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HLH ROTOR BLADE MANUFACTURING TECHNOLOGY DEVELOPMENT REPORT

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Final Report

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Prepared for

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APPLIED TECHNOLOGY LABORATORY POSITION STATEMENT

Due to the termination of the HLH program, reports summarizing the strides made in many of the supporting technology programs were never published. In an effort to make as much of this information available as possible, selected draft reports prepared under contract prior to termination have been edited and converted to the DOD format by the Applied Technology Laboratory. The reader will find many instances of poor legibility in drawings and charts which could not, due to the funding and manpower constraints, be redone. It is felt, however, that some benefit will be derived from their inclusion and that where essential details are missing, sufficient information exists to allow the direction of specific questions to the contractor and/or the U.S. Army.

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Improved Rotor Performance	

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This document describes the manufacturing technology development effort for the HLH/ATC rotor blade. Trade-off studies leading to the selection of the manufacturing and tooling concepts, and the details of blade fabrication are described herein; in addition, the nondestructive test and other quality assurance techniques used to ensure development of a flight-worthy rotor blade are described. Finally, the tooling and fabrication changes being implemented as

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20. ABSTRACT - Continued

a result of full-scale blade testing in the last six months of the ATC program are presented.

The success of the HLH/ATC rotor blade can be highlighted by the fact that the rotor blade has:

Exceeded its rotor performance figure of merit.

Achieved an ambitious weight target of 765 pounds making it 22% lighter than blades of conventional construction.

Demonstrated that a fiberglass/titanium rotor blade of advanced design promises significant reductions in production cost per pound over existing blade concepts.

The conclusions reached as a result of the 3-year HLH/ATC rotor blade manufacturing development effort have: (1) verified the tooling and manufacturing approach utilized; and (2) provided convincing evidence that the rotor blade design is cost-effective, producible, and has the potential for high-rate, low cost production through automated tooling and manufacturing methods.

TABLE OF CONTENTS

TABLE OF CONTENTS (CONT'D)

TABLE OF CONTENTS (CONT'D)

TABLE OF CONTENTS (CONT'D)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (CONT'D)

LIST OF ILLUSTRATIONS (CONT'D)

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1.0 OBJECTIVES AND APPROACH

The manufacturing development effort on the HLH rotor blade was oriented toward evolving a fabrication and tooling concept that would permit Engineering Design the flexibility of utilizing advanced composite materials that promised the greatest performance and operational advancements, while at the same time providing a cost-effective, producible design consistent with our design-to-cost philosophy.

Section 2 describes the trade-off analyses and specimen evaluations that led to finalization of the manufacturing and tooling concept to be used on the Advanced Technology Component Program. In addition, provided herein is a description of the detailed fabrication process, the problems encountered, and the corrective actions implemented.

Section 4 describes the Quality Assurance approach utilized in the destructive and nondestructive test segments of the program to ensure development of a flight-worthy rotor blade concept. Finally, Section 5 presents the tooling and fabrication changes being implemented as a result of the full-scale blade testing accomplished in the last six months of the ATC program.

The HLH/ATC rotor blade has:

- Exceeded its rotor performance figure of merit.
- Achieved an ambitious weight target of 765 pounds, making it 22% lighter than blades of conventional construction.
- Demonstrated that a fiberglass/titanium rotor blade of advanced design promises significant reductions in production cost per pound over existing blade concepts.

2.0 TRADE-OFF ANALYSES AND SPECIMEN EVALUATION

PROGRAM BACKGROUND

The HLH blade development program included a number of unique approaches and technological advances in the fabrication of composite rotor blades. Cost effectiveness and austerity were paramount throughout the entire program and, in many cases, dictated identification and selection of improved concepts and processes. From the beginning, cost avoidance was achieved by restricting initial fabrication to blade root ends. Although the root end segment represents only approximately 20% of a blade, it requires nearly 90% of the technological advances required for a composite blade of this size. From an overall view, this concept was well founded and proved to be very cost effective during the ATC program.

The program was structured to provide HLH Engineering with design support test data early in the development phase and prior to fabrication. Considering the lead time allocated for this task, it was apparent that efficient and decisive implementation would be required. The action that followed included establishment of an HLH Blade Fabrication Committee, consisting of all participating functional organizations, to facilitate and expedite the decision-making process. The program's success can be attributed directly to the creation of this committee, which is discussed in more detail in the following paragraphs.

MANUFACTURING CONCEPT DEVELOPMENT

During the early stages of the HLH program, the rotor blade design concept was based on the use of dual "coke bottle" fittings for root end attachment. The spar featured redundant load paths and in effect was a spar within a spar. Both were "C" shaped but were fabricated from different materials. The inner spar was glass and the outer spar was graphite fibers. The first series of root end specimens were fabricated around that concept and served as tool proving articles. As an economy measure, lower cost materials were substituted for the titanium and graphite parts within the root end specimen.

Fabrication of the specimens was required in order to develop the necessary technology advances and to provide Engineering with design support test data. By judicious planning, additional benefits were realized during the fabrication effort. Three of the four specimens were fabricated using different tooling concepts. This resulted in an inexpensive tool evaluation program which led to the tooling concept ultimately selected.

As a result of the materials evaluation program, and a fabrication cost study, the dual coke bottle blade concept was abandoned by Engineering. A new blade design referred to as the "wraparound" concept was then selected for development. Redirecting a program seven months after the start dictated even more stringent requirements, and meant an all-out effort in order to protect the program schedule.

The wraparound concept was developed and tested with excellent results. The blade designs were released, tools were designed and built, and seven full-size blades were fabricated. All of this was accomplished within a 23-month period and within a few days of the original scheduled completion date.

HLH Blade Fabrication Committee

On a blade development program of this magnitude, one task of tremendous scope is the implementation of timely decisions required for program guidance. Considering the program's schedule mandates, the need to expedite the decision-making process was obvious. The HLH Blade Fabrication Committee was established to fill this requirement.

The committee consisted of key representatives from each functional department participating in the blade development program. Included were representatives from Project Engineering, Tool Design, Manufacturing Technology, Manufacturing Engineering, Quality Assurance, and Operations Management. Starting with the basic blade design concept, the committee analyzed each detail and component to identify tool requirements, proprocesses to be utilized, and techniques required. In addition, potential problems or inherent risks were identified and analyzed. Primarily, the committee's action was achieved through the development of "daisy chain" charts of sequential operations for each part and component of the blade. A typical "daisy chain" chart is shown in Figure 1.

