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Advanced Composite Aileron For L-1011 Transport Aircraft -- Aileron Manufacture

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FOREWORD

This report was prepared by the Aerostructures Division, AVCO Corporation, Nashville, Tennessee. The Aerostructures Division of AVCO Corporation is a subcontractor to the Lockheed-California Company, Lockheed Corporation under contract UYTOP1950M. The program is sponsored by the National Aeronautics and Space Administration (NASA), Langley Research Center by Contract NAS1-15069 to the Lockheed Corporation. This is the final report of Task V, Aileron Manufacture. The Program Managers are: AVCO - Mr. W. L. Cobbs; Lockheed - Mr. F. C. English. The Project Manager for NASA, Langley is Mr. H. L. Bohon and the Technical Representative is Dr. H. A. Leybold.

The following AVCO personnel were principal contributors to the program during Task V: E. Dunning, Project Engineer; R. Legg, Composite Manufacturing Engineer; G. Quinn, Foreman Composite Fabrication; D. Armstrong, Foreman Aileron Assembly; C. Stevens, Superintendent Quality Assurance; M. Foutch, Tool Planning Engineer; H. Brewer, Industrial Engineer.

The following Lockheed personnel were principal contributors to the program during Task V: C. Griffin, Project Engineer; L. Fogg, Structures Engineer.

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AILERON MANUFACTURE

SUMMARY

The activities documented in this report are associated with the aileron manufacture portion of the Advanced Composite Aileron (ACA) program. These activities include: aileron manufacture, manufacturing development, quality assurance and cost analysis. The design and analysis of the composite aileron is described in Reference 1.

Five ship sets of inboard ailerons for the L-1011 transport aircraft have been fabricated of advanced composite materials. Of these, the first ship set has been installed and is currently flying on the Lockheed L-1011 test aircraft.

The tooling concepts and manufacturing processes, developed during the program Task II effort, were utilized during the production effort. Difficulties were experienced during the spar fabrication that required manufacturing development.

INTRODUCTION

The broad objective of NASA's Aircraft Energy Efficiency (ACEE) Composite Structures Program is to accelerate the use of composite materials in aircraft structures by developing technology for early introduction of structures made of these materials into commercial transport aircraft. This program, one of several which are collectively aimed toward accomplishing this broad objective, has the specific goal to demonstrate the weight and cost/saving potential of secondary structures constructed of advanced composite materials. The secondary structure selected for this program is the inboard aileron of the Lockheed L-1011 transport aircraft.

The scope of this program is to design, fabricate, qualify and certificate a composite inboard aileron; to test selected subcomponents to verify the design; to fabricate and test two ground test articles. The initial effort to fabricate, install and gather flight service data on ten ship sets of production ailerons was reduced to five ship sets as a result of inconsistencies in the graphite/epoxy prepreg tape material.

The Aerostructures Division of AVCO Corporation is teamed with Lockheed-California Company. Lockheed designed the aileron, conducted the materials, concept verification and ground tests, and will evaluate in-flight service experience. AVCO developed the manufacturing processes, fabricated the test specimens and fabricated the ground test and flight articles.

As shown on the master schedule, Figure 1, the program is being conducted in six nonsequential tasks. Task I, Engineering Development, and Task II, Design and Analysis, are the portions of the program wherein the composite aileron design was formulated and subcomponents fabricated and tested to verify design concepts and fabrication procedures. During Task III, Manufacturing Development, and Task IV, Ground Test and Flight Checkout, production quality manufacturing tools were constructed and two full-scale ailerons were fabricated and tested. Task V, Aileron Manufacture, consisted of a production run of five ship sets to provide manufacturing and cost information. In Task VI, Flight Service, inspection and maintenance data will be gathered on the five ship sets of ailerons to assess their potential for economical operation in routine service. The work performed during this program is intended to provide the data required to progress toward a production commitment.

This report describes work accomplished during Task V.

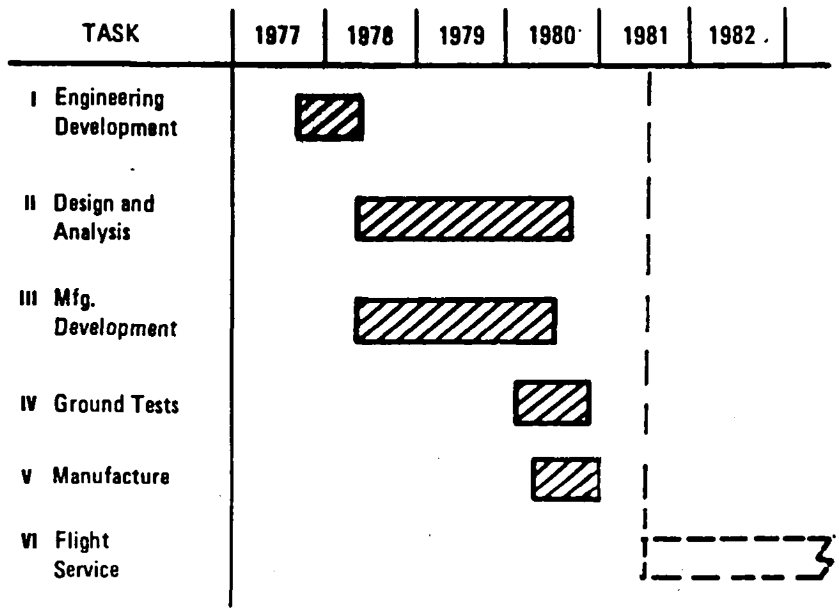

Figure 1. - Master Schedule

Use of commercial products or names of manufacturers in this report does not constitute official endorsement of such products or manufacturers, either expressed or implied, by the National Aeronautics and Space Administration.

MEASUREMENT VALUES

All measurement values in this technical report are expressed in the International System of Units and customary units. Customary units are used for the principal measurements and calculations.

1. MATERIAL

1.1 Material Description

Three types of materials are used in the fabrication of the advanced composite inboard aileron for the L-1011 aircraft. The ribs and the cover internal surface doublers use graphite/epoxy bidirectional woven fabric. The front spar and covers use graphite/epoxy unidirectional tape. The covers also use a syntactic epoxy core material.

1.1.1 Graphite/epoxy fabric - The woven fabric prepreg is 24 x 23 8-harness satin weave of 228 GPa (33 msi) modulus fiber impregnated with a 450K (350°F) curing epoxy. The general description of this material is shown in Table 1. The qualified material for this program is Narmco Material T300/5208.

1.1.2 Graphite/epoxy tape - The unidirectional graphite tape prepreg is non-woven 0.019 cm (0.0075 in) thick, 30.5 cm (12.0 in) wide, 2413 MPa (350 ksi) strength, 228 GPa (33 msi) modulus fiber impregnated with a low resin content 450K (350°F) curing epoxy. The general description of this material is shown in Table 2. The qualified material for this program is Narmco Material T300/5208.

1.1.3 Syntactic epoxy core - The syntactic epoxy material is a calendared epoxy film filled with surface treated glass microballoons and supported on a carrier. A general description of this material is shown in Table 3. The qualified source for this material is Hysol Division of the Dexter Corporation.

1.2 Acceptance

Prior to utilization of any of these materials, tests are required by the material specification for the user acceptance requirements. These tests include certain visual, mechanical and chemical tests that are performed on each batch of material prior to use in the production effort. The AVCO Quality Assurance Department does all of the composite material batch acceptance tests required by Tables 4 and 5 except the liquid chromatography tests are accomplished by the Lockheed California Company on samples supplied by AVCO.

2. MANUFACTURING

2.1 Manufacturing Requirements

The Aerostructures Division of AVCO has fabricated five ship sets of advanced composite ailerons for the L-1011 transport aircraft. This aileron may be used as a direct replacement of the metal ailerons presently in use on this airplane.

The composite aileron is a multirib configuration with single piece upper and lower covers mechanically fastened to the substructure. The covers and front spar are fabricated with graphite/epoxy unidirectional tape. Graphite/epoxy

TABLE 1. GRAPHITE WOVEN FABRIC PREPREG MATERIAL DESCRIPTION

<table>
<tr><th>Property</th><th colspan="3">Requirement</th></tr>
<tr><td>Basic Resin Type</td><td colspan="3">Modified epoxy</td></tr>
<tr><td>Cure Temperature, Nominal</td><td colspan="3">449.8K (350°F)</td></tr>
<tr><td>Heat Resistance</td><td colspan="3">355.4K (180°F) Service</td></tr>
<tr><td rowspan="6">Graphite Fiber Description</td><td><u>Property</u></td><td><u>Unit</u></td><td><u>Requirement</u></td></tr>
<tr><td>Strand Breaking Strength</td><td>MPa(psi)(min)</td><td>2655 (385,000)</td></tr>
<tr><td>Strand Modulus</td><td>GPa(psi x 10^6)</td><td>221-241 (32-35)</td></tr>
<tr><td>Fiber Density</td><td>g/cm^3 (lb/in^3)</td><td>1.70-1.78 (0.061-0.064)</td></tr>
<tr><td>Yield</td><td>g/m (lb/in x 10^{-6})</td><td>0.190-0.206 (10.6-11.5)</td></tr>
<tr><td>Sizing</td><td>%</td><td>0.5-1.6</td></tr>
<tr><td>Yarn Description</td><td colspan="3">Twisted yarns 0.157 twist per cm (0.4 twist per in), 3000 filaments per yarn</td></tr>
<tr><td>Fabric Description</td><td colspan="3">Bi-directional fabric, 24 x 23 8-harness satin weave, 9.4 warp yarns per cm (24 warp yarns per in), 9.1 fill yarns per cm (23 fill yarns per in). Width 105.4 ± 2.54 cm (41.5 ± 1.0 in) unless otherwise specified on purchase order, with selvage of 3.8 cm (1.5 in) max. on each side. Nominal cured thickness per ply 0.33 cm (0.013 in). Tracers shall be Kevlar 49 yarns, 195 denier.</td></tr>
</table>

TABLE 2. GRAPHITE UNIDIRECTIONAL TAPE PREPREG MATERIAL DESCRIPTION

Property	Requirement		
Basic Resin Type	Modified epoxy		
Cure Temperature, Nominal	449.8K (350°F)		
Heat Resistance	355.4K (180°F) Service		
Graphite Fiber Description	Property	Unit	Requirement
	Strand Breaking Strength	MPa (psi) (min)	2655 (358,000)
	Strand Modulus	GPa (psi x 10^{-6})	221-241 (32-35)
	Fiber Density	g/cm^3 (lb/in^3)	1.70-1.78 (0.061-0.064)
	Yield	g/m (lb/in x 10^{-6})	190-0.206 (10.6-11.5)
	Sizing	%	0.5-1.6
Yarn or Roving Description	Non-twisted yarns, 3000 filaments per yarn		
Reinforcement Form	Collimated tape, width as specified on purchase order, without scrim cloth backing		

TABLE 3. SYNTACTIC EPOXY CORE MATERIAL DESCRIPTION

Property	Unit	Requirement
Thickness	cm (in)	0.0953 ± .01 (0.0375 ± .004)
Weight	kg/m^2 (lb/ft^2)	0.600 ± .127 (0.123 ± .026)
Microballoon Content	% by wt.	20 ± 2
Flow @ 450 ± 5.55K (350 ± 10°F) and 0.59 ± .069 MPa (85 ± 5 psi)	%	35 - 55
Volatiles - Test Temp. 450 ± 5.55K (350 ± 10°F) Test Time 60 ± 5 min.)	% by wt.	0.5
Gel Time @ 450 ± 5.55K (350 ± 10°F)	minutes	Report for information
GLASS MICROBALLOON PROPERTIES		
Diameter	Microns	≤ 5% retained on a U.S. #80 standard sieve
Particle Density	g/cm^3 (lb/in^3)	0.20 ± .02 (0.007 ± .0007)
Chemical Resistance-Alkalinity	milliequivalents per gram (max)	0.3
Percentage of Intact Microballoons	% by volume (min)	99.0
Isostatic Pressure Check in Glycerol	psi at which 10% of microballoons are crushed	Report for information

TABLE 4A. BATCH ACCEPTANCE REQUIREMENTS FOR GRAPHITE/EPOXY MATERIALS (UNCURED PROPERTIES)

	UNIT	MATERIAL TYPE			
		UNIDIRECTIONAL TAPE		WOVEN FABRIC	
		QTY	REQUIREMENT	QTY	REQUIREMENT
Volatiles Test Temp. 450 ± 5.6K (350 ± 10°F) Test Time 60 ± 5 min.	% by wt. max	2	3.0	2	3.0
Uncured resin content	% by wt.	4	34.0 ± 3.0	4	41.0 ± 3.0
Flow @ 450 ± 5.6K (350 ± 10°F) and 0.59 ± .03 MPa (85 ± 5 psi) for 10 min.	%	4	9-18	2	15-29
Gel time @ 450° ± 5.6K (350 ± 10°F)	minutes	3	Report for information	3	Report for information
Liquid Chromatography	Report for information				
Areal weight	g/m^2 (lb/ft^2)	4	216 ± 5 (0.044 ± .001)	4	370 ± 14 (0.076 ± .003)

TABLE 4B. BATCH ACCEPTANCE REQUIREMENTS FOR GRAPHITE/EPOXY MATERIALS (CURED PROPERTIES)

PROPERTY	UNIT	TEST TEMP K (°F)	MATERIAL TYPE			
			UNIDIRECTIONAL TAPE		WOVEN FABRIC	
			QTY	REQUIREMENT	QTY	REQUIREMENT
Density	g/cm^3 (lb/in^3)	Ambient	3	1.54-1.60 (0.056-0.058)	3	1.54-1.59 (0.056-0.057)
Cured Fiber Volume	%	Ambient	3	60.0-68.0	3	57.0-63.0
Longitudinal/ Warp direction Tensile Strength	MPa (ksi) (min)	297 (75)	3	1310 (190)	3	483 (70)
Longitudinal/ Warp direction Tensile Modulus	10^4MPa (10^6psi) (min)	297 (75)	3	Shall conform to the material specification	3	5.2 (7.5)
Fill direction Tensile Strength	MPa (ksi) (min)	297 (75)			3	414 (60)
Fill direction Tensile Modulus	10^4MPa (10^6psi) (min)	297 (75)			3	4.8 (7.0)
Longitudinal/ Warp direction Flexural Strength	MPa (ksi) (min)	297 (75)	3	1450 (210)	3	621 (90)
		355.4 (180)	3	1379 (200)	3	621 (90)
Longitudinal/ Warp direction Flexural Modulus	10^4MPa (10^6psi) (min)	297 (75)	3	12.4 (18.0)	3	4.8 (7.0)
		355.4 (180)	3	11.0 (16.0)	3	4.8 (7.0)
Longitudinal/ Warp direction Short Beam Shear Strength	MPa (ksi) (min)	297 (75)	3	89.6 (13.0)	3	41.4 (6.0)
		355.4 (180)	3	82.7 (12.0)	3	34.5 (5.0)
Cured Thickness Per Ply	mm (in)	Ambient	5	0.178-0.211 (0.0070-0.0083)	5	0.345 ± .041 (0.0137 ±.0016)

TABLE 5A. BATCH ACCEPTANCE REQUIREMENTS FOR SYNTACTIC EPOXY MATERIALS (UNCURED PROPERTIES)

PROPERTY	UNIT	QUANTITY	REQUIREMENT
Thickness	mm (in)	5	0.953 ± .102 (0.0375 ± .004)
Weight	kg/m^2 (lb/ft^2)	2	0.601 ± .127 (0.123 ± .026)
Microballoon Content	%	2	20 ± 2
Flow @ 450 ± 5.6K (350 ± 10°F) and 0.59 ± .03 MPa (85 ± 5psi) for 10 min.	%	2	35-55
Volatiles Test Temp. 450 ± 5.6K (350 ± 10°F) Test Time 60 ± 5 min.	% by wt. (max)	2	0.5
Gel Time @ 450 ± 5.6K (350 ± 10°F)	minutes	2	Report for information
Liquid Chromatography	Report for information		

TABLE 5B. BATCH ACCEPTANCE REQUIREMENTS FOR SYNTACTIC EPOXY MATERIALS (CURED PROPERTIES)

PROPERTY	UNIT	TEST TEMP K (°F)	LAMINATE TYPE*			
			SYNTACTIC PANEL		GR/EP/SYN SANDWICH	
			QTY	REQUIREMENT	QTY	REQUIREMENT
Density	g/cm^3 (lb/in^3)	Ambient	3	0.637 ± .138 (0.023 ± .005)	3	0.95 ± .01 (0.034 ± .0004)
Cured Thickness	mm (in)	Ambient	5	5.33 ± .559 (0.210 ± .022)	5	3.07 ± .254 (0.121 ± .010)
Tensile Strength	MPa (psi) (min)	297 (75)	3	13.8 (2,000)		
Tensile Ultimate Strain	mm/mm (in/in)	297 (75)	3	0.008 (0.008)		
Interlaminar Tensile Strength	MPa (psi)	297 (75)			3	10.3 (1,500)
Short Beam Shear Strength	MPa (psi)	297 (75)			3	13.8 (2,000)

*Laminate Type: Syntactic panel: Six plies syntactic epoxy
Graphite/syntactic sandwich panel:
(45°/0°/135°/(2) syntactic/135°/0°/45°)

bidirectional fabric is used for construction of the ribs. The rear spar is fabricated from 7075-T6 clad aluminum alloy sheet. The composite aileron also utilizes the following parts that are common to the metal aileron: inboard and outboard fairings (fiberglass); trailing edge (Kevlar); leading edge shroud (aluminum); hinge, actuator and feedback fittings (aluminum). A schematic of the aileron assembly is shown in Figure 2.

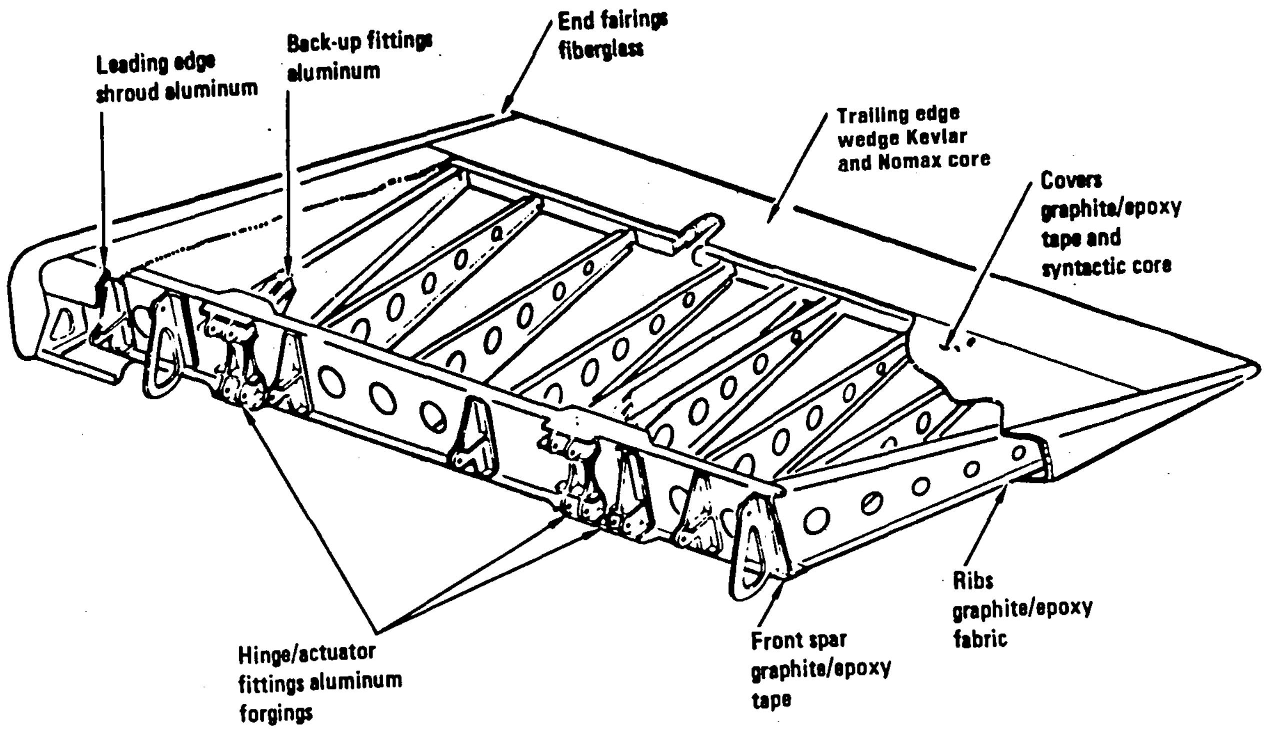

Figure 2. - Advanced Composite Aileron Assembly

The upper cover is permanently fastened to the ribs and spars with titanium Triwing screws and stainless steel Hi-Lok collars. The removable lower cover, trailing edge wedge, leading edge shroud and end fairings are attached with the same type screws and stainless steel nut plates. The nut plates are attached to the substructure with stainless steel cherry rivets.

