HUGHES AIRCRAFT COMPANY

CULVER CITY
CALIFORNIA

TRANSPARENT LAMINATED AND MONOLITHIC WINDOWS

by

Seymour Schwartz
Boyce G. Kimmel

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Hughes Aircraft Company
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ABSTRACT:

This report describes briefly the development of the processing techniques used in the fabrication of transparent, laminated and monolithic aircraft windows having good flame resistance through char formation on exposure to elevated temperatures. The monolithic windows were fabricated from a transparent cast epoxy while the laminated windows were fabricated by laminating the epoxy to polycarbonate with an ethylene terpolymer adhesive.

I. INTRODUCTION

A number of investigations are currently being made to improve aircraft windows from the standpoint of impact resistance and fire resistance. One of these investigations concerns the use of plastic windows for passenger aircraft. Such windows are lighter than glass, considerably more shatterproof and may possibly be fabricated of materials which would have high flame resistance, by virtue of char formation on exposure to high heat.

One concept for making plastic windows is to cast a monolithic window using a transparent char forming epoxy resin. Another concept is to laminate a very tough, strong transparent polycarbonate sheet, with the transparent char forming epoxy sheet.

To investigate the feasibility of these concepts, Hughes Aircraft Company was requested by NASA Ames Research Center to fabricate four windows of each type simulating the Boeing 737 outer window (Part No. 65-45791). An epoxy formulation, EX-112, developed by NASA Ames Research Center, was utilized in the fabrication of both types of

I. INTRODUCTION (Cont'd)

window. An ethylene terpolymer adhesive developed by Monsanto was used to laminate the epoxy to the polycarbonate.

II. SUMMARY AND CONCLUSIONS

This report describes the development of the processing technique used in the fabrication of transparent, heat-resistance aircraft windows of the Boeing 737 configuration. Two types of window were fabricated: 1) monolithic type, one-half inch thick, made from NASA epoxy formulation EX-112 (Epon 825 containing 5 PHR of trimethoxyboroxine) and 2) a laminated type consisting of a quarter-inch thick polycarbonate inner layer bonded to a quarter-inch thick EX-112 outer layer with an ethylene terpolymer interlayer material.

By the proper choice of processing conditions, the feasibility of fabricating heat-resistant aircraft windows of the above types was clearly demonstrated. The principal difficulties involved the development of conditions for the casting and curving of the relatively large epoxy sheets required. Completely curing these epoxy sheets in the casting mold was found to be impractical due to curing shrinkage and resultant cracking. Additionally, the curving of these completely cured sheets to the desired radius of curvature was difficult to control. Both problems were solved by partially curing the epoxy in the casting fixture and then completing the cure and curving to the required radius of curvature in a single operation. The laminating operation was accomplished readily in an autoclave which had been modified to allow its

II. SUMMARY AND CONCLUSIONS (Cont'd)

operation as a vacuum chamber. No difficulty was experienced in the machining of the monolithic or laminated blanks to the final 737 window configuration. The complete process is detailed in the attached Operation Instruction Sheets.

III. PROCEDURES

A. Description of Tooling

1. Casting Tools

Epoxy castings were made by pouring the resin formulation between two flat plates separated by means of metal spacers and sealed by means of a piece of square cross-sectioned, neoprene port gasketing.

Several modifications were necessary in the tooling and processes in order to obtain epoxy castings of good quality. Initially, quarter-inch thick glass plates covered with either a parting film or a mold release were used with only partial success. One-mil thick Mylar worked reasonably well as a parting film, except that some "orange peeling" was observed in the epoxy castings, apparently due to curing shrinkage. Several mold release agents were tried with the glass including PVA film, Ram 87x76 and Simoniz wax with little or no success.

Far better results were obtained by the use of half-inch thick aluminum tooling plates covered with stainless steel Ferrotype plates (bonded with FM 123-2 film adhesive).

