# DEVELOPMENT OF COMPOSITE CARRYTHROUGH BULKHEAD*

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## SUMMARY

A structural development program was recently completed in which the weight and fatigue advantages of an all composite major load carrying bulkhead was successfully demonstrated. Fabrication of a full scale article, including static and fatigue testing of the carry-through beam portion verified the producibility, strength and durability of this design, thereby presenting the opportunity for use on aircraft upgrades and new aircraft. A 15% weight saving is achievable and, more importantly, the fatigue problems that normally plague metal bulkheads are virtually eliminated.

## INTRODUCTION

Current use of composite materials for primary structure in Navy production aircraft has been limited mainly to wing structure, tail structure, and fuselage panels. The weight and cost savings which were achieved through the use of carbon/epoxy were largely the basis for which these structures were selected for production application. The use of advanced composite materials in other applications which are subjected to high concentrated loads have been investigated to a limited extent, but full scale development work leading to concept verification has not as yet been performed.

An application which shows considerable promise in eliminating recurrent structural problems is the use of composites in highly loaded fuselage bulkheads. Advantages such as corrosion resistance and fatigue insensitivity of composite materials could be exploited to reduce high life cycle costs associated with structures in these limited access areas.

This program addressed the development and test of a highly loaded bulkhead for use on an emerging Navy tactical aircraft. The F-18 F.S. 453, Figure 1, is the baseline bulkhead for this program. It was selected because it is highly loaded and can provide direct comparisons between aluminum and composite bulkheads to determine the benefits and risks of composite application.

This was a six phase program. Phase one was an industry-wide review to identify design approaches used in recent composite bulkhead development programs. Phase two consisted of identifying design requirements and preliminary designs, and conducting structural trade studies. In phase three coupon and element tests were conducted and design refinement took place. Phase four

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consisted of the fabrication of the first full size composite bulkhead. Phase five involved a payoff evaluation and risk assessment comparing the baseline and composite designs. Phase six included the fabrication of a quarter bulkhead subcomponent as a further manufacturing risk reduction and then the fabrication and testing of a second full-scale bulkhead.

Goals for the composite bulkhead relative to the aluminum bulkhead were: a 20% weight reduction, a 10% cost reduction, and improved durability relative to fatigue and corrosion. The cost reduction goal included acquisition costs as well as operations and support costs.

The end-product of this program was the demonstrated availability of composite carrythrough bulkhead technology for use on emerging Navy aircraft.

## BULKHEAD DESIGN AND FABRICATION

### TECHNOLOGY REVIEW

A comprehensive literature review of recent and ongoing composite bulkhead development work was conducted to assess the design approaches used and problems encountered. Composite fuselage subcomponents of several existing and future aircraft have been fabricated and tested and composite bulkheads of varying degrees of complexibility were addressed. The results of this review are documented in Reference 1 and 2.

It was evident from this literature survey that the fabrication of a composite bulkhead with the complexity of the F-18 F.S. 453 had not yet been attempted.

### A. BASELINE DESIGN

The baseline for this program was an aluminum bulkhead from the F-18. It was selected because it will permit a direct comparison of the benefits and risks for the same bulkhead made from composites. A large amount of manufacturing, service, and test data is available for the metal bulkhead.

The selected baseline, Figure 1, is the F-18 F.S. 453 bulkhead to which the wing is attached and from which the main landing gear forward trunnion is supported. The baseline is machined from 6 in. 7050-T73651 aluminum plate and weighs 264 lbs. Stiffeners, flanges, and wing attachment lugs are integral with the bulkhead. The upper dorsal section is made separately and is mechanically fastened to the bulkhead lower section. Cutouts in the center web area permit fuel system plumbing to pass through. The plumbing is joined at the web by fittings.

The maximum fuel pressures on the bulkhead are 13.2 psi ultimate forward-acting uniform pressure, occurring during arrested landing, and 8.2 psi aft-acting uniform pressure, occurring during a maximum acceleration catapult. Fuel constraints limit the temperature to 200°F; therefore, the bulkhead temperature does not exceed 200°F.

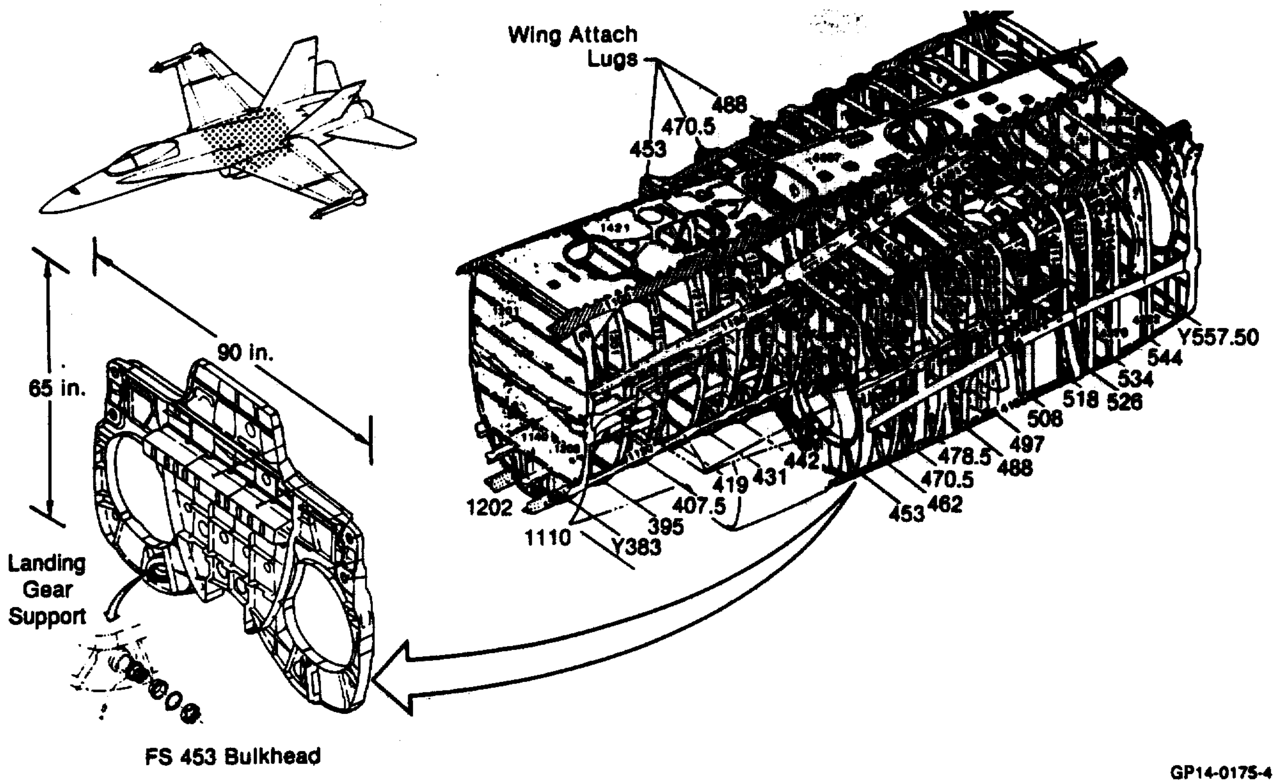



**Figure 1. F-18 Aluminum Production Bulkhead**

The wing support lugs are integral parts of the bulkhead. Lug thicknesses and pin diameters are different for the upper and lower lugs, reflecting the magnitude and direction of the primary loads carried by each lug. The upper lug load acts primarily inboard; therefore the lug is sized for compression bearing stress. The lug is 1.56 in. thick and the pin diameter is 2.42 in. The lower lug load acts primarily outboard and is sized to prevent failure due to cleavage and tearout. This lug is 3.20 in. thick and pin diameter is 2.67 in.

Load paths in bulkhead structures are not nearly as direct as sometimes presumed in the generic bulkheads studied during aircraft design development. Bulkheads include structural details like abrupt thickness changes, intersecting stiffener radii, cutouts for fuel and control systems, flange joggles, secondary bending caused by shifts in load paths, and infringement of inlet ducts on the ideal load path. Such situations are addressed on the F-18 F.S. 453 baseline.

