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Technical Report

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ABRAMS AIR INTAKE PLENUMS/PRECLEANER ASSEMBLIES

CONTRACT NUMBER DAAE07-88-C-R131

OCTOBER 1989

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19. ABSTRACT (Continue on reverse if necessary and identify by block number)
This report documents a program to develop and fabricate a composite material air intake plenum and precleaner assembly for the M1A1 tank. The air intake plenum incorporates organic composite materials to reduce weight and production costs, when compared to the aluminum counterpart. Aluminum design problems were eliminated and airflow enhanced by using composite materials.

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1.0. INTRODUCTION

This report, prepared by General Dynamics Land Systems Division (GDLS) for the U.S. Army Tank-Automotive Command under Contract DAAE07-88-C-R131, describes a process for developing and fabricating three air intake plenums, lighter and less expensive than the current M1A1 plenums, and five precleaner assemblies, also for the M1A1 Abrams main battle tank. By using organic composite materials, current aluminum design problems (i.e., air leaks, weld cracking, and inconsistent parts) were eliminated while maintaining required structural properties. The composite design and fabrication process allowed molding of the airbox/plenum into a one-piece structure which was 38% lighter than the current aluminum plenum and more economical to produce. The composite airbox/plenum also enhanced airflow by integrating rounded corners and more gradual directional changes into the design.

2.0. OBJECTIVE

The primary goal was to design and fabricate a composite airbox/plenum and precleaner assembly that would be interchangeable with the current aluminum components while reducing weight, production cost, and life-cycle costs. Major requirements in the Scope of Work for Contract DAAE07-88-C-R131 included:

- The airbox/plenum and precleaner assemblies must be interchangeable with the current metallic components. The assemblies must use the same hookup dimensions and locations as currently used, to ensure accurate interface into the M1A1 Abrams system.
- Target costs for the production airbox/plenum and precleaner assemblies were $550 and $1,600, respectively.
- Materials selected must be readily available in sufficient quantities to produce a minimum of 700 units annually.
- The developed components must be able to withstand an operational temperature range of -60F to +300F.
- The components must be resistant to NBC agents and decontaminates.
- The plenum area must be able to withstand a pressure test of 1.0 psig between both ends of the plenum and not depressurize more than 0.3 psig in 1.5 minutes.
- Three airbox/plenums and five precleaner assemblies must be fabricated and delivered.

3.0. CONCLUSION

Weight reduction in the M1A1 Abrams tank (and future M1A2) continues to be a highly desirable goal. The composite airbox/plenum and precleaner reduce weight when compared to the current aluminum component, while reducing production and life-cycle costs. The composite component is completely interchangeable with the current aluminum component, using the same mounting hardware and attachments. The composite airbox/plenum also satisfies the structural and material requirements. The low-profile precleaner design reduces weight and was qualified by testing performed concurrent to this program. It is compatible with either the composite airbox/plenum or the aluminum unit.

4.0. RECOMMENDATIONS

4.1. Molds

While epoxy tooling is sufficient for prototype applications, production molds should be made of aluminum or steel to ensure that degradation does not occur from fabricating large numbers of parts.

4.2. NBC/DS2 Testing

Additional testing should be performed on the materials used in the composite airbox/plenum to determine long-term exposure to NBC agents and DS2 decontaminates. Testing should be done on the fiber reinforcement, resin, and adhesive to determine these effects.

4.3. Production

Before placing the composite airbox/plenum into production, the assembly should be completely tested in the M1A1 tank. Level III drawings of the component should be completed. Planning should be initiated to incorporate the composite airbox/plenum into the M1A2 scheduled for implementation in 1991.

5.0. DISCUSSION

5.1. Background

The air intake plenum is located on left side of the M1A1 hull in the engine compartment. Its function is to clean and direct air into the engine.

Intake air is initially cleaned in the precleaner assembly, which is clamped to the top of the airbox. Intake air flows through a number of swirl tubes in the precleaner to remove large pieces of debris. About 85% of the contaminants are removed in the precleaner, with the remaining contaminates falling into the inner precleaner chamber and being exhausted out the rear of the tank through a scavenger duct. The precleaner air is then filtered through three Vee-Pack filters located inside the airbox to remove finer debris which could damage the engine. The air then passes through the remaining portion of the plenum to the engine. The current production M1A1 precleaner is purchased as a single unit from an outside source. The outer housing is fabricated from welded aluminum sheets with the exception of the plastic swirl tubes and a rubber gasket. Two designs, procured from separate vendors, are currently in use.

The current production M1A1 air airbox/plenum is also purchased as a single unit from an outside source. It is fabricated from numerous aluminum plates and angles which require several welding operations. This type of processing causes variations to occur in part dimensions during fabrication.

5.2. Design

GDLS developed a process to ensure the precleaner and airbox/plenum would minimize weight and production costs while keeping exterior dimensions and mounting attachments unchanged. In this way, the composite part would be interchangeable with the current assemblies.

The current Vee-Pac filters and seals were maintained. By using composite molding processes, the problems now encountered with the aluminum air plenum (i.e. air leaks, fit problems, weld cracking, and inconsistency) were eliminated. The composite assembly incorporated rounded corners and more gradual directional airflow changes which enhance performance and producibility of the part. After fabrication, each of the three airbox/plenum units delivered were pressure tested to ensure that air leakage is below the required rate of 0.3 psig in 1.5 minutes.

5.2.1. Precleaner. The role of the precleaner is to remove large contaminants and debris from the intake air before it reaches the Vee-Pac filters. This is accomplished by using numerous plastic swirl tubes located inside the precleaner. Intake air flows through the tubes which swirls the air, throwing the larger contaminants outside the tube into a inner chamber. A scavenger duct is attached to the inner precleaner chamber, which draws the contaminants and exhausts them out the rear of the tank (Figure 5-1). About 85% of the contaminants are removed from the intake air during this process.

The current production precleaner is fabricated from aluminum sheets (which are spot welded), the plastic swirl tubes, and a rubber sealing gasket. The weight of the current precleaner is approximately 60 pounds. There are two different precleaner designs currently being used; each is procured from different vendors. The two designs are shown in Figure 5-2.

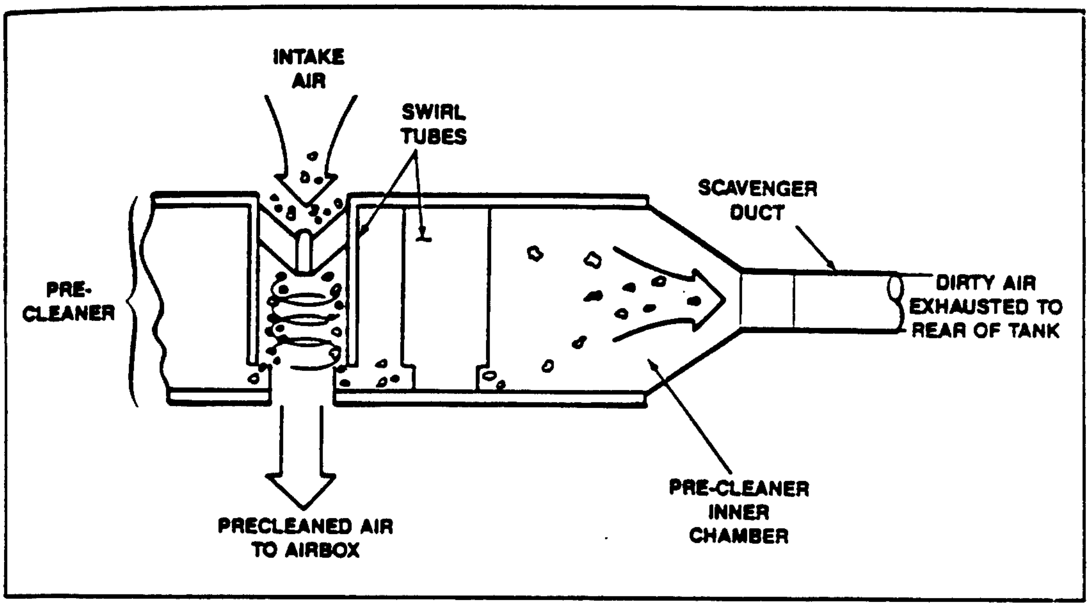


Figure 5-1. Precleaner Function and Operation

Design A is a high-profile type while Design B is a low-profile type. The main differences between the two design are the height and weight. The high-profile type is bulkier and has larger swirl tubes which give it a larger profile. It weighs 60 pounds. The low-profile type is a more compact design using smaller swirl tubes which reduce its weight. Both designs are currently qualified and employed interchangeably on the M1A1 Abrams tank.

The GDLS design approach was based on the low-profile type because weight savings was a major goal of the program. The target cost and weight of the precleaner were set at 40 pounds and $1,600, respectively. After conducting research, it was determined that the current supplier of the high-profile precleaner, Donaldson Company of Minneapolis, Minnesota, had just developed a low-profile design which weighed 38.1 pounds. The U.S. Army had recently ordered 300 of these low-profile precleaners to be used as replacement units. GDLS purchased five of the Donaldson Company's low-profile precleaners to be used in the program. It was a logical decision to use a new precleaner design which met the program objectives and was already tested and accepted by the Army, rather than to develop a completely new design.