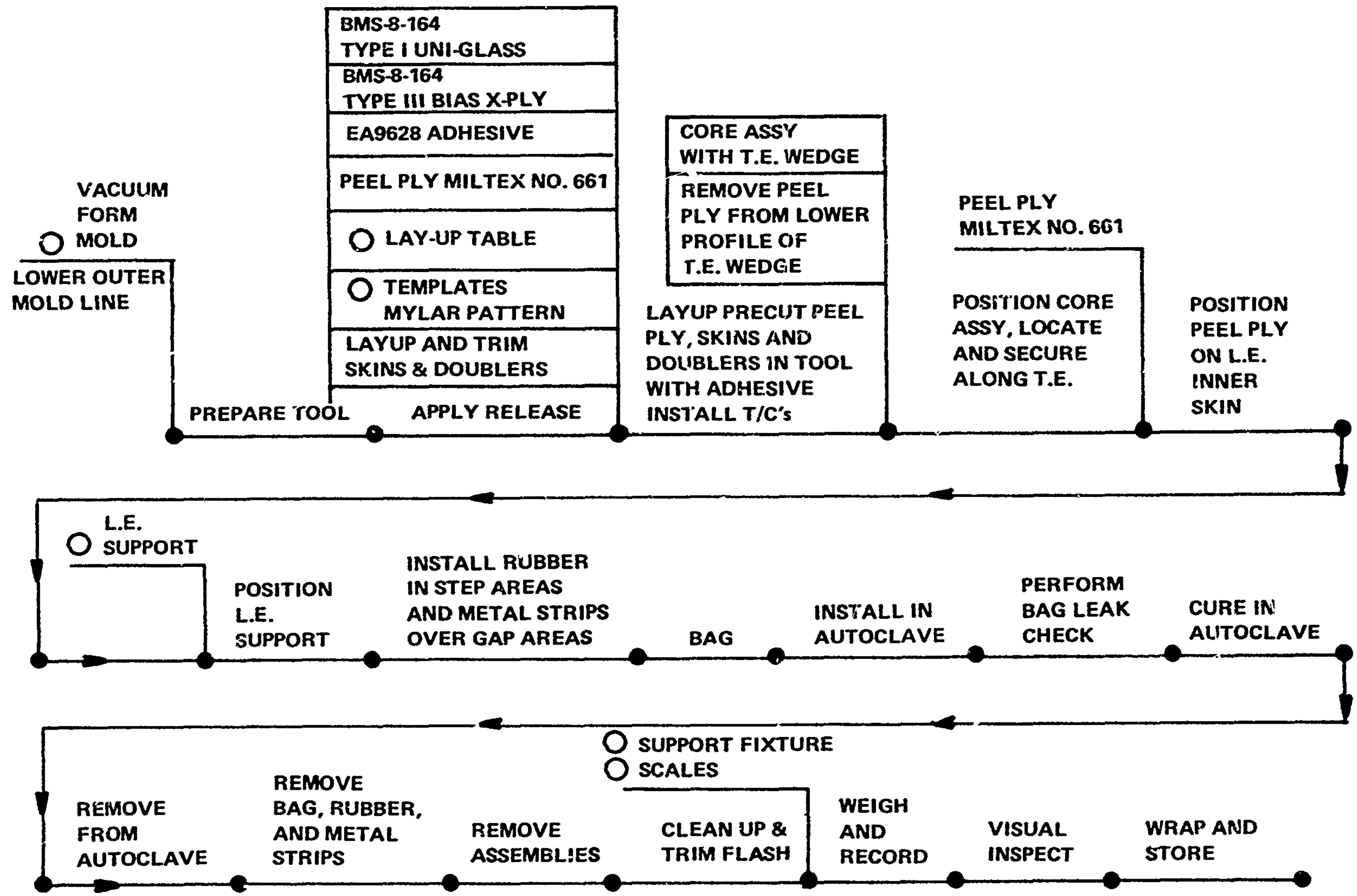


Figure 1. Typical Blade Operations Sequence "Daisy Chain" Chart

The operations sequence of the "daisy chain" identifies every element of work and each process involved in the fabrication of a part or component. The tools, shop aids, and facility requirements were also identified at the same time. This flow sequence was established and utilized to provide coordination between Manufacturing and Quality Control departments.

Inherent with the chart's development was the identification of problems and risks. In many cases, the problem was eliminated or the risk minimized during chart development and prior to fabrication. Overall, a "give and take" atmosphere prevailed, and the resultant decisions were normally in the best interests of the program. A number of significant design and tooling changes were introduced by this approach, on a timely basis, with an obvious objective of cost avoidance.

Prior to blade fabrication, the overall concept and plans were refined through a series of "daisy chain" reviews. After a number of iterations and refinements, the fabrication process was established and action initiated to start blade fabrication.

Another important byproduct of the committee was improved communication and coordination between departments. With each department represented and actively participating, the resultant action tended to receive better support. The decisions reached and actions initiated met little or no opposition during implementation.

In summary, the establishment of the HLH Blade Fabrication Committee proved to be a wise and practical decision. The overall program direction and quality of decisions were improved, and the desired results were achieved. The "Committee" or "Task Force" approach is definitely recommended for developmental-type programs of this magnitude.

Blade Fabrication Sequence

The charts within this section identify the fabrication sequence used for the HLH blades (ATC configuration). Each chart is structured to indicate flow of various subassemblies and assemblies into a final blade. The overall flow diagram is shown in Figure 2; Figures 3 through 11 depict operations performed for each task. The blocks in each flow chart have been sized to be time sensitive from a flow time viewpoint; i.e., small blocks represent short operations, larger blocks - longer operations.

Fabrication of detail parts feeding into the subassemblies are not shown unless they were considered essential to an understanding of the overall flow.

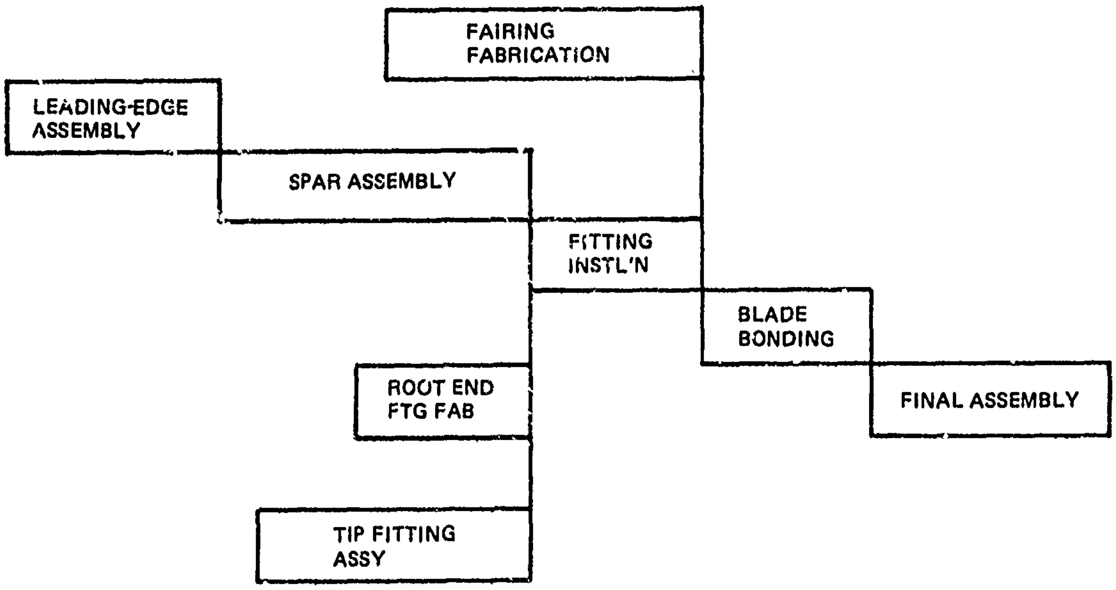


Figure 2. HLH Blade Fabrication Flow Diagram

FABRICATION SEQUENCE

- LEADING-EDGE ASSEMBLY
- SPAR ASSEMBLY
- ROOT END FITTING FABRICATION
- TIP FITTING ASSEMBLY
- FITTING INSTALLATION
- FAIRING FABRICATION
- BLADE BONDING
- DAMPER ARM ASSEMBLY
- FINAL ASSEMBLY

