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V-378A, A MODIFIED BISMALEIMIDE FOR ADVANCED COMPOSITES

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Addition polyimides cure with no evolution of gaseous by-products at relatively low temperatures and may be cured at low pressures to yield composites with excellent hot-wet strength retention. These properaties have made them excellent candidates as matrix resins for advanced composites. However, commercially available bismaleimides are solids and difficult to handle in preimpregnated form.

V-378A is an addition polyimide composed of a mixture of bismaleimides and other reactive ingredients formulated to provide good prepreg properties and handling, facile cure and excellent composite mechanical properties. Several curing mechanisms are utilized to provide the characteristics exhibited by V-378A. Part of the mechanism is free radical and takes place at ambient temperature and above. Other mechanisms are principally Diels-Alder in nature. V-378A prepregs are tacky at ambient temperature but do not have long tacky outlife similar to some epoxies. V-378A yields composites which exhibit hot-wet strength retention which is superior to that provided by epoxy resin systems.

Epoxy resins, the dominant matrix system for high modulus graphite (HMG) do provide very good composite properties and have been extensively used in the manufacture of sporting goods and aircraft parts including ailerons, rudders, flaps, vertical and horizontal stabilizers, and complete wing sections for commercial and military aircraft. Epoxy resin prepregs are commonly supplied at relatively high resin contents requiring "bleeding" to achieve the desired resin content.

Use of this technique (bleeding) results in non-uniformity of resin content in the composite since more resin is removed next to the bleeder. This non-uniformity of resin content induces stresses and often results in warped parts. Use of a "net" resin concept tends to overcome these problems. V-378A exhibits excellent fiber wet out during the initial prepregging step and can thus be provided as a net resin prepreg.

The 175°C curing epoxy resin systems exhibit long gel times at 175°C and very low "watery" viscosities which tend to make it difficult to achieve low void composites. Typically, 175°C curing epoxies require a "hold" at 150 - 175°C to build molecular weight (and viscosity) prior to full application of pressure. V-378A, in contrast, gels fairly rapidly at 125°C and exhibits moderate to low viscosity during heat up making it much easier to achieve very low void content composite structures. Pressure application is done at ambient temperature without the necessity of a hold.

LAY-UP AND CURE

V-378A exhibits light to medium tack at a prepreg net resin content of 30% which is significantly lower than epoxies typically supplied at 42%. The net resin concept is particularly useful for preparation of composites having both thick and thin sections. Due to the low temperature gel and relatively low exotherm, no difficulty has been encountered in curing virtually void-free laminates up to four inches in thickness.

Standard nylon vacuum bags and sealant tapes (same as used for 175°C epoxy) may be used versus expensive polyimide film bag and silicone sealant tape required for high temperature curing polyimides.

To cure the V-378A prepreg lay-up, 85 psi autoclave pressure and vacuum are applied at the beginning of the cycle, and the part heated to 60 - 90°C at a rate of 2 - 5°C/minute. The vacuum is released, the bag vented to the atmosphere, pressure increased to 100 psi and heat up continued to 175°C. The part is cured four hours at 175°C, cooled to ambient temperature, removed and post cured, unrestrained, from room temperature to 246°C for four hours. The four hour post cure at 246°C is required to develop good mechanical properties. Table 1 illustrates a study of ± 45° tensile ultimate and strain using more extensive post cures and indicates the four hour post cure at 246°C to be satisfactory.

Use of a one to two hour hold at 60 - 90°C for very thick parts allows more time before gelation in order for air, trapped between plies during lay-up, to be released.

Figure 1 shows the effect on viscosity of heating the resin to 67°, 70° and 90°C with holds of 5 hours, 3-1/2 hours and 2-1/2 hours respectively. A heating rate of 1°C/minute was used.

Figure 2 illustrates the effect of heating rate with lower minimum viscosities obtained at faster heating rates.

EFFECTS OF MOISTURE ON PREPREG

The 175°C curing epoxy matrix resins have exhibited much variability in processing due to moisture pickup of the uncured prepreg. This affinity for moisture results in variations in gel time, foaming during cure and porosity in the cured composite.

In contrast, V-378A prepreg exposed to 100% RH and 52°C for one hour, then laid up and cured, exhibited no deleterious effects. Figures 3 and 4 exhibit the effect of a sixteen hour exposure at 90% RH, 24°C on uncured films of V-378A. No porosity or foaming was noted during the RDS viscosity determination.

MECHANICAL AND PHYSICAL PROPERTIES

Figure 5 exhibits a Tg of V-378A (via Rheometric Dynamic Spectroscopy) in excess of 370°C. Translation of properties on high modulus graphite are excellent. Table 2 lists mechanical properties of V-378A/T-300·6K tape composites. Retention of dry flexure at 310°C is approximately 40% of the ambient temperature value. Wet flexure retention (98% RH, 71°C, 30 days) at ambient and 175°C of 23 ksi/22,500 μ in./in. and 15.7 ksi/29,000 μ in./in., respectively are also impressive. It is of interest to note the increase in composite strain at 175°C rather than a decrease usually noted in 175°C epoxies. No significant degradation in ambient or 175°C ultimate or strain values of the ± 45° tensile are exhibited after wet conditioning. Epoxies exhibit a significant drop in 175°C wet properties.

All wet elevated temperature testing was conducted using a five minute "soak" time, for the specimen to get to temperature in the preheated test chamber, in order to minimize drying of the specimen. V-378A composites lose moisture (and regain) at a more rapid rate than 175°C epoxies.

Transverse or 90° tensile ultimate and strain values of V-378A at ambient of 9.2 ksi/7,700 μ in./in. and 6.1 ksi/6,400 μ in./in. at 175°C are also higher than most 175°C epoxy systems.

EFFECTS OF PREPREG AGING AT 75°F

Table 3 exhibits flexure and shear tested at ambient and 177°C from prepreg which was laid up fresh and aged at 0, 7, 14 and 21 days intervals ambient temperature prior to cure. Ambient temperature tack retention, however, is much shorter than for typical 177°C curing epoxies. A vacuum bag debulk step is suggested at 2 - 3 hour intervals for large parts. Fresh prepreg should be laid up promptly and excess prepreg stored at -18°C. Storage stability of the prepreg is in excess of six months at -18°C.

GENERAL MECHANICAL PROPERTIES

Extensive mechanical properties on V-378A/T-300·6K unitape composites were determined by the University of Dayton Research Institute and reported under AF contract F 33615-78-C5172. This data includes 0°, ± 45° and 90° tensile, 0° and 90° compressive, 0° and 90° flexure and shear at -55°C, 22°C, 177°C and 232°C as well as static and creep testing.

Two major aircraft companies have found V-378A to exhibit open hole tensile values 50 - 70% higher than 175°C curing epoxies.

Table 4 contains properties of V-378A/T-300·6K, 5 HS woven graphite fabric composites with flexure and shear tests up to 232°C. This is a relatively new style using the heavier weight 6000 filament yarn and may replace the 3000 filament yarn 8HS fabric in many applications due to the lower cost of the yarn.

Properties of V-378A/7781 E-glass fabric are listed in Table 5 and also exhibit excellent strength retention at temperatures up to 371°C.

Table 6 lists properties of V-378A/6781 S-glass and illustrates the higher strengths attainable with S-glass.

Some properties of HI-TEX graphite fiber, HITCO's recent entry in the high strength, high modulus field on V-378A are listed in Table 7.

ELEVATED TEMPERATURE STABILITY OF CURED COMPOSITES

Flexure and shear of .080" thick V-378A/T-300 tape composites after aging six months at 177°C and nine months at 232°C in circulating air ovens are listed in Table 8. Composite weight loss after six months at 177°C is less than 0.6%. Flexure at ambient and 177°C appear to have increased slightly. Six months aging at 232°C exhibited a weight loss of 2.3% and good retention of flexure. Nine month aging produced composite weight loss of 3.5%. Retention of shear and flexure was quite high both at ambient and 232°C. Degradation appeared to be greatest on the surface.

Two new sets of panels were prepared and one set coated with 1 mil of Skybond 703, a condensation type polyimide, as a protective coating. The control panel exhibited a weight loss of 4% while the Skybond 703 coated panel lost 2.3% weight after aging one year at 232°C. Test of flexure and shear indicated about 15% better retention of 232°C flexure and slightly better shear on the coated panel after the one year at 232°C.

SMOKE DENSITY

Figure 6 illustrates the very low smoke density exhibited by V-378A composites. After a 20 minute burn, the smoke density (NBS Smoke Chamber) is about 1.5.