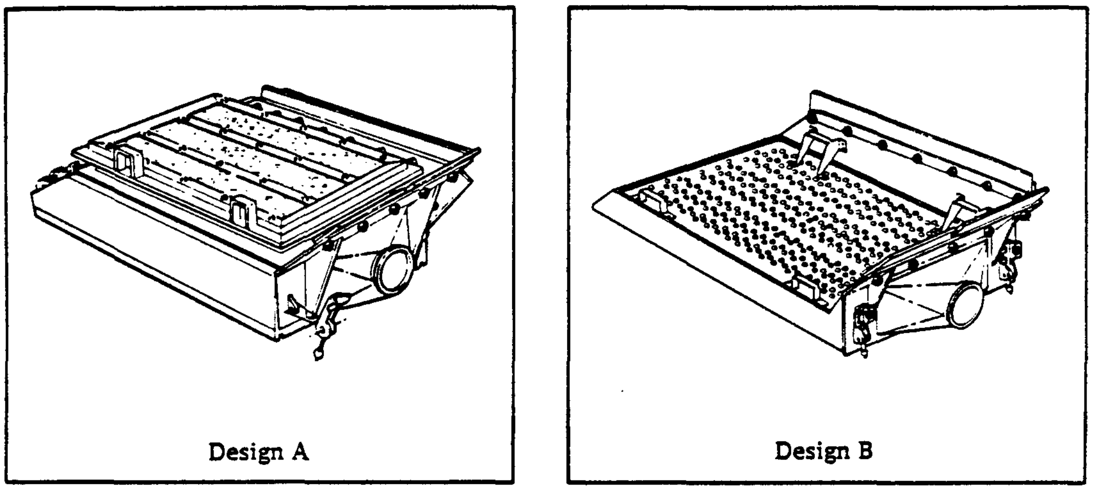


Figure 5-2. Current Precleaner Designs

One major alteration to the new low-profile design was the addition of a debris screen which was attached to the top of the precleaner. The debris screen keeps larger contaminants such as branches, twigs, and leaves from blocking the airflow through the swirl tubes. It also protects the swirl tubes from being damaged by a person walking on the precleaner unit. The debris screen weighs a total of 7.9 pounds, resulting in a total precleaner weight of 46.0 pounds.

The debris screen is not required in current production precleaners. The screen was previously required but was removed to reduce vehicle weight. The precleaners delivered by GDLS used the debris screens, but they are easily removed if desired. The Army required the debris screen on the low-profile precleaners purchased from Donaldson.

The production cost of the Donaldson Company low-profile precleaner, at a production rate of 700 units annually, is included in the economic analysis. A photograph of the Donaldson low-profile precleaner appears in Figure 5-3.

5.2.2. Airbox/Plenum. The airbox/plenum is located on left side of the hull engine compartment (Figure 5-4) and is responsible for removing contaminants from intake air, which could damage the engine. While the precleaner removes the larger contaminants from the intake air, the airbox/plenum uses three Vee-Pac filters to remove the smaller, finer contaminants. The filters press tightly against gaskets located in the front wall, which prevent contaminated air from entering the plenum before it has been cleaned by the Vee-Pac filters. The plenum area must also be airtight to ensure that no contaminants have a possibility of entering and damaging the engine.

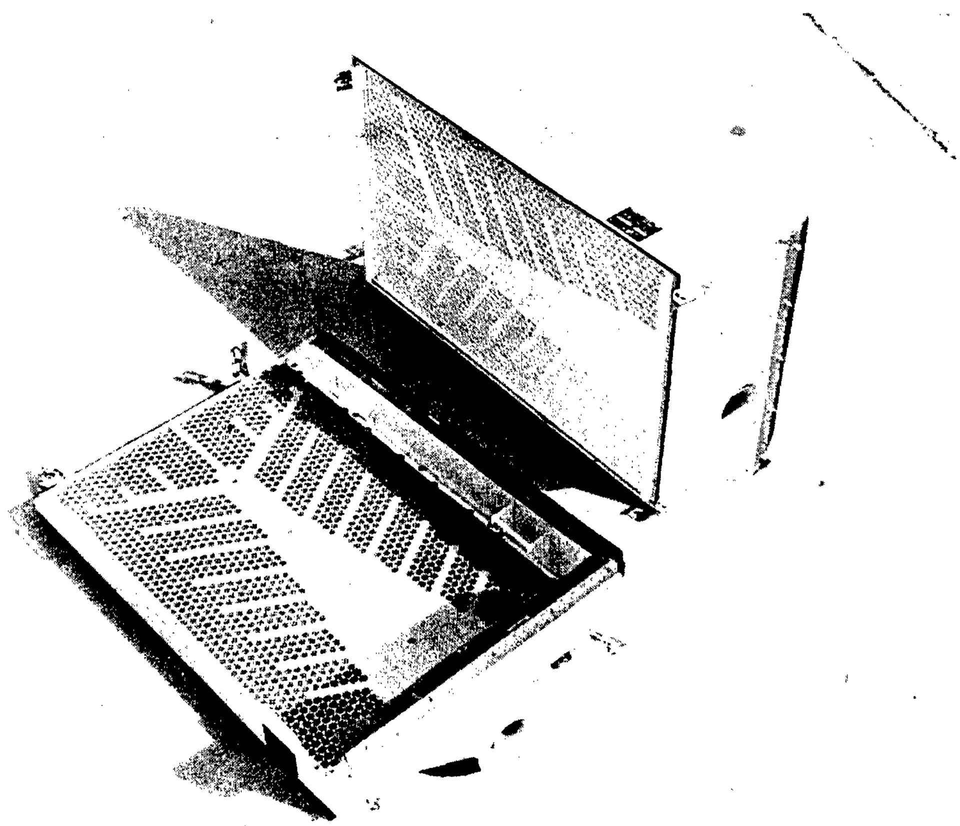


Figure 5-3. Donaldson Low-profile Precleaner

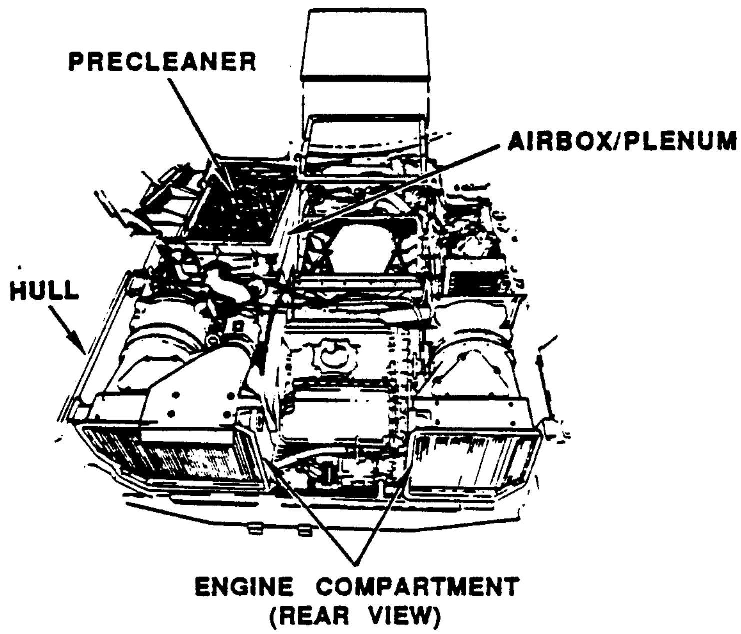


Figure 5-4. Location of Airbox/Plenum in M1A1 Tank

The current aluminum airbox/plenum has a history of manufacturing problems including air leaking, weld cracking, fit problems, and inconsistent quality. To overcome these problems, GDLS has developed a process in which the airbox/plenum was fabricated as a one-piece composite molding (Figure 5-5).

The exterior dimensions of the airbox/plenum remained the same to ensure interchangeability with the current aluminum assembly. The same basic shape of the airbox/plenum was retained, with some corners and radii added or changed to improve the airflow and enhance the producibility of the part. The fabrication process produces parts which are more consistent but less labor intensive.

The composite airbox/plenum developed is 38% lighter than the current aluminum assembly. The airbox wall sections used 0.25-inch balsa wood as a core material with thin fiberglass skins to significantly reduce weight when compared to the aluminum wall sections. The walls of the plenum area are fabricated of solid composite without using a core material because of its complex shape and thin wall (0.190-inch) cross-section.

The actual wall thicknesses of the composite airbox/plenum are nearly the same as the aluminum counterparts. The comparison of composite vs. aluminum wall thicknesses and weights can be found in Table 5-1. The only noticeable variation in wall thickness between the composite airbox/plenum and the aluminum sections is on the side walls. The aluminum assembly has side wall thickness of 0.25 inches while the composite side walls are 0.36 inches. The exterior dimensions of the composite component remain unchanged from the aluminum section. Four inches away from the airbox front wall, the balsa core terminates and the side wall thicknesses taper to 0.25 inches of solid composite material. This allows the Vee-Pac filters enough space to be properly positioned and secured in place (Figure 5-6).

The Vee-Pac filters rest upon support plates located in the bottom front and rear of the airbox section. The front support plate is .38 inches thick and uses a balsa wood and fiberglass core over approximately half of its length. The other half of the support plate is made of solid composite to allow mounting hardware to be bolted to the bottom of the airbox.