A manufacturing flow diagram defining the basic manufacturing operations to fabricate an advanced composite aileron is shown in Figure 3.

2.2 Detail Fabrication

The aileron structure is made up of ten ribs (three main, five intermediate and two closeout), one front spar and two covers. These details were fabricated by preplying the prepreg material, trimming with a shop knife and layup on a male tool. The cure of these composite details was accomplished to a common cure cycle which enhanced autoclave utilization.

2.2.1 Ribs - The three types of ribs are of similar construction and are fabricated in a like manner.

Main Ribs - The main ribs are a tapered channel section configuration constructed with four plies of graphite/epoxy bidirectional fabric, 0.36 mm/ply (0.014 in/ply), oriented at $45°/90°_2/45°$ where 0° is parallel to the wing reference plane (WRP). Five plies of graphite/epoxy tape are included between the two center fabric plies of the rib caps and are oriented at +5°/-5°/0°/-5°/+5° where 0° is lengthwise to the cap.

Intermediate and Closeout Ribs - The intermediate and closeout ribs are constant thickness tapered channel sections consisting of five plies of fabric oriented at 45°/90°/135°/90°/45° where 0° is parallel to the WRP. Each rib has five flanged lightening holes.

Tooling - The tool family required for fabrication of the ribs are prepreg trim templates, male layup/cure block and silicone rubber bag. The intermediate and closeout ribs have one trim template per rib, while the main ribs require six templates per rib. Four of these templates are required for the fabric plys due to the ply overlap requirements of the continuous aft flange, and two templates are required for the cap internal tape doublers. A typical family of tools for an intermediate rib is shown in Figure 4.

Preply and Trim - Graphite/epoxy fabric prepreg that has been batch acceptance tested is stored in the layup room freezer. The afternoon prior to preplying, the prepreg is removed from the freezer. The next morning, when the prepreg has reached room temperature, a template is placed on the fabric prepreg to the orientation required. The first ply is then trimmed with a shop knife and the backing is removed. The template is rotated to obtain the correct fiber orientation for the second ply and trimmed. This is repeated for the number of plies required. Figure 5 shows an intermediate rib template in position for 90° ply orientation trim. The completed preplied material adhering to the template from the prepreg tackiness is final trimmed and an awl is pushed through two coordinated tooling holes in the rib web area. These holes are used to align the material to targets on the layup block. Along with each rib preply, a process control specimen is prepared for layup and cure.

Layup - The trimmed prepreg is then aligned on the male layup block to the targets in the web area. The rib caps and the lightening hole flanges are wiped to the tool contour using Teflon paddles.

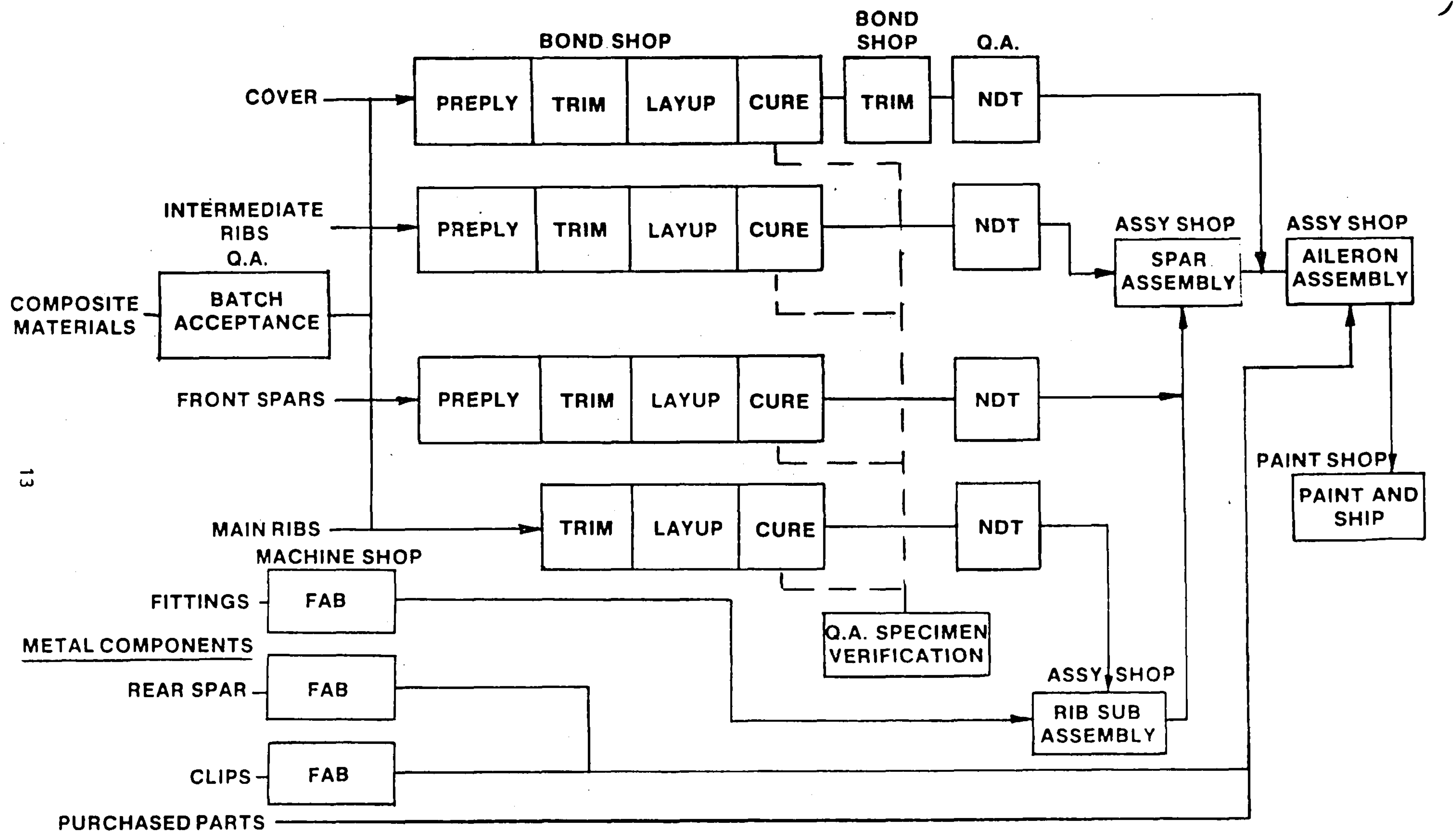

Figure 3. - Manufacturing Flow Diagram

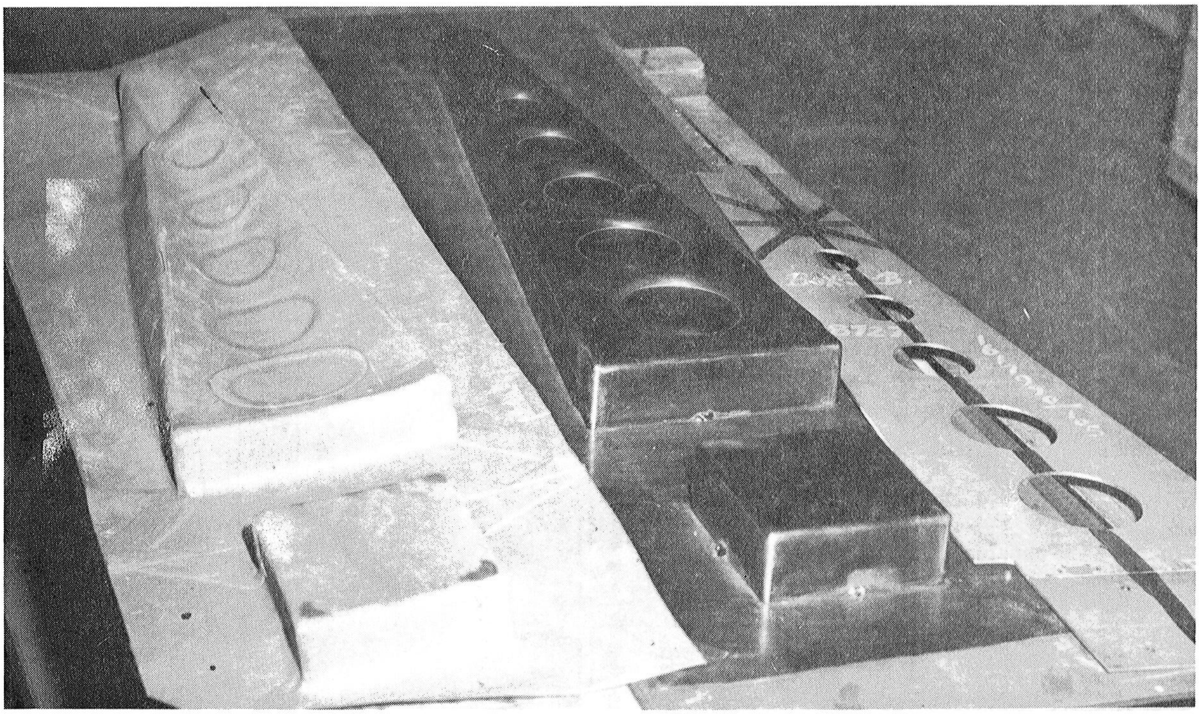

Figure 4. - Intermediate Rib Tools

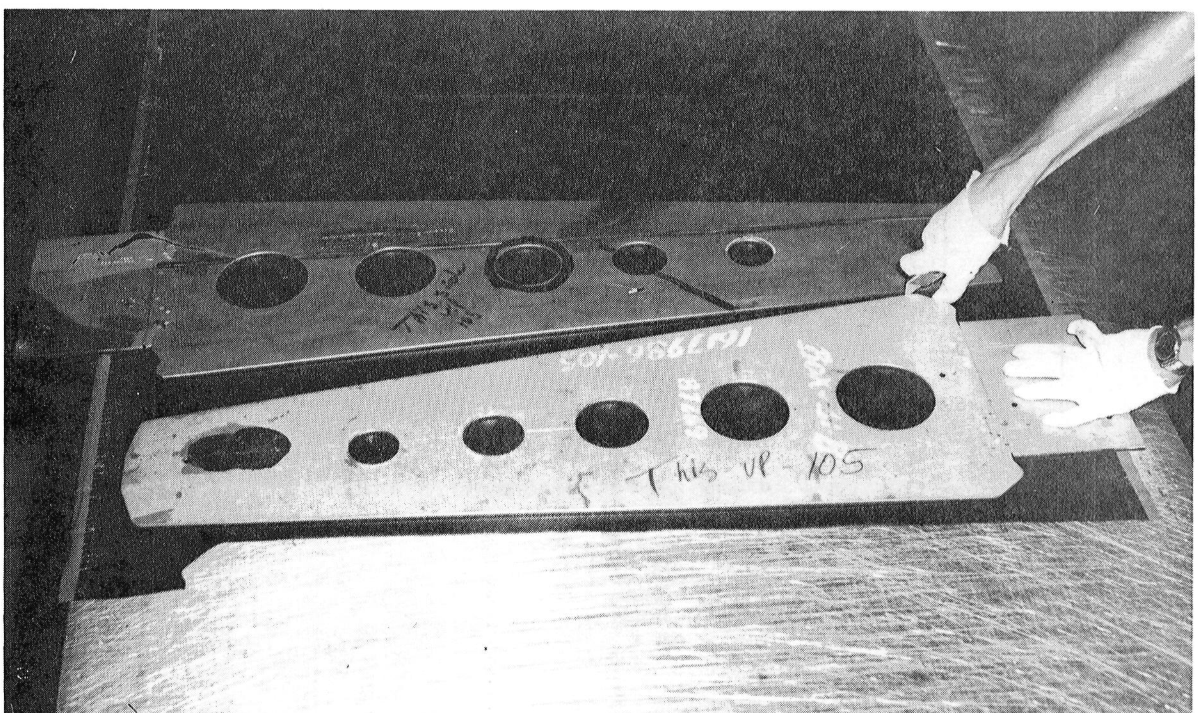

Figure 5. - Intermediate Rib Prepreg Trim Operation

Figure 6 shows the fabric prepreg laid up on the cure block ready for application of the bleeder/breather materials. Note the process control specimen on the adjacent layup block. The bleeder/breather materials are applied and trimmed in accordance with the layup schematic of Figure 7 as shown in the photograph of Figure 8. The Armalon (porous Teflon coated fiberglass) breather strips are then applied to the breather materials and tied to the vacuum source by the fiberglass cloth around the periphery of the layup block. The silicone rubber bag (see Figure 9) and the required thermocouples are applied to the layup. The layup is then sealed under a nylon vacuum bag.

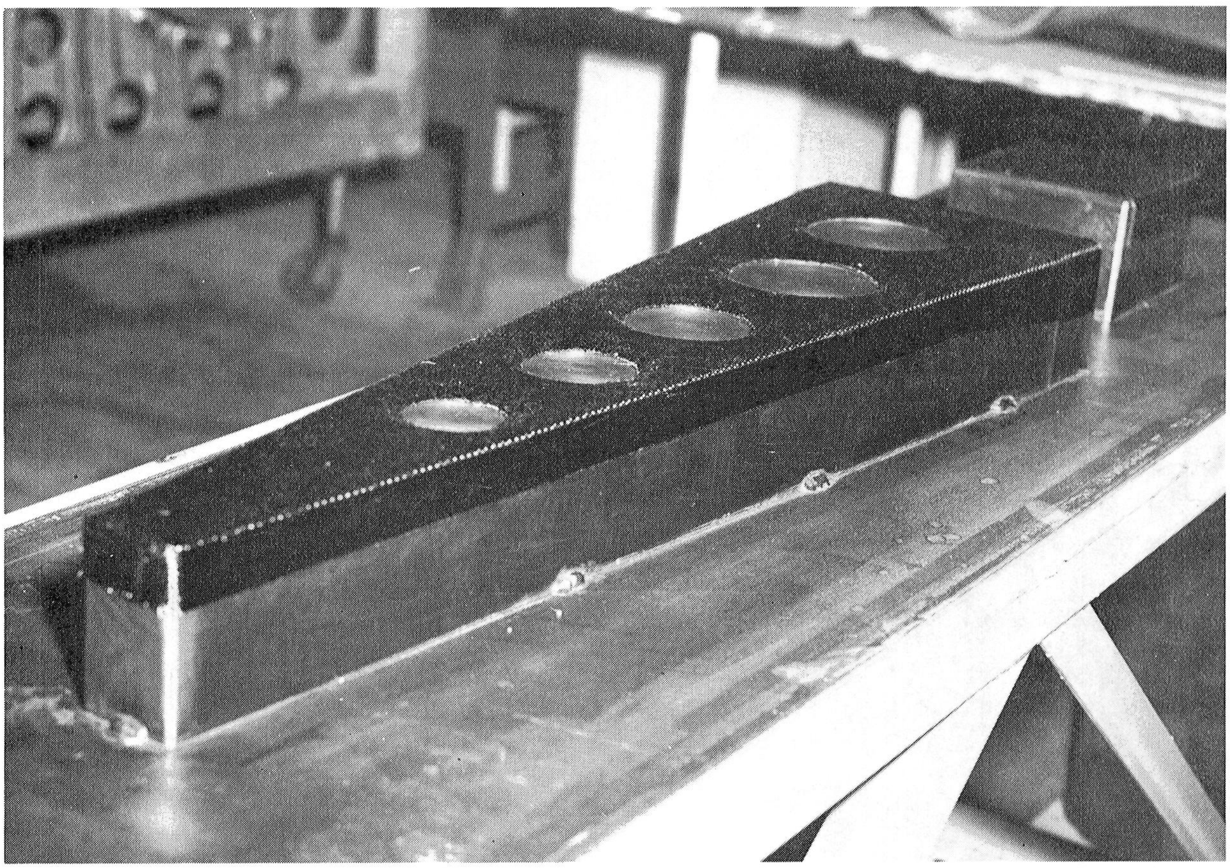

Figure 6. - Rib Preplied Graphite Prepreg on Cure Tool

Cure - The bagged details are held under vacuum until sufficient quantity are completed to load the autoclave or until the material "out time" necessitates cure. The layups are then loaded into the autoclave and cured per the cure cycle shown in Figure 10. After the ribs and process control specimens are unbagged, the flash is removed by hand using a putty knife and 200 grit emery cloth. The afore described tooling, layup and bagging procedure results in a net cured part which eliminates costly trim tools and labor. It should be noted that