## B. DESIGN REQUIREMENTS

The primary design requirement for the composite bulkhead was that it would have the form and function of this baseline bulkhead and would be capable of carrying all loads currently applied to the metal baseline. Specific requirements were that it must be able to withstand static ultimate loads (1.5 times limit load) without failure for critical design conditions, and that it must be capable of withstanding two lifetimes (12000 spectrum flight hours) of enhanced (to account for composite scatter) fatigue loading. Low energy damage tolerance requirements were also imposed on the structure. In addition, the bulkhead was designed for -65°F to +200°F service temperature with moisture equivalent to 10 years on Guam.

## C. TRADE STUDIES

Ten preliminary design concepts were defined and evaluated with respect to weight, cost, supportability, and fabricability. Selection of the best overall concept was made based on the results of this evaluation. Weight was the most important consideration in the selection of the preferred concept followed by cost, producibility, and supportability, in that order. The design concept selected is shown in Figure 2.

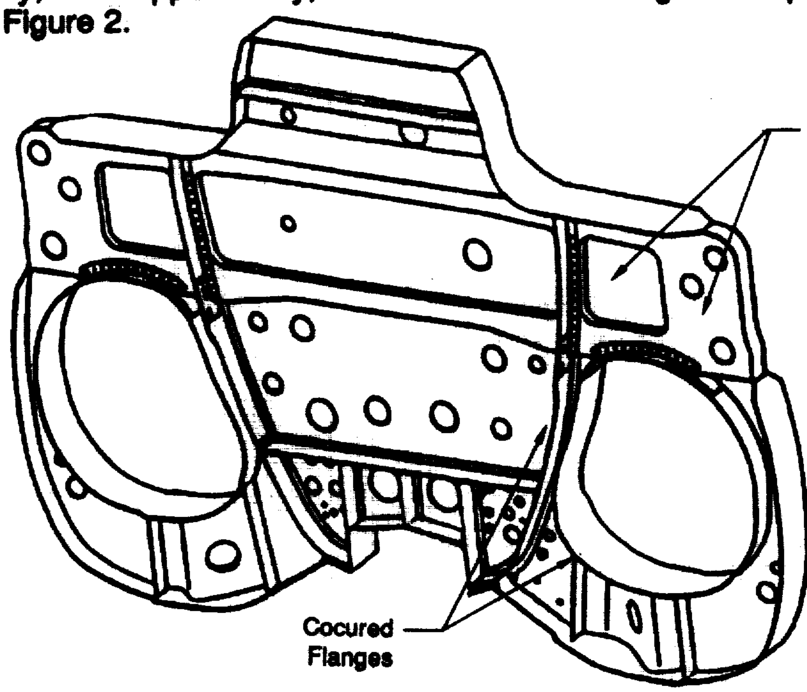



**Figure 2. Selected Composite Bulkhead Concept**

A number of thermoset, both epoxy and bismaleimide, and thermoplastic matrices was considered. Critical properties for the selection of a matrix were the elevated temperature wet compressive strength, the residual strength after low velocity impact, and its resistance to microcracking. Based on these parameters, 8551-7 toughened epoxy, produced by Hercules Aerospace Co., was selected as the most appropriate matrix. AS4 and IM7 carbon fibers, also produced by Hercules Aerospace Co., were selected to reinforce this matrix. The high modulus IM7 fibers were used in unidirectional tape, wherever practical, to satisfy stiffness requirements with minimum weight, and AS4 cloth was used for web plies that wrapped around corners to form flanges. (AS4/8551-7 cloth was not available at this time.) Subsequent to this survey, Hercules modified the 8551-7 resin to improve tack and increase use temperature. The modified resin was labeled 8551-7E. This resin was further modified to improve out time and was designated as 8551-7A.

## PRELIMINARY DESIGN AND TESTING

Coupons and critical structural elements were fabricated and tested to demonstrate fabrication methods, determine static strength and fatigue life and to validate critical design details. The structural elements represented specific areas of the bulkhead, as shown in Figure 3. Various elements were static and fatigue tested in room temperature dry and elevated temperature wet environments. In addition, some specimens were tested after low velocity impact damage had been introduced. Test conditions and results are summarized in Figure 4.

## FIRST BULKHEAD FABRICATION

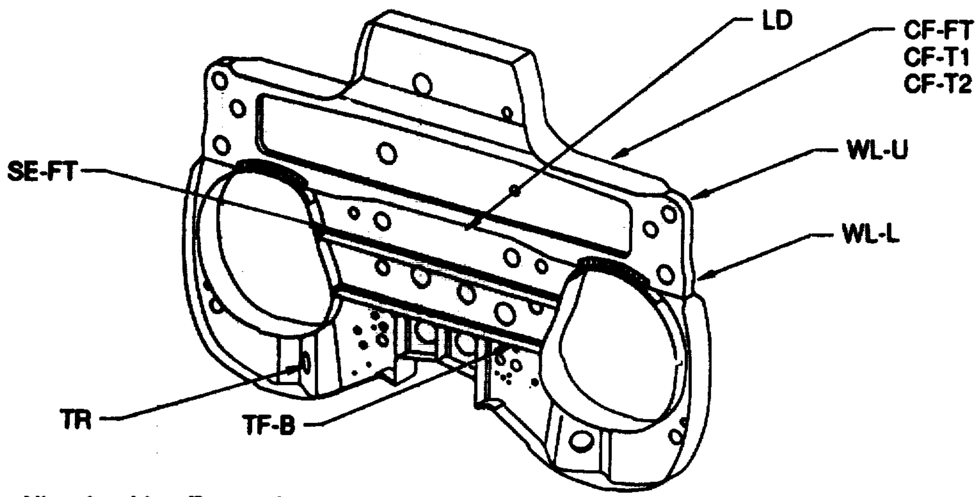
Tooling used to fabricate the bulkhead consisted of aluminum, graphite, steel, carbon/epoxy and conformal pieces. The most important feature of the tooling is the conformal tool. The conformal tool is flexible and is pressurized during the autoclave cycle. This tool is capable of providing uniform pressure, simultaneously, against the web and adjacent flanges of the bulkhead. This tooling concept produces excellent corner details on the bulkhead and leaves no tool mark off. Figure 5 shows two conformal tools being used against the two sides of a bulkhead.

The design of the bulkhead was such that it could be fabricated as an assembly of subcomponents. These subcomponents consisted of 1) the carrythrough beam, 2) trunnion webs, 3) stiffeners, 4) the forward web plies, and 5) the aft web plies. The carrythrough beam, trunnion webs, and stiffeners were all made up of unidirectional tape plies. The carrythrough beam and trunnion webs were similar, in that each consisted of two complementary ply packs that sandwiched the main web of the bulkhead. The plies for each pack were cut, collated, room temperature debulked, and held under vacuum until ready for final assembly.

The fore and aft web subcomponents were made of cloth plies that formed the main web of the bulkhead as well as the centermost plies of the carrythrough beam and trunnion webs. In addition, these plies were folded perpendicular to the plane of the bulkhead to form the innermost plies of the duct and moldline flanges. As with the other subcomponents, the web plies were room temperature debulked before final assembly.

The fabrication of a large and complex component such as the F-18, FS453 carrythrough bulkhead was an industry achievement in 1989. Figure 6 shows the full scale bulkhead. In this figure, the mechanical fittings as shown in Figure 2 are not yet attached. Non-destructive Inspection (NDI) indicated the bulkhead contained porosity and delaminations. Load testing was not performed on this bulkhead.

The material system of this first bulkhead was AS4/8551-7A cloth and IM7/8551-7A. IM7/8551-7A cloth was not available at the time of the fabrication effort. The previously fabricated test elements contained AS4/8551-7E cloth and IM7/8551-7E tape. The change from the 8551-7E to the 8551-7A resin allowed longer out-time and the subsequent retention of mechanical properties.




