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CRACK FORMATION IN F-15 AIRCRAFT CANOPIES

Geoffrey J. Frank
Gregory J. Stenger

University of Dayton Research Institute
Dayton, Ohio 45469-0110

October 1990

Interim Report for Period May 1990 - September 1990

Approved for public release; distribution is unlimited.

FLIGHT DYNAMICS DIRECTORATE
WRIGHT LABORATORY
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433-6553

NOTICE

This technical report has been reviewed and is approved for publication.

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Project Engineer

Duncan A. Dversdall, Capt, USAF
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Program Office

Richard E. Colclough
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13. ABSTRACT *(Maximum 200 words)*
Cracks have been reported in F-15 transparencies. The cracks extend from the free edge of the transparency into the acrylic parallel to the transparency surface. Similar cracks were reported on F-4 transparencies in the early 1970's. Investigations at that time indicated that the crack growth had two phases: crack initiation and crack growth. Crack initiation was attributed to absorption and desorption of moisture. Crack growth was caused by thermal stresses due to the difference in coefficients of thermal expansion between the stretched acrylic transparency and the fiberglass edge attachment. Tests have been performed on samples from F-15 canopies to validate the crack growth mechanism. Research on the F-4 cracks showed that crack growth does not occur if nylon-acrylic composite, which has a coefficient of thermal expansion similar to that of stretched acrylic, is used as an edge reinforcement material.

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FOREWORD

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The work described herein was conducted during the period May 1990 through September 1990. University of Dayton project supervision was provided by Mr. Dale H. Whitford, Supervisor, Aerospace Mechanics Division, and Mr. Blaine S. West, Head, Structures Group.

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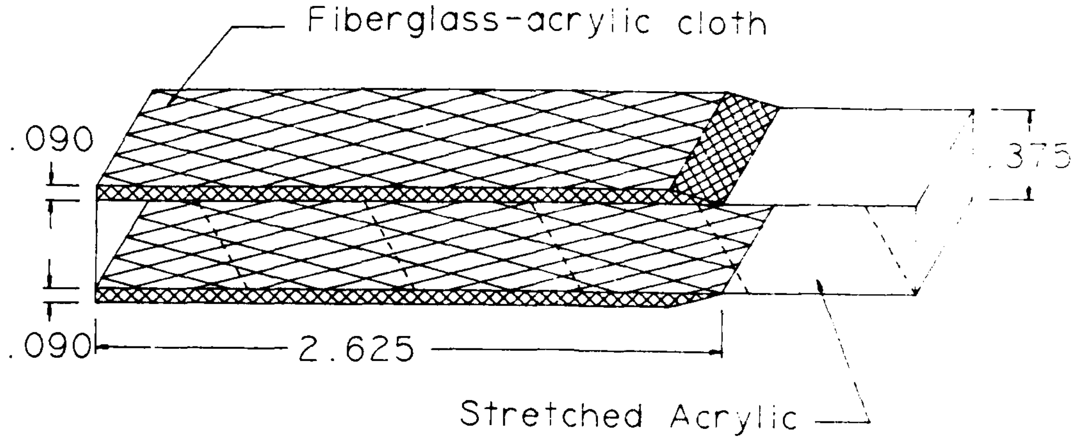
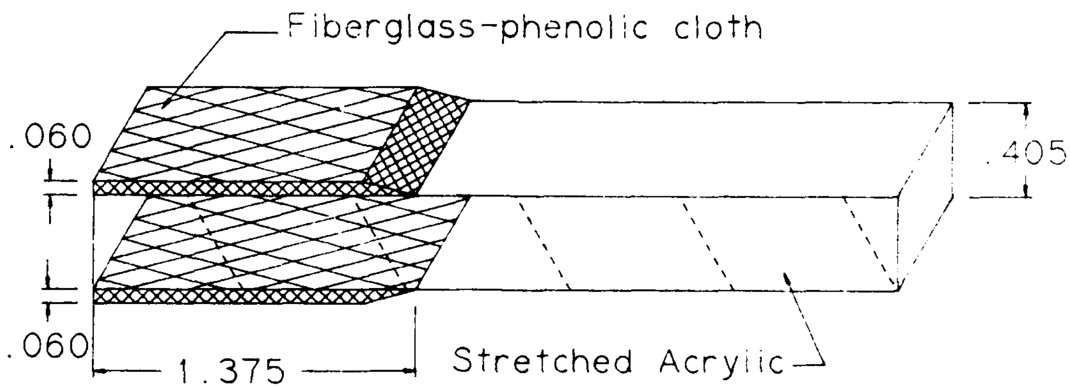
SECTION 1
INTRODUCTION

The formation of cracks was observed in the stretched acrylic of F-15 canopies and windshields during service. The cracks start at the free edge of the transparencies and extend into the acrylic parallel to the surface of the transparency. The cracks generally occur near the mid-surface of the acrylic and were not observed to extend as far as the line of bolt holes near the edge of the transparencies. The majority of the cracks are tightly closed, but the cracks on some windshields are visibly open.

Similar edge cracks were previously investigated for F-4 canopies [1]. The F-4 canopies were made of stretched acrylic with fiberglass edge attachments similar to those of the F-15. The cracks on F-4 canopies occurred during storage and extended the entire width of the edge attachment. The results of the investigation of the F-4 cracks are summarized below, and the entire article (Reference 1) is included as an appendix. The geometry and materials for the F-4 and F-15 edge attachments are shown in Figure 1. Although the canopy edge configurations are not identical, they are similar enough to indicate that the results of the F-4 investigation are applicable to the F-15. A limited number of experiments was performed to verify that the crack propagation mechanism presented in the earlier work applies for the F-15 transparencies.



F-4 Canopy Edge Attachment (Ref 1)



F-15 Canopy Edge Attachment

Figure 1. Edge Attachments for F-4 and F-15 Canopies.

SECTION 2

PHYSICAL APPEARANCE OF CRACKS

Specimens were cut from the edges of both forward and aft canopies. The cracks appeared to be typical of those examined on several canopies. The cracks on one sample are shown in Figure 2, where the edge attachment has been removed. Microscopic evaluation of the edge cracks showed a large number of microcracks originating at tool marks and abrasions on the edge. Most of these cracks are less than 0.05 in. deep. A single larger crack usually occurs near the mid-surface of the canopy. The larger cracks have alternating regions of cyclic marks, indicating fatigue, and river patterns, indicating a tensile overload. In none of the samples examined does the crack front continue beyond the bolt holes. Also, cracks which originate at the bolt holes do not propagate outside of a region near the bolt hole. This indicates that compression from the bolts arrests the crack growth.

