NASA CONTRACTOR REPORT 166410

Edge Attachment Study for Fire-Resistant Canopies

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CONTRACT NAS2–10065
September 1982

NASA

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Prepared for
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N83-10119 #

FOREWORD

This is the final technical report on a program conducted to evaluate materials and study designs suitable for constructing compatible edge attachments on fire-resistant aircraft transparencies in which NASA-Ames formulation EX-112 is utilized as the fire barrier component.

The program was performed by Goodyear Aerospace Corporation, Arizona Division, Litchfield Park, Arizona, under Contract Number NAS2-10065, Project No. RFP2-27572.

The work was done for the NASA-Ames Research Center, Moffett Field, California. The NASA technical monitor is Mr. Richard H. Fish.

Goodyear Aerospace Corporation has assigned GERA-2424 as a secondary number to this report.

G.E. Wintermute is the Project Engineer for Goodyear Aerospace. This report was submitted by the author in November 1979 for publication as a technical report.

This report covers work conducted between October 1978 and September 1979.

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SECTION I
INTRODUCTION

In the continuing effort to improve the fire-resistant capabilities of aircraft transparencies, it has become apparent that the design of the edge attachment is very important.

Impressive advancements have been made in the development of fire-resistant transparent plastics. The NASA-Ames formulation, EX-112, can provide a lifesaving barrier against the intense thermal radiation created by a jet fuel fire.

However, the resistance of the transparent plastic is of little significance if the edge attachment construction, which fastens the transparent component to the aircraft frame, is consumed by the flame or seriously weakened by the heat. In one full-scale fire test, the flame entered the pilot compartment through the edge attachment area around the transparency.

To provide a satisfactory barrier, the edge attachment must resist the thermal radiation and retain sufficient strength to support the transparency until the fire can be extinguished or the occupants evacuated. Stated simply, this means both elements of an aircraft transparency - edge attachment and transparent component - must act as an integrated unit to perform as a viable barrier against the intense thermal radiation of a fuel fire.

In the overall effort on fire-resistant transparencies, the edge attachment has been generally neglected. The effort conducted in this contract was aimed at obtaining preliminary information on the materials and design of edge attachments suitable for fire-resistant transparencies incorporating EX-112.

SECTION II
SUMMARY AND CONCLUSIONS

1. SUMMARY

Twenty-two resin systems were evaluated in laminate form for possible use as edge attachment material for fire-resistant canopies. The evaluation uncovered an unexpected development when the laminates were subjected to an intense flame:

1. The high-heat-resistant materials could withstand the flame test quite well. However, heat transfer through the test specimen was rapid. On an aircraft canopy enveloped in fire, the rapid heat flow could weaken the substrate at the bolt line, causing collapse of the canopy.

2. The laminates which exhibited a low rate of heat transfer were materials with low heat resistance. These materials decomposed, delaminated, and blistered. Laminate strength was rapidly lost in the presence of the flame. In an aircraft fire, this loss of strength could also lead to collapse of the canopy.

Analysis of the screening data indicated that the NASA - Ames EX-112 resin had the best balance between heat transfer rate and retention of strength during the flame tests.

The evaluation of reinforcements provides conclusive results. Fiberglass was best for fire-resistant laminates. The organic fibers - nylon, Dacron, Orlon - burned and softened in the flame. A carbon filament reinforcement cannot be economically justified over fiberglass.

The NASA - Ames T-3 Fire Test was used as the final laboratory evaluation for the performance of the edge attachments. Test samples were developed specifically for the T-3 facility.

Because of the key role played by the resin in the resistance of the edge attachment to an intense flame, three resin systems were tested: EX-112; a high-heat-resistant epoxy; and a low-heat-resistant polyester.

All three specimens tested successfully. On the basis of the T-3 test results, it appeared that all three systems would provide four or more minutes of protection to the pilot in a crash fire.

2. CONCLUSIONS

An analysis of actual and potential fighter aircraft crash fires (Navy) indicated that a protection period of four to five minutes provides sufficient time to extinguish the fire and rescue the aircraft occupants.

Based on the foregoing analysis, it is feasible within the current state of the art to fabricate transparent enclosures for fighter aircraft that will protect the occupants during a post-crash fire until rescue can be accomplished.

The data collected during this contract indicated that a transparent composite incorporating an EX-112 fire-resistant layer affords more protection than any of the edge attachment laminate materials evaluated. The bolt line area seemed to be the weakest link in the transparency design.

Therefore, any additional effort on fire-resistant enclosures should concentrate on raising the protective capabilities of the edge laminate (particularly at the bolt line) to the same level as the transparent composite.

One approach toward the attainment of this goal would be the investigation of hybrid laminates.

SECTION III
TECHNICAL DISCUSSION

1. GENERAL

This program, which had as its objective the evaluation of materials and the study of designs for edge attachments for fire-resistant aircraft transparencies, was conducted in four tasks:

Task 1 - Resin Study
Task 2 - Reinforcement Study
Task 3 - Design Study
Task 4 - Test and Evaluation.

The work accomplished in each task is discussed in detail in the following paragraphs.

2. TASK 1 - RESIN STUDY

a. General

Edge attachments for fire-resistant aircraft transparencies must have some special characteristics. In this task, 22 resin systems were evaluated for processability, physical properties, environmental resistance, and reaction to intense thermal radiation.

To provide a common base for comparative purposes, woven fiberglass cloth was used as the reinforcement throughout the Task 1 study. Fiberglass cloth is a low-cost, high-strength material used extensively as a reinforcement in structural laminates. Since fiberglass does not burn, the data obtained in Task 1 also served as a baseline by which the other reinforcements evaluated in Task 2 could be judged.

b. Selection of Materials

(1) Standard Laminating Resins

All the general types of laminating resins were included in the study:

Epoxy
Polyester
Phenolic
Silicone
Polyimide.

The silicones and polyimides are expensive, high-performance resin systems. They were included in the study to determine if ultrahigh thermal resistance would be noticeably beneficial. The silicone resin evaluated was specially formulated to resist intense thermal radiation. Two other resins, EX-112 and GAC 30-1A, both epoxies, were also specialty resins formulated to resist intense heat.

Preimpregnated systems and resins for wet layup were both evaluated.

A literature search and discussions with material suppliers and users resulted in the selection of specific materials in each resin type category. These selections are shown in Table 1.

All materials were ordered from factory runs to ensure standard products. The delivery of some items was delayed because the requirement for any one material for this contract was not sufficient to warrant an individual setup and run (without penalty assessment for setup and startup wastage). To be economically feasible, material was taken from the end of a larger production run. This meant waiting until a production run had been scheduled for the material of interest. None of the delivery delays encountered had any appreciable effect on the program.

(2) Acrylic Laminate

Many of the edgebands on current aircraft are prepared using an acrylic resin. Since acrylic is quite flammable, it was not a resin considered suitable for this study. However, because of its widespread use and overall suitability (except for burn rate) as an edge attachment reinforcement resin, it was felt appropriate to include an acrylic/fiberglass laminate in the study as a general "control" specimen.

Four- and six-ply acrylic laminates are fabricated in the edgeband production facility at Goodyear Aerospace, Arizona Division. Portions of these laminates were combined as follows, to provide a panel of the desired thickness:

1. Each production laminate was measured for exact thickness. The required number of pieces was selected to give the desired final thickness.

TABLE 1. RESIN SYSTEMS EVALUATED IN TASK 1

Resin type	Liquid for wet layup		Preimpregnant	
	Code	Supplier	Code	Supplier
Epoxy	Epon 828	Shell	E-293	Ferro
			CE-9010	Ferro
			F-164	Hexcel
			3203	Narmco
	EX-112	NASA-Ames	E-293FR	Ferro
	GAC 30-1A	Goodyear Aerospace	E-760	U.S. Polymeric
Polyester			F-141	Hexcel
	Paraplex P-49	Rohm & Haas	PE-285	Ferro
	Selectron 5016	PPG	IF RR	Ferro
			P 604	U.S. Polymeric
Phenolic			F120	Hexcel
			F507	U.S. Polymeric
			AC	Ferro
			CPH 2251	Ferro
			506	Narmco
Silicone	XI-2556	Dow Corning		
Polyimide			F-174	Hexcel
Acrylic (control only)	C715A	Goodyear Aerospace		

2. Each bonding surface was sanded to remove contamination and glaze.

3. Each prepared surface was coated with the bonding resin, GAC formulation C-715A, an acrylic adhesive.

4. The pieces were stacked, covered with film to catch the resin squeeze-out, and placed in a cold hydraulic press.

5. A pressure of 3-4 pounds per square inch was applied to squeeze out excess adhesive resin. The press was cold during this operation.

6. After the initial squeeze-out of adhesive, the press was heated to 125-150 deg F.

7. Cure was continued until the adhesive resin squeezed out at the edge of the panel had hardened.

The resulting laminates were the proper thickness: dense and uniform.

c. Test Plan

The test plan developed for the screening evaluation of the resins in Task 1 is shown in Table 2.

It was felt that the test program would provide an excellent basis on which to evaluate and compare the resin systems. At the start of Task 1, it was envisioned that the optimum resin would be selected for use in Task 2, evaluation of reinforcements.

As described later in the discussion of the Task 1 effort, no single resin - or resin system - could be selected as dominantly superior.

d. Test Laminate Configuration

A 12-in. x 12-in. laminate was prepared from each material listed in Table 1. Glass cloth, 181 style weave, was used as the reinforcement for the liquid resins. The preimpregnant materials all incorporate a glass cloth carrier. Cloth styles included: 181, 1581, and 7781.

TABLE 2. SCREENING TEST PLAN FOR TASK 1 RESIN STUDY

Test area	Type of test	Test method	Test specimen dimensions (inches)
Processing	Handling characteristics Pressure required Temperature cycle Postcure Appearance		
Physical properties	Tensile strength 75 deg F 300 deg F	FTMS No. 406, Method 1011	8 x 3/4
	Flexural strength 75 deg F 300 deg F	FTMS No. 406, Method 1031	6 x 1/2
	Hardness	Shore D	
	Edgewise compression	FTMS No. 406, Method 1021	3 x 1/2
Fire resistance	Horizontal burn	ASTM D-635	5 x 1/2
	Goodyear Aerospace special flame test	Discussed on Page 32	4 x 4
Environmental resistance	Humidity	48 hr/120 deg F/ 95% RH	
	Thermal aging	MIL-STD-810C, Method 501.1, Procedure 1 (48 hr at 160 deg F)	Rerun flexural test and special flame test
	Ultraviolet radiation	FTMS No. 406, Method 6024 (10-day duration)	

The method of fabrication was vacuum bag, autoclave, or press, depending on the supplier recommendation. The autoclave technique was generally used where a choice of processing was available.

The 12-in. x 12-in. laminates were cut into test specimens as shown in Figure 1. This configuration permitted adequate testing with efficient use of material.

e. Fabrication of Test Laminates

(1) Prepreg Materials

The polyester, epoxy, phenolic, and polyimide preimpregnated materials were fabricated into laminates according to supplier recommendations. All laminating operations were successful. Processing information on these materials is presented in Tables 3 through 6.

(2) Wet Layup Resins

(a) Standard Resins

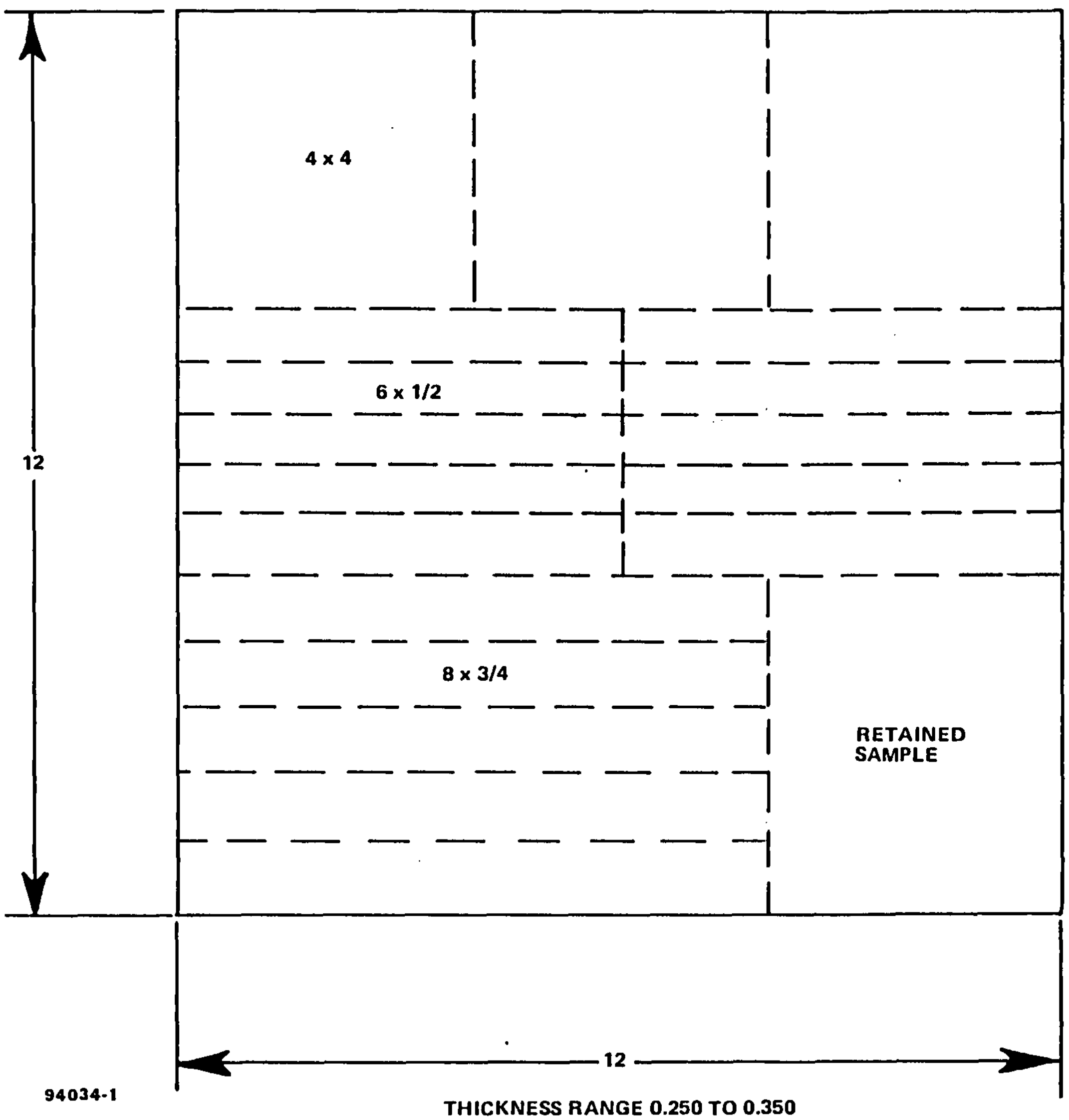
The two polyester resins, Paraplex P-49 and Selectron 5016, were fabricated into laminates using a standard wet layup vacuum bag technique compatible with the supplier's instructions. Processing information is presented in Table 7. The reinforcement was style 181 fiberglass cloth.

The liquid epoxy resin, Epon 828, was fabricated into a laminate using an approved hydraulic press method. Style 181 woven fiberglass cloth was the reinforcement. Processing information is given in Table 8.

(b) Specialty Resins

The specialty resins - EX-112, GAC 30-1A, and X1-2556 - are casting resins not designed for laminating. All three resins are relatively viscous and quite reactive. They require special handling techniques to ensure the preparation of dense, void-free laminates.

The EX-112 and X1-2556 resins were fabricated into laminates using a vacuum bag technique. The step-by-step processing method which



TEST SPECIMENS

3 PIECES	4 x 4
10 PIECES	6 x 1/2
5 PIECES	8 x 3/4

DIMENSIONS IN INCHES.

Figure 1. Test Specimen Preparation.

TABLE 3. PROCESSING INFORMATION - POLYESTER PREPREGS

Processing condition	P-604C	F-141
Handling characteristics	Good	Fair to poor (sticky)
Number of plies in layup	33	35
Bag vacuum	28 inches	22 inches
Cure schedule	Oven cure under vacuum. Placed in oven. Applied full vacuum. Raised oven to 275 deg F. Cured for 2 hr at 275 deg F. Shut off oven. Cooled under vacuum.	With autoclave at 45 PSI, raise temperature to 180 deg F for 1 hr. Then to 225 deg F for 1 hr. Then 290 deg F for 4 hr.
Postcure schedule	None required.	None required.
Appearance	Excellent Grayish green Opaque Dense	Excellent Opaque tan
	PE 285	IFRR
Handling characteristics	Fair to poor (sticky)	Fair to poor (sticky)
Number of plies in layup	34	33
Bag vacuum	28 inches	Press cured

TABLE 3. PROCESSING INFORMATION - POLYESTER PREPREGS (CONT)

Processing condition	PE 285	IFRR
Cure schedule	Set autoclave at 45-50 PSI. Cure: 1 hr at 180 deg F 1 hr at 225 deg F 4 hrs at 290 deg F. Maintain vacuum. Cool to room temperature.	Placed in cold press and applied minimum pressure. Heated platens to 375 deg F. Cured 90 minutes.
Postcure schedule	None required.	None required.
Appearance	Excellent Dark green Translucent Dense	Excellent Grayish green Opaque Dense

TABLE 4. PROCESSING INFORMATION - EPOXY PREPREGS

Processing conditions	E 293 FR	E-760A	3203
Handling characteristics	Fair to poor (sticky)	Excellent	Excellent
Number of plies in layup	32	33	33
Bag vacuum	28 inches	28 inches	29 inches
Cure schedule	Set autoclave at 325 deg F and 200 PSI. At 50 PSI vent the vacuum to the atmosphere. Cure: 2 hr at 325 deg F. Reapply vacuum and cool to room temperature.	Placed in autoclave. Applied 30 PSI pressure. Applied full vacuum. Raised temperature from ambient to 250 deg F in 45 minutes. Held at 250 deg F for 3 hr, cooled under vacuum.	Oven cure under vacuum. Applied full vacuum. Placed in oven. Increased heat to 260 deg F at a rate of 3 deg F/minute. Cured at 260 deg F for 90 minutes. Cooled under vacuum.
Postcure schedule	1/2 hr at 200 deg F 1/2 hr at 250 deg F 1 hr at 300 deg F 2 hr at 375 deg F 2 hr at 400 deg F	None required.	None required.
Appearance	Excellent Olive green Faintly translucent Dense	Good Grayish green Opaque Dense Slightly mottled surface	Excellent Off-white Opaque Dense

TABLE 4. PROCESSING INFORMATION - EPOXY PREPREGS (CONT)

Processing conditions	E-293	CE 9010	F-164
Handling characteristics	Excellent	Excellent	Excellent
Number of plies in layup	37	32	33
Bag vacuum	22 inches	28 inches	28 inches
Cure schedule	Set autoclave at 325 deg F and 200 PSI. When autoclave reaches 50 PSI, vent bag vacuum to atmosphere. Cure part at 325 deg F for 2 hr.	Placed in autoclave and applied vacuum. Pressurized autoclave to 50 PSI. Raised temperature to 350 deg F. Held at 350 deg F for 2 hr. Cooled under vacuum (excessive flow).	Placed in autoclave and applied vacuum. Pressurized autoclave to 100 PSI. Raised temperature to 300 deg F at rate of 4-8 deg per minute. Held at 300 deg F for 1-1/2 hr. Cooled under vacuum.
Postcure schedule	1/2 hr at 200 deg F 1/2 hr at 250 deg F 1 hr at 300 deg F 1 hr at 350 deg F 2 hr at 375 deg F 2 hr at 400 deg F	None required.	1 hr at 200 deg F 2 hr at 300 deg F 3 hr at 400 deg F
Appearance	Excellent Translucent Green	Excellent Tan Opaque Dense	Excellent Light green Opaque Dense

TABLE 5. PROCESSING INFORMATION - PHENOLIC PREPREGS

Processing condition	AC	F-507	F-120
Handling characteristics	Fair to poor (sticky)	Fair	Excellent
Number of plies in layup	33	33	33
Bag vacuum	Press cured	28 inches	22 inches
Cure schedule	Placed in cold press and applied minimum pressure. Heated platens to 375 deg F. Cured 60 minutes (excessive flow).	Placed in autoclave-applied pressure to 100 PSI. Raised temperature to 320 deg. Cured at 320 deg F for 3 hr. Cooled under vacuum.	With autoclave at 100 PSI, raise temperature at rate of 7-1/2 deg F per minute to 350 deg F Hold at 350 deg F for 90 minutes.
Postcure schedule	None required.	None required.	2 hr at 250 deg F 2 hr at 300 deg F 2 hr at 350 deg F 1 hr at 400 deg F
Appearance	Fair Black Opaque Slightly porous	Excellent Yellow tan Opaque Dense	Reddish brown Opaque Dense Slightly dry
	506		CPH 2251
Handling characteristics	Excellent		Poor
Number of plies in layup	33		30
Bag vacuum	29 inches		Press cured
Cure schedule	Oven cure under vacuum		Placed in cold press at contact pressure.

TABLE 5. PROCESSING INFORMATION - PHENOLIC PREPREGS (CONT)

Processing condition	506	CPH 2251
	Placed in oven. Applied full vacuum. Increased temperature to 200 deg F at a rate of 10 deg/minute. Soaked at 200 deg F for 30 minutes. Raised temperature to 250 deg F. Soaked at 250 deg F for 30 minutes. Raised temperature to 300 deg F. Soaked at 300 deg F for 30 minutes. Raised temperature to 350 deg F. Soaked at 350 deg F for 2 hr. Cooled under vacuum.	Raised temperature to 325 deg F. Monitored resin cure condition when gel was noted. Raised pressure to 50 PSI. Cured for 75 minutes at 325 deg F. Cooled under pressure. Part was uncured: Raised pressure to 100 PSI. Raised temperature to 325 deg F. Cured for additional 50 minutes at 325 deg F. Cooled under pressure. Laminate was cured.
Postcure schedule	None required.	None required.
Appearance	Excellent Tan Opaque Very slightly porous	Good Tannish yellow Opaque Dense Slightly mottled surface

TABLE 6. PROCESSING INFORMATION - POLYIMIDE PREPREG

Processing condition	F-174
Handling characteristics	Excellent
Number of plies in layup	33
Bag vacuum	28 inches
Cure schedule	Raise autoclave temperature to 240 deg F at 2-4 deg F/minute. Raise temperature from 240 deg to 270 deg F at 1-2 deg F/minute. Hold at 270 deg F for 30 minutes. Apply 50 PSI pressure. Raise temperature from 270 deg to 350 deg F at 1-2 deg F/minute. Hold at 350 deg F for 1 hr. Maintain vacuum. Cool to room temperature.
Postcure schedule	1 hr at 200 deg F 2 hr at 300 deg F 3 hr at 400 deg F
Appearance	Fair Light brown Opaque Dense Slightly dry

TABLE 7. PROCESSING INFORMATION - POLYESTER RESINS - WET LAYUP METHOD

Processing conditions	Paraplex P-49	Selectron 5016
Catalyst (resin/catalyst ratio)	Benzoyl peroxide (100/1.6)	Benzoyl peroxide (100/1.6)
Handling characteristics	Fair	Excellent
Number of plies in layup	28	24
Type of cure	Oven cure under vacuum	Over cure under vacuum
Bag vacuum	28 inches	28 inches
Cure schedule	Drew vacuum. Paddled out air and excess resin. Cured in oven at 240 deg F for 1 hr. Cooled under vacuum.	Drew vacuum. Paddled out air and excess resin. Cured in oven at 240 deg F for 1 hr. Cooled under vacuum.
Postcure schedule	None	None
Appearance	Excellent Light green Opaque Dense	Good Grayish green Opaque Dense Slightly low resin content

TABLE 8. PROCESSING INFORMATION - EPOXY RESIN - WET LAYUP METHOD

Processing conditions	Epon 828
Catalyst (resin/catalyst ratio)	Versamid 125 (60/40)
Handling characteristics	Fair
Number of plies in layup	25
Type of cure	Press
Bag vacuum	Not applicable
Cure schedule	Placed in 150 deg F press. Closed to contact pressure. When resin thinned out and flowed-closed press to 0.250-in. shims. Raised temperature to 300 deg F. Cured 1-1/2 hr. Cooled under pressure.
Postcure schedule	None
Appearance	Excellent (center*) Amber-green Translucent Dense

*Resin did not flow completely to corners of laminate.

was developed for these resins is shown in Table 9. The laminating procedures were successful, and satisfactory laminates were prepared.

Pertinent processing information on EX-112 and X1-2556 is presented in Table 10.

The GAC 30-1A resin system was fabricated into a laminate by the press method. The process developed for this operation is described in Table 11. The resulting laminate was satisfactory. The processing information on GAC 30-1A is given in Table 12.

f. Evaluation

(1) General

All the laminates fabricated in Task 1 were suitable for evaluation. Supply, handling characteristics, and processability of all materials were satisfactory. As the evaluation program progressed, it became apparent that it was unnecessary to determine mechanical properties and environmental endurance of all the resins. The resins behaved as expected for the various types: polyester, epoxy, phenolic. Therefore, a representative number from each resin type was tested to establish the general relationship between the types.

Since the primary emphasis in the program was on fire resistance, it was considered necessary that each laminate be subjected to a test which measured resistance to intense flame.

Results of the evaluation program are presented in both tabular and graphic form.

(2) Physical Properties

The physical properties tests conducted on the edge attachment laminates are shown in Table 13.

Results of the test program are shown in Tables 14 through 18. Table 14 presents tensile strength values at room temperature and at 300 deg F. A column has been added to show the percent tensile strength retained at 300 deg F.

TABLE 9. PROCESSING FOR SPECIALTY RESINS EX-112 AND X1-2556

This process is applicable to both EX-112 and X1-2556:

1. Cut glass cloth to proper size. Weight.
2. Weight out the base resin using an amount of resin equivalent to the weight of glass cloth.
3. Catalyse. Mix the resin/catalyst system thoroughly.
4. Saturate the glass cloth with resin one ply at a time on a prepared aluminum plate.
5. Place thick layer of bleeder material around the periphery of the laminate. Allow a one-inch gap between the laminate and the bleeder.
6. Bag with PVA film.
7. Draw vacuum and paddle out air and excess resin.
8. Cure.
9. Cool under vacuum.

TABLE 10. PROCESSING INFORMATION - SPECIALTY RESINS EX-112 AND X1-2556

Processing conditions	EX-112	X1-2556
Catalyst (resin/catalyst ratio)	Trimethoxy boroxine (TMB) 100/5	Special system
Handling characteristics	Fair	Fair
Number of plies in layup	32	28
Type of cure	Oven cure under vacuum.	Oven cure under vacuum.
Bag vacuum	28 inches	28 inches
Cure schedule	Drew vacuum. Paddled out air and excess resin. Cured in oven at 190 deg F for 4 hr. Cooled under vaccuum.	Drew vacuum. Paddled out air and excess resin. Cured in oven at 160 deg F for 2 hr. Cooled under vacuum.
Postcure schedule	2 hr at 250 deg F 1 hr at 300 deg F	2 hr at 200 deg F 2 hr at 250 deg F 1 hr at 300 deg F
Appearance	Good Green Slightly translucent Dense	Good Grayish green Very slightly translucent Dense

TABLE 11. PROCESSING FOR SPECIALTY RESIN GAC 30-1A

1. Cut woven fiberglass cloth (Style 181) to proper size.
2. Weigh cloth and formulate an equal weight of resin.
3. Prepare press bag using 2-mil release cloth.
4. Pour and spread resin one ply at a time.
5. Cut 3-in. widths of 3-in-thick foam. Place around laminate leaving four corners open.
6. Close bag and seal with 2-in. tape.
7. Place in room temperature press and close slowly to stops.
8. Cure.
9. Cool under pressure.