III. PROCEDURES (Cont'd)

A. Description of Tooling (Cont'd)

1. Casting Tools (Cont'd)

Fair to good release was obtained by coating the Ferrotype plates with mold releases such as 87x76 followed by Simoniz wax or carnauba was. However, much difficulty was experienced with cracking of the epoxy casting during the final cure. Virtually all problems with cracking were eliminated by only partially curing (two hours at 150°F) the casting between the plates and completing the cure later as part of the curving process. Epoxy castings of excellent quality were made by curing the resin formulation at low temperatures between the Ferrotype plates which had been coated with a relatively heavy coating of carnauba wax.

2. Bend Fixture

A separate bend fixture was made to shape the polycarbonate sheets. This consisted on a 17 x 22 x 1/8 inch aluminum sheet curved to a 72 inch radius. This was a two inch smaller radius than specified on Boeing print #65 45791. The slight overbend was used to compensate for possible springback which would occur when the polycarbonate was thermoformed. A Ferrotype plate was used on the top surface of the curved sheet to provide a polished surface for the plastic sheet to contact.

III. PROCEDURES (Cont'd)

A. Description of Tooling (Cont'd)

3. Laminating Fixture

The laminating fixture consisted of a 22 x 20 x 3/16 inch aluminum sheet which was curved to a 74 inch radius. The curved sheet was fastened to a support fixture which held it rigidly in the curved position. On the bottom (concave) surface of the curved plate, a 22 x 18 inch Type III, 230 volt, 1980 watt, silicone coated heating blanket* was bonded using GE RTV 90 (a silicone adhesive).

Lamination was performed in an autoclave which had been modified for use as a vacuum chamber. The laminating fixture, containing the bagged laminate, was installed in the autoclave, using two vacuum lines--one at each end of the laminate. One line fed through the autoclave to a small volume, relatively high vacuum pump. The other line from the laminate also went through the chamber to a "T" connector. One side of the "T" was connected to a standard mercury manometer, so the absolute pressure in the bag could be determined. The other side of the "T" was connected to one leg of a differential manometer whose other leg was connected to a tube leading to the autoclave interior. Thus, the differential pressure between the bag interior and the autoclave interior could be ascertained at all times.

*Electroflex Heat, Inc., Northwood Industrial Park, Bloomfield, Conn. 06002

III. PROCEDURES (Cont'd)

B. Process Development

1. Casting of Epoxy Sheets

The formulation was prepared from Epon 825 and 5 PHR of trimethoxyboroxine as described in the attached O.I.S. Since high temperature curing resulted in considerable yellowing of the epoxy, a small quantity of blue dye, Perox blue, was added to the resin formulations used in making the last few epoxy castings.

As described previously, the casting process developed involved partially curing (two hours at 150°F) the epoxy between aluminum plates covered with Ferrotype plates. The resulting, partially cured casting was flexible and rubber-like with no tendency to crack, as had been observed in castings completely cured in the casting tool.

2. Bending of Epoxy Sheets

The fixture used for bending consisted of a curved aluminum plate to which was bonded a stainless steel Ferrotype plate. As in the casting, the curving fixture was coated with a relatively heavy layer of carnauba wax.

The partially cured epoxy was simply laid on the center of the curving fixture contained in an oven preheated to 150°F. The cure of the epoxy was completed and the curving to the final shape was accomplished by heating for three hours at 270° - 280°F and three hours at 350° - 360°F.

III. PROCEDURES (Cont'd)

B. Process Development (Cont'd)

3. Drying of Polycarbonate

Prior to bending the polycarbonate sheets to the correct curvature, it was necessary to oven-dry them thoroughly to prevent loss of transparency during subsequent curving and lamination. Either one of two drying conditions can be used: 1) 24 hours at 265° - 270°F or 2) 96 hours at 220° - 255°F.

4. Bending of Polycarbonate

The polycarbonate sheet, after drying, was bent exactly as given in Operation Instruction Sheet 45791-L-1. Temperatures up to 177°C (350°F) were used; however, this resulted in excessive mark-off, so a maximum temperature of 157°C (315°F) was established.