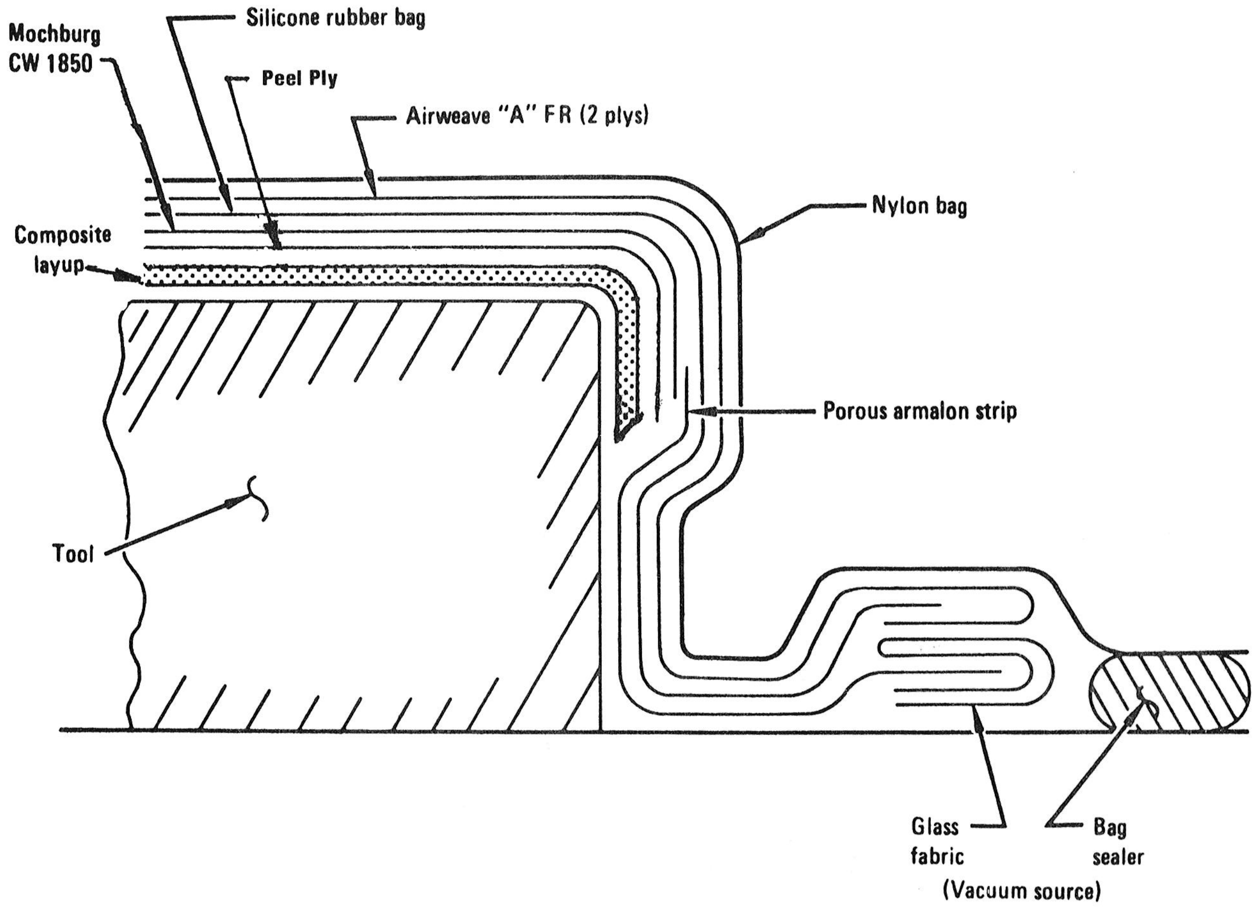

Figure 7. - Schematic of Rib Bleeder/Breather Arrangement

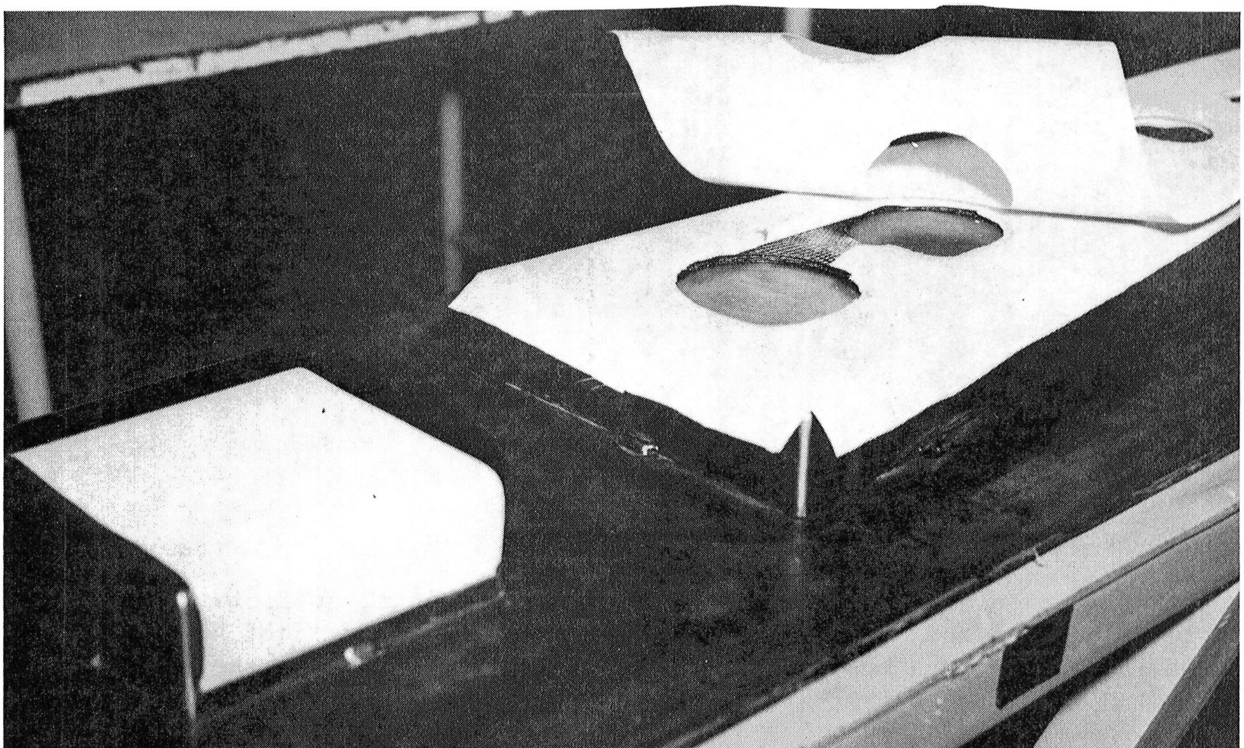

Figure 8. - Rib Bleeder/Breather Arrangement

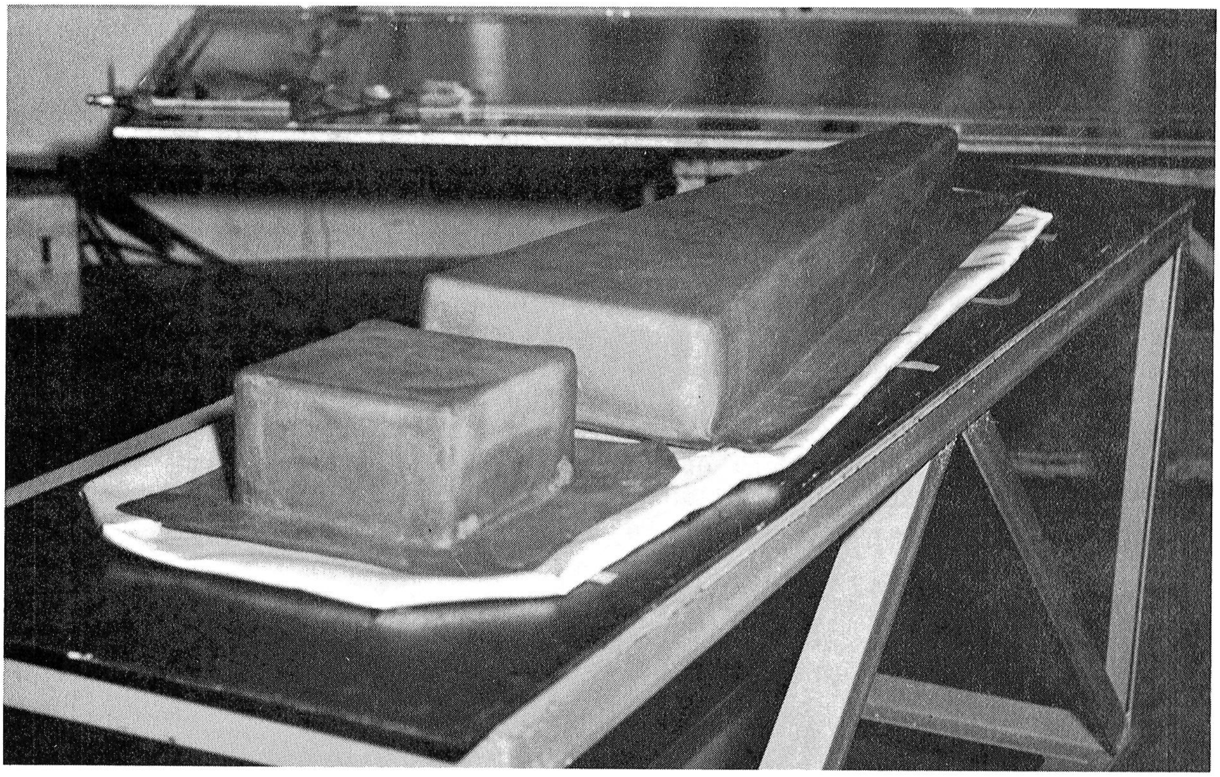

Figure 9. - Rib Layup with Silicone Rubber Bag

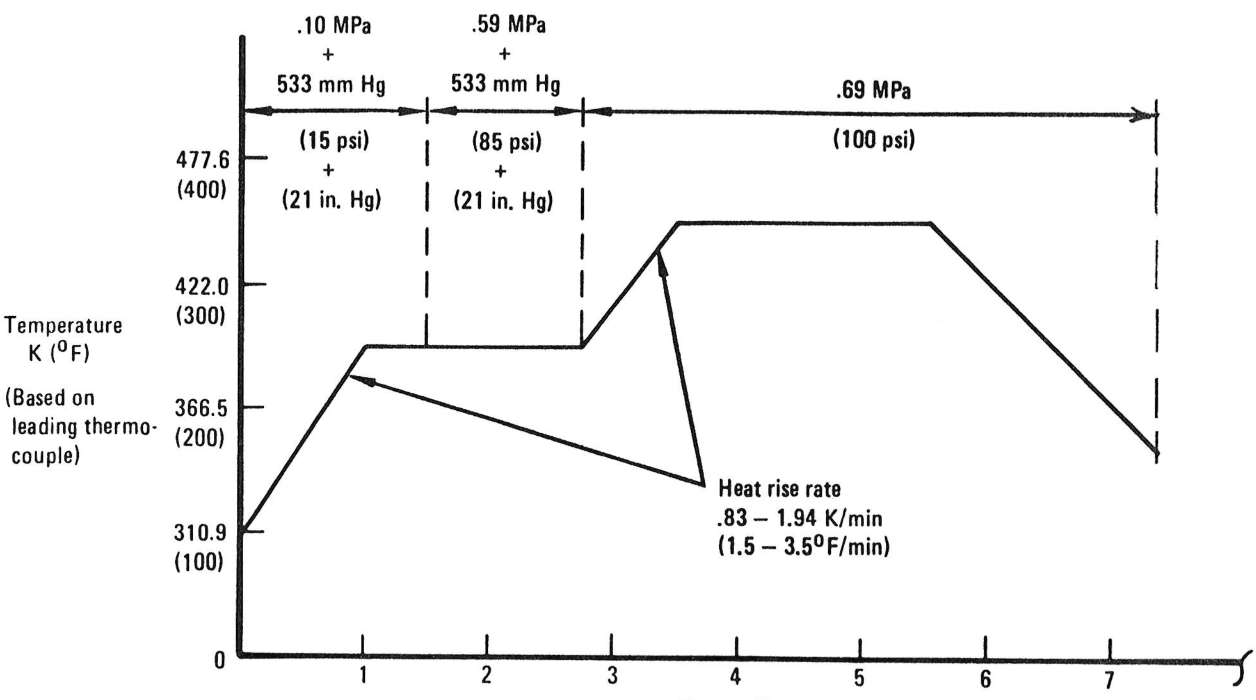

Figure 10. - Cure Cycle Profile

this technique required coordination during the detail design since the edges of all caps have a 0.1 cm (0.040 in) long taper. The ribs are sent to ultrasonic inspection and the process control specimens are processed into the required physical and mechanical test coupons.

Manufacturing routing sheets (Manufacturing Plans) were prepared for each composite detail, subassembly and assembly. These plans define the materials, parts, tools, work description and station for each manufacturing operation and inspection points.

2.2.2 Covers - The cover configuration, shown in Figure 11, is a syntactic core sandwich consisting of three plies of graphite/epoxy unidirectional tape 0.19 mm/ply (0.0075 in/ply) on each side of a layer of 0.953 mm (0.0375 in) syntactic epoxy core. The ply orientation of the sandwich face sheets is 45°/0°/135° with 0° established as the spanwise direction. External graphite tape doublers are used at all rib and spar locations, and internal doublers replace the syntactic core at the main rib and spar locations. Both covers, upper and lower, utilize the same construction and differ only in peripheral dimensions.

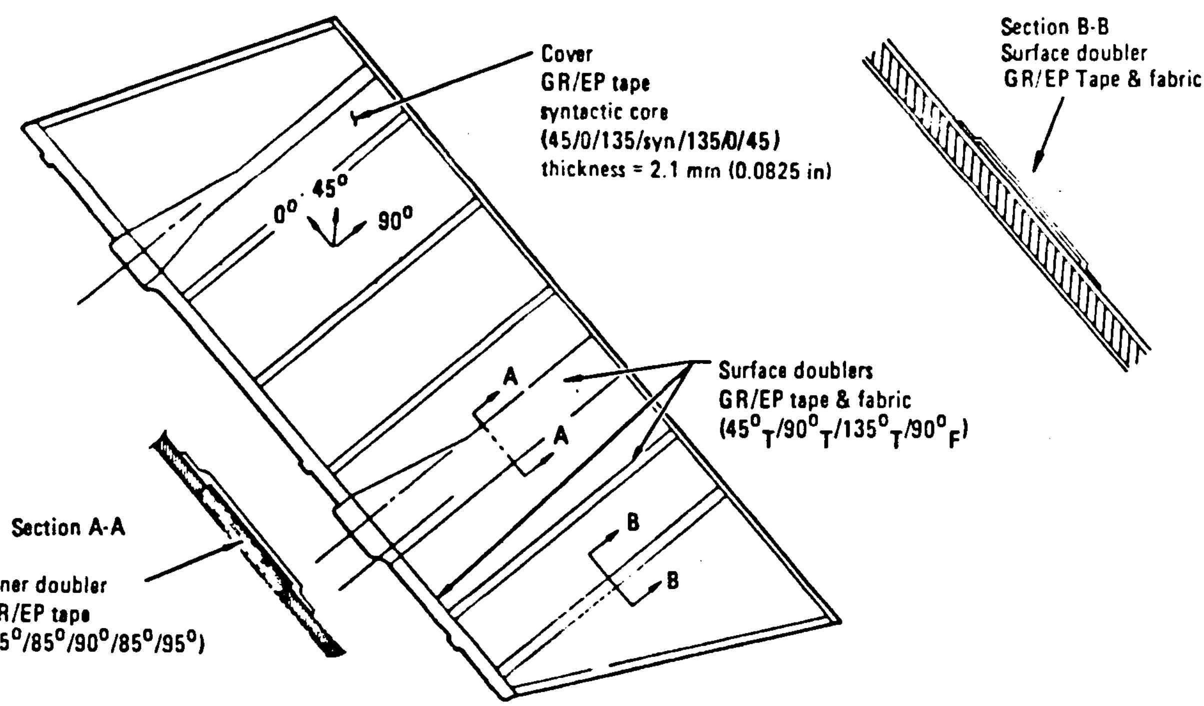

Figure 11. - Aileron Cover Configuration

Tooling - The tool family for fabrication of the cover consists of prepreg trim templates and a cure plate. A set of cover trim templates (seventeen required) is shown in Figure 12. The cure plate is a flat aluminum plate 1.59 cm (0.625 in) thick with a strip bonded lengthwise on the surface which forms the joggle at the leading edge of the outer surface. This plate is indexed for all rib stations for location of the doublers and syntactic core during layup.

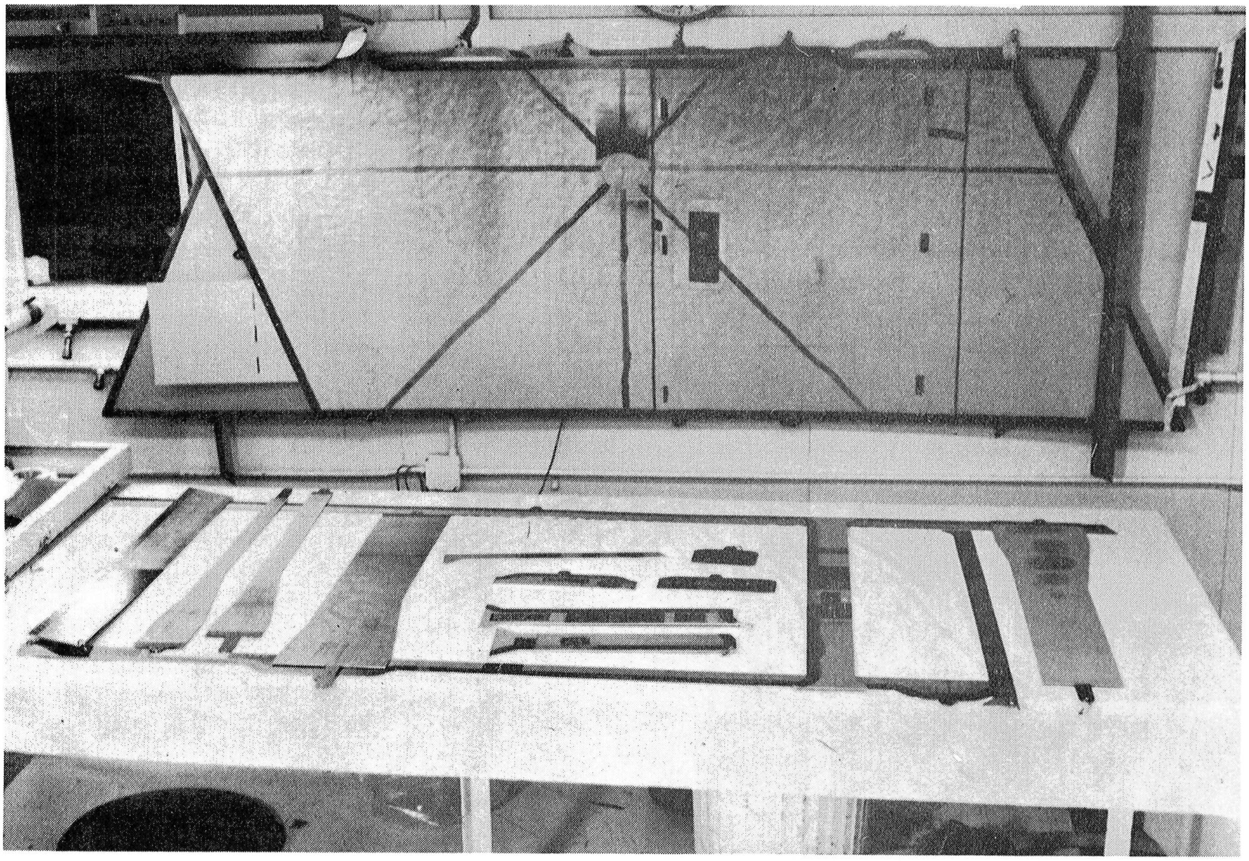

Figure 12. - Cover Trim Template Family

Preply and Trim - Graphite tape is preplied for the internal doublers (95°/85°/90°/85°/90°/95°) and surface doublers (45°/90°/135°). The required doubler templates are oriented on the preplied graphite sheets and the material is trimmed net using a shop knife. These prepreg details are identified, wrapped and sealed in a Tedlar film. If these details are not to be laid up during the week of kitting, they are placed in the freezer until needed.

The graphite tape prepreg is preplied into sheets for the cover face sheets (45°/0°/135°). These sheets are then trimmed with a shop knife to 2.54 cm (1.0 in) oversize. During the preply of all these prepreg details, hand rubbing with Teflon paddles to remove air pockets is kept to a minimum.

Layup - The cleaned cover cure plate is covered with a 0.0381 mm (0.0015 in) film of solid Tedlar. The trimmed outer face sheet prepreg detail is then located by aligning the tooling holes in the prepreg over the plate targets. Using these same targets, the main rib internal doubler prepreg details are located on the face sheet. Teflon paddles are used to wipe out any air bubbles at the faying surface and to assure good tack between the details. Any necessary wiping is in the fiber direction. Peripheral internal doublers are then added to the layup while being located to the tooling targets and the edge of part. The syntactic core material is trimmed with a shop knife to fit between these doublers. During this trimming operation, the backing paper is left on both sides of the syntactic and is removed from each side just before that side is contacted to the graphite prepreg faying surface. This is necessary to prevent wrinkles in the core material. Application of the syntactic core is next. The inner face sheet prepreg detail is then applied to the layup using tooling holes and targets for orientation. The previously trimmed external doublers are applied to the inside surface of the cover and located to the station lines scribed on the tool. The required graphite fabric prepreg doublers are then added over the tape doublers. The completed cover layup, less the bleeder/breather materials, is shown in Figure 13.