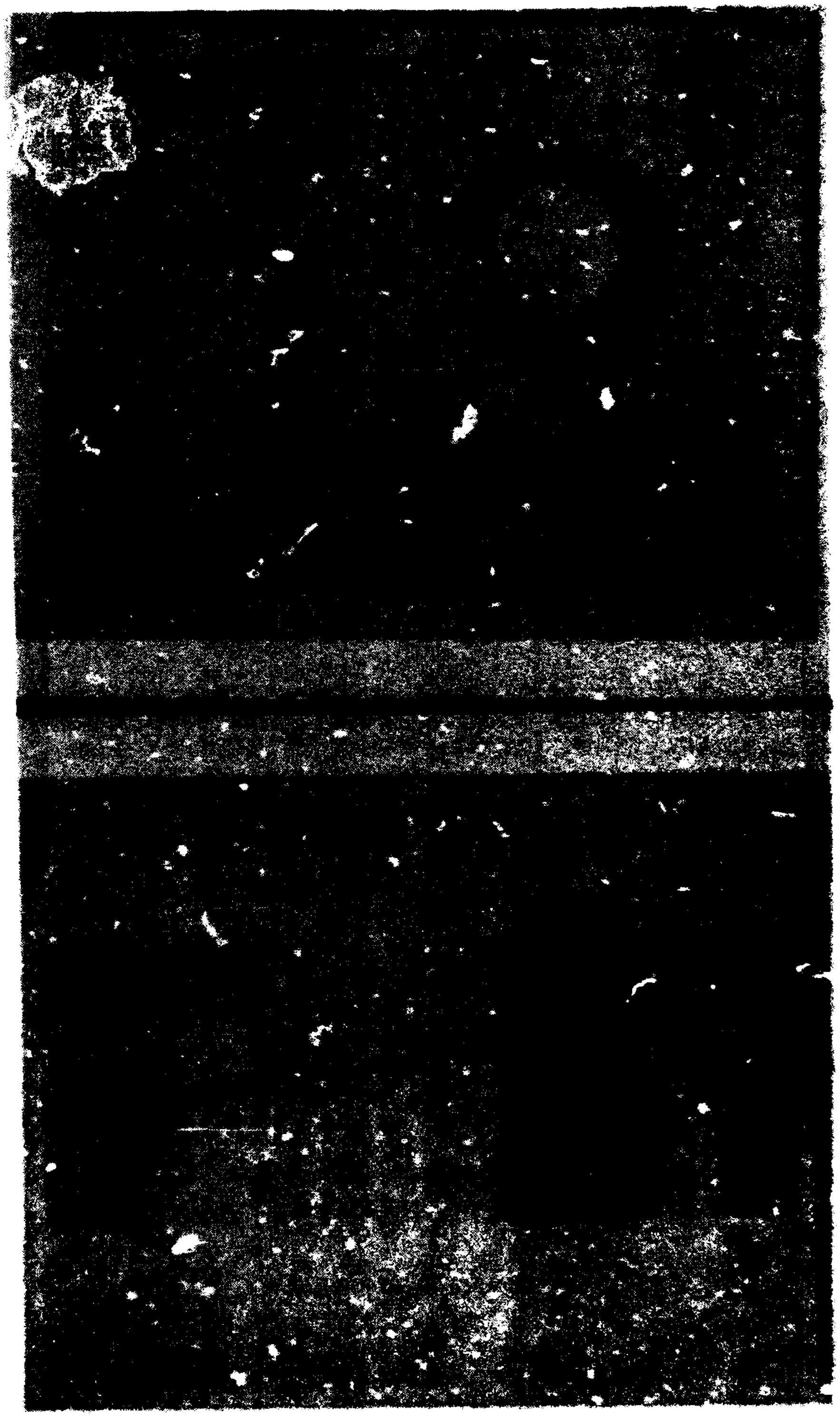


Figure 2. Typical Edge Crack Patterns in F-15 Canopy.

SECTION 3

SUMMARY OF F-4 INVESTIGATION

An investigation of edge cracks which formed in F-4 aircraft canopies during storage was divided into 3 parts: bearing strength evaluation, determination of conditions for crack initiation, and determination of conditions for crack propagation. The F-4 edge crack investigation is presented in the appendix. A summary of the results is presented below.

3.1 Bearing Strength Evaluation

Tensile tests were conducted to evaluate the change in bearing strength of the edge attachment due to the presence of in-plane cracks (Appendix, p.14). Test specimens were manufactured from samples of canopies and from new material as a control. Tests were conducted on samples with and without fiberglass edge attachments and with nylon edge attachments. The results indicated:

1. The bearing strength of specimens with edge attachments was not decreased by the presence of in-plane cracks.

2. Stretched acrylic specimens with fiberglass edge attachments actually failed in tension at the tapered junction of the edge attachment and acrylic due to stress concentrations.

3. Canopy specimens with fiberglass edge attachments failed at loads 1/3 less than those for the control specimens without edge attachments.

4. Stretched acrylic specimens without edge attachments failed in bearing at a higher loads than specimens with edge attachments.

3.2 Crack Initiation Studies

Tests were conducted to determine the effect of temperature and moisture on stretched acrylic (Appendix, p. 15). The edge attachment specimens used had no initial cracks. Results were:

1. No cracks were initiated by heating the specimens to 160°F for extended lengths of time, or after 64 3-hour cycles between room temperature and 160°F.

2. Preconditioning specimens at 95% relative humidity (RH) for 16 days at room temperature followed by heating to 160°F produced cracks in some specimens. Longer times or higher temperatures for preconditioning increased the percentage of samples which cracked.

3. Preconditioning to a moisture content of 1.6% (achieved after 7 days at 160°F and 95% RH) produced cracks in all specimens when subsequently exposed to low RH. Preconditioning to 1.1-1.3% moisture content produced cracks in some specimens when exposed to low RH. Cracks were not initiated in specimens with lower moisture contents.

