviation and distortion was found after testing.
B. No visible distortion evident over entire panel.
C. No visible distortion evident in central panel inside 2-in. peripheral area. Visible distortion in panel within 2 in. of edge measures 1 in 20 slope or less.

TABLE 12. UH-1D TRANSPARENT ARMOR OPTICAL TEST DATA (CONT)

Part no.	Serial no.	Optical deviation (minutes)			Optical distortion (slope)		Luminous transmittance (percent)		Haze (percent)	
		Original		Posttest	Original	Posttest	Original	Posttest	Original	Posttest
		Min	Max							
3149000-007-102	1	1.0	1.0	-	Note C	-	82.7	-	2.7	-
	2	0	1.0	-	Note B	-	82.4	-	3.1	-
	3	1.0	1.0	-	Note B	-	82.4	-	2.9	-
3149000-008-101	1	0	0.50	Note A	Note B	Note A	82.2	82.2	3.2	3.2
	2	1.0	1.5	-	Note C	-	82.5	-	2.9	-
	3	1.0	1.0	-	Note C	-	82.5	-	3.1	-
3149000-008-102	1	0.50	1.0	-	Note C	-	83.2	-	3.2	-
	2	0.50	1.0	-	Note B	-	82.5	-	3.0	-
	3	1.0	2.0	-	Note B	-	82.7	-	3.[illegible]	-
3149000-012-101	1	0.50	2.0	-	Note C	-	82.7	-	3.2	-
	2	1.0	3.0	-	Note C	-	82.6	-	3.1	-
	3	0.50	1.0	-	Note C	-	82.7	-	3.0	-
3149000-012-102	1	1.0	1.5	-	Note C	-	82.7	-	3.3	-
	2	1.0	2.0	-	Note C	-	82.8	-	3.2	-
	3	1.0	1.5	-	Note C	-	82.5	-	3.1	-

Notes: A. No measurable change in optical deviation and distortion was found after testing.
B. No visible distortion evident over entire panel.
C. No visible distortion evident in central panel inside 2-in. peripheral area. Visible distortion in panel within 2 in. of edge measures 1 in 20 slope or less.

Delamination running 17 inches along the bottom edge from the inboard corner extended up to 1-3/8 inches into the optical area. An 8-inch-long delamination extending 1-1/2 inches into the optical area was also apparent at the top outboard corner.

It was felt that the unexpected delamination of the windshields was possibly due to stresses resulting from contour mismatch of the glass and plastic plies. All of the first three shipsets of windshields, from which the low-temperature test articles were selected, were fabricated with the plastic backing ply formed on a nominal contour mold. The formed plastic backing was vacuumed to a hard casting tool which had been fabricated to match the inner contour of the individual contoured windshield glass component. Individual sets of matched contour tooling for forming and casting were used to produce each of the last five shipsets of windshields.

One of these articles, P/N 3149000-002-101, S/N 5 was subjected to retesting at low temperature. The S/N 5 windshield selected for retesting had a considerable amount of optical distortion resulting from fabrication experimentation. It was hoped that the tooling requirements necessary to produce quantities of acceptable windshields could be minimized by reuse with those glass components having nearly identical center crossbend measurements.

During the filling of the S/N 5 windshield cavity with interlayer, large thickness variations were observed. Additional details pertaining to the tooling and fabrication aspects of this experiment are included in Section 3, paragraph 4.

Examination of the S/N 5 windshield following 18 hours of exposure at -65 deg F disclosed a 2-1/4 × 2-1/4-inch area of interlayer cleavage and delamination. The damage was located near the upper outboard corner of the windshield in the area of greatest curvature. Examination of the test article and manufacturing records showed that the interlayer was extremely thin in this corner because of the aforementioned mismatch of component contours. The thickness of the interlayer was insufficient to prevent a destructive level of thermally induced shear stress from developing.

d. Temperature Shock

The ability of the test articles to withstand rapid temperature change was measured by temperature shock testing in accordance with MIL-STD-810B, Method 503, Procedure 1. Testing to this method imposes the following conditions:

1. Minimum of 4 hours at 160 deg F
2. Transfer to -65 deg within 5 minutes
3. Minimum of 4 hours at -65 deg F
4. Transfer to 160 deg F within 5 minutes
5. Minimum of 4 hours at 160 deg F
6. Repeat steps 2 through 5
7. Repeat steps 2 and 3
8. Return test articles to standard ambient conditions and stabilize.

Two each P/N 3149000-002 windshields and P/N 3149000-004 sliding door panels were subjected to temperature shock testing. Both P/N 3149000-004 test articles completed the test schedule without visible sign of change or degradation. The P/N 3149000-002-101, S/N 1 windshield delaminated during -65 deg F conditioning following the second 160 to -65 deg F temperature change. The delamination located on the top edge near the outboard corner measured 5 inches in length and extended 1-1/4 inches into the optical area. An additional delamination measuring 1/2 × 4-3/4 inches was found along the windshield inboard edge after completing the third 160 to -65 deg F temperature change.