TABLE 12. PROCESSING INFORMATION - SPECIALTY RESIN GAC 30-1A

Processing conditions	GAC 30-1A
Catalyst (resin/catalyst ratio)	Special system
Handling characteristics	Fair
Number of plies in layup	24
Type of cure	Press
Bag vacuum	Not applicable
Cure schedule	Placed in room temperature press. Closed press to 0.250-in. shims. Heated to 250 deg F. Cured 1 hr. Cooled under pressure.
Postcure schedule	None
Appearance	Fair Grayish-green Slightly translucent Dense Surfaces slightly dry

TABLE 13. PHYSICAL PROPERTIES TESTS

Type of test	Test method	Test specimen dimensions (inches)
Tensile strength 75 deg F 300 deg F	FTMS No. 406, Method 1011	8 x 3/4
Flexural strength 75 deg F 300 deg F	FTMS No. 406, Method 1031	6 x 1/2
Hardness	Shore D	
Edgewise compression	FTMS No. 406, Method 1021	3 x 1/2

TABLE 14. TENSILE STRENGTH - COMPARATIVE VALUES

Material code	Material type	Room temperature tensile ultimate	300 deg F tensile ultimate	% strength retained
CE 9010	Epoxy	66,654	48,148	72.2
E 293	Epoxy	53,013	30,599	57.7
IFRR	Polyester	51,980	31,297	60.2
F-141	Polyester	50,157	32,293	64.4
E293FR	Epoxy (additive)	49,945	28,969	58.0
AC	Phenolic	49,517	39,523	79.8
F164	Epoxy	44,202	37,687	85.3
PE285	Polyester	41,580	34,706	83.5
F120	Phenolic	39,264	34,823	88.7
F174	Polyimide	30,857	32,818	106.4
EX-112	Special epoxy	30,138	9,678	32.1
AC/FG	Acrylic/fiberglass	27,742	3,332	12.0
X1-2556	Special silicone	20,429	11,014	54.4

TABLE 15. FLEXURAL STRENGTH - COMPARATIVE VALUES

Material code	Material type	Room temperature flexural strength	300 deg F flexural strength	% strength retained
CE 9010	Epoxy	95,996	59,677	62.2
E293FR	Epoxy (additive)	73,800	34,273	46.4
E293	Epoxy	67,701	43,538	64.3
F-141	Polyester	66,661	29,694	44.5
AC	Phenolic	61,740	54,829	88.8
F120	Phenolic	61,563	55,000	89.3
F164	Epoxy	61,277	51,083	83.4
IFRR	Polyester	59,743	37,472	62.7
PE285	Polyester	55,604	42,673	76.7
EX-112	Special epoxy	49,032	8,620	17.6
AC/FG	Acrylic/fiberglass	38,186	600	1.6
F174	Polyimide	12,579	11,053	87.9
X1-2556	Special silicone	9,900	3,151	31.8

TABLE 16. PERCENT STRENGTH RETAINED AT 300 DEG F

Tensile strength			Flexural strength		
Material code	Material type	% strength retained	Material code	Material type	% strength retained
F174	Polyimide	106.4	F120	Phenolic	89.3
F120	Phenolic	88.7	AC	Phenolic	88.8
F164	Epoxy	85.3	F174	Polyimide	87.9
PE285	Polyester	83.5	F164	Epoxy	83.4
AC	Phenolic	79.8	PE285	Polyester	76.7
CE 9010	Epoxy	72.2	E293	Epoxy	64.3
F-141	Polyester	64.4	IFRR	Polyester	62.7
IFRR	Polyester	60.2	CE 9010	Epoxy	62.2
E293FR	Epoxy (additive)	58.0	E293FR	Epoxy (additive)	46.4
E293	Epoxy	57.7	F-141	Polyester	44.5
X1-2556	Special silicone	54.4	X1-2556	Special silicone	31.8
EX-112	Special epoxy	32.1	EX-112	Special epoxy	17.6
AC/FG	Acrylic/fiberglass	12.0	AC/FG	Acrylic/ fiberglass	1.6

TABLE 17. SHORE D HARDNESS

Code	Material	Process	Cure	Shore D
CPH 2251	Phenolic	Prepreg	Press	90-91
AC	Phenolic	Prepreg	Press	90-91
F-120	Phenolic	Prepreg	Autoclave	90-91
F-141	Polyester	Prepreg	Autoclave	90-91
PE-285	Polyester	Prepreg	Autoclave	90-91
E293FR	Epoxy	Prepreg	Autoclave	89-91
E760A	Epoxy	Prepreg	Autoclave	89-91
CE 9010	Epoxy	Prepreg	Autoclave	88-91
F-507	Phenolic	Prepreg	Autoclave	90
F-164	Epoxy	Prepreg	Autoclave	90
EX-112	Special epoxy	Hand layup	Oven-vacuum	90
E293	Epoxy	Prepreg	Autoclave	90
P-604C	Polyester	Prepreg	Oven-vacuum	88-90
AC/FG	Acrylic/fiberglass	Secondary bond	Press	88-90
IFRR	Polyester	Prepreg	Press	87-90
506	Phenolic	Prepreg	Oven-vacuum	80-90
3203	Epoxy	Prepreg	Oven-vacuum	80-87
X1-2556	Special silicone	Hand layup	Autoclave	82-83
F-174	Polyimide	Prepreg	Autoclave	81-83

TABLE 18. EDGEWISE COMPRESSION RESULTS

Code	Material	Edgewise compression (PSI)
CE 9010	Epoxy	88,116
F-141	Polyester	78,093
E293	Epoxy	69,750
F164	Epoxy	68,948
F120	Phenolic	68,493
E293FR	Epoxy (additive)	68,460
EX-112	Special epoxy	66,410
PE285	Polyester	65,057
IFRR	Polyester	59,570
AC	Phenolic	54,091
AC/FG	Acrylic/fiberglass	37,733
F174	Polyimide	21,399
X1-2556	Special silicone	15,189

Table 15 presents values for flexural strength at room temperatures and at 300 deg F. A column has been added to show the percent of flexural strength retained at 300 deg F.

Table 16 arranges the materials in order of strength retained at 300 deg F for both tensile and flexural strengths. There are no surprises in the table. Tensile strength is influenced strongly by the reinforcement. For this reason, the standard fiberglass-reinforced laminates retain a high proportion of their strength at 300 deg F. The acrylic/fiberglass laminate indicates a complete softening of the resin binder.

The resin binder has somewhat more influence on flexural strength and this is reflected in the flexural strength test results. Table 17 gives the Shore D hardness values for the various laminates. The hardness values seem all fairly comparable. Some of the laminates were slightly porous; this is reflected in a wider range of readings.

Table 18 presents the results of the edgewise compression tests. Performance in this test is dependent almost entirely on the resin binder.

(3) Fire Resistance Tests

(a) ASTM Flammability Test

The ASTM horizonal burn test (ASTM D635) was used to help compare the relative flammability of the various resin systems. Information reported from the data was:

Time of burning (seconds)
Extent of burning (millimeters)
Burning rate (centimeters per minute).

Results of the test are presented in Table 19. As noted in the table, nearly all the laminates were nonflammable except the acrylic resin laminate. This laminate burned readily.

TABLE 19. FLAMMABILITY TEST - ASTM D635

Sample code	Sample thickness (in.)	Total burning time (min)	Time of burning t-30 (sec)	Extent of burning (mm)	Burning rate (cm/min)	Remarks
F 164	0.298	0.5	<5	<5	0	Burning stopped as flame was removed.
E293	0.395	1.50	60	5	>5	Constantly diminishing burn when flame was removed.
AC	0.258	0.5	<5	<5	0	No flame from sample.
F 120	0.314	0.5	<5	<5	0	Burning stopped as flame was removed.
IFRR	0.327	0.5	<5	<5	0	Bright flame-stopped as flame was removed.
X 2556	0.310	0.62	7	<5	0	End turned white and flared out.
E293 FR	0.324	0.5	<5	<5	0	Bright flame-stopped when flame removed-end flared out.
CE 9010	0.275	0.5	<5	<5	0	Burning stopped as flame was removed-strong flame.
F174	0.349	0.5	<5	<5	0	Burning stopped as flame was removed-tiny flame.

TABLE 19. FLAMMABILITY TEST - ASTM D635 (CONT)

Sample code	Sample thickness (in.)	Total burning time (min)	Time of burning t-30 (sec)	Extent of burning (mm)	Burning rate (cm/min)	Remarks
PE 285	0.344	2.56	118	11.8	0.60	Large bright flame-slowly diminishing.
F-141	0.318	0.5	<5	<5	0	Burning stopped as flame was removed-bright flame.
EX-112	0.429	1.77	76	17.2	1.36	Medium flame-slowly diminished when flame was removed.
AC/FG	0.301	7.30	408	100	1.47	Maintain a steady flame and rate of burning-complete resin burn-out.

It will be noted that the EX-112 laminate had a detectable burning rate. This had been noted previously. The EX-112 resin forms a protective char but while doing so, does burn slowly.

(b) Goodyear Aerospace Special Flame Test

1. Equipment and Procedure

The Goodyear Aerospace Special Flame Test facility is shown in Figure 2.

In operation of the facility, a butane flame is directed against a special thermocouple away from the specimen area and adjusted to 2000 deg F. The test specimen, 4 x 4 inches in size, is clamped

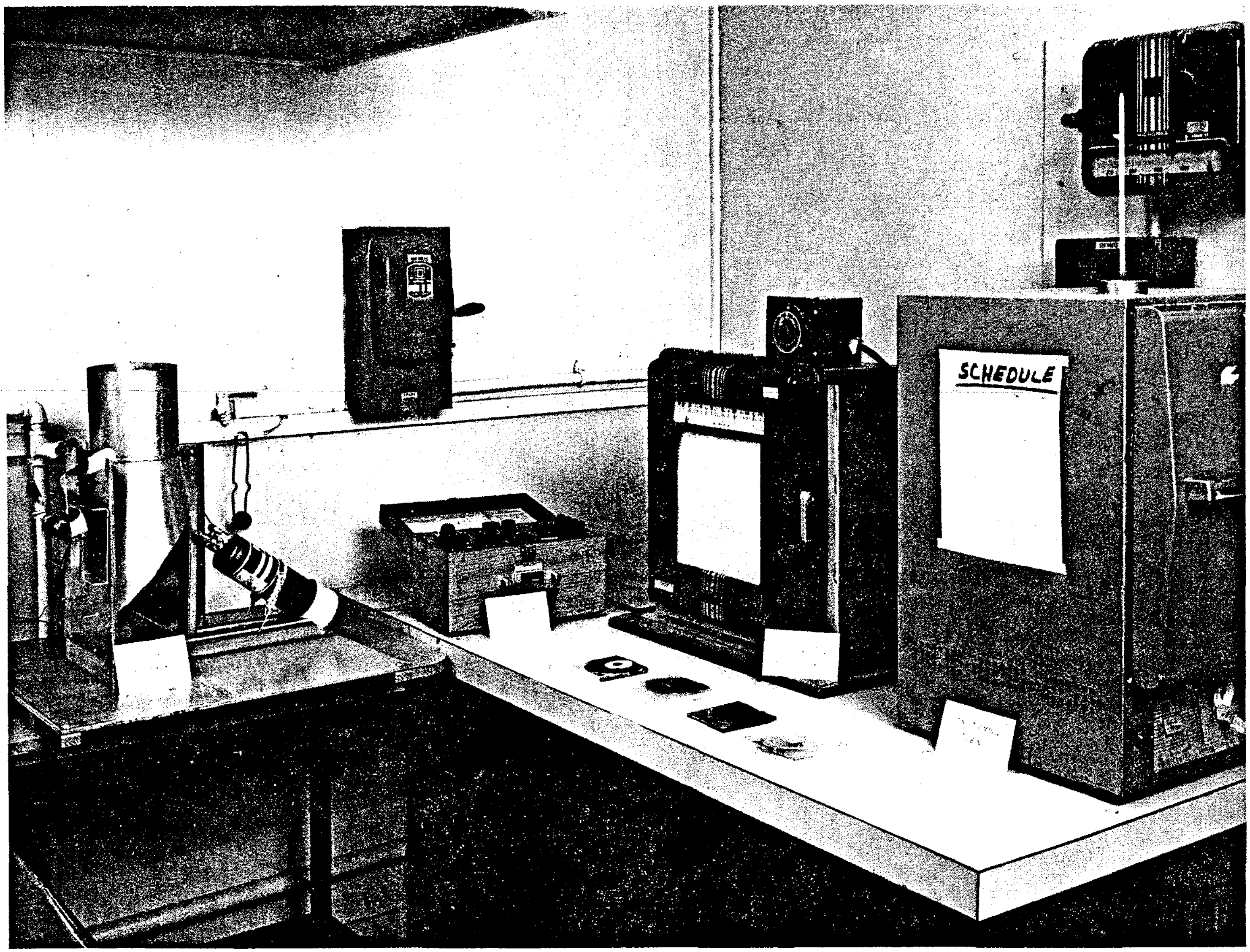


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Figure 2. Goodyear Aerospace Special Fire Test Equipment.

in place beneath the flame hood. A recording thermocouple is pressed against the backside of the specimen. The adjusted flame is then pivoted against the specimen face. The test starts when the flame impinges the specimen (see Figure 3).

The time required for the backside to reach 400 deg F is recorded as the end point. Notes on the reaction of the material to the flame during the test and the appearance of the specimen after the test are also recorded.

The format of the data sheet utilized for the Special Flame Test is shown in Figure 4.

The use of a backside temperature of 400 deg F as a critical data point for the flame test is based on two considerations:

1. It is a well defined end-point reached in reasonable test time. It should be fairly reproducible and useful for comparative testing of a variety of materials.

2. The 400 deg F temperature seems realistic from a practical point of view. Two typical edge attachment designs are shown in Figure 5. In both designs, the fiberglass laminate (either as a filler strip or structural linkage) must protect the structural transparent ply along the bolt line. The attachment bolts go directly through the structural ply as shown in Figure 5. This is standard practice when polycarbonate is used (as shown) and also when stretched acrylic is the structural ply. Any serious loss of strength along the bolt line will cause the canopy to collapse into the cockpit.

   Both stretched acrylic and polycarbonate lose strength at elevated temperatures. As shown in Figures 6 and 7, both materials approach zero strength around

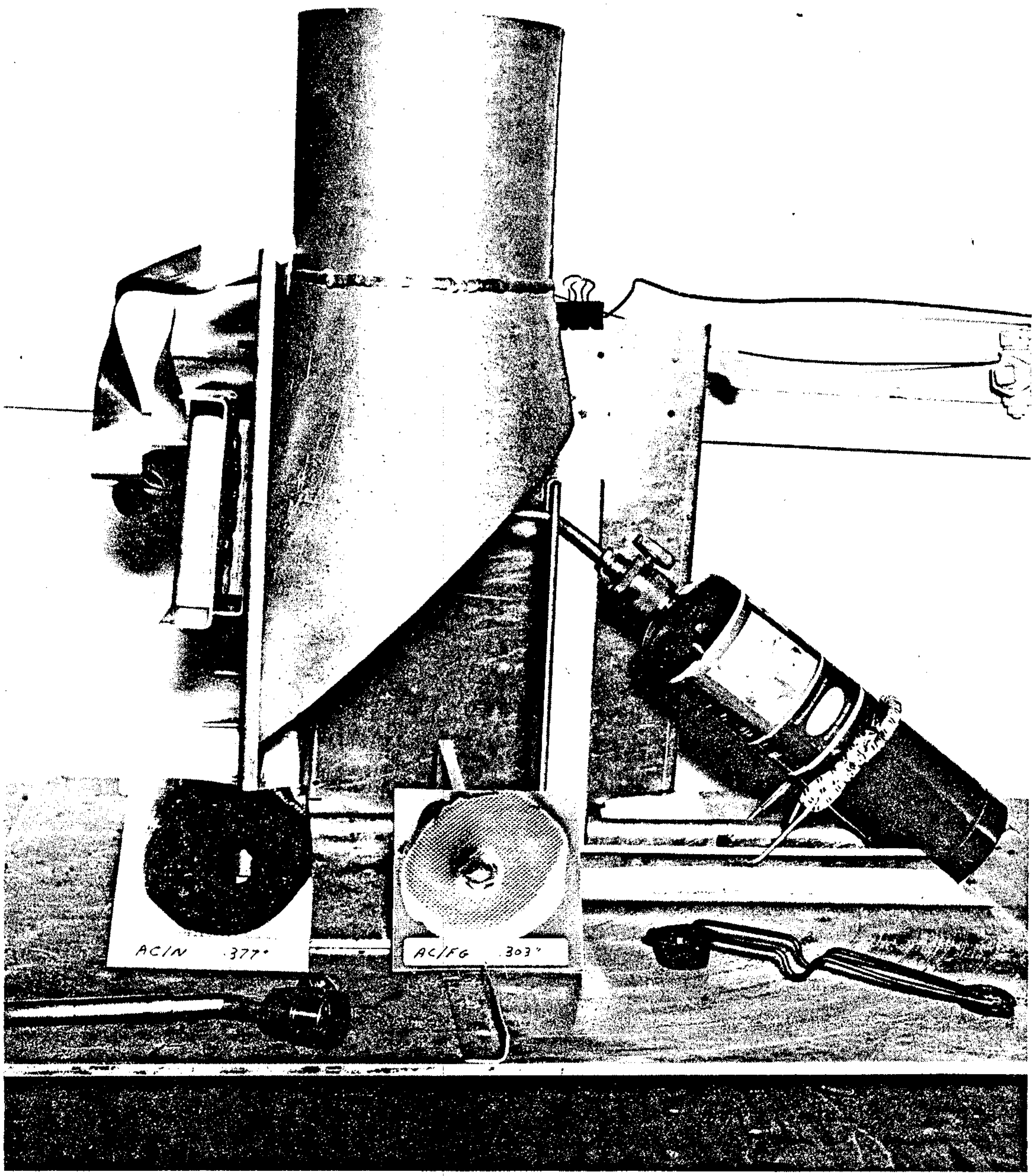

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Figure 3. Goodyear Aerospace Flame Tester.

MATERIAL		THICKNESS (IN.)	TIME FOR BACKSIDE TO REACH 400 DEG F		REACTION DURING TEST	APPEARANCE AFTER TEST
CODE	TYPE		STOP WATCH	CHART		

DATE: ____________________

TIME: ____________________

FLAME TEMPERATURE-2000 DEG F ________________ (CHECKED)

CHART SPEED ______________________________

TESTER ______________________________

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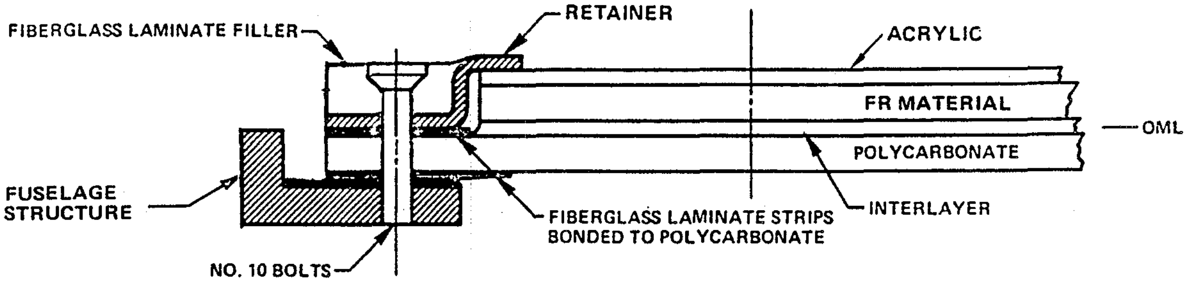
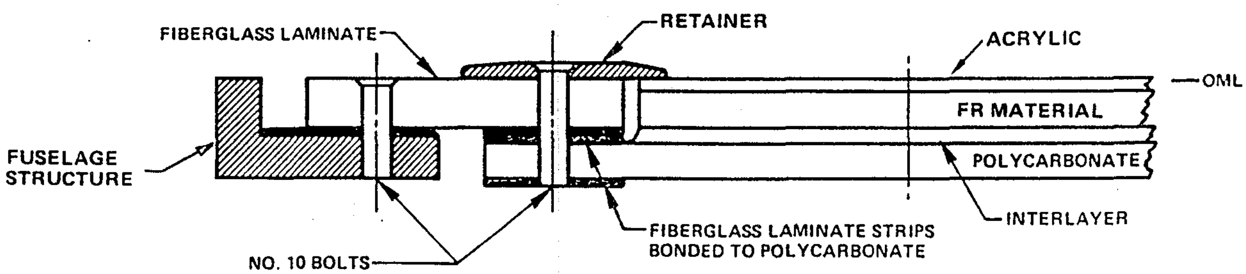
Figure 4. Goodyear Aerospace Special Flame Test – Data Sheet.



EDGEBAND TEST COUPON CONFIGURATION "A"
(OUTSIDE OML)



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EDGEBAND TEST COUPON CONFIGURATION "B"
(INSIDE OML)

Figure 5. Edgeband Alternate Attachment Configurations.

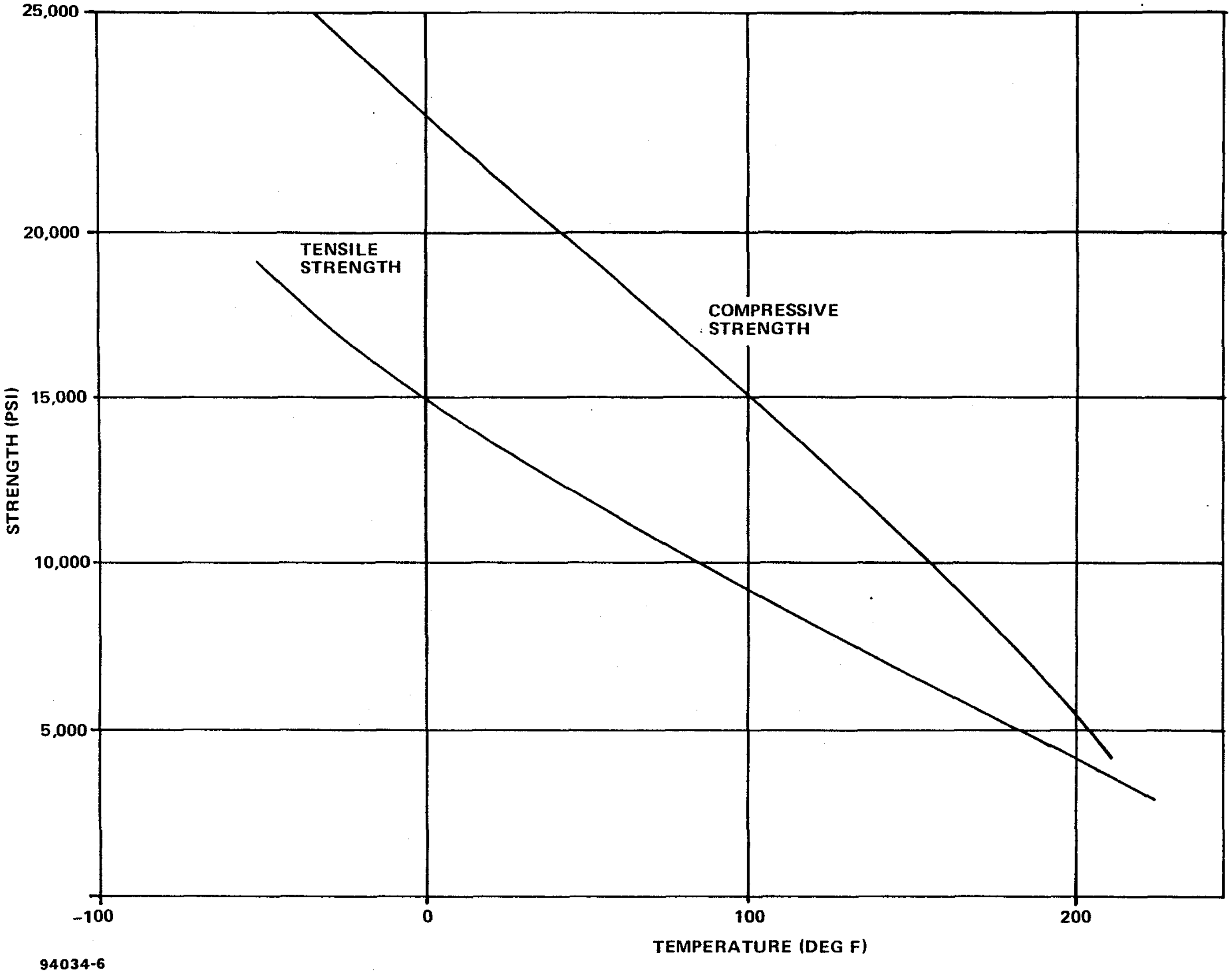

Figure 6. Effect of Temperature on Tensile and Compressive Strengths of Stretched Acrylic Sheet (MIL-P-25690).

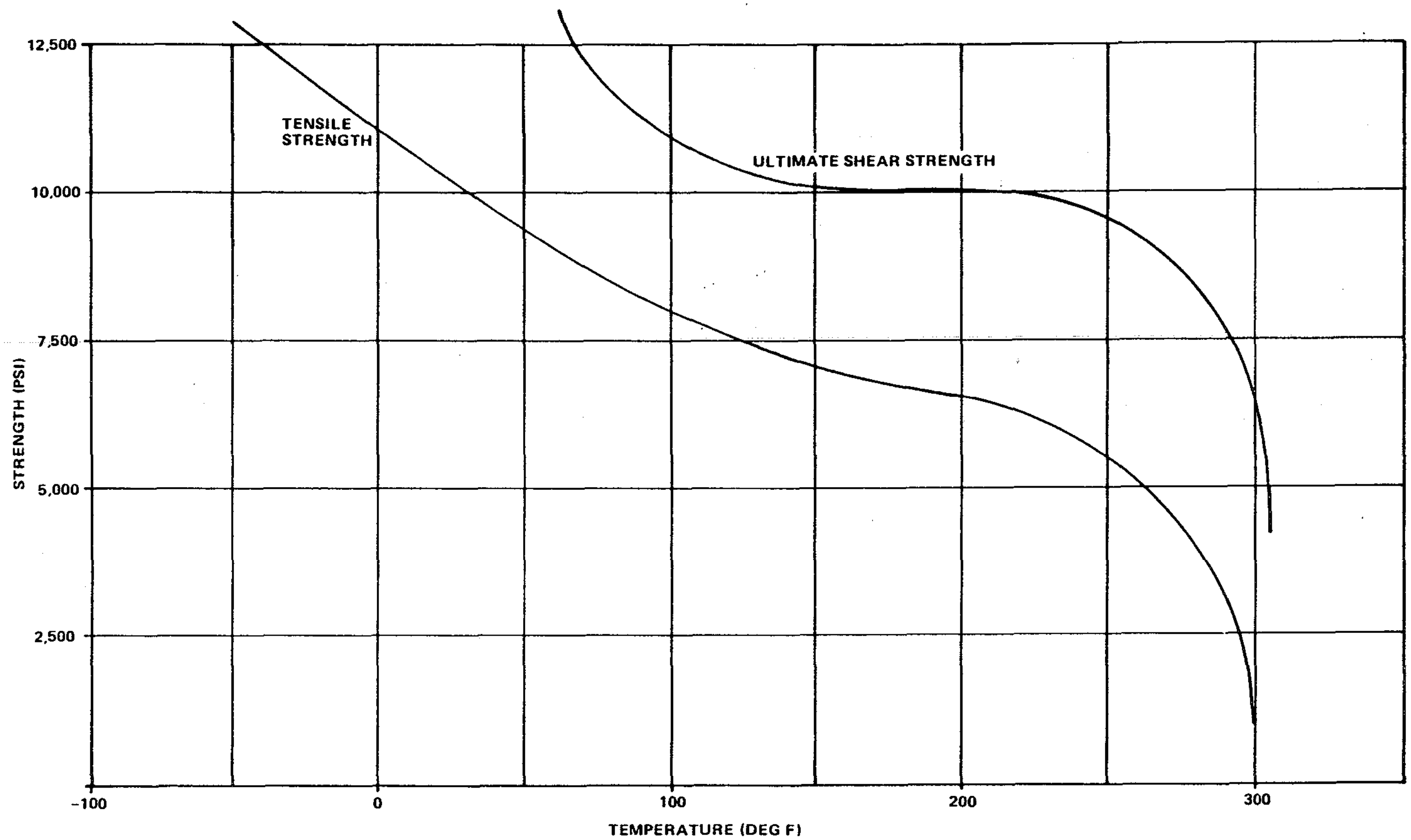

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Figure 7. Effect of Temperature on Tensile and Shear Strengths of Polycarbonate Sheet (MIL-P-83310).

300 deg F. It is reasoned that, when consideration is given to the thermal gradient across the materials and to the heat sink represented by the attachment bolts and airframe supports, a temperature of 400 deg F at the fiberglass laminate/structural transparent ply interface represents the collapse point of the canopy.

Based on the foregoing considerations, a backside temperature of 400 deg F for 0.250-in.-thick specimens was used throughout this program as a critical end point for the Goodyear Aerospace Flame Test.

2. Flame Test Results

Results of the tests performed on the Goodyear Aerospace Special Flame Test unit are presented in Tables 20 through 23.

The end point of the test was the time required for the backside temperature of the specimen to reach 400 deg F. Variations in specimen thickness obviously affect this time interval. Since the thickness values for the test laminates varied, it became necessary to establish a common basis for comparison. The time required for the backside temperature to reach 400 deg F for a specimen thickness of 0.250-in. was selected as the basis for comparison.

With limited material it is difficult to laminate a single specimen to an exact thickness and still maintain an optimum resin/reinforcement ratio. The specimens could have been ground to thickness, but this would have added time and costs, and left undersized pieces unresolved. It seemed expedient, therefore, to develop a technique for using the time/thickness relationship (as shown in Tables 20 through 23) to estimate the time for a 0.250-in.-thick specimen to reach the 400 deg F mark.