**View Looking Forward**

| Specimen | Region Represented | Loading | Test Load (kips) | No. of Tests | Environment | Remarks |
|---|---|---|---|---|---|---|
| LD | Web Area Between Inlet Ducts | Spectrum Fatigue | 14.0 | 2 | RTD | Tested for 1 Lifetime at DLL Following LVID |
| TF-B | Tank Floor Support, Bending | Static Shear<br>Spectrum Fatigue<br>Spectrum Fatigue | 0.8<br>0.5<br>0.5 | 1<br>1<br>1 | ETW1<br>ETW2<br>RTD | Bending of Tank Floor Support Flange<br>After LVID |
| SE-FT | Stiffener End Tie-In, Flatwise Tension | Static Tension<br>Static Tension<br>Spectrum Fatigue<br>Spectrum Fatigue<br>Spectrum Fatigue | 2.1<br>2.1<br>1.3<br>1.3<br>1.3 | 1<br>1<br>2<br>1<br>1 | ETW1<br>RTD<br>ETW2<br>RTD<br>RTD | After LVID |
| WL-U | Wing Attach Lug-Upper | Static | 307 | 1 | ETW1 | Full Scale |
| WL-L | Wing Attach Lug-Lower | Static | 308 | 1 | ETW1 | Full Scale |
| CF-FT | Carrythrough Beam Flange Flatwise Tension | Static<br>Spectrum Fatigue | 2.2<br>1.5 | 1<br>1 | ETW1<br>ETW2 | |
| CF-T1 | Carrythrough Beam Flange Inboard/Outboard Tension | Static<br>Spectrum Fatigue | −12.0<br>−8.0 | 1<br>1 | ETW1<br>ETW2 | |
| CF-T2 | Carrythrough Beam Flange Fore/Aft Tension | Static<br>Spectrum Fatigue | 12.4<br>8.3 | 1<br>1 | ETW1<br>ETW2 | |
| TR | Trunnion Attach Lug | Static | 140 Inbd<br>160 Vert | 1 | ETW1 | |

**Notes:**
1. ETW1: 200°F, saturation after 75 days. Used for static tests.
   ETW2: 160°F, saturation after 75 days. Used for fatigue tests.
2. All static tests will be to failure except specimen TR, which will be tested to ultimate load at the two most critical design conditions.
3. All fatigue tests will utilize the F-18 wing root spectrum.
4. All fatigue tests except those for LVID specimens will be tested to failure.
5. LVID specimens will be impacted, and then spectrum fatigue tested at DLL for one lifetime, while monitoring damage growth.

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**Figure 3. Element Test Matrix**

| Specimen ID | Test Requirement | | Design Requirement | | Test | | Comments |
|---|---|---|---|---|---|---|---|
| | Type | Temperature | Load (lb) | Life (SFH) | Load (lb) | Life (SFH) | |
| LD-1 | SF After LVID | RTD | 4,700 | 6,000 | 4,700 | 6,000 | No Growth in Delamination Area |
| LD-2 | SF After LVID | RTD | 5,577 | 6,000 | 5,577 | 6,000 | No Growth in Delamination Area |
| LD-3 | SF After LVID | RTD | 6,455 | 6,000 | 6,455 | 6,000 | No Growth in Delamination Area |
| TF-B-1 | Static | 200°F Wet | 284 | Static Ultimate | 525 | Static | First Load Drop – Failure at 1,286 lb |
| TF-B-2 | SF | 160°F Wet | 217 | 12,000 | 217, 260, 290, 320, 370 | 12,000 at Each Load Level | No Failure |
| TF-B-3 | SF After LVID | RTD | 217 | 6,000 | 217 | 6,000 | No Growth in Delamination Area |
| SE-FT-1 | Static | RTD | 2,550 | Static Ultimate | 5,387 | Static | Separation of Stiffener End From Flange |
| SE-FT-2 | Static | 200°F Wet | 2,100 | Static Ultimate | 4,948 | Static | Separation of Stiffener End From Flange |
| SE-FT-3 | SF | RTD | 1,584 | 12,000 | 1,584, 3,700,4,000, 4,200, 4,700, 5,000 | 12,000 SFH Each Load | Failure at 5,000 lb, 7,661 SFH |
| SE-FT-4 | SF After LVID | RTD | 1,584 | 6,000 | 1,584, 1,800, 1,985 2,620 | 6,000 SFH Each Load | Failure at 2,620 lb, 897 SFH |
| SE-FT-5 | SF | 160°F Wet | 1,266 (80% DLL) | 12,000 | 1,266, 2,200, 2,500, 2,800 | 12,000 SFH Each Load Except Failure | Failure at 2,800 lb, 2,784 SFH |
| SE-FT-6 | SF | 160°F Wet | 1,740 (110% DLL) | 12,000 | 1,740, 2,200, 2,500 2,650 | 12,000 SFH Each Load Except Failure | Failure at 2,650 lb, 10,300 SFH |
| WL-U | Static | 200°F Wet | 307,000 | Static Ultimate | 310,800 | Static | Shear Failure, No Bearing Failure |
| WL-L | Static | 200°F Wet | 308,000 | Static Ultimate | 400,000 | Static | Reached Test Machine Capability With No Failure |
| CF-FT-1 | Static | 200°F Wet | 2,960 | Static Ultimate | 6,718 | Static | Flange Peeled From Cap |
| CF-FT-2 | SF | 160°F Wet | 1,960 | 12,000 | 1,960, 2,160 | 12,000, 1,535 | Failure at 2,160 lb, 1,535 SFH, Start of Flange Peel |
| CF-T2-1 | Static | 200°F Wet | 12,400 | Static Ultimate | 13,425 | Static | Fasteners Failed. No Specimen Failure |
| CF-T2-2 | SF | 160°F Wet | 9,360 | 12,000 | 9,360, 13,325 | 12,000 SFH Each Load Level | No Failure |
| TR-1 | Static | 200°F Wet | 160,000 Vertical | Static Ultimate | 126,000 | Static | Interlaminar Shear Failure (Web Delamination). Crippling Failure of Upper Cap |

SF denotes Spectrum Fatigue
LVID denotes Low Velocity Impact Damage
RTD denotes Room Temperature Dry
SFH denotes Spectrum Flight Hours

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**Figure 4. Summary of Element Test Results**