5. Laminate Fabrication

Laminate fabrication was carried out in accordance with Operation Instruction Sheet 45791-L2. The terpolymer, because of its somewhat tacky, wrinkled surface, had to be installed with great care to minimize entrapment of air. An effort was made to place the terpolymer on top of the polycarbonate with a rolling motion, rather than simply laying the terpolymer down, to minimize air entrapment. Nevertheless, some air inevitably was entrapped in the wrinkles between the terpolymer

III. PROCEDURES (Cont'd)

B. Process Development (Cont'd)

5. Laminate Fabrication (Cont'd)

and the polycarbonate. A needle was used to pierce the bubble, and the material was pressed flat using a Teflon squeegee.

Two types of vacuum bag sealant were used since the softer, low temperature sealer would make a good seal initially, causing the vacuum bag to exert pressure on the harder, high temperature sealant material. At approximately 110°C (225°F) the higher temperature sealant would soften sufficiently to ensure maintenance of a good seal throughout the heating cycle. Initially, lamination cycles were made using only the softer sealer, but loss of seal occurred at the higher temperatures. Initial parts were made using a formed, glass fabric reinforced silicone bag. Because of the leaks which developed in the silicone bag, after very few cycles, the Capran film bags were made. These were one-time use only.

6. Edge Routing and Buffing

No particular problems were found in cutting, edge routing or buffing the completed laminates. The epoxy surfaces were buffed, as needed, using the techniques and materials described in the Operation Instruction Sheet. Only a small amount of buffing at very light pressures was done on the polycarbonate surfaces in order to minimize possibility of stress crazing.

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OPERATION INSTRUCTION SHEET
(Please see reverse side for instructions.)

SHEET 1 OF 2

DOCUMENT CONTROL NO.

CHARGE NUMBER	QUALITY LEVEL	PART NAME	PART NUMBER	REV LTR
B458-A2D	PQ R8 1B	Laminated Window, Polycarbonate Component	45791-L-1	-

PREPARED BY	NEXT ASSEMBLY	AUTHORIZING DOCUMENT	EO/DCN NUMBER	REQ'D	ATTR	TOTAL
S. Schwartz	Lamination	CMER 45941	--	-	-	-

ORG CODE	DATE	APPROVED BY	PROGRAM NAME	RESP. ENGINEER	EXT.	QCHR/FQR NO.	INVENTORY CODES: STORE	PROJECT	ACCT.	DUE DATE	S/N
27-17-31	1-15-74		Monolithic & Laminating Wind.	S.Schwartz	6693						

SPECIAL INSTRUCTIONS

Use polycarbonate sheet 1/4 inch thick, MIL-P-46144, Type 1, GrA Cl 2.

SHOP: ESTIMATED HRS. / RECEIVED BY / ACTUAL HRS. / DATE

OP'N NO.	PERFORMING ORG	OPERATION DESCRIPTION	OPERATOR
10	26-39	QA verify material	
20	27-17	Cut 17 x 13 x 1/4 inch polycarbonate panels and dry for 24 hours at 130 ± 3°C (265° - 270°F), or 96 hours at 115 ± 3°C (220° - 225°F) (over weekends and holidays). Place in polyethylene bag with dessicant.	
30	26-39	Inspect operation 20 to insure clarity.	
40	27-17	Place ferrotype tin on curved form and place polycarbonate on ferrotype and hold down with five (5) spring clamps and a 1 x 18 x 1/4 inch aluminum bar at each end. Use one clamp and a small bar in the middle at each side. Place two thermocouples on the plastic sheet, one at each end; one under the sheet and one on top of the sheet, held by aluminum foil tape, or the aluminum bar. Use fine (#36) wire couples.	