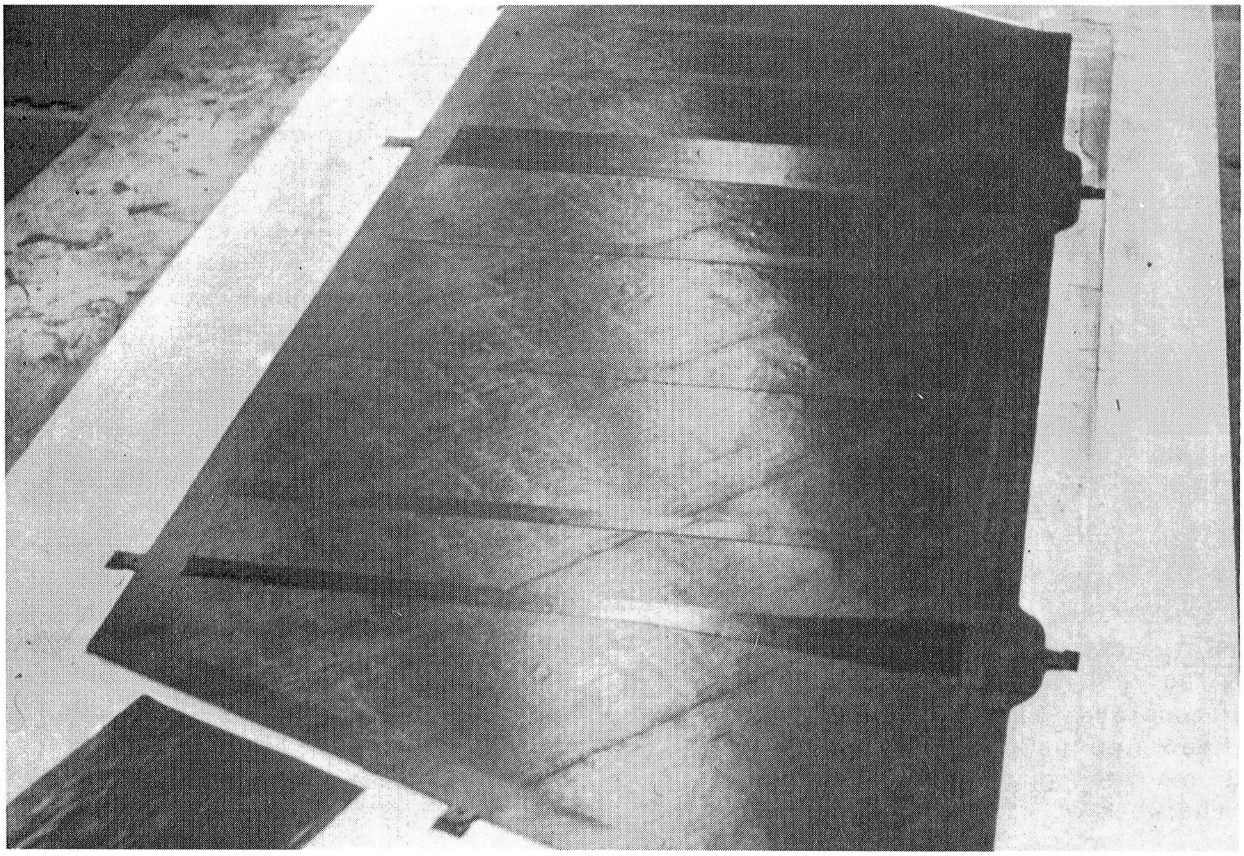

Figure 13. - Completed Cover Layup

A 0.635 cm (0.250 in) thick Corprene dam is applied along the leading edge of the cover layup. The bleeder/breather materials are applied to the layup in accordance with the layup schematic shown in Figure 14. The porous Armalon breather plies are cut on a bias and slit down each side of the doublers. This is done to eliminate any possibility of bridging of these materials. The completed layup is then bagged. During the bagging, the required thermocouples are applied to the layup. Two vacuum sucksticks and one gage line are used during the bagging operation to minimize the possibility of vacuum blockoff. This particular layup is used to allow vertical breathing of the layup during cure. This is accomplished by placing A4000P3, a halogen release film perforated on 0.127 cm (0.50 in) centers, and A4000P4, a halogen release film perforated on 10.2 cm (4.0 in) centers, between the bleeder plies forcing air and/or volatiles up to the Airweave SS FR breather, a synthetic fiber mat, and then laterally to the vacuum source and vent.

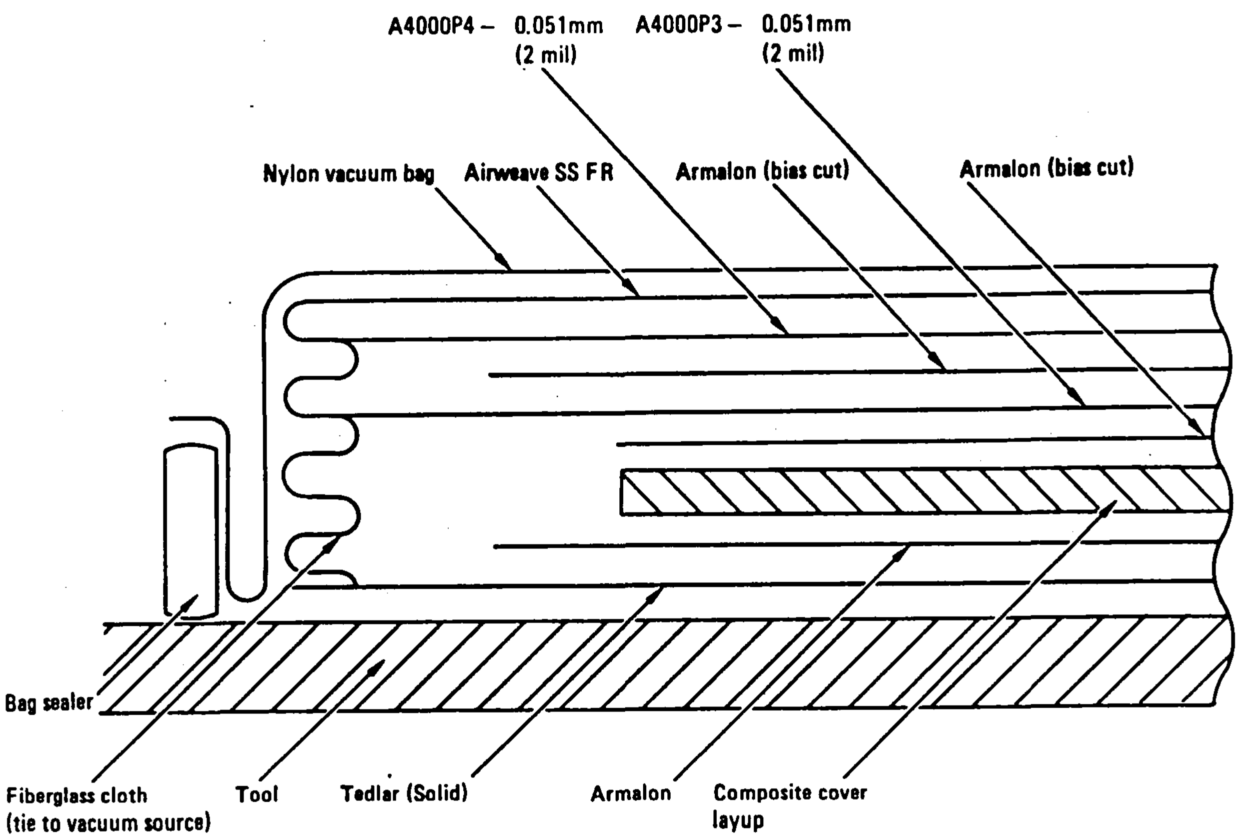

Figure 14. - Schematic of Cover Bleeder/Breather Arrangement

Cure - As with the ribs, the cover layups are held under vacuum until a full autoclave load is available, but not to exceed the material "out time life". The cover cure cycle (identical to the ribs) is shown in Figure 10.

The cured cover is removed from the autoclave and unbagged. After removal of the bleeder/breather materials, the cover is trimmed using a hand router with a diamond router bit as shown in Figure 15. The covers, together with the process control coupon, are sent to NDI and subsequently to the quality assurance laboratory for the required physical and mechanical tests.

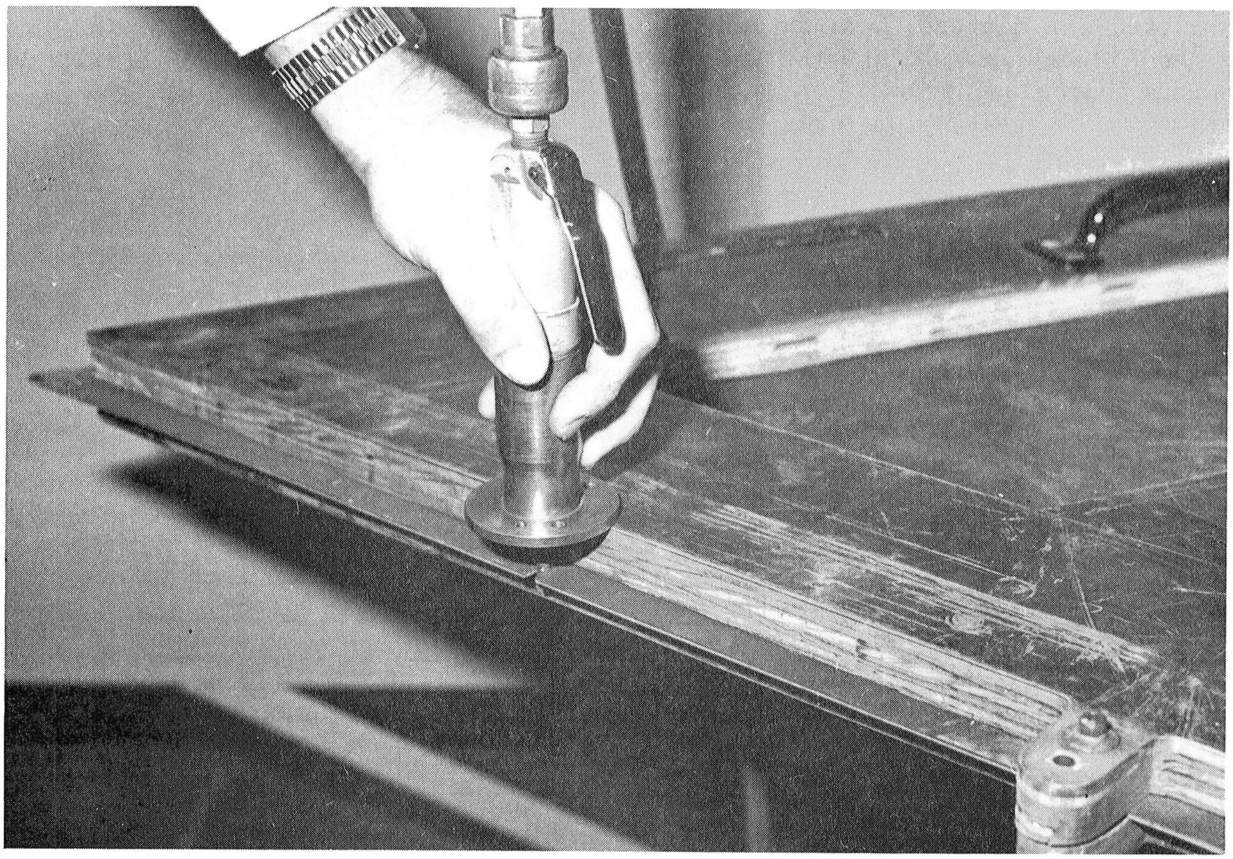

Figure 15. - Preparation for Cover Hand Routing Operation

2.2.3 Spar - The front spar of the composite aileron is of graphite tape construction and is a closed angle channel member. The spar channel height is tapered from 24.13 cm (9.5 in) to 25.4 cm (10.0 in), is 238.178 cm (93.771 in) long and has six flanged lightening holes. The ply orientation of this ten ply laminate is $(45°/0°/135°/90°/0°)_s$ where the 0° direction is spanwise.

Tooling - The tool family required for fabrication of the spars is the prepreg trim template, male layup and cure block and the silicone rubber bag. The trim template is common for the left and right hand parts, being flipped for opposite hand parts. A photograph of this tool family is shown in Figure 16.

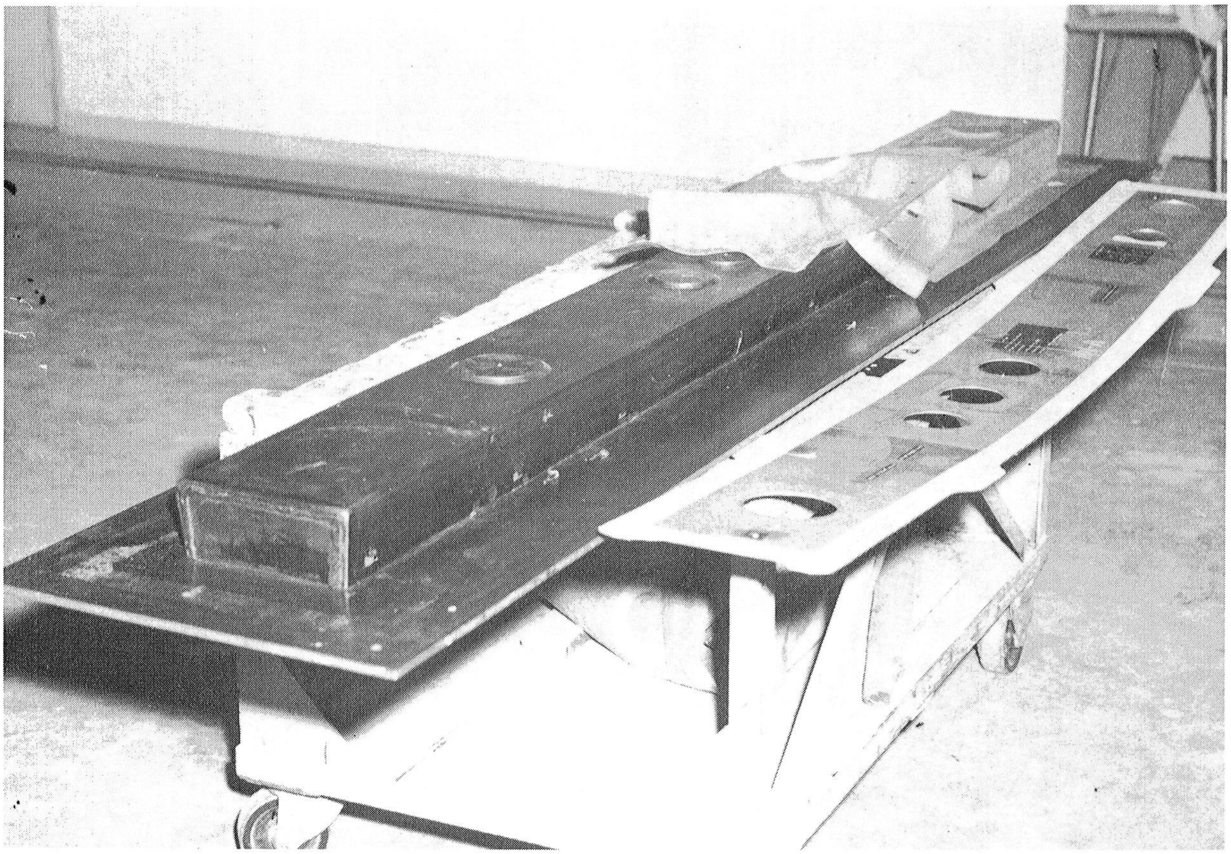

Figure 16. - Spar Tools

Preply and Trim - The graphite/epoxy tape that has been thawed and brought to room temperature is preplied and trimmed to the spar template configuration. The tape is preplied in the following sets: (45°/0°/135°), (90°/0°), (0°/90°) and (135°/0°/45°). Figure 17 shows three of the preplied sets awaiting layup.

The trimmed preplied prepreg material includes a tooling hole near each end. These holes are applied by separating the fibers with an awl, and are used for alignment of the preplied material on the layup/cure block. Each preply segment has an integral tag end that is required for process control testing after cure.

Layup - The male layup tool is oven heated to 324.8K (125°F). The tooling holes in the preplied and trimmed prepreg are then centered on the tool alignment targets. Each set is then formed to contour using a Teflon paddle on the spar caps and the flanged lightening holes.

When the four sets of preplied composite prepreg have been laid up on the tool, the bleeder/breather stack, silicone rubber bag and vacuum bag are applied.

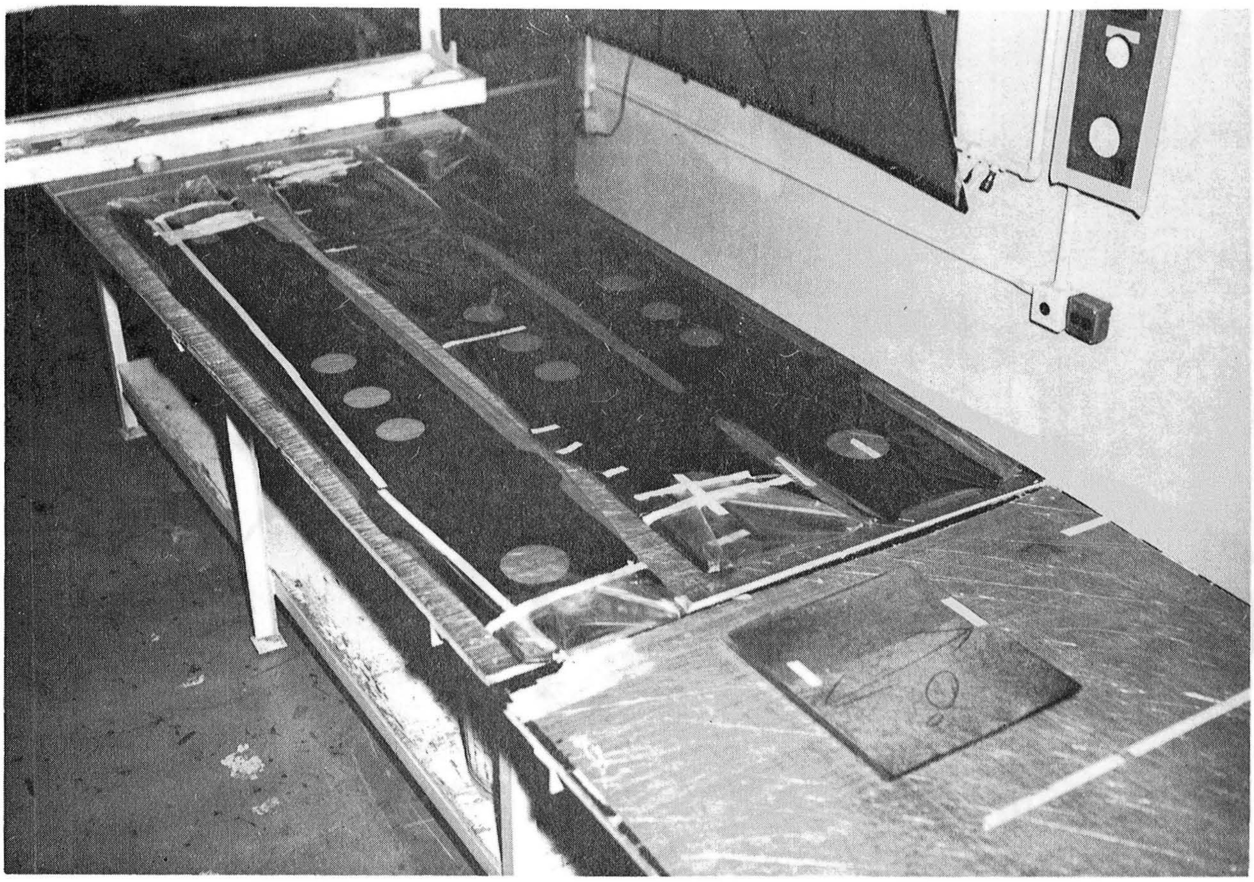

Figure 17. - Spar Preplied and Trimmed Tape Prepreg

The initial process developed for the spar fabrication was used to produce the process development and verification test articles. Prior to fabrication of the spar for the first ground test article, the cure cycle was changed to improve the process of the rib and cover fabrication. During the production fabrication effort, inconsistencies in the finished part occurred which led to the conclusion that the developed process was inadequate for the specified material. To facilitate manufacturing, additional process development was initiated which continued throughout the production of the five ship sets of spars.

The following discussion defines the rationale of the bleeder/breather iterations during this manufacturing process development effort and is summarized in Table 6 and the histogram of Figure 18.

<u>Process "A"</u> - The process "A" bleeder/breather system was used to produce two process verification spars. A change in the cure cycle was made to accommodate the rib and cover fabrication. Since the rib fabrication showed exceptional results using the no dam technique of layup, the additional manufacturing development was initiated predicated on this technique and cure cycle.