APPLICATIONS

V-378A is being evaluated in a number of applications for commercial and military aircraft as well as industrial applications. One of the most impressive of these is for manufacture of the complete wing skins and ribs for the new F-16XL cranked arrow fighter plane. The first prototype of this new concept aircraft flew on July 3, 1982 and is under intensive evaluation by General Dynamics.

Figure 7 is a view of a V-378A/T-300·6K composite wing skin during lay-up. Figure 8 shows several skins in various stages of lay-up. Figure 9 is a completed skin removed from the tool and after post cure. This part had less than 0.030" warp after post cure. Extensive C-scans indicated essentially no voids. Figure 10 illustrates the completed wing structure with internal ribs mechanically fastened to the upper and lower wing skins. The root thickness of each skin is approximately 0.4" tapering to approximately 0.60" at the tip. The completed wing attached to the fuselage is shown in Figure 11. Figure 12 exhibits both wings attached to the fuselage and finally the finished cranked arrow, delta wing F-16XL is shown in Figure 13.

Proposed specifications for the F-16XL versus the current F-16A manufactured by General Dynamics, Ft. Worth, are listed in Table 9. Initial results from flight tests indicate performance is close to analytical predictions.

Figure 14 shows a wing flap from another prototype aircraft with integrally cocured V-378A/T-300 ribs bonded to a wing skin.

V-378A/T-300·6K is also being used to produce a firewall for an advanced concept helicopter and in numerous other applications.

SUMMARY

V-378A, a modified bismaleimide resin has been developed for composite applications requiring greater hot-wet strength retention than currently available with 175°C curing epoxy resins.

The new resin also exhibits good prepreg parameters, facile, epoxy-like, curing characteristics and appears useful for applications at temperatures of 232°C for extended periods of time and in areas where low smoke density is required.

Assistance from the U. S. Polymeric analytical, physical testing laboratories and from Lee McKague and Clarence Hart of General Dynamics for their help in providing photographs and technical assistance is gratefully acknowledged.

TABLE 1
EFFECT OF POST CURE ON ±45° TENSILE V378A/T-300-6K UNITAPE COMPOSITES

I. PREPREG PROPERTIES

RESIN CONTENT, % WT	30.0 (NET)
TACK	LIGHT – MEDIUM
RECOMMENDED STORAGE TEMPERATURE	18°C OR BELOW

II. LAYUP AND CURE

EIGHT PLIES V378A, ± 45° (LOT 2W4872) WERE LAID UP ON A FREKOTE 33 RELEASED CAUL PLATE. ONE PLY TX1040 ADDED ON TOP OF LAYUP PLUS RELEASED TOP CAUL PLATE. COROPRENE SIDE DAMS APPLIED WITH 3 MIL TEDLAR ("L" SLITS AT EACH CORNER) TAPED TO TOP OF CORPORENE DAMS. TWO PLIES 1581 BREATHER OVER ENTIRE LAYUP TO VENT HOLES

APPLY VACUUM PLUS 85 PSI AND HEAT FROM ROOM TEMPERATURE TO 82°C AT 3 ± 2°C MIN, HOLD 30' AT 82°C, THEN VENT BAG TO ATMOSPHERE AND INCREASE PRESSURE TO 100 PSI. HEAT FROM 232°C TO 177°C. HOLD FOUR HOURS AT 232°C. COOL, REMOVE AND POST CURE AS NOTED BELOW:

POST CURE	4 HR AT 246°C	8 HR AT 246°C	12 HR AT 246°C	24 HR AT 246°C	4 HR AT 246°C +1 HR AT 288°C
± 45° TENSILE ULT, KSI AT R.T.	21.49 23.71 23.77	22.97 22.46 22.37	23.41 22.18 23.04	21.16 22.31 21.74	19.60 20.15 19.62
AVERAGE	23.0	22.6	22.9	21.7	19.8
± 45° TENSILE STRAIN, μ IN./IN. AT R.T.	16740 16600 16700	17400 16960 17660	16920 16600 15000	15300 11400 15600	17000 16440 13500
AVERAGE	16680	17340	16170	14100	15650
± 45° TENSILE ULT, KSI AT 350°F	18.64 17.23 16.55	15.10 15.81 17.53	17.38 14.12 17.79	16.85 16.87 16.77	16.80 – 16.48
AVERAGE	17.5	16.1	16.4	16.8	16.6
± 45° TENSILE STRAIN, μ IN./IN.	24600+ 28600+ 29400+	28000+ 27340+ 24000+	25600+ – 25000+	24400+ 21400+ 26600+	25000+ 25800+ –
AVERAGE	27500+	26400+	25300+	24100+	25400+

LAMINATE DENSITY, GR/CC	1.56
FIBER VOLUME, %	64.6
VOIDS, %	0.1
LAMINATE RESIN SOLIDS, % WT	27.2

TABLE 2
TYPICAL MECHANICAL AND PHYSICAL PROPERTIES OF CURED V-378A/T-300-6K, HMG/PI TAPE COMPOSITES

TEST	"AS-IS"	4 WK, 71°C 98% RH	8 WK, 71°C 98% RH
0° FLEXURE, ULT, KSI, R.T.	265.0	263.0 (1.73)**	254.0 (1.78)**
0° FLEXURE, ULT, KSI, 177°C	197.5	157.0	135.0
0° FLEXURE, ULT, KSI, 232°C	179.0	–	–
0° FLEXURE, ULT, KSI, 288°C	122.0	–	–
0° FLEXURE, ULT, KSI 316°C	107.0	–	–
0° FLEXURE MODULUS, MSI, R.T.	19.8	20.7	18.4
0° FLEXURE MODULUS, MSI, 177°C*	20.7	18.3	15.3
0° FLEXURE MODULUS, MSI, 232°C	19.2	–	–
0° FLEXURE MODULUS, MSI, 288°C	18.4	–	–
0° FLEXURE MODULUS, MSI, 316°C	17.6	–	–
0° HORIZONTAL SHEAR, KSI, R.T.	18.3	16.1 (1.85)**	13.7 (1.91)**
0° HORIZONTAL SHEAR, KSI, 177°C	10.9	8.0	7.4
0° HORIZONTAL SHEAR, KSI, 232°C	9.2	–	–
0° HORIZONTAL SHEAR, KSI, 288°C	6.4	–	–
0° HORIZONTAL SHEAR, KSI, 316°C	5.8	–	–
90° TENSILE, ULT, KSI, R.T.	9.0	4.3 (1.74)**	4.6 (1.87)**
90° TENSILE, ULT, KSI, 177°C	5.9	1.40	1.58
90° TENSILE MODULUS, MSI, R.T.	1.40	1.60	1.40
90° TENSILE MODULUS, MSI, 177°C	1.00	0.70	0.85
90° TENSILE STRAIN, μ IN./IN., R.T.	6,570	2,400	3,100
90° TENSILE STRAIN, μ IN./IN., 177°C	5,900	2,200	1,800
± 45° TENSILE ULT, KSI, R.T.	23.0	22.6 (1.60)**	22.3 (1.59)**
± 45° TENSILE ULT, KSI, 177°C	15.7	15.8	15.5
± 45° TENSILE MODULUS, MSI, R.T.	2.43	3.00	2.50
± 45° TENSILE MODULUS, MSI, 177°C	1.63	1.35	1.34
± 45° TENSILE STRAIN, μ IN./IN. R.T.	22,500	22,600	22,300
± 45° TENSILE STRAIN, μ IN./IN. 177°C	29,280	30,000	29,000
0° TENSILE ULT, KSI, R.T.	228.9	–	–
0° TENSILE MODULUS, MSI, R.T.	21.8	–	–
0° TENSILE STRAIN, μ IN./IN. R.T.	10,470	–	–

*5-MIN SOAK AT TEST TEMPERATURE
**% WEIGHT GAIN OF MOISTURE LISTED IN PARENTHESES

	0° TENSILE	0° FLEXURE	± 45° TENSILE	90° TENSILE
COMPOSITE, SPECIFIC GRAVITY, GR/CC	1.60	1.60	1.57	1.60
COMPOSITE, VOID CONTENT, %	0.5	–0.9	0.9	–0.9
COMPOSITE, FIBER VOLUME, %	68.3	64.8	63.6	64.8
COMPOSITE, RESIN SOLIDS, % WT	25.2	28.6	29.0	28.6