Structural analysis was performed on each of the composite airbox/plenum walls to determine stress levels and safety margins. Design loads are summarized in Table 5-2. A summary of wall deflections, stress levels, and safety margins are shown in Table 5-3.

Table 5-1. Comparison of Wall Thicknesses and Weights

Component	ALUMINUM DESIGN Thickness (in)	ALUMINUM DESIGN Weight (lbs)	COMPOSITE DESIGN Thickness (in)	COMPOSITE DESIGN Weight (lbs)	Weight Savings (lbs)	Weight Savings (%)
Airbox Sides (L & R)	.25	23.0 X 2 = 46.0	.36	10.4 X 2 = 20.8	25.2	54.8
Airbox Rear	.50	28.4	.50	14.4	14.0	49.3
Airbox Bottom	.38	41.5	.36	26.8	14.7	35.4
Airbox Front	1.00	21.2	1.00	13.9	7.3	34.4
Plenum	.19	66.0	.19	42.7	23.3	35.3
Precleaner	---	60.0	---	38.1*	21.9	36.5
Mounting Hardware	---	12.9	--	16.4**	(3.5)	---
Support Plate (rear)	.38	7.6	.19	4.1	3.5	46.1
Support Plate (front)	.38	2.4	.38	0.9	1.5	62.5
TOTAL		286.0		178.1	107.9	37.7

* Excludes Removable Debris Screen (7.9 lbs)

** Additional Weight Due to Extra Hardware Required for mounting

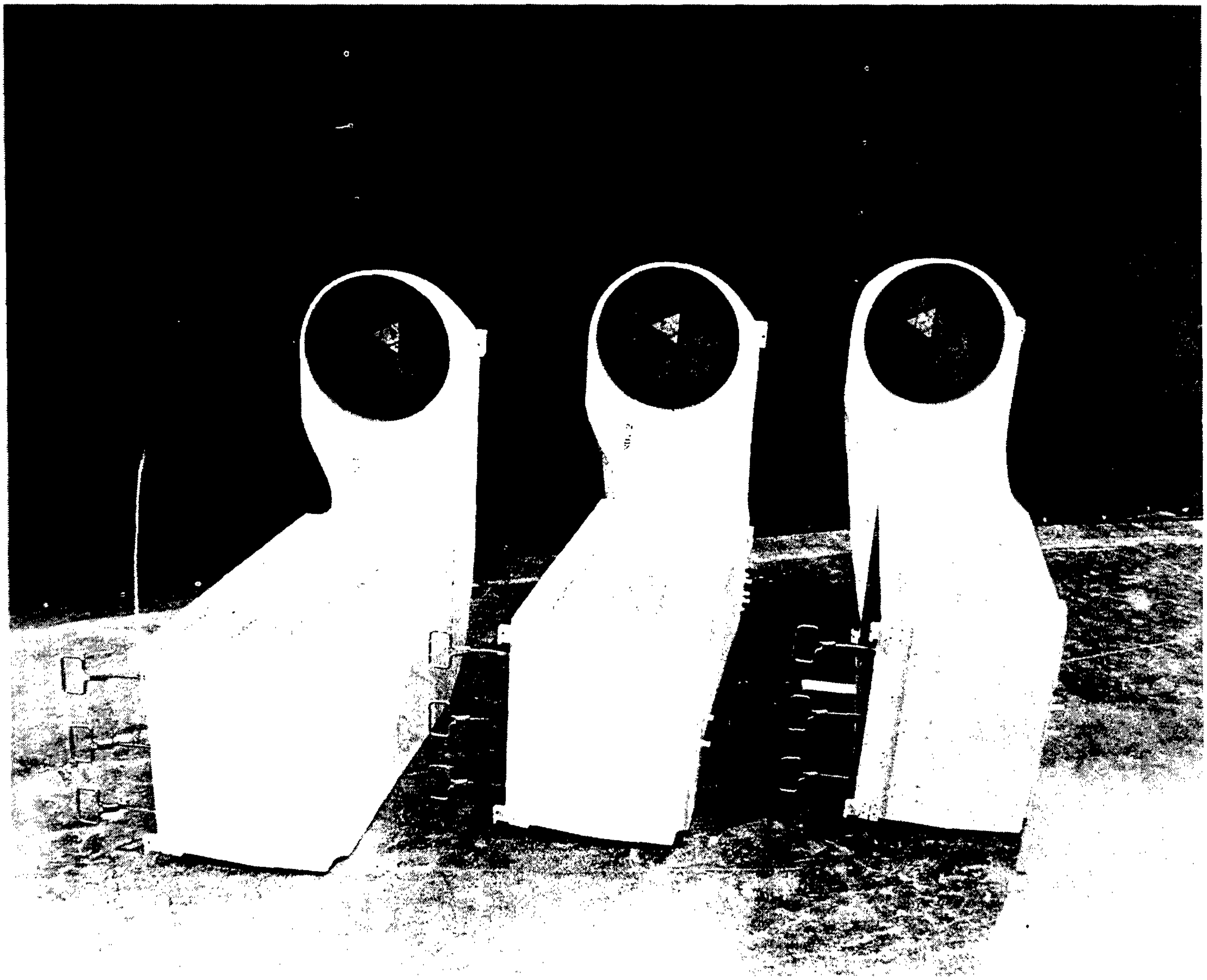


Figure 5-5. Completed Composite Airbox/Plenum

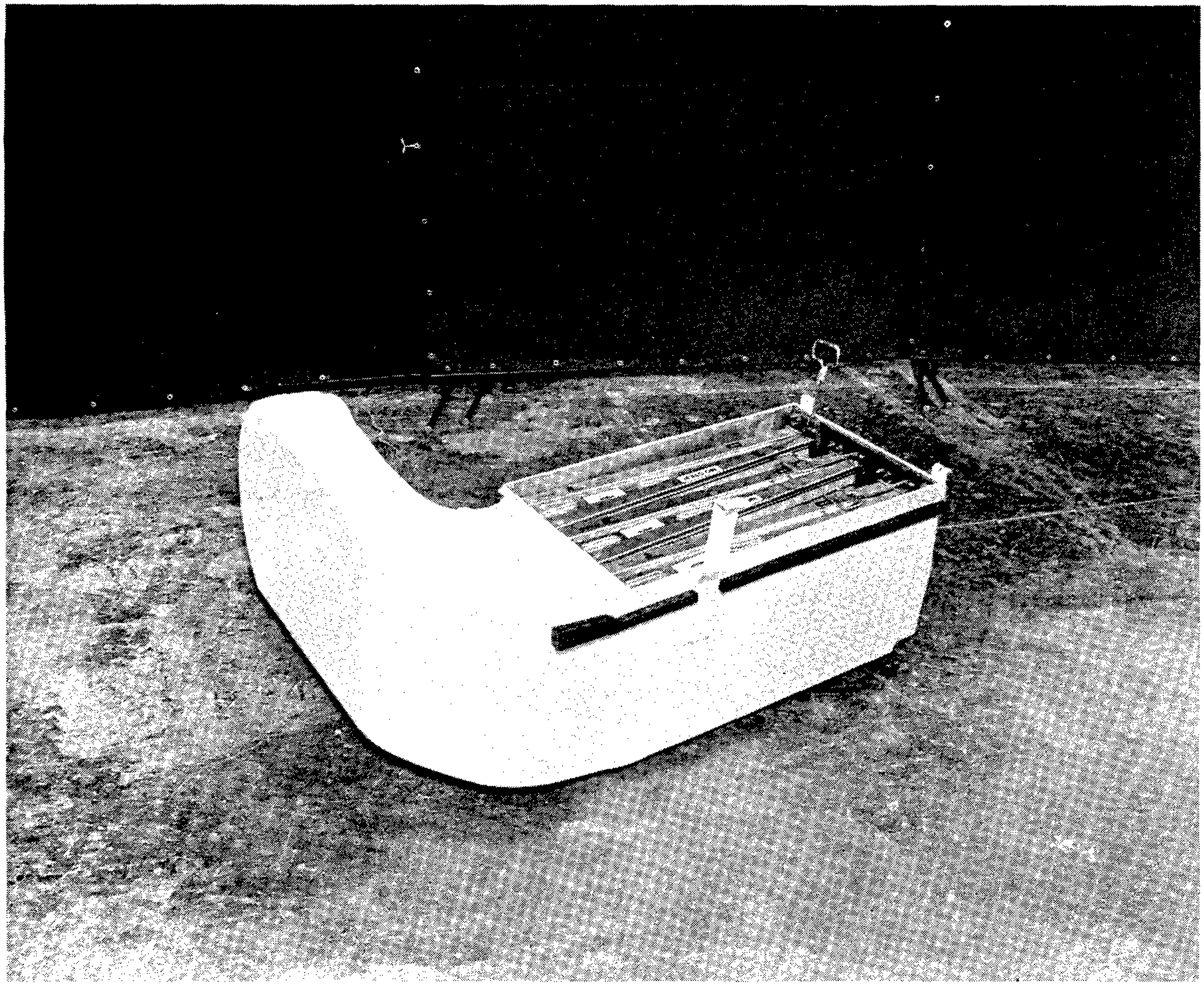


Figure 5-6. Position of Vee-Pac Filters

Table 5-2. Airbox/Plenum Design Loads

Condition	Nx	Ny	Nz	Pressure
Normal Operation	± 1 g	± 1 g	± 1 g	1 psi
Ballistic Shock	± 75 g	± 75 g	± 75 g	N/A
Gunfire Shock	± 50 g	± 50 g	± 50 g	N/A