4. Increasing the smoothness of acrylic sample edges by polishing appeared to decrease the time for crack initiation. However, insufficient tests were conducted to quantify any changes in crack initiation time.

3.3 Crack Propagation Studies

A fracture mechanics model was developed to determine the temperature at which crack propagation would begin due to stresses caused by the mismatch in coefficients of thermal expansion (CTE) between fiberglass and acrylic (Appendix, p. 16). The model treated one-half of the thickness of the edge attachment as a cantilever beam under uniform bending. The temperature T at which a crack would propagate was found to be:

$$T = \frac{(GbEI)^{\frac{1}{2}}\, h}{2(\alpha_1 - \alpha_2)EI} + T_0$$

where G is the fracture energy, b is the specimen width, EI is the flexural rigidity of the beam, h is the beam thickness, T_0 is a reference temperature, and $\alpha_1 - \alpha_2$ is the difference between the CTE's of the acrylic and fiberglass. Using temperature dependent values for α_1 and E found in [2] and a room temperature fracture energy 0.188 in•lb/in^2 from [3], the critical temperature for fracture of the F-4 canopy acrylic was estimated to be 170°F. Using this method, the critical temperature for fracture of the F-15 canopy acrylic was calculated to be 160°F.

Tests were conducted to experimentally determine conditions for crack propagation. Results of these experiments were:

1. Milling 60° grooves in the edge of the samples with fiberglass edge attachments and heating to 160°F did not cause crack propagation.

2. Initiating a crack at the base of the groove and heating to 160°F did cause crack propagation.

3. Cracks propagated after 3 or more hours at temperatures between 110°F and 120°F.

4. No cracks propagated in samples where nylon was used in place of the fiberglass edge attachment.

SECTION 4

CRACK PROPAGATION VERIFICATION

The ability of thermal stresses to propagate cracks in F-15 canopies was verified using finite element analysis and experiments.

A non-linear finite element (FE) model of the F-15 canopy edge was developed using the COSMOS/M program. Plain-strain conditions and uniform temperature throughout the material were assumed. Temperature dependent moduli and CTE's were used. Acrylic properties from [2] and fiberglass-phenolic properties from [4] were used. Stress at the edge of the acrylic on the centerline is shown in Figure 3. The stress is directed along the edge. The values are much lower than the 3000 psi tensile strength measured through the thickness of specimens cut from F-15 windshields.

An FE model like that described above was developed which included an 0.05 inch long crack extending in from the edge at the centerline. The stress intensity factor K_I at the crack tip is shown in Figure 4. Ref. [5] gives a room temperature fracture toughness (critical stress intensity factor) for stretched acrylic of K_I = 600 lb-in$^{3/2}$. Based on this value the model predicts crack propagation at 125°F. Thus, the models indicate that thermal stresses are not sufficient to cause fracture but can propagate existing cracks, in agreement with the results of the F-4 investigation.

To further validate the results from the F-4 investigation, five samples cut from an F-15 canopy (Swedlow Inc., F1608-86-G-0627-RJOS) were heated to observe crack growth. Samples were tested with both microscopic (less than 0.01 in) and macroscopic (≈0.20 in) cracks. Fiberglass edge attachments were removed from some of the samples. Nominal sample dimensions were 3x5 in. The samples were heated using an infra-red heat source on one side to

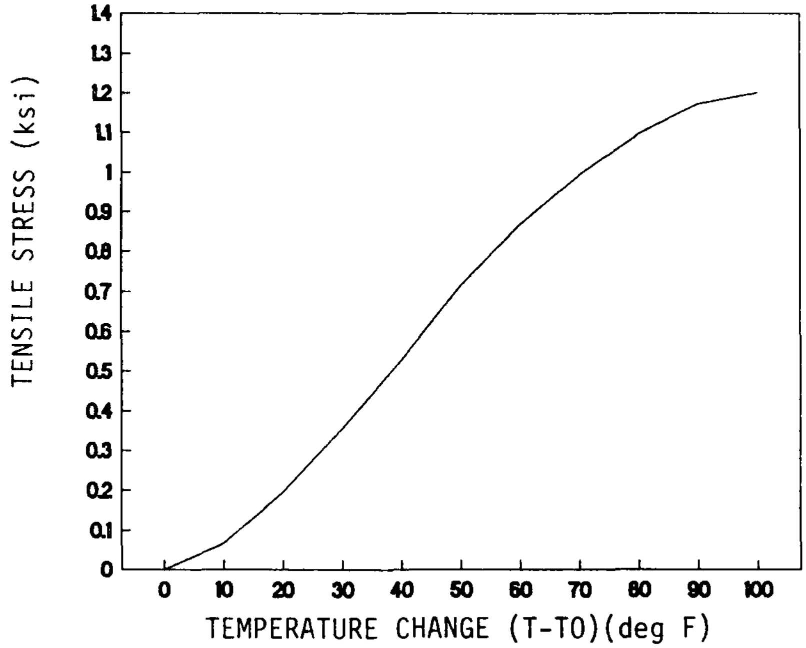


Figure 3. Stress in Thickness Direction at F-15 Edge.

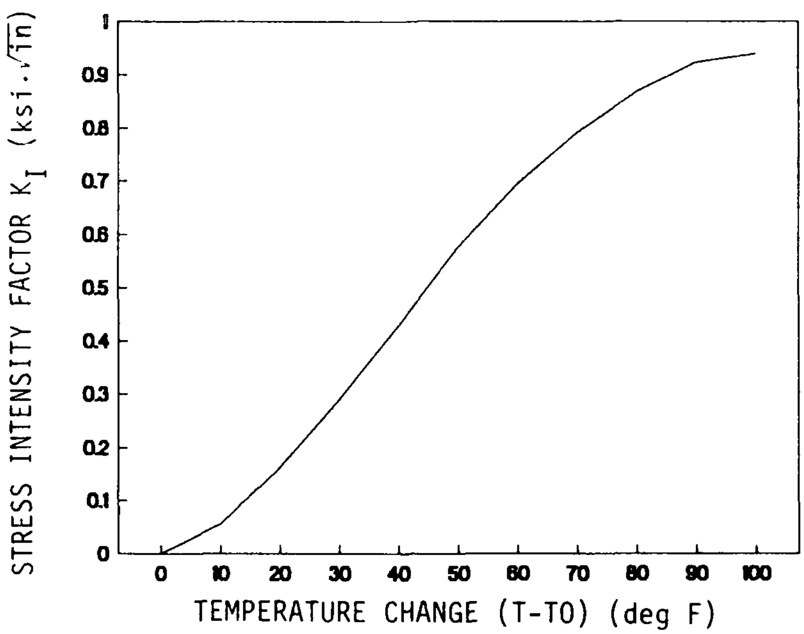


Figure 4. Stress Intensity at the Tip of 0.05 in. Crack in F-15.

approximate aerodynamic heating. The specimens were heated at 4°F/min as measured by a thermocouple mounted on the side closer to the heat source. Five tests were performed. The specimen configurations and test results are listed in Table 1.