TABLE 3
EFFECT OF
PREPREG AGEING AT 23°C PRIOR TO CURE

DAYS AGING	0 FRESH	7-DAYS	14 DAYS	21 DAYS
FLEX/MODULUS AT R.T., KSI/MSI	289.1/18.9	266.9/17.6	302.8/19.1	285.1/18.5
	280.2/19.0	268.2/19.3	287.8/18.9	260.8/19.2
	290.3/18.9	256.2/17.1	273.8/17.3	304.7/20.3
	263.0/18.3	273.4/16.7	295.5/18.6	270.0/18.8
	–	262.9/18.4	274.1/18.4	285.2/19.0
AVERAGE	280.7/18.8	265.5/17.8	286.8/18.5	281.2/19.2
FLEX/MODULUS AT 177°C, KSI/MSI	228.4/17.1	218.6/17.8	208.3/19.4	198.4/18.3
	243.4/19.6	218.1/17.3	209.8/18.4	204.8/17.5
	225.0/17.7	224.2/18.1	206.2/18.3	205.0/17.3
	231.0/18.6	222.2/19.4	205.6/18.6	202.4/17.6
	–	216.3/18.5	216.1/17.2	194.8/18.2
AVERAGE	232.0/18.3	220.9/18.2	209.2/18.4	201.1/17.8
SBS AT R.T., KSI	17.1	18.2	17.5	17.1
	17.8	18.4	18.0	17.0
	18.5	18.4	17.8	–
	16.9	18.2	18.1	15.8
	17.9	17.2	18.1	15.9
AVERAGE	17.7	18.1	17.9	16.5
SBS AT 177°C, KSI	11.5	11.2	10.6	10.0
	11.5	11.1	10.4	10.3
	11.5	10.7	10.7	10.6
	11.9	10.4	10.8	10.3
	12.1	11.4	10.3	10.3
AVERAGE	11.7	11.0	10.6	10.3
DENSITY GR/CC	1.59	1.57	1.57	1.58
RESIN SOLIDS, %	28.1	31.1	30.5	28.0
FIBER VOLUME, %	65.1	61.5	62.0	64.4
VOIDS, %	0.40	0.10	0.50	0.90

TABLE 4
V-378A/S/T-300 · 6K, 5 HS
POLYIMIDE/BIDIRECTIONAL FABRIC,
LOT NO. D07220

I. PREPEG PROPERTIES

WET RESIN CONTENT, % WT	32.0
VOLATILES, % WT, 10′ AT 135°C	7.0
FLOW, % — 15 PSI, 135°C, 15′	8.0

II. LAYUP AND CURE (NET RESIN, NO BLEEDER)

EIGHT PLIES V-378A/T-300 · 3K, 8HS FABRIC ON FREKOTE 33 RELEASED CAUL PLATE, ONE PLY TX1040 ON TOP LAYUP PLUS RELEASED TOP CAUL PLATE AND TEDLAR TOP RELEASE FILM WITH "L" SLITS AT CORNERS TAPED TO COROPRENE SIDE DAMS, TWO PLIES 7581 BREATHER OVER ENTIRE LAYUP PLUS VENT HOLES. APPLY NYLON VACUUM BAG WITH SEALANT

APPLY VACUUM PLUS 85 PSI AND HEAT FROM ROOM TEMPERATURE TO 82°C AT 3 ± 2°C MIN. VENT BAG TO ATMOSPHERE AT 82°C AND HOLD 30′ AT 82°C. INCREASE PRESSURE TO 100 PSI, THEN CONTINUE HEATING TO 177°C. CURE FOUR HOURS AT 177°C AND COOL TO 60°C OR BELOW BEFORE REMOVING. POSTCURE FOUR HOURS AT 232°C UNRESTRAINED

III. MECHANICAL PROPERTIES

TEST	RESULTS
FLEX/MODULUS AT R.T., KSI/MSI	153/8.0
FLEX/MODULUS AT 177°C, KSI/MSI	135/7.7
FLEX/MODULUS AT 232°C, KSI/MSI	98/7.3
SHORT BEAM SHEAR AT R.T., KSI	9.4
SHORT BEAM SHEAR AT 177°C, KSI	8.2
SHORT BEAM SHEAR AT 232°C, KSI	7.2
TENSILE/MODULUS AT R.T., KSI/MSI	101/10.3
TENSILE/MODULUS AT 177°C, KSI/MSI	103/10.5
TENSILE/MODULUS AT 232°C, KSI/MSI	104/10.9
COMPRESSIVE/MODULUS AT R.T.	93/9.2
COMPRESSIVE/MODULUS AT 177°C	63/9.1
COMPRESSIVE/MODULUS AT 232°C	62/9.1
LAMINATE RESIN SOLIDS, % WT	27.5
LAMINATE DENSITY, GR/CC	1.62
FIBER VOLUME, %	66.8
VOID CONTENT, %	0.3

TABLE 5
PRELIMINARY DATA
V-378A/7581 CS272, POLYIMIDE/BIDIRECTIONAL E-GLASS FABRIC

I. PREPREG PROPERTIES

RESIN CONTENT, % WT	30%

II. LAYUP AND CURE (NET RESIN, NO BLEEDER)

TWELVE PLIES V-378A/7581 LOT NO. 2W4822 ON FREKOTE 33 RELEASED CAUL PLATE. ONE PLY TX1040 ON TOP LAYUP PLUS RELEASED TOP CAUL PLATE AND TEDLAR TOP RELEASE FILM WITH "L" SLITS AT CORNERS TAPED TO COROPRENE SIDE DAMS, TWO PLIES 7581 BREATHER OVER ENTIRE LAYUP PLUS VENT HOLES. APPLY NYLON VACUUM BAG WITH SEALANT

APPLY VACUUM PLUS 85 PSI, HEAT FROM R.T. TO 177°C AT 3 ± 2°C/MIN, HOLD 30' AT 82°C THEN VENT BAG TO ATM AT 82°C AND INCREASE PRESSURE TO 100 PSI, THEN CONTINUE HEAT TO 177°C. CURE FOUR HOURS AT 177°C AND COOL TO 60°C OR BELOW BEFORE REMOVING. POSTCURE FOUR HOURS AT 246°C

III. MECHANICAL PROPERTIES

WARP ONLY – 4 EACH	RESULTS AS-IS	RESULTS *WET
FLEX/MODULUS AT R.T., KSI/MSI	100/3.8	
FLEX/MODULUS AT 177°C, KSI/MSI	89/4.0	
FLEX/MODULUS AT 232°C, KSI/MSI	84/4.0	
FLEX/MODULUS AT 316°C, KSI/MSI	75/3.9	
FLEX/MODULUS AT 371°C, KSI/MSI	48/3.5	
COMPRESSIVE/MODULUS AT R.T., KSI/MSI (ASTM D695 – DOGBONES)	78/5.3	72/4.0
COMPRESSIVE/MODULUS AT 177°C, KSI/MSI	62/4.5	46/4.0
COMPRESSIVE/MODULUS AT 232°C, KSI/MSI	57/4.3	
TENSILE/MODULUS AT R.T., KSI/MSI	69/4.7	
TENSILE/MODULUS AT 177°C, KSI/MSI	64/4.1	
TENSILE/MODULUS AT 232°C, KSI/MSI	64/4.0	
LAMINATE RESIN SOLIDS, % WT	26.8	
LAMINATE DENSITY, GR/CC	2.0	
LAMINATE FIBER VOLUME, %	57.7	
LAMINATE VOIDS, %	0.1	

*WET = 30 DAYS AT 71°C, 95-100% RH

TABLE 6
PRELIMINARY DATA
V-378A/6781 CS272, POLYIMIDE/BIDIRECTIONAL S-GLASS FABRIC

I. PREPREG PROPERTIES

RESIN CONTENT, % WT	30%

II. LAYUP AND CURE (NET RESIN, NO BLEEDER)

TWELVE PLIES V-378A/6781 LOT NO. D07207 ON FREKOTE 33 RELEASED CAUL PLATE, ONE PLY TX1040 ON TOP LAYUP PLUS RELEASED TOP CAUL PLATE AND TEDLAR TOP RELEASE FILM WITH "L" SLITS AT CORNERS TAPED TO COROPRENE SIDE DAMS, TWO PLIES 7781 BREATHER OVER ENTIRE LAYUP PLUS VENT HOLES. APPLY NYLON VACUUM BAG WITH SEALANT