TABLE 20. RESULTS FROM GOODYEAR AEROSPACE FLAME TEST - POLYESTER LAMINATES

Material		Thickness (in.)	Time for backside temperature to reach 400 deg F (sec)	Remarks	
Code	Type			During test	Appearance of specimen after test
PE 285	Polyester	0.303	560	Smoke-flame	Front-resin burn-out, some glass melting, sooty char. Back-discoloration, delamination.
IFRR	Polyester	0.325	600	Smoke-glow	Front-resin burn-out, black sooty. Back-slight bulge, resin darkened.
F-141	Polyester	0.315	795	White smoke during test.	Front-resin burn-out and some char. Star cracks. Back-delamination.
P 604C	Polyester	0.370	277	Light white smoke-heavy white smoke when flame removed.	Front: 1-in.-diameter char; 3-in.-diameter black area. Back: 2-in.-diameter delamination and blister.
P-49	Polyester	0.279	192	Heavy white smoke, burning.	Front: 2-1/2-in.-diameter dark circle; 1-in.-diameter resin burn-out. Back: no change.
5016	Polyester	0.200	72	Very light white smoke. Heavy when flame removed. Burning.	Front: 2-in.-diameter circle near resin burn-out. Back: no change.

TABLE 21. RESULTS FROM GOODYEAR AEROSPACE FLAME TEST - EPOXY LAMINATES

Material		Thickness (in.)	Time for backside temperature to reach 400 deg F (sec)	Remarks	
Code	Type			During test	Appearance of specimen after test
E760A	Epoxy	0.282	328	Slight amount of dark smoke.	Front: resin burn-out 1-1/2-in.-4-in.-diameter black. Back: 1-in. dark spot; 2-1/2-in.-diameter delamination.
Epon 828	Epoxy	0.242	90	Medium grey smoke, burning.	Front: 2-1/2-in.-diameter burned area; 1-in.-diameter resin burn-out; small cracks. Back: 2-1/2-in.-diameter dark spot-no blistering.
3203	Epoxy	0.350	318	Light white smoke. Medium white smoke when flame removed.	Front: 3-in.-diameter dark spot; 3/4-in. resin burn-out. Surface cracks. Back: 1-in.-diameter brown scorch.
E 293	Epoxy	0.385	342	Little resin loss. Low smoke level.	Front-mild surface char. Star cracks. Back-delamination.
CE 9010	Epoxy	0.260	113.3	Smoke and fumes.	Front-black sooty. Back-resin discoloration, very slight bulge.
E293FR	Epoxy	0.340	206.7	Smoke and flame.	Front-black sooty. Back-slight discoloration.
F-164	Epoxy	0.290	290	Smoke, flame, post-ignition.	Front-black, sooty, slight bulge. Back-bulge, resin discoloration, delamination.

TABLE 22. RESULTS FROM GOODYEAR AEROSPACE FLAME TEST - PHENOLIC AND POLYIMIDE LAMINATES

Material		Thickness (in.)	Time for backside temperature to reach 400 deg F (sec)	Remarks	
Code	Type			During test	Appearance of specimen after test
506	Phenolic	0.350	161	Nothing visible.	Front: 2-in.-diameter dark spot-small surface cracks. Back: 1-in-diameter brown scorch.
CPH 2251	Phenolic	0.217	65	Red glow on surface during flame impingement.	Front: 1-1/2-in.-diameter char. Back: 1-in.-diameter dark spot.
F-507	Phenolic	0.309	190	Nothing visible.	Front: 2-in.-diameter burn area. Back: 2-in.-diameter delamination.
F-120	Phenolic	0.315	180	No smoke or fumes.	Front-specimen marked very little. Slight blackening and star cracks. Back-slight discoloration.
AC	Phenolic	0.260	106.7	No smoke-no flame.	Front-faint dulling of surface at point of flame. Back-no change.
F-174	Polyimide	0.347	166.7	Some smoke-glow.	Front-slight resin burn-out, slight char. Back-small spot of resin discoloration, no delamination.

TABLE 23. RESULTS FROM GOODYEAR AEROSPACE FLAME TEST - SPECIAL RESIN LAMINATES

Material		Thickness (in.)	Time for backside temperature to reach 400 deg F (sec)	Remarks	
Code	Type			During test	Appearance of specimen after test
EX-112	Special epoxy	0.425	675	Slight to moderate white smoke.	Front-some char, star cracks, slight bulge. Back-delamination.
X1-2556	Special silicone	0.316	288	No smoke.	Front-very little char, slight cracking. Back-delamination.
GAC 30-1A	Special epoxy	0.249	124	Medium white smoke when flame removed. Burning.	Front: 2-1/2-in.-diameter dark circle. Small cracks at center. Back: 1-1/2-in.-diameter light brown spot. No blistering.
AC/FG (control)	Acrylic/ fiberglass reinforcement	0.303	600	Smoke-flame-reinforcement glowing and melting.	Front-considerable resin burn-out, glass plies melted (several plies deep). Back-resin burn-out (glass reinforcement exposed).

The extrapolation technique used for this program was developed as follows:

1. Observations made during the performance of the Special Flame Test showed that the various resin types reacted differently to the flame:

   a. The polyesters which had low heat resistance generally decomposed and delaminated

   b. The epoxies which had moderate heat resistance suffered slight blistering and charring.

   c. The phenolics and polyimides which had good heat resistance showed little change in the test.

   d. The Special Resins developed a char along with delamination (except for the acrylic laminate, in which the resin burned out completely; acrylic was never considered a viable resin for this program and was used only as a control).

2. Because of the foregoing observation, the various resin groups were considered separately. Several resins were selected from each group and fabricated into flame test specimens of various thickness.

3. Each specimen was subjected to the Special Flame Test. Results of the test program are shown in Table 24.

4. The data from Table 24, along with previous data from Tables 20, 21, 22, and 23, was used to construct graphs showing the relationship of specimen thickness to the time required for the backside temperature to reach 400 deg F. The plots are shown in Figures 8, 9, 10, and 11.

TABLE 24. EFFECT OF THICKNESS ON TIME FOR BACKSIDE TEMPERATURE TO REACH 400 DEG F

Code	Type	Thickness (in.)	Time for backside temperature to reach 400 deg F (sec)	Remarks
IFRR	Polyester	0.084	30	Blistered-darkened.
		0.224	124	Resin burn-out; delamination.
PE 285	Polyester	0.085	26	Severe blistering-delamination.
		0.226	245	Resin burn-out; delamination.
F-141	Polyester	0.193	310	Resin burn-out; delamination.
		0.200	260	Resin burn-out; delamination.
CE 9010	Epoxy	0.055	22	Slight blister.
		0.210	68	Very slight blister.
F-164	Epoxy	0.137	46	Slight char on front.
		0.159	71	Slight char on front.
E293	Epoxy	0.065	33	Char. Resin burn-out-front. Delamination-back.
		0.189	82	Slight char on front.
		0.226	146	Slight char on front.
		0.270	213	Slight char on front; delamination-back.
		0.398	355	Slight char on front; delamination-back.
E293FR	Epoxy	0.140	60	Resin burn-out.
		0.173	92	Resin burn-out.
AC	Phenolic	0.080	37	Little change.
		0.160	74	Little change.
F-174	Polyimide	0.087	28	Slight darkening-little change.
		0.212	142	Slight darkening-little change.
EX-112	Special epoxy	0.185	108	Surface char-slight delamination.
		0.210	149	Surface char-slight blister, slight delamination.

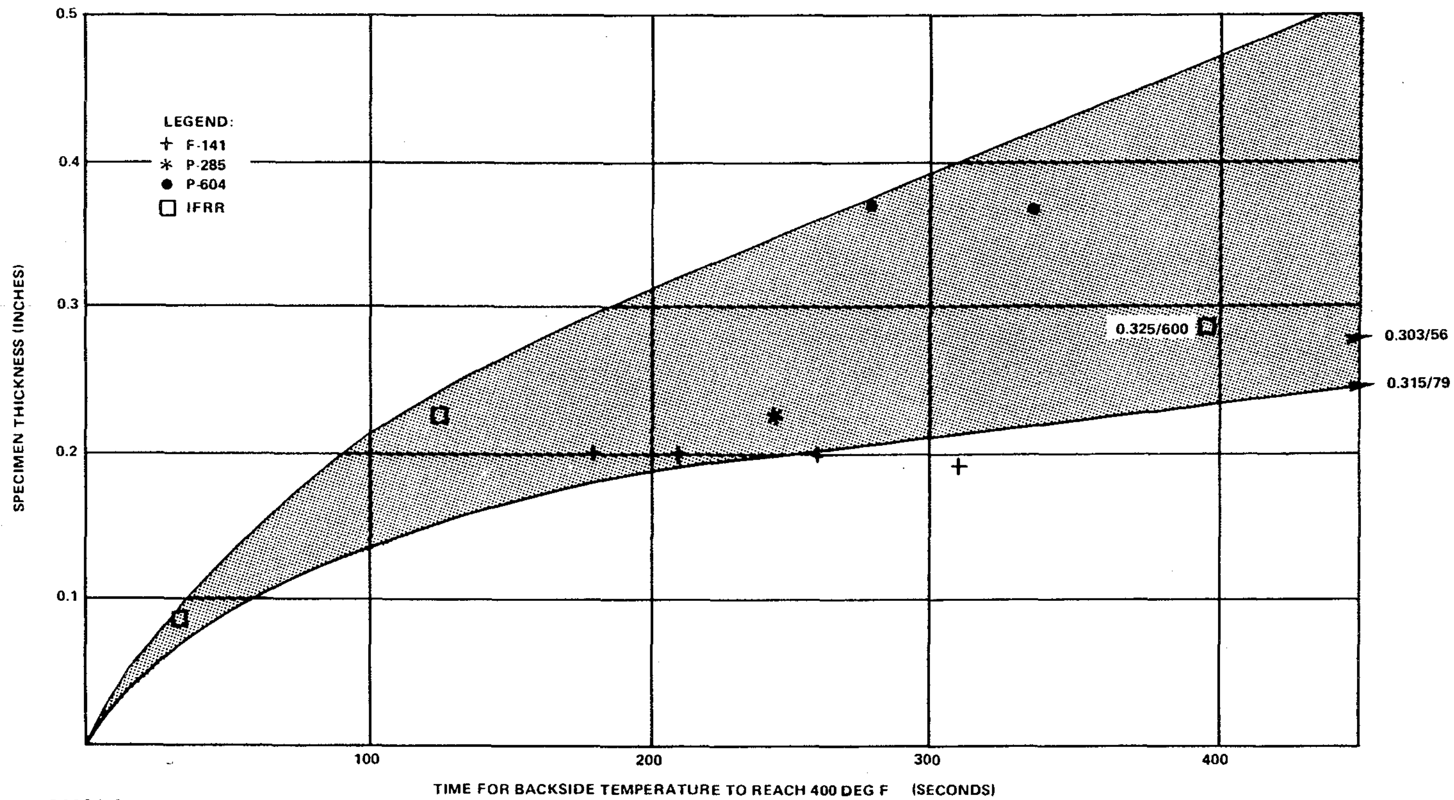

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Figure 8. Effect of Specimen Thickness on Time Required for Backside Temperature to Reach 400 Deg F - Polyesters (Fiberglass Reinforcement).

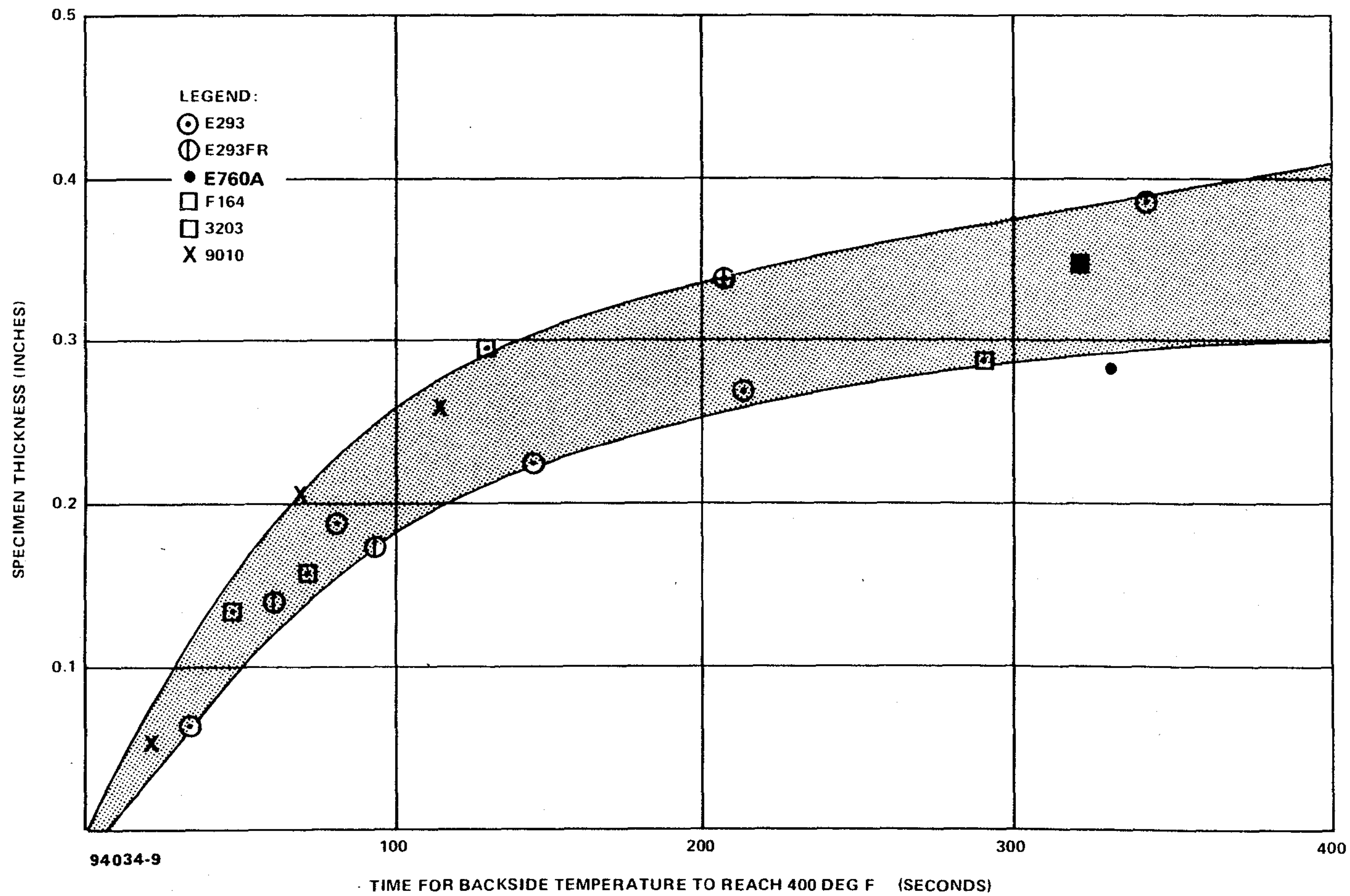

Figure 9. Effect of Specimen Thickness on Time Required for Backside Temperature to Reach 400 Deg F - Epoxies (Fiberglass Reinforcement).

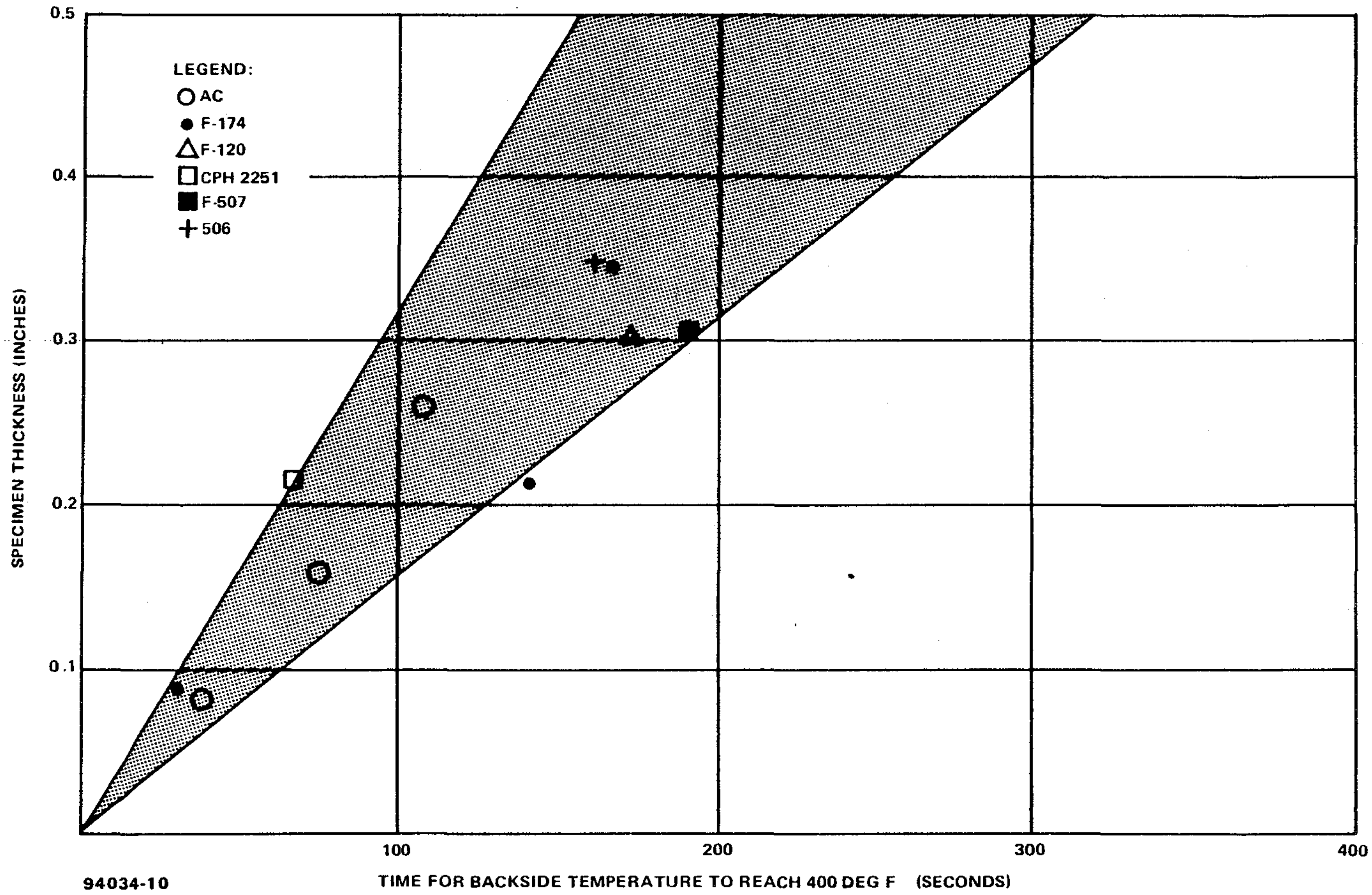

Figure 10. Effect of Specimen Thickness on Time Required for Backside Temperature to Reach 400 Deg F - Phenolics and Polyimide (Fiberglass Reinforcement).

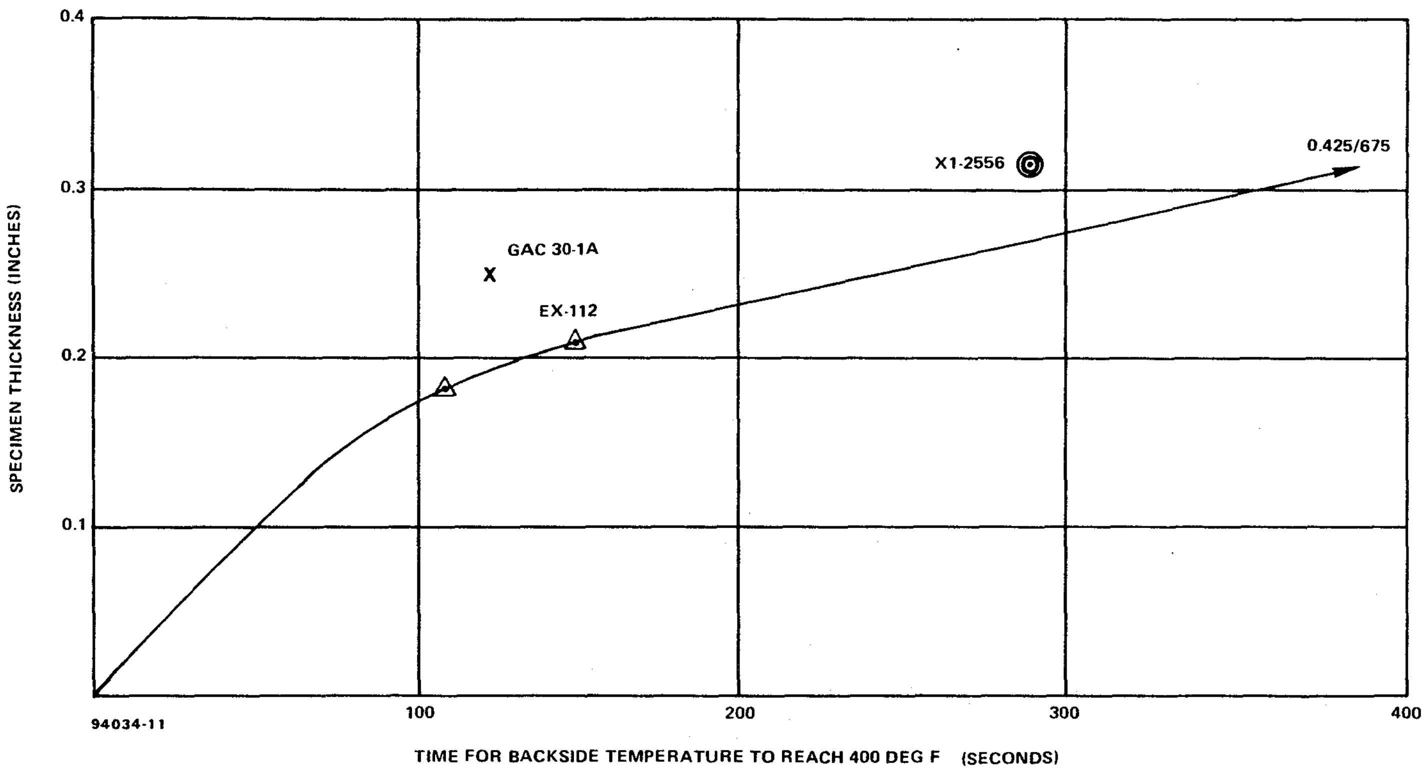

Figure 11. Effect of Specimen Thickness on Time Required for Backside Temperature to Reach 400 Deg F - Special Resins (Fiberglass Reinforcement).

5. Using the plots in Figures 8 through 11, extrapolations were made to estimate the time for the backside temperature to reach 400 deg F with 0.250-in.-thick laminates of each material in the program. The results are shown in Table 25.

3. Analysis of Flame Test Results

In the general evaluation of data from the Special Flame Test, those materials with the longest time rating are considered to possess the better heat resistance. With this in mind, the initial reaction to the listing in Table 25 (Times for Backside Temperature to Reach 400 Deg F) is one of surprise. The materials with known resistance to high temperatures, such as the phenolics and the polyimide, have low time intervals and are therefore rated poorly by the flame test. The polyester materials with unimpressive thermal properties are rated highest by the test.

A study of the mechanisms of the Special Flame Test showed that, when burn-through time is considered as the end point, the more heat-resistant materials rate best. However, when a 400 deg F backside temperature is used as an end point, the controlling factor in the heat transfer rate of the specimen is decomposition of the material. Those laminates with good thermal resistance that are relatively unaffected by the flame transfer the heat rapidly to the backside and require only a short time to reach the 400 deg F end point. Those materials that are decomposed, blistered, and delaminated by the flame create conditions that cause the heat to progress slowly through to the backside and require a longer time to reach 400 deg F.

TABLE 25. TIMES FOR BACKSIDE TEMPERATURE TO REACH 400 DEG F FOR 0.250-INCH THICKNESS

Material code	Material class	Time (0.250-in. thick) (400 deg F back) (seconds)	Remarks
CPH 2251	Phenolic	75	High-temperature resistant.
Epon 828	Epoxy	95	Temperature resistant.
AC	Phenolic	110	High-temperature resistant.
CE9010	Epoxy	110	Most flame-resistant epoxy system available.
5016	Polyester	115	Standard material.
506	Phenolic	115	High-temperature resistant.
GAC 30-1A	Epoxy (special)	124	Char-forming resin.
F-174	Polyimide	135	High-heat resistant.
F-120	Phenolic	140	Self-extinguishing.
F-164	Epoxy	140	Self-extinguishing.
E293 FR	Epoxy	145	Flame-resistant, Brominated.
3203	Epoxy	150	Standard material.
P604	Polyester	150	Fire resistant.
F507	Phenolic	155	Standard material.
P-49	Polyester	160	Standard material.
E293	Epoxy	170	Standard material.
X1-2556	Silicone (special)	185	Char-forming resin.
IFRR	Polyester	225	Self-extinguishing.
EX-112	Epoxy (special)	240	Char-forming resin.
E760	Epoxy	250	Fire resistant.
PE 285	Polyester	340	Standard.
AC/FG	Acrylic/fiberglass	345	Acrylic resin burns.
F-141	Polyester	470	Standard.

A comparative review of Figures 8, 9, 10, and 11 helps illustrate the condition:

1. The thermally resistant phenolics and polymide, shown in Figure 10, are the most predictable, being essentially straight line plots.

2. The epoxies, shown in Figure 9, are less predictable, but do fall within a fairly narrow band.

3. The polyesters, with low thermal resistance, shown in Figure 8, have the most scatter and are the most variable in performance.

4. The Special Resins, because of the limited sampling and unique char characteristic, are difficult to predict (Figure 11).

5. There is naturally some overlap of the various plots because within each resin family the fire resistance properties can vary noticeably. It is interesting to note that it was the most heat-resistant polyesters that performed similar to the epoxies.

Additional evidence of the heat transfer mechanism was obtained by a review of the reaction of the laminates to the flame and an analysis of the tested specimens.

Figure 12 shows the front face of four specimens which reacted differently in the flame test. Specimen AC/N burned rapidly, causing the backside to quickly reach the 400 deg F end point. The material continued to burn after the impinging flame was removed. (This specimen was fabricated for the reinforcement study and is discussed later in the report. It is included here to help illustrate a point.)

Specimen AC/FG also burned. However, in this case, only the resin burned, unlike AC/N where both resin and reinforcement

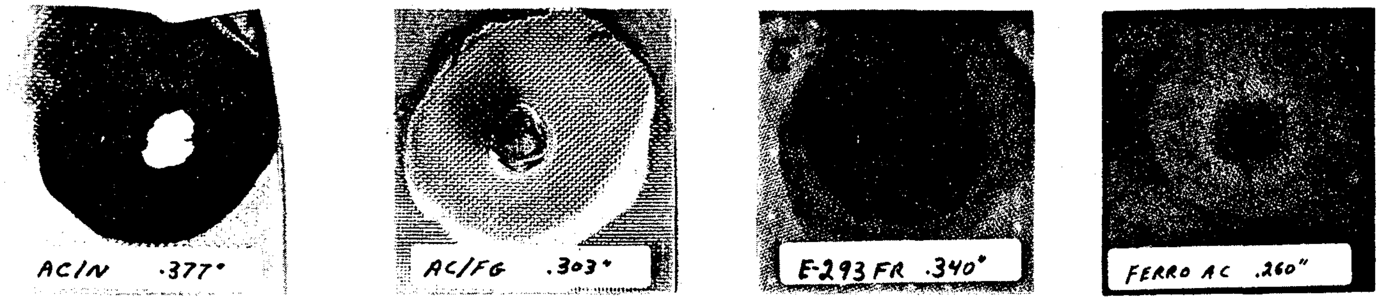

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Figure 12. Specimens Tested on the Goodyear Aerospace Flame Test - Front Face.

were flammable. In AC/FG the resin burned ply by ply, leaving dry reinforcement which started to melt before completion of the test. The heat progressed slowly through the laminate.

Specimen E-293 FR exhibited moderate resistance to the flame. The front side surface resin smoked and flamed. A sooty char was formed. Heat progressed at a fairly rapid rate through the sample.

Specimen Ferro AC was relatively unaffected by the flame test. The front side was dulled slightly. Resin loss and charring were nearly undetectable. Heat transfer was rapid.

Figure 13 shows the backside of four panels after testing. Specimen Ferro AC was least affected by the flame test. The backside shows practically no change. Heat transfer through the sample was extremely rapid.

Specimen F-174 was nearly as resistant to the flame test as Ferro AC. The backside shows a small area of discoloration. Heat transfer through the specimen was again quite rapid. Specimen CE 9010, a special heat-resistant epoxy, had a heat transfer rate in the same range as specimens F-174 and Ferro AC. The effect of the flame test was slightly more noticeable only because of increased discoloration of the light-colored resin.

