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AV-8B Composite Fuselage Design

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The AV-8B composite forward fuselage development structure was designed as a flight vehicle. Thus the design incorporates provisions for all functional systems as they relate to the structure. The final design required efforts in structure layout, functional systems integration, trade studies, materials characterization, process development, and configuration iteration. Primary considerations were low cost and light weight. The approach was to design with as few parts and fasteners as possible. This was accomplished by cocuring large graphite/epoxy structural components which required no secondary bonding operations. Component sizes were based on practical geometric shapes, complex tooling limitations, inspection accessibility, and manufacturing assembly sequences.

Nomenclature

ARBS	= angle rate bombing system
AWLS	= all weather landing system
C_L	= centerline
EMI	= electromagnetic interference
FSD	= full-scale development
HUD	= head-up display
IFF	= identification, friend or foe
IVD	= ion vapor deposition
OWE	= operating weight empty
RCS	= reaction control system
V/STOL	= vertical/short takeoff and landing
X	= buttock line
Y	= fuselage station
Z	= water line

Background

THE AV-8B forward fuselage development program was an outgrowth of a very timely Navy funded study which investigated the potential for composite materials in an advanced AV-8 system. Following that 1974 study several structural areas were designated for composite materials. This included the forward fuselage (see Fig. 1).

The work described here was the recently completed second phase of a two-part contract. As indicated in Fig. 2, the program was perfectly timed for the AV-8B full-scale development aircraft.

Aircraft Description

The AV-8B (Fig. 3) is a second generation V/STOL aircraft which derives its superior performance from selective improvements to the AV-8A. It has twice the payload-radius capability of the AV-8A, better weapon delivery accuracy, and increased operational readiness. These improvements have been validated by YAV-8B prototype flight testing.

The AV-8B combines U.S. V/STOL technology with the proven vectored thrust concept. A new, larger wing has a higher aspect ratio and a supercritical airfoil. It applies positive circulation to increase lift in the vertical and short takeoff modes. A raised and larger cockpit is incorporated into a larger forward fuselage (Fig. 4). Pilot vision is improved and additional usable space is provided for advanced avionics which improve weapon delivery accuracy, enhance survivability, and reduce pilot workload. The major structural elements of the wing, forward fuselage, and horizontal tail are of composite materials.

Forward Fuselage Design

The forward fuselage (Fig. 5) is a conventional single-seat structure with multiframe and stringer construction. It has the added advantages of small size and light weight and contains no fuel. The nose landing gear is mounted in the center fuselage but retracts into the forward fuselage. Equipment access doors are in the fuselage side walls and bottom. Avionics and other aircraft equipment are located below the cockpit floor and forward of the Y 152.60 bulkhead. Access to cockpit controls is through the doors on each side of the fuselage above the cockpit floor. The cockpit pressure boundaries are the Y 152.60 bulkhead, the seat bulkhead, and the cockpit floor.

The forward fuselage is spliced to the center fuselage at the Y 225.93 frame behind the seat bulkhead. There are four primary longerons, with the two lower ones providing lateral boundaries for the under floor equipment bay and the nose wheel bay. The upper longerons are the cockpit sill members. They also provide support for the top of the frames, the windshield, and the canopy. A tie rod at Y 174.87 joins the two upper longerons to react to the cockpit pressure loads.

The nose cone is attached to the fuselage circumferentially at Y 133.70. It is hinged to one side for equipment access. A cutout in the underside of the nose cone accommodates the exhaust port for the reaction control system (RCS) pitch valve. The valve is attached to frames which carry the thrust reaction load to the side-wall skins. The nose tip is cut out to accommodate a sensor for the angle rate bombing system (ARBS).

Composite Aspects of the Design

The composite structure was designed to the requirements of the AV-8B rather than a hypothetical or generic nondimensional structure. This approach facilitates an immediate payoff.

The design incorporates provisions for flight controls, hydraulic systems, nose landing gear, avionics, etc., as these relate to the structure (Fig. 6). Accomplishment of the final design required efforts in structural layout, functional systems integration, trade studies, materials characterization, process development, and configuration iteration.