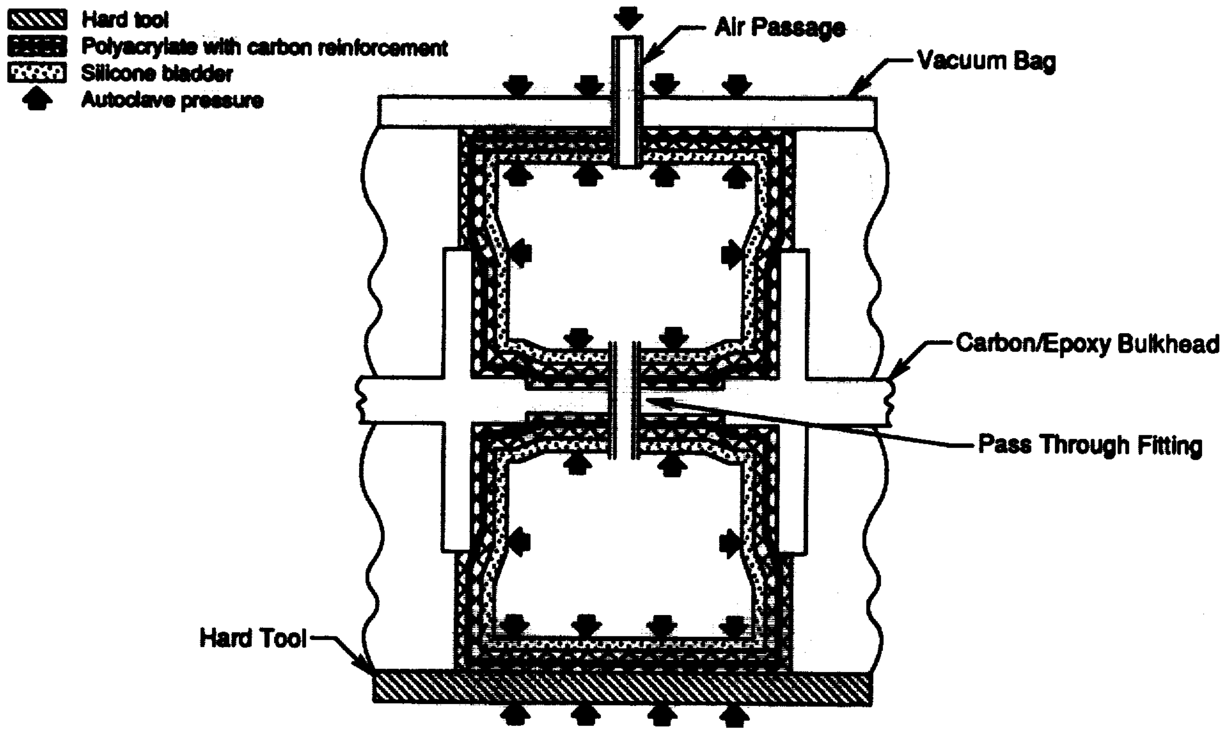



**Figure 5. Conformal Tooling for First Bulkhead**

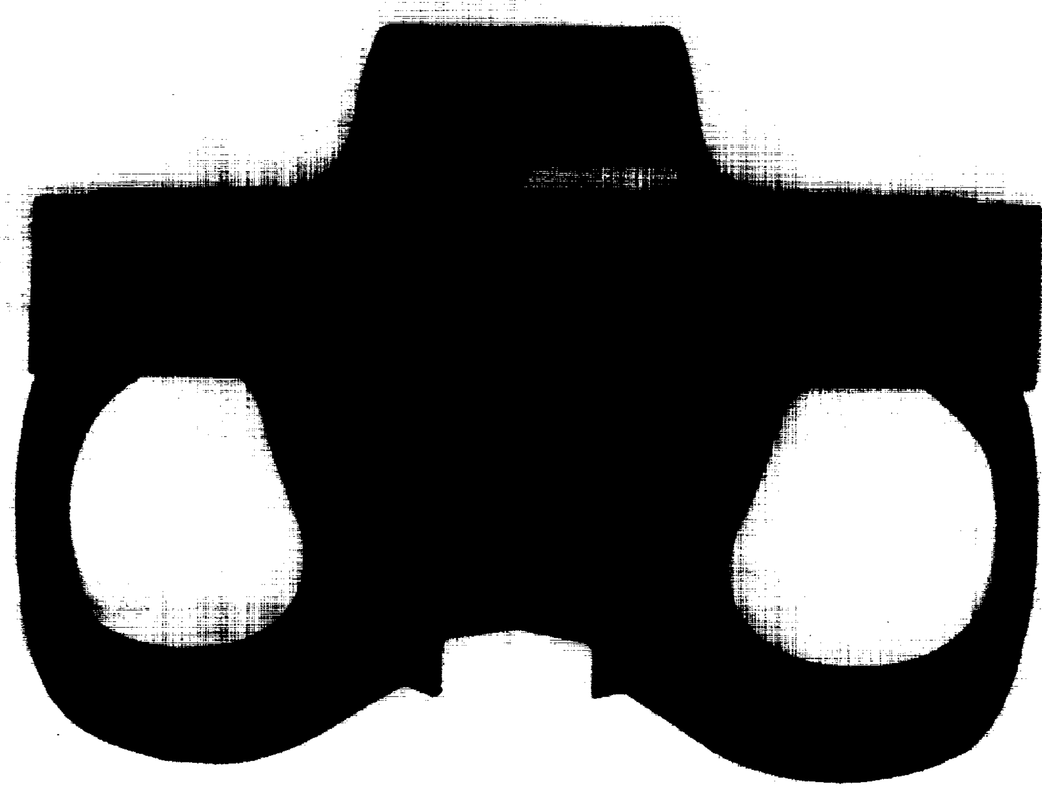



**Figure 6. First Bulkhead**
Forward Side

## MANUFACTURING RISK REDUCTION FOR THE SECOND BULKHEAD

The first bulkhead played a significant role in this program in terms of manufacturing lessons learned. An example is air leakage detected from the conformal tools during the autoclave cycle. The lack of the appropriate pressure in the conformal tools during the autoclave cycle caused the porosity and delaminations of the bulkhead. Conformal tooling improvements were identified.

Lessons learned from the first bulkhead fabrication now went into planning the second bulkhead. As part of this risk reduction effort, design modifications, tooling changes, and processing changes were first demonstrated on a quarter bulkhead subcomponent. This subcomponent was fabricated prior to the second bulkhead to verify the manufacturing, cure cycle, and detail changes.

The summary of the risk reduction effort is:

- Reduced the number of conformal tools.
- Built new conformal tools, with improvements, to reduce leakage
- Refined the processing cycle.
- Implemented a bulkhead design improvement.
- Fabrication of the subcomponent.

The material system which was used on the subcomponent as well as what was used on the second bulkhead is IM7/8551-7A tape and cloth.

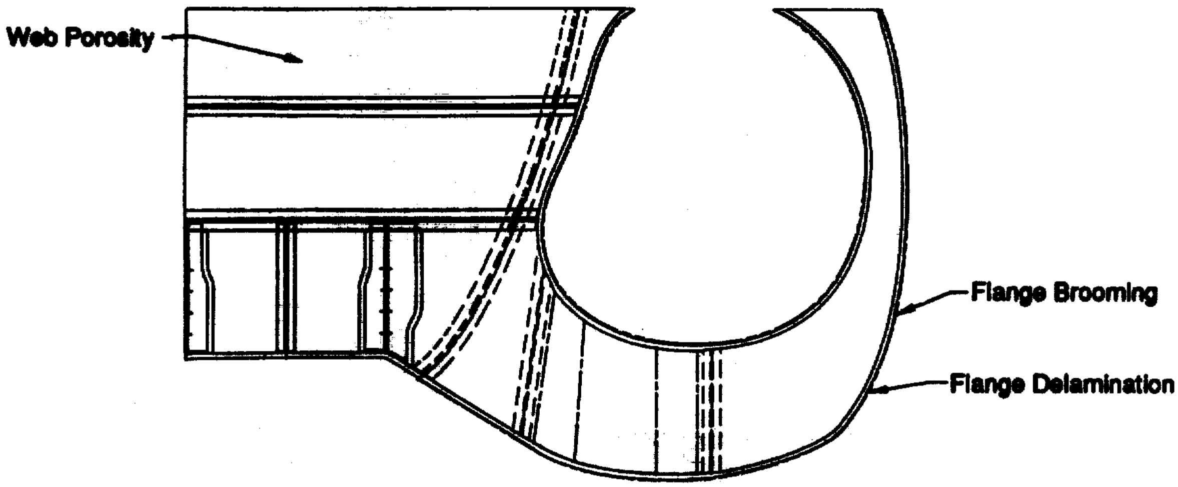
The risk reduction subcomponent had significantly improved quality from the first bulkhead but still contained some abnormalities. Figure 7 shows the few abnormalities of the subcomponent and the further corrective action to be applied to the second bulkhead.

To prevent the flanges from brooming, the flange width was reduced. Narrower flange width avoids flange contact with the bond tool. This approach has no detrimental impact to the bulkhead; the flanges are oversized during the cure cycle and then later trimmed to blueprint width.

The flange delamination occurred where the tape ply pack and cloth ply pack interface. FM300 adhesive was inserted at this interface on the second bulkhead.

The corrective action for the web porosity was to lay porous teflon cloth between the bulkhead web and the conformal tool. The porous teflon cloth helps to prevent the entrapment of air between the bulkhead web and the bond tools.

Outcome of the Subcomponent




Corrective Action to Be Applied to the 2nd Bulkhead

- Flange Brooming: Pre-Machined Flange Width Reduced to Avoid Tool Contact
- Flange Delamination: FM300 Inserted Between the Tape Ply Pack and Cloth Ply Pack
- Web Porosity: Porous Teflon Inserted Between the Bulkhead and the Conformal Tool

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**Figure 7. Lessons Learned From Subcomponent Fabrication**

## SECOND BULKHEAD FABRICATION

The second bulkhead fabrication procedure benefited from the lessons learned from the first bulkhead and the quarter-bulkhead subcomponent. Figure 8 shows this bulkhead after curing. The mechanical fittings shown in Figure 2 are not yet installed.

Automated through transmission C-scan and pulse-echo A-scan ultrasonic inspections were performed on the bulkhead webs and flanges. Abnormalities detected were further investigated by radiography.

The second bulkhead was of significantly better quality than the first bulkhead. Some porosity, delaminations, and foreign material were detected. Figure 9 shows the NDI results.

The porosity, delaminations, and foreign material damage were all reviewed for possible repair to blueprint equivalent strength.

Resin injection and mechanical fastening were considered for repair methods of the delaminations. While limited resin injected repair data are available for the 3501 resin system, little data exist for the 8551-7A system. Hence, mechanical fastening was chosen for the delamination repair. Figure 10 shows this repair.