Table 1 - Crack Propagation Tests on F-15 Edge Attachment

Sample	Edge Attachment	Initial Crack Length	Results
1	X	micro	No effect after 2 hr @ 180°F
2		micro	Cracks after 12 min @ 180°F
3		0.20"	Crack growth @ 168°F
4		0.22"	Crack growth @ 163°F
5	X	0.25"	No effect after 2 hr @ 180°F

(X indicates fiberglass edge attachment was removed)

Crack growth occurred only on samples which had fiberglass edge attachments. Cracking initiated at the corners where the resultant stress through acrylic would be the greatest. On specimens 3 and 4 the fracture extended the existing crack at the mid-surface. On sample 2, fracture occurred near the heated surface due to the asymmetric heating. Since most of the transparency cracks were observed to lie nearly in the middle of the acrylic, it is likely that fracture occurs due to uniform heating, such as occurs in storage or on the flight line.

SECTION 5
SUMMARY AND CONCLUSIONS

Similarities in the geometry and materials of the F-4 and F-15 edge attachments indicate that the results of edge crack studies for the F-4 are applicable to the F-15. Simple experiments conducted on F-15 canopy materials verified the reported crack growth mechanism. Principle results of the investigation are:

1. Stresses due to a mismatch in coefficient of thermal expansion (CTE) between fiberglass/epoxy edge attachment and stretched acrylic propagate cracks at the edge of the acrylic. The stresses are too low to cause fracture in uncracked specimens, but do propagate cracks.

2. Cracks will not propagate if an edge attachment material which closely matches the CTE of acrylic is used. A suitable material is a nylon-acrylic composite.

3. Visual inspection shows that many microcracks exist at the edge of the acrylic. Absorption of moisture followed by exposure to low humidity or prolonged exposure to high temperature and humidity can initiate cracks. Other processes may also occur which initiate the cracks.

4. Bearing strength was not significantly affected in F-4 samples cracked the entire width of of the edge attachment. Similar results can be expected for F-15 samples which have a similar geometry. Tensile tests showed that the presence of cracks does not significantly reduce the bearing strength of the edge. However, a reduction in bending strength may occur.

5. None of the cracks on the test specimens or inspected canopies were observed to remain open at room temperature, as has been reported on some F-15 windshields. Operating temperatures of F-15 windshields are in a range where stress relaxation and thermal relaxation may cause permanent deformation which results in the cracks remaining open at room temperature. These effects have not been investigated.

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APPENDIX
(Reference 1)

CRACK FORMATION IN F-4 AIRCRAFT CANOPIES

by

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Abstract

The initiation of cracks in stretched acrylic plastic has been reported for F-4 canopies under storage conditions. The cracks started at the edge and propagated parallel to the plane of the sheet between the fiberglass-acrylic edge attachments. However, laboratory tests indicated that the presence of these cracks has negligible effect on the bearing strength of the edge attachment.

A limited investigation was undertaken to determine the conditions under which the crack formed in the canopy. There appears to be two separate processes: crack initiation and crack propagation.

The former is the more complex phenomenon. It was shown that cracks will initiate in stretched acrylic plastic when it contains over 1.6% moisture and is then exposed to low humidity. The exact conditions for crack initiation were not defined.

Cracks will propagate in stretched acrylic with a fiberglass edge attachment if cracks are present and the assembly is heated to 120°F or higher. They do not propagate with a nylon edge attachment. Using a fracture mechanics approach, in which the difference in thermal expansion produces an opening mode force, it is possible to predict the temperature at which an existing crack will propagate. This was calculated to be approximately 170°F. which was substantially verified in experimental tests. However, existing crack do not propagate at elevated temperatures when a nylon reinforced edge attachment is used because there is little difference in the coefficients of thermal expansion of the acrylic and the nylon-acrylic laminate.

Introduction

The formation of cracks was observed in the stretched acrylic of F-4 aircraft canopies while in storage prior to service. The cracks initiated at the end of the edge attachment and propagated parallel to the plane of the sheet into the interior of the canopy as far as the end of the edge attachment. These canopies are formed of 3/8-inch thick stretched acrylic and have a fiberglass-acrylic edge attachment. An investigation was undertaken of the origin of these cracks and of their effect on the performance of the canopy.

The investigation is divided into three parts: bearing tests, crack initiation studies and crack propagation studies. The effect of in-plane cracks on the performance of the edge attachment was evaluated by determining the bearing strength of specimens modeling an edge attachment assembly. In studying the problem of the origin of the in-plane cracks, attention was directed to the effects of variations in temperature and in humidity, since those are the two parameters that would vary during the storage of the canopies. This part of the study was subsequently divided into two separate problems; crack initiation and crack propagation, since it became apparent during the investigation that these processes occurred under different conditions.

Materials

Two F-4 aircraft canopies that had formed edge cracks during storage were furnished by Mr. R. E. Wittman of the Air Force Flight Dynamics Laboratory at Wright-Patterson Air Force Base. The stock number was 1560 788 6502. Uncracked specimens were obtained from samples of the typical edge attachment, purchased from Swedlow Inc. (Fig. 1). In addition, to provide a comparison, edge attachment material of the same configuration was obtained using nylon fabric as the reinforcement instead of fiberglass. In some cases, tests were also conducted on control stretched acrylic and on stretched acrylic taken from the canopy, both without an edge attachment.