The materials selected for the fuselage structure were available off the shelf: AS/3501-6 graphite/epoxy unidirectional tape or broadgoods, and T300/3501-6 eight harness satin weave cloth. The unidirectional tape was included in stiffener and longeron caps. All other structure was cloth.

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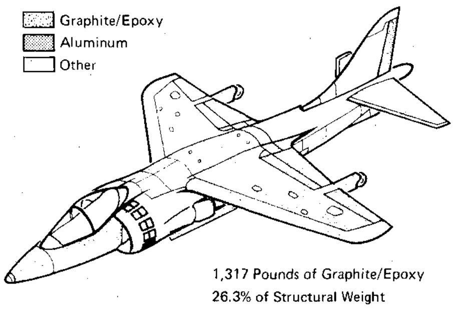

Fig. 1 AV-8B material distribution.

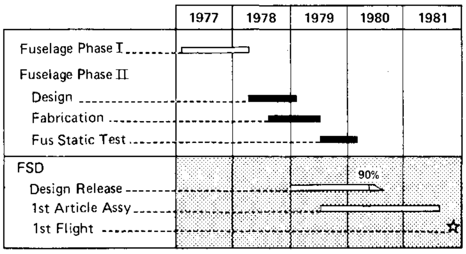

Fig. 2 Overall program AV-8B forward fuselage development.

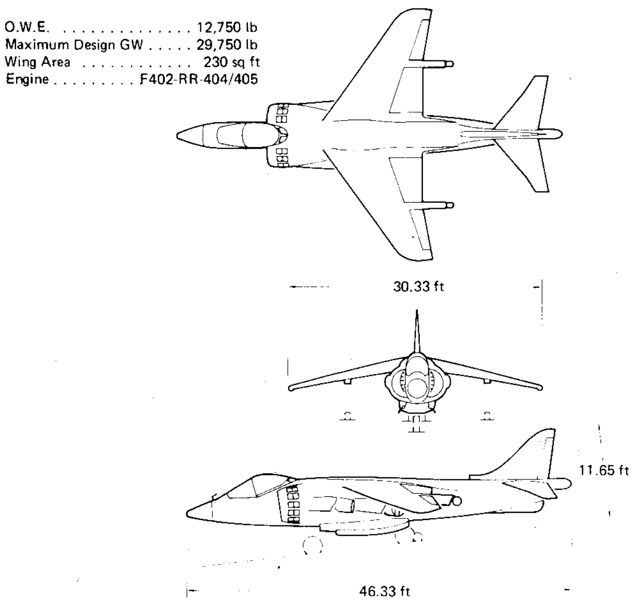

Fig. 3 AV-8B aircraft.

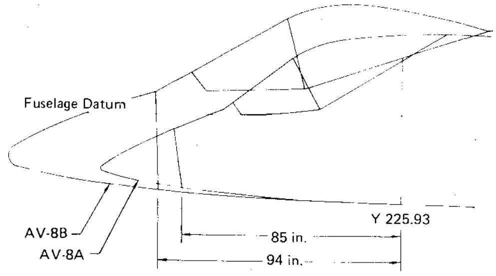

Fig. 4 Forward fuselage shape comparison.

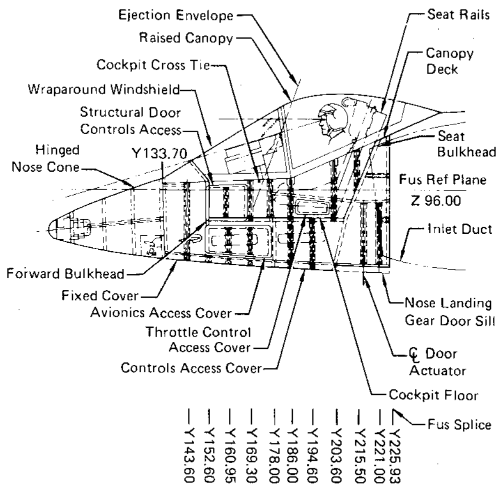

Fig. 5 Forward fuselage structural arrangement.