APPLY VACUUM PLUS 85 PSI, HEAT FROM R.T. TO 177°C AT 3 ± 2°C/MIN, HOLD 30' AT 82°C THEN VENT BAG TO ATM AT 82°C AND INCREASE PRESSURE TO 100 PSI, THEN CONTINUE HEAT TO 177°C. CURE FOUR HOURS AT 177°C AND COOL TO 60°C OR BELOW BEFORE REMOVING. POSTCURE FOUR HOURS AT 246°C

III. MECHANICAL PROPERTIES

WARP ONLY – 4 EACH	RESULTS AS-IS	RESULTS *WET
FLEX/MODULUS AT R.T., KSI/MSI	117/4.6	
FLEX/MODULUS AT 177°C, KSI/MSI	102/4.6	
FLEX/MODULUS AT 232°C, KSI/MSI	89/4.3	
FLEX/MODULUS AT 316°C, KSI/MSI	67/4.1	
FLEX/MODULUS AT 371°C, KSI/MSI	43/3.6	
COMPRESSIVE/MODULUS AT R.T., KSI/MSI (ASTM D695 – DOGBONES)	76/5.1	74/5.1
COMPRESSIVE/MODULUS AT 177°C, KSI/MSI	65/4.8	50/4.5
COMPRESSIVE/MODULUS AT 232°C, KSI/MSI	63/4.5	
TENSILE/MODULUS AT R.T., KSI/MSI	84/5.0	
TENSILE/MODULUS AT 177°C, KSI/MSI	72/4.7	
TENSILE/MODULUS AT 232°C, KSI/MSI	78/4.2	
LAMINATE RESIN SOLIDS, % WT	27.8	
LAMINATE DENSITY, GR/CC	1.9	
LAMINATE FIBER VOLUME, %	56.5	

*WET = 30 DAYS AT 71°C, 95-100% RH

TABLE 7
PRELIMINARY DATA
HIGH TEMPERATURE PROPERTIES, V-378A/HI-TEX-12K, POLYIMIDE/HIGH MODULUS GRAPHITE UNIDIRECTIONAL COMPOSITE

I. PREPREG PROPERTIES

WET RESIN CONTENT, % WT	30%
NONREACTIVE VOLATILES, % WT	0
TACK	LIGHT – MEDIUM
RECOMMENDED STORAGE TEMPERATURE	−18°C OR BELOW

II. LAYUP AND CURE (NET RESIN, NO BLEEDER)

FIFTEEN PLIES V-378A/HI-TEX12K (LOT 3W2320) 0° UNITAPE WERE LAID UP ON A FREKOTE 33 RELEASED CAUL PLATE. ONE PLY TX1040 ADDED ON TOP OF LAYUP PLUS RELEASED, TOP CAUL PLATE. COROPRENE SIDE DAMS APPLIED WITH 3 MIL TEDLAR WITH "L" SLITS AT EACH CORNER TAPED TO TOP OF COROPRENE DAMS. TWO PLIES 1581 BREATHER OVER ENTIRE LAYUP TO VENT HOLES

APPLY VACUUM PLUS 85 PSI AND HEAT FROM ROOM TEMPERATURE TO 82°C AT 3 ± 2°C/MIN. HOLD 30' AT 82°C, THEN VENT BAG TO ATMOSPHERE AND INCREASE AUTOCLAVE PRESSURE TO 100 PSI AND CONTINUE HEATING FROM 82°C TO 177°C. CURE FOUR HOURS AT 177°C. REMOVE, AND POSTCURE UNRESTRAINED FOUR HOURS AT 246°C

III. MECHANICAL AND PHYSICAL PROPERTIES, V-378A/T300-6K COMPOSITE

TEST	RESULTS
0° FLEXURE/MODULUS, KSI/MSI, R.T.	324/18.5
0° FLEXURE/MODULUS, KSI/MSI, 177°C	243/18.2
0° SHORT BEAM SHEAR, KSI, R.T.	15.3
0° SHORT BEAM SHEAR, KSI, 350°F	10.8
LAMINATE DENSITY, GR/CC	1.60
LAMINATE RESIN SOLIDS, % WT	28.7
LAMINATE FIBER VOLUME, %	64.6
LAMINATE VOIDS, %	0.2

NOTE: 5 MIN SOAK AT TEST TEMPERATURE

TABLE 8
TYPICAL PROPERTIES OF
V-378A/T-300 UC309, LOT 2W4941, 5 MIL UNITAPE COMPOSITES AGED AT SIX MONTHS AT 177°C AND 232°C

	AS-IS	COMPOSITES AGED 6 MONTHS AT 177°C	COMPOSITES AGED 6 MONTHS AT 232°C	COMPOSITES AGED 9 MONTHS AT 232°C
0° FLEXURE/MODULUS, KSI/MSI AT R.T.	298/18.2	320/20.0	275/19.0	267/21.1
0° FLEXURE/MODULUS, KSI/MSI AT 177°C	245/17.4	271/21.1	–	–
0° FLEXURE/MODULUS, KSI/MSI AT 232°C	233/17.4	–	180/19.3	205/21.4
SHORT BEAM SHEAR, KSI AT R.T.	15.8	–	–	15.5
SHORT BEAM SHEAR, KSI AT 177°C	10.1	–	–	–
SHORT BEAM SHEAR, KSI AT 232°C	7.7	–	–	8.6
	0°	0°	0°	0°
DENSITY	1.60	1.62	1.57	–
RESIN SOLIDS, %	27.3	28.5	26.6	–
FIBER VOLUME, %	66.1	63.8	64.9	–
VOIDS, %	0.2	0.2	2.6	–
WEIGHT LOSS, % WT	–	0.57	2.3	3.4

TABLE 9
F-16XL SPECIFICATIONS

	F-16XL SCAMP	F-16A
WINGSPAN	32.4 FT	32.8 FT*
WING ROOT CHORD	499 IN.	195 IN.
WING AREA	646.4 SQ FT	300 SQ FT
OVERALL LENGTH	52.4 FT	47.6 FT
EMPTY WEIGHT	17,402 LB	15,137 LB
MAXIMUM TAKEOFF GROSS WEIGHT	37,500 LB	35,400 LB
FUEL CAPACITY	12,750 LB	6,972 LB
TAKEOFF ROLL (AIR-AIR COMBAT)	1,640 FT	2,425 FT
TAKEOFF ROLL (AIR-GROUND SUPPORT)	1,980 FT	3,030 FT
LANDING DISTANCE (AIR-AIR COMBAT)	1,990 FT†	2,480 FT
LANDING DISTANCE (AIR-GROUND SUPPORT)	2,230 FT**	2,830 FT
MAXIMUM SPEED	MACH 2.5	MACH 2.0
MAXIMUM CRUISE SPEED	MACH 2.2	MACH 0.93

*WITH WINGTIP MISSILES. WITHOUT MISSILES, SPAN IS 31 FT

†USING BRAKES ONLY. USING DRAG PARACHUTE, LANDING DISTANCE ESTIMATED AT 1,180 FT

**USING BRAKES ONLY. USING DRAG PARACHUTE, LANDING DISTANCE ESTIMATED AT 1,360 FT

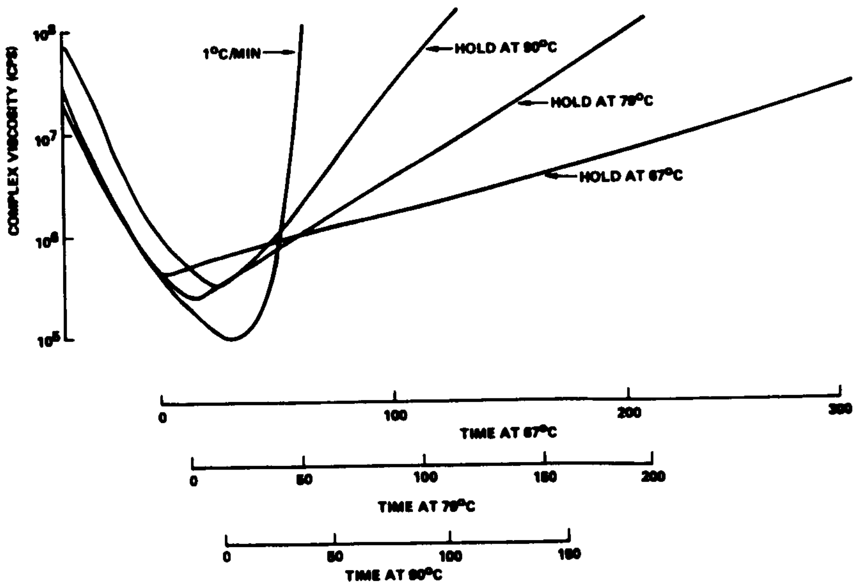

Figure 1. - USP V-378A (Lot WR6080) isothermal cure curves.