Specimen PE 285 conducted the heat very slowly through the panel, yet was one of those that showed the most effect from the flame test. Considerable resin burn-out occurred, leaving a soft, powdery char. More significantly, massive delamination and blistering occurred within the specimen as the resin decomposed and outgassed. The heat required to decompose and burn the resin, coupled with the insulating air gaps caused by delamination and blistering, created a condition that drastically reduced the rate of the heat transfer through the specimen.

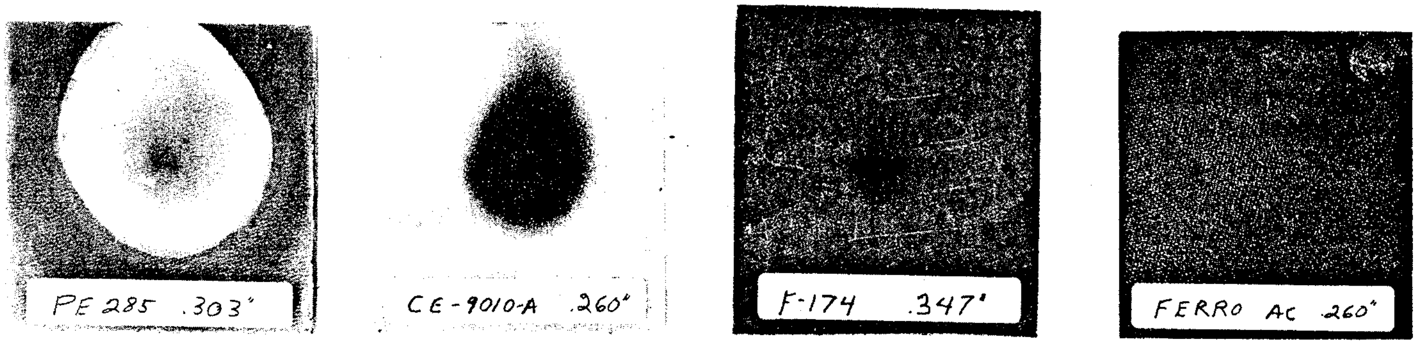

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Figure 13. Specimens Tested on the Goodyear Aerospace Flame Test - Backside.

4. Comments on Heat Transfer Rate

The analysis of the flame test results generated an important question with respect to the selection of the best resin system for fire-resistant edge attachments:

> What is the best resin choice: a heat-resistant material with high heat transfer; or, a material that transfers the heat slowly but burns, delaminates, or blisters?

It was estimated that in a crash-generated fuel fire, when the flames engulf the fuselage, a fire-resistant canopy must provide an impervious barrier lasting four to five minutes to ensure the successful rescue of the cockpit occupants.

Considering the bolt-through edge attachment designs (Figure 5), where the structural ply of the transparent composite serves as the load-bearing element between the transparency and the airframe, it is apparent that a laminated edgeband which transmitted heat so rapidly that the bolt circle failed in less than four minutes would be unsatisfactory. Regardless of how thermally resistant the edgeband material and the transparent component were, if the transparent structural ply failed at the bolt circle, the transparent enclosure would collapse.

On the other hand, an edgeband material which had a relatively low heat transfer rate, but which was seriously weakened quickly by the flames, would also be unsatisfactory. This would be especially true for configuration B in Figure 5, where the fiberglass laminate is part of the structural link between the canopy and the airframe.

It would seem that the laminated edge attachment must transfer heat slowly enough to maintain the backside temperature below

400 deg F for four to five minutes and at the same time retain a high level of strength.

As mentioned previously, the data indicated that the laminates which provided the greatest time lag before the backside temperature reached 400 deg F were those laminates in which the resin binder decomposed. The decomposition products caused the laminate to blister and delaminate. In other words, it appeared that the lower heat transfer was achieved at the sacrifice of laminate strength and integrity. It became important to know the effects of flame impingement on the strength of the laminate.

5. Effect of Flame Test on Laminate Strength.

In addition to the physical properties data collected earlier in Task 1 (as outlined in Table 13), it was considered necessary to determine the loss of strength sustained by the materials in raising the backside temperature to 400 deg F in the flame test. The primary loss of strength induced in the glass-reinforced laminates by the flame test was caused by degradation of the resinous binder. Since contribution of the binder to the strength of the laminate could best be determined by an edgewise compression test, the effect of the flame test on the strength of the laminates was measured by comparing the edgewise compressive strength of the virgin laminate versus the strength of a specimen cut from the burned area of the sample subjected to the flame test.

Edgewise compression samples were cut from the portion of the flame test specimens subjected to the most intense heat.

These "after flame test" compression specimens were tested and the results compared with the compressive strength of the virgin laminates.

Data from this test series are shown in Table 26. A column has been added showing percent strength retained. A study of the data confirms the premise that the heat-resistant materials which transfer heat rapidly retain a fair share of their strength through the flame test. Those materials which impede heat flow by decomposition lose most of their strength in the flame test. This condition is shown more clearly in Tables 27 and 28. Table 27 gives the materials a ranking according to their ability to retard heat flow through the laminate. For example, the material that required the longest time for the backside temperature to reach 400 deg F was ranked No. 1; and the materials with the shortest time were ranked at the bottom, No. 11.

Table 28 compares the ability of a material to prevent heat flow with the strength retained after completion of the flame test. The materials which retained the most strength ranked lowest in preventing heat flow.

Figure 14 presents a graphic illustration of the foregoing discussion. The cross-sections through the burn test areas of several typical materials are shown along with the rankings for strength retention and ability to prevent heat flow.

The material which seemed to show the most promise was EX-112. It retained 37.3 percent of the original strength and required 4 minutes for the backside temperature of a 0.250-in.-thick specimen to reach 400 deg F.

(4) Environmental Tests

The test plan used for the environmental evaluation is shown in Table 29. Results of the environmental study are shown in Tables 30 and 31.

Table 30 shows the effects of the environmental exposure on flexural strength of the laminates. Flexural strength was chosen because it responds to effects

TABLE 26. STRENGTH RETENTION AFTER GOODYEAR AEROSPACE FLAME TEST

Code	Material	Original edgewise compression strength (PSI)	Edgewise compression strength after flame testing (PSI)	Percent strength retained
F174	Polyimide	21,399	10,370	48.5
AC	Phenolic	54,091	25,439	47.0
EX-112	Special epoxy	66,410	24,764	37.3
F120	Phenolic	68,493	24,803	36.2
E293	Epoxy	69,750	21,649	31.0
E293FR	Epoxy (additive)	68,460	18,750	27.4
X1-2556	Special silicone	15,189	3,224	21.2
CE9010	Epoxy	88,116	9,191	10.4
PE285	Polyester	65,057	5,793	8.9
IFRR	Polyester	59,570	4,247	7.1
AC/FG	Acrylic/ fiberglass	37,733	1,225	3.2
F-141	Polyester	78,093	1,975	2.5

TABLE 27. TIMES FOR BACKSIDE TEMPERATURE TO REACH 400 DEG F - ESTIMATED FOR 0.250-INCH THICKNESS

Material code	Material class	0.250-in.-thick specimen: time for backside to reach 400 deg F (seconds)	Ranking for preventing heat flow
F-141	Polyester	470	1
AC/FG	Acrylic/fiberglass	345	2
PE285	Polyester	340	3
EX-112	Epoxy (special)	240	4
IFRR	Polyester	225	5
XI-2556	Silicone (special)	185	6
E293	Epoxy	170	7
E293FR	Epoxy (additive)	145	8
F-120	Phenolic	140	9
F-174	Polyimide	135	10
CE9010	Epoxy	110	11
AC	Phenolic	110	11

TABLE 28. STRENGTH RETENTION AFTER GOODYEAR AEROSPACE FLAME TEST COMPARED TO ABILITY TO PREVENT HEAT FLOW

Code	Material	Percent strength retained	Ranking for preventing heat flow
F174	Polyimide	48.5	10
AC	Phenolic	47.0	11
EX-112	Special epoxy	37.3	4
F120	Phenolic	36.2	9
E293	Epoxy	31.0	7
E293FR	Epoxy (additive)	27.4	8
X1-2556	Special silicone	21.2	6
CE9010	Epoxy	10.4	11
PE285	Polyester	8.9	3
IFRR	Polyester	7.1	5
AC/FG	Acrylic/fiberglass	3.2	2
F-141	Polyester	2.5	1

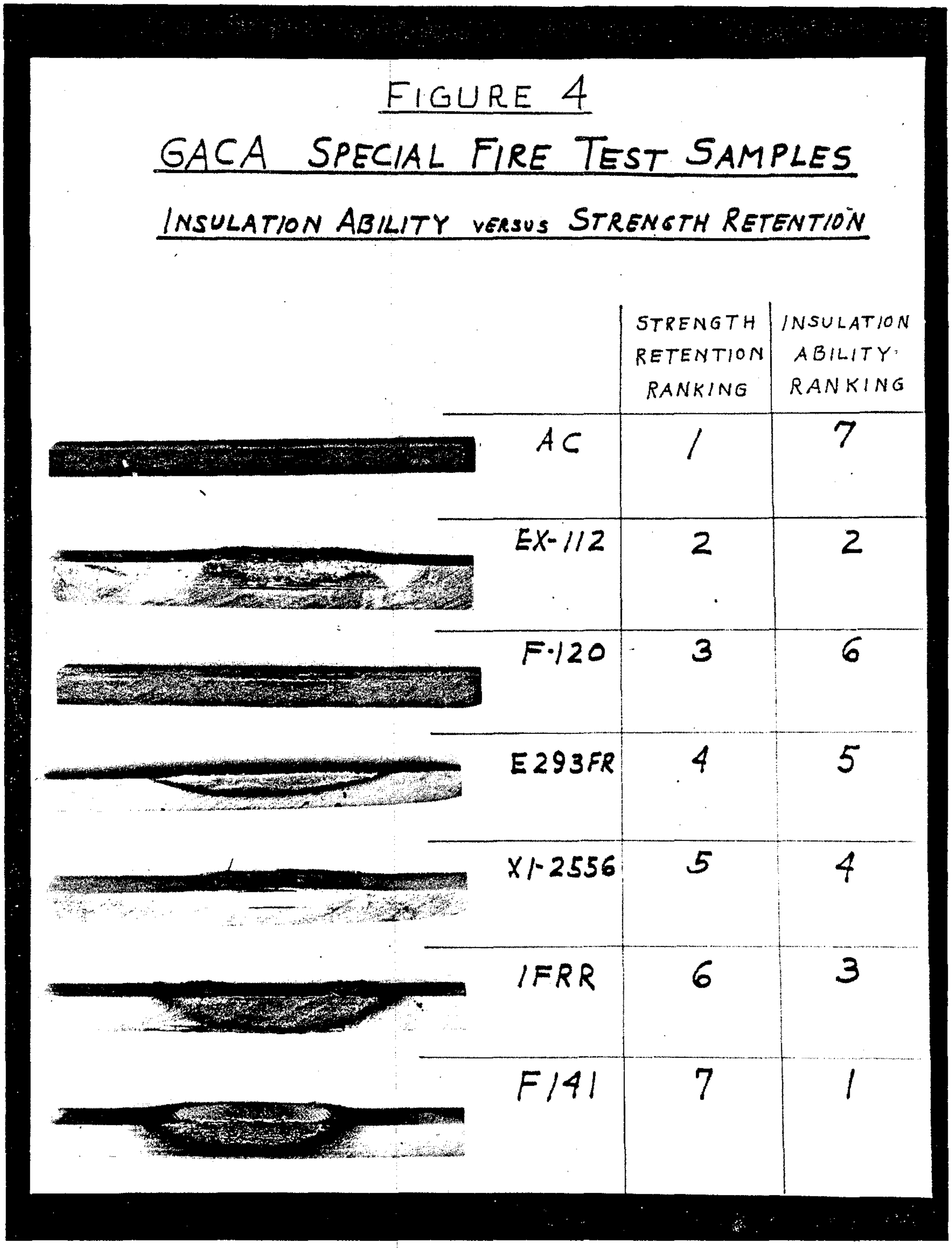

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Figure 14. Goodyear Aerospace Special Flame Test Samples - Insulation Ability versus Strength Retention.

TABLE 29. PROGRAM TO DETERMINE ENVIRONMENTAL RESISTANCE OF THE EDGE ATTACHMENT LAMINATES

Type of test	Test method	Evaluation
Humidity	48 hr/120 deg F/ 95-percent relative humidity	Rerun flexural test and special flame test.
Thermal aging	MIL-STD-810C, Method 501.1, Procedure 1 (48 hr at 160 deg F)	
Ultraviolet radiation	FTMS No. 406, Method 6024 (10-day duration)	

TABLE 30. EFFECT OF ENVIRONMENTAL EXPOSURE ON FLEXURAL STRENGTH

Material code	Material type	Original flexural strength (PSI)	Flexural strength after environmental exposure (PSI)	Change (percent)
CE9010	Epoxy	95,996	95,154	-0.8
E293FR	Epoxy (additive)	73,800	75,964	+2.9
E293	Epoxy	67,701	72,411	+7.0
F-141	Polyester	66,661	70,102	+5.2
AC	Phenolic	61,740	64,412	+4.3
F120	Phenolic	61,563	63,658	+3.4
F164	Epoxy	61,277	61,320	+0.1
IFRR	Polyester	59,743	61,615	+3.1
PE285	Polyester	55,604	63,950	+15.0
EX-112	Special epoxy	49,032	44,152	-10.0
AC/FG	Acrylic/fiberglass	38,186	42,000	+10.0
F174	Polyimide	12,579	12,427	-1.2
X1-2556	Special silicone	9,900	16,320	+64.9

TABLE 31. EFFECT OF ENVIRONMENTAL EXPOSURE ON FLAME RESISTANCE (GOODYEAR AEROSPACE SPECIAL FLAME TEST)

Material code	Material type	Thickness (in.)	Time for backside temperature to reach 400 deg F (seconds)	Reaction during test	Appearance after test	Estimated time for backside temperature to reach 400 deg F for 0.250-in. thickness	
						Material before environmental test	Material after environmental test
AC	Phenolic	0.256	101	No smoke-no flame.	Front: 3/4-in.-diameter rough surface. Back: no change.	110	105
F-120	Phenolic	0.307	146	No smoke-no flame.	Front: 1-1/4-in.-diameter black area; 1-in.-diameter partial resin burn-out. Back: no change.	140	120
F-174	Polyimide	0.326	176	Slight smoke-no flame.	Front: 1-1/2-in.-diameter resin burn-out. Back: 1-in.-diameter slightly brown area.	135	130
E293FR	Epoxy	0.340	185	Smoke-flames. Required extinguishing.	Front: 2-1/2-in.-diameter black area; 1-in.-diameter partial resin burn-out.	145	130

TABLE 31. EFFECT OF ENVIRONMENTAL EXPOSURE ON FLAME RESISTANCE (GOODYEAR AEROSPACE SPECIAL FLAME TEST) (CONT)

Material code	Material type	Thickness (in.)	Time for backside temperature to reach 400 deg F (seconds)	Reaction during test	Appearance after test	Estimated time for backside temperature to reach 400 deg F for 0.250-in. thickness	
						Material before environmental test	Material after environmental test
					Back: 1-1/2-in.-diameter brown area.		
CE9010	Epoxy	0.261	121	Light white smoke.	Front: 2-1/2-in. diameter black area; 3/4-in.-diameter partial resin burn-out. Back: 1-3/4-in. diameter brown area with 3/4-in. diameter black area.	110	110
F164	Epoxy	0.296	201	Smoke-flames. Required extinguishing.	Front: 2-1/2-in. diameter black area; 1-in.-diameter partial resin burn-out. Surface cracks. Blistered. Back: 1-1/4-in.-diameter brown area.	100	115

TABLE 31. EFFECT OF ENVIRONMENTAL EXPOSURE ON FLAME RESISTANCE (GOODYEAR AEROSPACE SPECIAL FLAME TEST) (CONT)

Material code	Material type	Thickness (in.)	Time for backside temperature to reach 400 deg F (seconds)	Reaction during test	Appearance after test	Estimated time for backside temperature to reach 400 deg F for 0.250-in. thickness	
						Material before environmental test	Material after environmental test
IFRR	Polyester	0.327	464	Light white smoke.	Front: 2-1/2-in.-diameter black area; 1-1/4-in.-diameter resin burn-out. Back: 3/4-in.-diameter black area; 1-1/4-in.-diameter brown area; blistered.	225	220
PE285	Polyester	0.340	368	Medium blue smoke-flames.	Front: 3-in.-diameter brown-black area; 1-in.-diameter resin burn-out. Back: 2-1/2-in.-diameter delamination.	340	225
F-141	Polyester	0.315	842	Light white smoke-flames.	Front: 3-in.-diameter black area; 1-1/4-in.-diameter resin burn-out. Back: 2-in.-diameter blistered/delaminated.	470	470

TABLE 31. EFFECT OF ENVIRONMENTAL EXPOSURE ON FLAME RESISTANCE (GOODYEAR AEROSPACE SPECIAL FLAME TEST) (CONT)

Material code	Material type	Thickness (in.)	Time for backside temperature to reach 400 deg F (seconds)	Reaction during test	Appearance after test	Estimated time for backside temperature to reach 400 deg F for 0.250-in. thickness: Material before environmental test	Estimated time for backside temperature to reach 400 deg F for 0.250-in. thickness: Material after environmental test
EX-112	Special epoxy	0.422	854	Medium white smoke-flames-popping noise.	Front: 4-in.-diameter black area; 3/4-in.-diameter resin burn-out; small surface cracks. Back: 3-in.-diameter slight discoloration.	240	300
X1-2556	Special silicone	0.311	249	Little smoke-flames. Required extinguishing.	Front: 3-in.-diameter black area; 1-in.-diameter surface cracks/blisters; some resin burn-out. Back: minor blistering.	185	175
E-293	Epoxy	0.391	344	Smoke-flames. Required extinguishing.	Front: 2-1/2-in.-diameter black area; 1-in.-diameter partial resin burn-out. Back: no change.	170	165

TABLE 31. EFFECT OF ENVIRONMENTAL EXPOSURE ON FLAME RESISTANCE (GOODYEAR AEROSPACE SPECIAL FLAME TEST) (CONT)

Material code	Material type	Thickness (in.)	Time for backside temperature to reach 400 deg F (seconds)	Reaction during test	Appearance after test	Estimated time for backside temperature to reach 400 deg F for 0.250-in. thickness	
						Material before environmental test	Material after environmental test
AC/FG	Acrylic/ fiberglass	0.305	724	Vigorous burning. Required extinguishing.	Front: 3-1/2-in.-diameter total resin burn-out. Back: 2-in.-diameter area of melted resin.	345	415

on the resin binder, the reinforcement, and the bond between them. Most of the laminates showed a slight increase in strength, which indicated the environmental exposure provided some additional cure to the resin binder. The large increase in strength developed by the X1-2556 laminate was somewhat surprising. Earlier work with the X1-2556 system had shown that a postcure was necessary. The laminate used in this study had been subjected to a postcure. The strength increase caused by the environmental exposure indicates the postcure schedule could have been extended. However, the earlier work had also indicated that the char forming capability and the resistance to intense thermal radiation was affected very little by a prolonged postcure. The results of the flame test on the X1-2556 laminate are therefore valid.

Table 31 presents data showing the effect of the environmental exposure on flame resistance as determined by the Special Flame Test. A review of Table 31 shows the data to be quite consistent. A comparison of the times for the backside temperature to reach 400 deg F indicates the environmental exposure had little effect on the flame resistance.

The few materials which registered a noticeable change in flame resistance - PE 285, EX-112, and AC/FG - are materials which undergo decomposition (combustion, delamination, and blistering) when exposed to the flame. This reaction to the flame can be expected to be nonuniform and unpredictable. The results of the environmental study showed that the laminates tested were not degraded by exposure to the various accelerated environmental tests.

g. Task 1 Summary

During the Task 1 effort, it was determined that the type of resin had an influence on the performance of a fiberglass laminate subjected to an intense flame. The type of resin rather than any specific resin was the most important factor, as discussed in the following paragraphs:

1. Thermally stable resins, affected little by the flames, experienced rapid heat transfer, raising backside temperatures to 400 deg F quickly. This resin group included mainly the phenolics and polyimides.

2. Resins that had little thermal stability - that decomposed, burned, and softened - transfered heat relatively slowly through the laminate. However, the delamination, blistering, and burning that helped keep backside temperatures from rising steeply, caused a rapid, drastic reduction in useful strength. This material group was generally the polyesters.

3. The epoxies - which have moderate thermal resistance - fell somewhere between the polyesters and phenolics in performance in a flame test. There was some overlap, of course, between resin families, depending on thermal stability.

4. The special resins had some of the better features of all the groups. The EX-112 laminate was considered to have the best compromise features.

All laminates tested had physical properties that were adequate and adaptable for use as aircraft transparency edge attachment materials.

All prepreg systems and the standard wet layup resins were processed satisfactorily and produced acceptable laminates.

The special resins were somewhat difficult to handle because of high viscosity and short working life. Efficient processing techniques were developed and fully acceptable laminates prepared.

The environmental test series had no noticeable effect on the physical or thermal performance of the laminates tested.

h. Selection of Resins for Task 2

The selection of the best resin for Task 2, based on the Task 1 data, was complicated by consideration of the possible failure modes for the edge attachment of a canopy enveloped in flames.

The thermally resistant edge laminates with rapid heat transfer could fail because of overheating and softening of the transparent material beneath the edge attachment. The edge laminates which delaminate and blister could fail from loss of strength. A compromise between these two extremes also might not be the optimum solution.

Another consideration dealt with the thermal test.

The Special Flame Test is valuable as a comparative tool but may not relate to the real world of an aviation fuel fire. It was realized that the actual performance and validity of any of the edge attachment constructions would have to be determined in Task 4 by the NASA - Ames T-3 Fire Test.

With these considerations in mind, it was decided to use four different resins in Task 2:

1. Epon 828 - a thermally stable resin
2. Paraplex P-49 - polyester resin with limited thermal resistance
3. GAC 30-1A - special char-forming resin
4. C-715A - a flammable acrylic resin used for a control.

These were all wet layup liquid resins. This process was required because the reinforcements to be studied were in the form of woven fabrics.

3. TASK 2 - REINFORCEMENT STUDY

a. General

Five types of reinforcements were compared in the Task 2 study:

Fiberglass
Nylon
Orlon
Dacron
Carbon.

All reinforcements were in the form of woven fabrics to simplify the preparation of laminates and to provide a standard base for the comparison testing.

Four types of resins were used as binders. As discussed at the conclusion of Task 1, the decision to use four different resins was made because it had been determined that the type of resin had a considerable influence on the performance of the laminate in the Special Flame Test. The resins selected were:

Paraplex P-49	Polyester
Epon 828	Epoxy
C-715A	Acrylic
GAC 30-1A	Special epoxy

b. Preparation of Laminates

The following laminates were prepared for evaluation in Task 2:

1. Polyester:

   P-49/fiberglass
   P-49/nylon
   P-49/Orlon
   P-49/Dacron
   P-49/carbon

   Processing information on the P-49 polyester resin laminates is presented in Table 32.

2. Epoxy:

   Epon 828/fiberglass
   Epon 828/Orlon

   Processing information on the Epon 828 epoxy resin laminates is presented in Table 33.

3. Special Epoxy:

   GAC 30-1A/fiberglass
   GAC 30-1A/nylon

   Processing information on the GAC 30-1A special resin laminates is presented in Table 34.

TABLE 32. PROCESSING INFORMATION - P-49 RESIN SYSTEM

Processing conditions	P-49/fiberglass	P-49/nylon
Catalyst (resin/catalyst ratio)	Benzoyl peroxide (100/1.6)	Benzoyl peroxide (100/1.6)
Handling characteristics	Fair	Good
Number of plies in layup	25	11
Type of cure	Press	Press
Cure schedule	Spread resin on glass cloth two plies at a time. Paddled out excess resin and air. Placed layup in cold press. Closed to stops. Cured at 240 deg F for 90 minutes. Cooled under pressure; no postcure required.	Spread resin on nylon cloth two plies at a time. Paddled out excess resin and air. Placed layup in cold press. Closed to stops. Cured at 240 deg F for 90 minutes. Cooled under pressure; no postcure required.
Appearance	Poor* Light green Opaque Dense	Good Creamy tan Opaque Dense

*Wet plies slipped when the press was closed. Laminate nonuniform. Center portion only was usable.

TABLE 32. PROCESSING INFORMATION - P-49 RESIN SYSTEM (CONT)

Processing conditions	P-49/Orlon	P-49/Dacron
Catalyst (resin/catalyst ratio)	Benzoyl peroxide (100/1.6)	Benzoyl peroxide (100/1.6)
Handling characteristics	Good	Fair
Number of plies in layup	12	50
Type of cure	Press	Press
Cure schedule	Spread resin on orlon fabric one ply at a time. Paddled out excess resin and air. Placed layup in cold press. Closed to stops. Cured at 240 deg F for 90 minutes. Cooled under pressure; no postcure required.	Spread resin on Dacron fabric two plies at a time. Paddled out excess resin and air. Placed layup in cold press. Closed to stops. Cured at 240 deg F for 90 minutes. Cooled under pressure; no postcure required.
Appearance	Poor* Creamy tan Opaque Dense	Poor** Cream color Opaque Dense

*Both surfaces badly wrinkled.
**Wet plies slipped when press was closed. Laminate nonuniform. Center portion usable.

TABLE 32. PROCESSING INFORMATION - P-49 RESIN SYSTEM (CONT)

Processing conditions	P-49/carbon cloth***
Catalyst (resin/catalyst ratio)	Benzoyl peroxide (100/1.6)
Handling characteristics	Poor - cloth unraveled, slipped, distorted.
Number of plies	13
Type of cure	Press
Cure schedule	Impregnated carbon cloth - one ply at a time. Surrounded laminate with resilient foam dams and sealed in a press bag. Placed layup in cold press and closed slowly to stops. Raised platen temperature to 240 deg F. Cured laminate for 90 minutes. Cooled under pressure.
Appearance	Good - some slippage of plies in the press. Black color. Opaque. Dense.

***Reinforcement data:
Carbon cloth designation: "Thornel" Type P
Fabric grade: VCB-45
Weave: 8 harness satin weave
Thickness: 0.019 inch.

TABLE 33. PROCESSING INFORMATION - EPON 828 RESIN SYSTEM

Processing conditions	Epon 828/Orlon	Epon 828/fiberglass
Catalyst (resin/catalyst ratio)	Versamid 125 (60/40)	Versamid 125 (60/40)
Handling characteristics	Good	Fair
Number of plies in layup	14	25
Type of cure	Press	Press
Cure schedule	Spread resin on Orlon cloth one ply at a time. Placed layup in cold press. Raised temperature to 150 deg F. Closed press slowly to stops. Increased temperature to 300 deg F. Cured at 300 deg F for 90 minutes. Cooled under pressure. No postcure required.	Placed in 150 deg F press. Closed to contact pressure. When resin thinned out and flowed, closed press to 0.250-in. shims. Raised temperature to 300 deg F. Cured 1-1/2 hr. Cooled under pressure.
Appearance	Excellent Light tan Opaque Dense	Excellent (center*) Amber-green Translucent Dense

*Resin did not flow completely to corners of laminate.

TABLE 34. PROCESSING INFORMATION - GAC 30-1A RESIN SYSTEM

Processing conditions	GAC 30-1A/fiberglass	GAC 30-1A/nylon
Catalyst	Special system	Special system
Handling characteristics	Fair	Good
Number of plies in layup	24	11
Type of cure	Press	Press
Cure schedule	Impregnated cloth two plies at a time. Placed in room temperature press. Closed press to 0.250-in. shims. Heated to 250 deg F. Cured 1 hr. Cooled under pressure.	Spread resin on nylon fabric two plies at a time. Placed layup in cold press. Raised platen temperature to 200 deg F. Closed press slowly to stops. As soon as press was closed, shut off heat. Cooled platens to 100 deg F. Let resin gel. After gel, temperature was increased to 250 deg F. Resin flow noted. Cured at 250 deg F for 90 minutes. Cooled under pressure. No postcure required.
Appearance	Fair Grayish-green Slightly translucent Dense Surfaces slightly dry	Good Cream color Opaque Dense

4. Acrylic:

C-715A/fiberglass
C-715A/nylon
C-715A/Orlon

Processing information on the C-715A acrylic resin laminates is presented in Table 35.

c. Evaluation

(1) General

Edge attachments with organic reinforcements (nylon, Orlon, Dacron) are used extensively on the transparent enclosures of a number of current aircraft. The binder resin is generally acrylic; however, other resin systems are feasible and are utilized.

Since the primary consideration for the contract was resistance to intense thermal radiation, all Task 2 laminates were evaluated for fire resistance by means of the Goodyear Aerospace Special Flame Test.