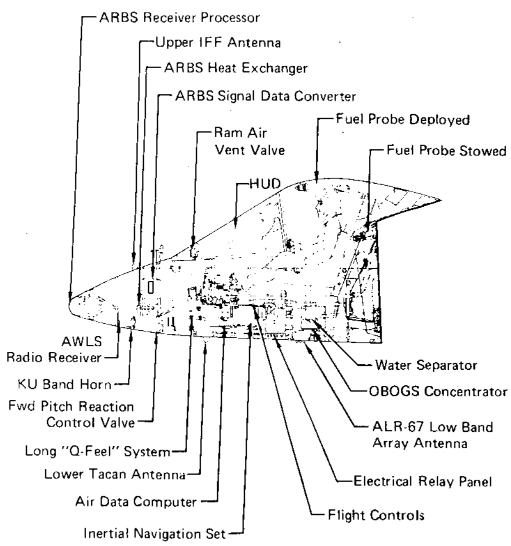

Fig. 6 AV-8B forward fuselage equipment installation.

The structure is moderately loaded from both air and inertia loads, and it must withstand cockpit pressurization.

As with any well-designed aircraft structure, many design considerations were brought to bear which would result in a well-balanced practical structure (see Fig. 7). However, in this case, primary considerations were low cost and light weight through composite material utilization. Our approach was to design the structure to contain as few parts and fasteners as possible. This was accomplished by cocuring large graphite/epoxy structural components which required no secondary bonding operations. Neither honeycomb nor sandwich construction was used. No metal plates were incorporated in the laminates. Component sizes were based on tooling limitations, inspection accessibility, and manufacturing assembly sequences, as well as geometric practicality. (see Fig. 8). These components were bolted together to create the final fuselage structure. Figure 9 shows several structural details.

Additionally, since equipment changes are common, the structure was designed to be readily modified. The structure also offers protection for electromagnetic interference (EMI) and lightning.

On the older AV-8A metal airplane, the skins are made of chem milled aluminum sheets. To resist the pressure loading, many small stiffeners are used, being attached with rivets through the skin. The AV-8B graphite/epoxy skins provide the necessary stiffness via integrally molded stiffeners configured to resist the cockpit pressure loading. This concept greatly reduces the parts required in the assembly and saves appreciable weight. Similarly, the floor and bulkheads are integrally molded stiffener/panel combinations. Table 1

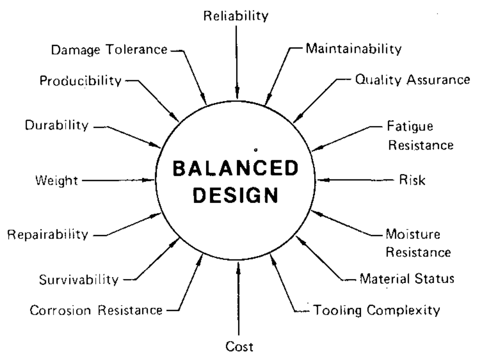

Fig. 7 Design considerations.

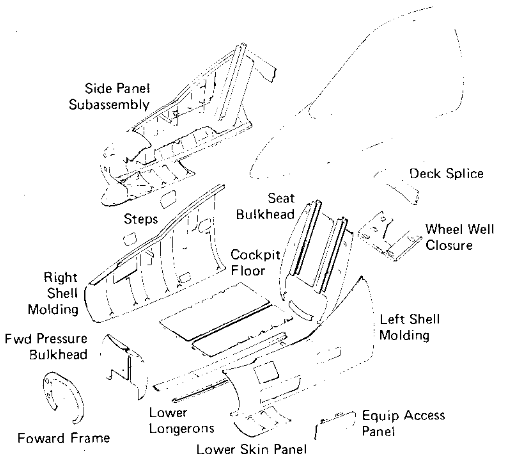

Fig. 8 AV-8B forward fuselage structural components.