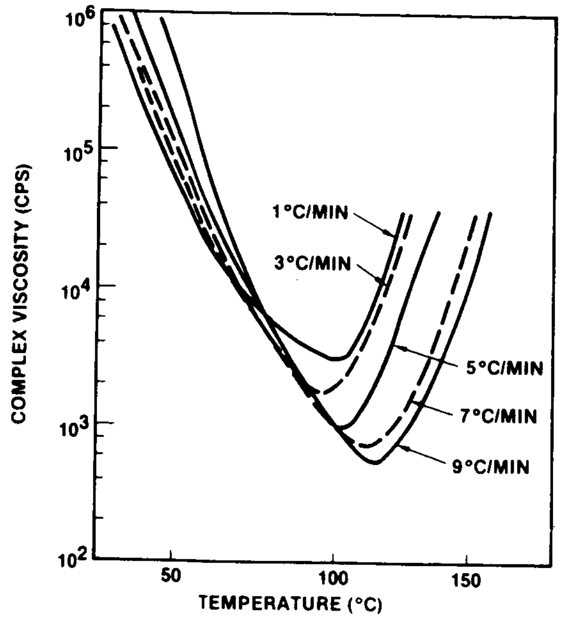

Figure 2. - USP V-378A, effect of heating rate.

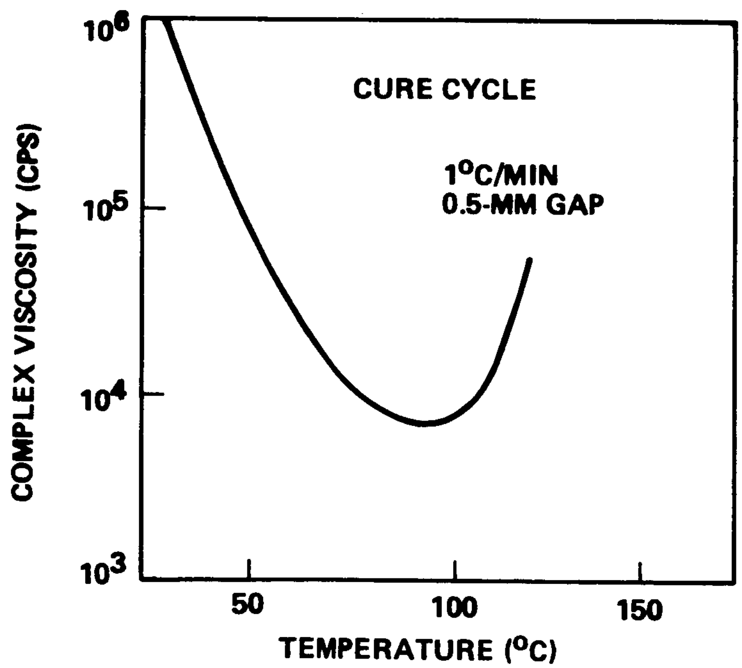

Figure 3. - USP V-378A exposed to 50 percent RH at 24 °C (for 18 hr).

C-5

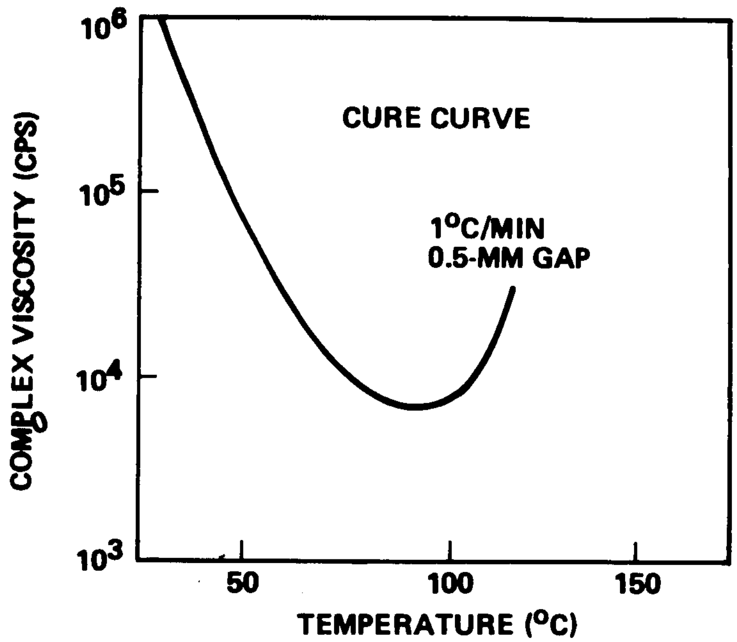

Figure 4. - USP V-378A exposed to 90 percent RH at 24 °C (for 16 hr).

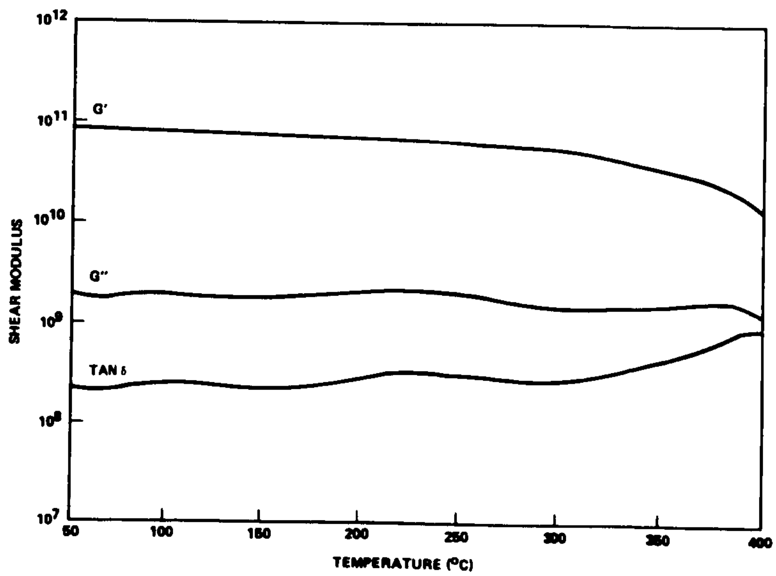

Figure 5. - Tg shear modulus by rheometric dynamic spectroscopy.

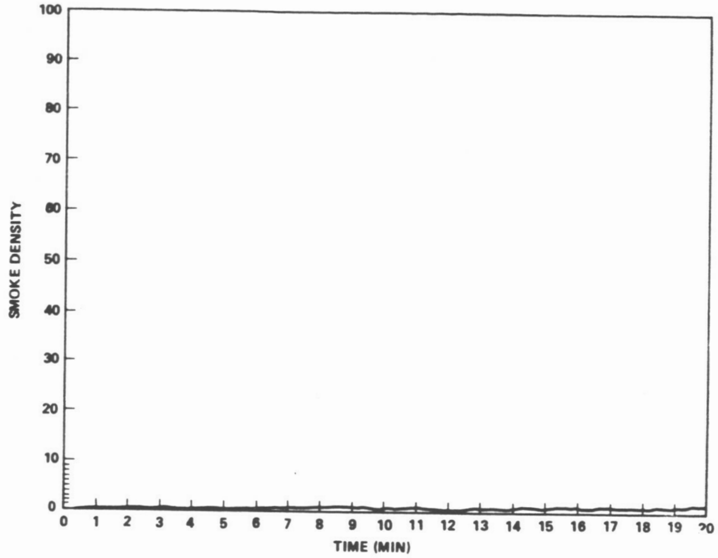

Figure 6. - V-378A/Celion, polyimide/graphite smoke density (NBS chamber).

