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FABRICATION PROCESS OF A HIGH TEMPERATURE POLYMER MATRIX ENGINE DUCT

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The purpose of this paper is to discuss the process that was used in the molding of an advanced composite outer by-pass duct planned for the F404 engine. This duct was developed as a potential replacement for the existing titanium duct in order to reduce both the weight and cost of the duct. The work was performed under Contract NAS3-21854 and was funded by both NASA and the Navy.

The composite duct is now completing its development phase and is going into the manufacturing technology portion of the program under Navy ManTech sponsorship. The duct is fabricated using graphite cloth impregnated with the PMR15 matrix system developed by NASA/Lewis.

The General Electric Company has applied advanced polymeric composite materials in a variety of development jet engine components for the past decade. Among these components are fan blades, stator vanes, fan frames, fan ducting, cowlings, and shrouds. The matrix resins for composite parts with a service temperature up to 149°C (300°F), are mostly epoxies. For service temperatures of 149°C (300°F) to 316°C (600°F) several polyimide type systems have been explored. PMR15 polyimide resin, developed by NASA/Lewis Research Center, emerged as the matrix system selected by General Electric for the F404 composite outer duct. PMR15 offers several advantages over other polyimide systems that were tried in earlier projects. They are:

1) Uniform, high quality material, at competitive costs is available from several prepreg sources

2) Consistent low void processability in a variety of configurations has been demonstrated

3) The system has excellent physical and mechanical properties even after exposure to severe engine mission cycle environments

4) Adequate thermal stability.

The concept for making the duct was to vacuum bag-autoclave mold a cylindrical laminate shell of Graphite/PMR15 (Gr/PMR) on the outside of a steel mandrel mold. The mandrel mold allows for ease of laying-up the Gr/PMR prepreg and provides an as-molded surface on the airflow side of the finished part. The laminate would incorporate various changes in thickness and material orientation as required for strength, stiffness and configuration.

Sometime after molding, the duct shells would be cut into upper and lower half cylinders, titanium end flanges riveted into place, axial composite side doublers added, and all other fittings added to complete the duct. The composite portion of the duct would weigh approximately 13.6 kg (30 pounds) at assembly. The slightly tapered cylindrical duct is approximately 76 cm (30 inches) in diameter X 102 cm (40 inches) in length. From a design standpoint, the composite duct is required to be fully interchangeable with the titanium duct it replaces. (see Figure 1).

Producibility was perhaps the prime consideration in the selection of graphite fabric impregnated with PMR15 as the prepreg form of the Gr/PMR material for fabricating the F404 composite duct. Fabric could be cut into large easily handled laminae patterns and readily laid-up on the mold tool. (see Figure 2).

T-300 graphite fiber, produced by Union Carbide, woven into a 24 x 23-8 harness satin fabric was selected as the reinforcement for the duct. This selection was made in part because of the processing experience and a data base GE gained in designing and fabricating the Gr/PMR core cowling of the Quiet Clean Short-Haul Experimental Engines (QCSEE) GE built for NASA/Lewis. T-300 and PMR15 as a composite was shown to have adequate thermal stability as well as the strength and modulus of elasticity required for weight efficient duct design.

Allowance for thermal growth of the mold steel and the shrinkage of the Gr/PMR laminate material was provided for in fabricating an oversize (diameter) mold tool. Annular Gr/PMR test pieces were molded and then measured precisely to establish the final sizing of the mold. The mold tool was made with an axial spindle supported at each end with frames mounted to an all steel cart. This allowed for a convenient working height, rotating the mold during the lay-up, and mobility to and from the autoclave. (see Figure 3).

An assembly fixture was designed and built for positioning the end flanges to the composite duct shell. This fixture allows for match drilling the holes for rivets used in assembling the titanium end flanges to the duct body. A drill fixture for the axial split line doublers was also made.