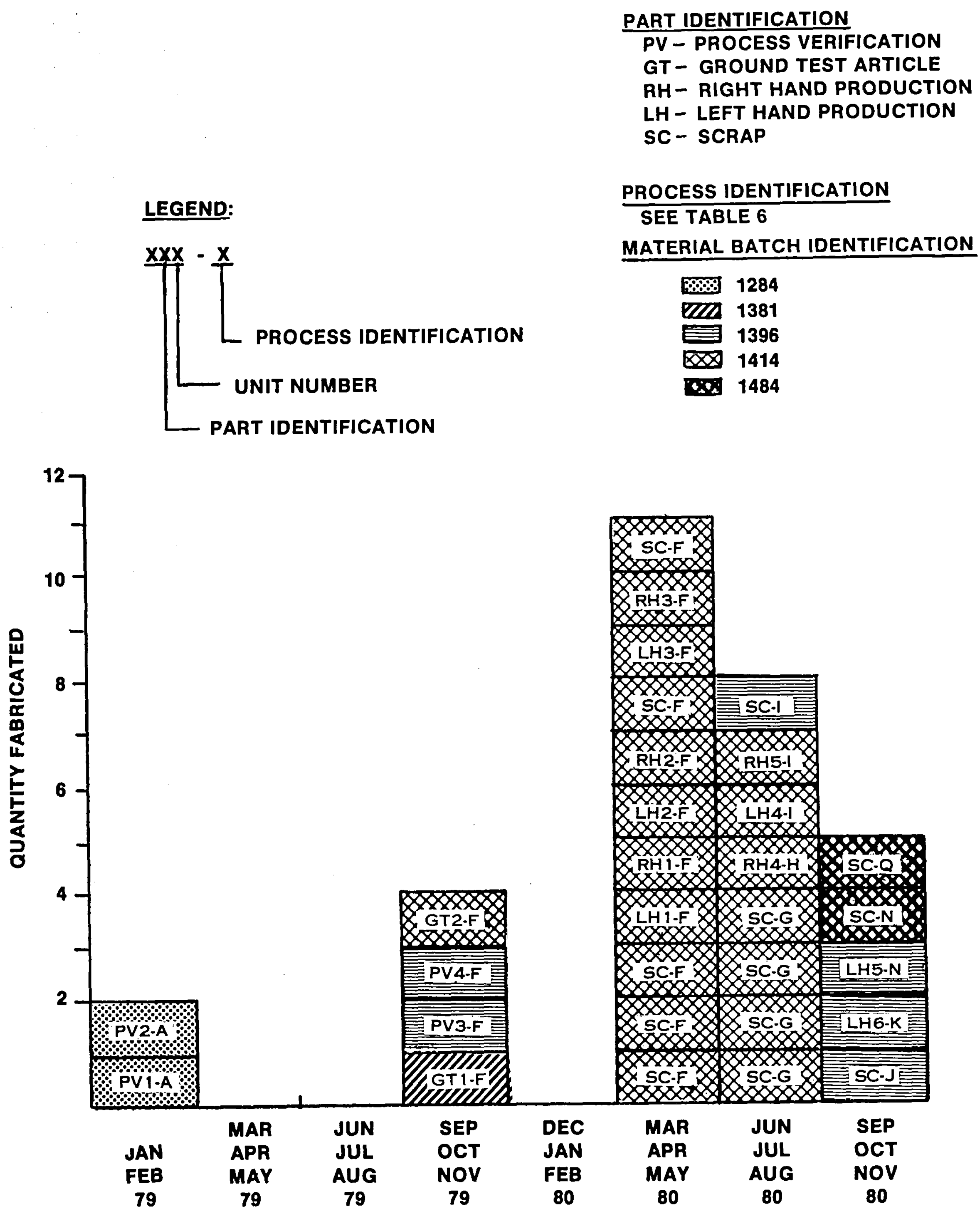

Figure 18. - Spar Fabrication Histogram

Process "B" and "C" - Preliminary laboratory efforts using process "A" resulted in a non-wetted surface at the composite/tool faying surface. This condition was the result of having insufficient breathing of the composite part during the initial layup on the heated tool. The layup systems defined as process "B" and "C", were used to provide a sufficient breather path on the tool side of the laminate to eliminate the "dry" appearing surface and gave acceptable resin content and NDI test results. These layups were half size (length) spars which were processed at the same time and provided the "no trim" edge finish desired. Since the glass string mark-off was objectional, development was continued to eliminate the string as a breather path.

Process "D" and "E" - The layups using process "D" and "E" were also made on half length spars and substituted 2.54 cm (1.0 in) wide strips of porous Armalon as breather paths. These systems produced acceptable resin content and NDI test results. The porous Armalon strips provided sufficient breathing path without the undesirable mark-off from the glass strings. During this period, the ultrasonic technician reported difficulty in maintaining a water wetted surface on the porous Armalon finish side of the spar.

Process "F" - To facilitate ultrasonic inspection, process "F" utilized a peel ply breather on the tool side of the layup. This produced four consecutive acceptable spars using three different material batches (see Table 6). In April 1980, production was iniated for the flight hardware.

The first three spars produced had voids in the area of the flanged lightening holes. To correct this condition, pressure intensifiers were added to the silicone rubber bag. This corrected the voids in the lightening hole area, and four consecutive acceptable spars were produced. Three of these four spars reflected a low resin content based on the process control coupon test data. The spars were accepted based on thickness and mechanical properties. Two of the next four spars were acceptable, one of which had low resin content. The two unacceptable spars were scrapped for voids primarily in the web area. These voids were attributed to the high humidity conditions in the layup area. The recurrence of these inconsistencies in the finished spar necessitated additional process changes.

Process "G" - A laboratory test was conducted that showed porous Armalon to be a better breather material than peel ply, that is, it did not saturate with resin as early in the cure cycle. Process "G" was devised using porous Armalon in lieu of the peel ply. This process was tried during the worst humidity period for this geographical area, and of four parts fabricated, all had voids in the web area. All the above processes utilized a lateral breathing technique. It was decided that the implementation of a vertical bleeder/breather system would improve the breathing capabilities during cure.

Process "H" - A ply of perforated film, A4000P4, perforated on 10.16 cm (4.0 in) centers, was added between the bleeder and breather material

TABLE 6. SPAR DEVELOPMENT SUMMARY

Process Ident	A	B	C	D	E
Bleeder/ Breather Arrangement	Tool Composite 2 Peel Ply (EOP) Armalon (tie to Vac) Bag Air Dam	Tool Glass Yarns (to Vac) Peel Ply (EOP) Composite 2 Peel Ply (EOP) Glass Yarns (to Vac) Bag No Dam	Tool Glass Yarns (to Vac) Armalon (EOP) Composite 2 Peel Ply (EOP) Glass Yarns (to Vac) Bag No Dam	Tool Armalon (EOP) Composite 2 Peel Ply (EOP) Armalon Strips (to Vac) Bag No Dam	Tool Armalon Strips (to Vac) Composite 2 Peel Ply (EOP) Armalon Strips (to Vac) Bag No Dam
No. Parts Fabricated	2	1	1	1	1
Cure Cycle	Initial - Ref Task II Final Report	Revised - Figure 10	Revised	Revised	Revised
Batch	1284	1381	1381	1381	1381
Date of Mfg.	1-79 and 2-79	9-79	9-79	9-79	9-79
NDI	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable
Cured Resin Content (%)	26.4 - 30.2	27.1 - 28.7	27.8 - 28.9	28.1 - 28.9	28.7 - 30.0

Process Ident	F	G	H	I	J
Bleeder/ Breather Arrangement	Tool Peel Ply (EOP) Composite 2 Peel Ply (EOP) Armalon Strips (to Vac) Bag No Dam	Tool Armalon (EOP) Composite Armalon (EOP) Armalon Strips (to Vac) Bag No Dam	Tool Peel Ply (EOP) Armalon Strips (to Vac) Composite Peel Ply (EOP) A4000P4 (to Vac) Bag No Dam	Tool Armalon (EOP) Composite Armalon (EOP) A4000P4 (to Vac) 2 Armalon (to Vac) Bag No Dam	Tool Armalon (to Vac) Composite Armalon (to Vac) A4000P4 (EOP) 2 Armalon (to Vac) Bag No Dam
No. Parts Fabricated	15	4	1	3	1
Cure Cycle	Revised	Revised	Revised	Revised	Revised
Batch	1381, 1396, 1414	1414	1414	1414 and 1396	1396
Date of Mfg.	9-79 to 11-79 and 4-80 to 5-80	6-80 to 7-80	7-80	8-80	9-80
NDI	10 - Acceptable 3 - Voids L/H; 2 Voids Web	4 - Voids Web	Voids/Porosity - Web Acceptable	2 - Acceptable 1 - Voids in Web	Voids in Web
Cured Resin Content (%)	23.6 - 30.9	26.5 - 31.6	26.5 - 27.5	27.0 - 29.0	28.0 - 30.5

TABLE 6. SPAR DEVELOPMENT SUMMARY (Continued)

Process Ident	K	L	M	N	O
Bleeder/ Breather Arrangement	Tool Armalon (to Vac) Composite Armalon (to Vac) A4000P4 (EOP) Airweave SS FR (EOP) Armalon Strips (to Vac) Bag No Dam	Tool Armalon (to Vac) Composite Armalon (to Vac) A4000P3 (EOP) Armalon (to Vac) A4000P4 (EOP) Ariweave SS FR (to Vac) Bag No Dam	Tool Armalon (to Vac) Composite Armalon (to Vac) A4000P4M 2 Armalon (to Vac) Bag No Dam	Tool Armalon (to Vac) A4000P4 (EOP) Armalon (to Vac) Composite Armalon (to Vac) A4000P4M (EOP) 2 Armalon (to Vac) Bag No Dam	Tool Peel/Ply (EOP) Composite Armalon (to Vac) A4000P3 (to Vac) Armalon (to Vac) Bag No Dam Edges Taped
No. Parts Fabricated	1	2	2	2	1
Cure Cycle	Revised	Revised	Revised	Revised	Material Specification
Batch	1396	1396	1396	1396, 1484	1484
Date of Mfg.	9-80	10-80	10-80	10-80	11-80
NDI	Acceptable	Minor Voids - Web Acceptable	Minor Voids - Web Acceptable	1 - Acceptable 1 - Voids in Web	Voids in Web
Cured Resin Content (%)	24.2 - 27.0	26.9 - 31.6	29.2 - 30.9	27.8 - 28.3	Not Tested

Process Ident	P	Q	
Bleeder/ Breather Arrangement	Tool Peel Ply (EOP) Composite A4000P3 (EOP) Peel Ply (to Vac) Armalon (to Vac) Bag No Dam Edges Taped	Tool Peel Ply (EOP) Composite A4000P3 (EOP) Peel Ply (to Vac) Armalon (to Vac) Bag No Dam Edges Taped	
No. Parts Fabricated	1	1	
Cure Cycle	Material Specification	Revised	
Batch	1484	1484	
Date of Mfg.	11-80	11-80	
NDI	Acceptable	Voids in Web	
Cured Resin Content (%)	27.3 - 29.1	Not Tested	

on the bag side of the composite layup. This process produced an acceptable spar; however, it did have minor voids in the web and was near the minimum allowable resin content.

Process "I" - This process is identical to process "H", except that porous Armalon was substituted for the peel ply. The next two spars fabricated were void free with a resin content lower than nominal but higher than process "H". These spars used prepreg material batch 1414. When this process was repeated using material batch 1396, voids appeared in the web; however, the resin content was acceptable. This spar was made in September 1980.

Process "J" - In order to enhance the breathing capabilities, the porous Armalon on the tool side of the composite was tied to the vacuum. Although the resulting resin content of this spar was nominal, voids existed in the web in the area of the main ribs.

Process "K" - To enhance the breathing capabilities on the bag side of the laminate, two plies of Airweave SS FR replaced the two plies of porous Armalon on top of the perforated film. This spar was acceptable in accordance with the ultrasonic NDI. The initial laboratory report showed the resin content to be below acceptable tolerances. Since the mechanical test results and the thickness measurements were within tolerance, the resin content was retested and found to be acceptable. Since the resin content was near the low tolerance limit, additional development was deemed advisable.

Process "L" and "M" - While the process "K" spar was being retested, two half spar sections were laid up and cured to process "L" and "M" on opposite ends of the same tool. Process "L" utilized an additional ply of porous Armalon and perforated film, A4000P3, perforated on 1.27 cm (0.50 in) centers, against the composite. Process "M" was identical to process "J" except the film was perforated on 5.08 cm (2.0 in) centers. Both of these systems produced acceptable spar sections; however, minor voids were evident near the tool side of the laminate. This layup and cure was repeated with identical results.

Process "N" - The vertical breathe technique was used between the composite and the tool to improve the composite tool side breathing capability. This consisted of adding a ply of A4000P4 and porous Armalon on the tool side. The first spar fabricated with this process used material batch 1396 and was acceptable in all regards. The second part using material batch 1484 had unacceptable voids in the spar web.

Previous experience during the cover fabrication indicated that this material batch was not processing identical to previous batches of tape prepreg material.

Process "O" and "P" - As a result of this material inconsistency, processes "O" and "P" were run on half length spars. These processes were chosen to give a high probability of success when used with the original specification cure cycle. By taping the edges to minimize edge bleed, it was expected that any moisture, air or volatiles would be percolated through the composite plies into the bleeder/breather system. Process "O", with the perforated film between the bleeder/breather plies, failed to accomplish this. However, in process "P" when the perforated film was between the composite and the breather, the section was void free.

Process "Q" - This process is identical to process "P" except the cure cycle was changed to be common with the proven cure cycle for ribs and covers. The resulting full size spar exhibited a web with voids.

Concurrent with the last two development process changes, the material was retested for batch acceptance. Duplicate tests were conducted and the material failed to pass cured resin content and density on both tests. Evaluation of the results of other details fabricated using the same material batch indicates that this batch (1484) was exhibiting different processing properties than other batches. Samples of this material were tested by liquid chromatography which showed a lower than normal degree of resin advancement. Since the procurement specification did not control such chemical characteristics as resin advancement, process development was suspended until a more consistent material was available. This delay had a net effect of stopping the assembly effort which would negate the position on the learning curve for detail fabrication and assembly.

2.2.4 Quality Assurance - The quality assurance requirements for the composite detail part fabrication are included in a processing document. This document defines the in-process controls on material and labor, as well as the NDI and process control coupon tests required for each part. Each aileron detail was processed in accordance with these requirements. There were a total of 261 composite details fabricated on this program, thirty of which were rejected, for an overall acceptance rate of 85.5%. The reasons for rejection were: voids - 20; vacuum bag blow-by - 5; tool preparation - 2; layup error - 2; and tooling error - 1. A summary of the program detail fabrication effort, including process verification, GTA fabrication and flight articles, is shown in Table 7.

In accordance with the engineering requirements, each detail had thickness measurement determinations, and was ultrasonically inspected for voids (see Figure 19). In addition, specimens were cut from the process control coupons for each detail and tested for resin content and short beam shear property determinations. Three graphs showing summaries of these test results are shown in Figures 20, 21 and 22. Figure 22 shows four spars were below minimum requirements for resin content. NMR's (Nonconforming Material Review) were prepared for disposition for these spars. Engineering authorized their use based on the laminate thickness and the short beam shear test results.

The detail acceptance rate on this program was lower than normal for new program start-up. However, as shown in Figure 23, the acceptance rate was continually improving. The reductions in acceptance rate at assembly seven were the direct result of the rejection of five consecutive spars caused by material problems discussed in paragraph 2.2.3.

TABLE 7. FABRICATION SUMMARY OF COMPOSITE AILERON DETAILS

INTERMEDIATE RIBS 99 Fabricated 4 Scrapped	1 Process Verification 10 GTA 42 Production (R/H) 42 Production (L/H) 4 Scrapped - Production Errors
CLOSEOUT RIBS 41 Fabricated 1 Scrapped	4 GTA 1 GTA Scrapped - Inboard Rib Flanges too wide and angles were closed 18 Production (R/H) 18 Production (L/H)
MAIN RIBS 61 Fabricated 4 Scrapped	1 Process Verification 6 GTA 1 GTA - Scrapped - Missing Ply in Cap 25 Production (R/H) 25 Production (L/H) 3 Scrapped - Production Errors
COVERS 34 Fabricated 9 Scrapped	1 Process Verification 4 GTA 1 GTA Scrapped - Voids 10 Production (R/H) 10 Production (L/H) 8 Production - Scrapped - Voids
SPARS 26 Fabricated 12 Scrapped	1 Process Verification 2 GTA 5 Production (R/H) 6 Production (L/H) 11 Production - Scrapped - Voids 1 Production - Scrapped - Production Errors

Figure 19. - Ultrasonic Inspection of Cured Rib Detail

2.3 Subassembly

During the fabrication of the aileron it is necessary to prepare main rib and spar subassemblies. There are three different main rib subassemblies consisting of a main rib and four backup fittings per subassembly. The spar subassembly is made up of the three main rib subassemblies, five intermediate ribs, two closeout (end) ribs, the front spar, the shroud ribs, and the hinge, actuator and feed back fittings.

2.3.1 Main Rib Subassembly - The main rib detail and aluminum backup fittings are loaded into the assembly fixture. The backup fittings are located and clamped flush to the rib cap, and the forward face is located to the most forward point of the fixture. When machining tolerances of these fitup faces exceed 0.0254 cm (0.010 in), stainless steel laminated shims are prefit to fill the gap. The rib and fittings are then drilled using the drill system defined in the Ref. 1 final report. The rib assembly fixture is complete with drill blocks to locate the hole and maintain hole perpendicularity, as shown in Figure 24. The rib and fittings are then removed from the fixture. The fitting holes are deburred and faying surface sealant applied. The fasteners are wet installed outside the fixture.

2.3.2 Spar Subassembly - The ten ribs are located and clamped in the front spar assembly fixture. The front spar is then loaded into the fixture. After positioning the hinge and actuator fittings (see Figure 25), the spar web, ribs and fittings are drilled full size. The feed back fittings and the shroud ribs are then fixture loaded and drilled. The drilled details are removed from the fixture for deburring of the metal parts. Faying surface sealant is