Table 5-3. Composite Airbox Analysis Summary

	DEFLECTION (in.)	STRESS (ksi)	ALLOWABLE STRESS (ksi)	MARGIN OF SAFETY
AIRBOX REAR WALL	.250	10.8	30.0	1.78
AIRBOX SIDE WALL	.312	3.3	23.2	6.03
AIRBOX BOTTOM WALL	.392	3.3	23.2	6.03
AIRBOX FRONT WALL	.050	2.1	23.2	10.05
PLENUM WALL	.326	3.9	23.2	4.95

Classical lamination theory was used to calculate moduli and perform stress and deflection analysis. The rear wall of the airbox was subjected to the highest stress due to the three Vee-Pac filter clamps, each exerting 300 pounds of force against the rear wall. This large clamping force is required to secure the Vee-Pac filters tightly against the front wall seals to prevent air leakage. If the rear wall deflects too much, the Vee-Pac filters will not seal properly. Currently, the .50-inch thick aluminum rear wall deflects .265 inches and uses a welded aluminum channel stiffener for additional stiffness. The composite rear wall is also .50 inches thick and features unidirectional fiberglass and a small amount of unidirectional carbon to improve stiffness. The composite design also uses an aluminum channel with a larger flange resulting in a rear wall deflection of .25 inches. The analysis of the rear wall is shown in Figure 5-7.

Current mounting hardware was used on the composite airbox/plenum to ensure that the part would fit into the tank. Because the airbox/plenum is fabricated of composite material, the current aluminum mounting hardware could not be welded to the structure. Therefore, alterations were made to the mounting hardware, allowing for different fastening techniques. Adhesive and bolts were used to attach the mounting hardware to the composite airbox/plenum.

Design analysis was performed on the mounting hardware to determine the major loading areas. Worst-case scenarios and the lowest material properties were used during the analysis to determine safety margins.

The composite airbox/plenum is bolted in the engine compartment by four separate mounting blocks and one hanger support. Each supports a portion of the load from the part's structural weight (178.1 lbs.). The composite part is also subjected to vibrational shock occurring during normal operation of the tank. The two load cases of concern are gun fire shock (55 g's) and ballistic shock (75 g's).

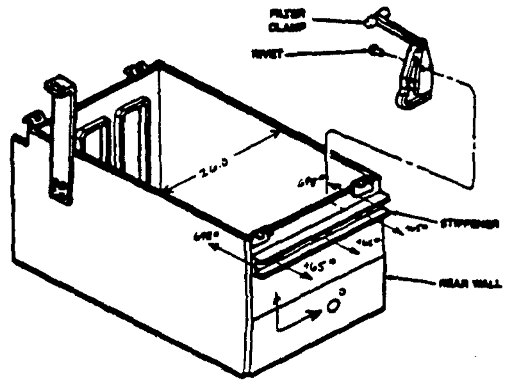
The mounting attachment subjected to the highest loading stress is located in the back plenum wall opposite the plenum ring. The stress analysis for this attachment is shown in Figure 5-8.

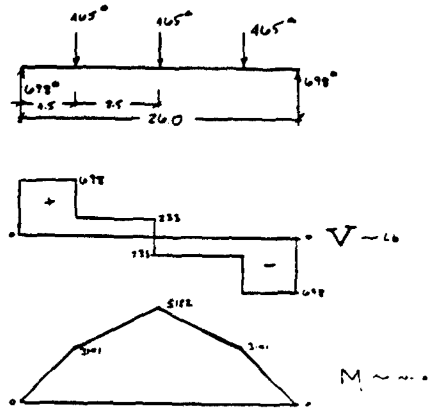
Structural analysis shows the composite airbox/plenum to be a sound structure and safely satisfies all design requirements. While the composite is not as rigid a structure as the current aluminum assembly, this should prove beneficial in being able to absorb the shock and vibrational forces present in the M1A1 tank.

A photograph of the completed assembly, including the composite airbox/plenum and low-profile precleaner, is shown in Figure 5-9.

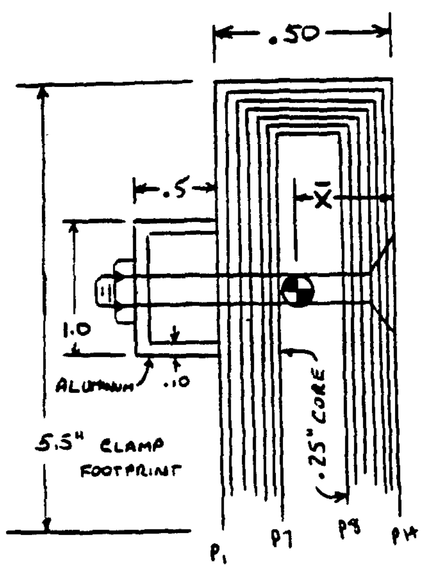
LOADING

310 Lb × 1.5 FACTOR OF SAFETY = 465 Lb ULT





WALL GEOMETRY & PROPERTIES



PLY TABLE

PLY #	LAYUP DIRECTION	MATERIAL
1, 14	0°	10 OZ GLASS 0/90 FABRIC
2, 3, 12, 13	0°	8 oz GRAPHITE UNI-FABRIC
4, 7, 8, 11	0°	18 OZ GLASS 0/90 FABRIC
5, 6, 9, 10	0°	18 oz GLASS UNI-FABRIC

SECTION PROPERTIES

$I = .448$ @ $E = 3.0 \times 10^6$ PSI

DEFLECTION CHECK

DEFLECTION $\delta = \frac{Pa}{24EI}\left(3L^2 - 4a^2\right) + \frac{PL^3}{48EI}$

WHERE $P = 465$ Lb ULT
$L = 26.0$ in
$a = 4.5$ in
$E = 3 \times 10^6$ PSI
$I = .448$

$\delta = .35$ in OK

Figure 5-7. Rear Wall Deflection Analysis

Total Weight of Composite Airbox / Plenum and Precleaner = 178.1 lbs

ASSUMPTIONS:

Possible Forces Present in Airbox / Plenum System:

Gun Fire Shock = 55 g's

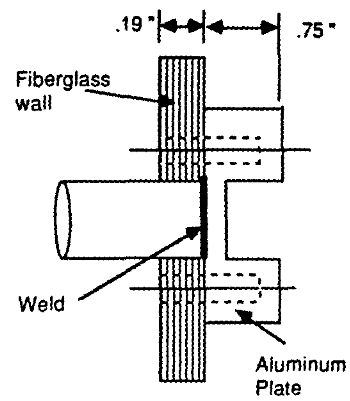
Ballistic Shock = 75 g's

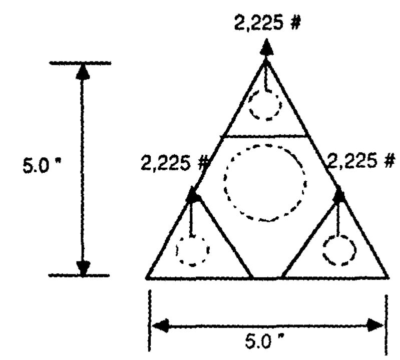
Mount will carry 1/2 the part weight (178.1 / 2 = 89 lbs)

Worst Case - Mount will see load of 89 X 75 = 6,675 lbs

Using 3 bolts, each bolt will see 6,675 / 3 = 2,225 lbs

Bolts will carry the entire load





Using 3 / 8 " bolts: Area = $\frac{D^2}{4}$ = .11045 in^2

Shear Stress = $\frac{P}{A} = \frac{2225}{.11045}$ = 20.1 ksi

Allowable Shear Stress = 95 ksi

Margin of Safety = $\frac{95.0}{20.1} - 1$ = 4.73

BEARING STRESS (Composite Wall)