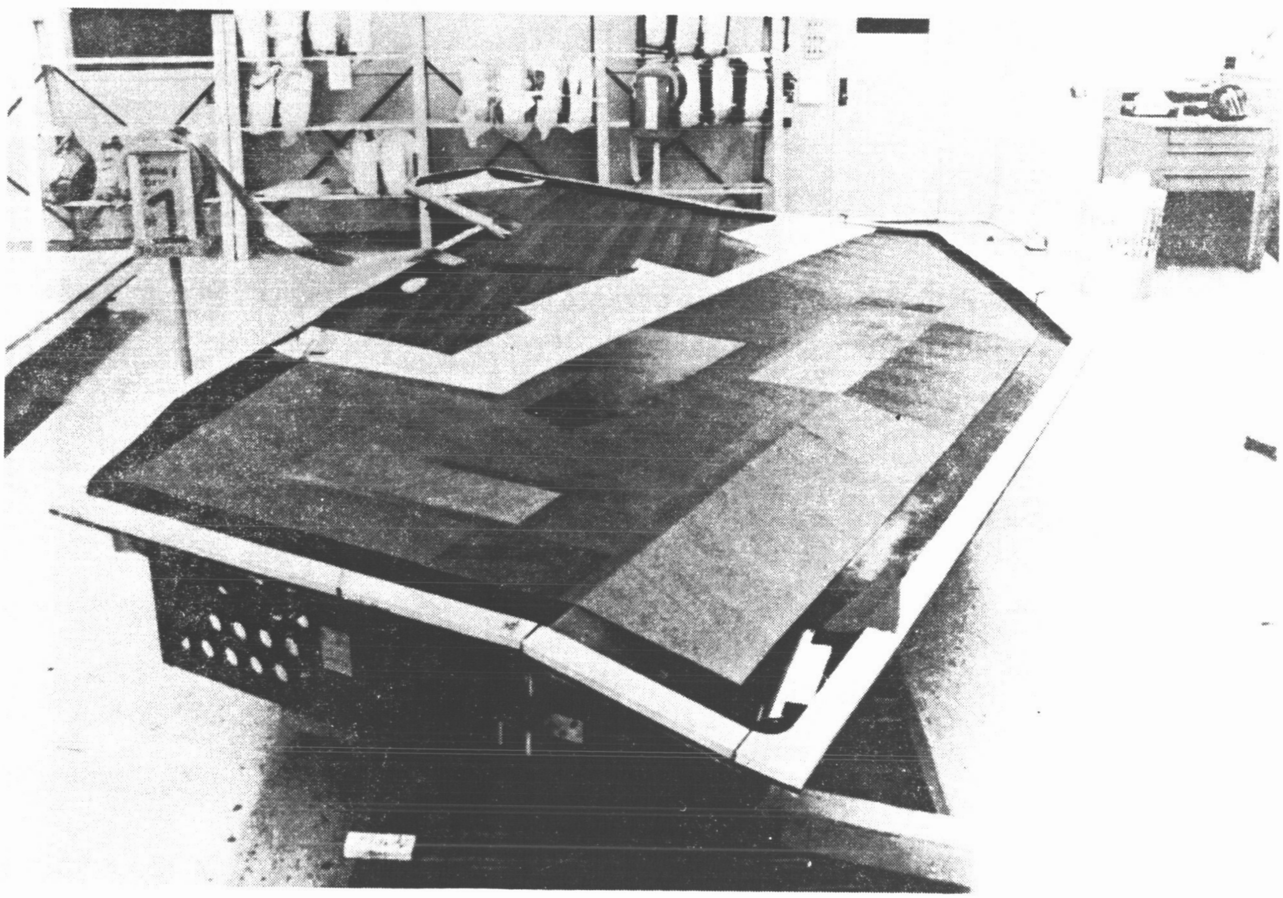

Figure 7. - V-378A/T-300•6K composite wing skin during lay-up.

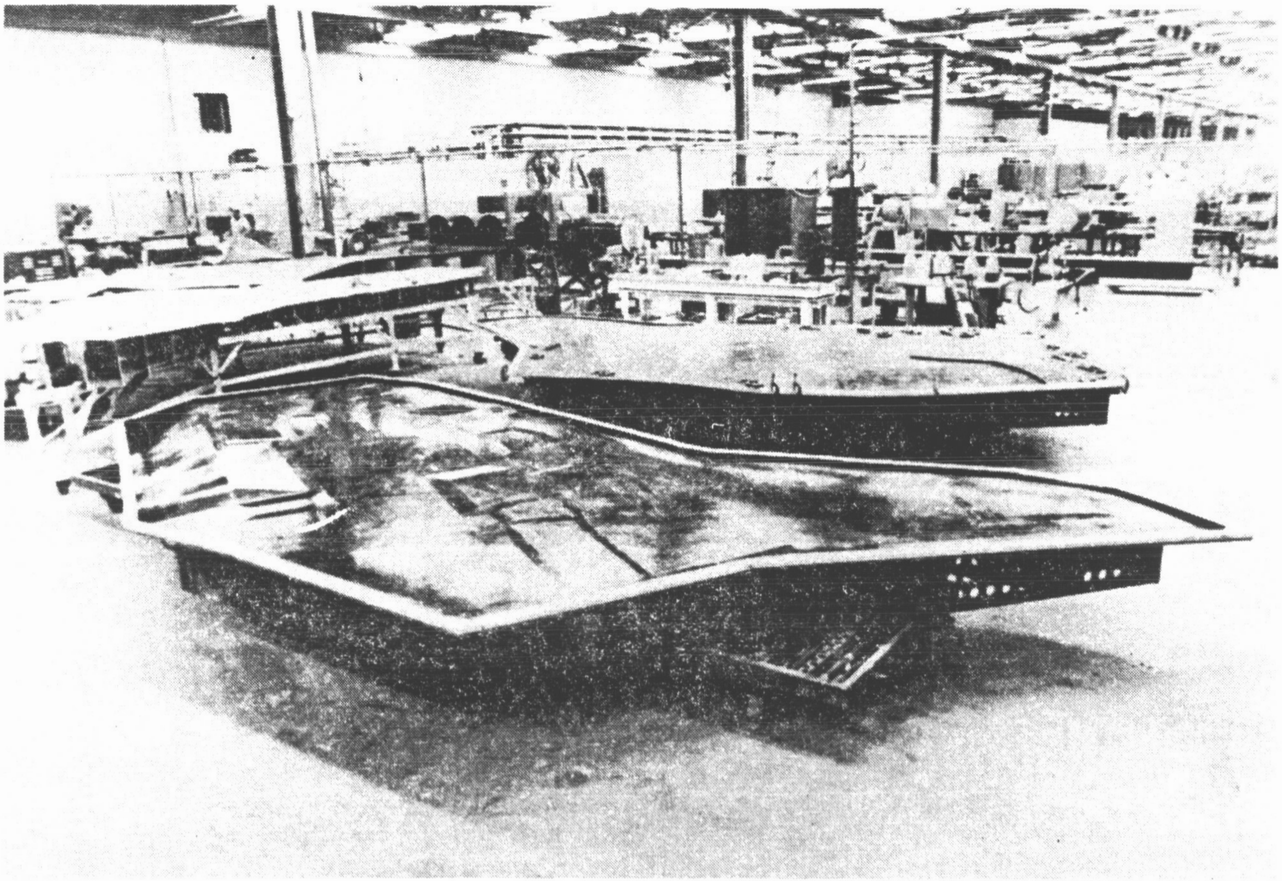

Figure 8. - Wing skins in various stages of lay-up.