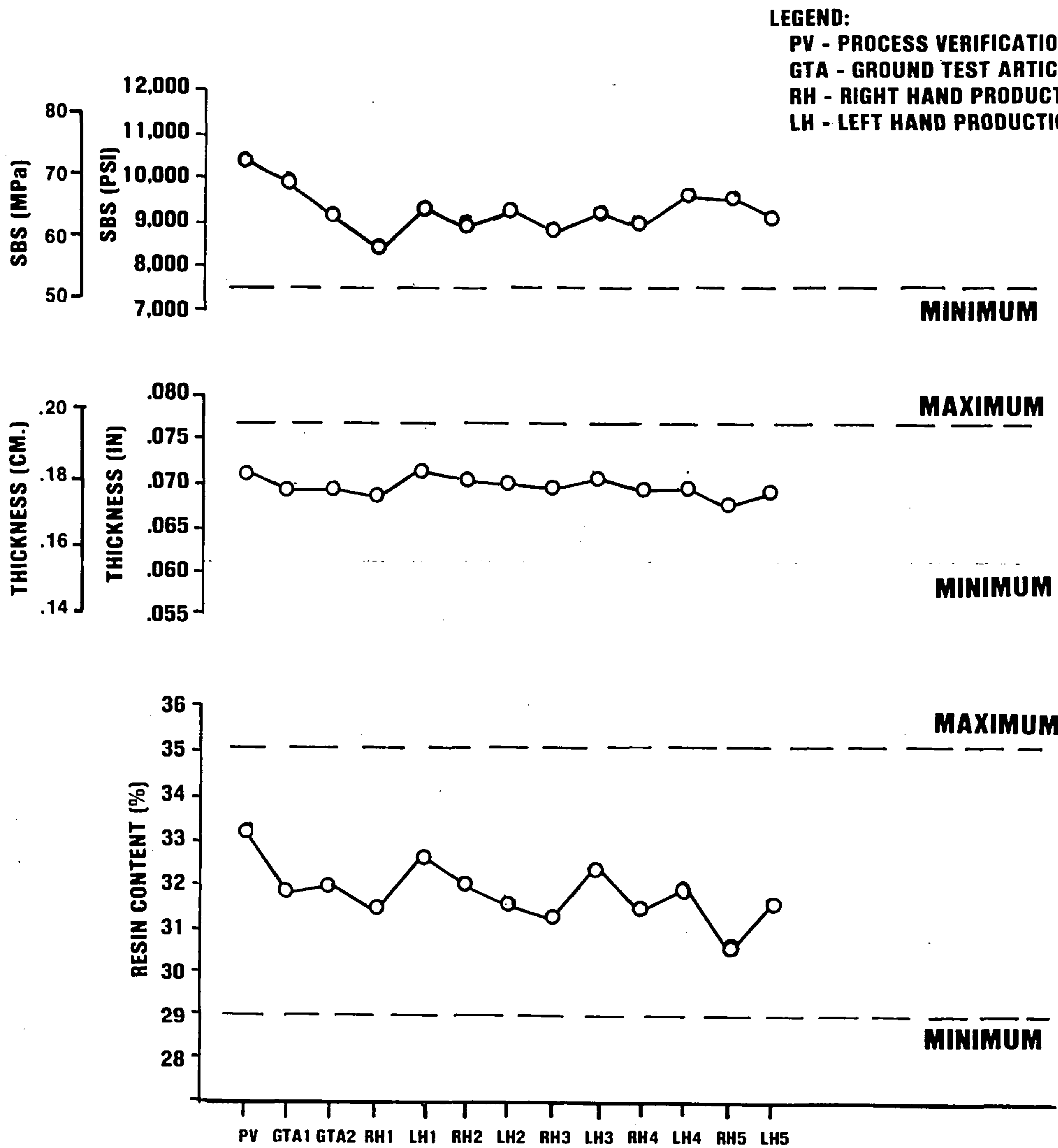

Figure 20. - Rib Process Control Data

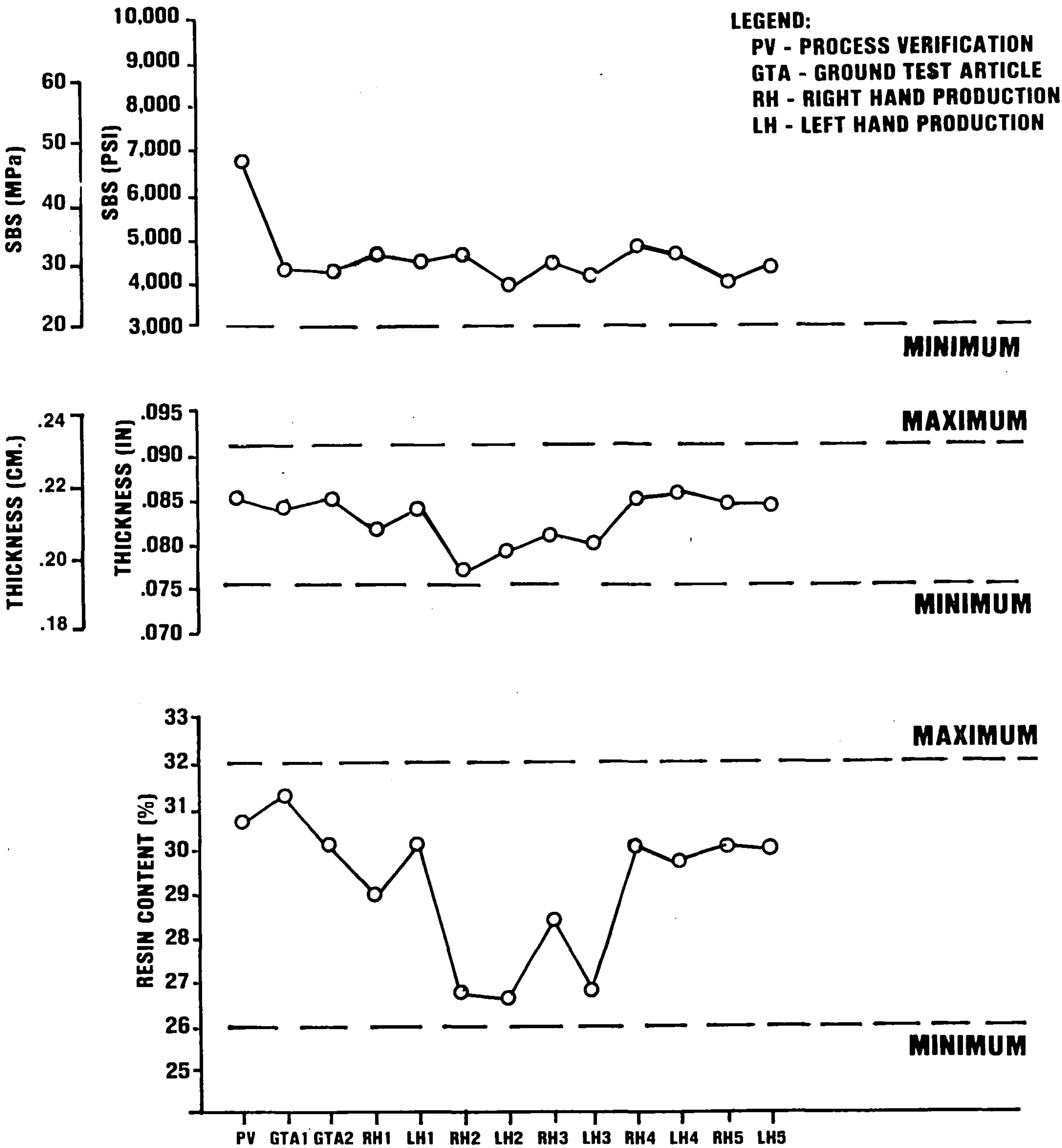

Figure 21. - Cover Process Control Data

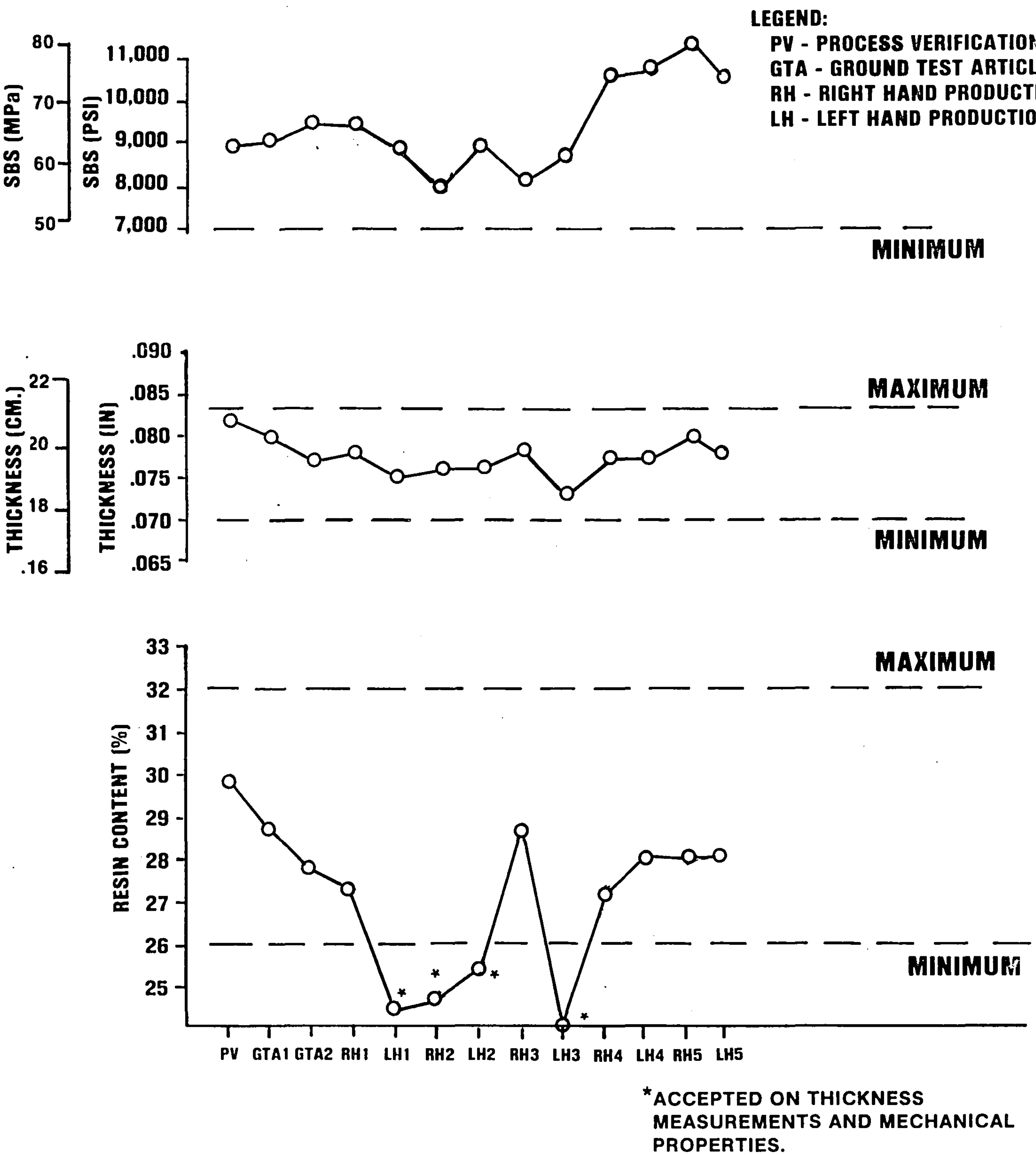

Figure 22. - Spar Process Control Data

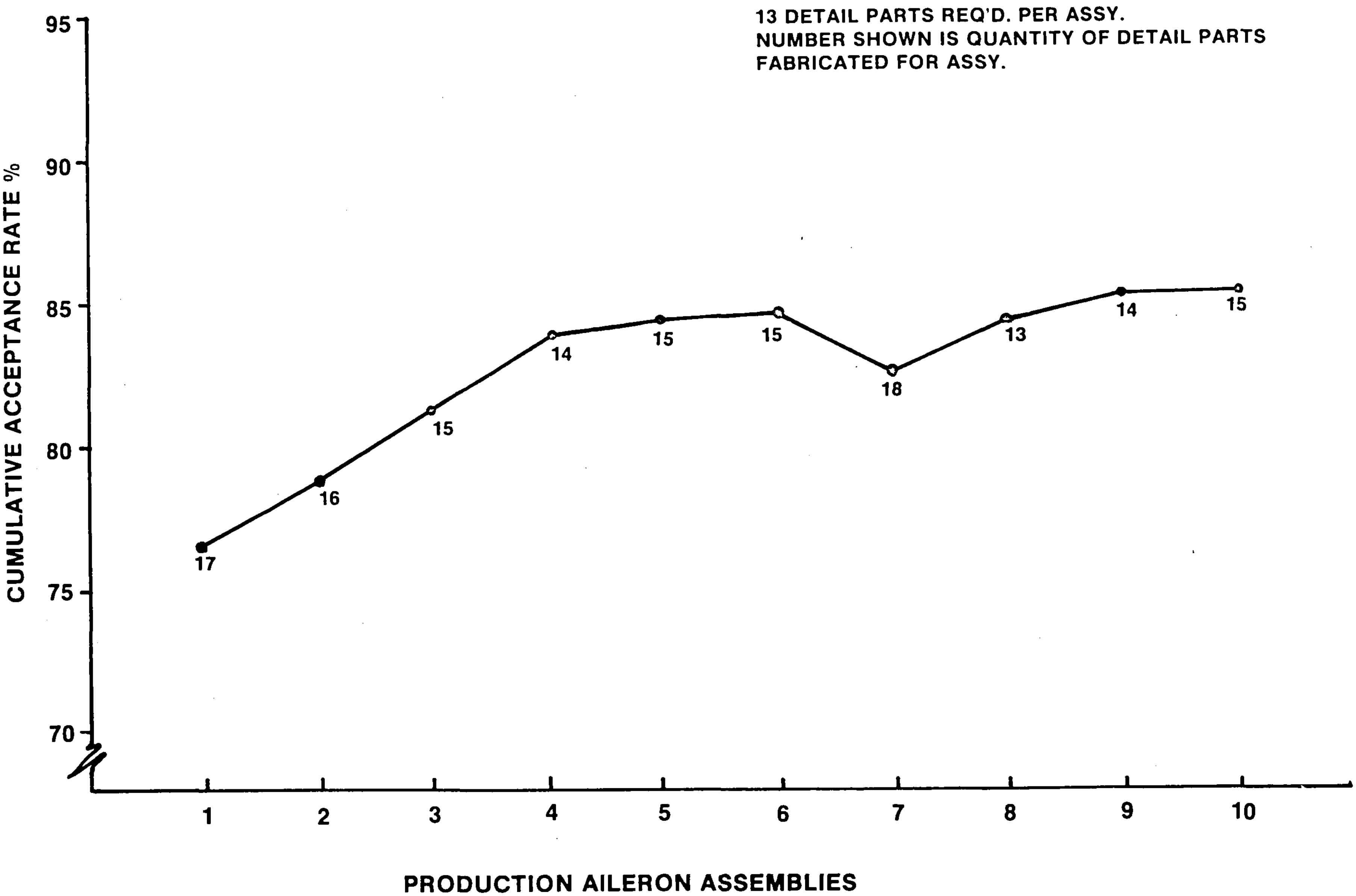

Figure 23. - Composite Detail Acceptance Rate

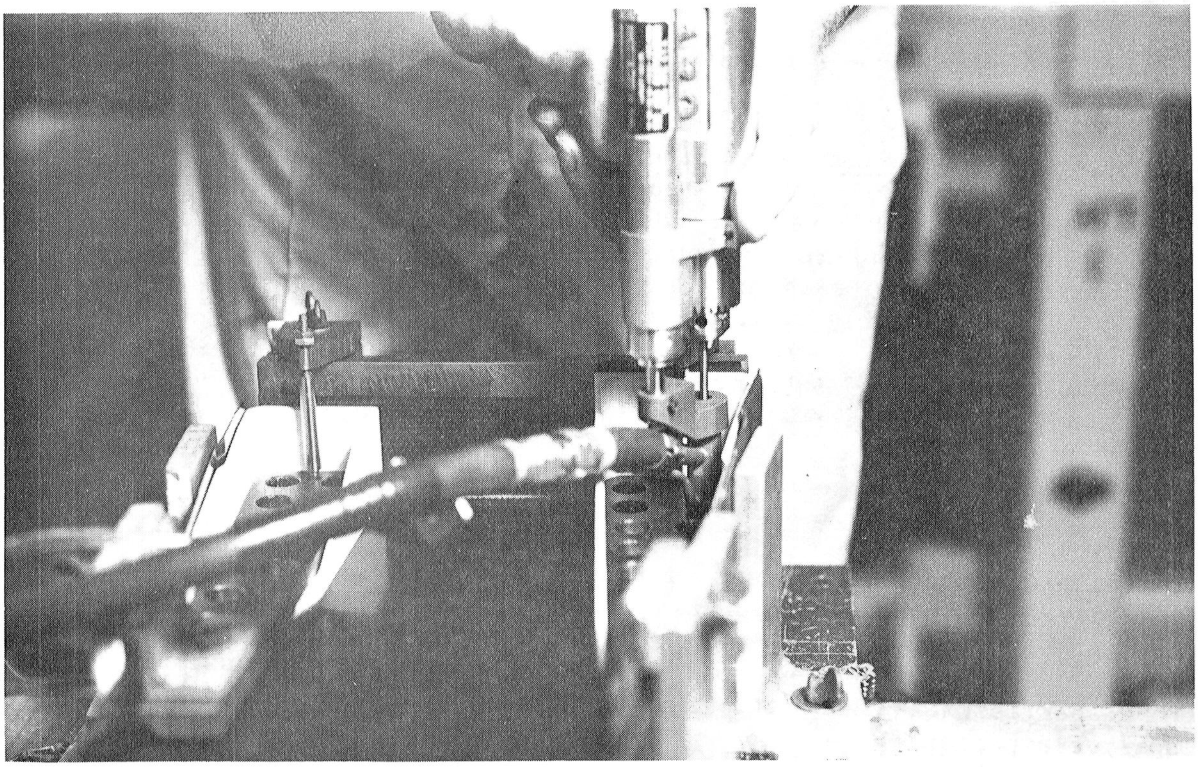

Figure 24. - Drilling Main Rib Subassembly

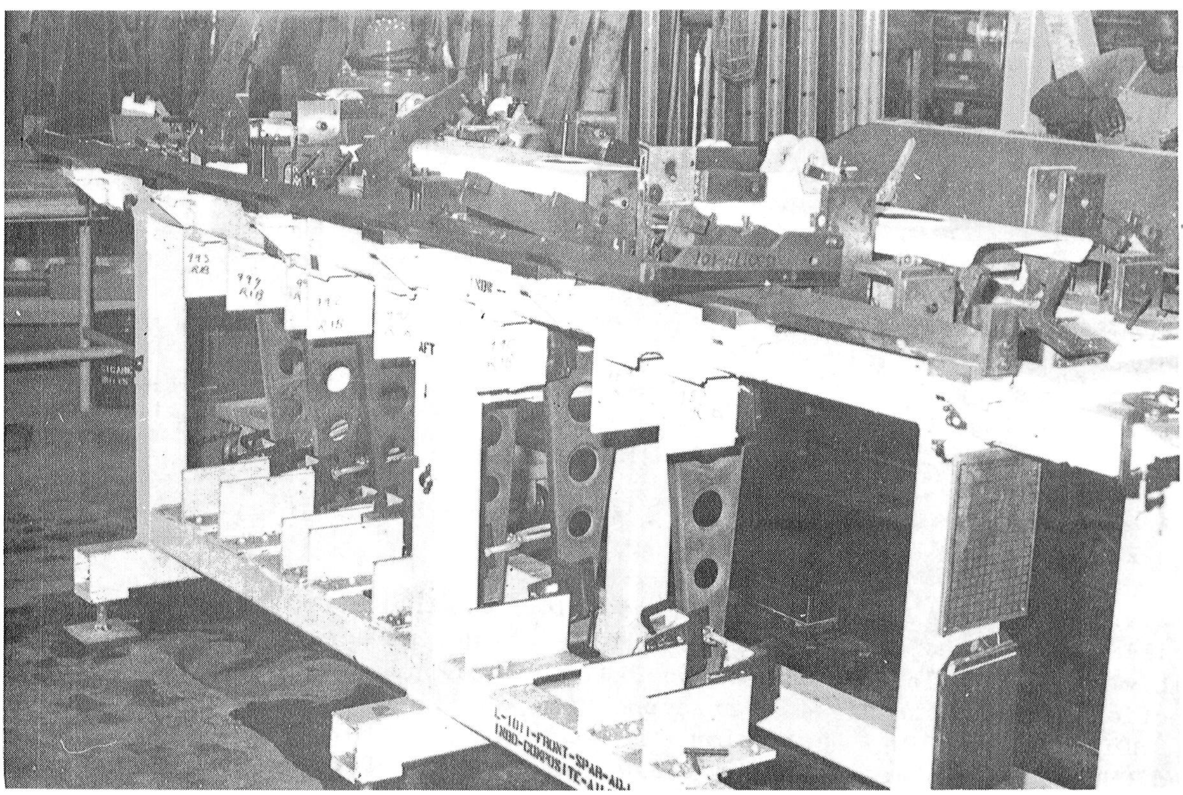

Figure 25. - Spar Subassembly Fixture

applied and the details are reassembled using the required Hi-Lok collars and Triwing fasteners.

2.3.3 Quality Assurance - As the assembly fixtures are loaded, the detail parts are checked by the quality assurance inspector for part numbers, detail acceptance stamp, proper location and fitup. Detail part serial numbers are recorded in the AIR (Assembly Inspection Record) Book. After drilling and removal from the fixture, each hole is checked for size, tolerance and quality. Each step of the subassembly operation is monitored to assure compliance with the engineering requirements. Any conditions not in accordance with these requirements are either reworked to engineering or placed on a NMR (Non-Conforming Material Review) tag for disposition.

2.4 Final Assembly

The aileron assembly consists of the spar subassembly, rear spar, covers, trailing edge, end fairings and shroud panels.

2.4.1 Assembly - The rear spar is first loaded into the assembly fixture. The front spar assembly then follows. The aft end of the ribs are faired to the rear spar, clamped into position and drilled. The upper cover is loaded in the fixture, and the fitup to the substructure is checked for gaps to determine shim requirements. The cover is then drilled and removed from the fixture. The lower cover is fixture loaded and drilled in a like manner. The nut plate rivet holes are then drilled in the ribs and spars lower flanges, and the nut plates are installed. The rear spar is removed from the fixture and all metal parts are deburred. The rear spar is reloaded and permanently attached. The upper cover is then positioned with the required faying surface shims and sealants and permanently fastened in place (see Figure 26). The lower cover is then installed. The assembly is removed from the final assembly fixture and placed in a holding fixture for installation of the trailing edge, upper and lower leading edge shroud panels, shroud doors and end fairings. Special alignment gages are used to position the trailing edge to assure compliance with aileron contour requirements.