Bearing Studies

A limited investigation was conducted of the effect of in-plane cracks in the acrylic on the bearing strength of the edge attachment at room temperature. Specimens were prepared using the geometry which approximated the configuration used in the aircraft. 1/4-inch diameter holes were drilled in specimens 1/2-inch from the end. The specimens were 1-inch wide, since the bolt holes on the canopy were that distance apart. The holes were drilled through the fiberglass edge attachment and the acrylic, and a metal face plate applied to each surface and the assembly bolted together using a typical service bolt tightened to the aircraft manufacturer's specified torque of 40 in.-lb. Tensile loading was applied to the acrylic plastic at one end of the specimen and to the edge attachment assembly at the other end through the bolt.

Tests were conducted on the control edge attachment material as well as on specimens taken from F-4 canopies and on specimens of stretched acrylic with no edge attachment. Some of the specimens were tested containing cracks parallel to the surface whereas others were uncracked.

Most of the specimens were tested with the bolts torqued to 40 inch-lbs., but several were tested with the bolts just finger tight.

The results are presented in Table I. They indicate the following:

1. Edge attachment specimens with cracks fail at approximately the same loads as those specimens without cracks. The presence of a crack parallel to the surface in the stretched acrylic does not reduce the bearing strength of the material.

2. Actually, stretched acrylic specimens with a fiberglass edge attachment do not fail in bearing. They fail in tension at the tapered junction of the edge attachment and the stretched acrylic due to the stress concentration caused by the difference in stiffness.

3. The canopy specimens with edge attachment failed at loads approximately 1/3 less than those for control edge attachment material. This reduction is probably caused by degradation of the resin matrix in the edge attachment composite, increasing the stress concentration at the tapered end of the edge attachment.

4. Stretched acrylic, tested in bearing, fails at the same or slightly higher load than control material with a fiberglass edge attachment. However, the acrylic does not decrease in bearing strength due to aging, and as a result its strength is almost double that of the aged canopy edge attachment material. The need for edge attachment reinforcement in combination with stretched acrylic glazing must again be questioned.

5. The data are not definitive with regard to the effect of bolt torque on the load at failure.

Crack Initiation Studies

In studying the initiation of cracks in the edge attachment assembly a series of tests were conducted to determine the effect of moisture and temperature on the behavior of the acrylic plastic with no initial cracks.

The results are summarized in Table II. It was found that heating the control fiberglass edge attachment assembly at 160°F for extended period of time did not result in crack initiation, nor did cycling from room temperature to 160°F for sixty-four cycles result in crack initiation. The possible role of moisture was introduced by conditioning the specimens at high humidity at various temperatures before heating to 160°F. Conditioning at 75°F and 95% RH followed by heating to 160°F did not result in crack formation. However preconditioning at 140°F and 95% RH did result in crack initiation in a number of specimens. Preconditioning at 160°F and 95% RH also resulted in some crack initiation, but when the preconditioning period was extended to 7 days, all of the specimens cracked except for the stretched acrylic with no edge attachment, taken from the canopy. Making the exposed acrylic edge extremely smooth by polishing decreased the time for crack initiation, whereas roughening the surface with a coarse file increased the time required for a crack to form. Finally, preconditioning the specimen in water at 160°F for 7 days led to crack initiation in all of the specimens tested, including the stretched acrylic with no edge attachment exposed to 75°F and low RH.

To determine how the preconditioning affected the moisture content of the stretched acrylic, water absorption measurements were made on test specimens for various conditions for 7 days. The results are presented in Figure 2. It appears that if the moisture content of the stretched acrylic is 1.6%, which is achieved in water at 160°F in 7 days, then cracks will initiate in all specimens when exposed to low RH. From 1.4 to 1.6%, which is achieved at 160°F and 95% RH in 7 days, cracks will initiate in specimens with edge attachment when heated to 160°F. If the moisture content is approximately 1.1-1.3%, which is reached at 160°F and 95% RH in 4 days or 140°F and 95% RH in 7 days, then some specimens will crack. At lower moisture contents, stretched acrylic specimens will not form cracks when heated to 160°F.

The acrylic plastic edge of the as-received edge attachment assembly was fairly rough and tool marks were visible. However the limited tests conducted indicated that polishing would not retard the formation of cracks and instead might accelerate their initiation.

In several of the tests, acrylic plastic from the aged canopy did not crack whereas the remaining test specimens did. The reason for this behavior is not apparent.

There are a number of questions regarding crack initiation that were not answered by this limited investigation. Conditions under which cracks may initiate have been determined but it was not demonstrated that conditions of this type were encountered in the storage of the canopies that cracked. However, due to the limited scope of this investigation, further studies to clarify these questions were not pursued.

Crack Propagation Studies

The difference in coefficient of thermal expansion between acrylic plastic and fiberglass-acrylic laminate is well known and is presented in Figure 3 (Ref. 1). An analysis was conducted to determine under what conditions the stresses induced in the stretched acrylic plastic due to this thermal mismatch could produce crack propagation in the acrylic.

If the edge attachment segment is analyzed as a cantilever beam under uniform bending (Figure 4), a failure criterion can be developed to predict the temperature at which the initial crack will propagate.

At the acrylic-fiberglass interface the strain is

$$(\Delta\alpha\ \Delta T) = (\alpha_1 - \alpha_2)\ (T-To)$$

where $\Delta\alpha$ is the difference in coefficients of thermal expansion, $(\alpha_1 - \alpha_2)$, of the acrylic and the fiberglass, respectively, and ΔT is the difference in temperature (T-To). Using this value of strain, the corresponding bending moment is,

$$M = \frac{2(\Delta\alpha\Delta T)\ EI}{h}$$

where h is one-half the thickness of the acrylic, and EI is the flexural rigidity of the beam.

For a cantilever beam under uniform bending, the strain energy release rate, $\mathcal{G}$, can be expressed as

$$\mathcal{G} = \frac{M^2}{bEI}$$

where b is the width of the acrylic specimen. Substituting the expression for the thermally induced moment, M, yields a relation between, $\mathcal{G}$, and temperature,

$$\mathcal{G} = \left[\frac{2(\alpha_1 - \alpha_2)\ (T-To)\ EI}{h}\right]^2 \frac{1}{bEI}$$

This expression can then be solved for the temperature as follows,

$$T = \frac{(\mathcal{G}bEI)^{\frac{1}{2}}\ h}{2(\alpha_1 - \alpha_2)EI} + To$$

Since both α and E are temperature dependent, these quantities must be represented as function of temperature in order to calculate the critical temperature at which crack propagation occurs, T.