$f_{bn} = \frac{P}{DT}$

P = 2225 lbs

D = .375 in

T = .19 in

f_{bn} = 31.2 ksi

Allowable = 32 ksi

Margin Of Safety = $\frac{32.0}{31.2}$ -1 = .03

Figure 5-8. Example Plenum Mounting Analysis

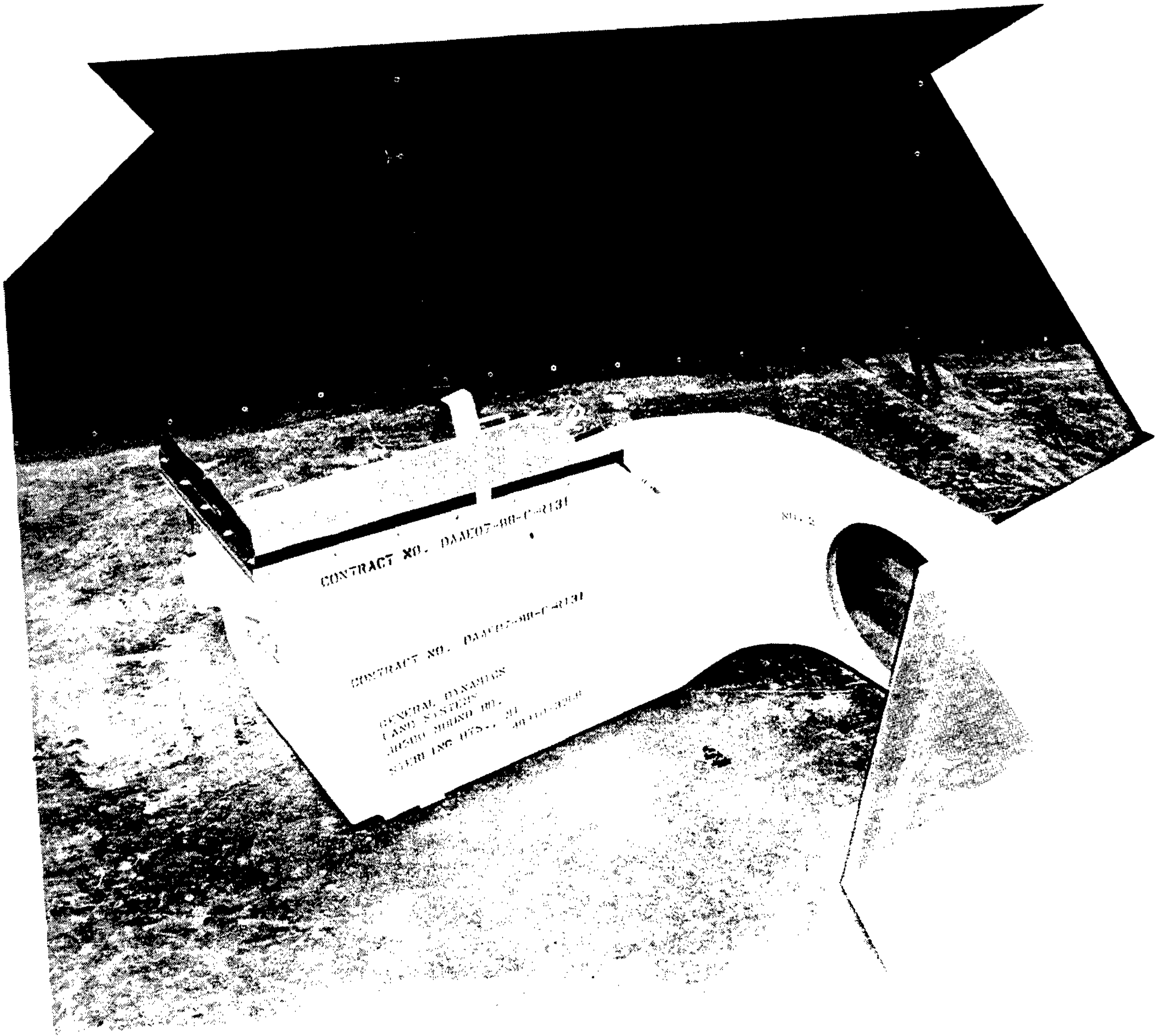


Figure 5-9. Final Complete Assembly

5.3. Material Selection

The materials used for the composite airbox/plenum were optimized for strength, heat resistance, NBC effects and cost. While several types of materials were considered in the design, GDLS selected materials based on satisfying program requirements which are readily available in quantities required to support M1A1 production.

5.3.1. Resin. The main consideration for selection of the resin matrix was satisfying the 300°F service temperature requirement. GDLS chose an epoxy resin system, TACTIX 123, manufactured by DOW Chemical. Polyester and vinylester resins were eliminated from consideration due to an inability to meet the temperature requirement. Other high-temperature resins such as BMI's and polyimides are substantially higher in cost and difficult to process. The TACTIX system meets the temperature requirement, is self-extinguishing, has good resistance to oils and chemicals found in the M1A1 engine compartment, is resistant to DS2 decontamination (sec. 5.6.4), has good wet-out properties, and is suitable for the Resin Transfer Molding (RTM) process. The resin is also compatible with epoxy type CARC paints and adhesives which were used in the secondary fabrication operations of the assemblies. Properties for this resin are shown in Table 5-4.

Table 5-4. Properties of Dow Tactix 123/H31 Resin System

Viscosity at 90 °F	250 cps
Pot Life at 100 °F	1.0 hours
Glass Transition Temperature	306 °F
Flexural Strength	20.9 ksi
Flexural Modulus	397.0 ksi
Tensile Strength	11.1 ksi
Tensile Modulus	431 ksi
Elongation at UTS	5.7 %

5.3.2. Fiber Reinforcement. The fiber reinforcement chosen for the composite airbox/plenum was based upon strength and cost requirements. Heat resistance was not a major consideration, because the epoxy resin will degrade at a significantly lower temperature than the fiber reinforcements considered. E-glass was chosen as the fiber reinforcement because of its structural properties and low cost, when compared to other available reinforcement.

Three types of E-glass were used in the fabrication process: 10 oz/sq. yd. bidirectional woven fabric, 18 oz/sq. yd. bidirectional knitted fabric, and 10 oz/sq. yd. unidirectional knitted fabric. The majority of the composite airbox/plenum was fabricated with the 18 oz./sq. yd. material. A small amount of the unidirectional fabric was used in the rear wall for added strength and directional stiffness, with the 10 oz/sq. yd. woven fabric being used on the outer layers to achieve a quality surface finish. A small amount (0.5 lbs.) of carbon was also used in the rear wall to increase structural stiffness in that area. The use of carbon was kept at a minimum because of its high cost. Properties for the E-glass and carbon are compared with those of other fibers in Table 5-5.

5.3.3. Core Material. The main advantage of using a core material is increased stiffness at a reduced weight. GDLS chose end-grain balsa wood as a core material in fabricating the composite airbox/plenum based upon its density, modulus, shear strength, chemical resistivity, temperature and flammability resistance, cost, and suitability to the RTM process.

While other core materials available were capable of producing similar structural integrities, the end-grain balsa wood was cheaper in cost. Properties of core materials considered are given in Table 5-6. The balsa wood can withstand continuous temperatures of 350°F with no structural degradation and is self-extinguishing. Even though the balsa wood is itself chemical resistant, it is enclosed in the resin/fiber matrix separating it from any chemical contamination. The end-grain balsa wood is a closed-end structure and will not absorb the resin during the fabrication process.

A 0.25-inch balsa, with a density of 9.5 lbs./ft3, from Baltech Corporation, was used in fabricating the sides, bottom, and rear walls of the airbox section of the composite part. Properties of the end-grain balsa wood include a density of 9.5 lb/ft3, shear modulus of 23 ksi, and a compressive strength of 1,800 psi.

Table 5-5. Properties of Composite Fibers

Fiber Type	Density (lb/in3)	Tensile Strength (psi)	Tensile Modulus (E) (psi)	Elongation to Break (%)	Cost ($/lb)
E-Glass	.094	500,000	10.5×10^6	4.8	0.80 - 1.50
S-Glass	.090	665,000	12.6×10^6	5.4	3.50
Kevlar™	.053	430,000	19.0×10^6	2.3	22
High-Strength Carbon	.064	550,000	34.0×10^6	1.6	14-25
High Modulus Carbon	.065	400,000	52.0×10^6	0.7	30-50

Table 5-6. Properties of Core Materials

	Hexcel 2024 Aluminum Honeycomb	Hexcel HRH10 Nomex	Rohacell 71WF Foam	Baltek Balsa Core 9.5 lb/ft^3
Modulus (ksi)	200	60	15	23
Compressive Strength (psi)	810	1075	213	1800
Density (lbs/ft^3)	5.0	6.0	4.4	9.5
Cost	Very High	High	Mod	Low
Suitable to Wet Molding Process	No	No	Yes	Yes

5.3.4. Adhesive. The adhesive used on the composite airbox/plenum was chosen from a number of possibilities based upon its shear strength, service temperature, gap-filling ability, chemical resistance, working time and ease of use. While many adhesives could have been used, a high-temperature epoxy adhesive, EP33, from Masterbond, Inc., was chosen, mainly due to its high service temperature of 450°F. It is resistant to DS2 decontaminate (sec. 5.6.4) and compatible with the DOW TACTIX 123 epoxy resin and CARC epoxy paints. Properties of the MASTERBOND EP33 epoxy adhesive are shown in Table 5-7.

Table 5-7. Properties of MASTERBOND EP33 Adhesive

• Mixing ratio, parts A to B	100/70
• Viscosity of part A, 75°F, cps	80-120,000
• Working life after mixing, 75°F,	
200 gram mass, minutes	120-140
1 quart mass, minutes	45-60
• Cure schedule, room temperature:	
85% of maximum strength developed within	24-48 hours
• Bond strength, shear, aluminum/aluminum, room temperature cure, 75°F, psi (Kg/cm^2)	3100 (217)
After 30 days water immersion, 75°F, psi (Kg/cm^2)	2900 (203)
After 30 days at 400°F, 77°F, psi (Kg/cm^2)	1750 (122)
After 7 days at 400°F, 400°F, psi (Kg/cm^2)	850 (60)
• Service temperature range, °F	−60°F to +450°F
• Shelf life at 75°F	6 months
• Parts A and B available in pint, quart, 1 (one) gallon and 5 (five) gallon containers.	