Standard aircraft assembly procedures and techniques are used throughout the assembly. The primary differences are: 1) the critical drilling of the composite components and 2) the extra surveillance in quality assurance in the areas of detail handling, prefit and hole quality, which required specialized personnel training.

A ship set of inboard ailerons loaded in the handling dollies is shown in Figure 27.

2.4.2 Quality Assurance - In addition to the typical assembly quality surveillance defined in the subassembly section (paragraph 2.3.3), the final assembly of each aileron received an FAA conformity inspection. The conformity inspection documentation included supporting data, such as material acceptance logs, NDI test results, inspection tag history, weights and copies of any processed NMR tags. Table 8 reports the weight history of the ground test articles and five ship sets of ailerons.

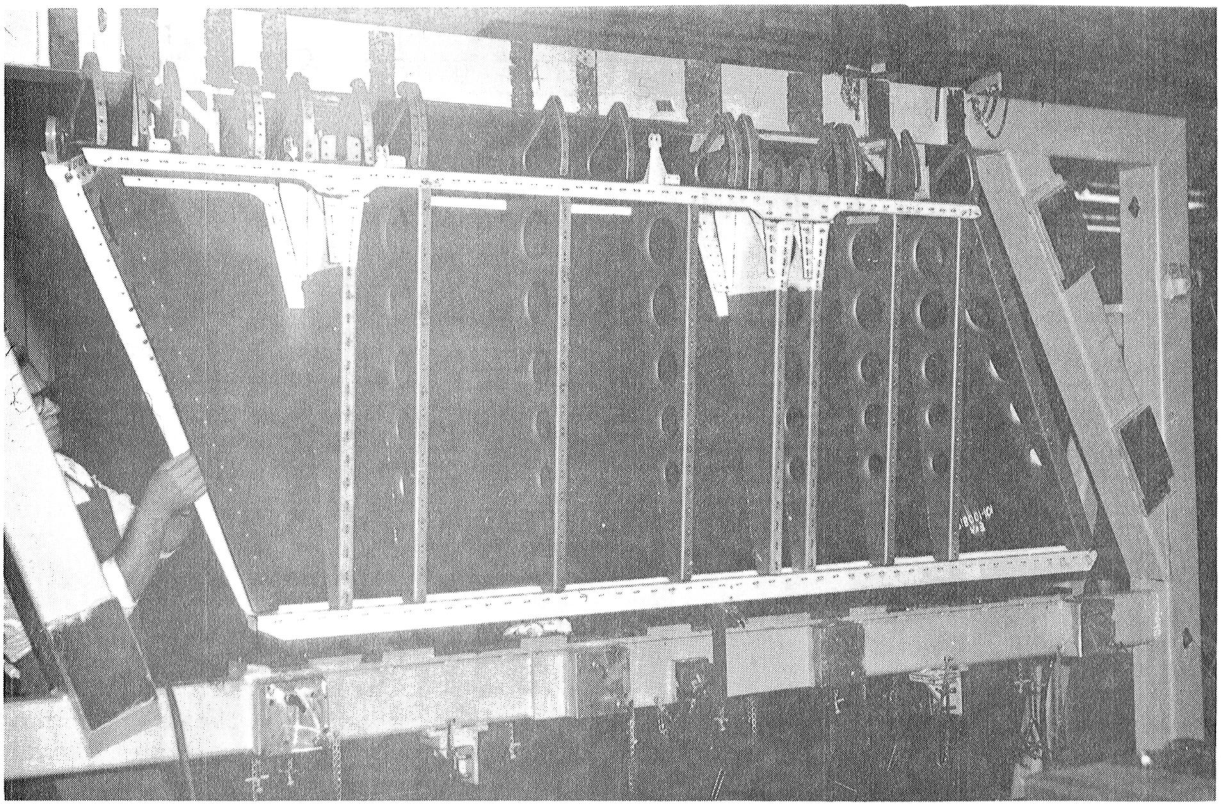

Figure 26. - Installing Upper Cover in Final Assembly Fixture

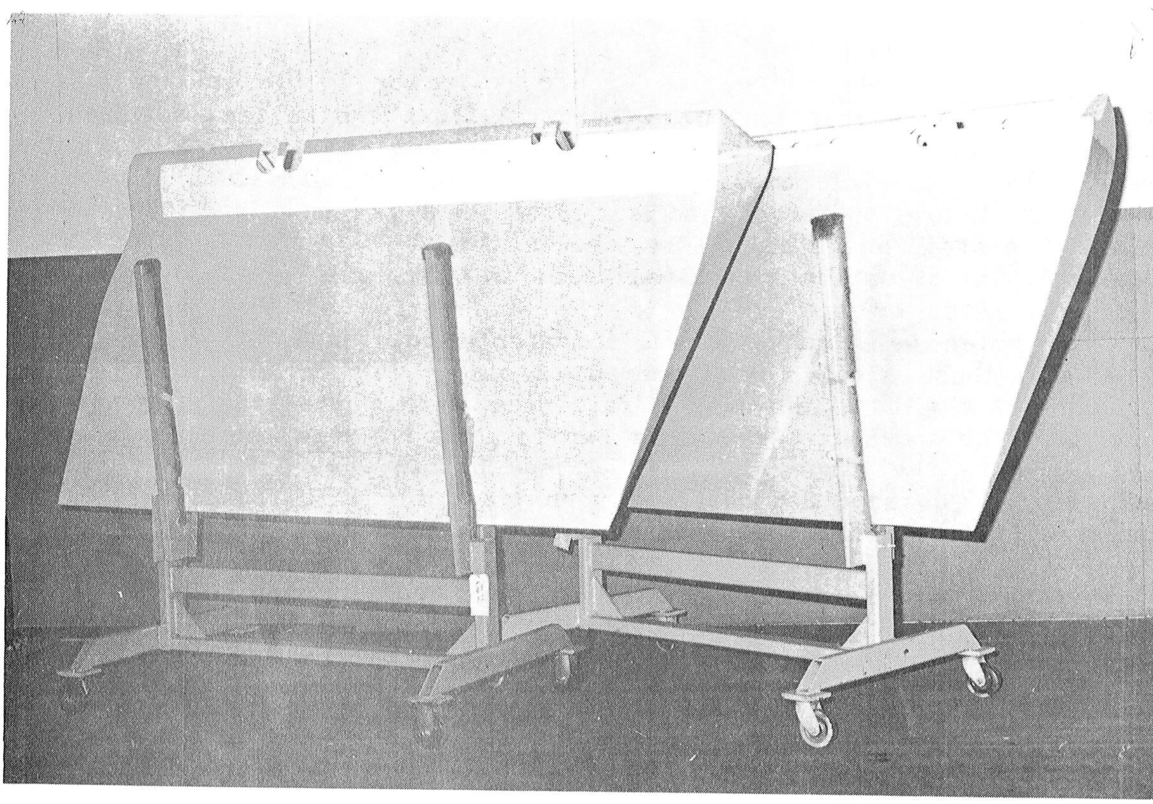

Figure 27. - Completed Ship Set of Ailerons

TABLE 8. ADVANCED COMPOSITE AILERON ACTUAL WEIGHTS

UNIT		WEIGHT	
		Kg	lb
GTA	1	48.99	108.0
	2	48.44	106.8
Ship Set 1	LH	48.42	106.75
	RH	49.76	109.7
Ship Set 2	LH	48.53	107.0
	RH	48.99	108.0
Ship Set 3	LH	48.76	107.5
	RH	48.31	106.5
Ship Set 4	LH	48.53	107.0
	RH	49.21	108.5
Ship Set 5	LH	49.76	109.7
	RH	50.03	110.3

2.5 Shop Repairs

During any manufacturing effort there are occasions when articles do not conform to engineering or specification requirements. These conditions may be caused by equipment malfunctions, worker error or foreign object damage. Since the production of the graphite composite aileron was not immune to these conditions, certain shop repairs were implemented to correct nonconforming conditions, such as oversize holes, deep countersinking, mislocated holes, frayed and/or splintered edges and delaminated edge plies. These repairs were undertaken only at the direction of engineering and documented by the Material Review Board.

2.5.1 Oversize Holes - Details with oversize or double drilled holes are used by implementing the following: 1) installing oversize fasteners, 2) using next larger diameter standard fasteners, 3) using a stainless steel sleeve or 4) manufacturing a special shoulder bushing to match the particular discrepancy. Methods 1 and 2 are preferred and are used when the required fasteners are available. The stainless steel A-286 sleeves (Acres Fastener Sleeves from J. O. King, Atlanta, GA) of method 3 are available for 0.079 cm (0.031 in) and 0.039 cm (0.016 in) oversize holes. Prior to the application of any of these repair systems, the holes were opened to a comparable tolerance as in the original requirements. These sleeves were bonded in place with ambient curing two part epoxy resin (EA 9309.1), while the fasteners were installed per engineering requirements. The shoulder bushings of repair method 4 were used when holes were double drilled in the hinge fittings. These bushings were machined from 7075 aluminum alloy. The anodized bushings were press fit into the discrepant hole, and then drilled to the original engineering requirements.

2.5.2 Deep Countersinking - The large quantity of countersunk holes in the aileron covers resulted in occasional fastener under flush. The repair for this discrepancy was to use next larger size fastener or to use stainless steel beveled washers which were bonded in place with ambient curing epoxy resin (EA 9309.1).

2.5.3 Mislocated Hole - During production fabrication, only one hole was mislocated in drilling the graphite composite that required major rework. This hole was located in the forward end of a closeout rib cap resulting from accumulation of allowable manufacturing tolerances. This hole had less than 0.254 cm (0.10 in) edge distance. The repair consisted of curing a 5 ply graphite fabric patch to the rib inner surface. The patch was identical to the basic rib material and ply arrangement. The repair included a ply of film adhesive EA-9649R between the graphite patch and the rib. The bleeder/breather arrangement and cure cycle were identical to the basic rib specification. A photo of the bagged layup is shown in Figure 28. The cured repair is shown in Figure 29. The rib was then ultrasonically inspected, and loaded into the final assembly fixture for redrilling. The only assembly deviation was the utilization of the next grip length fastener through the patch.

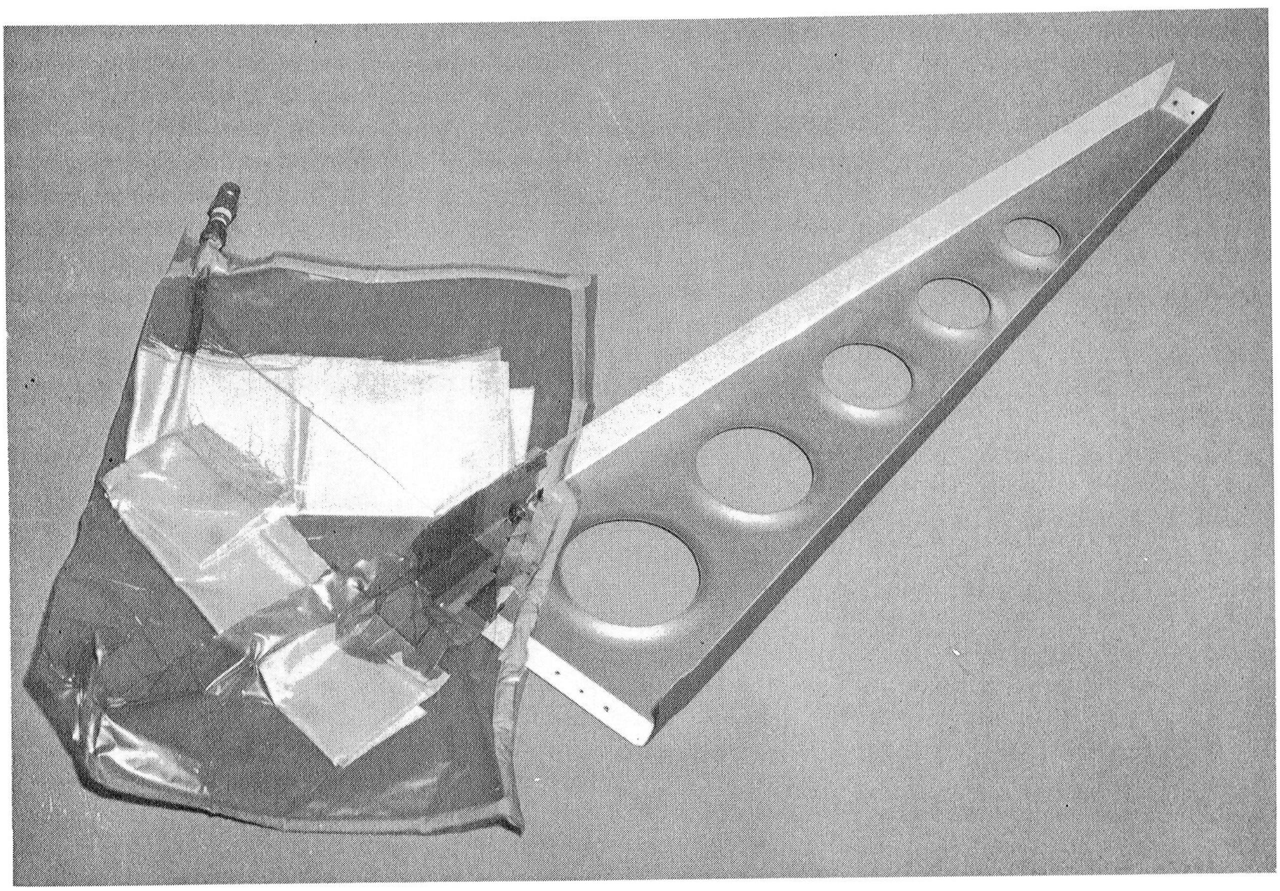

Figure 28. - Rib Repair Bagged Layup

2.5.4 Frayed and Splintered Edges - During the routing of the cover, the surface plies of graphite at the edges of the early units were splintered and frayed. This condition never exceeded 0.318 cm (0.125 in) wide and one ply deep. The repair was primarily cosmetic, and consisted of applying a thin coat of epoxy resin (EA 9309.1) to the edges and allowing to cure at ambient temperatures. The edges were then lightly sanded with 180/200 grit abrasive paper and finished per engineering requirements.

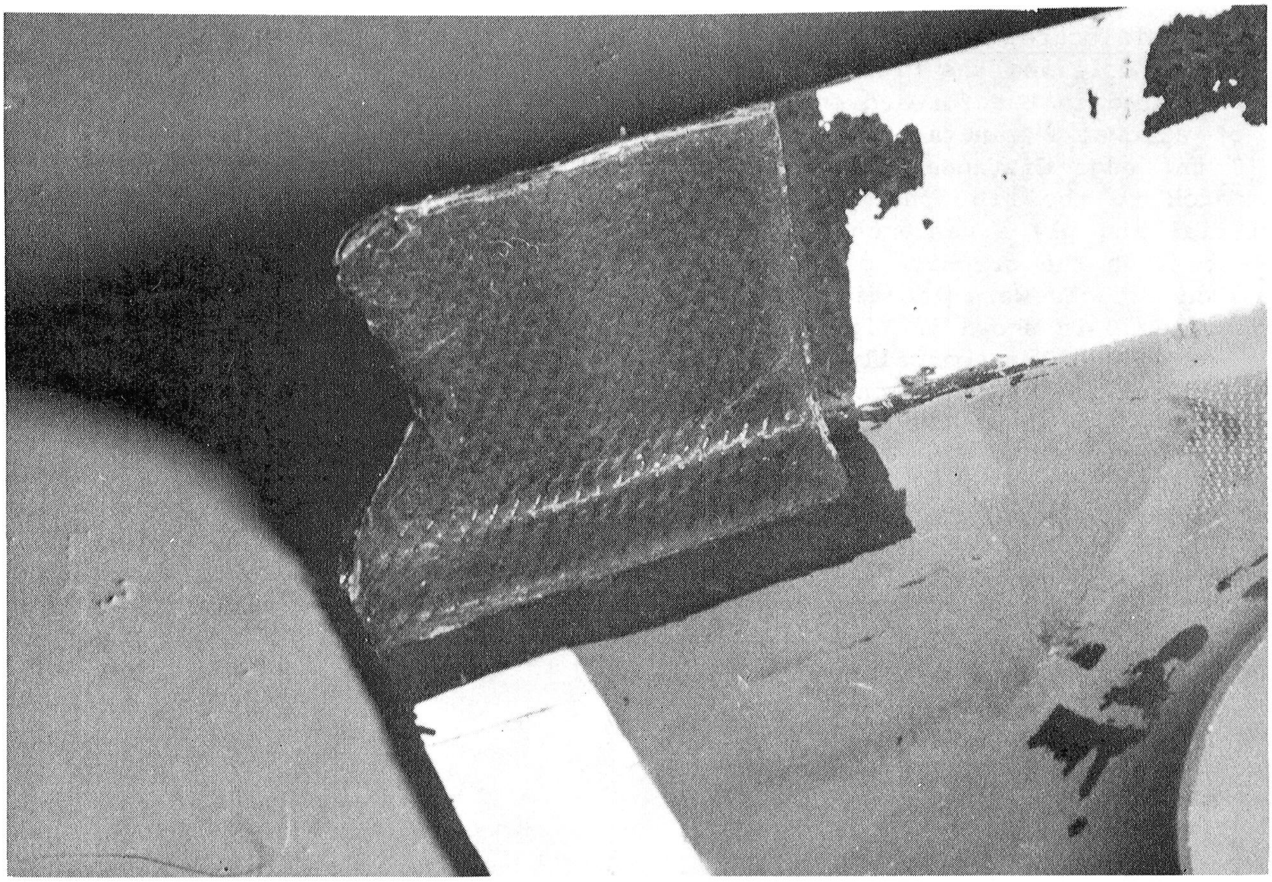

Figure 29. - Rib Repair as Cured

2.5.5 Delamination - During the removal of peel ply from a cured cover, the cover was delaminated over a triangular area of approximately 5.0 x 6.0 x 13.0 cm (2.0 x 2.4 x 5.2 in) at the forward inboard corner of a lower cover. In order to affect a repair, a piece of 5208 resin film was applied into the delaminated area. Heat was applied using a 394.3K (250°F) heat gun to tack the plies together. One ply of graphite/epoxy tape prepreg was added to the cover external surface, oriented to the surface ply and extended from the edge of the part to 2.54 cm (1.0 in) beyond the damaged area. The layup was completed with one ply each of peel ply, perforated film (A4000P3) and porous Armalon and a nylon vacuum bag. One thermocouple was taped to the edge of the part. The patch was then cured in accordance with the specification cure cycle. After cure, the cover was ultrasonically inspected.

3. MANUFACTURING COST DATA

3.1 Introduction

Uncertainties concerning the actual cost of labor and materials relative to fabricating advanced composite components have prompted and guided the development of a manufacturing cost plan between Avco and Lockheed for the Advanced Composite Aileron. The financial conclusions concerning the use of advanced composite materials will be the result of three major phases of cost analyses. The first task of cost estimating was accomplished by Lockheed-California Company in the intial phases of the program. During this time the evolving composite design was compared to the existing metal design, and estimates of fabrication costs were derived for both the metal and the composites. Estimates for the metal structure were necessary since a foreign subcontractor, Short Brothers of Northern Ireland, has the contract for providing metal ailerons on the existing L-1011 program. The second phase, which will be discussed later in detail, is the effort of cost tracking which was undertaken by Avco Aerostructures Division, the fabricator of the composite ailerons. The last phase will be the data evaluation by Lockheed-California which will culminate in the realistic cost estimate for producing advanced composite ailerons in comparison to the cost estimated for similar metal construction.

3.2 Cost Tracking

A primary objective of the program was to accumulate composite manufacturing labor and material usage information from which more pertinent data could be extracted and used by Lockheed in the evolvement of useful cost estimating relationships. To accomplish this objective, seven selected composite detail parts were tracked and their manhours to complete recorded. These parts represented similar left-hand parts from the two ground test articles and the five ship sets (ten units) of flight hardware ailerons, both of which constituted a fabrication lot. From this data gathering the labor costs, the material usage and a learning curve were documented.