The Gr/PMR materials was received in rolls as uncured prepreg with a colored polyethylene separator film on one side. The PMR15 contains a certain amount of free methanol, as received, which gives the material tack and drape in the prepreg form. In preparing the prepreg laminae for the duct, a second ply of polyethylene separator film of another color was applied to the exposed side of the material as it was unrolled for cutting. The Gr/PMR, now having polyethylene on both sides, could be cut into laminae patterns and handled without losing its tack and drape from evaporation of the methanol. The different color polyethylene film sides provided an easy means for retaining identity of the symmetrical laminae patterns with off-axis orientations. Laminae kits were then prepared for the duct lay-up, according to the engineering design.

Teflon mold release was applied to the mold tool prior to applying the first ply of laminae. It was necessary to add additional methanol to the mold side of this first ply after the polyethylene separator film was removed, so that the material would have sufficient tack to adhere to the mold surfacc during the preforming operation.

The Gr/PMR material, as received, can be debulked to about 406 to 432 microns (16 to 17 mils) prior to molding. Debulking is necessary to eliminate the potential for wrinkling the material during auto-clave molding.

After the final ply was layed-up a spiral wrap of heat shrinkable Dacron fabric tape, known as Ceconite, was then applied and shrunk tightly into place. The Ceconite fabric was used over the preform to permit venting of the volatiles produced when the preform was imidized. The preform was imidized in an air circulating oven according to the following schedule:

- Room temperature to 77°C at 1/2°C/min
- Hold 77°C for 60 minutes
- Raise to 135°C at 1/2°C/min
- Remove immediately from the oven to room temperature.

This schedule does not complete the imidization of the PMR15 system.

After imidization to 135°C, the preform was stripped of the Ceconite and release fabric and then recovered with porous release fabric and two plies of knit-fiberglass cloth breather. Four-inch wide strips of heavy tooling glass cloth were added parallel to the axis of the tool and overlapped two inches with each adjacent piece. The assembly was held tightly to the preform with a spiral wrap of glass cloth tape. A steel sash chain was wrapped into the glass cloth at each end of the preform to act as a 'header' for the venting of the vacuum bag to be applied. Kapton H film from DuPont was used as the vacuum bag. The bag was sealed with a high temperature sealant and checked for leaks by pulling a vacuum. The assembly was double bagged for insurance against loss in the autoclave with another ply of Kapton H. It was separated from the inner bag with a ply of style 1581 glass cloth breather and then checked for leaks with vacuum.

The entire assembly was moved into the autoclave and rechecked for leaks in the vacuum bags using the vacuum system in the autoclave. The assembly was autoclave molded according to the following schedule:

- apply 13 kPa of vacuum
- raise temperature to 204°C at 3.5°C/min
- hold 204°C for 15 minutes, then apply full vacuum
- raise temperature to 238°C at 2/3°C/min then apply 1277 kPa autoclave pressure and continue 1277 kPa and full vacuum throughout
- raise temperature to 252°C in 30 minutes
- hold 252°C for 30 minutes
- raise temperature to 307°C at 1°C/min
- hold 307°C/1277 kPa and full vacuum for 180 minutes

- release the vacuum and pressure slowly (to prevent buckling) before lowering temperature

- cycle complete - post cure later

The duct shells were easily removed from the mandrel tool after debagging. After a thorough visual inspection the duct shells were inspected by ultrasonic thru transmission with a 'C' scan readout. The 'C' scan indicates apparent defects as varying shades of grey on electro sensitive record paper. The grey scale is proportional to the attenuation of the ultrasonic signal and can be adjusted so as to show the extent of the laminates void content in the range level chosen. The design called for a maximum allowable void content of three (3) percent. The 'C' scan grey scale was adjusted to show a near black readout for this level of voids. The duct shells used were proven to contain less than three percent voids and no delaminations. A more thorough ultrasonic survey was also made by measuring the actual attenuation of the ultrasonic signal at grid locations marked on the ducts. Precise void content values were calculated and recorded for these locations. (see Figure 4).