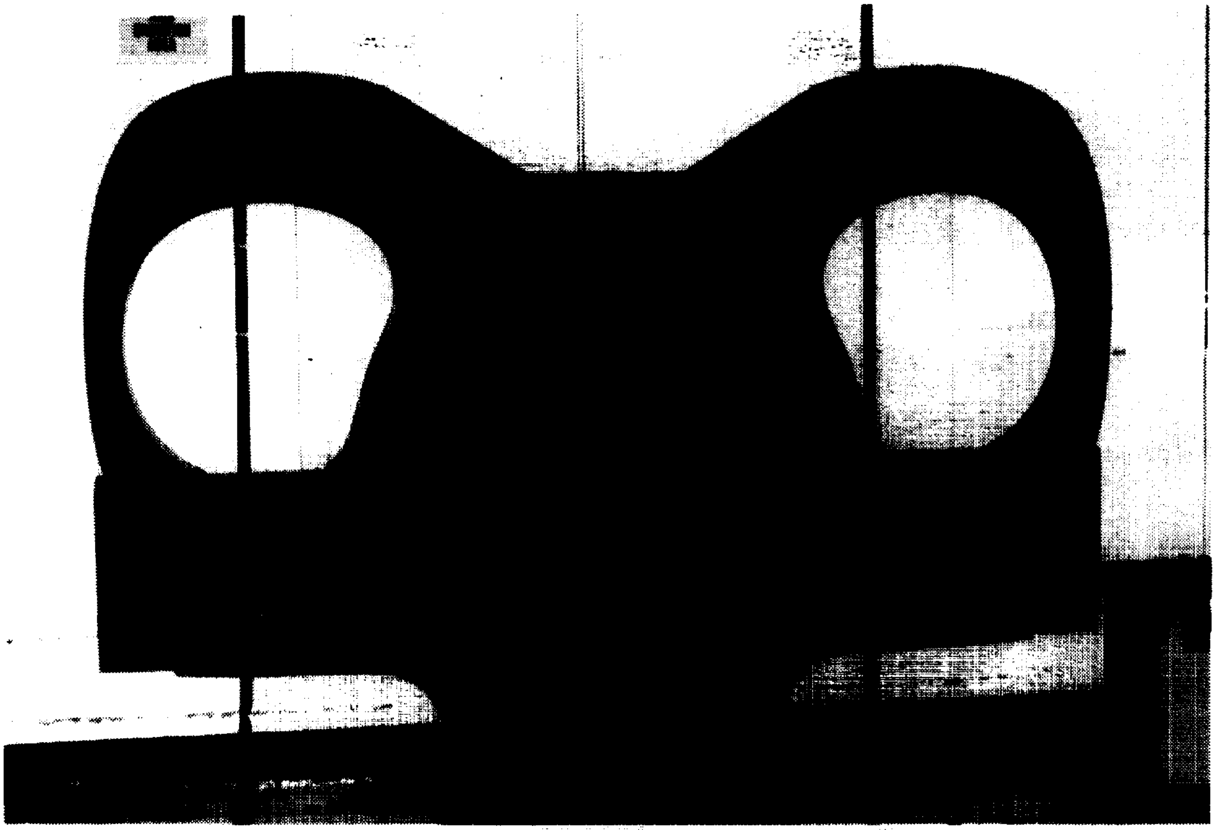

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**Figure 8. Second Bulkhead**
Forward Side

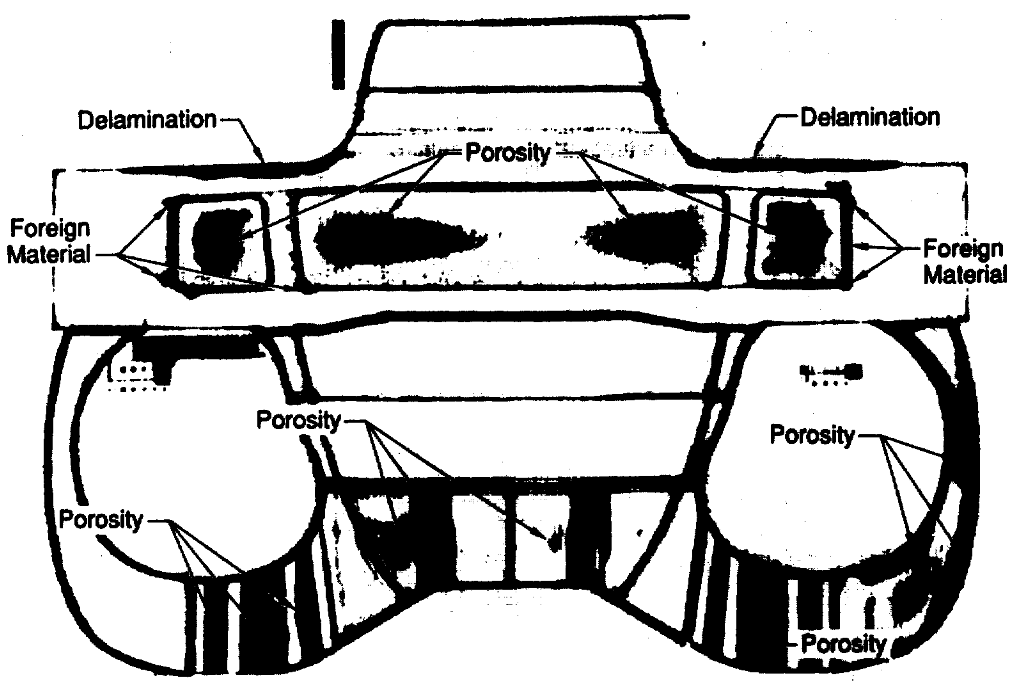


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**Figure 9. Ultrasonic Inspection Summary of Second Bulkhead**

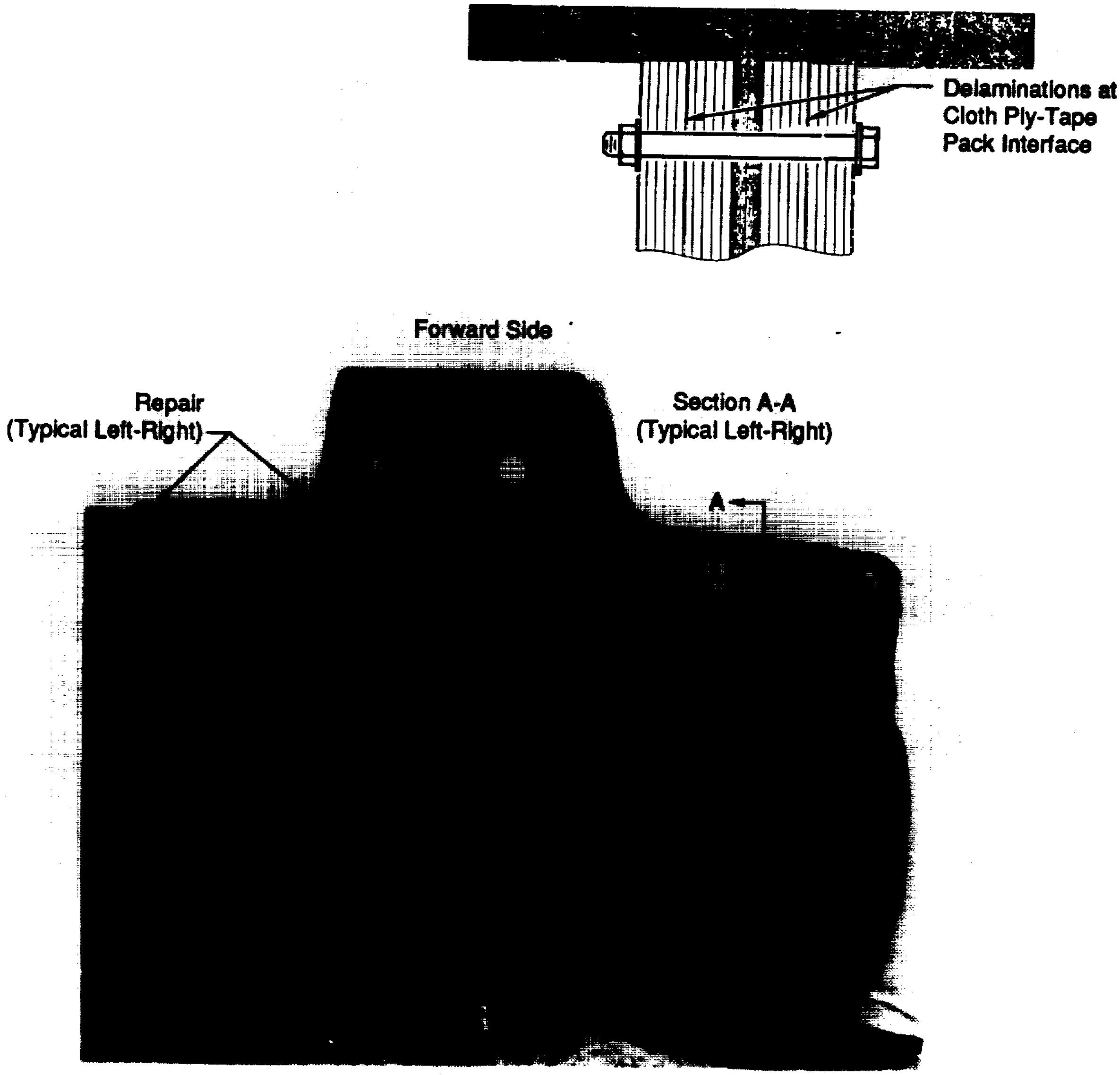


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**Figure 10. Delamination Repair**