Only limited testing was conducted on other properties. For evaluation of physical properties and environmental resistance, the acrylic laminates were selected as a representative series. Data on the acrylic laminates established comparative performance values for the various reinforcements.

The carbon cloth reinforcement was included in the program to determine if any advantages in fire resistance could be realized by high-strength, high-temperature, high-modulus fibers.

(2) Flame Test Evaluation

(a) Test Results

The Task 2 laminates were evaluated for fire resistance by use of the Goodyear Aerospace Special Flame Test Unit. Results of the flame tests are presented in Table 36. The P-49 laminate series after testing is shown in Figure 15.

TABLE 35. PROCESSING INFORMATION - C-715A RESIN SYSTEM*

Processing conditions	C-715A/fiberglass	C-715A/nylon	C-715A/Orlon
Catalyst	Special system		
Handling characteristics	Good		
Number of plies in layup	Ply count depended on thickness of production laminates. See below under Cure Schedule.		
Type of cure	Press		
Cure schedule	Four- to six-ply GAC production laminates used. Production laminates measured for thickness; selection was made to produce desired panel thickness. Bonding surfaces sanded to remove glaze. Surfaces coated with C-715A resin. Plies stacked; covered with press bag. Placed in room temperature press; pressured to 3-4 PSI to squeeze out resin. Press heated to 125-150 deg F. Cure continued until squeeze-out resin had hardened.		
Appearance	Excellent Translucent Dense Color: C715A/fiberglass - light green C715A/nylon - light tan C715A/Orlon - off-white		

*All C-715A acrylic laminates were processed in the same way.

TABLE 36. RESULTS FROM GOODYEAR AEROSPACE SPECIAL FLAME TEST

Material		Thickness (inches)	Time for backside temperature to reach 400 deg F (seconds)	Remarks	
Code	Type			During test	After test
P-49/FG	Polyester/ fiberglass	0.281	236	Burning-yellow flame. Light white smoke. Required extinguishing.	Front: 2-1/2-in.-diameter resin burn-out. Back: no change.
P-49/N	Polyester/ nylon	0.245	105	Burning-bright yellow flame. Light to medium white smoke. Required extinguishing.	Front: black melt residue. Burn-through 1/2-in.-diameter hole. 2-1/2-in.-diameter char area. Back: hole from burn-through; otherwise no change.
P-49/O	Polyester/ Orlon	0.245	136	Burning-bright yellow flame. Char buildup. White smoke. Required extinguishing.	Front: 2-1/2-in.-diameter char area. Back: 1-in.-diameter char area. Specimen split from char area to top.
P-49/D	Polyester/ Dacron	0.270	113	Bright vigorous flame. Dense black	Front: 3-in.-diameter cone to 1/2-in.-diameter hole.

TABLE 36. RESULTS FROM GOODYEAR AEROSPACE SPECIAL FLAME TEST (CONT)

Material		Thickness (inches)	Time for backside temperature to reach 400 deg F (seconds)	Remarks	
Code	Type			During test	After test
				smoke. Black melted residue. Required extinguishing.	Back: no change except hole.
P-49/C	Polyester/ carbon	0.239	191	Light flame. No smoke. Heavy smoke after 1-1/2 minutes. Required extinguishing.	Front: resin burn-out in 3-in.-diameter area. Carbon fibers intact. Back: no change.
GAC 30-1A/FG	Special epoxy/ fiberglass	0.249	124	Medium white smoke when flame was removed. Required extinguishing.	Front: 2-1/2-in.-diameter dark area. Small cracks at center. Back: 1-1/2-in.-diameter light brown area. No blistering.
GAC 30-1A/N	Special epoxy/ nylon	0.243	428	Heavy white smoke. Extreme warping of specimen.	Front: black face. Large char cone-hollow. 3/8-in.-diameter hole. Back: 3/4-in.-diameter dark area. 3/8-in.-diameter melt spot

TABLE 36. RESULTS FROM GOODYEAR AEROSPACE SPECIAL FLAME TEST (CONT)

Material		Thickness (inches)	Time for backside temperature to reach 400 deg F (seconds)	Remarks	
Code	Type			During test	After test
					where thermocouple made contact.
AC/FG	Acrylic/ fiberglass	0.303	600	Smoke-flames. Reinforcement glowing and melting.	Front: considerable resin burn-out. Surface glass plies melted. Back: resin burn-out. Glass reinforcement exposed.
AC/N	Acrylic/ nylon	0.377	120	Smoke-flames. Required extinguishing.	Front: hole burned completely through specimen. Heavy char. Back: hole-some char.
AC/O	Acrylic/ Orlon	0.344	157	Smoke-flames. Required extinguishing.	Front: hole burned completely through specimen. Black char. Back: hole-some char.
Epon 828/FG	Epoxy/ fiberglass	0.242	90	Medium gray smoke. Burning. Required extinguishing.	Front: 2-1/2-in.-diameter burned area. 1-in.-diameter resin burn-out. Small cracks. Back: 2-1/2-in.-diameter dark area. No blisters.

TABLE 36. RESULTS FROM GOODYEAR AEROSPACE SPECIAL FLAME TEST (CONT)

Material		Thickness (inches)	Time for backside temperature to reach 400 deg F (seconds)	Remarks	
Code	Type			During test	After test
Epon 828/0	Epoxy/ Orlon	0.245	136	Vigorous flames. Medium black smoke. Required extinguishing.	Front: several cracks burned deep into sample. Back: front side cracks had formed ridges on back of panel.

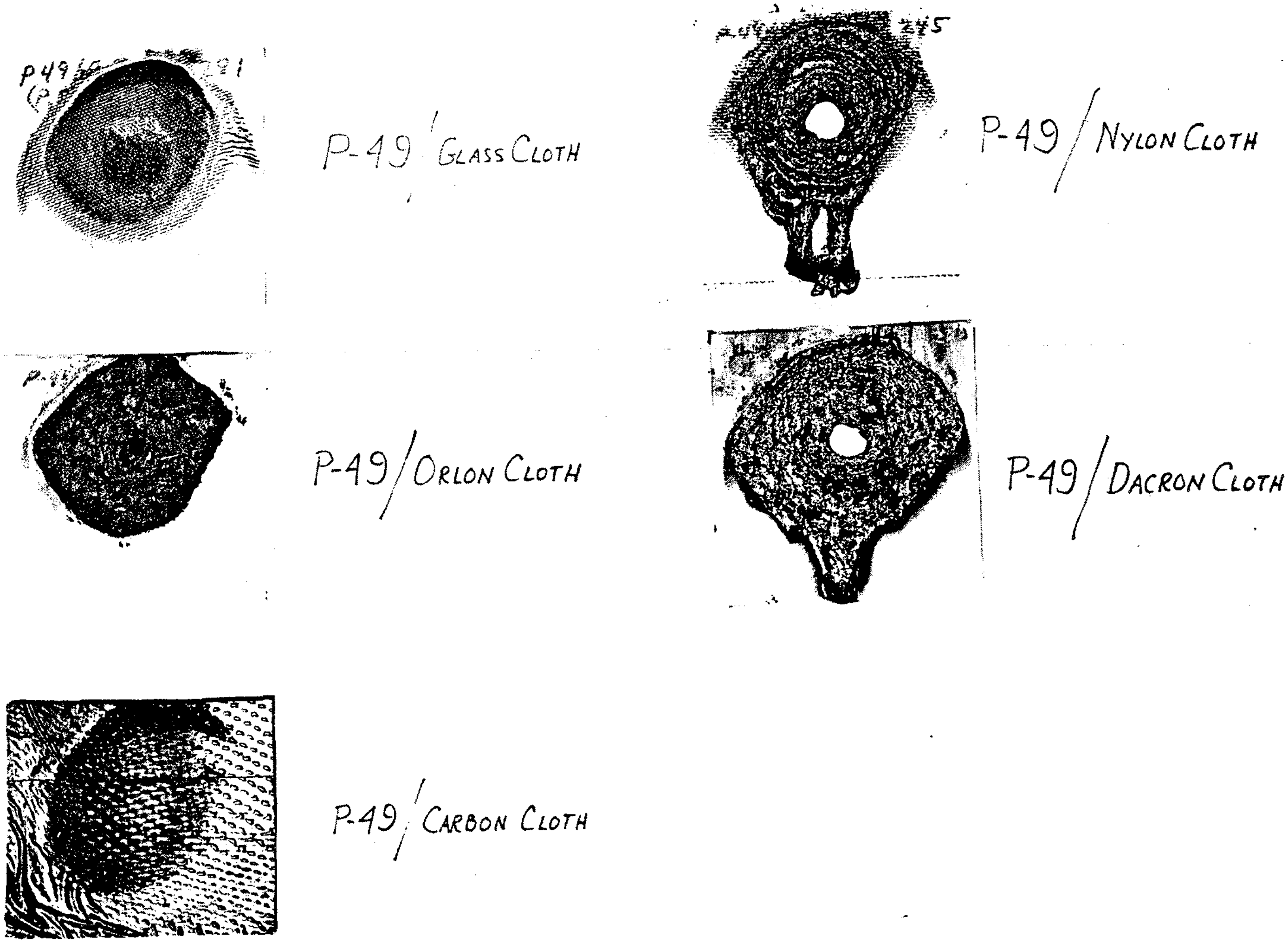

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Figure 15. Specimens after Testing by the Goodyear Aerospace Special Flame Tester.

Table 37 shows the estimated times for a 0.250-inch-thick specimen of each laminate to reach 400 deg F on the backside.

The reaction of each bare reinforcement to intense flame was also determined:

> Fiberglass - Glowed red. Did not burn. Melted slowly.
>
> Nylon - Burned while in flame. Extinguished when flame was removed. Melted rapidly. Dripped - formed strings.
>
> Orlon - Flamed quickly and easily. Continued to burn when the flame was removed. Melted-dripped.

TABLE 37. TASK 2 LAMINATES: TIMES FOR BACKSIDE TEMPERATURE TO REACH 400 DEG F FOR 0.250-INCH THICKNESS

Material code	Material type	Time in seconds (400 deg F backside - 0.250 in. thick)
AC/N	Acrylic/nylon	80
828/FG	Epoxy/fiberglass	93
P-49/D	Polyester/Dacron	105
P-49/N	Polyester/nylon	107
AC/O	Acrylic/Orlon	114
30-1A/FG	Special resin/fiberglass	124
828/O	Epoxy/Orlon	139
P-49/O	Polyester/Orlon	139
P-49/FG	Polyester/fiberglass	200
P-49/C	Polyester/carbon	205
30-1A/N	Special resin/nylon	440
AC/FG	Acrylic/fiberglass	495

<u>Dacron</u> - Flamed quickly and easily. Continued to burn when the flame was removed. Melted-dripped.

<u>Carbon</u> - Glowed red. Did not burn. Did not melt.

(b) Comments on Flame Test Results

As indicated by the data in Table 36 and the visual appearance in Figure 15, the reinforcement made a noticeable difference in the performance of the laminates in the flame test.

Observations during the flame tests, examination of the tested specimens, and analysis of the data resulted in this conclusion: organic reinforcements are not feasible in edge attachment laminated for flame-resistant aircraft transparent enclosures.

The organic reinforcements tested in this program (nylon, Orlon, Dacron) had several deficiencies:

1. They supported combustion
2. They softened under moderate heat
3. They charred, melted, and decomposed under intense heat.

These deficiencies essentially negated the use of those reinforcements in laminates subjected to intense flame.

The P-49/carbon laminate performed in the flame test as a typical polyester laminate composed from an inert reinforcement and a moderately thermal-resistant resin. The estimated time for the backside temperature of a 0.250-inch-thick P-49/carbon laminate to reach 400 deg F in the Special Flame Test was 205 seconds. This compared closely with the time of 200 seconds for a 0.250-inch-thick P-49/fiberglass cloth laminate.

The carbon cloth reinforcement offered no advantage with respect to flame resistance over fiberglass cloth reinforcement. The carbon cloth would provide higher strength, greater stiffness, and somewhat lighter weight. Fiberglass cloth, on the other hand, has adequate strength and stiffness. Fiberglass is also less expensive, more available, and easier to handle.

(c) ASTM D635 Flammability Test

The acrylic series of Task 2 laminates were subjected to the ASTM D635 flammability test. The results are shown in Table 38. As expected, all three laminates had relatively high burning rates.

(3) Physical Properties

Physical properties were determined on the acrylic series Task 2 laminates. Results of the tests are shown in Table 39.

TABLE 38. FLAMMABILITY TEST - ASTM D635

Sample code	Sample thickness (in.)	Total burning time (minutes)	Time of burning t-30 (seconds)	Extent of burning (mm)	Burning rate (cm/minute)	Remarks
AC/O	0.344	4.93	266	100	2.26	Maintain a steady flame and rate of burn.
AC/N	0.381	6.05	333	100	1.80	Maintain a steady flame and rate of burn.
AC/FG	0.301	7.30	408	100	1.47	Maintain a steady flame and rate of burn; complete resin burn-out.

TABLE 39. PHYSICAL PROPERTIES: TASK 2 ACRYLIC LAMINATES

Material code	Tensile strength			
	Material type	Room temperature tensile ultimate	300 deg F tensile ultimate	Percent strength retained
AC/FG	Acrylic/fiberglass	27,742	3,332	12.0
AC/N	Acrylic/nylon	13,408	1,602	11.9
AC/O	Acrylic/Orlon	6,956	366	5.3

Material code	Flexural strength			
	Material type	Room temperature flexural strength	300 deg F flexural strength	Percent strength retained
AC/FG	Acrylic/fiberglass	38,186	600	1.6
AC/N	Acrylic/nylon	16,216	280	1.7
AC/O	Acrylic/Orlon	15,611	98	0.6

Code	Edgewise compression strength	
	Material	Edgewise compression (PSI)
AC/FG	Acrylic/fiberglass	37,733
AC/N	Acrylic/nylon	35,183
AC/O	Acrylic/Orlon	26,361

Code	Shore D hardness			
	Material	Process	Cure	Shore D
AC/FG	Acrylic/fiberglass	Secondary bond	Press	88-90
AC/N	Acrylic/nylon	Secondary bond	Press	84-85
AC/O	Acrylic/Orlon	Secondary bond	Press	87-88

The strength factors of the nylon and Orlon laminates are lower than those of the fiberglass laminate, but still adequate for transparency edge attachments in a moderate temperature environment. None of the acrylic laminates has sufficient high-temperature strength for use in a structural capacity at 300 deg F.

The organic reinforcements are softened by heat, which limits their use to a moderate temperature range.

The strength retained by the Task 2 acrylic laminates after testing by the Special Flame Test is shown by Table 40. The organic reinforcements burn through during the test, completely destroying the laminate in the flame area (see Figure 15).

(4) Environmental

The Task 2 acrylic laminates were subjected to the environmental exposure program outlined in Table 29. The results of the environmental study are shown in Table 41.

TABLE 40. TASK 2 ACRYLIC LAMINATES - STRENGTH RETENTION AFTER GOODYEAR AEROSPACE SPECIAL FLAME TEST

Code	Material	Original edgewise compression strength (PSI)	Edgewise compression strength after flame testing (PSI)	Percent strength retained
AC/FG	Acrylic/fiberglass	37,733	1,225	3.2
AC/N	Acrylic/nylon	35,183	0*	0
AC/O	Acrylic/Orlon	26,361	0*	0

*These specimens were burned through during the test.

TABLE 41. ENVIRONMENTAL STUDY: TASK 2 ACRYLIC LAMINATES

Effect of environmental exposure on flexural strength

Material code	Material type	Original flexural strength (PSI)	Flexural strength after environmental exposure (PSI)	Change (percent)
AC/FG	Acrylic/fiberglass	38,186	42,000	+10.0
AC/N	Acrylic/nylon	16,216	18,888	+16.5
AC/O	Acrylic/Orlon	15,611	15,356	-1.6

Effect of environmental exposure on flame resistance
(Goodyear Aerospace Special Flame Test)

Material code	Material type	Thickness (in.)	Time for backside temperature to reach 400 deg F (seconds)	Reaction during test	Appearance after test	Estimated time for backside temperature to reach 400 deg F for 0.250-in. thickness	
						Material before environmental test	Material after environmental test
AC/FG	Acrylic/ fiberglass	0.305	724	Vigorous burning. Required extinguishing.	Front: 3-1/2-in. diameter total resin burn-out. Back: 2-in.-diameter area of melted resin.	345	415
AC/N	Acrylic/ nylon	0.380	180*	Vigorous burning. Light white smoke. Required extinguishing.	Front: 3-in.-diameter black indented cone; 0.292 in. deep. Back: no change.	66	100

*Thermocouple failed. Time estimated.

As expected, the environmental exposure series had no adverse effect on the laminates.

(5) Summary

Analysis of the data generated in Task 2 leads firmly to a basic conclusion: The preferred reinforcement for edge attachments for fire-resistant canopies is woven fiberglass cloth.

4. TASK 3 - DESIGN STUDY

a. General

The concluding and decisive evaluation test series for this contract was scheduled for the NASA-Ames Research Center T-3 Fire Test Facility. The purpose of Task 3, therefore, was to select a practical design for the specimens to be tested in the T-3 facility.

The test specimens had to simulate the actual anticipated construction for flyable, practical, fire-resistant canopies.

b. Design Considerations

(1) Transparent Composite

The configuration for the fire-resistant transparent composite had been established by the NASA Ames Research Center Chemical Research Project Office during a previous contract in 1977 and 1978. The composite structure selected for that contract (NASA Purchase Order No. A45309B) was as follows:

0.080 in. outer ply of acrylic
0.320 in. EX 112 ply directly bonded to acrylic
0.050 in. of silicone interlayer
0.250 in. of polycarbonate structural ply.

This laminate configuration gave a total thickness of 0.700 in. This configuration is shown pictorially in Figure 16, and was used in the test specimens for the T-3 Fire Test.

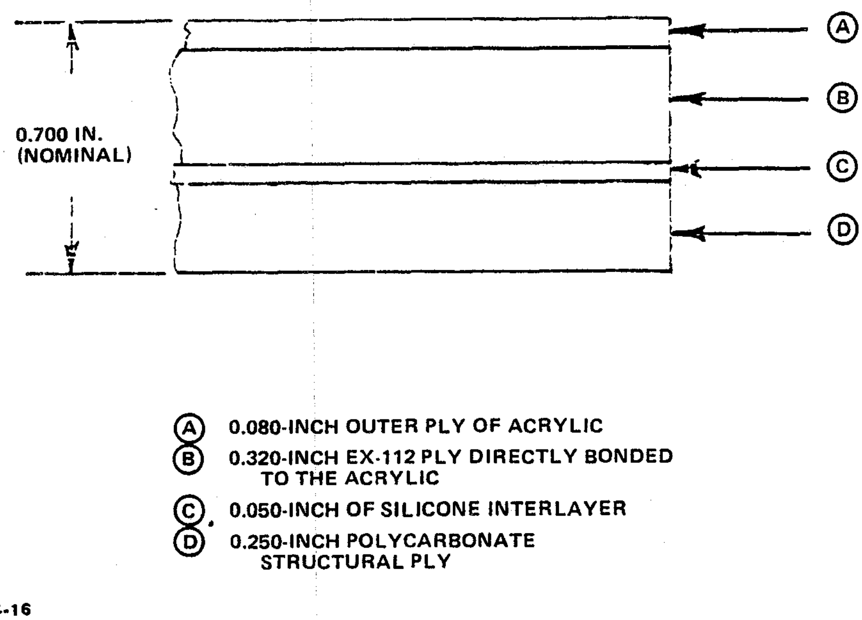


Figure 16. Fire-Resistant Transparent Composite.

(2) Edge Design

Two general edge designs for fire-resistant canopies have been studied extensively. These are shown in Figure 5, and were discussed briefly earlier in this report.

As noted in Figure 5, Design Concept "A" places the extra thickness required for the fire-resistant construciton outside the mold line of the aircraft. Design Concept "B" places the extra thickness inside the aircraft mold line.

Both concepts have their advantages and disadvantages. It is reasoned that in any design effort to provide fire-resistant canopies for specific aircraft, both design concepts would be considered. The design selected for an aircraft would depend an aerodynamics, cockpit interference, aircraft structural design, ease of fabrication, etc.

For the T-3 test specimens to be evaluated in this contract, simplified versions of the two edge design concepts were considered. These are shown in Figure 17.

Design Concept "B" (of Figure 17) was selected. This design provided a test specimen that more clearly demonstrated the performance capability of the edge attachment laminate under intense heat. The laminate had to resist the flames sufficiently to continue to support the transparency and, at the same time, needed to protect the structural ply of the transparent composite at the attachment points.

(3) Edge Attachment Laminate Materials

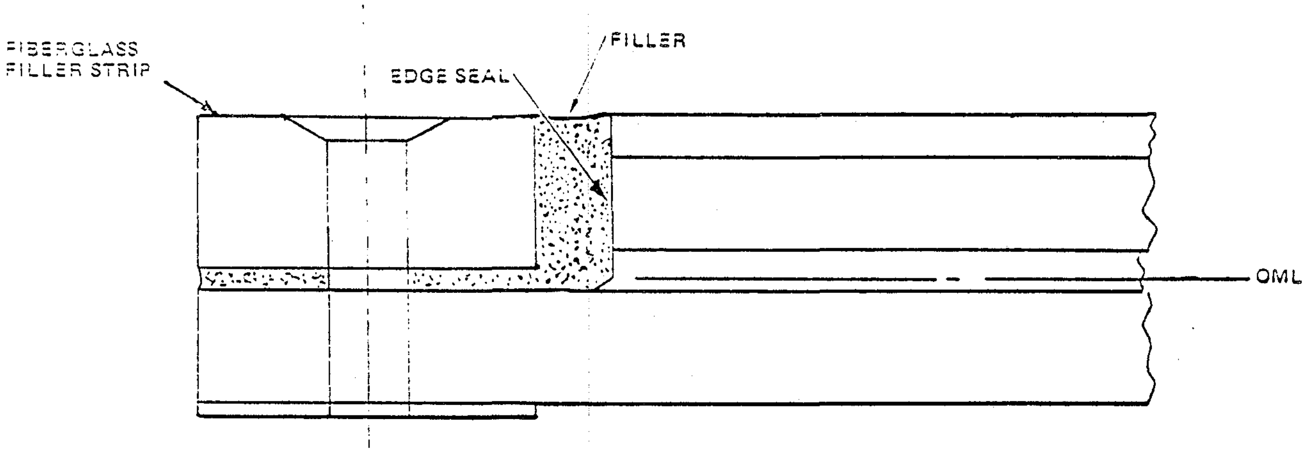
The resin selection study in Task 1 provided an unexpected insight into resin performance in a fire-resistant edge attachment laminate.

Resin performance was discussed in detail in the summary of Task 1. The reaction of the various resin systems to the Special Flame Test can be summarized as follows:

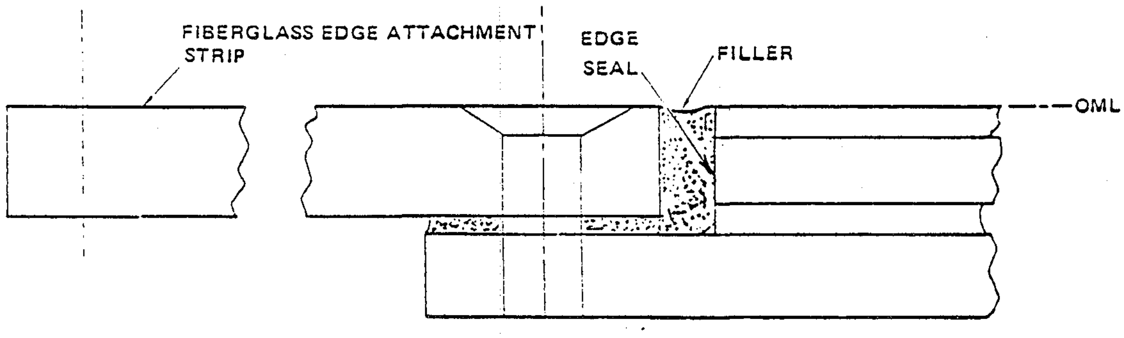
The thermally resistant resins maintained good structural integrity when subjected to a 2000 deg F flame on one surface. The heat transferred quickly through the panel, however, causing the temperature on the backside to raise rapidly. In an actual canopy, this could soften the thermoplastic transparent ply to which the edging was attached. The end result would be a premature weakening of the supporting edge and subsequent collapse of the canopy structure. The resin systems which were not thermally resistant decomposed, causing blisters and delaminations that drastically reduced the rate of heat flow through the panel. Backside temperatures rose slowly. The decomposition of the resin, however, weakened the edge attachment laminate. In an actual canopy, this would also eventually cause collapse of the canopy.

Of the resins evaluated, the EX-112 material gave the best all-around performance.

Because of the uncertainty as to which of the resin systems would perform best in the NASA-Ames T-3 Fire Test Facility, it was decided to provide



EDGE DESIGN - A



EDGE DESIGN - B

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Figure 17. Edge Attachment Designs for T-3 Fire Test Specimens.

three test panels. All three panels used woven fiberglass cloth as the reinforcement. The resins selected were:

1. EX-112 Special Resin. This was the resin with the best combination of retained strength and insulation capacity.

2. F-141 Polyester. This system had one of the best capabilities to resist heat flow and maintain low backside temperatures.

3. Epon 828 Epoxy. A thermally resistant resin system with one of the fastest heat transfer rates.

c. Test Specimen Design

The final design of the test specimen developed for evaluation by the NASA-Ames T-3 Fire Tester is shown in Figure 18. The specimen was oriented in the test facility so that the flame impinged on the surface that is shown as the top side in Figure 18. This would be the outside surface of a canopy.

Details of the specimen edge attachment joint are shown in Figure 19.

5. TASK 4 - TEST AND EVALUATION

a. General

The T-3 test specimens were successfully fabricated and tested. Analysis of the test data indicated that a fire-resistant transparent enclosure for combat aircraft could be constructed that would provide a fire barrier lasting four to five minutes.

Considerable data has been compiled by the Goodyear Aerospace Plastics Engineering department on the development of aircraft transparencies that are resistant to intense thermal radiation. This data includes specific information on the performance of the component plies in a transparent composite, on the evaluation of adhesives, sealants, fasteners, etc., and on techniques for processing, machining, and finishing specialized transparencies.

A condensation of this vast amount of data is included in this section, since the processing techniques used to fabricate the T-3 test specimens were based primarily on this background knowledge.

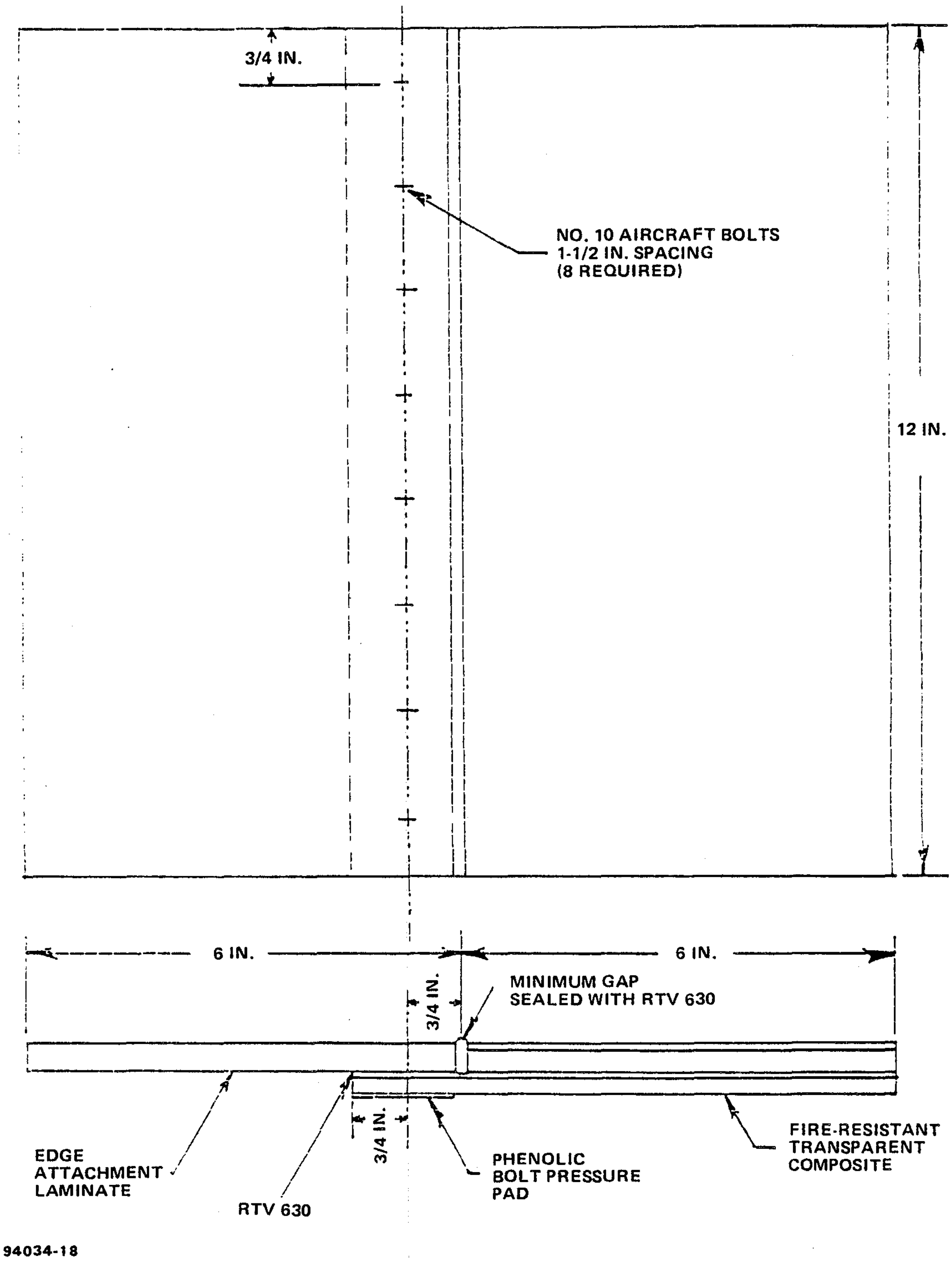

Figure 18. Test Specimen for NASA-Ames T-3 Fire Test Facility.