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OPERATION INSTRUCTION SHEET (CONTINUATION)

DATE PREPARED	QCHR/FQR NO.	PART NAME	PART NUMBER	REV LTR
1-15-74	PQ R8 1B	Laminated Window, Polycarbonate Component	45791-L-1	-

OP'N NO.	PERFORMING ORG	OPERATION DESCRIPTION	OPERATOR
50	26-39	Inspect operation 40	
60	27-17	Set oven at 157° ± 2°C (315 ± 5°F). Monitor part temperature by recorder. Bring sheet to 155° ± 2°C (310 ± 10°F), hold for 10 minutes. Turn off oven and open doors. Allow to cool to room temperature before removing (preferably overnight).	
		NOTE: Check assembly during heating to make sure part is not buckling due to differential expansion. If sheet does lift from fixture, then remove clamps from one end and center and smooth down. A slight over or under bend (approx. 1/8 in.) after cooling is permissable.	
70	26-39	Inspect operation 60	

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OPERATION INSTRUCTION SHEET
(Please see reverse side for instructions.)

DOCUMENT CONTROL NO.

CHARGE NUMBER	QUALITY LEVEL	PART NAME	PART NUMBER	REV LTR
B458-A2D	PQ R8 1B	Epoxy Cast Window Component	45791-L-2	-

PREPARED BY	NEXT ASSEMBLY	AUTHORIZING DOCUMENT	EO/DCN NUMBER	REQ'D	ATTR	TOTAL
B. G. Kimmel and S. Schwartz	Lamination	CMER 45941	-	-	-	-

ORG CODE	DATE	APPROVED BY	PROGRAM NAME	RESP. ENGINEER	EXT.	QCHR/FQR NO.	INVENTORY CODES: STORE	PROJECT	ACCT.	DUE DATE	S/N
27-17-31	1-21-74										

SPECIAL INSTRUCTIONS

SHOP: ESTIMATED HRS. / ACTUAL HRS. — RECEIVED BY / DATE

OP'N NO.	PERFORMING ORG	OPERATION DESCRIPTION	OPERATOR
10	26-39	QA verify epoxy resin and trimethoxyboroxine hardener	
20	27-31	Prepare casting forms - Two aluminum plates 1/2" x 16" x 22" covered on one side with a stainless steel ferrotype plate (bonded with American Cyanamide FM 123-2 adhesive). Apply Ram 87X76 mold release agent to each ferrotype. Bake 30 minutes at 175°C (350°F). While plates are hot apply one coat of Carnauba wax and polish to a high gloss. *Ram Chemical Co., Gardena, CA	
30	27-31	Lay one form on table top and place 1" x 1/4" (or 1" x 1/2") spacer bar around three edges. (Leave one 22 in. edge bare). Place 1/4" or 1/2" square (whichever is applicable) 50 Shore neoprene port gasketing inside of the bars, leaving a space approximately 14" x 20" for casting.	
40	27-31	Spray both plates, spacer bars and rubber gasketing lightly with MS-122** fluorocarbon mold release. ** Miller-Stephenson Chemical Co., Inc., Los Angeles, CA	

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OPERATION INSTRUCTION SHEET (CONTINUATION)

DATE PREPARED	QCHR/FQR NO.	PART NAME	PART NUMBER	REV LTR
1-21-74		Epoxy Cast Window Component	45791-L-2	

OP'N NO.	PERFORMING ORG	OPERATION DESCRIPTION	OPERATOR
50	27-31	Assemble plates with required number of heavy spring clamps, and preheat in oven to 72° - 77°C (160°F - 170°F).	
60	26-39	Inspect Operation 10 through 50.	
70	27-31	Prepare resin formulation as follows: Shell Epon 825 Epoxy Resin - 1200 gm (for 1/4" sheet) 36 drops of a 0.17 wt-% dispersion of Perox Blue Whitener in Epon 825 resin. Callery Chem. Co. - Trimethoxyboroxine - 60 gram (for 1/4" sheet). Prior to mixing warm Epon 825 to 48° - 52°C (120 - 125°F) and degas under vacuum until bubbling ceases. Allow resin to cool to 33° - 38°C (90° - 100°F) before adding TMB. Add TMB, mix thoroughly and degas under vacuum for approximately 10 minutes. For 1/2 inch plates, use twice as much material.	
		*Patent Chemical Co., Paterson, New Jersey.	
80	26-39	Inspect Operation 70.	
90	27-31	Pour resin formulation into preheated mold, until the cavity is completely full. Introduce the resin through a hose and funnel so the cavity is filled from the bottom with a minimum of air bubbles introduced.	