5.4. Process Development

The process used in fabrication of the composite airbox/plenum was RTM. RTM was chosen because of its low processing difficulty, relatively inexpensive molds, and ability to produce high quality parts. It is a good process for fabricating a moderate volume of parts (500 - 1000 units/year). Since RTM is a closed-mold process, it is clean and efficient, resulting in minimum waste and cleanup.

A simple RTM process uses a multi part (usually two-part) mold system. The first step is to apply mold release as required. Dry fiber reinforcement is then laid into the mold and, the mold system is closed and sealed. Resin is then injected into the mold. Vents are located on the assembled mold to allow air, gases and excess resin to escape. When resin is flowing freely from the vents, the vents are blocked off, and resin injection is ceased. The part is then cured before being removed from the mold.

The fabricating process used in the composite airbox/plenum was more difficult, due to the complex shape of the part. A urethane foam core was used to obtain the inner dimensions of the airbox/plenum. The dry-fiber reinforcement and end-grain balsa wood were wrapped around the urethane foam core. The wrapped core was placed in a mold cavity along with core prints which helped to define the structural slope of the part. The top half of the mold was then lowered onto the bottom mold cavity. The two halves were clamped together using a number of bolts. A rubber gasket ran between the two mold halves effectively sealing them together. Resin was then injected into the mold. The resin flowed through the mold impregnating the dry reinforcement fiber inside. When all the air had been forced out of the mold and resin was flowing freely through a series of vents, the vents were blocked off, and the injection of resin stopped.

The part was then cured by heating the mold to at least 180°F for up to 8 hours. After the part was cured, it was removed from the mold. Because of the low-curing temperature, the part had to be post cured in an oven at slowly progressing temperatures up to 320°F. This insures that the part will withstand the service temperature requirement of 300°F.

After the part was fully cured, it was dimensionally inspected, and secondary processes were performed on the unit. These included bolting and bonding the mounting hardware to the composite part. Because current mounting hardware was used on the composite airbox/plenum, the part is interchangeable with the aluminum assembly. Other secondary processing procedures included performing an air-pressure leak test on the unit and applying an epoxy primary per MIL-P-53022 and a CARC paint topcoat per MIL-C-22750.

Three complete composite airbox/plenum units were fabricated by this process and delivered to TACOM.

5.5. Tooling

Tooling for the airbox/plenum consisted of a high-temperature filled epoxy mold reinforced by steel tubing. Because of the complex shape of the part and surfaces which required zero-degree draft, core prints were used in part fabrication. There were a total of seven core prints used in the molding process; each insert was constructed of the same high-temperature filled epoxy used in the mold. A photograph of the airbox/plenum mold appears in Figure 5-10.

Heating lines were fabricated into the walls of the mold allowing it to be heated to a maximum of 280°F. Heating the mold is required to properly cure the composite part. Without heat, the composite airbox/plenum would not be able to withstand the 300°F service temperature requirement.

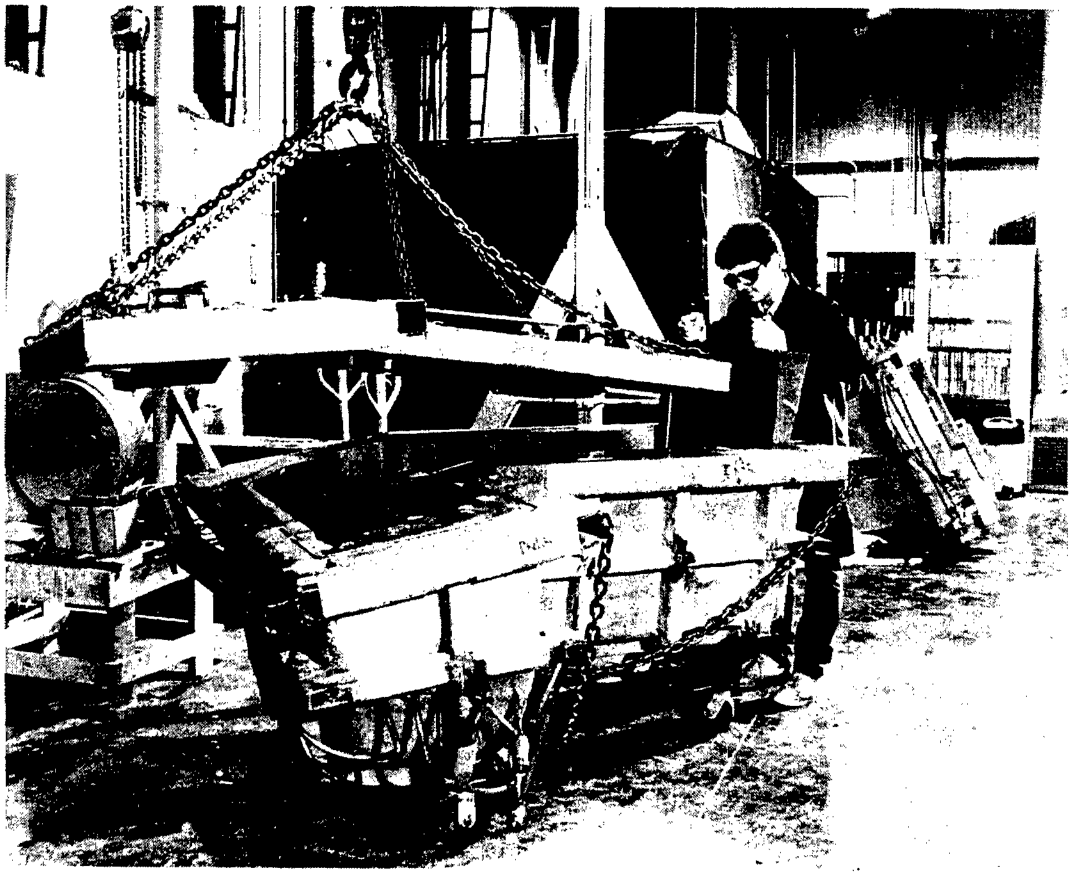


Figure 5-10. Airbox/Plenum RTM Mold

A plaster mold was also used in the fabrication process of the composite airbox/plenum. The plaster mold was used to make the urethane foam cores which were wrapped with dry fiber reinforcement and placed in the RTM mold. A plaster mold was used because it was less time consuming to fabricate, requiring inexpensive materials. For production, a steel-reinforced fiberglass mold would be recommended. The foam cores fabricated are illustrated in Figure 5-11.

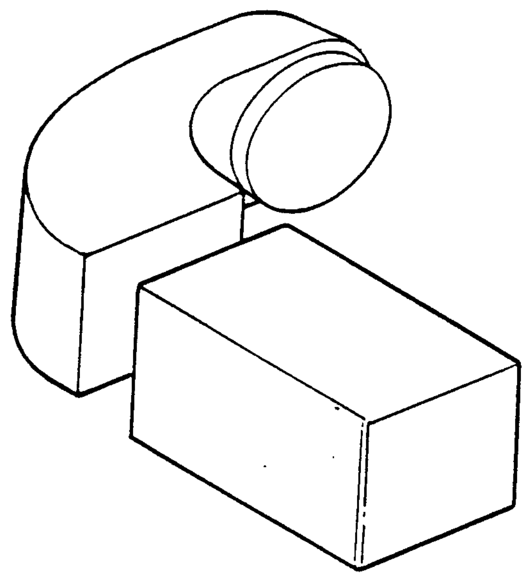


Figure 5-11. Foam Cores Used in RTM Process

5.6. Testing

Various tests were performed during the fabrication of the composite airbox/plenum. Some tests were performed on the individual materials used in the construction of the composite part. The remaining test requirement was an air-leak pressure test of the composite material plenum.

5.6.1. Pressure Test. An air-leak pressure test was performed on each of the three composite units delivered. A sketch of the test fixture is shown in Figure 5-12. The plenum section of the composite unit was the area being tested. A .50-inch thick aluminum plate and rubber gasket were used to block off the air outlet opening of the plenum and the openings for the Vee-Pac filters.

A vacuum was then pulled on the plenum through an air valve located in the aluminum plate covering the air outlet opening. After it had been pressurized to -1.0 psig, the vacuum was shut off and pressure readings were taken every ten seconds. The pressure gage was located in the air outlet cover plate. Pressure readings were taken for 1.5 minutes. The plenum was required to maintain a leakage rate of no more than 0.3 psig during a 1.5 minute period. Negative pressure was used during the test because it represents the operating environment of the airbox/plenum.

All three of the prototype airbox/plenums successfully passed the air-leak test. Each plenum proved to be virtually air tight, losing less than .05 psig in the 1.5 minute test period. Test data is shown in Appendix A. A minimum of three tests were performed on each airbox/plenum.