As with all thermosets, porosity is not repairable. The approach to evaluating the strength impact of porosity was to create "delta dB (decibel) vs. strength retention" data for the material system in use. Delta dB is the difference of ultrasonic attenuation between a "flaw free" laminate and a "flawed" laminate. By having the delta dB of a family of flawed laminates, and through mechanical testing to obtain the drop in strength properties for these laminates, curves of this nature can be created. This program took advantage of "delta dB vs. strength retention" curves for IM7/8551-7A that were created by MCAIR during a previous program.

The foreign material contamination is of little strength consequence to the bulkhead due to its location.

The final assembled bulkhead has mechanically attached fittings. One set of these fittings is used to complete the upper portion of the inlet flange, another set to splice the fuselage interface flange, and the other set is used to carry high-magnitude "kick" loads along the lower-inboard moldline flange.

## LOAD TESTING THE SECOND BULKHEAD

Load testing of the bulkhead focused on the wing attach lugs. Wing bending moment was applied to the wing attach lugs but no wing vertical shear loads were applied. The wing vertical shear was not applied due to extreme complexities of simulating the "as installed in the aircraft" bulkhead boundaries in the test fixture.

The load test events for the wing attach lugs were:

- Proof load to the highest load in the enhanced fatigue spectrum (142% design limit load)*
- F-18 wing root enhanced spectrum fatigue test - 2 Lifetimes (12000 Spectrum Flight Hours)
- Static test to ultimate load - 150% design limit load
- Static test to failure

During the initial proof load testing, a load noise was heard at 113% design limit load. Upon inspection, a fracture along the carrythrough beam and the basic bulkhead web interface was found. This fracture existed on both the left and right side of the part. Since there were no strain gages in this immediate vicinity, no unusual strain indications were observed during loading. Testing was stopped and an investigation into the cause of this fracture was initiated. During this investigation, it was determined that a problem existed with the finite element model.

In the finite element model, an axial load path in the moldline flange was modeled where it did not exist. This modeling error caused a misrepresentation of the adjacent web strains; hence the web strains in the model were lower than actual since the moldline flange was carrying the load in the model when in reality it could not. It is important to recognize this fracture was due to a finite element modelling oversight and should not reflect upon the potential of composite structure of the type being addressed in this program. The finite element model was remodeled to properly represent the moldline flange and to account for the lost load path of the fractured web.

Further analysis indicated that this discontinuity should not present a problem with continuing the test of the carrythrough beam portion of the bulkhead, but would require repair if the trunnion area were to be tested as planned. Strain gages were installed in the vicinity of the fracture to monitor any growth during subsequent testing. Proof loading and subsequent fatigue testing were completed without any additional incidents.

* The fatigue testing included an enhancement factor to account for composite scatter. Reference 3 is the source of this enhancement factor.

Fatigue testing consisted of the application of two lifetimes of enhanced, to account for composite fatigue scatter, spectrum loads to the bulkhead carrythrough beam in order to demonstrate the durability of the design. The maximum fatigue load of this enhanced spectrum was equivalent to 142% design limit load.

Following the fatigue testing, the bulkhead was loaded to failure which occurred at 186% design limit load. Failure was a tension failure in the lug area. This failure load exceeds 150% DLL by a sufficient margin to account for environmental degradation and statistical scatter of the composite material.

The planned testing of the trunnion area was deleted from the program due to lack of funding required to perform the test and to repair the carrythrough beam and web interface.

## PAYOFF EVALUATION AND RISK ASSESSMENT

Weight - The second composite bulkhead, including the mechanical fittings weighs 233 lbs. after trim. This weight also includes the fasteners used to repair the delamination. The F-18 aluminum bulkhead weighs 265 lbs. Thus, a weight savings of 12% was achieved, however, a larger weight savings (approximately 15%) would result if the repair was not necessary. This scenario demonstrates the need for follow-on programs to develop composite materials or forms which will not have penalties for the lack of out-of-plane strength. This comment is made in light of the fact that some of the mechanical fittings on the second bulkhead were installed to carry out-of-plane loads.

Cost and Supportability - Figure 11 shows the relative cost of the composite bulkhead to the comparable aluminum bulkhead. This figure also shows the relative supportability efforts.

Damage Tolerance - Damage tolerance was demonstrated during the bulkhead load testing. Porosity, which did occur in the second bulkhead, simulated the planned inducement of low velocity impact damage. No load testing results were degraded due to the presence of porosity.

Repairability - The second bulkhead did contain some delaminations and porosity. Repairability of the delaminations was achieved as described earlier.

| Concept | Relative Weight (Actual) | Relative Cost (Estimated) | Relative Supportability (Estimated) |
|---|---|---|---|
| Composite | 0.89 | 2.37 | 0.94 |
| Aluminum | 1.0 | 1.00 | 1.00 |

Note: Low value is better

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Figure 11. Payoff Evaluation

## RESULTS AND DISCUSSION

The bulkhead developed in this program is one of the more complex one-piece composite structures ever attempted. The geometry of this bulkhead, coupled with the use of a new material system and an advanced tooling concept, have provided a substantial technical challenge. While not perfect, the prototype component has met this challenge and represents a significant step forward in the development of composite bulkhead technology.

The use of composite materials for large, complex, and highly loaded components has been advanced as a result of this program. Further research is recommended in design and fabrication so that flight worthiness of components of this type can be demonstrated. This is an essential step for the transition of this technology into emerging aircraft programs.

Engineering design guidelines and manufacturing guidelines are listed to aid future composite bulkhead work.

### ENGINEERING DESIGN GUIDELINES

- Avoid ply darting. When laying broadgoods into complex surfaces, the fabric may not be formable to all surfaces. If ply darting cannot be avoided, verify dart details through analysis and structural testing. An example of ply darting is shown in Figure 12.
- Avoid abrupt ply termination. An example of abrupt ply termination is shown in Figure 13.
- Design for secondary loads induced onto the mating structure of the part. Figure 14 shows an example of secondary loads. Another consideration is the secondary loads that develop from the curved flange phenomenon.

### MANUFACTURING GUIDELINES

- Use conformal tools for fabrication of parts with multiple integral flanges. The conformal tools could be of the nature shown in Figure 15. If a remain-in-place mandrel is used for bladder lay-up and fabrication, it should be a material that will not puncture the bladder.
- It is advised to use film adhesive during the component lay-up to fill voids. A commonly occurring void is shown in Figure 16.
- To avoid porosity in thick laminates the use of multiple debulk cycles should be considered as shown in Figure 17.
- Use computer codes such as "Computer Aided Curing of Composites" (Reference 4) for the development of the autoclave cycle.
- Verify the manufacturing and design details by fabrication of a subcomponent.