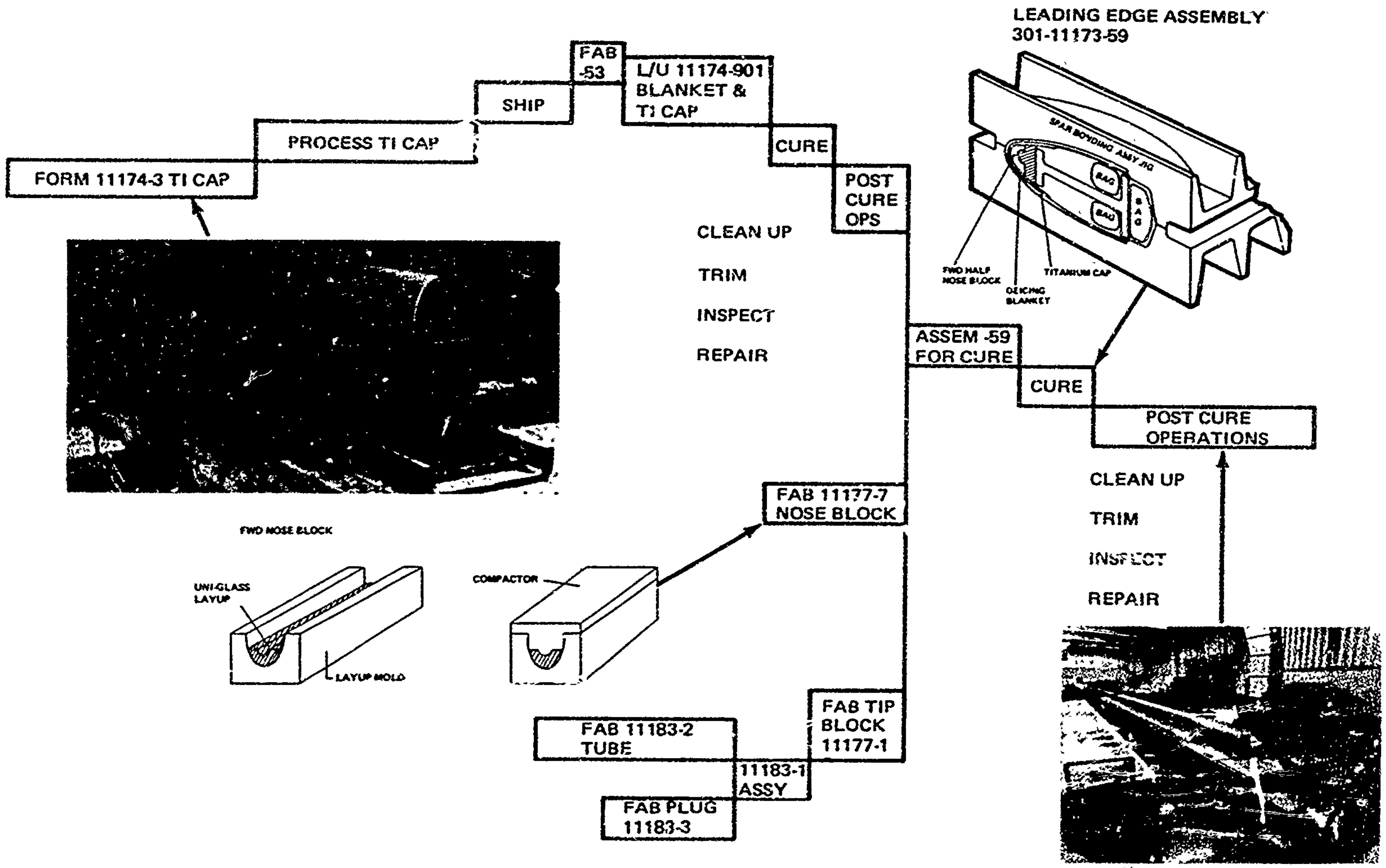


Figure 3. Leading-Edge Assembly Flow Chart

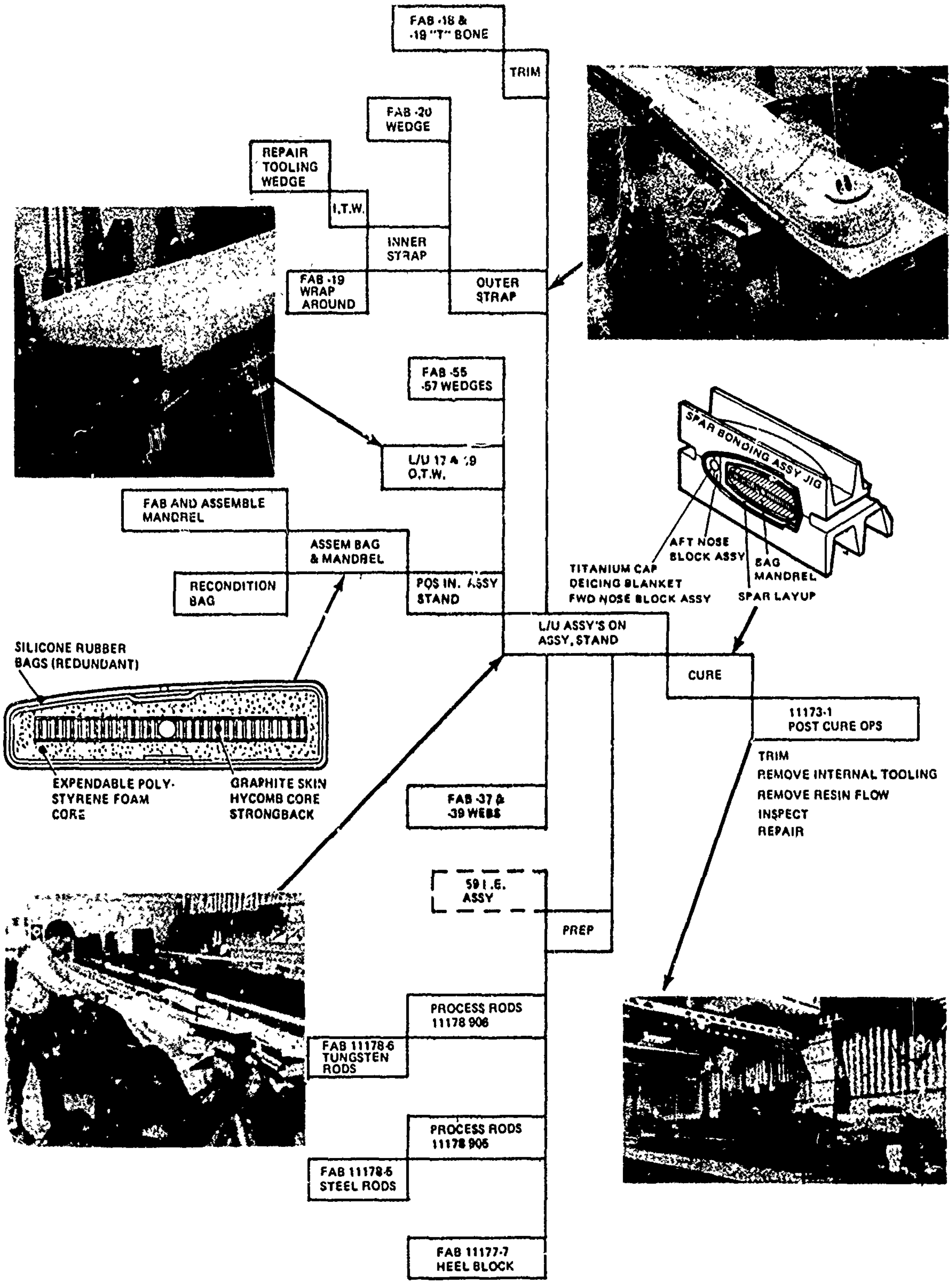


Figure 4. Spar Assembly Flow Chart

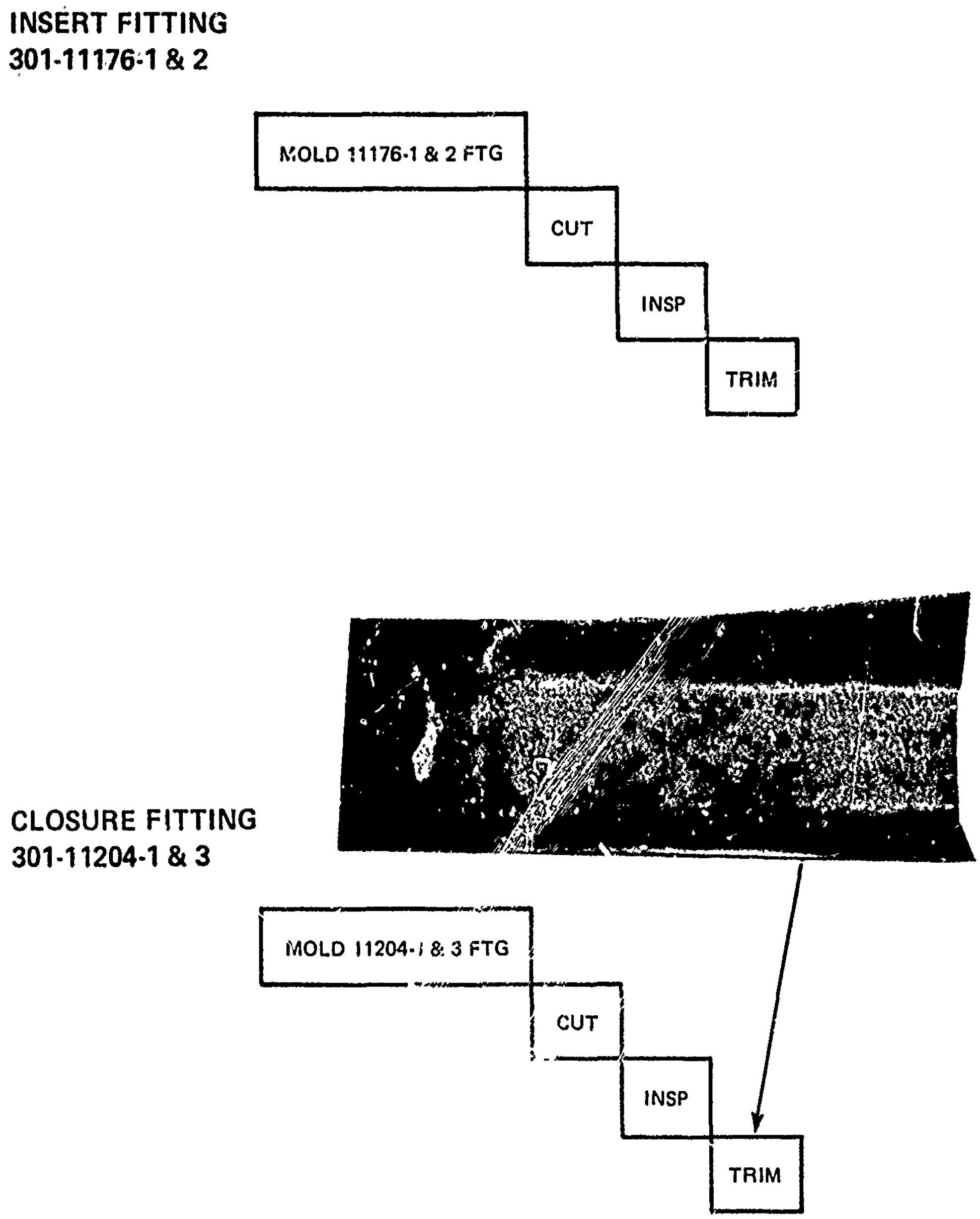


Figure 5. Root End Fitting Fabrication Flow Chart

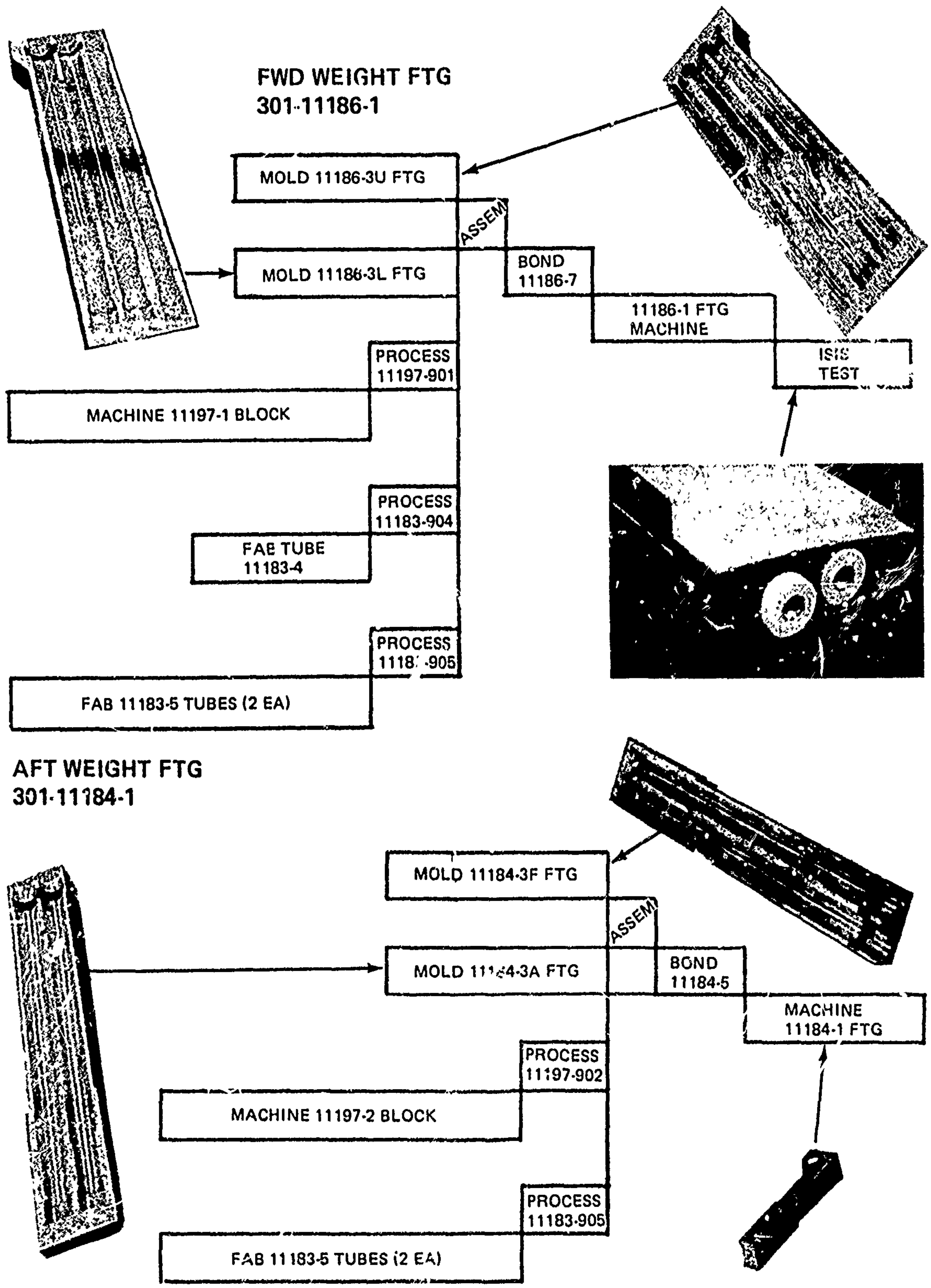