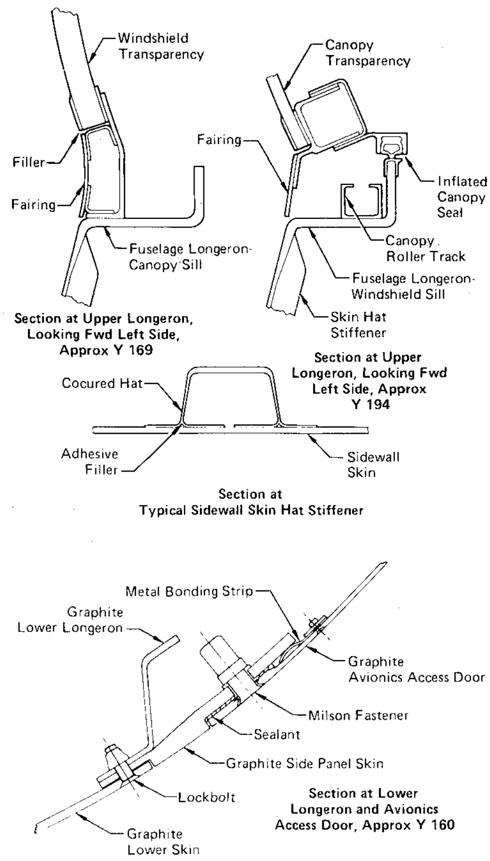

Fig. 9 Forward fuselage structural details.

compares the parts required for metal and composite structures.

Some of the engineering criteria used in the design are as follows: 1) Floor deflections had to be minimized owing to stiffness requirements of floor mounted controls. 2) Metal fittings in the cockpit were designed for 28,000 pressure cycles between 0 and 5.5 psig. 3) Side-wall panels forward of engine inlets were not permitted to flutter or buckle below limit load. 4) Attachments were made to the sidewebs of hat-section stiffeners and not to the caps. 5) Peel prevention fasteners were installed in the flanges at all hat stiffener terminations. 6) Knife edged fastener countersinks in sidewalls are permitted. 7) All rivets were made of a titanium-columbium alloy and installed by squeezing only. 8) All basic webs had at least four plies of cloth, considered a minimum for both damage tolerance and pressure integrity. 9) Castings which support critical controls were designed using a 1.5 design factor. All other castings used a 1.33 factor. Table 2 is a summary of the graphite/epoxy design strain allowables used.

Weights Compared

The composite forward fuselage is calculated to weigh 171 lb. This compares to the 229 lb calculated for a comparable metal forward fuselage adjusted to the design criteria for the AV-8B (see Table 3). These weights are for structural components between Y 133.7 and Y 225.9. The canopy and windshield weights are common to both designs.

Material distribution of each component group in the composite fuselage is presented in Table 4. In essence, 114.8 lb of composite material are utilized to yield a 58-lb savings in the calculated design weight. The design weight savings for the composite forward fuselage represents a 25.3% weight savings over a metal design weight.

Table 1 Comparison of parts required

Composite (monolithic cocured molded structures)	Metal (conventional riveted aluminum structure)
88 parts 5450 fasteners	237 parts 6440 fasteners

Table 2 Strain allowables, graphite/epoxy

Tension	4000 μin./in. (Reduced linearly to 2500 μin./in. as bolt bearing stress increased from 0 to 70,000 psi)
Compression	-5000 μin./in. (limited to 70 ksi bearing)
Bending	± 5000 μin./in.
Hat stiffener caps without holes	
Tension	7500 μin./in.
Compression	-5500 μin./in.

Table 3 Forward fuselage structural weight

	Metal, lb	Composite, lb	Savings, lb	Savings, %
Skin and doors	88	65	23	26.1
Frames	75	54	21	28.0
Longerons	28	19	9	32.1
Flooring	24	24	0	0
Miscellaneous	14	9	5	35.7
Total	229	171	58	25.3

Table 4 Forward fuselage material distribution

Component	Component weight, lb	Material weight, lb				
		Composite	Al	Ti	Fasteners	Other
Skin and doors	65.4	48.1	2.9	4.3	9.9	0.2
Frames	54.3	32.7	14.9	2.1	4.5	0.1
Longerons	18.6	15.0	0.0	3.1	0.5	0.0
Flooring	23.8	19.0	2.0	0.2	2.6	0.0
Miscellaneous	8.9	0.0	6.0	0.0	0.1	2.8
Total	171.0	114.8	25.8	9.7	17.6	3.1
Distribution, %	100.0	67.1	15.1	5.7	10.3	1.8