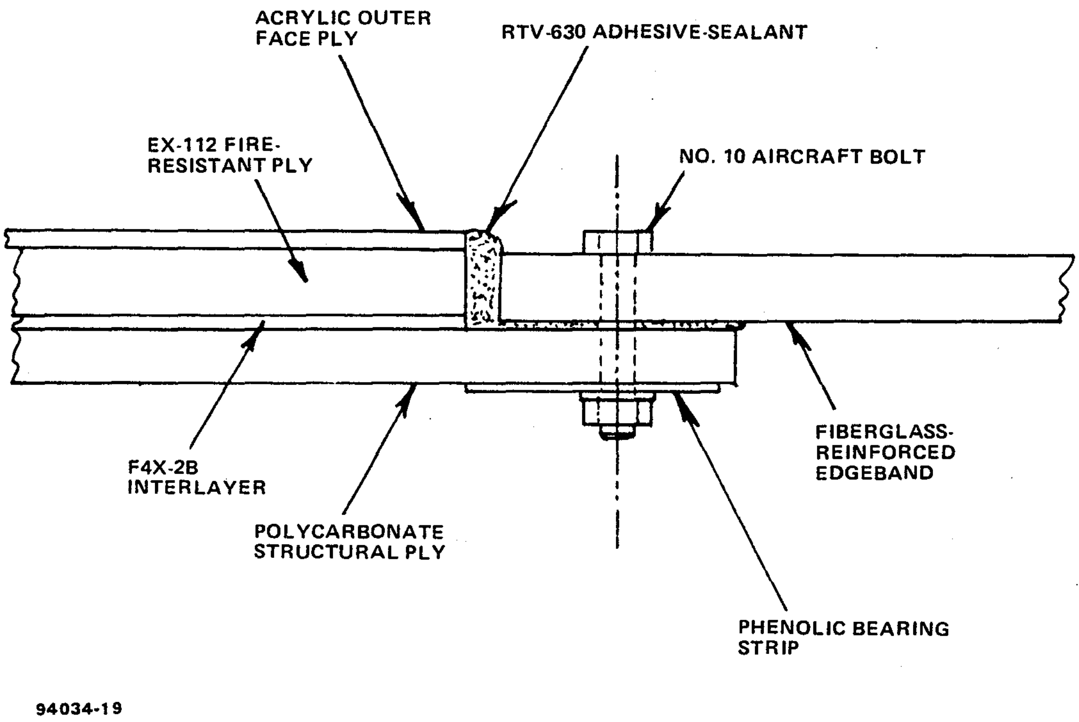

Figure 19. Details of Edge Attachment Design.

b. T-3 Test Specimens

(1) General

The T-3 test specimens were fabricated according to the material and design selections which evolved from the Task 3 effort.

The specimens were tested at the NASA-Ames Research Center T-3 Fire Test Facility.

Analysis of the data indicated all specimens met the requirements for a fire-resistant aircraft component.

(2) Transparent Composite

The processing procedure for fabricating the transparent composite is outlined in Table 42.

TABLE 42. PROCESSING METHOD FOR EX-112 CONCEPT V TRANSPARENT COMPOSITE

I. Casting EX-112

1. Clean Plex II face sheet.
2. Prepare cell:
   a. One side Plex II supported by glass plate.
   b. Other side glass plate with released surface.
3. Mix EX-112 formulation.
4. Cast EX-112 into cell.
5. Cure 1-1/2 hr at 190 deg F.
6. Cool and disassemble cell.

II. Casting F4X-2B interlayer

1. Prepare EX-112 surface on acrylic/EX-112 panel prepared in Step I.
2. Clean polycarbonate face sheet.
3. Assemble cell:
   a. Polycarbonate as one side supported by glass plate.
   b. Acrylic/EX-112 panel as other side; EX-112 inward; glass plate support.
4. Mix F4X-2B formulation.
5. Cast F4X-2B into cell.
6. Cure 16 hr at 190 deg F.
7. Cool and disassemble cell.

III. Postcure

1. Clean Concept V composite prepared in Step II.
2. Postcure 16 hr at 250 deg F.

The composite consisted of an outer protective ply of acrylic bonded directly to the EX-112 fire-resistant ply: the EX-112 layer was bonded to a polycarbonate structural ply by a silicone interlayer. This ply orientation has been designated a "Concept V" composite by Goodyear Aerospace engineers. A cross section of the Concept V configuration is shown in Figure 16.

The finished composite had a severe primer blush; otherwise, it looked quite good. The primer haze did not affect the structural integrity nor the fire resistance of the composite. It was confined to some optical degradation only. The haze was caused by a slight attack of the interlayer primer on the surface of the EX-112. Experience had shown that such a blush could be caused by the application of too much primer or by a slight undercure of the EX-112. For the composite prepared for the T-3 test specimens, it was felt that a little of both of these two factors came into play.

(3) Edgeband Laminates

Processing information on the edgeband laminates is presented in Table 43. For all three laminates, the fabrication procedures went smoothly.

(4) Goodyear Aerospace Special Flame Test

Specimens were taken from each of the three edgeband laminates and from the Concept V transparent composite. Quality assurance tests were conducted for fire resistance using the Special Flame Tester.

Results of the flame test series are shown in Table 44. All specimens showed normal behavior.

(5) Fabrication of Test Specimens

The T-3 test specimens were fabricated according to the developed design shown in Figure 18.

TABLE 43. PROCESSING INFORMATION

Processing conditions	EX-112	Epon 828	F-141
Catalyst	Trimethoxy boroxine (5 percent)	Versamid 125 (60/40)	Not applicable
Handling characteristics	Fair	Fair	Fair
Number of plies	36	32	39
Layup technique	Wet layup; spread resin one ply at a time.	Wet layup; spread resin one ply at a time.	Prepreg
Type of cure	Press	Press	Autoclave
Bag vacuum	Not applicable	Not applicable	22 inches
Cure schedule	Seal in press bag. Place in cold press. Close slowly to stops. Cure 2 hr at 190 deg F. Cool under pressure. Postcure 16 hr at 250 deg F.	Seal in press bag. Place in cold press. Close slowly to stops. Cure 1-1/2 hr at 300 deg F. Cool under pressure.	Seal in vacuum bag; draw vacuum. Place in autoclave. Pressure to 50 PSI. Cure: 1 hr at 180 deg F 1 hr at 225 deg F 4 hr at 290 deg F Cool under vacuum.

TABLE 43. PROCESSING INFORMATION (CONT)

Processing conditions	EX-112	Epon 828	F-141
Appearance	Excellent Green Slightly translucent Dense Thickness: 0.300 in. Hardness: Shore D 88-89 Release film carbonized to surface. Removed with heat and wire brush.	Excellent Brown Translucent Dense Some surface wrinkles Thickness: 0.317-0.342 in. Hardness: Shore D 85-88	Excellent Tan Opaque Dense Thickness: 0.340-0.355 in. Hardness: Shore D 90

TABLE 44. RESULTS FROM GOODYEAR AEROSPACE SPECIAL FLAME TEST

Material		Thickness (in.)	Time for backside temperature to reach 400 deg F (seconds)		Remarks	
Code	Type		Actual	Estimated for 0.250 in.	Reaction during test	Appearance after test
EX-112	Special epoxy	0.301	282	220	Light-medium white smoke. Occasional yellow flame. Required extinguishing.	Front: 2-1/2-in.-diameter. 1-in.-diameter resin burn-out. 1-1/4-in. vertical crack. Blistered. Back: 1-1/2-in. dark area.
Epon 828	Epoxy	0.338	369	125	Bright flame. Heavy white smoke. Required extinguishing.	Front: 2-1/2-in.-diameter char. 3/8-in. crack in center. Molten resin at edges. Back: no change.
F-141	Polyester	0.353	645	450	Nothing obvious.	Front: 2-in.-diameter resin burn-out. 3/4-in.-diameter molten glass at center. 1-in. crack in center. Back: 2-1/2-in.-diameter delamination. 1-in. dark spot in center.
Concept V transparent composite	EX-112 fire-resistant ply	Total: 0.700 EX-112 layer: 0.320	1583	1237	Visible flame for 840 seconds. Visible formation of char cone.	Front: Acrylic burned away in a 4-in.-diameter area. Prominent char cone. Back: polycarbonate bubbled in a 3-in.-diameter area.

Figures 20 through 25 show photographs of the completed test specimens. The edgeband constructions for the specimens are designated below:

Figure 20 - Edgeband construction:
EX-112 resin - fiberglass reinforcement

Figure 21 - Edgeband construction:
Epon 828 resin - fiberglass reinforcement

Figure 22 - Edgeband construction:
F-141 prepreg with fiberglass reinforcement.

Details of the specimen construction as shown by the photographs are:

Figure 23 - F-141 specimen
Front view - showing edgeband to transparent composite transition

Figure 24 - F-141 specimen
Backside view - showing phenolic bearing strip

Figure 25 - F-141 specimen
Edge view - showing the joint construction for attaching the edgeband to the transparency.

(6) T-3 Fire Test

(a) General

The NASA T-3 Fire Test has been used extensively to evaluate a variety of materials for resistance to an intense fuel fire.

The final test series in this contract was conducted on the T-3 fire test facility. Results of the test provided a quantitative measure of how the designed edge attachment area for a fire-resistant transparent enclosure would perform in an actual crash-created fuel fire.

(b) Facility

The NASA-Ames Research Center T-3 Fire Test Facility (see Figure 26) used a JP-4 fuel fire in a specially constructed fire box. The heat flux of about 10 $BTU/ft^2/s$ imposed was composed of about 90 percent

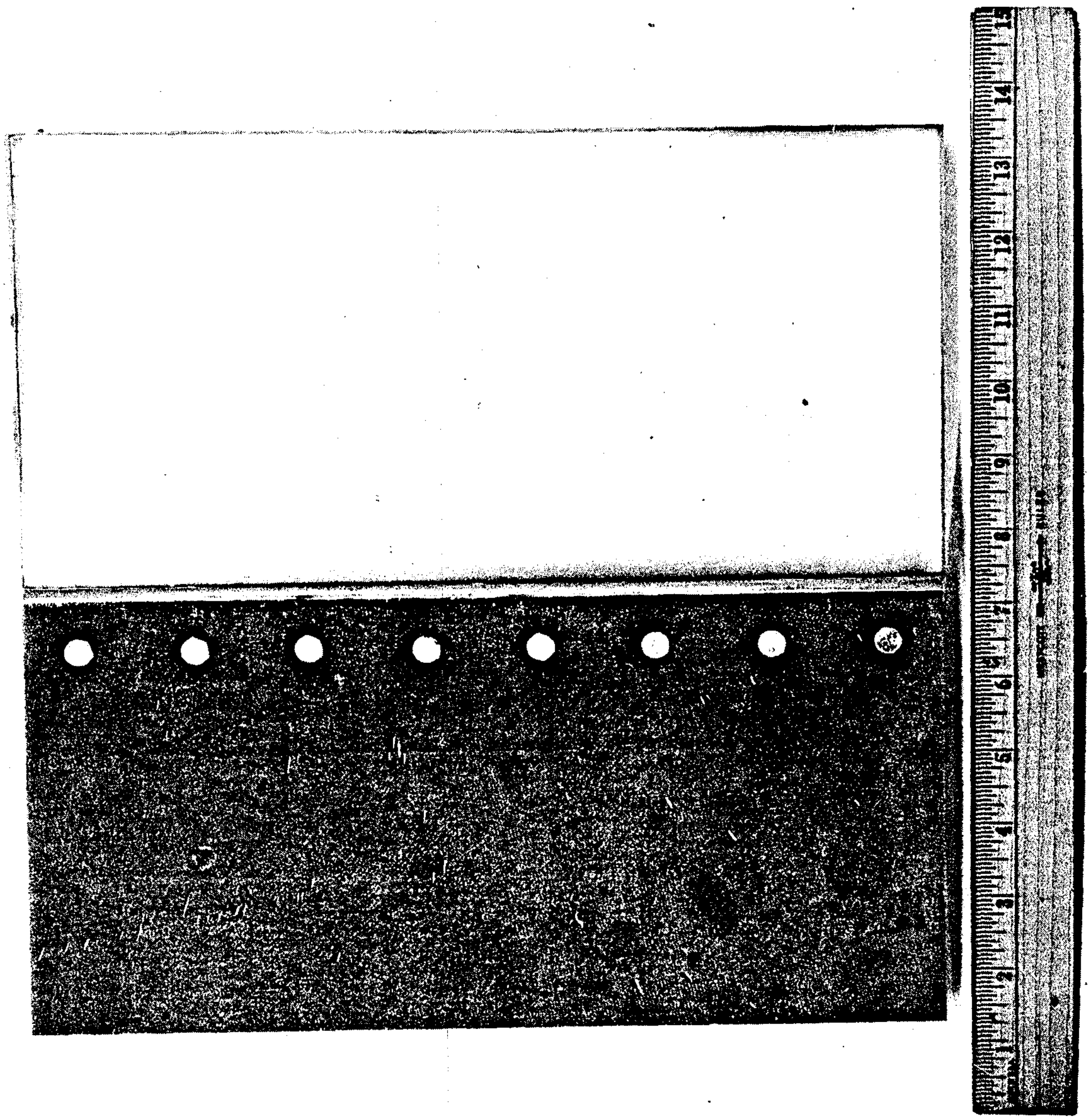

Figure 20. T-3 Fire Test Speciment - EX-112 Resin.

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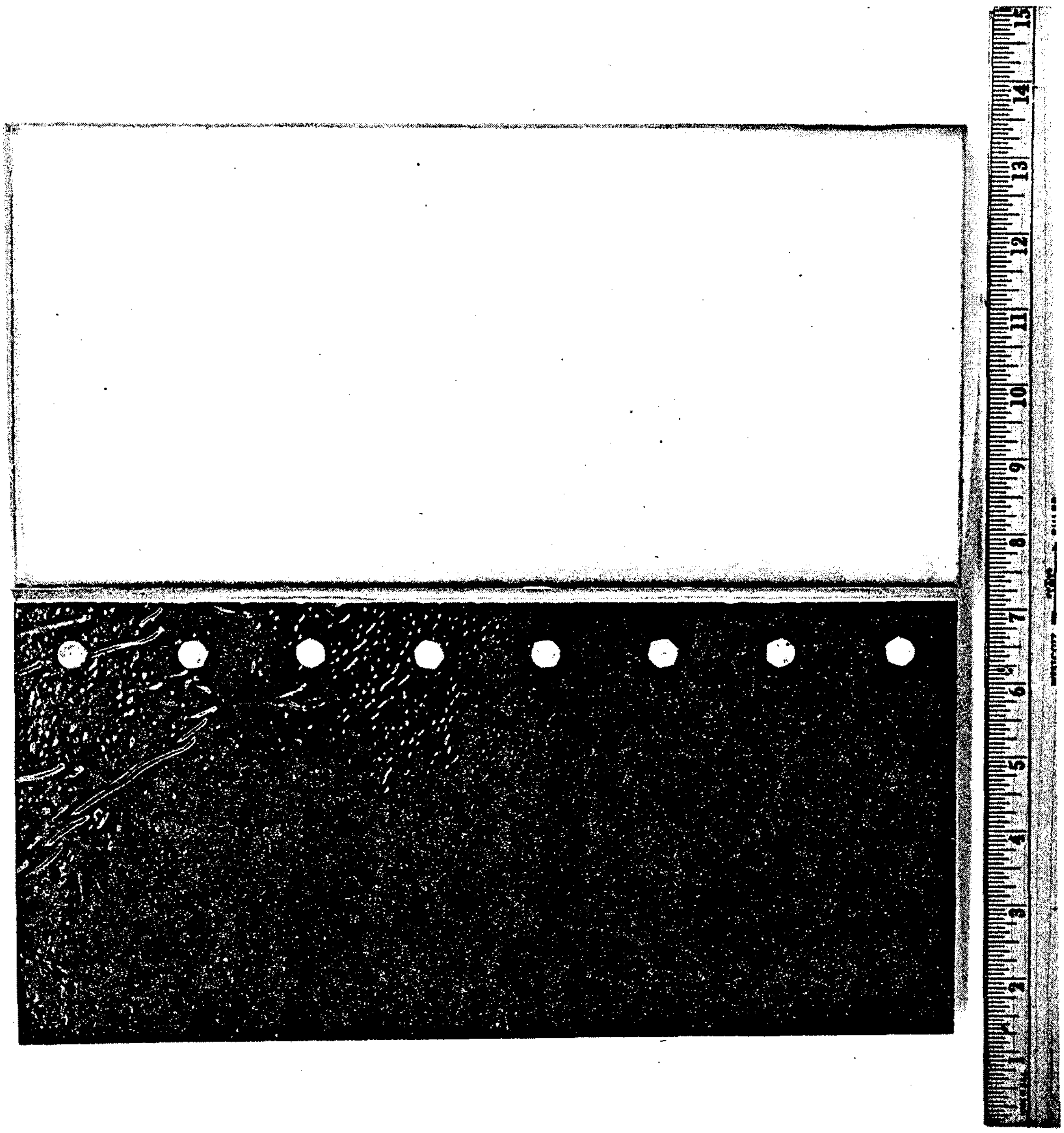

Figure 21. T-3 Fire Test Specimen - Epon 828 Resin.

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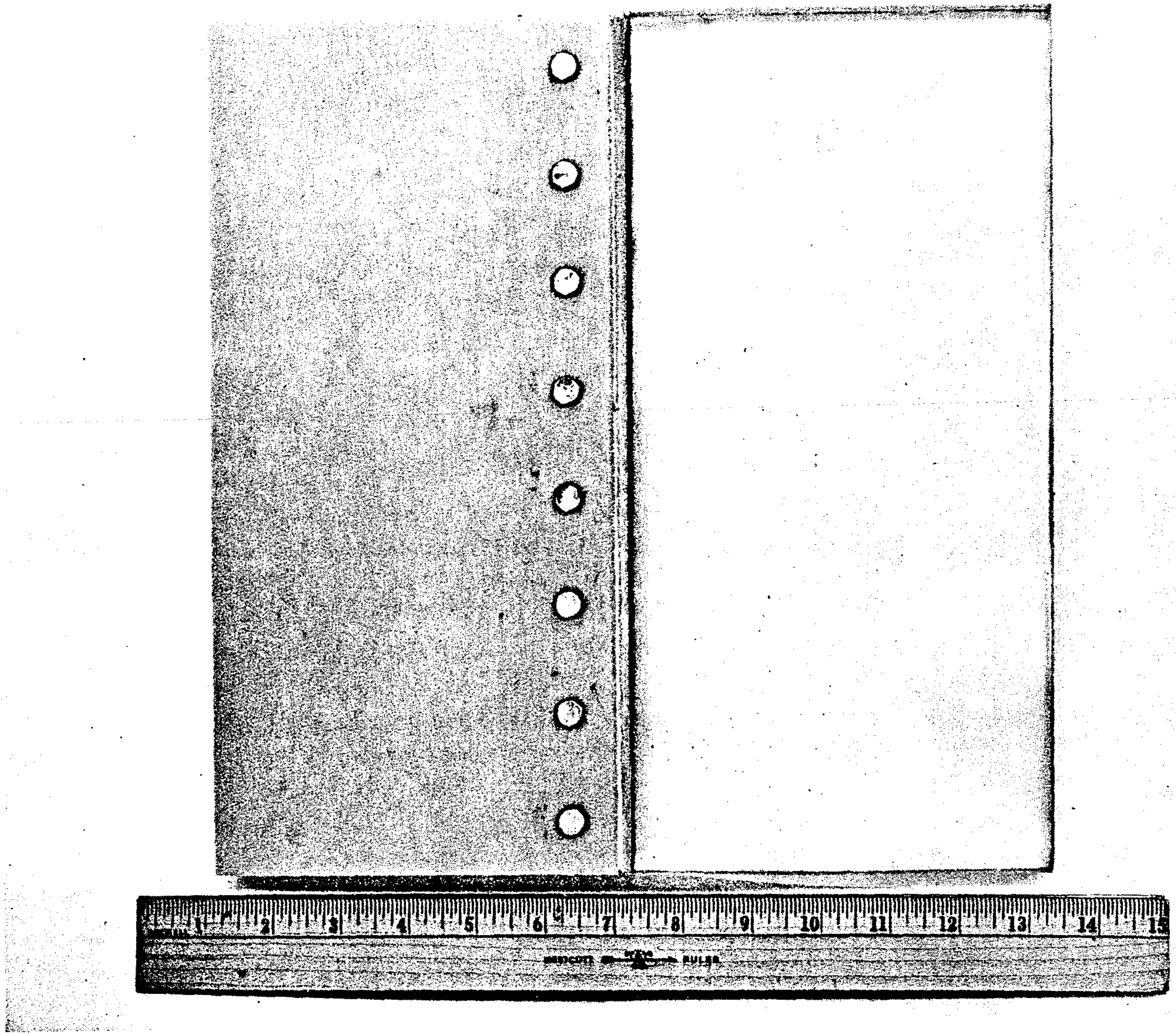

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Figure 22. T-3 Fire Test Specimen - F-141 Prepreg.

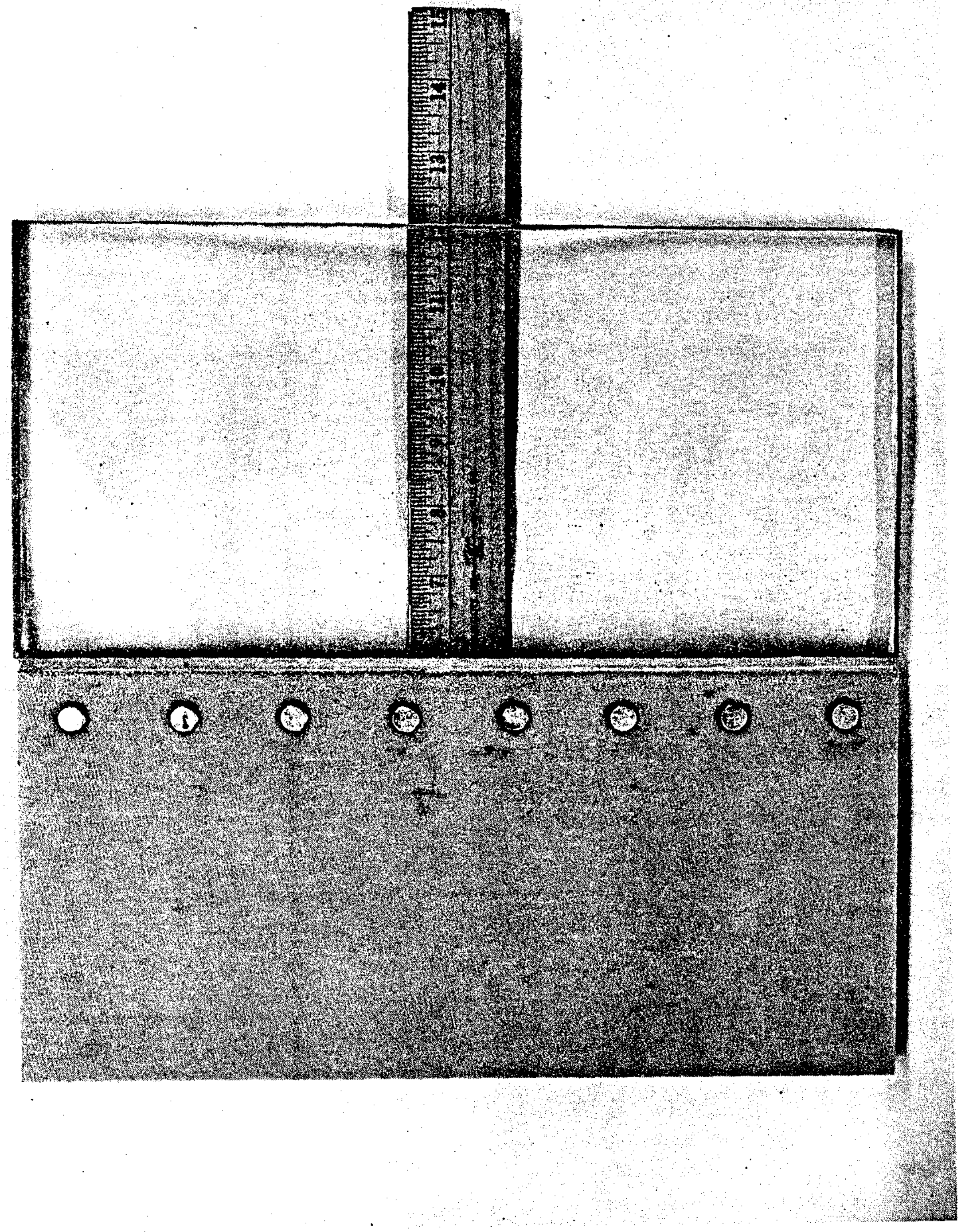

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Figure 23. F-141 T-3 Fire Test Specimen - Front View.

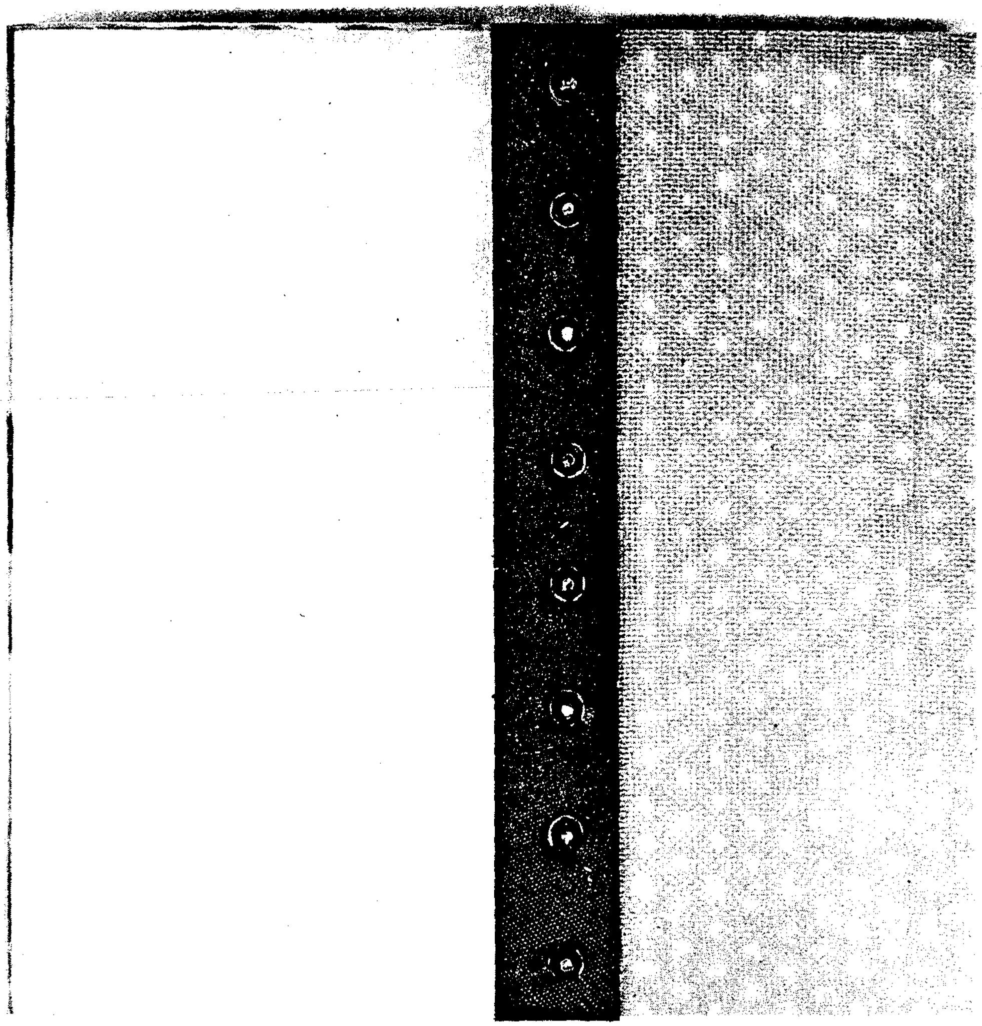

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Figure 24. F-141 T-3 Fire Test Specimen - Back View.