The extensive hardware to be attached to the ducts at engine assembly required adding embossments to the duct shell in order to have spatial location identical to that on the titanium ducting to be replaced. These embossments along with areas requiring added stiffness or strength and the axial split line doublers, all made of Gr/PMR15, were then laid up on the duct shells. They were molded and bonded into position in several vacuum bag-autoclave cycles. These secondary laminations were not oven imidized separate from the autoclave as were the duct shells as it was necessary to hold the position of the various laminae for embossments, stiffeners and doublers with a vacuum bag. The operations used to add these secondary laminations were:

- Mark the position of the buildup areas on the duct shell from precise mylar overlays

- Prepare the surface for bonding using a chlorothene solvent wipe before and after a light grit blast

- Prepare the prepreg kits for the buildups

- Apply one ply of Style 120 glass cloth/PMR15 to the area (50% resin PBW). This material serves as an adhesive

- Apply the buildup plies to the duct shell and dampen them with methanol, if required, to 'tack' them into position

- Apply Teflon release fabric over the laminae

- Apply glass fabric bleader and breather

- Double envelope bag with Kapton film.

The secondary laminations were autoclave molded as follows:

- Apply 13.6 kPa of vacuum

- Raise temperature to 71°C at 0.83°C/min
- Hold 71°C for 60 minutes
- Raise temperature to 116°C at 0.42°C/min
- Apply full vacuum
- Raise temperature to 249°C @ 1.2°C/min
- Apply 1277 kPa autoclave pressure
- Hold 249°C for 30 minutes
- Raise Temperature to 307°C at 1.2°C/min
- Hold 307°C with full vacuum and 1277 kPa pressure for 180 minutes.

With all the secondary laminations completed, the duct was ready for machining and assembly to the end flanges. The sequence of events were:

- Trim the duct and the axial doublers to dimension
- Match drill the axial doublers with the duct shell for the bolting
- Cut the duct shell into upper and lower halves
- Using the assembly fixture, match drill and rivet the titanium end flanges to the duct shell
- Complete all other machining of the embossments and mounting areas for the hardware assembly
- Final ultrasonic inspection
- Seal coat with Skybond 703 polyimide resin
- Assemble and bond inserts
- Post cure
- Install studs
- Part marking
- Final inspection

The composite duct subjected to static load testing, exceeded requirements. The composite duct installed on a factory engine is still in test and performing well. The manufacturing technology portion of the program is now underway to ready the composite duct for production.

GE F404 Composite Duct Program

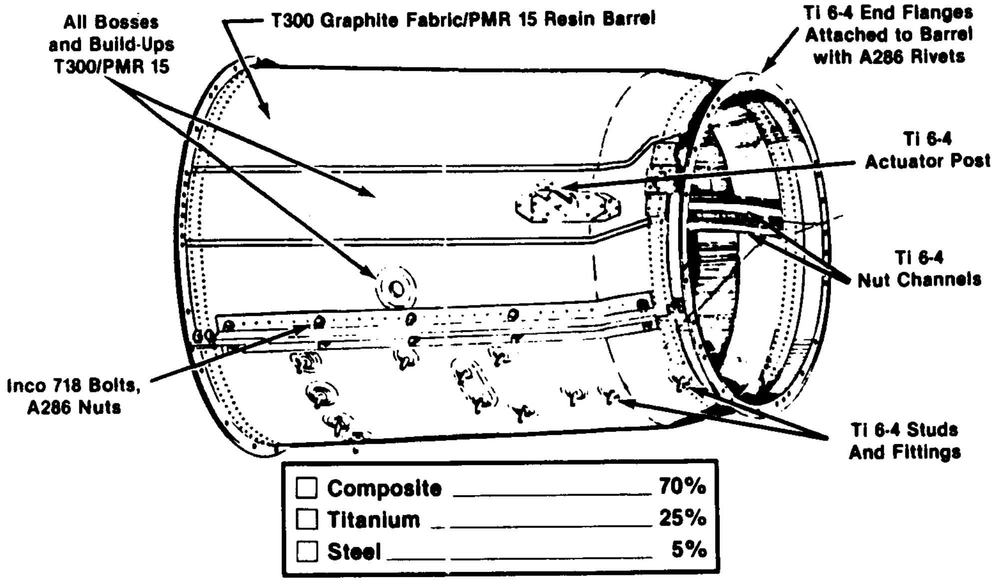

Figure 1

F404 Composite Duct Ply Arrangement

Ply	∢A	Warp To Axis ∢
1	36°	0°
2	51°	−45°
3	24°	0°
4	39°	+45°
5	54°	−45°
6	42°	+45°
7	30°	−45°
8	45°	+45°
9	60°	0°
10	33°	−45°
11	48°	0°