In addition the strain energy release rate for this mode of crack propagation must be known. Broutman and McGarry (Ref. 2) have reported values of the surface work (or one-half the fracture energy) for crack propagation parallel to the plane of a multiaxially stretched (55%) acrylic sheet of 1.65×10^4 ergs/cm^2 (0.094 in.-lb/in.^{2}) at room temperature.

Using this value to compute the strain energy release rate, the critical temperature is estimated to be approximately 170°F. It should be noted that this is a two-dimensional analysis, and that the experimental value of fracture energy was reported for room temperature and not at the critical temperature. At corners of the canopy the bending moment acts in two directions, and hence initiation and propagation of cracks are more likely to occur here at lower temperatures.

Tests were conducted to determine experimentally under what conditions cracks would propagate in the stretched acrylic at the edge attachment. The results are summarized in Table III. In the first set of tests, it was found that when specimens with 60° grooves machined in the acrylic at the end of the edge attachment were heated to 160°F, cracks did not propagate from the tip of the groove. In the next set of tests, an actual crack was initiated in each specimen by machining a notch in the end and then driving a wedge into the notch until a uniform crack formed along the length of the specimen. When specimens of this type with a fiberglass-acrylic edge attachment were heated to 160°F, the crack propagated. However, with a nylon-acrylic edge attachment, the cracks did not propagate.

A third group of tests were conducted to determine the minimum temperature at which cracks will propagate. This was found to be between 110° and 120°F for stretched acrylic with a fiberglass-acrylic attachment.

Finally, tests were conducted to determine if there is a minimum length crack that will propagate when the assembly is heated. Cracks approximately 1/16-, 1/8-, and 1/4-inch long were initiated in specimens with a fiberglass edge attachment. Cracks propagated in all of the specimens when heated to 160°F.

Thus when a crack is initiated in stretched acrylic with a fiberglass edge attachment, the crack will propagate if the assembly is heated to 120°F or higher. Cracks do not propagate with a nylon edge attachment even at 160°F.

Summary and Conclusions

Studies were conducted to determine the effects of in-plane cracks in the stretched acrylic on the performance of a fiberglass edge attachment assembly and to determine the origin of cracks that form in storage in canopies using this material.

Bearing tests on the edge attachment assembly indicated that:

1. The presence of cracks parallel to the surface in the stretched acrylic does not reduce the bearing strength of the material.

2. This assembly does not fail in bearing but instead in tension at the tapered end of the fiberglass reinforcement due to the stress concentration caused by the change in stiffness.

3. The aged edge attachment material fails at loads approximately one-third less than that for unaged material.

4. When the stretched acrylic alone is tested in bearing, it fails in tension at the bolt hole at loads that are the same or slightly higher

than the control material with fiberglass reinforcement and approximately double that of the aged edge attachment. This again raises the question of the justification for fabric reinforcement when stretched acrylic is used in aircraft canopies.

Studies of the initiation of cracks in stretched acrylic indicate that if the moisture content is 1.6% or above, cracks will initiate when the material is exposed to low humidity. At lower moisture contents, crack initiation is not consistent. The exact conditions at which cracks will form after this preconditioning were not determined.

Once a crack has initiated in stretched acrylic with a fiberglass edge attachment, it will propagate if the assembly is heated to 120°F or higher. However, cracks will not propagate with a nylon edge attachment even at 160°F. Using a fracture mechanics approach, in which the difference in thermal expansion produces an opening mode force, it is possible to predict the temperature at which an existing crack will propagate. This analysis predicts the behavior of the fiberglass edge attachment as well as the nylon edge attachment.

This limited investigation has not established that F-4 canopies can attain a moisture content of approximately 1.6% in storage. However, it is not unreasonable that this condition is attained and that subsequent environmental conditions could lead to the formation and propagation of cracks that have been observed in the canopies. The use of a nylon edge attachment would eliminate the propagation of the cracks. However, it has not been demonstrated that these in-plane cracks pose a danger to the structural integrity of the canopy.

Acknowledgement

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TABLE 1. BEARING TESTS OF F-4 EDGE ATTACHMENTS

	CRACKED[a]	EDGE ATTACHMENT[b]	BOLT TORQUE[c]	FAILURE LOCATION[d]	FAILURE LOAD lb.
CONTROL MATERIAL		X	40	EAB	1700
		X	F	EAB	1750
	X	X	40	EAB	1990
	X	X	F	EAB	1840
			40	HOLE	2150
			F	HOLE	1710
CANOPY MATERIAL		X	40	EAB	1180
		X	40	EAB	1245
		X	40	EAB	1210
	X	X	40	EAB	1160
	X	X	40	EAB	1070
	X	X	40	EAB	1260
			40	HOLE	2250
			40	HOLE	2300

a. X indicates crack in stretched acrylic parallel to the plane of the sheet.
b. Specimens without X were stretched acrylic with no reinforcement.
c. 40 inch-pounds or finger tight.
d. EAB indicates tensile failure in the acrylic at the end of the edge attachment. Hole indicates tensile failure initiating at the bolt hole.

TABLE II: CRACK INITIATION STUDIES OF F-4 EDGE ATTACHMENT

	CONTROL			CANOPY
	FIBERGLASS E/A[a]	NYLON E/A	NO E/A	NO E/A
1. 160°F	(1/15) Cracked			
2. Cycle 75°-160°F 64 3 Hr Cycles	No Cracks			
3. 75°F/95%RH/16 Days to 160°F	No Cracks			
4. 140°F/95%RH/7 Days to 160°F	(1/3) Cracked in 1 Hr. [b]	(3/3) Cracked in 1½, 1½, 5 Hr.	(2/3)Cracked in 3,5 Hr.	(1/3)Cracked in 3 Hr.
5. 160°F/95%RH/4 Days to 160°F	(1/3) Cracked			(0/3 Cracked)
6. 160°F/95%RH/7 Days to 160°F	(3/3) Cracked in 1/3, 3, 3 Hr.	(3/3) Cracked in 5 Hr.	(3/3)Cracked in 2/3, 2/3, 3 Hr.	(0/3 Cracked)
Varied Surface Roughness	Polished - 20 Min. A/R - 40 Min.[c] Roughened - 120 Min.	A/R - 20 Min.		
7. 160°F Water/7 Days to 160°F	(3/3) Cracked in 2/3, 1, 1½ Hr.	(3/3) Cracked in 1/3, 1½, 1½ Hr.	(3/3) Cracked in 2/3, 2/3, 2/3 Hr.	(3/3) Cracked in 2/3, 1, 1½ Hr.
8. 160°F Water/7 Days to 75°F Low RH			(4/4) Cracked	

a. E/A = Edge Attachment
b. (1/3) = 1 specimen out of 3 specimens tested
c. A/R = As received