Similar delaminations occurred on the P/N 3149000-002-102, S/N 1 windshield following the third 160 to -65 deg F temperature change. This delamination, in two closely spaced areas on the top edge, measured 3/4 × 1-1/4 and 3/4 × 3-3/4 inches. A third delamination measuring 3/8 × 2-1/2 inches became apparent on the bottom edge several days after the test article had been returned to ambient conditions and stabilized.

The comments made with regard to the cause of similar delaminations observed in the low-temperature test articles are also felt to apply here.

e. Humidity

Two each P/N 3149000-002 windshields and P/N 3149000-004 sliding door panels were subjected to humidity testing. The test articles were conditioned in accordance with one of the Phase I humidity test procedures at a constant 160 deg F and 37 percent relative humidity for 240 hours. Periodic inspections were made during the 240 hours. After completion of this exposure, the test articles were returned to ambient conditions and stabilized. No change in appearance or other visible signs of degradation were evident for any of the four test articles. Posttest evaluation of the Code 701 abrasion resistant coating on the armor inner surface disclosed no change in hardness or adhesion properties.

f. Ultraviolet Stabilization

Two P/N 3149000-005 test articles were subjected to accelerated exposure of ultraviolet radiant energy. The test was conducted using a test chamber to Federal Test Method Standard No. 406, Method 6024 requirements as modified by Goodyear Aerospace. The basic chamber, bulb type, bulb placement, and reflector correspond to that described in the specification. The Goodyear Aerospace apparatus does not utilize a rotating turntable, circulating controlled hot air source, or fog generating source. This apparatus and test procedure were substituted for the ASTM D1499-64D test used in Phase I. The ASTM test apparatus would not accommodate even the smallest actual UH-1 configuration armor panels. The test articles were visually examined and luminous transmittance and haze determinations were made at 100, 250, 500, and 1000 exposure hours. Data measured during the ultraviolet stabilization test series are shown in Table 13. No visible signs of degradation were evident on either test article. A slight change in appearance was noticed which was attributed to the breakdown of the coloring agent used in the polycarbonate ply. This change, manifested as a loss of color or whitening, was accompanied by a small reduction in haze. A similar, although slower, change has been documented during outdoor weathering exposure of polycarbonate.

g. Contamination

A contamination test was conducted on a P/N 3149000-008-101, S/N 1 test article. The armor panel was subjected to high atmospheric concentration of vapor from TT-S-735 Type III hydrocarbon test fluid at 75 deg F. The details of the contamination test apparatus are shown in Figure 22. The test article was examined at weekly intervals and luminous transmittance and haze values were measured. The test was terminated after four weeks and a final inspection of the armor panel was made. Data recorded during the conduct of the contamination test are included in Table 14. A slight haziness was apparent in the panel edge sealant following the second week of exposure. Very little increase in haziness was observed during the remaining two weeks of the test. No other visible changes or signs of degradation were apparent in the test article after completing the four-week exposure.

TABLE 13. ULTRAVIOLET STABILIZATION TEST DATA,
UH-1D GLASS/PLASTIC COMPOSITE

Part no.	Serial no.	Luminous transmittance (percent) Exposure hours					Haze (percent) Exposure hours				
		Original	100	250	500	1000	Original	100	250	500	1000
3149000-005-101	1	83.1	83.2	83.1	83.1	82.8	3.4	3.4	3.2	3.2	3.2
3149000-005-102	1	83.3	83.2	83.1	83.0	82.8	3.3	3.3	3.2	3.2	3.0
		825[a]	710	675	650	650					
		130[b]	126	125	125	122					

[a]Measured test chamber radiant energy in lumens per square foot.

[b]Measured test chamber temperature in deg F.