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Figure 12. Ply Dart for the Trunnion Support Web

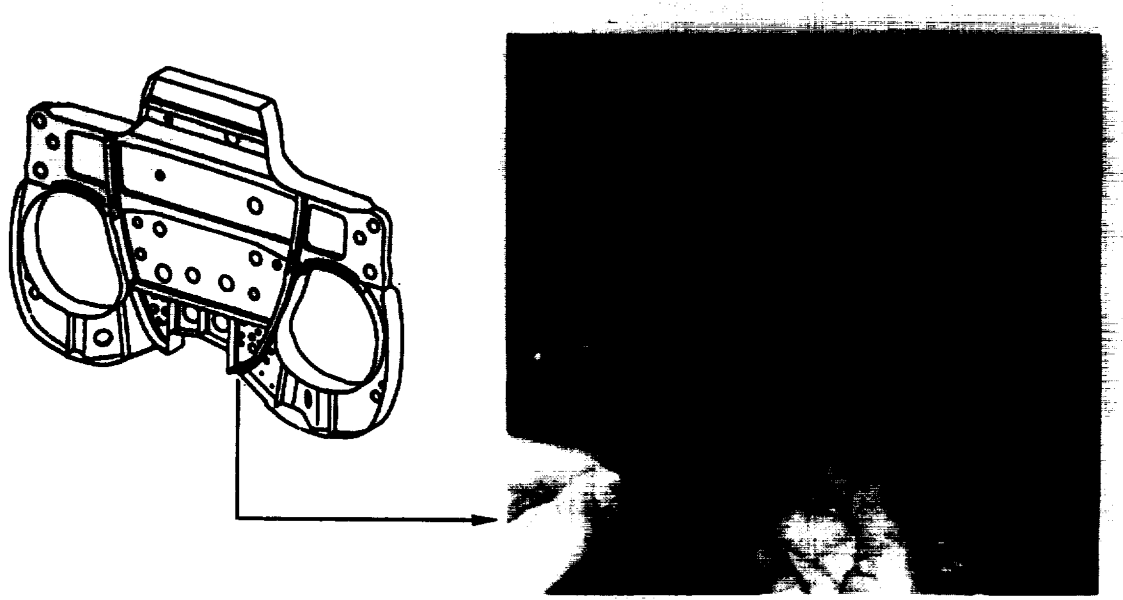

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Figure 13. Ply Termination Conjunction on First Bulkhead