The sections to follow describe how the tracking and documentation were accomplished, and the results obtained for the fabrication of the tooling, the ground test articles and the flight hardware at Avco Aerostructures Division.

3.2.1 <u>Non-Recurring Tooling Costs</u> - The progress of each tool from its inception to its completion was monitored using existing Avco accounting, scheduling and computer reporting methods. A tool order was issued for each tool required and the actual building and inspection hours were recorded by tool shop order number for each tool. Design hours and material costs were also tracked by tool order number.

Table 9 presents the resulting average non-recurring tooling cost for the typical left-hand composite layup and assembly tools. Table 10 combines all of these costs along with their right hand counterparts into a total production tooling cost for the program, less the final general and administrative (G&A) cost and sales tax add-ons. As is typical of most composite fabrication endeavors, the tooling requirements were a major part in overall cost responsibility.

3.2.2 <u>Tracking Recurring Costs</u> - During the fabrication of the two ground test articles and the flight hardware lot, a series of left-hand parts were tracked and documented for resulting average assembly labor, fabrication labor,

TABLE 9. LEFT-HAND AILERON NON-RECURRING TOOLING COST

COST ELEMENT	UPPER COVER	RIBS	FRONT SPAR	STRUCTURAL ASSEMBLY
Material $	2,270.83	386.90	6,123.30	3,993.30
Fabrication Labor hrs	847.3	197.1	3,188.9	3,440.7
Design Labor hrs	89.0	67.3	1,074.0	849.4
Inspection Labor hrs	29.6	10.4	157.0	191.0

TABLE 10. TOTAL NON-RECURRING TOOLING COST

COST ELEMENT	PRODUCTION COMPONENT TOOLING COST
Direct Labor and Manufacturing Overhead	$364,884.08
Engineering	174,345.93
Other	18,208.70
Material	101,960.49
Total	$659,399.20

support material and production material expenditures. These cost aspects were observed for a front spar, an upper cover, a particular main rib, a particular intermediate rib and the final assembly of each unit.

The program was conducted in a totally production oriented environment. As a result, it was necessary to limit the data to segregated lot results with individual values resulting from averages and consolidations within each lot rather than individual part by part designations, which is not Avco's normal cost center data gathering method.

Fabrication and Assembly Labor Costs - In the case of the fabrication and assembly labor, all ACA actual touch labor (direct charge hands-on production labor) as gathered through time card entries, was charged to a program master authorization identification number by cost center. Each cost center's results were then percentage allocated to the specific parts being tracked. This percentage allocation was based on the total standard hours established to fabricate/assemble the specific part versus the total standard hours established to fabricate/assemble all the parts in this pool. Tables 11 and 12 accompanied with Figures 30 and 31 present the results of this effort. Also included are the recurring labor costs exhibited in the sustaining effort for tool conditioning, engineering support and set up as shown in Table 13.

TABLE 11. COMPOSITE DETAIL FABRICATION

RECURRING LABOR COSTS PER UNIT

(HOURS)

OPERATION		UPPER COVER	AVERAGE RIB	FRONT SPAR	PER AILERON	% OF TOTAL
GTA	Tool Preparation, Preply & Layup	57.3	9.4	39.9	249.3	41.0
	Bagging, Cure & Cleanup	27.9	7.3	17.6	146.5	24.1
	Trimming	20.2	4.0	9.0	89.7	14.8
	Finishing	0.4	0.1	0.1	1.5	0.3
	Quality Assurance	26.0	5.2	16.9	120.6	19.8
	Total	131.8	26.0	83.5	607.6	100.0
LOT 1	Tool Preparation, Preply & Layup	57.9	8.9	40.5	245.6	47.5
	Bagging, Cure & Cleanup	15.8	5.1	9.5	91.8	17.8
	Trimming	11.7	5.0	15.9	89.5	17.3
	Finishing	0.6	0.1	0.2	2.0	0.4
	Quality Assurance	18.1	3.9	13.0	88.1	17.0
	Total	104.1	23.0	79.1	517.0	100.0

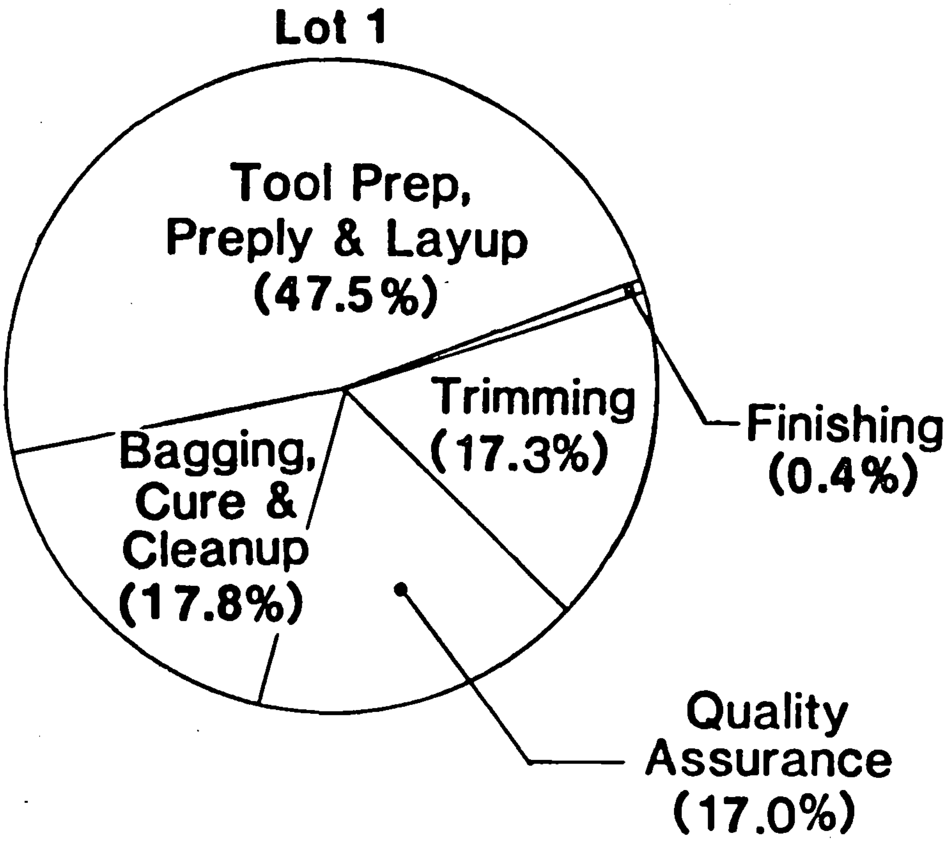

Figure 30. - Composite Detail Fabrication Recurring Labor Cost

TABLE 12. COMPARISON OF GTA AND LOT 1 ASSEMBLY RECURRING LABOR COSTS

OPERATION	PER AILERON-HOURS		% OF TOTAL ASSEMBLY	
	GTA	LOT 1	GTA	LOT 1
Finishing	1.8	1.8	0.2	0.3
Assembly	858.5	505.9	78.3	83.9
Quality Assurance	236.4	95.2	21.5	15.8
Total	1,096.7	602.9	100.0	100.0

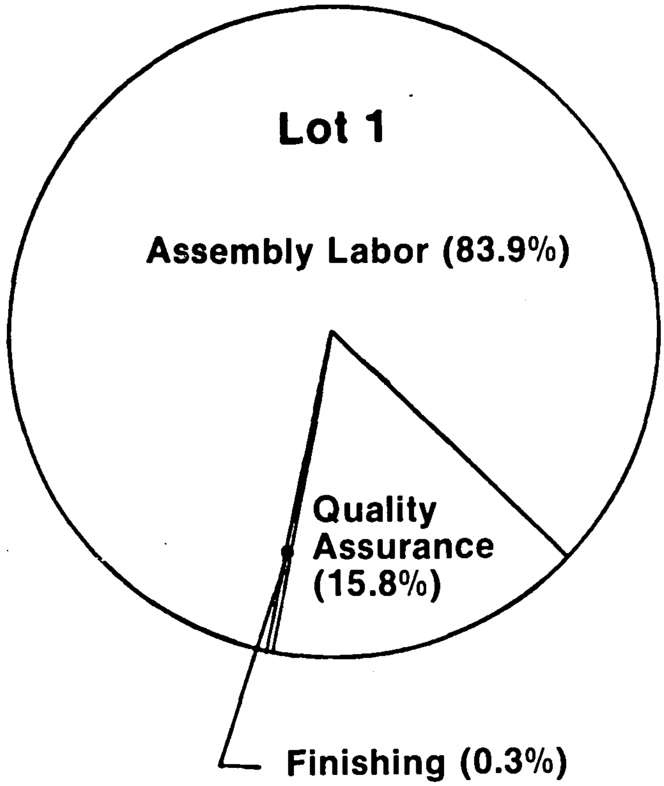

Figure 31. - Assembly Labor Cost

TABLE 13. COMPARISON OF GTA AND LOT 1 MANUFACTURING SUPPORT RECURRING LABOR COSTS

LABOR ELEMENT	PER AILERON-HOURS		TOTAL HOURS	
	GTA	LOT 1	GTA	LOT 1
Tooling	121.5	3.4	242.9	33.6
Engineering	1,633.3	223.2	3,266.6	2,231.9
Set up	4.3	0.9	8.5	8.7
Total	1,759.1	227.5	3,518.0	2,274.2

Recurring Material Costs - Support and production materials were issued at the start of each manufacturing lot and charged to the program master authorization identification number. As each lot was completed, the total amount of expendable material charged to the program was determined and prorated to the various parts being tracked by size and quantity of the parts. Due to the limited composite aileron operations in the shared confines of the AVCO bond shop facility and the existing production cost accounting practices, certain expendables, such as bagging materials, were not singled out from the other L-1011 bonding operations, and, therefore, not charged specifically to the program. The absence of these costs is insignificant on the final cost evaluation. The results of the study of the GTA and Lot 1 fabrication usage are shown in Table 14.

3.2.3 Time Standards - At the program's outset it was estimated that approximately 80 percent of the manufacturing operations involved in touch labor on the program would parallel those operations on which time standards had been previously established. These standards were developed by either conducting time studies during the actual fabrication of various components, or from formulated data based on similar experiences.

For the manufacturing operations unique to the program, standards were used based on similar operations performed on fiberglass cloth and honeycomb core layups. Standard manhours for quality assurance inspection labor and recurring tool maintenance labor were established as a percentage of the total standard manufacturing labor. The historical labor data generated in the area performing the work was used as the basis for arriving at an appropriate percentage.

With the conclusions of the two lots, Table 15 was calculated to compare the estimated labor hours based on manufacturing standards to the actual labor hours expended. Although discrepancies were present in various catagories, the overall estimated labor hour expenditures for each lot were reasonably closely matched.

3.2.4 Learning Curve Development - Manhours were accumulated for each lot of units produced. When the production lot of ten units was completed, learning curves were plotted and calculated from the data in Table 15 as shown in Figure 32. The overall learning curve calculates at 85.05% and the assembly at 84.98%. Although only having two points to create this curve seems rather speculative, assumptions were nonetheless proposed for consideration as to levels of labor hour reduction by the 100th unit. Since the amount of labor hours expended in the assembly effort is an important factor in overall cost performance, it too was plotted and extended to the 100th unit for estimates of future labor values.

TABLE 14. PER UNIT RECURRING MATERIAL COSTS (Dollars)

MATERIAL	MATERIAL TYPE	UNIT	COMPOSITE DETAIL				STRUCTURAL ASSEMBLY
			Upper Cover	Main Rib	Intermediate Rib	Front Spar	
SUPPORT	Peel Ply	GTA & Lot 1	38.18	5.45	5.45	12.27	
	Mochburg Paper	GTA & Lot 1		2.16	2.16		
	Release All	GTA		17.17	17.17	3.83	
		Lot 1		12.16	12.16	2.44	
	Surface Preparation	GTA & Lot 1		23.12	23.12	4.62	
	Aluminum Foil	GTA & Lot 1					11.80
	Paint	GTA & Lot 1					16.51
PRODUCTION	GR/EP Tape*	GTA & Lot 1	1,400.00	28.00		448.00	
	GR/EP Fabric*	GTA & Lot 1	88.40	272.00	244.80		
	Syntactic Epoxy Core*	GTA & Lot 1	232.50				
	Fasteners	GTA					2,665.04
		Lot 1					3,041.11
	Purchased Components	GTA					9,097.76
		Lot 1					8,534.25

*Tape @ $56/lb
*Fabric @ $68/lb
*Syntactic @ $7.50/ft^2

TABLE 15. DIRECT LABOR HOUR COMPARISON - ESTIMATED TO ACTUAL

LABOR ELEMENT	GTA			LOT 1		
	Estimated Hours	Actual Hours	% Difference	Estimated Hours	Actual Hours	% Difference
PRODUCTION						
Unplanned	0	86.6	-	0	22.4	-
Metal Fabrication	51.4	28.4	-44.7	249.8	97.9	-60.8
Process	5.8	4.5	-22.4	4.6	4.3	- 6.5
Shot Peen	.8	0	-	4.2	0	-
Machine Shop	748.3	385.1	-50.9	1,548.2	883.8	-42.9
Total Fabrication	842.3	418.0	-50.4	1,806.8	986.0	-45.4
Composite Detail Fabrication	752.7	970.7	+29.0	3,112.4	4,267.7	+37.1
Final Assembly	2,048.5	1,718.2	-16.1	7,717.6	5,076.6	-34.2
Total Production	3,643.5	3,193.5	-12.4	12,636.8	10,352.7	-18.1
INSPECTION						
Unplanned	0	250.3	-	0	650.4	-
Metal Fabrication	7.0	1.1	-84.3	10.5	1.9	-89.7
Process & Shot Peen	.3	.5	+66.7	.9	4.1	+355.6
Machine Shop	40.4	3.7	-90.8	151.2	20.4	-86.5
Paint	3.9	1.0	-74.4	10.7	7.1	-33.6
Total Fabrication Inspection	51.6	256.6	+397.3	181.3	683.9	+277.2
Composite Fabrication Inspection	112.9	240.7	+113.2	373.5	844.3	+126.1
Final Assembly Inspection	304.1	472.4	+55.3	762.5	949.0	+24.5
Tool Maintenance Inspection	9.4	39.5	+320.2	26.3	8.0	-69.6
Total Inspection	478.0	1,009.2	+111.1	1,343.6	2,485.2	+85.0
TOOL MAINTENANCE	72.9	164.0	+125.0	252.7	25.6	-89.9
PACKAGING	3.0	8.0	+166.7	0	24.7	-
TOTAL PROGRAM	4,197.4	4,374.7	+ 4.2	14,233.1	12,888.2	- 9.5

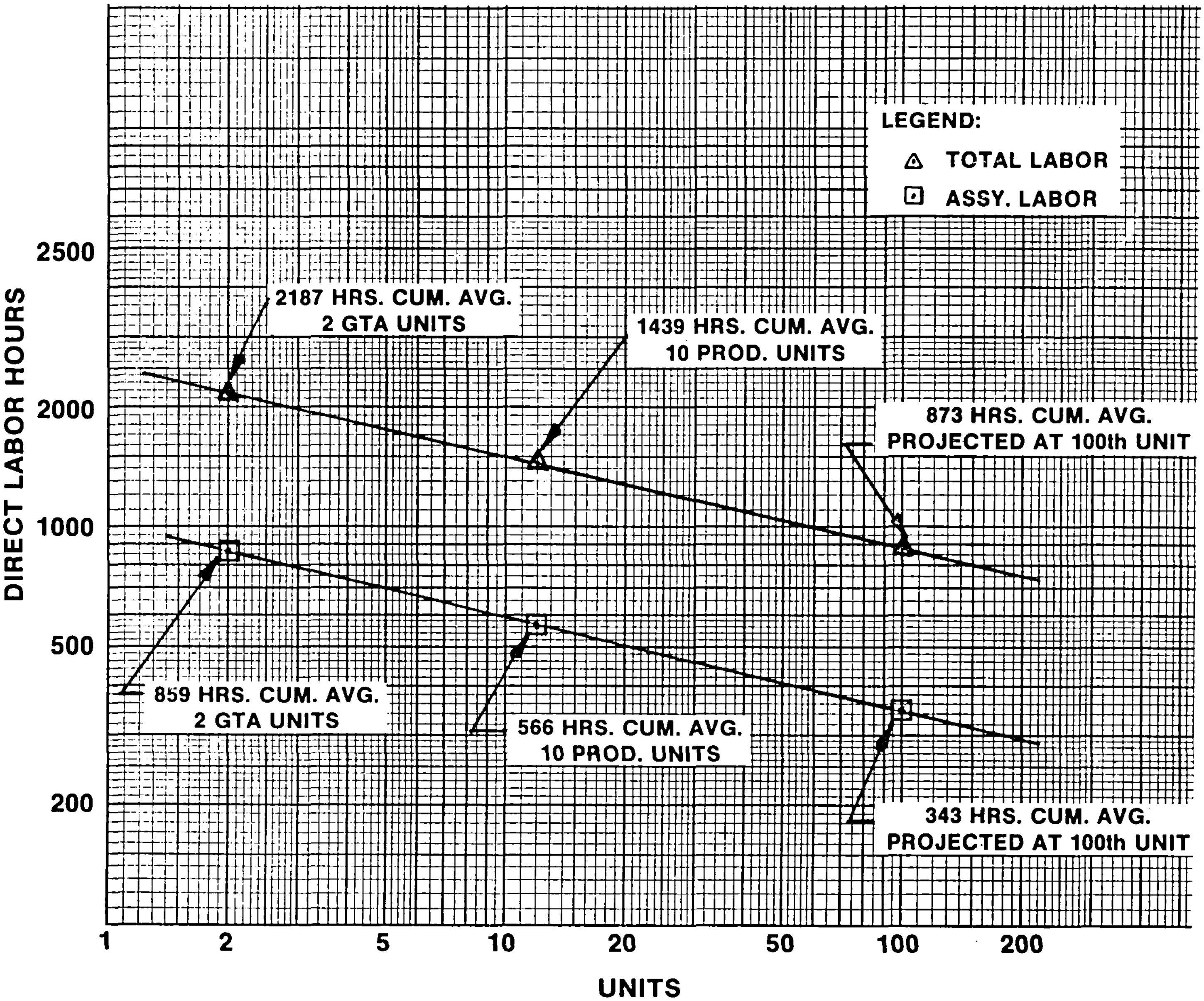

Figure 32. - Actual Learning Curve Development

CONCLUSIONS

The manufacturing techniques which were utilized in the composite aileron fabrication and assembly have resulted in a viable light weight alternative to aluminum aircraft structures. The significant manufacturing processes incorporated were male type tools, net configuration cure and a common cure cycle for all details resulting in the fabrication of high quality composite components. These processes, coupled with the innovative method of manual drilling which produced high quality close tolerance holes, has resulted in an assembly which has proven to be as simple and reliable to manufacture as an aluminum structure.

From the manufacturing experiences of this program, it has been concluded that graphite fabric is superior to tape in layup and machining operations. It has also been determined that low resin content prepreg utilized on this program did not offer the manufacturing process tolerance required for low rejection rate production.

The composite aileron is 23 percent higher, with 50 percent fewer parts and fasteners, than the metal aileron and the preliminary cost data indicates that the labor cost for producing the composite aileron will not exceed that of the metal aileron.

REFERENCES

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16. ABSTRACT

The activities documented in this report are associated with the fabrication of the Advanced Composite Aileron (ACA) program. These activities included detail fabrication, manufacturing development, assembly, repair and quality assurance.

Five ship sets of ailerons have been manufactured. The detail fabrication effort of ribs, spar and covers was accomplished on male tools to a common cure cycle. Graphite/epoxy tape and fabric and syntactic epoxy materials were utilized in the fabrication. The ribs and spar were net cured and required no post cure trim. Material inconsistencies resulted in manufacturing development of the front spar during the production effort.

The assembly effort was accomplished in subassembly and assembly fixtures. The manual drilling system utilized a dagger type drill in a hydraulic feed control hand drill.

The manufacturing integrity was verified by the quality assurance department performance of NDI and coupon testing for each detail.

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