Figure 6. Tip Fitting Assembly Flow Chart

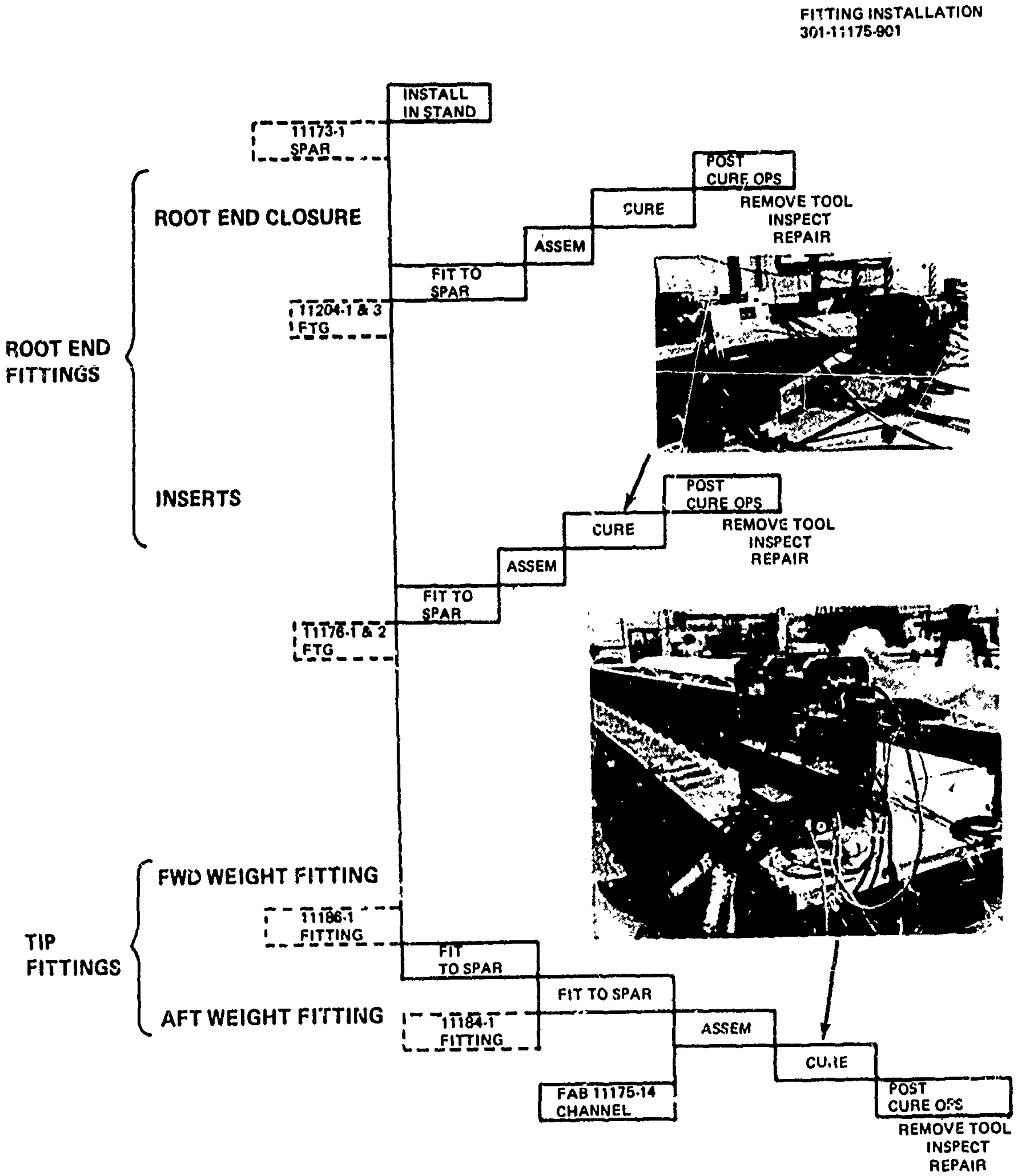


Figure 7. Fitting Installation Flow Chart

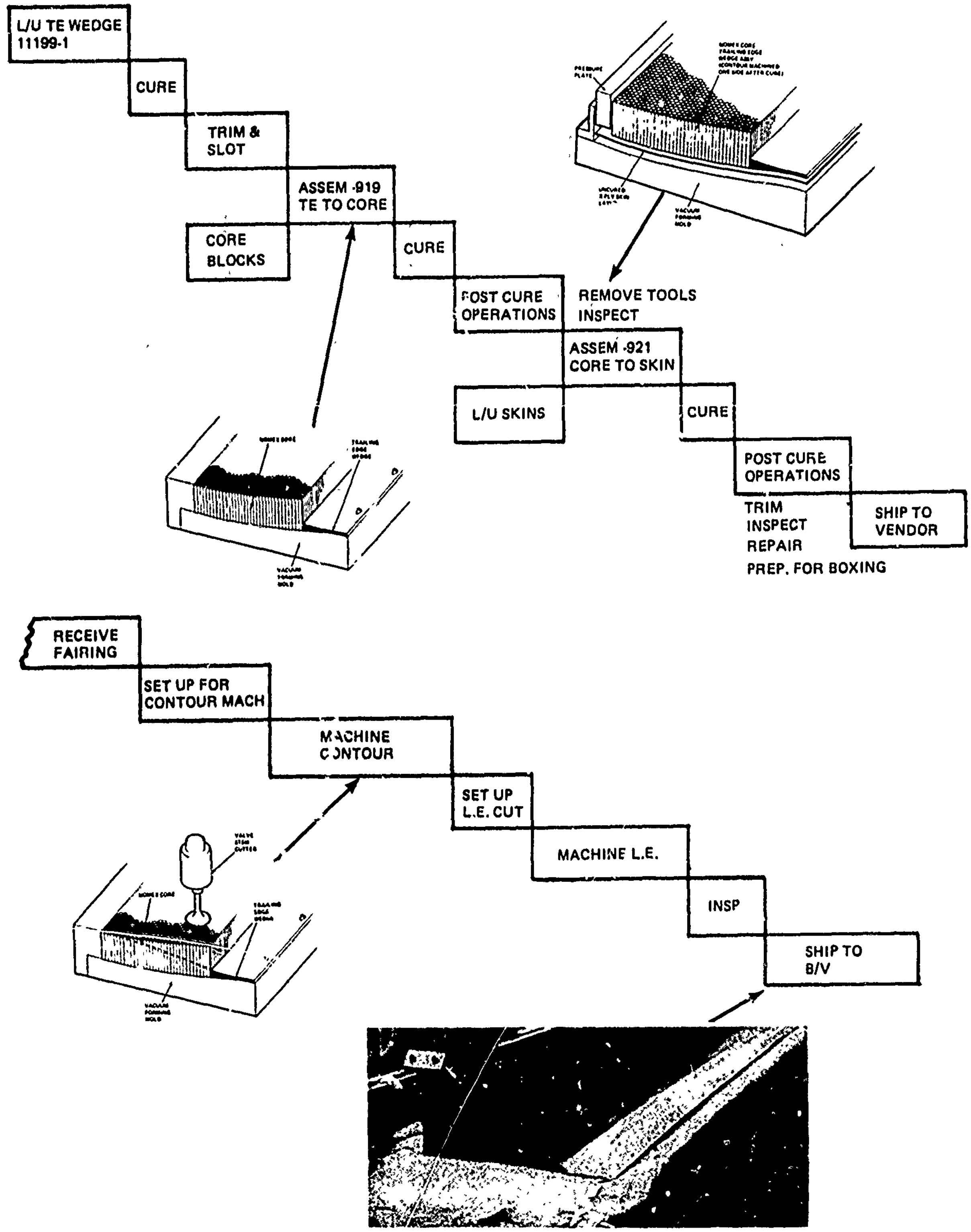


Figure 8. Fairing Fabrication Flow Chart

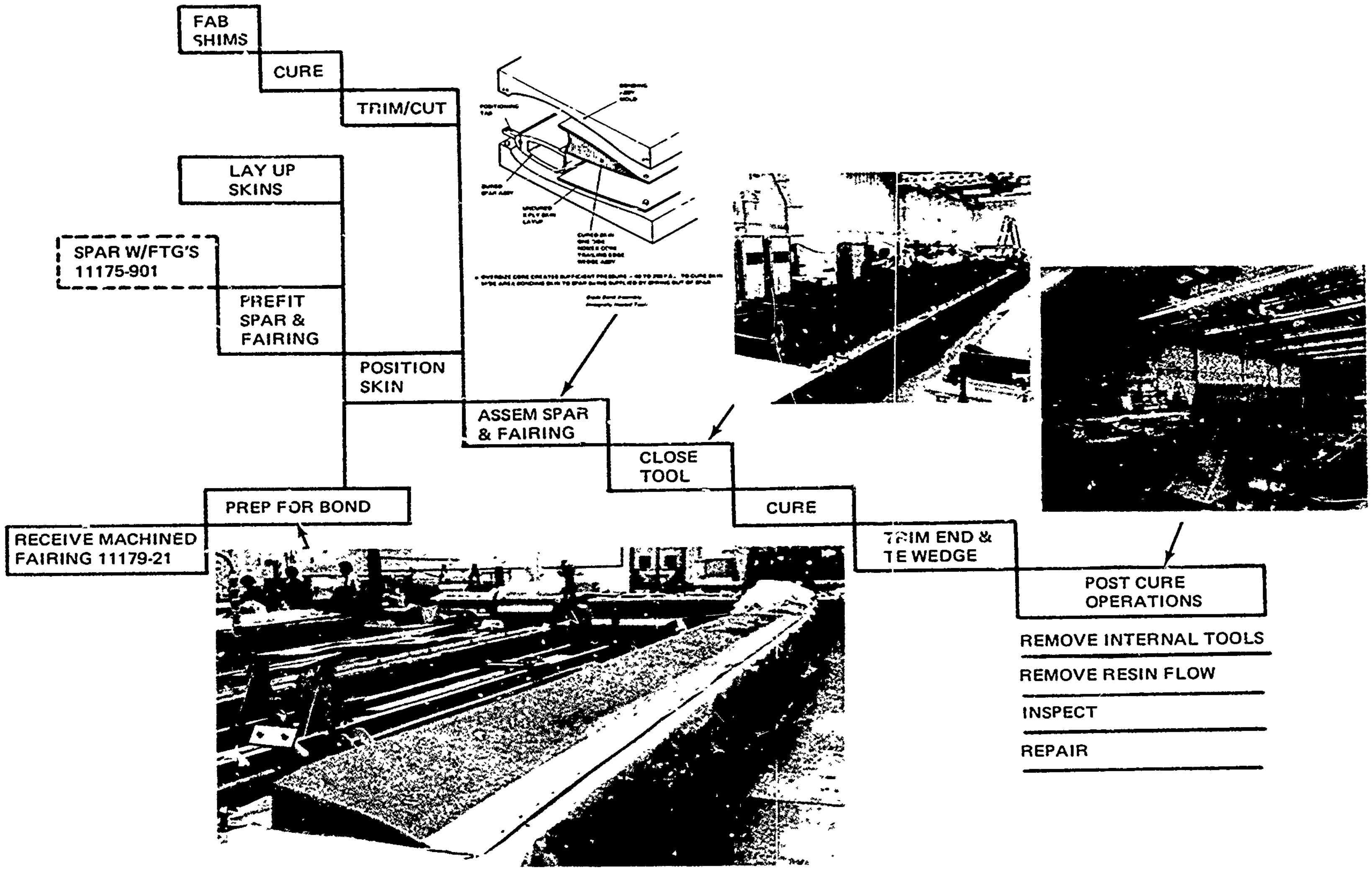