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Figure 25. F-141 T-3 Fire Test Specimen - Edge View.

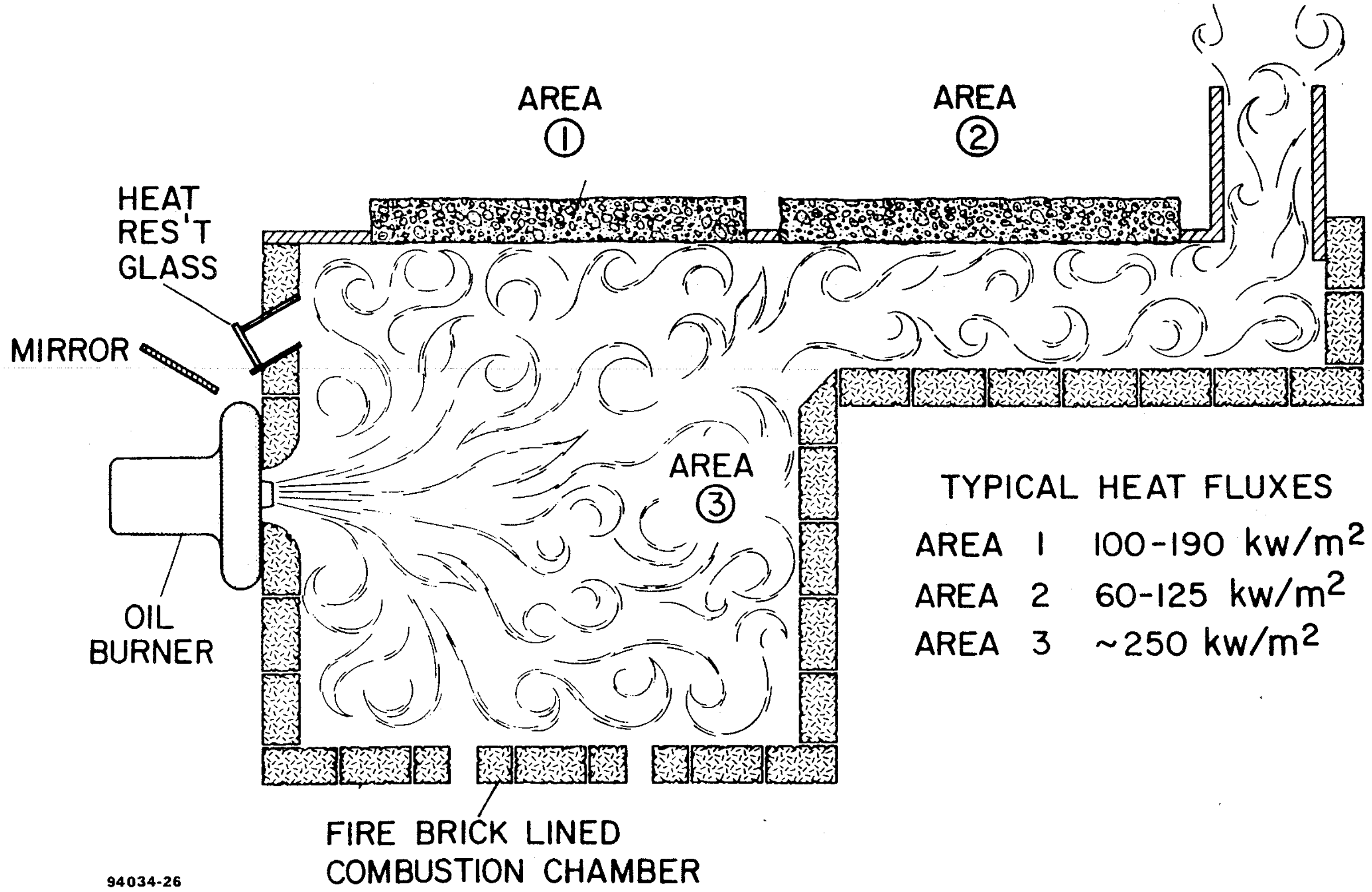

Figure 26. NASA-Ames Research Center T-3 Fire Test Facility.

radiative and 10 percent convective components. The device was designed to simulate the thermal and chemical conditions of the interior of a large fire cone at approximately the midheight of a crashed aircraft fuselage. The data obtained included time for the test material backside temperature to reach 400 deg F.

(c) Observations During the Test

The following observations were made during the test:

1. The fire box was stabilized with a recorded flame temperature of approximately 1950 deg F

2. The specimens were placed on the test opening of the fire box (area 1 of Figure 26) so that the flames impinged on the "exterior" surface of the canopy construction. Insulation was packed along the edges of the specimen to confine the fire to the one surface.

3. The backside temperatures of the specimens were recorded electronically by six thermocouples: three on the edge attachment laminate, two on the transparent composite, and one at the bolt line. The data was recorded by a printer and on computer tape.

4. Timing of the test began as soon as the specimen was placed on the fire box opening.

5. The test on each panel was continued until it was obvious that the backside temperature of the edge attachment had exceeded 400 deg F.

6. The backside temperature of the transparent composite rose more slowly and stayed well below that of the edge attachment laminate in all three tests.

7. The temperature at the bolt line varied, depending on the proximity of the thermocouple to the metal bolt. This

temperature was recorded but not considered in the termination of the test.

8. All tests were terminated after six to eight minutes.

9. The samples survived but were badly burned and blistered.

10. The EX-112 layer in the composite formed a large thick insulating char.

11. The weak point was the bolt line between the composite and laminate. The polycarbonate softened, extruded, and bubbled. One specimen (F-141) broke apart at the joint when removed from the test facility.

12. All panels continued to burn after removal from the test unit and had to be extinguished with a CO_2 extinguisher.

13. Smoke generation from all panels was severe both during the test and after their removal from the test unit.

(7) Analysis of Test Results

(a) General

Backside temperature data from the T-3 Fire Test series has been plotted in Figures 27, 28, and 29. The curves for the temperature profile of the joint were prepared from single thermocouple readings; the curves from the transparent composite are averaged from two thermocouple readings; and the curves for the edge attachment laminate are averaged from three thermocouple readings.

Photographs of the specimens after testing are shown in Figures 30 and 31. Figure 30 shows the backside of the specimens (side away from the flames). The thermocouples were attached to this surface. Figure 31 shows the side of the specimen exposed to the fire box. This simulated the exterior surface of a canopy.

Times for the average backside temperature of the edge attachment laminates to reach 400 deg F in the T-3 Fire Test are compared in

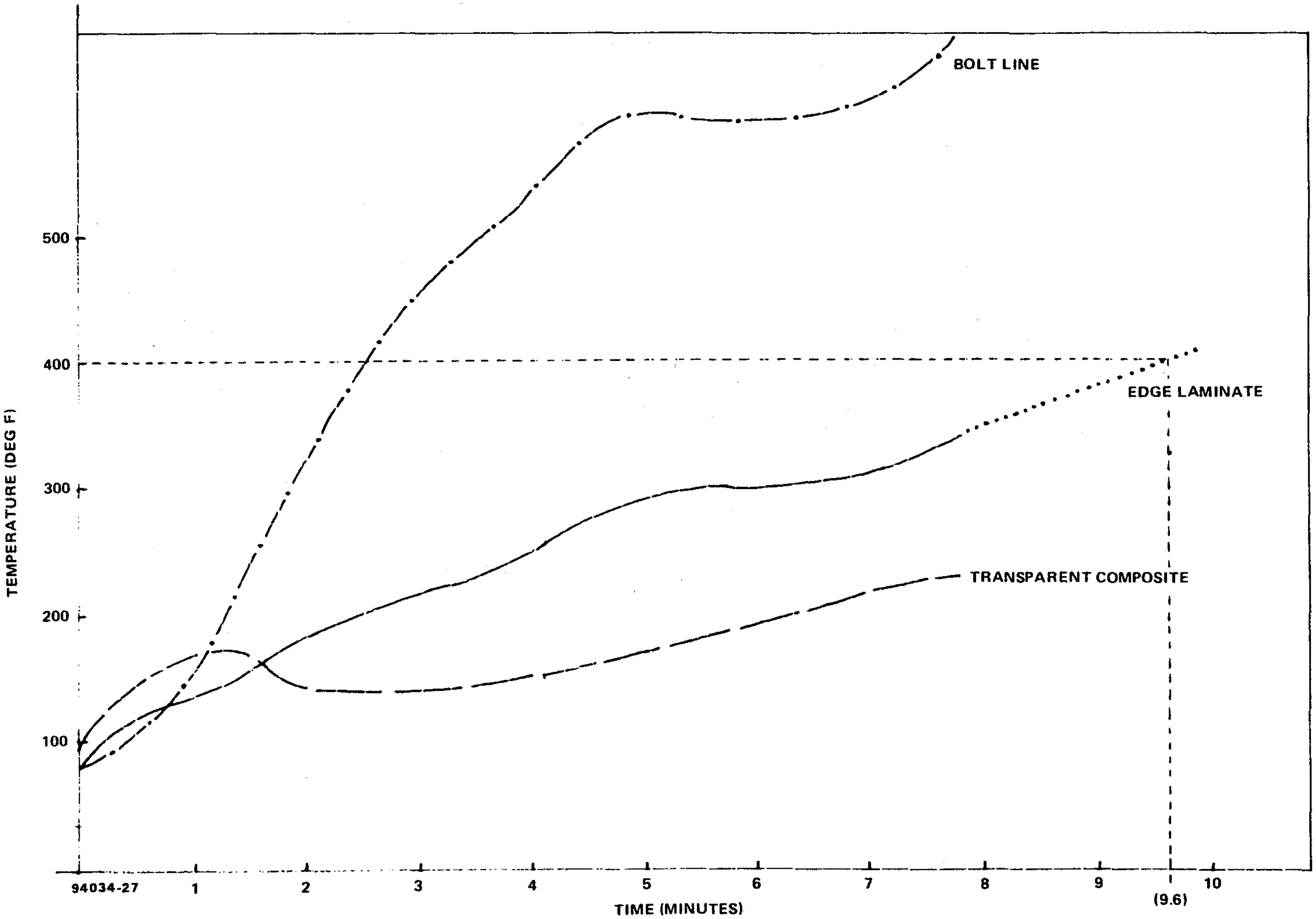

Figure 27. Backside Temperature Profiles - NASA-Ames T-3 Fire Test - F-141 Edge Attachment Laminate.

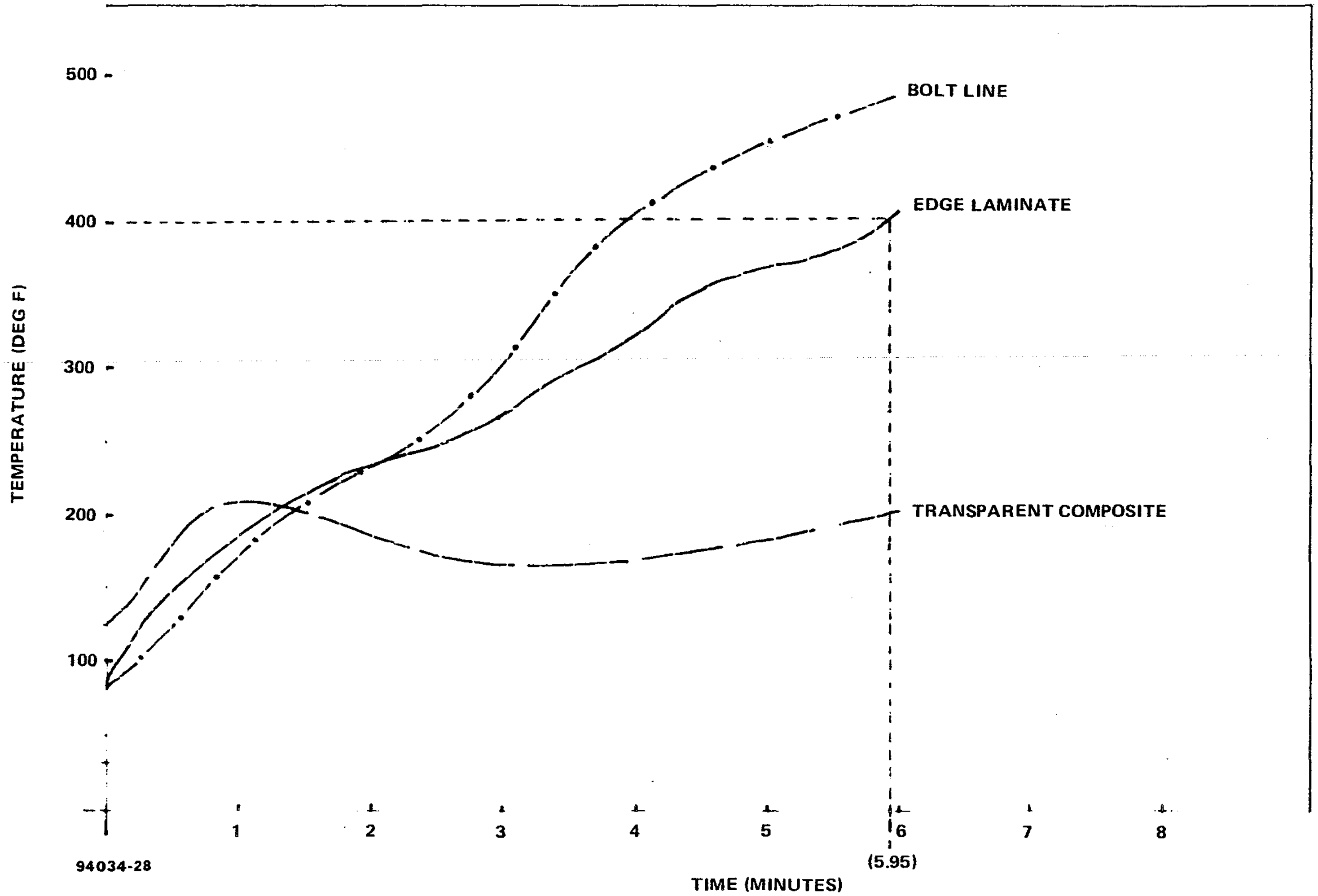

Figure 28. Backside Temperature Profiles - NASA-Ames T-3 Fire Test - Epon 828 Edge Attachment Laminate.

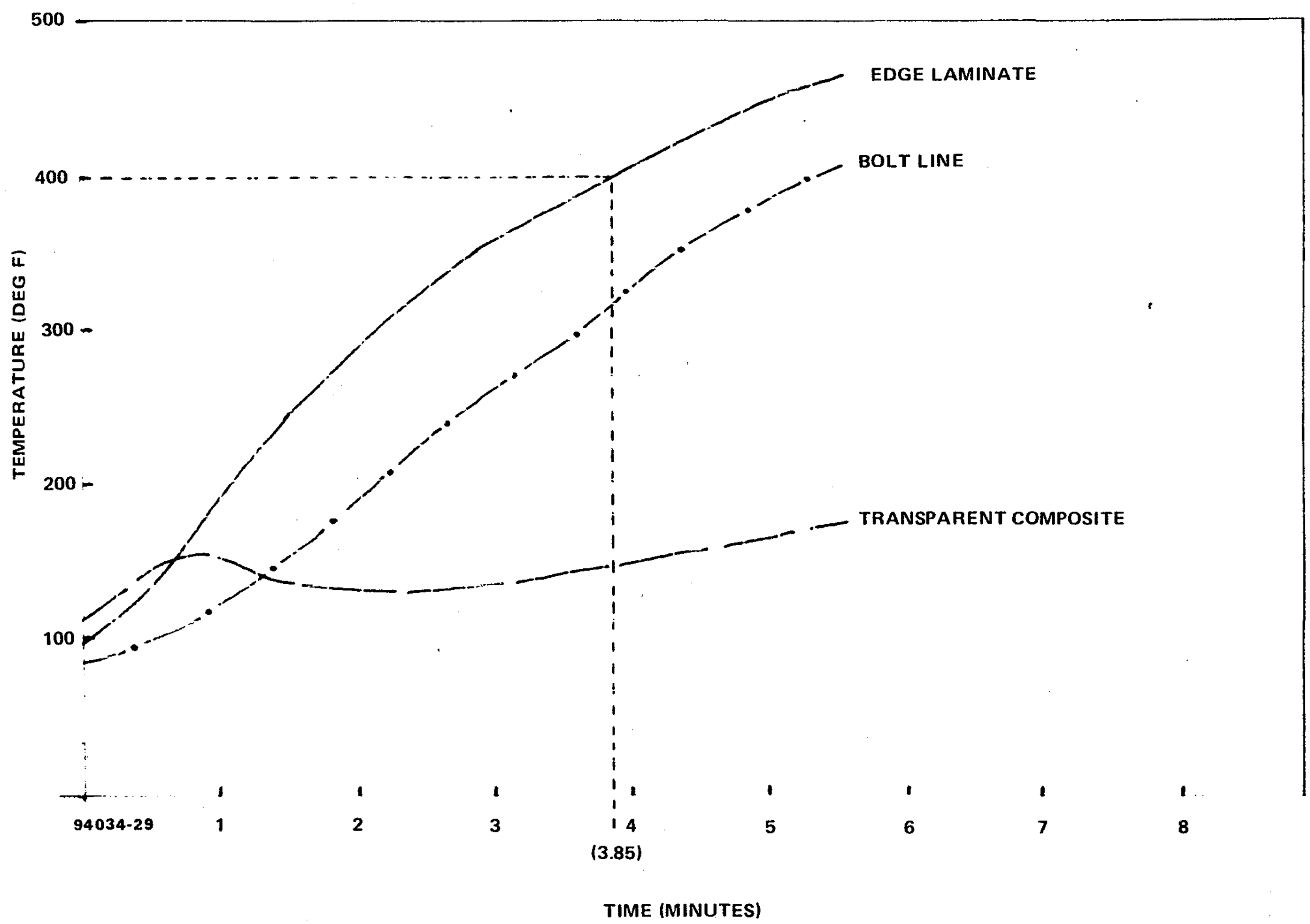

Figure 29. Backside Temperature Profiles - NASA-Ames T-3 Fire Test - EX-112 Edge Attachment Laminate.

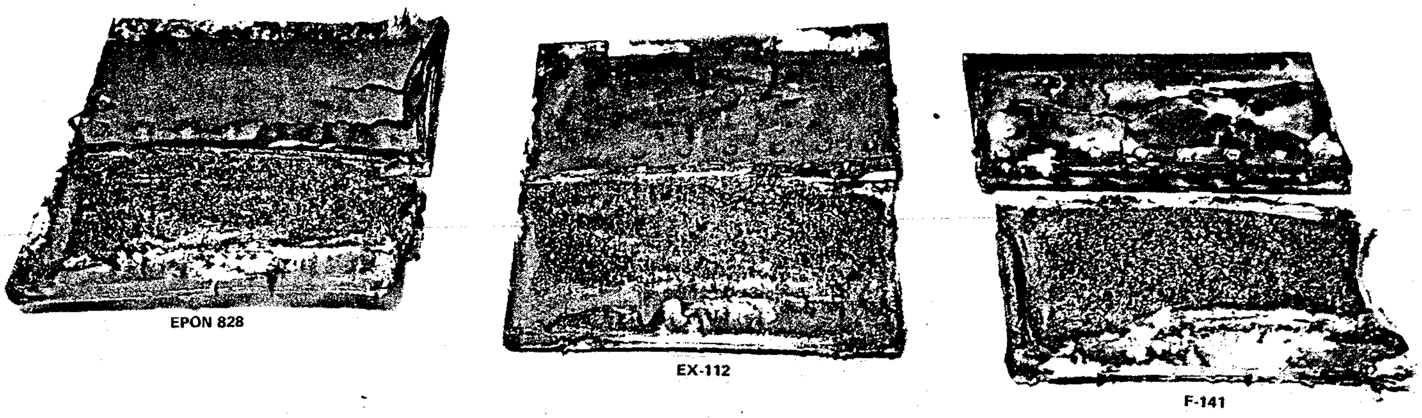

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Figure 30. NASA-Ames T-3 Fire-Tested Specimens - Backside (Away from Flames) Surface.

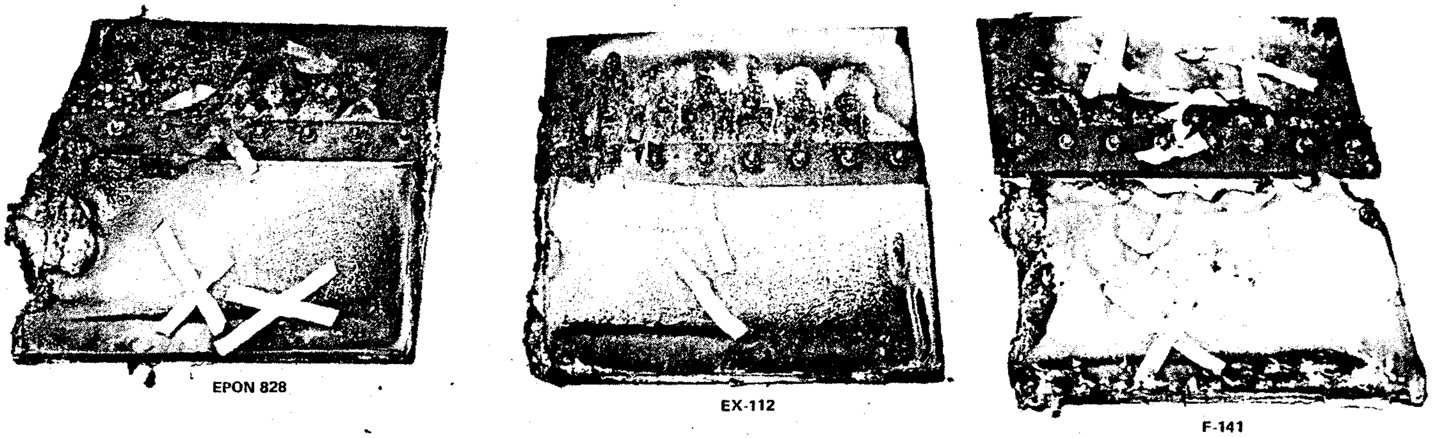

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Figure 31. NASA-Ames T-3 Fire-Tested Specimens - Front (Flame Impingement) Surface.

Table 45 to the times from the Goodyear Aerospace Special Flame Test. As noted in the table, the times between the two tests compared favorably.

Comments on the performance of the specimens are presented in the following paragraphs.

(b) F-141 Edge Attachment Laminate

The F-141 edge attachment laminate performed as expected. Resin decomposition, surface blistering, and massive interply delamination occurred. Heat flow through the laminate was slowest of the three specimens. The spread between the three thermocouple readings on the laminate was broadest of the specimens tested. This was probably due to the localized blistering on the backside, as noted in Figure 30. Depending on location of the thermocouples, the blisters could provide increased insulation. Because of visible deterioration of the specimens,

TABLE 45. COMPARISON OF FLAME TEST RESULTS

Edge laminate information		Test results (seconds)	
Resin	Thickness (inches)	Goodyear Aerospace Flame Test	T-3 Fire Test
EX-112	0.301	282	231
Epon 828	0.338	369	357
F-141	0.353	645	576

the test was terminated when one of the thermocouples on the laminate exceeded 400 deg F (even though the average was below 400 deg F as shown in Figure 27).

The specimen broke apart at the bolt line when removed from the fire chamber, indicating that the sample joint design had reached its practical useful life. It is reasoned that a canopy of similar joint design would remain essentially intact for an equal period of time (approximately nine minutes) before collapse occurred.

(c) Epon 828 Edge Attachment Laminate

The Epon 828 edge laminate suffered massive delamination and resin burn-out on the flame impingement surface (as noted in Figure 31).

Resin decomposition and bubbling also occurred on the backside of the laminate (Figure 30). Some deterioration along the bolt line had started by the time the test was terminated. The tested specimen was still intact and relatively strong at the conclusion of the test.

(d) Ex-112 Edge Attachment Laminate

The EX-112 edge attachment laminate was the most heat stable of the three laminates tested. There was minimum evidence of blistering and delamination. At the conclusion of the test, the specimen was still intact and retained a high degree of its initial overall strength. The heat transfer rate was the highest of the three laminates, again indicating excellent thermal stability.

(e) Transparent Composite

The transparent composite portion of each test specimen reacted in an identical way to the T-3 test conditions. The acrylic face sheet burned off quickly, and the EX-112 fire-resistant layer formed an immediate char. By the completion of each test, the char layer had expanded three to four inches in height. This char was dense and strong, and provided an efficient insulating layer against the flames (See Figures 27, 28, and 29). The char layer remained intact during removal of the specimens from the fire box and extinguishing of the flames.

The char was physically removed so that the specimens could be packaged and returned to Goodyear Aerospace; therefore, the massive char buildup does not show in Figure 31.

Extrapolation of the backside temperature curves for the transparent composite plotted in Figures 27, 28, and 29 indicates the temperature would reach 400 deg F in 15 to 20 minutes. This compares with the 20.6 minutes required in the Goodyear Aerospace Special Flame Test.

(8) Conclusions

The following conclusions may be drawn:

1. All systems tested would provide in excess of four minutes' protection against an intense fuel fire.

2. Ex-112 was the most thermally stable resin tested.

3. The bolt line of the T-3 Fire Test specimens was the weakest area of the construction concept.

4. The transparent composite afforded more protection against intense thermal radiation than any of the laminate systems.

5. Hybrid laminates - during the analysis of test results, it was noted that the EX-112 resin appeared to provide a much superior barrier to intense heat in the transparent composite form than in the edge attachment laminate. The char formation from the EX-112 layer in the transparent composite was vigorous, tenacious, and expansive. The char formation on the laminate was quite sparse. It was reasoned that the fiberglass cloth reinforcement in the laminate restricted the char growth of the EX-112 resin binder.

   The possibility was considered that a hybrid laminate could be developed that would possess both high-temperature strength and the full capabilities of the EX-112 resin against intense flame. Some experiments were conducted on Goodyear Aerospace IR&D funds to explore the potential of hybrid laminates. This effort is discussed in Appendix A.

c. Data

(1) General

The information presented in this section was compiled not only from the accomplishments on this contract but also from the extensive work Goodyear Aerospace had conducted on IR&D programs and other contracts relating to transparent composites resistant to intense thermal radiation. The largest amount of contractual effort had been conducted for the Air Force Materials Laboratory.

(2) Physical Properties

Fire-resistant epoxy - TMB resin systems have been evaluated for the following properties:

Light transmission
Haze
Color
Appearance
Hardness
Tensile strength
Flexural strength, ultimate
Flexural strength, modulus
Impact strength, Izod
Crack propagation, K-test
Moisture absorption.

Some of the resin systems evaluated were slight modifications of the basic EX-112 formula. However, the physical properties were altered but little, and Table 46 represents acceptable average values for monolithic specimens of the EX-112 resin.

The EX-112 resin is sensitive to moisture, as shown in Table 47. The epoxy formulation absorbs water rapidly, and to a degree that the transparency is impaired. This emphasizes the need for a composite construction where the fire-resistant epoxy resin ply is protected by outer surface plies.

Table 48 indicates that the absorbed moisture can be removed by extended drying.

In the Concept V configuration, the fire-resistant ply is protected by an acrylic face sheet on the exterior surface and a polycarbonate sheet plus an interlayer on the interior surface. This protection, plus the reversible

TABLE 46. PHYSICAL PROPERTIES

Property	EX-112
Color, Gardner	1-3
Light transmission (percent)	88.6-89.3
Haze (percent)	5.3
Appearance	Very good
Hardness, Shore D	88-90
Tensile strength (PSI)	10,752
Flexural strength (PSI)	
Ultimate	15,800
Modulus	506,000
Impact strength, Izod (ft-lb/in. width)	
Notched	0.46
Unnotched	4.67
Crack propagation - K test	490
Moisture absorption (percent)	+0.901

TABLE 47. MOISTURE ABSORPTION TEST DATA

Cure	Preconditioned weight (grams)	Conditioned weight (grams) (Note 2)	Δ weight (grams)	Weight change (percent)	Comments
Partial cure 7 hr, 87.8 deg C (190 deg F)	28.1133	28.3776	0.2643	(+)0.940	Specimen appearance opaque white after water immersion
Full cure 7 hr, 87.8 deg C (190 deg F); 16 hr, 121 deg C (250 deg C)	25.4859	25.7155	0.2296	(+)0.901	Specimen appearance opaque white after water immersion

Notes:

1. Testing in accordance with ASTM D570-63 (1970).
2. Conditioned weight taken following 24-hr water immersion at 23 ±1 deg C (73 deg F).
3. All test specimens were 0.635 x 5.1 x 7.6 cm (0.25 x 2 x 3 in.).