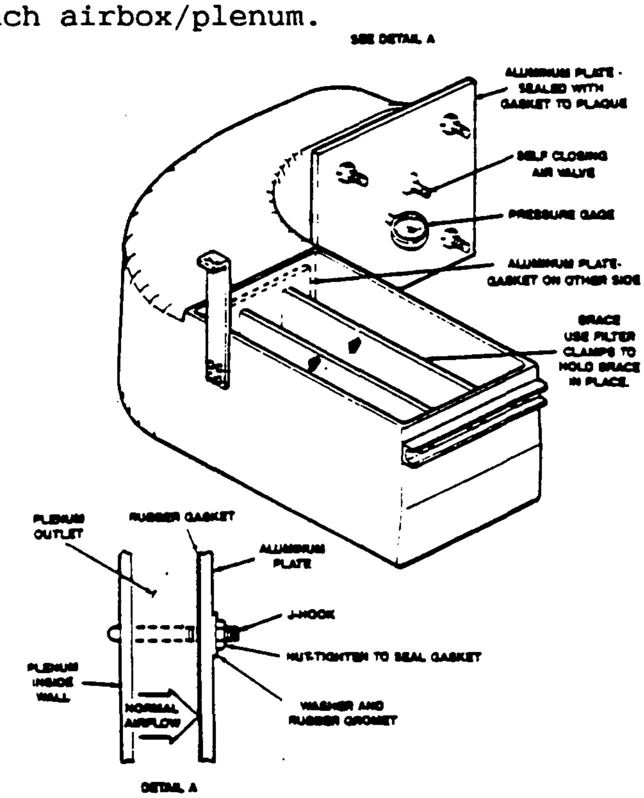


Figure 5-12. Plenum Pressure Test Fixture

5.6.2. Adhesive Shear & Bend Test. Shear and bending tests were performed on the MASTERBOND EP33 epoxy adhesive to determine its structural strength for use in the composite airbox/plenum. Specimens are described in Figures 5-13 to 5-15. Testing was performed at room temperature, although some specimens received prior conditioning at elevated temperatures. Details of testing are summarized in Table 5-8.

Results of the testing proved the adhesive to be acceptable for use on this program. It is recommended that the optimum cure schedule (room temperature for 12 hours followed by 2.3 hours at 250°F) be used when curing the adhesive to obtain the highest possible strength.

5.6.3. DS2 Test. A DS2 decontamination test was also performed on test specimens used for the adhesive shear test. Each specimen was placed in a container of DS2 for 16 hours and visually inspected for affected areas. No visible effects were observed on the MASTERBOND EP33 adhesive or a composite/balsa sandwich specimen which had not been heat degraded.

A specimen which had been heat degraded at 300°F showed some slight attack of the balsa wood and composite layer, but no attack on the adhesive. The balsa wood was observed to absorb some of the DS2 decontaminate, but it was only a surface absorption and did not penetrate into the cells of the wood. Also, there is no exposed balsa in the composite airbox/plenum, so it will not be subjected to direct contact with contaminants or decontaminates. Further testing is recommended to determine long-term and cyclical-exposure effects to the materials used in the composite airbox/plenum.

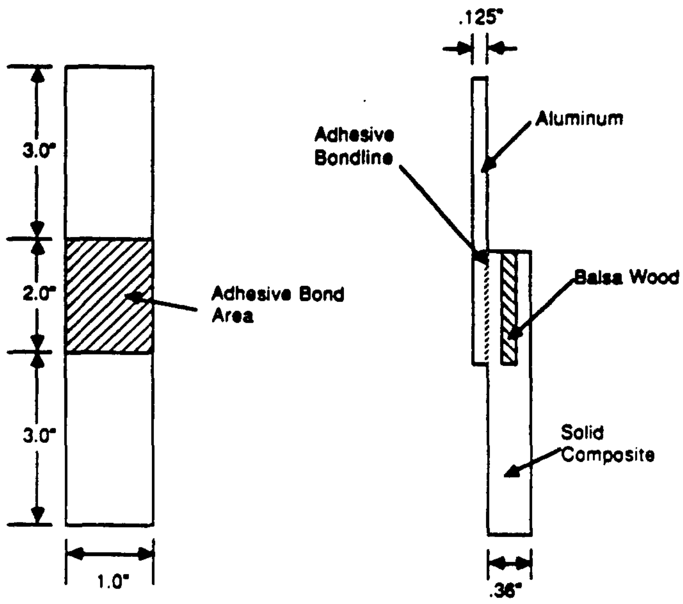


Figure 5-13. Unstabilized Shear Test Specimens

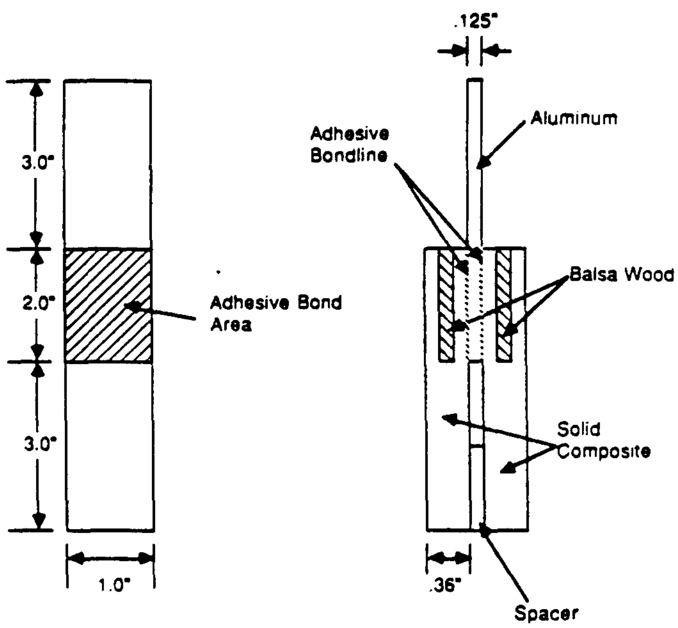


Figure 5-14. Stabilized Shear Test Specimens

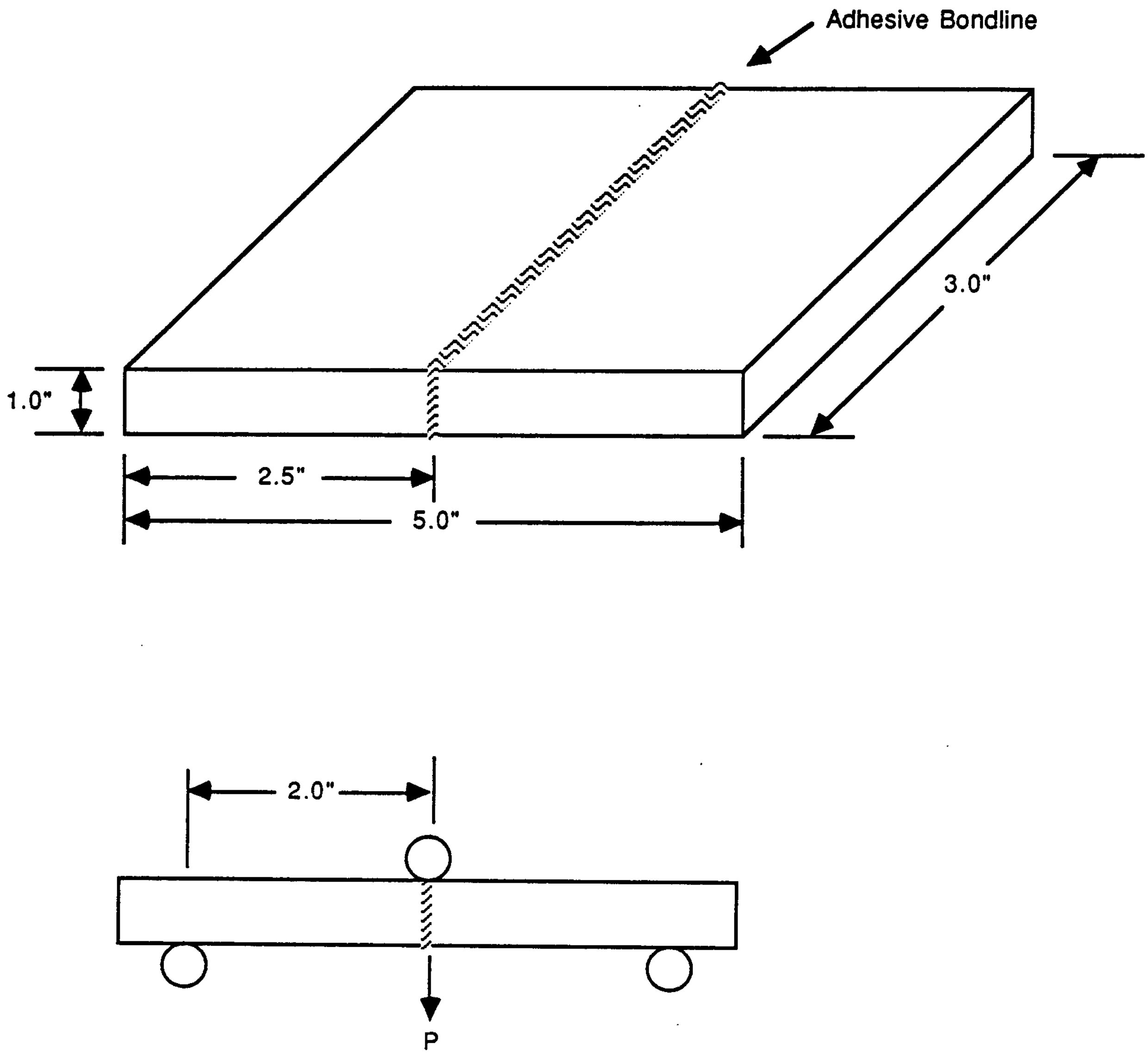


Figure 5-15. Bend Test Specimen and Fixture

Table 5-8. Adhesive Test Results

TEST TYPE	NO. OF SPECIMENS	CONDITIONING	AVERAGE FAILURE STRESS
Three Point Bend	4	72 Hours @ 300 F	± 5533 psi
"	4	Room Temp.	± 3701 psi
Unstabilized Shear	8	24 Hrs. @ 200 F	± 854 psi
"	4	24 Hrs. @ 200 F & 48 Hrs. @ 300 F	± 884 psi
"	3	24 Hrs. @ 200 F & 96 Hrs. @ 300 F	± 761 psi
"	6	Room Temp.	± 622 psi
Stabilized Shear	4	24 Hrs. @ 200 F &72 Hrs. @ 300 F	± 1010 psi
"	3	Room Temp.	± 638 psi