Figure 9. Blade Bonding Flow Chart

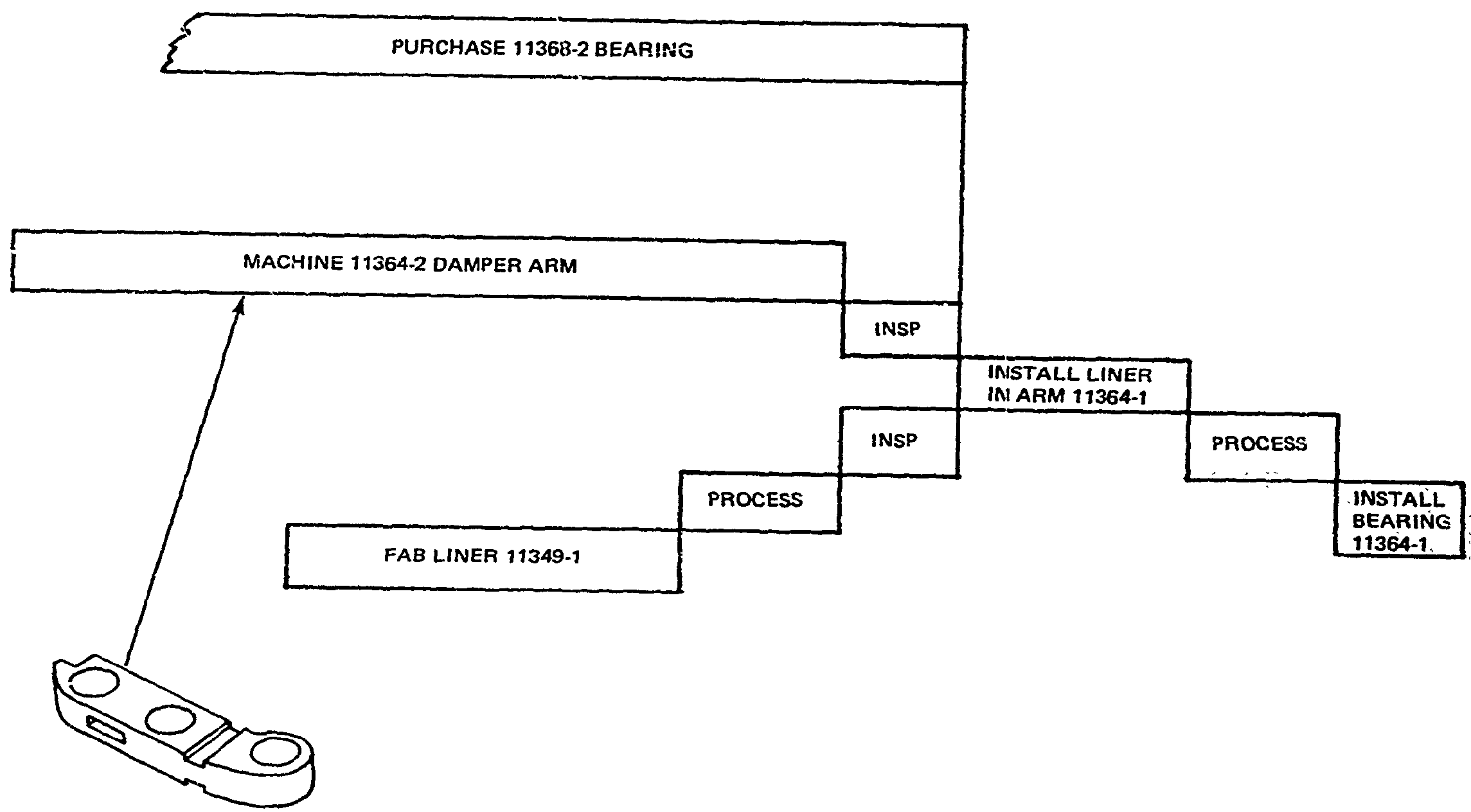


Figure 10. Damper Arm Assembly Flow Chart

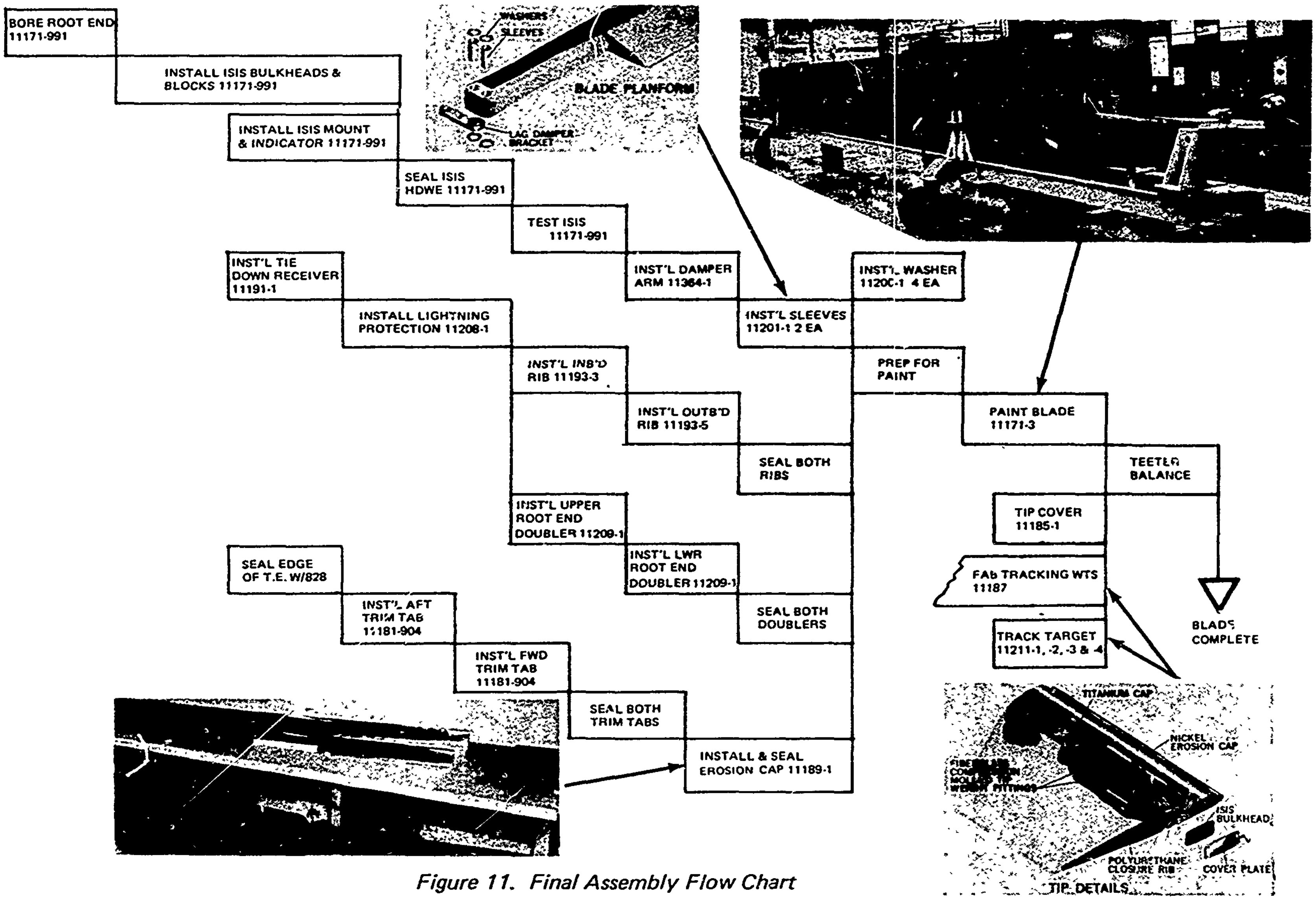


Figure 11. Final Assembly Flow Chart

TOOLING

At the outset of the HLH ATC rotor blade program, many decisions were required regarding the method of assembly and the type of tooling to be produced employing existing facilities wherever possible. The small quantity of blades to be produced dictated adoption of the most cost-effective tooling concept.

Tools were provided only when necessary. Lay-up tools and other less critical items were fabricated from wood or other inexpensive materials wherever possible.

The major concern of both HLH Engineering and Tool Design was design and fabrication of the root end of the blade. During this time, several engineering designs were considered.