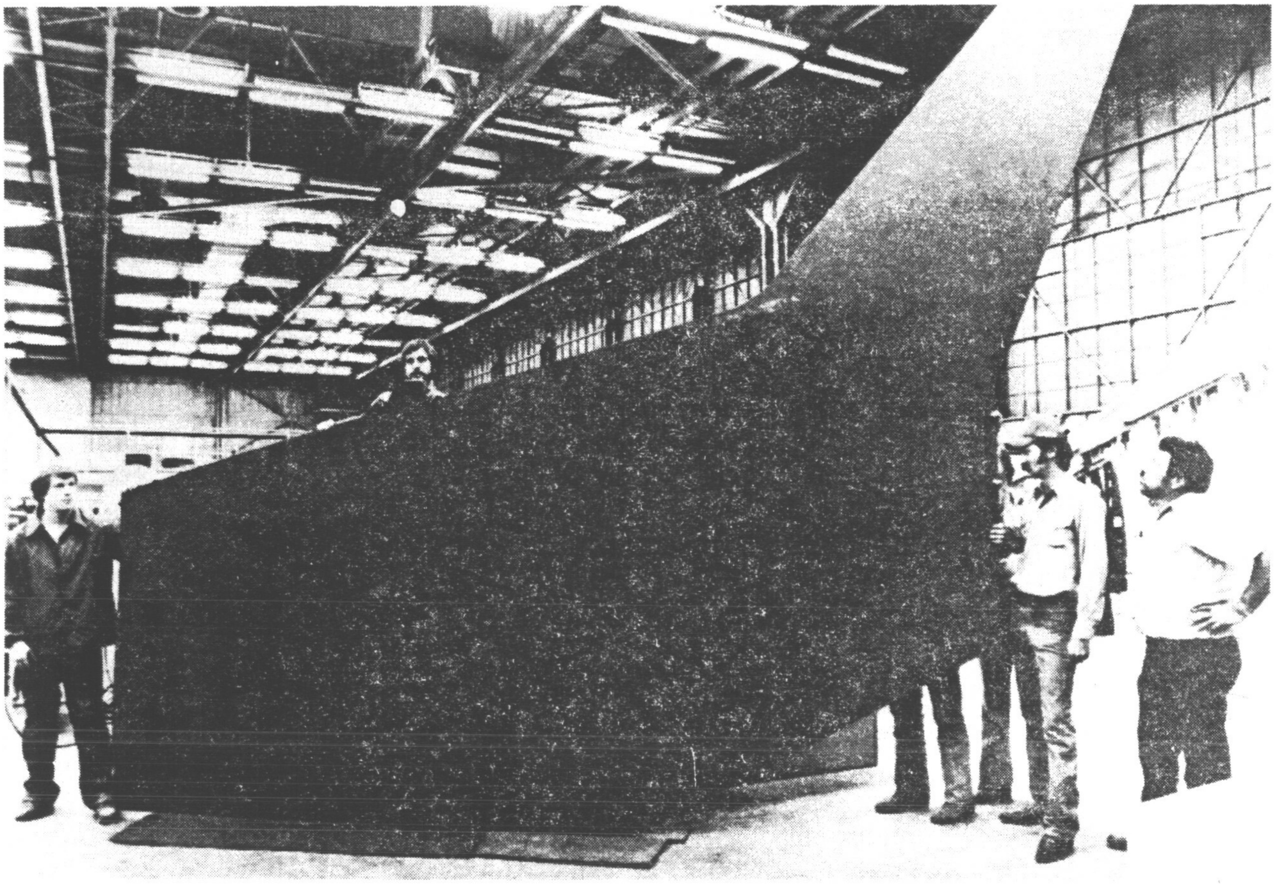

Figure 9. - Completed skin removed from tool after post cure.

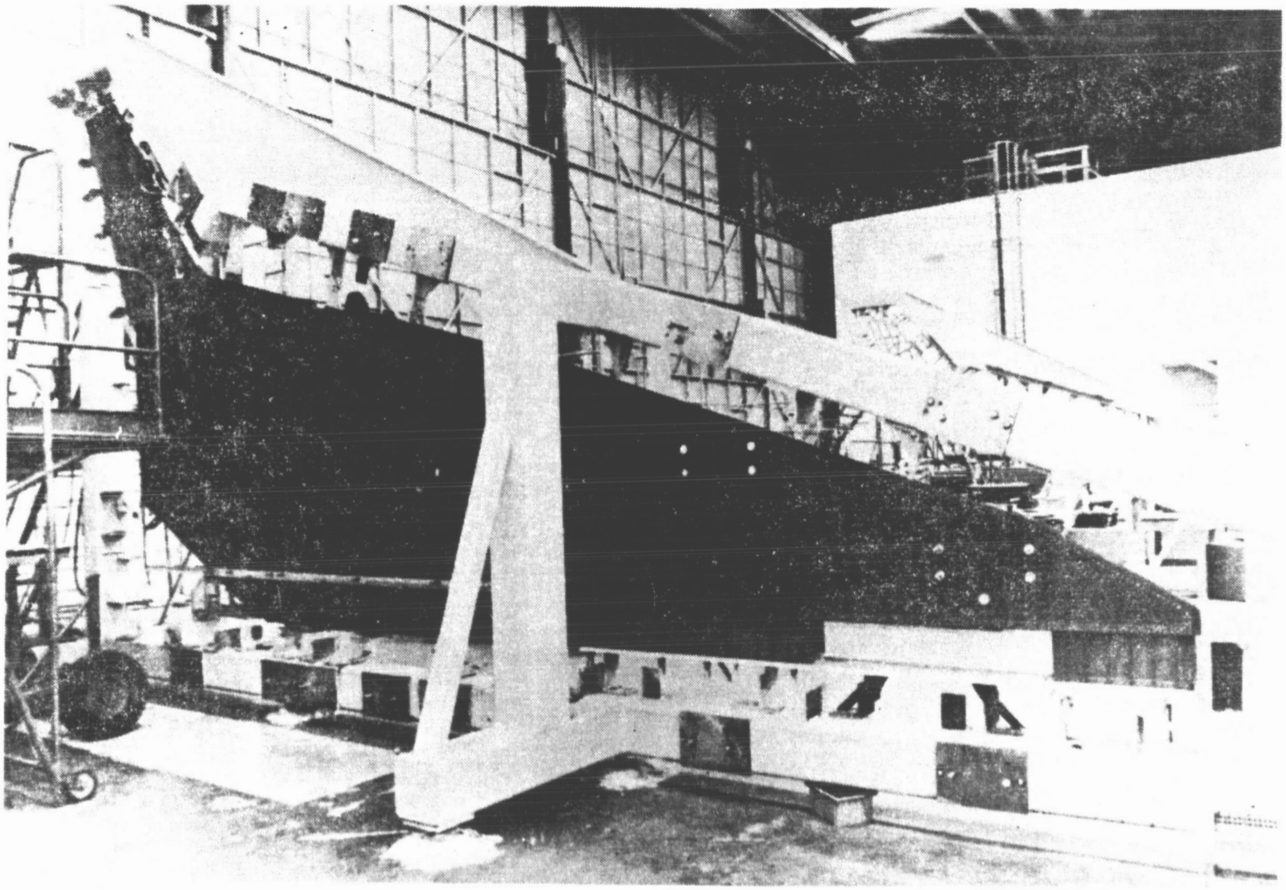

Figure 10. - Completed wing structure with internal ribs mechanically fastened to the upper and lower wing skins.

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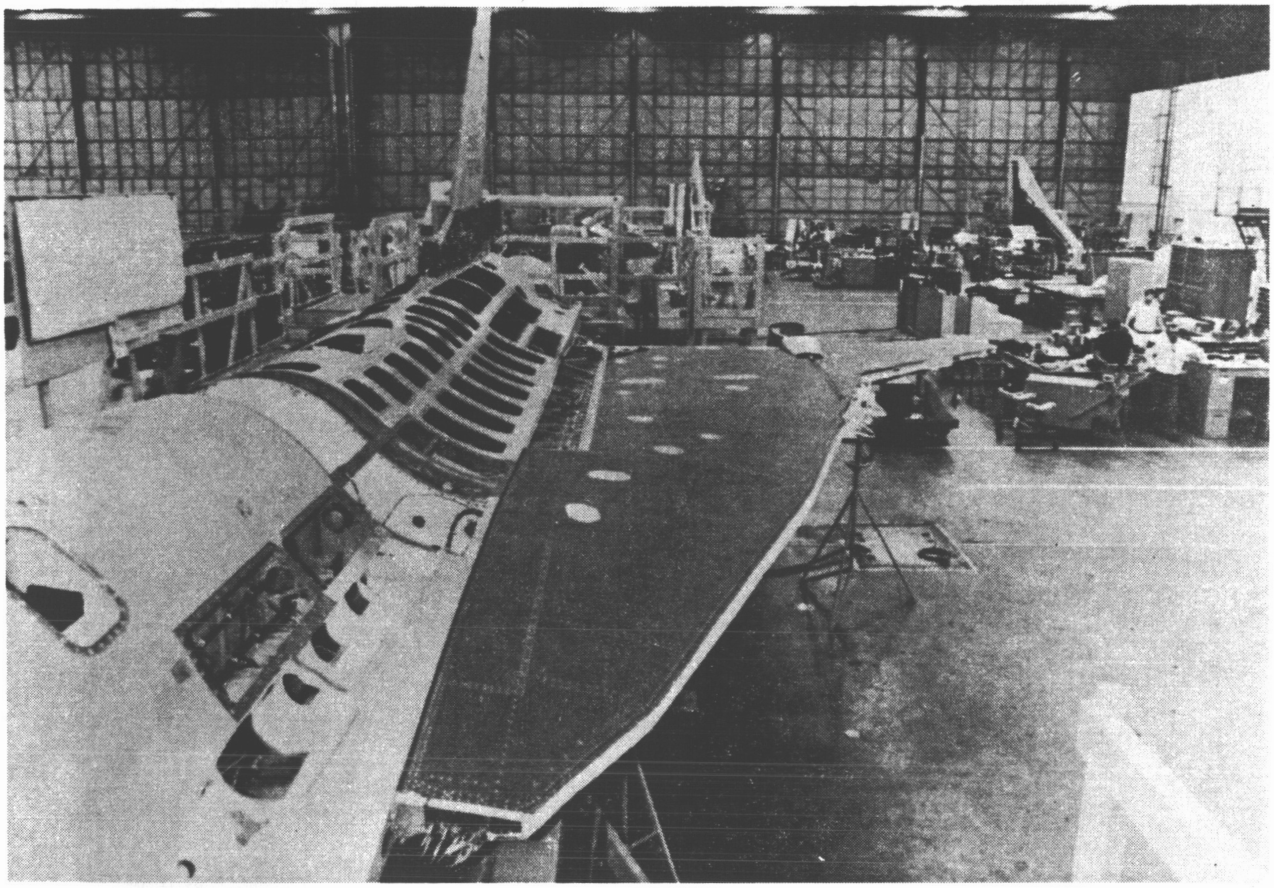

Figure 11. - Completed wing attached to fuselage.