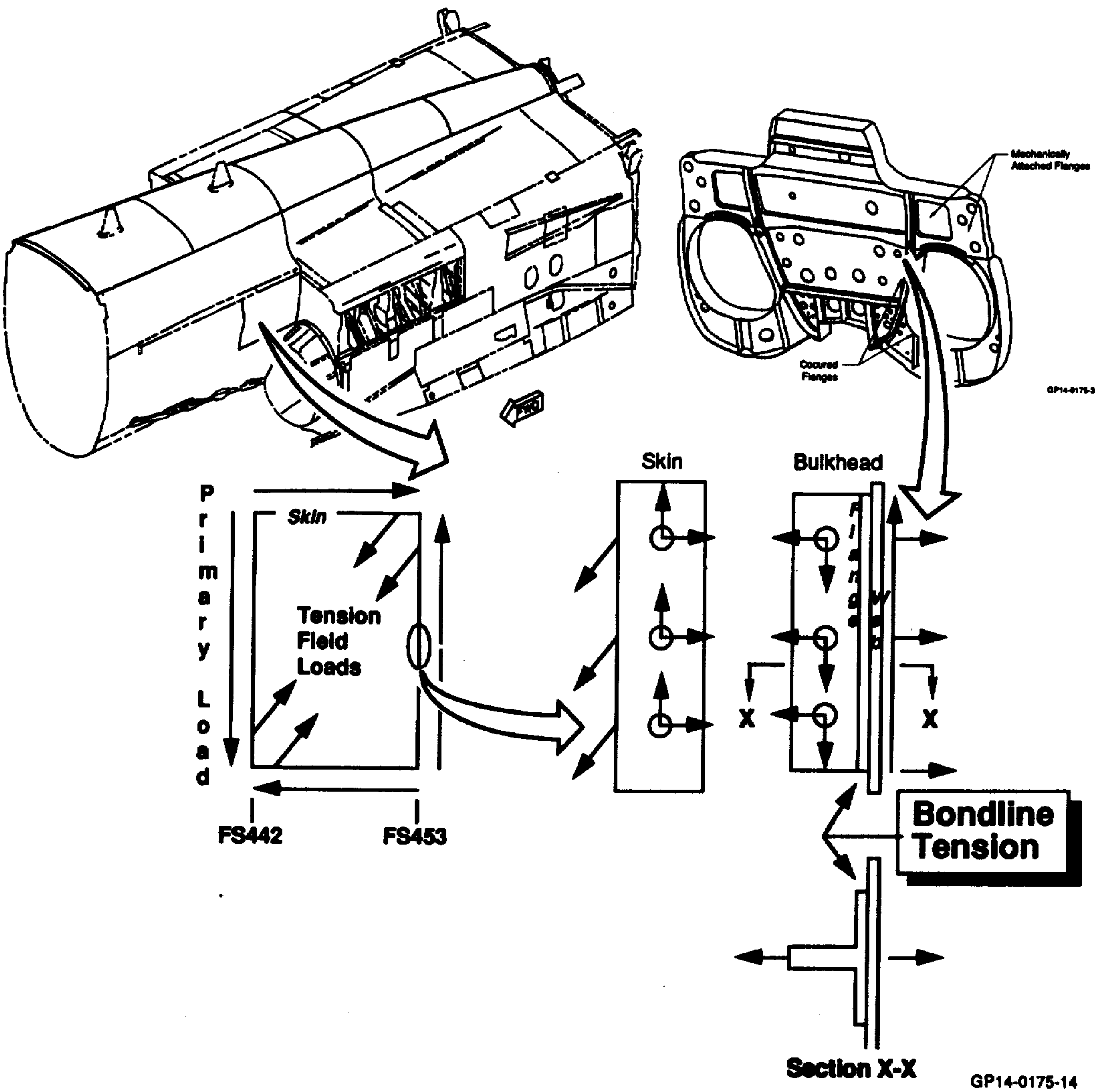


**Figure 14. Bondline Tension From Secondary Loads**

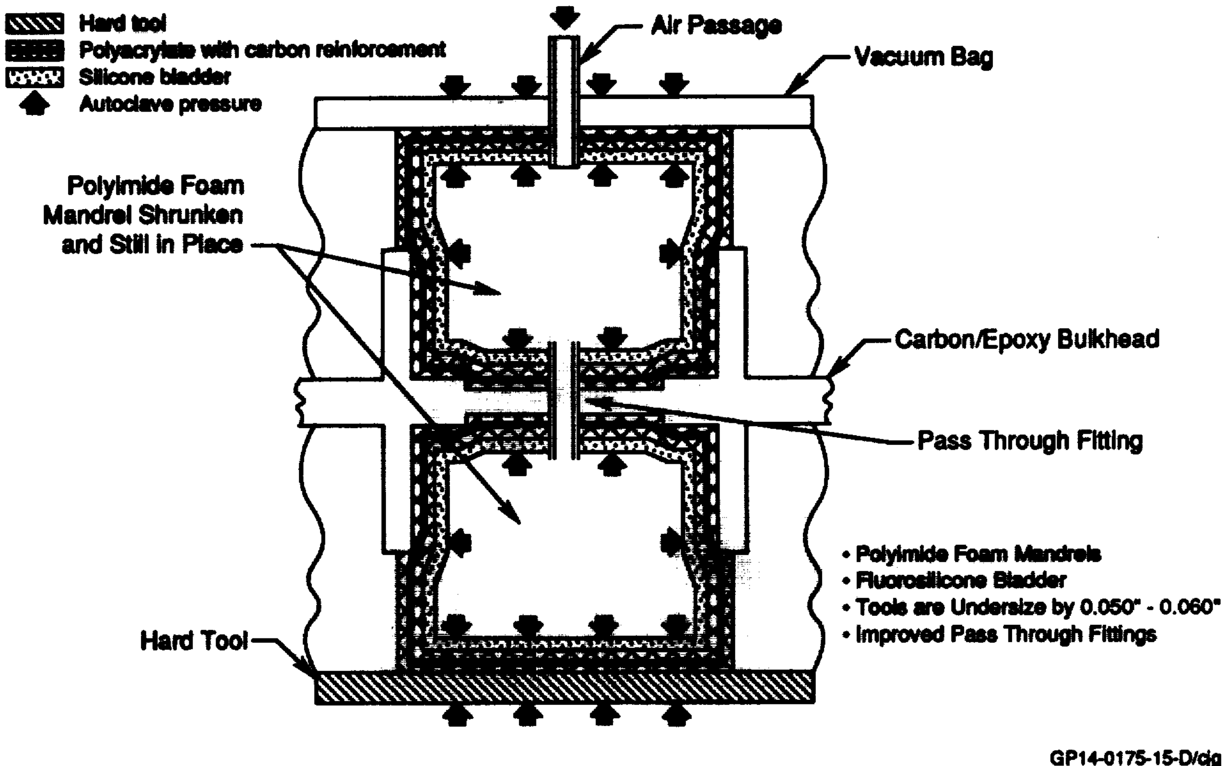


**Figure 15. Conformal Tooling for Second Bulkhead**

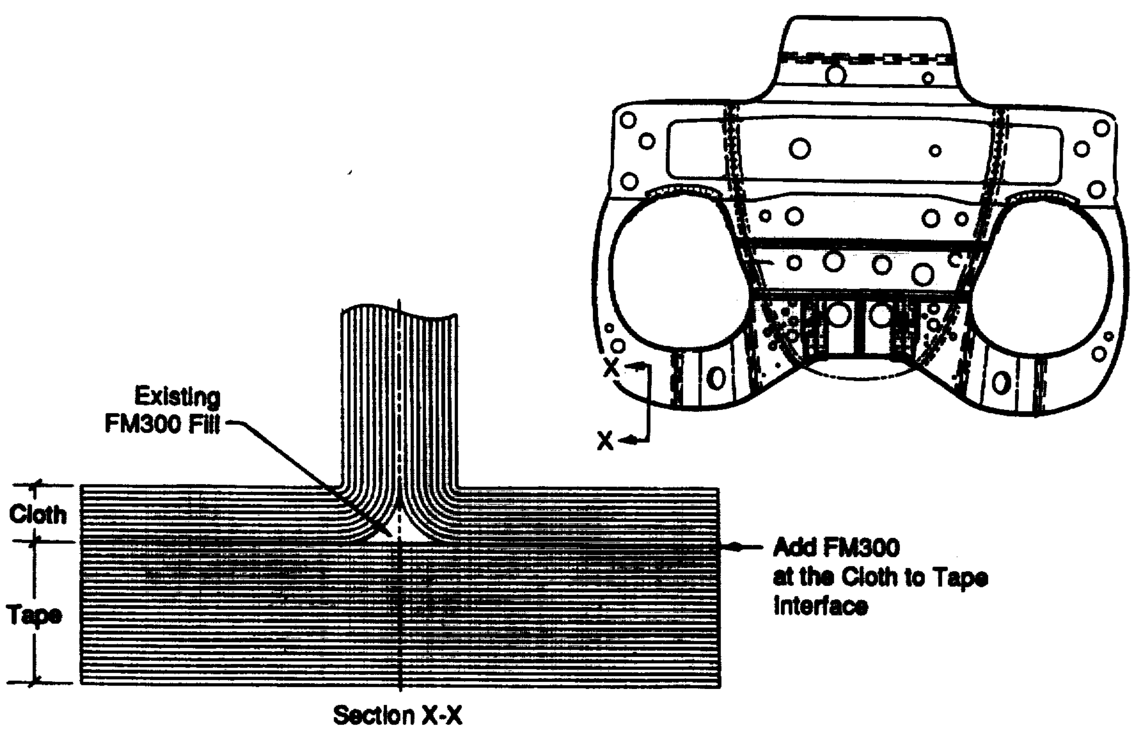


**Figure 16. Adhesive Usage During Layup**

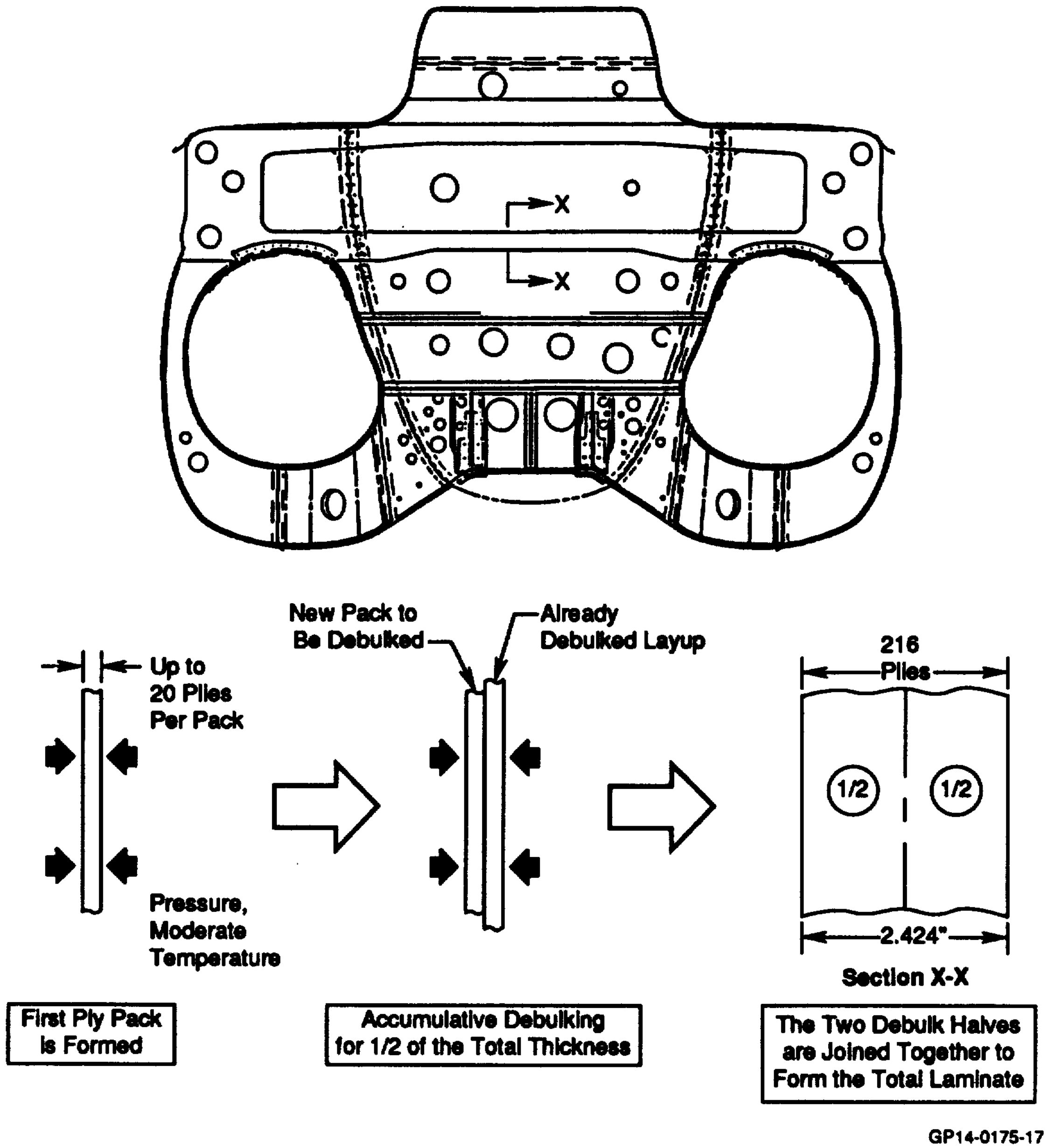


Figure 17. Multiple Hot Debulking Cycles

## CONCLUDING REMARKS

In 1992, the Final Technical Report should be available through the Defense Technical Information Center (DTIC). Details of this program can be found in this report.

## REFERENCES


1. Behrens, R.S., Goering, J.C., "Development of Composite Carrythrough Bulkhead: Interim Technical Report", Naval Air Development Center Report No. NADC-90032-60, June, 1989.

2. Goering, J.C., Libeskind, M., "Development of Composite Wing Carrythrough Bulkheads for Fighter Aircraft", Eighth DoD/NASA/FAA Conference on Fibrous Composites in Structural Design", November, 1989.

3. Whitehead, R.S., et al., "Certification Methodology for Composite Structure", Naval Air Development Center Report No. NADC-87042-60, October, 1986.

4. Thomas, J.A., et al., "Computer-Aided Curing of Composites", Wright Research and Development Center Report No. WRDC-TR-89-4084, October 1989.

## CONCLUDING REMARKS

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