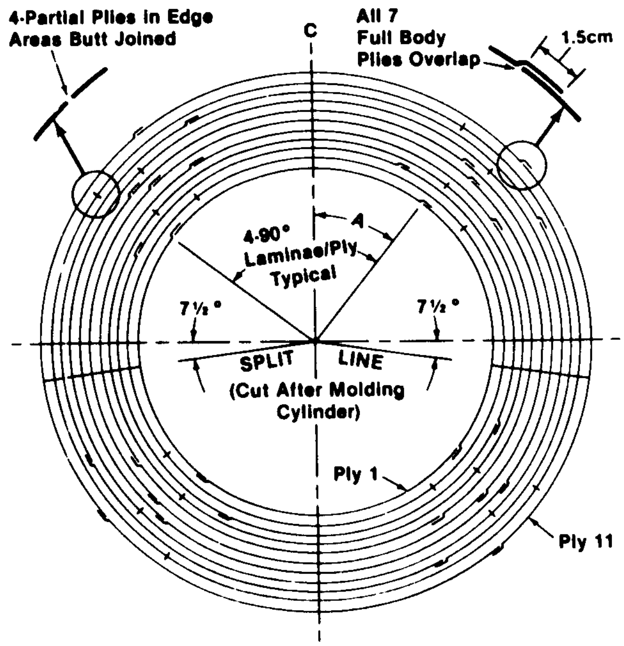

Figure 2

F404 Composite Duct Mold

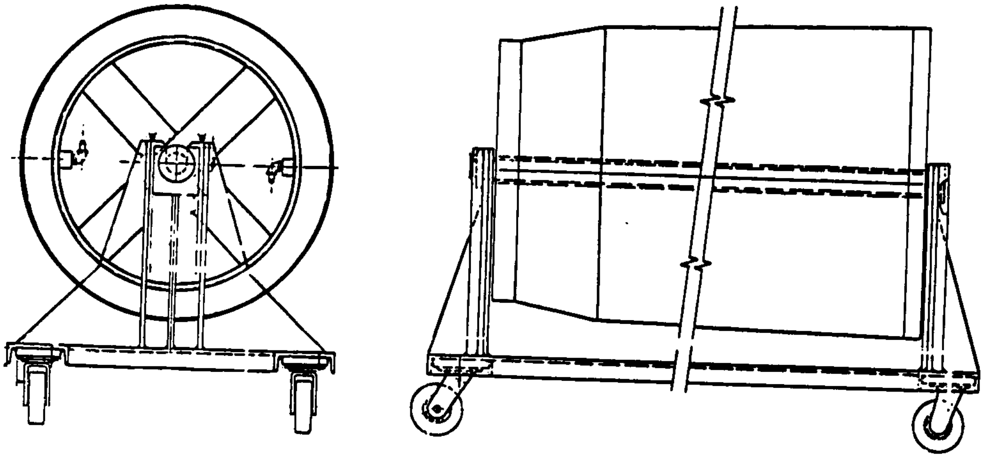

Figure 3

F404 Duct S/N 80003

Void Content Determined from the Attenuation of the Thru Transmission Ultrasonics

Degrees are CCW from Aft end

Dist. from Aft End	Top ℄ 0°	60°	100° Ply Build Up	120°	153°	Bot ℄ 180°	240°	260° Ply Build Up	300°
5cm	1.5%	1.5%	1.5%	1.5%		1.5%	1.5%	1.5%	1.5%
25cm	1.5%	1.5%	1.5%	2.5%		2.0%	1.5%	1.5%	1.5%
46cm	1.5%	1.5%	1.5%	3.0%		2.5%	1.5%	1.5%	1.5%
66cm	1.5%	1.5%	1.5%	2.0%	3.5%	3.5%	2.0%	1.5%	1.5%
86cm	1.5%	1.5%	1.5%	2.0%	5.0%	4.0%	2.0%	1.5%	1.5%
104cm	1.5%	1.5%	1.5%	1.5%		1.5%	1.5%	1.5%	1.5%

Figure 4