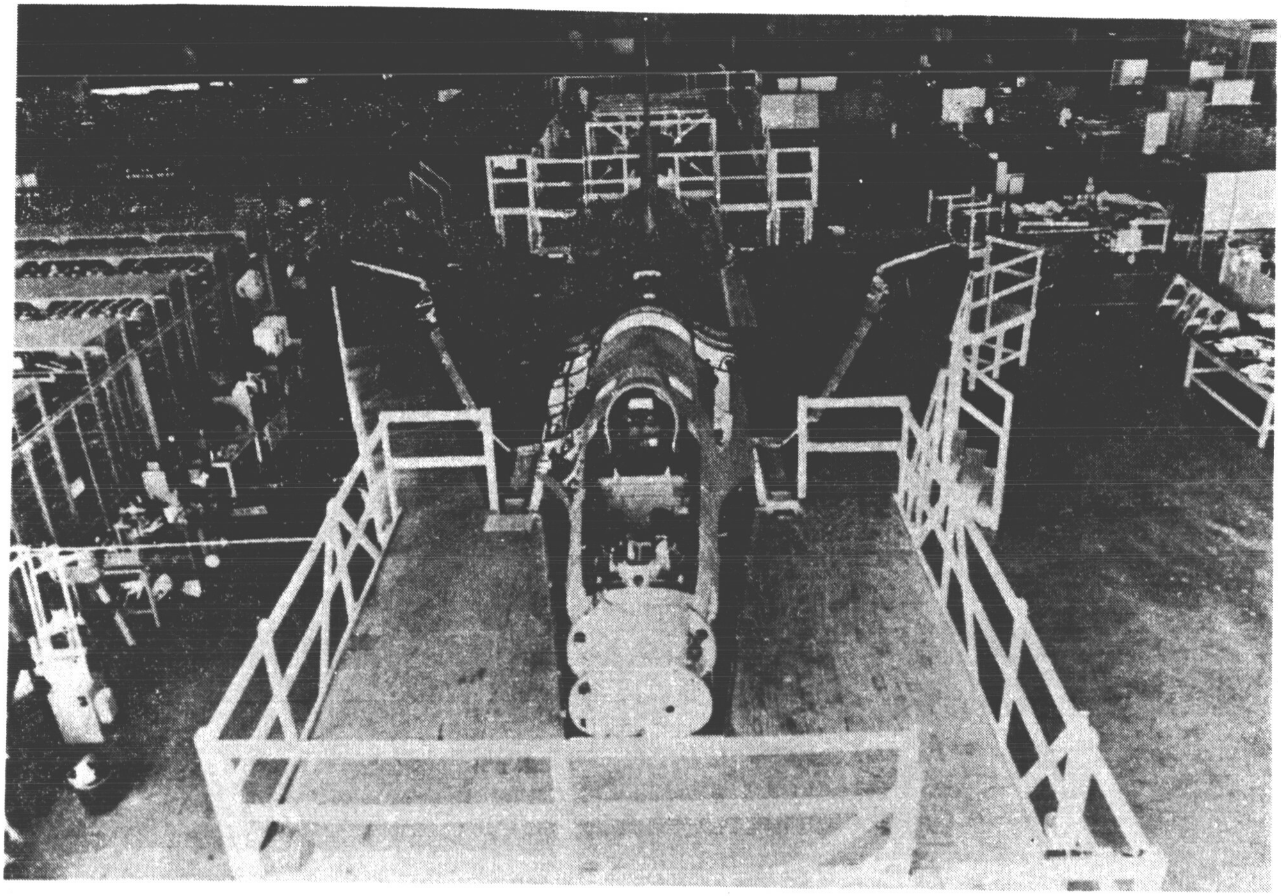

Figure 12. - Fuselage with both wings attached.

Figure 13. - Finished cranked arrow, delta wing F-16XL fighter plane.

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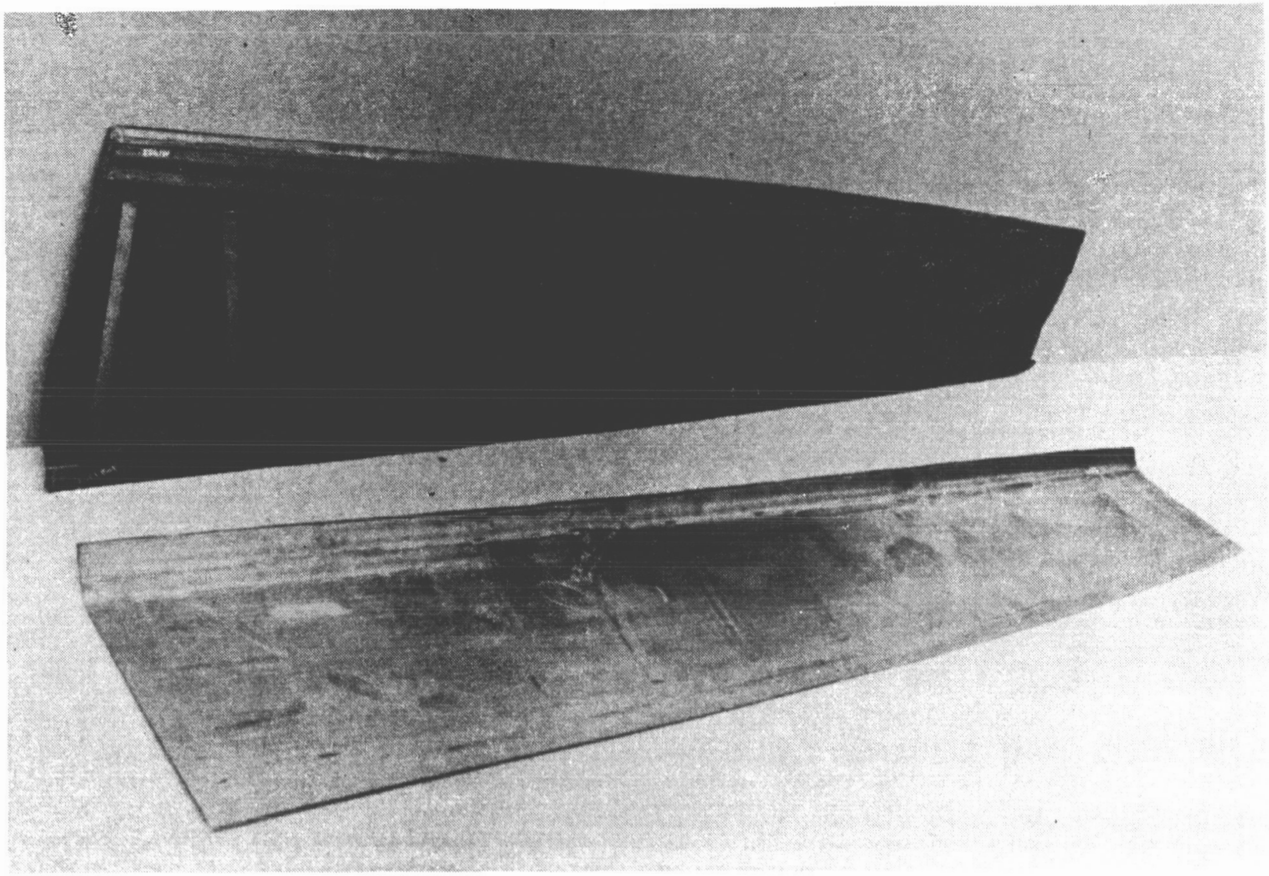

Figure 14. - Wing flap from another prototype aircraft with integrally cocured V-378A/T-300 ribs bonded to a wing skin.