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OPERATION INSTRUCTION SHEET (CONTINUATION)

DATE PREPARED	QCHR/FQR NO.	PART NAME	PART NUMBER	REV LTR
1-21-74		Epoxy Cast Window Component	45791-L-2	-

OP'N NO.	PERFORMING ORG	OPERATION DESCRIPTION	OPERATOR
100	27-31	Place assembly in 63° - 68°C (145° - 155°F) oven and cure for 2 hours at 63° - 68°C (145° - 155°F).	
110	27-31	Remove assembly from oven and remove casting while still warm.	
120	27-31	Place casting on ferrotype covered bend fixture and subject to the following oven cycle:	
		3 hrs. at 132° - 137°C (270° - 280°F) (Starting at room temperature)	
		3 hrs. at 178° - 183°C (350° - 360°F)	
		Cool slowly in oven to room temperature.	
130	26-39	Inspection Operation 120.	
140	27-31	Trim curved epoxy casting to final nominal 13 x 17 inch size.	

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OPERATION INSTRUCTION SHEET
(Please see reverse side for instructions.)

DOCUMENT CONTROL NO.

CHARGE NUMBER	QUALITY LEVEL	PART NAME	PART NUMBER	REV LTR
B458-A2D	PQ R8 1B	Laminated Window	45791-L	

PREPARED BY	NEXT ASSEMBLY	AUTHORIZING DOCUMENT	EO/DCN NUMBER	REQ'D	ATTR	TOTAL
S. Schwartz		CMER 45941		-	-	-

ORG CODE	DATE	APPROVED BY	PROGRAM NAME	RESP. ENGINEER	EXT.	QCHR/FQR NO.	INVENTORY CODES: STORE	PROJECT	ACCT.	DUE DATE	S N
27-17-31	1-15-74		Monolithic & Laminated Wind.	S.Schwartz	6693						

SPECIAL INSTRUCTIONS

1. Polycarbonate and epoxy sheets must be curved, cut to 13 x 17 in. and dried prior to lamination.
2. Cleaning of materials and assembly of laminate must be done in the "clean" room.

SHOP	
ESTIMATED HRS.	RECEIVED BY
ACTUAL HRS.	DATE

OP'N NO.	PERFORMING ORG	OPERATION DESCRIPTION	OPERATOR
10	26-39	QA verify epoxy castings, polycarbonate and terpolymer sheet.	
20	27-17	Wash each sheet with detergent and water until a water break-free surface is obtained. Rinse twice with denatured ethyl alcohol or isopropyl alcohol. Dry each sheet for a minimum of four (4) hours at 50° ± 2°C (120 ± 5°F). Wash a 13 x 17 inch sheet of terpolymer with two rinses of alcohol. Dry in a vacuum oven for a minimum of four hours at 50° ± 2°C (120 ± 5°F).	
30	26-39	Inspect Operation 20	
40	27-17	Assemble the laminate, with the polycarbonate next to the ferrotype covered convex tool surface. Fasten two (2) fine (#36) gage thermocouples to opposite edges of the laminate, using aluminum foil tape. Wrap the assembly with two layers of Burlington #51789 nylon fabric. Place four (4) layers of 1/8 inch felt* under and over the assembly as shown below:	
		*SAE STD F-6	