5.7. Economic Analysis

An economic analysis has been performed to compare the potential production costs of the composite airbox/plenum and low-profile precleaner assemblies with the aluminum components. The average unit cost (AUC) for the current production aluminum air plenum and precleaner were obtained from the GDLS Material Resource Planning (MRP) system. The AUC for the precleaner was obtained from the Donaldson Company and compared with the current production precleaners. The MRP cost does not include GDLS profit, G&A, or overhead.

The composite airbox/plenum design cost analysis was based on a production rate of 700 units annually on a one-shift, 8-hour, 5-day work week (1-8-5). All costs are expressed in constant FY89 dollars using January 1989 as the production start-up date and 31 December 1994 as the production end date. All research and development costs were considered "sunk" and not included in the analysis. All other assumptions made in the economic analysis for each cost element are stated in the calculations.

The bottom-up cost estimating model was used in the economic analysis for the composite airbox/plenum. This approach is derived from standard pricing methodology where each cost element is identified and defined. The unit cost and labor associated with each element were then estimated, and an average unit cost derived.

The cost estimates for the composite airbox/plenum were derived by GDLS engineering and subcontractor, Nero Plastics. Material costs were calculated from current vendor prices and actual material used in developmental part fabrication. Labor and tooling were determined from the knowledge and experience gained in the research and development of the composite airbox plenum.

The nonrecurring cost elements consisted of initial hand tooling and production line setup to support full-scale production. Included in these costs were all necessary tooling core prints, inspection jigs, and test fixtures. All material and labor costs related to tooling fabrication are included in the overall cost.

The following assumptions were used in development of the tooling costs:

- The models used in fabricating the prototype tools will be available for production tooling fabrication.
- Production tools will last for the complete production run.
- Tooling costs will be amortized over the complete production run per unit basis (4,200 units.)

The production cost elements consisted of the costs directly associated with manufacturing the composite airbox/plenum. Included were all material, labor, and other expenses related to fabricating the parts and integrating all mounting hardware to produce a working component. Any maintenance or repair costs on tooling were considered and included in the set-up costs and tool preparation labor. A 95 percent learning curve for labor was used.

The labor hours required to fabricate the airbox/plenum are summarized below. Using a 95 percent learning curve over a 6-year period, the average time is calculated to be 58.26 percent of the original manhour requirement. This results in the 23.9 labor-hour estimate used in the economic analysis.

Urethane Foam Core Fabrication	4
RTM Molding	17
Hardware Attachment	10
Front Wall Fabrication	6
Inspection	1
Paint	3
	--
Total Labor Hours	41

The cost of production tooling is summarized below. Based on a production of 4,200 units over 6 years, the average cost of tooling per unit is approximately $22.

Foam Core Mold	$ 8,000
Three RTM Airbox/Plenum Molds	75,000
Jig Set-up to Fabricate Foam Core Reinforcements	1,000
Inspection Jig and Tools	5,000
Pressure Test Fixture	2,000

Total Tooling	$91,000

The economic analysis for the airbox/plenum is summarized in Figure 5-9. The estimated AUC for the composite airbox/plenum and low-profile precleaner are compared below:

Composite Airbox/Plenum	$1,354
Current Aluminum Airbox/Plenum	$1,732
Low-profile Precleaner	$1,250
Current Production Precleaner	$1,007

Results of the economic analysis show the composite airbox/plenum having a unit-cost reduction of approximately $378 per unit. The low-profile precleaner from Donaldson Company increases the production costs by $243. The initial target cost for both the composite airbox/plenum and precleaner was set at $2150.

Table 5-9. Airbox/Plenum Economic Analysis Summary

COST ITEM	AMOUNT	UNIT COST	COST,$
Resin	57.7 lb.	2.79	161
Hardener	8.8 lb.	3.00	26
18 oz. Fabric	97.7 lb.	1.67	163
10 oz. Fabric	15.0 lb.	3.75	56
10 oz. Uni. Glass	2.1 lb.	1.95	4
8 oz. Uni. Carbon	0.5 lb.	34.00	17
Balsa Wood	40 sq. ft.	0.86	34
Foam Core Material	55 lb.	1.19	65
Foam Core Skins	1 set	20	20
Mounting Hardware	1 set	100	100
Adhesive	.05 gal.	300/gal.	15
Miscellaneous	1 set	30	30
Mold Sealer and Release	.5 gal.	46/gal.	23
Primer and Topcoat	.5 gal.	42/gal.	21
Manhours	23.9	25	597
Tooling	n/a	22	22
Total			1354

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APPENDIX A

AIR LEAK TEST DATA

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GENERAL DYNAMICS
Land Systems Division

AIR LEAK TEST DATA

10-4-89

COMPOSITE PLENUM # 1

Pass Fail

Elapsed Time (seconds)	Air Pressure (psig)				
	Test # 1	Test # 2	Test # 3	Test # 4	Test # 5
0	-1.00	-1.00	-1.00		
10	-1.00	-.99	-.99		
20	-.99	-.99	-.99		
30	-.99	-.99	-.99		
40	-.99	-.99	-.99		
50	-.99	-.99	-.99		
60	-.99	-.98	-.99		
70	-.99	-.98	-.98		
80	-.99	-.97	-.98		
90	-.98	-.97	-.97		
Air Leakage Rate (psi/min) *	.013	.020	.020		

$$* \text{ Air Leakage Rate} = \frac{\text{Pressure}_0 - \text{Pressure}_{90}}{1.5 \text{ minutes}}$$

AVERAGE AIR LEAKAGE RATE = .018 psi/min

REMARKS/COMMENTS:

SEALING GREASE, TEFLON, & TACKY TAPE USED TO SEAL ALUMINUM PLATES TO PLENUM.

RTV USED IN SEAL GROOVES.

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GENERAL DYNAMICS
Land Systems Division

AIR LEAK TEST DATA 10-3-89

COMPOSITE PLENUM # 2 | (Pass) Fail

Elapsed Time (seconds)	Air Pressure (psig)				
	Test # 1	Test # 2	Test # 3	Test # 4	Test # 5
0	-1.00	-1.00	-1.00	-1.00	
10	-.96	-.96	-.96	-1.00	
20	-.92	-.92	-.92	-1.00	
30	-.89	-.90	-.89	-1.00	
40	-.86	-.87	-.86	-1.00	
50	-.83	-.83	-.83	-.99	
60	-.81	-.81	-.81	-.99	
70	-.78	-.78	-.78	-.99	
80	-.76	-.76	-.76	-.99	
90	-.74	-.74	-.74	-.99	
Air Leakage Rate (psi/min) *	.173	.173	.173	.007	

$$* \text{ Air Leakage Rate} = \frac{\text{Pressure}_0 - \text{Pressure}_{90}}{1.5 \text{ minutes}}$$

AVERAGE AIR LEAKAGE RATE = .1315 psi/min

REMARKS/COMMENTS:

TEST #1, #2, & #3 WERE OBSERVED TO HAVE LEAKS IN THE TEST FIXTURE ITSELF.

TEST #4 WAS PERFORMED AFTER CORRECTING THE LEAKY FIXTURE.

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AIR LEAK TEST DATA 10-4-89

COMPOSITE PLENUM # 3

Pass Fail

Elapsed Time (seconds)	Air Pressure (psig)				
	Test # 1	Test # 2	Test # 3	Test # 4	Test # 5
0	-1.00	-1.00	-1.00		
10	-.99	-1.00	-1.00		
20	-.99	-.99	-.99		
30	-.98	-.99	-.99		
40	-.98	-.99	-.99		
50	-.97	-.98	-.98		
60	-.97	-.98	-.98		
70	-.96	-.98	-.98		
80	-.96	-.98	-.98		
90	-.96	-.97	-.97		
Air Leakage Rate (psi/min) *	.03	.02	.02		

$$\text{* Air Leakage Rate} = \frac{\text{Pressure}_0 - \text{Pressure}_{90}}{1.5 \text{ minutes}}$$

AVERAGE AIR LEAKAGE RATE = .023 psi/min

REMARKS/COMMENTS:

SEALING GREASE, TEFLON, TACKY TAPE, & RTV USED TO SEAL TEST FIXTURE.

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