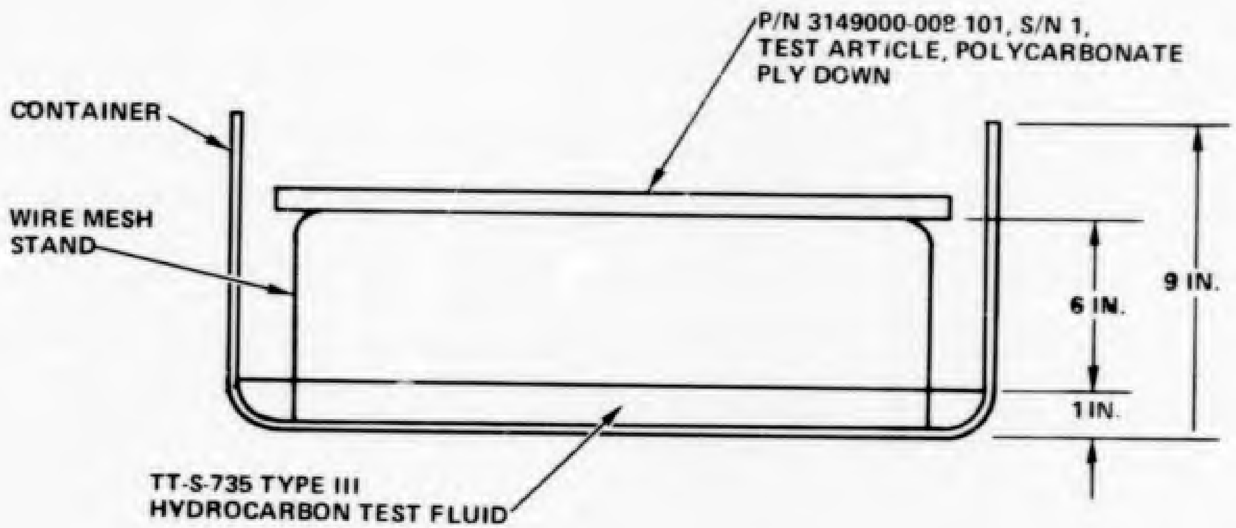


Figure 22. Contamination Test Apparatus

TABLE 14. CONTAMINATION TEST DATA, UH-1D GLASS/PLASTIC COMPOSITE

Part no.	Serial no.	Luminous transmittance (percent)					Haze (percent)				
		Exposure (weeks)					Exposure (weeks)				
		Original	1	2	3	4	Original	1	2	3	4
3149000-008-101	1	82.2	82.0	82.2	82.5	82.5	3.2	3.0	3.2	3.5	3.2

SECTION 5

CONCLUSIONS AND RECOMMENDATIONS

1. CONCLUSIONS

The conclusions resulting from the work effort performed on the contract are as follows:

1. Glass/plastic transparent armor offers the unique combination of improved ballistic defeat characteristics and low areal density (armor weight per square foot) necessary for aircraft usage. The armor is capable of projectile or fragment defeat without backside spalling of injurious particles. This performance can be obtained at an areal density which permits a significant amount of coverage within allowable weight limits. The transparent armor installation increases overall survivability by protecting vital components of the aircraft as well as the aircrew

2. It is possible to utilize flat armor panels to obtain the required coverage in many typical areas in the aircraft which require visibility. Flat armor panels are preferred for reasons of cost and optical properties. The crew door and lower cabin window areas of the UH-1D aircraft were both protected by suitably configured flat panels of the transparent armor

3. Improvement is required in glass bending technology to minimize part-to-part contour variance. It is not economically feasible to produce tooling for each windshield or other contoured armor panels in production quantities. It is reasonable to expect improvement in part-to-part contour match using the same basic glass bending procedure which produced the

prototype articles if larger quantities were being processed. The degree of improvement to be realized in this manner is unknown.

4. The composite used to fabricate the transparent armor panels on this contract offers marginal performance characteristics in certain environments. Improvement of the armor resistance to extended periods of elevated temperature and relative humidity is desirable. Improvement in the cast-in-place interlayer bond safety margin would also be beneficial. The present system does not ensure composite integrity in large contoured articles when exposed to severe conditions, including extended periods at -65 or 160 deg F temperature shock

5. A moderate redesign effort is required to provide additional clearances and adjustability for the transparent armor panels in the lower forward window areas.

2. RECOMMENDATIONS

The following recommendations are made as a result of work accomplished on this contract.

The flight testing and field evaluation effort presently in progress on the armored test aircraft at Yuma Proving Ground should be continued. Periodic inspection at approximately three-month intervals should be jointly performed by Goodyear Aerospace and government personnel. The results of this effort should be summarized in a report at the end of one year.

The redesign of the UH-1D lower forward window transparent armor installation should be undertaken to bring the overall design to production readiness.

Additional development effort should be authorized to refine glass bending procedures. Improvements in obtaining reproducible glass contours will have significant impact on factors of cost, optics, and reliability. UH-1H configuration windshield test articles should be produced using the improved contour glass facings. This effort will provide test articles to document the effect of such an improvement.

Consideration should be given to utilizing refined glass bending procedures to produce windshield test articles having greater ballistic defeat capability. This effort would process glass plies of increased thickness to demonstrate the feasibility of combining improved protection and acceptable optics. Representative articles of these windshields should be installed in an aircraft for flight evaluation.

A study should be conducted to demonstrate the feasibility of adding glass/plastic transparent armor in newer inventory Army aircraft. After defining those aircraft which by mission requirements can most benefit by such armor, a feasibility and prototype design study will be required. The possibility of incorporating scaled protection level composites in various transparency locations should be included.

Additional development effort should be authorized to improve the abrasion resistant coating for polycarbonate as used on the transparent armor backing ply. Improvements in this area may also benefit maintenance and service life factors for other aircraft glazings which could use such a coating.

It is felt that the complexity and scope of this coating development effort would warrant a separate program.