TABLE III: CRACK PROPAGATION STUDIES OF F-4 EDGE ATTACHMENT

	CONTROL	
	FIBERGLASS E/A[a]	NYLON E/A
1. HEAT AT 160°F (60° GROOVES IN END)[b]	NO EFFECT	
2. HEAT AT 160°F (CRACKS INITIATED IN END)	PROPAGATE	DO NOT PROPAGATE
3. HEAT AT VARIOUS TEMP. (CRACKS INITIATED IN END)	PROPAGATES @ 130°F/1 HR. PROPAGATES @ 120°F/3 HR. NO PROPAGATION @ 110°F	NO PROPAGATION UP TO 130°F
4. HEAT AT 160°F (CRACKS INITIATED IN END)	1/16-[c], 1/8-, 1/4-INCH CRACKS PROPAGATE	

a. E/A = edge attachment.

b. End refers to stretched acrylic at free edge of canopy, in between fiberglass reinforcement. (See Fig. 1). Grooves or cracks were parallel to the plane of the sheet.

c. Length of cracks initiated in end.

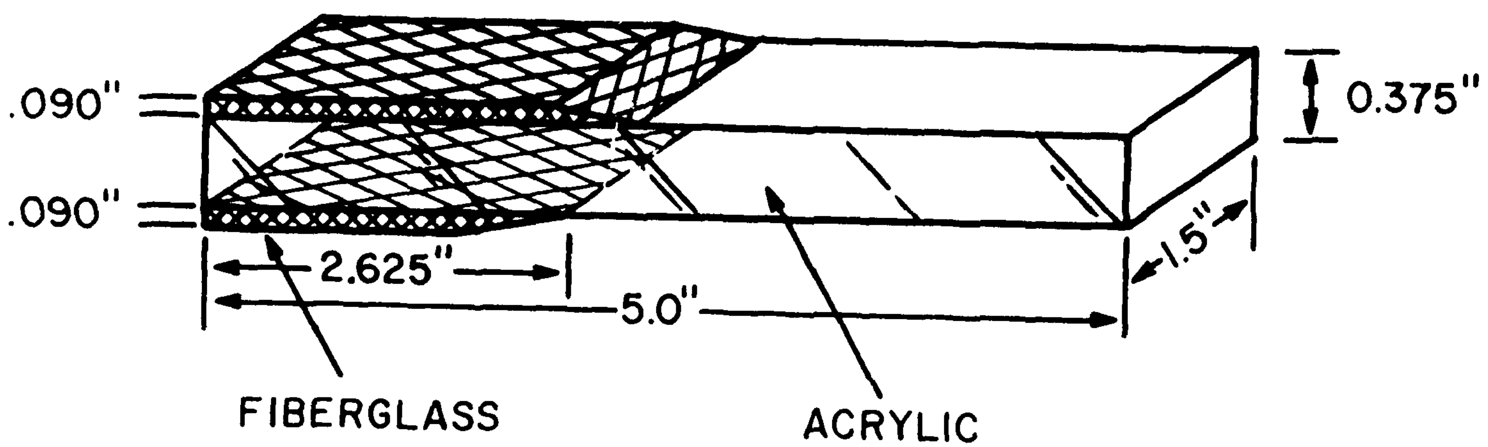

Figure 1: F-4 Canopy Edge Attachment

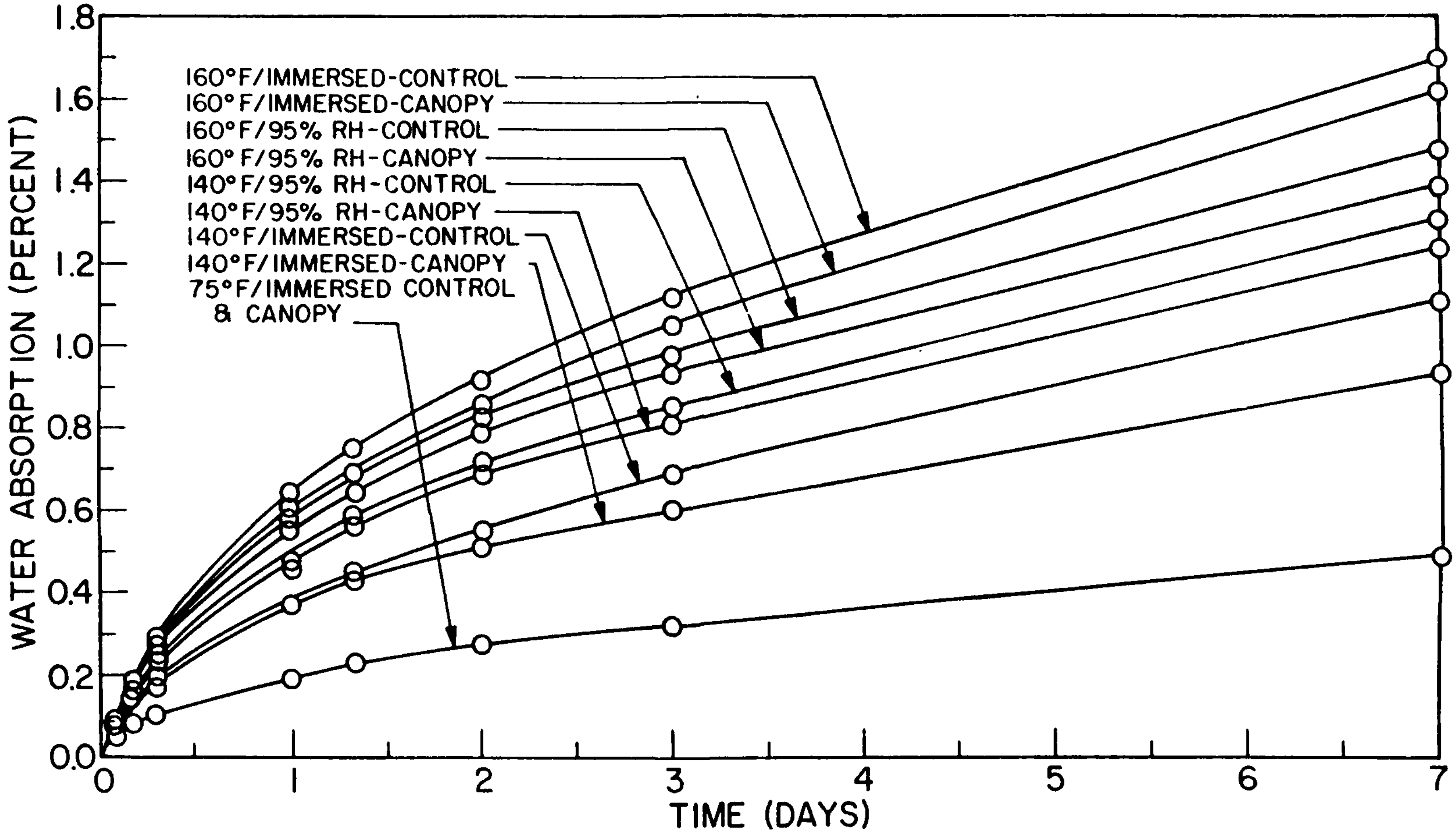

Figure 2 Water Absorption of Stretched Acrylic (65%)

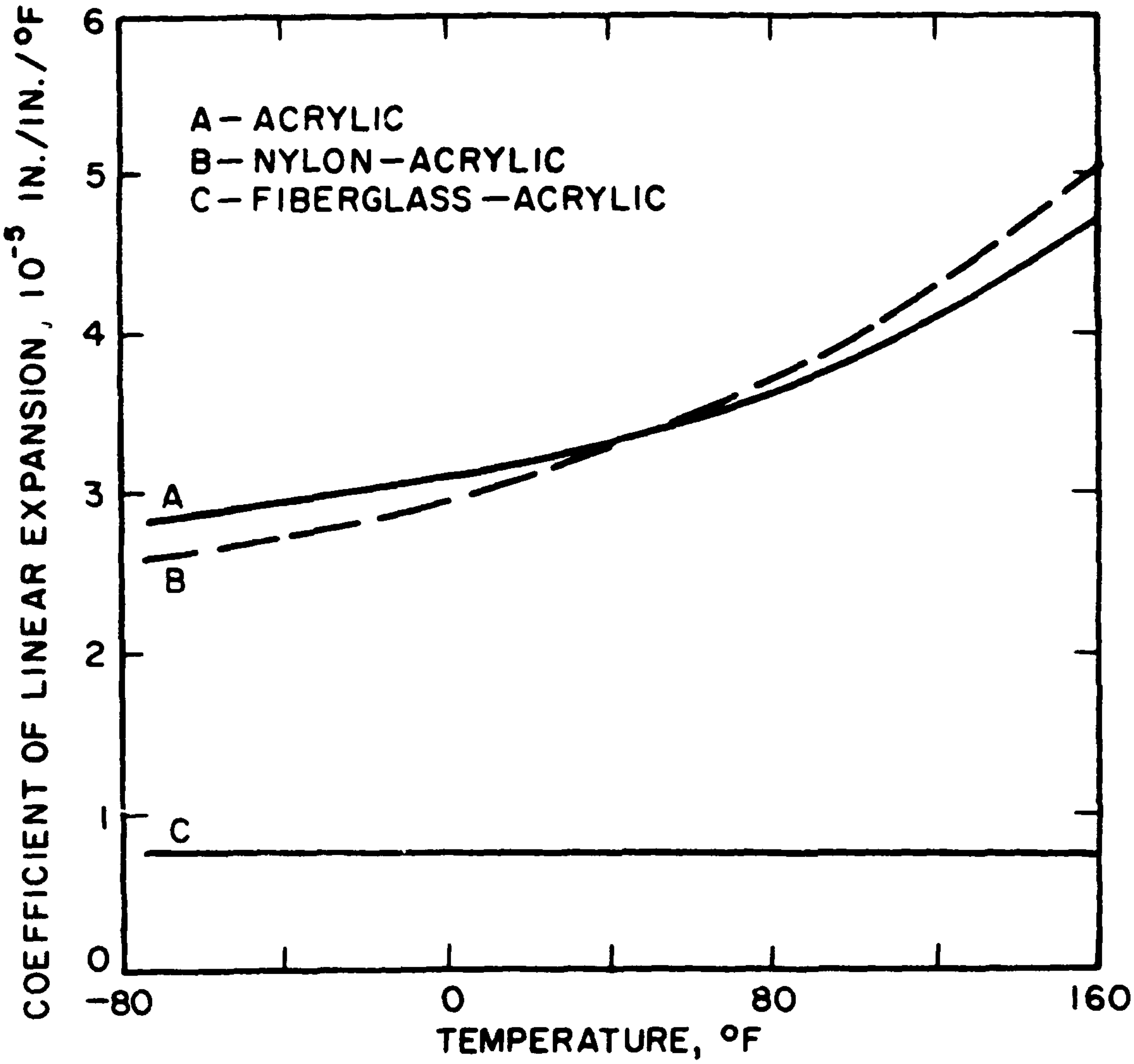

Figure 3 Effect of Temperature on Linear Coefficient of Thermal Expansion for Various Materials (Ref. 1)

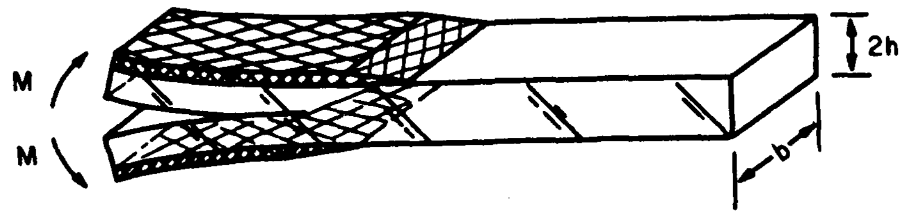

Figure 4: Effect of Thermal Loading on F-4 Edge Attachment

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