TABLE 48. MOISTURE ABSORPTION AND DRYING RATE TEST DATA

Cure	Preconditioned weight (grams)	Conditioned weight (grams)	Weight change (percent)	Weight after drying (grams), 16 minutes 121 deg C (250 deg F) 2.5 hr 110 deg C (230 deg F)	Weight change (percent)	Weight after drying (grams), 16 minutes 121 deg C (250 deg F) 20.5 hr 110 deg C (230 deg F)	Weight change (percent)
7 hr, 87.8 deg C (190 deg F) 16 hr, 121 deg C (250 deg F)	25.4859	25.7155	(+)0.901	25.5399	(+)0.212	25.4928	(+)0.027

nature of the absorbed moisture, provides the Concept V construction with a high degree of weatherability.

(3) Environmental Resistance

(a) General

The environmental endurance of the fire-resistant epoxy system in Concept V composite form was determined by the following tests:

Humidity	49 deg C (120 deg F) - 95 percent relative humidity
EMMA	DSET, Inc.
Thermal aging	Up to 120 deg C (300 deg F).

(b) Humidity

At the completion of 15 days in the humidity environment, the results were as follows:

	Fire-Resistant Epoxy	
Property	Control	15 days
Appearance	Very good	No change - very slight haze around periphery of specimen
Light transmission (percent)	78.5	78.8
Haze (percent)	7.2	8.1

In 18 to 20 days in the 120 deg F/95-percent relative humidity environment, moisture began to penetrate the protective face plies. The haze in the epoxy layer then started to climb and soon reached unacceptable limits. It is believed, however, that the 120 deg F/95-percent relative humidity steady-state test condition is more severe than would be encountered in real life.

(c) EMMA

The EMMA is an intensified outdoor weathering exposure test conducted on a special test machine at DSET, Inc., New River, Arizona.

The EMMA machine is a follow-the-sun rack having 10 flat mirrors so positioned that the sun's rays strike them at about 90 deg all day and reflect to the samples in the target area. The mirrors reflect from 70 percent to 80 percent of the ultraviolet (UV) and about 85 percent of the total radiation. The samples therefore receive about eight times as much radiation as samples exposed on a simple follow-the-sun rack during equal periods of time.

Results of the EMMA test are shown in Table 49.

(d) Thermal Aging

Thermal aging tests were conducted on a monolithic sample of a modified epoxy/TMB fire-resistant material. Results of these tests are shown in Table 50. As shown by the test results, the epoxy/TMB resin system was quite thermally stable.

(e) Adhesion Studies

In the Concept V composite construction, the fire-resistant ply was bonded to the acrylic face ply by a cast-in-place (in-situ) bond. The fire-resistant ply was bonded to the polycarbonate by an interlayer. The strength of both the in-situ bond and the interlayer bond was important to the durability and performance of the composite.

The acrylic/fire-resistant ply in-situ bond strength was determined by a flatwise tensile test. Results are summarized as follows:

<u>Flatwise Tensile Test Results</u>
<u>In-Situ Bond</u>

Flatwise Tensile Value (PSI)	1,000 - 1,700

The fire-resistant ply/interlayer/polycarbonate bond strength was determined by the flatwise tensile test and a tensile-shear test. These tests

TABLE 49. ACCELERATED OUTDOOR WEATHERING TEST DATA (EMMA)

Material		Exposure (weeks)	Total Langleys	Color (Gardner)	Luminous transmittance (percent)	Haze (percent)	Comments
Code 30-I Concept V	1	2	59,230	1 (1)	79.0 (78.5)	6.3 (7.7)	Masked no change, unmasked exposed slightly more tan - less change than 30-III below.
	2	3	96,930	1 (1+)	79.1 (79.8)	5.7 (7.5)	Same as above.
	3	4	132,770	1 (1+)	80.1 (79.2)	5.6 (6.1)	Same as above.
	4	5	166,670	1 (1+)	80.2 (79.4)	5.7 (6.1)	Slight progression of color change visible, 2-5 weeks.
	5	8	256,200	1 (1+)	79.7 (79.4)	6.1 (7.0)	No change from 5 weeks, very slight change overall.
	6	10	332,960	1 (1+)	80.0 (81.6)	5.6 (7.0)	Same as above.
Code 30-III Concept V	1	2	59,230	1 (1)	80.5 (79.2)	5.3 (6.0)	Masked no change, unmasked exposed slightly more tan.
	2	3	96,930	1 (1+)	80.3 (79.5)	5.2 (7.1)	Same as above.
	3	4	132,770	1 (1+)	80.8 (79.7)	5.7 (6.0)	Same as above.

TABLE 49. ACCELERATED OUTDOOR WEATHERING TEST DATA (EMMA) (CONT)

Material	Exposure (weeks)	Total Langleys	Color (Gardner)	Luminous transmittance (percent)	Haze (percent)	Comments
4	5	166,670	1 (1+)	80.5 (79.2)	5.5 (5.7)	Same as above.
5	8	256,200	1 (1+)	80.7 (79.8)	5.7 (6.0)	Slightly more tan than 30-I, very slight change overall.
6	10	332,960	1 (1+)	80.4 (80.1)	5.2 (5.9)	Appearance change, color very slight tan, now identical to 30-I, 10 weeks.

Notes:

1. All specimens are 4- x 6-in. Concept V configuration with 0.080-in. Plex II UVA facing, 0.25-in. fire-resistant ply, 0.06-in. F4X-2B interlayer, 0.25-in. 9030-112 polycarbonate.
2. Control data for each specimen is shown first; data taken after exposure follows.
3. The majority of the haze increase is attributable to light surface abrasion of the polycarbonate ply during exposure and subsequent cleaning operations. The polycarbonate ply did not have an abrasion-resistant coating.
4. Code 30-I and Code 30-III are modified Epoxy-TMB systems.

TABLE 50. THERMAL AGING TEST RESULTS

Material	Thermal condition		Shore D hardness	Flexural strength, kN/m^2 (PSI)		Appearance
	Temperature, deg C (deg F)	Hours		Ultimate	Modulus	
GAC 30-I		Control	85	59,685 (8,650)	1,417 x 10^3 (205,400)	Clear, colorless
	88 (190)	24	88	105,114 (15,234)	3,071 x 10^3 (445,400)	No change
	88 (190)	72	89	102,396 (14,840)	3,572 x 10^3 (517,700)	No change
	88 (190)	144	90	102,396 (14,840)	5,368 x 10^3 (777,800)	Faint golden color
	169 (250)	6	89	114,623 (16,612)	3,112 x 10^3 (450,800)	No change
	169 (250)	24	90	99,705 (14,450)	3,998 x 10^3 (507,260)	No change
	169 (250)	48	90	121,785 (17,650)	3,850 x 10^3 (558,400)	Faint golden color
	197 (300)	3	89	125,994 (18,260)	3,333 x 10^3 (483,300)	No change
	197 (300)	6	89	125,718 (18,220)	3,588 x 10^3 (520,440)	No change
	197 (300)	24	90	156,906 (22,740)	3,657 x 10^3 (530,130)	Faint golden color

showed that the cohesive strength of the interlayer material was the limiting end point for the bond:

Flatwise tensile strength	325-425 PSI
Tensile shear - ultimate	200-250 PSI
Tensile shear - modulus	38- 50 PSI.

(f) Adhesive - Sealants for Edge Attachment

Goodyear Aerospace engineers have conducted a number of tests to evaluate the effectiveness of adhesive-sealant compounds for bonding and sealing edge attachments on fire-resistant transparencies. The sealant material must resist moisture penetration, be weatherable, and compatible with the components of the Concept V composite (especially polycarbonate).

Some of the sealants evaluated include:

Silkaflex - 1a (FC)
G.E. Construction Sealant 1200 (silicone)
G.E. Autoglass Sealant 1400 (silicone)
RTV-140
RTV-156
RTV-630
GAC 56
CRTV-6425.

For the T-3 Fire Test specimens, RTV-630 was the adhesive-sealant selected for bonding and sealing the edge attachment to the transparent composite. RTV-630 was a proven silicone sealant. It had been recommended for use on the transparencies of high-performance aircraft.

(g) Machinability

The machining quality of the fire-resistant transparent materials was determined for sawing, drilling, and routing. These were the three areas of mechanical working necessary for the fabrication of aircraft transparencies.

All the fire-resistant materials could be machined satisfactorily provided proper precautions were taken with material orientation, feed rate, and machine cutter design. Tables 51, 52, and 53 present summaries of the sawing, drilling, and routing studies, respectively.

The investigation on saw cutting revealed a specific characteristic that had considerable value and importance. The orientation of the composite on the saw table as it was advanced into the saw blade was perhaps the most important factor in developing a successful sawing operation.

It was determined that the fire-resistant ply was much less susceptible to cracking, chipping, and spalling if the composite was oriented with the acrylic face down rather than the polycarbonate face down. Examination of the sawing process provided a simple explanation. Because of the intimate in-situ bond at the acrylic-epoxy ply interface, the epoxy ply was firmly supported when oriented with the acrylic surface down.

However, with the polycarbonate surface down, the relatively soft interlayer between the epoxy ply and the polycarbonate ply did not support the epoxy ply firmly. The action of the saw blade caused some flexing of the epoxy ply. Because of the brittle nature of the material, this flexing could initiate cracking and chipping.

(h) Edge Attachment Specimen Tests

The edge attachment test specimen is shown in Figure 32.

Table 54 lists the tests that were conducted.

The edge attachment coupons were tested using two separate attachment configurations designated "A" and "B". As shown in Figure 33, the "A" configuration style resulted in a canopy profile that projected

TABLE 51. SUMMARY OF BANDSAWING CHARACTERISTICS - CONCEPT V COMPOSITES

Material code	Feed rate, cm/minute (in./minute)	Blade pitch	Fire-resistant ply position
28D	7.6 (3)	14, 18, 24	Down
	7.6 (3)	14, 18, 24	Up
30-I	7.6 (3)	14, 18, 24	Down
	7.6 (3)	24	Up
35	7.6 (3)	14, 18, 24	Down
28D	89 (35)	None for all cure stages	
30-I	89 (35)	14, 18, 24	Down
	89 (35)	24	Up
35	89 (35)	24	Down

Best results:

1. Low feed rate
2. High blade pitch
3. Epoxy ply down.

TABLE 52. SUMMARY OF DRILLING AND REAMING CHARACTERISTICS - CONCEPT V COMPOSITES

Drilling

1. Drill into polycarbonate ply (acrylic and epoxy ply down).
2. Back up acrylic ply with sacrifice material to preclude cracks and chips.
3. Use medium drilling speeds (1500 RPM).
4. Use liquid soap as coolant and lubricant.
5. Use very low drill feeds - remove drill from hole several times to facilitate chip removal and to preclude heat buildup.
6. Use special ground drill for plastics (60-deg drill point).
7. Advanced or final cure composites result in best hole finish.

Reaming

1. Use low reaming speeds (185 RPM).
2. Use liquid soap as coolant and lubricant.
3. Use slow feeds.
4. Reaming operation improved hole finish in the epoxy material.

TABLE 53. SUMMARY OF MACHINING AND ROUTING CHARACTERISTICS - CONCEPT V COMPOSITES

1. Use high-speed routers (18,000 to 20,000 RPM).
2. Cutters - 0.635 cm (1/4 in.), 0.95 cm (3/8 in.), or 1.27 cm (1.2 in.) diameter.
3. 2 or 4 flute - straight and spiral.
4. Can obtain 80 to 125 RMS - router finish.
5. Use normal precautions:
   a. Keep vibrations and chatter to a minimum.
      (1) Clamp work to guide bar securely.
      (2) Keep cutters sharp and clean.
   b. Feed router into work smoothly and slowly.

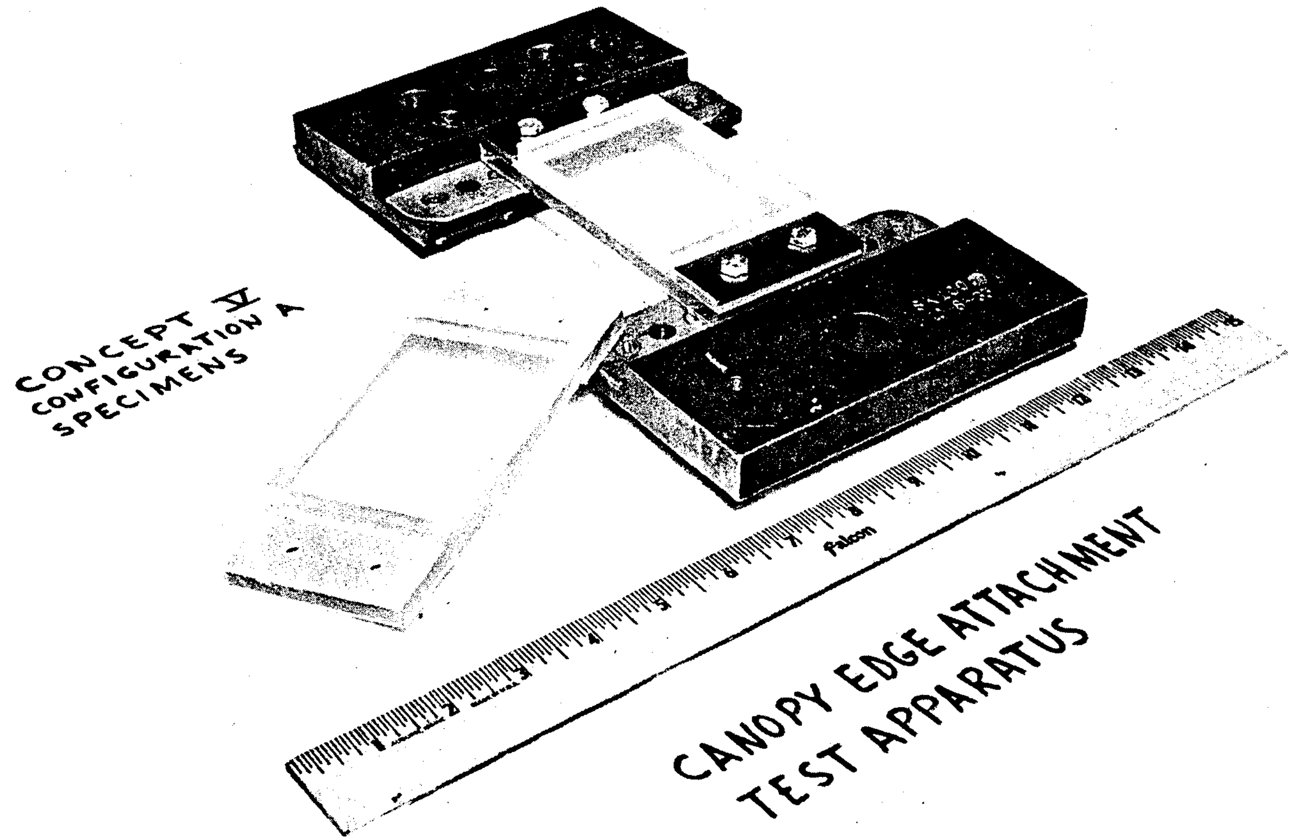

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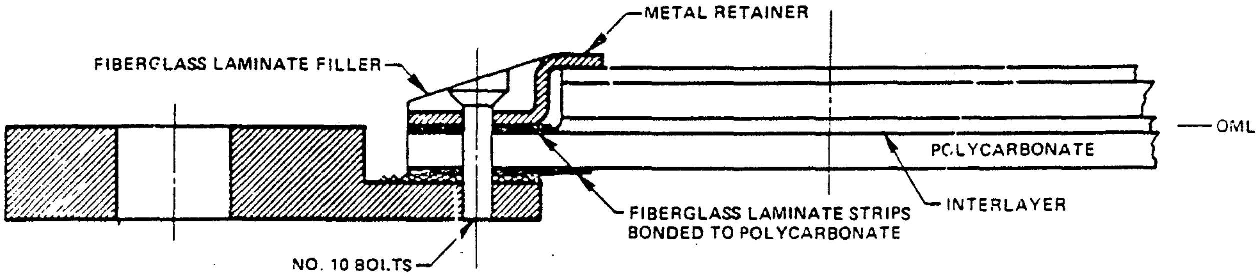
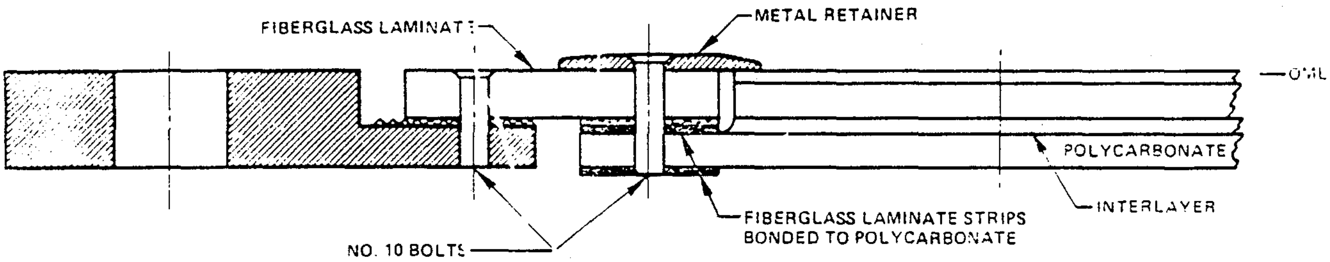
Figure 32. Edge Attachment Test Coupons.

TABLE 54. STRUCTURAL TEST COUPONS

Edge attachment coupons
a. Tension ultimate load at:
1. Room temperature
2. -40 deg F
3. 160 deg F
4. Room temperature after environmental exposure.
b. Tension repeated load at:
1. Room temperature
2. 160 deg F.



EDGEBAND TEST COUPON CONFIGURATION "A"
(OUTSIDE OML)



EDGEBAND TEST COUPON CONFIGURATION "B"
(INSIDE OML)

Figure 33. Edgeband Test Coupon Attachment Configurations.

outside the present outer mold line (OML) of the existing canopy but did not project into the cockpit area. The "B" style configuration maintained the existing OML of the canopy, but it encroached slightly into the cockpit area because of the increased overall thickness of the laminated transparency.

The tension ultimate load tests on the edgeband coupons consisted of applying a tensile load of 200 lb/in. (which was approximately equal to the tensile load on a modern combat aircraft canopy during maximum pressure condition) holding for five minutes, and then increasing the load to failure.

This was done at room temperature, at -40 deg F and at +180 deg F. These temperatures covered the extremes which the structural ply (polycarbonate) was expected to experience.

Also, a set of configuration "A" specimens was subjected to the ultimate load test at room temperature after environmental exposure. The environmental exposure was 30 days on the EMMAQUA exposure machine at the Desert Sunshine Exposure Test site.

The tension repeated load tests on the edgeband coupons consisted of applying a tensile load of 120 lb/in. and releasing it in approximately a one-minute cycle (30 seconds loading, 30 seconds unloading). This was done at room temperature and +180 deg F for 100 cycles at each temperature on configuration "A" coupons. The 120 lb/in. load was about 20 percent above the tensile load on a combat aircraft canopy during the cyclic pressure condition.

The test results are tabulated in Table 55. Based on a nominal 2.5-inch width for each test coupon the maximum design load was 500 lb. As indicated by Table 55, an approximate factor of 4 existed between the test failure load at 180 deg F and the maximum design load. The safety factors at room temperature and -40 deg F were somewhat larger.

TABLE 55. EDGE ATTACHMENT COUPON TEST RESULTS

	Ultimate load (lb)			Ultimate load after 30 days EMMAQUA	Repeated load (100 cycles) (pounds)	
	At -40 deg F	At room temperature	At 180 deg F	At room temperature	At room temperature	At 180 deg F
Concept V Configuration A						
1	4025	4020	3120	4125	300	300
2	4140	3930	2830	4025	300	300
3	4760	3925	3120	4150	300	300
4	4480	4025	3030	4190	-	-
5	4030	3990	3070	3950	-	-
Concept V Configuration B						
1	3635	2800	2650	-	300	300
2	3810	2925	2575	-	300	300
3	3630	3165	2475	-	300	300

The typical failure modes encountered during these tests involved bolt bending and/or bearing failures on one of the reinforcing laminates of the edge attachment. This was the expected mode of failure because of the single shear type of bolt loading for both Configuration A and Configuration B. Bolt bending tended to be more severe for the configuration B attachment style. Interlayer delamination occurred on only a small percentage of the tests and involved small portions of the total area. Only tensile failure of the overall composite occurred on a couple of coupons during low-temperature testing. Use of larger-diameter edge attachment bolts would lower the bearing and bolt bending stresses and thus increase the overall load capacity of the transparency, especially at elevated temperatures.

The 100-cycle repeated tensile load testing did not result in any visible degradation to any of the test coupons.

The edge attachment coupon test program showed that all the construction concepts tested had ample safety margins above the expected maximum design load. The load-carrying capability of the Configuration A style edge attachment was slightly higher than the Configuration B style except at elevated temperatures. The ultimate strengths of both styles could be increased by using larger-diameter attachment fasteners.

APPENDIX A -

HYBRID FIRE-RESISTANT LAMINATES

APPENDIX A - HYBRID FIRE-RESISTANT LAMINATES

1. GENERAL

The analysis of designs for fire-resistant edge attachments showed the following needs: (1) a laminate that retained a high degree of physical strength when subjected to an intense flame, and (2) also insulated against rapid heat flow through the laminate.

The early evaluation of edge attachment laminate materials indicated that the heat-resistant laminates had a rapid heat flow rate, while the laminates which provide a low thermal flow rate did so at a considerable sacrifice in strength.

It was considered appropriate to investigate in a preliminary manner, on Goodyear Aerospace IR&D funds, the possible advantages of hybrid laminates. A hybrid laminate is comprised of two or more reinforcement materials in a single matrix. The purpose is to tailor the performance of the composite so that optimum effectiveness is realized.

The unique individual performance of each reinforcing material enables the composite to exhibit properties that neither reinforcement can provide by itself.

The research undertaken in this preliminary effort was to investigate means by which an insulating char layer could form on the face of a laminate that still maintained high temperature strength.

2. EXPERIMENTAL LAMINATES

Woven fiberglass reinforcement provides an excellent high-temperature laminate when combined with a heat-resistant resin, such as EX-112. However, as demonstrated by the flame test results on an EX-112/fiberglass laminate, the fiberglass strands prevent or restrict formation of an expanded protective char.

On the other hand, organic fibers, such as nylon, Orlon, and Dacron, are softened and consumed by the flame. They expose the binder resin to the action of the flame.

Two experimental laminates were prepared from materials on hand. A sheet of char-forming resin, GAC-79 (a Goodyear Aerospace experimental fire-resistant transparent material) was used as the primary insulating layer against intense thermal radiation. The two experimental laminates were:

1. 3203/GAC79/3203 - A 0.225-in. layer of GAC-79 resin was faced with a 0.025-in. layer of 3203 epoxy/fiberglass laminate on the fronts and a 0.095-in. layer of 3203 on the backside.

2. Acrylic-nylon/GAC79/acrylic-nylon - A 0.225-in. layer of GAC 79 resin was faced on both surfaces with a 0.127-in. acrylic-nylon laminate.

These test laminates were prepared to determine the reaction of the char forming GAC-79 layer when the laminates were subjected to intense flame on the front face.

3. GOODYEAR AEROSPACE SPECIAL FLAME TESTER RESULTS

The two experimental laminates were tested on the Special Flame Test Facility. Results of the tests are shown in Table A-1.

On the first specimen, the epoxy-fiberglass face ply, even though it was quite thin, restricted the formation of an efficient protective char layer. The time required for the backside temperature to reach 400 deg F was nearly identical to the time required for the standard 3203 laminate tested during the evaluation tests in the contract.

However, as the face ply cracked and split, the char could expand slightly and provide some insulation as indicated by the leveling off of the backside temperature.

With the second experimental test specimen, the acrylic-nylon face ply burned away, permitting the GAC-79 layer to form an effective insulating char. The standard acrylic-nylon laminate evaluated during the contract had reached a backside temperature of 400 deg F in two minutes. The experimental laminate with the GAC-79 layer exceeded 20 minutes, which is comparable to the performance of the fire-resistant transparent Concept V composite.

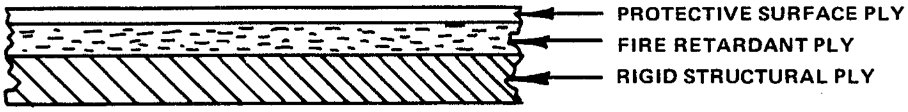
4. CONCLUSIONS

The preliminary tests discussed in this section indicate that a hybrid laminate could be designed that would greatly increase the insulating factor of an edge attachment laminate without noticeably sacrificing strength.

TABLE A-1. RESULTS OF GOODYEAR AEROSPACE SPECIAL FLAME TEST ON EXPERIMENTAL LAMINATES

Laminate construction	Thickness (inches)	Time for backside temperature to reach 400 deg F (minutes)	Reaction during test	Appearance after test	Remarks
Front face: 3203 fiberglass laminate	0.025	5.3	Light white smoke. Medium white smoke when flame was removed.	Front: 3-in.-diameter dark spot. 1-1/2-in. resin burn-out. Surface cracks with swelled up area. Back: 1-1/2-in.-diameter brown scorch.	Backside temperature was leveling off as it reached 400 deg F. Temp (deg F) / Time (minutes) 400 / 5.3 450 / 7.6 480 / 17+
Core: GAC-79	0.225				
Back face: 3203 fiberglass laminate	0.095				
Total	0.345				
Front face: acrylic-nylon laminate	0.127	20 (maximum temperature 382 deg F)	Sample burned. Light white smoke. Sample continued to burn when flame was removed. Required extinguishing.	Front: 3-in.-diameter cone-shaped char area. Back: 2-in.-diameter area slightly discol-ored. No blisters. Sample slightly warped.	Backside temperature had not reached 400 deg F after 20 minutes. The test was terminated. The peak temperature reached was 382 deg F.
Core: GAC-79	0.225				
Back face: acrylic-nylon laminate	0.127				
Total	0.480				

A tentative design is shown below:



Each component would function as follows:

1. The protective surface ply would protect the fire-retardant ply from environmental exposure and physical abuse. It would also support the bearing force of retaining bolts. The surface ply would use an organic reinforcement which would burn away in a fire, exposing the fire-retardant layer. This would allow the fire-retardant ply to char and form an insulating layer. The binder could be the same resin as used in the fire-retardant layer.

2. The fire-retardant ply resin must be an efficient char former, such as EX-112. For strengthening purposes, it may have to be reinforced with glass screen, metal screen, or an organic fiber net.

   It is possible that the fire-retardant ply could be reinforced to the extent that strength and bearing properties would be high enough to allow elimination of the separate protective surface ply. It would be necessary that the reinforcement did not prevent or seriously restrict the resin from forming an expanded insulating char. This could perhaps be accomplished by using consumable organic fibers for reinforcement.

Additional developmental effort would be necessary to determine the optimum reinforcement loading for proper balance between strength and char formation.

3. The structural ply would use fiberglass reinforcement with the same resin, if possible, as used for the fire-retardant ply. The structural ply would be the load carrying member. It would have to retain good physical properties at high temperatures (up to 400 deg F).

The minimum amount of effort conducted on this IR&D task indicates strongly that a satisfactory hybrid laminate could be designed that would provide an improved edge attachment laminate.

The selection of best materials, the proper balance for binder to reinforcement, and refinement of design will require additional developmental effort.

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
CR-166410		

4. Title and Subtitle	5. Report Date
Edge Attachment Study for Fire-Resistant Canopies	November 1979
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
G. E. Wintermute	GERA-2424
9. Performing Organization Name and Address	10. Work Unit No.
Goodyear Aerospace Corporation Arizone Division Litchfield Park, AZ 85340	RFP2-27572
	11. Contract or Grant No.
	NAS2-10065
12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
NASA-Ames Research Center Moffett Field, California 94035	Oct. 1978--Sept. 1979
	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

Twenty-two resin systems were evaluated in laminate form for possible use as edge attachment material for fire-resistant canopies. The evaluation uncovered an unexpected development when the laminates were subjected to an intense flame: (1) the high-heat-resistant materials could withstand the flame test quite well, but experienced rapid heat transfer through the test specimen; (2) the laminates which exhibited a low rate of heat transfer were materials which lost strength rapidly in the presence of the flame by decomposition, delamination, and blistering.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Edge Attachment Laminating Resin Fire-Resistant Transparency Fire Tests Transparent Composite Laminate Reinforcement	

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	155	

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