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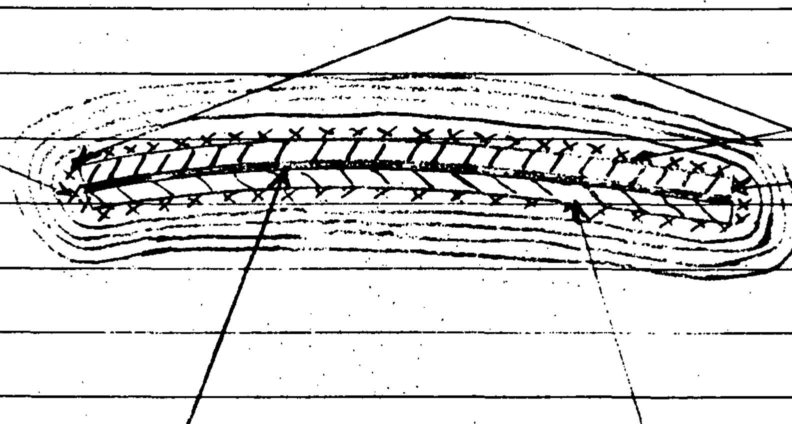
OPERATION INSTRUCTION SHEET (CONTINUATION)

DATE PREPARED	QCHR/FQR NO.	PART NAME	PART NUMBER	REV LTR
1-15-74		Laminated Window	45791-L	

OP'N NO.	PERFORMING ORG	OPERATION DESCRIPTION	OPERATOR
40 (Cont'd)	27-17		
		NOTE: Smooth all air bubbles from terpolymer before installing epoxy sheet.	
50	26-39	Install Capran vacuum bag on assembly using two vacuum bag sealing compounds* Place the assembly in the autoclave and connect the vacuum bag to the auxiliary vacuum system. Pump down to a minimum gage reading of 29-1/2 inch Hg and check bag for even pressurization. Connect thermocouples to autoclave connectors. Turn on autoclave vacuum system and pull down until the reading is 2 in. Hg (1 psi) above the auxiliary pump; e.g., auxiliary pump = 29-1/2, Autoclave = 27-1/2 in. Hg.	
		*Low Temperature sealer on outside - L. T. Fuller - Obrien #3992. <u>High Temperature vacuum bag</u> sealer on inside - Schnee and Morehead #9156.	

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OPERATION INSTRUCTION SHEET (CONTINUATION)

DATE PREPARED	QCHR/FQR NO.	PART NAME	PART NUMBER	REV LTR
1-15-74		Laminated Window	45791-L	

OP'N NO.	PERFORMING ORG	OPERATION DESCRIPTION	OPERATOR
70	26-39	Inspect Operation 60	
80	27-17	When correct 2 in. Hg. differential pressure has been established, turn on fixture heater. Heating rate should be approximately 42°C (75°F) per hour. (Voltage reading approx. 140).Monitor the assembly temperature rise with a recorder and maintain a constant 2 in. Hg. differential throughout the cycle. Attempt to maintain temperature rise in accordance with Fig. 12 of AFML-TR-72-109, dated July 1972.	
		At approximately 110°C (230°F) reduce the voltage to the fixture heater (and adjust as required to 115 volts). Maintain the fixture temperature 127°C (260°F) for one (1) hour, after which turn heat off, vent autoclave, and open autoclave door. Maintain vacuum bag at 29-1/2 in Hg., until part temperature is below 40°C (100°F).	
90	26-39	Inspect operation 80 and quality of lamination.	
100	27-17	Remove assembly and trim to Boeing Print #65-45791, for edge routing	
110	26-39	Inspect part for dimensions.	
120	20-83	Rout edges, .560 in. wide, .125 in. deep, 1/16 in. radius three places. Use 3/4 in. dia. bit, with 1/16 in. radius ground on ends.	

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OPERATION INSTRUCTION SHEET (CONTINUATION)

DATE PREPARED	QCHR/FQR NO.	PART NAME	PART NUMBER	REV. LTR
1-15-74		Laminated Windows	45791-L	

OP'N NO.	PERFORMING ORG	OPERATION DESCRIPTION	OPERATOR
140	26-92	Polish and buff as needed. Use Learock #155* for heavy cutting and/or Learock #884E for light cutting, at 4700 sfm. Use dry flannel or cotton wheel for final luster. *The Lea Manufacturing Co., Waterbury, Conn.	