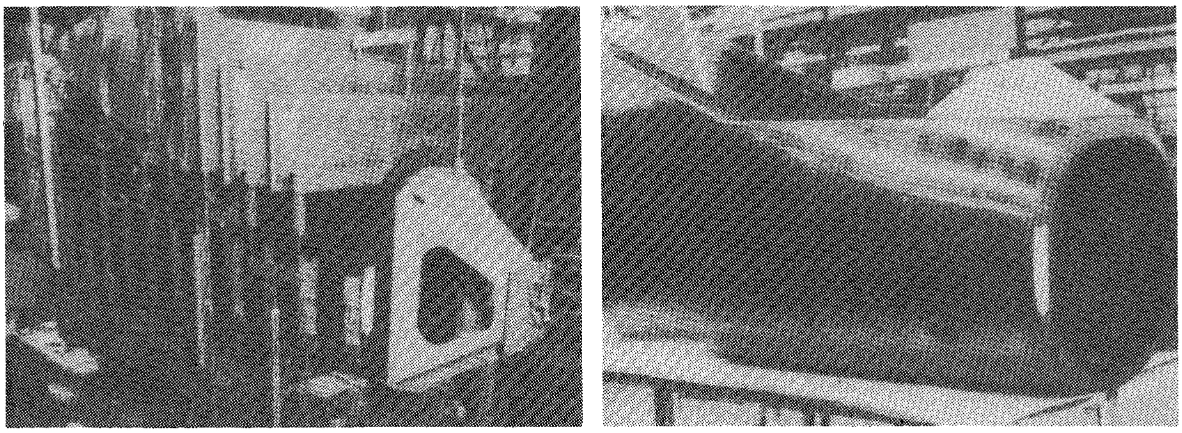

Fig. 10 Fuselage structure during and after test.

More About the Materials

Materials were selected on the basis of structural efficiency. Other factors which counted heavily in the selection were environmental resistance, durability, and cost.

Composite material selections focused on graphite/epoxy because it incorporates low-density, high-strength filaments into a durable matrix. Strength and stiffness can be oriented to meet specific loading conditions. Many graphite/epoxy components already had been developed in the YAV-8B and the F-18 programs and were available for AV-8B production. Other nonmetallic materials, such as sealants and adhesives, were selected on the basis of functional performance and resistance to environmental and service exposure.

Since many of the substructure components are aluminum, extensive corrosion protection has been provided. Either anodizing or ion vapor deposition (IVD) aluminum plus paint is used on parts, and in addition, a single ply of fiberglass/epoxy (0.0035 in. thick) is cocured onto the interfaces. This barrier extends 0.25 in. beyond the edge of the aluminum part whenever practicable. Also, the metal parts receive an additional fay surface seal with a polysulfide compound.

Repairability of the Composite Design

The side panels require few fasteners and permit relatively simple repair techniques. Where the surface has been penetrated, the structure can be repaired by patches that are either bolted in or bonded, whichever is more practical. A prime advantage of the eight harness weave cloth is its resistance to splintering. Damage remains very confined and, therefore, easy to repair.

Repair strength is less critical because most of the fuselage structure is designed to requirements for stiffness, dynamic response, or handling, not for strength. Minor damage could result in problems of surface roughness, or possible engine contamination or loss of cockpit pressure. In such cases, cosmetic repairs may be adequate. Patches are installed easily, especially in areas where access is available from both sides.

Since the bulkhead and floor elements of the half-shells are bolted in place, it is feasible to remove them for major repair and replace them without on-site bonding. Of course, equipment, wiring, etc., must be removed; but this also would be required for metal structure.

Payoff

This structural development program was completed after successful laboratory testing (see Fig. 10). Both subcomponent and full-scale article static and fatigue tests were conducted. Thus this program established a basic design concept for a V/STOL fuselage structure which has been incorporated in the AV-8B full-scale development aircraft.

Fifty-eight pounds of weight have been saved in this weight sensitive aircraft. Since part and fastener counts are greatly reduced, assembly costs will be reduced. The structure is almost impervious to fatigue or corrosion, a major maintenance improvement. Also, the materials are relatively simple to repair by either bonded or bolted methods, so the cost of ownership promises to be minimal.

This structural technology is readily applicable to other high performance aircraft structures as well as to other areas of the AV-8B V/STOL aircraft.