They were, in order of development, as follows:

1. Double Coke Bottle Fitting (Figure 12a)
2. Single Coke Bottle Fitting (Figure 12b)
3. 10-inch Wraparound (Figure 12c)
4. Fittingless Root End (Figure 12d)

Tool Design and Fabrication

To prove the feasibility of these configurations and to establish the best tooling concept for producing them, a program was established to fabricate specimens of each root end design (blade Stations 66 to 138 approx). Various heat sources and tool materials were evaluated during the fabrication of these specimens.

Tool Concepts and Materials

Autoclave Cure - Plastic Molds

The Double Coke Bottle specimen (Figure 13) was layed-up on a bean bag and cured in a fiberglass tool in the autoclave. The bean bag was a contoured rubber bag made to the inner mold line (IML) of the spar minus a 30% bulk factor and filled with hollow aluminum balls. The bag was filled in a split mold to produce the contour, and then vacuum was

ROOT END CONFIGURATIONS

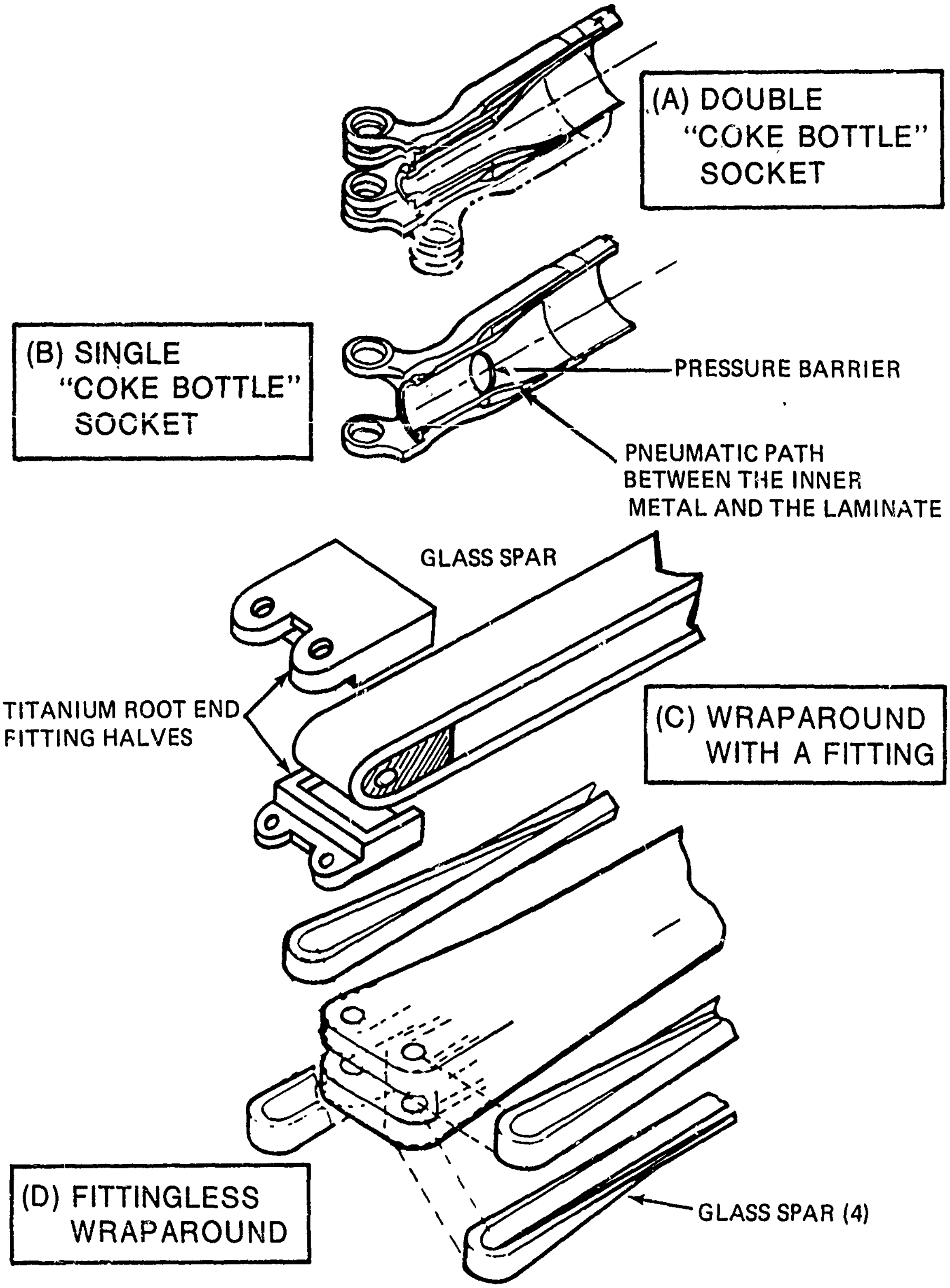
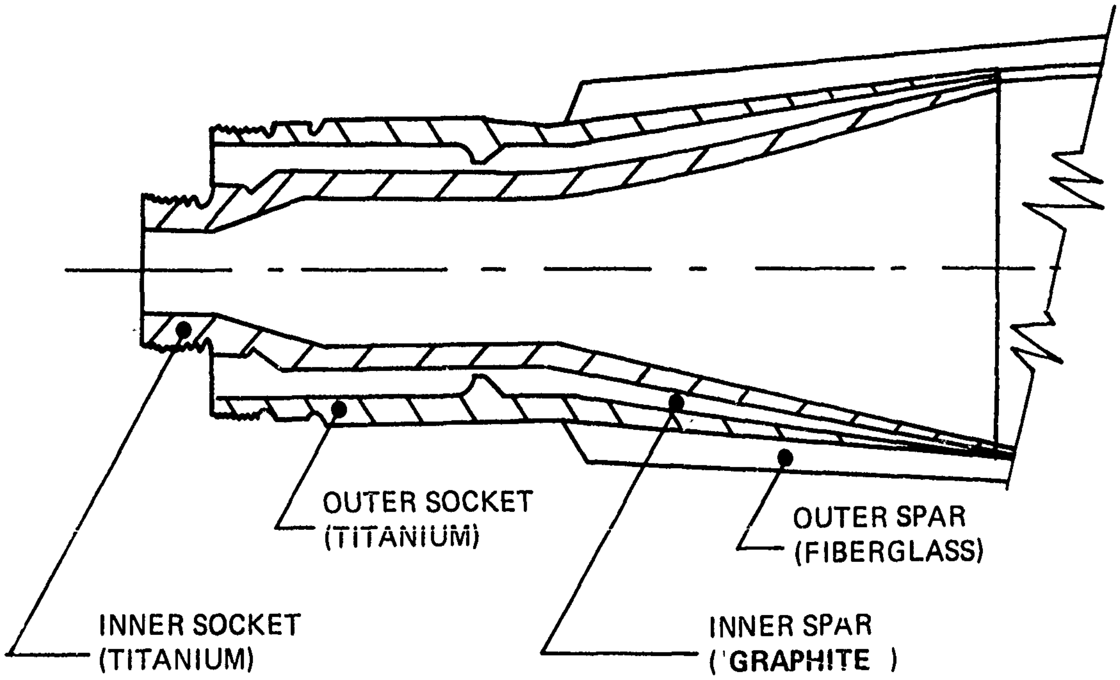
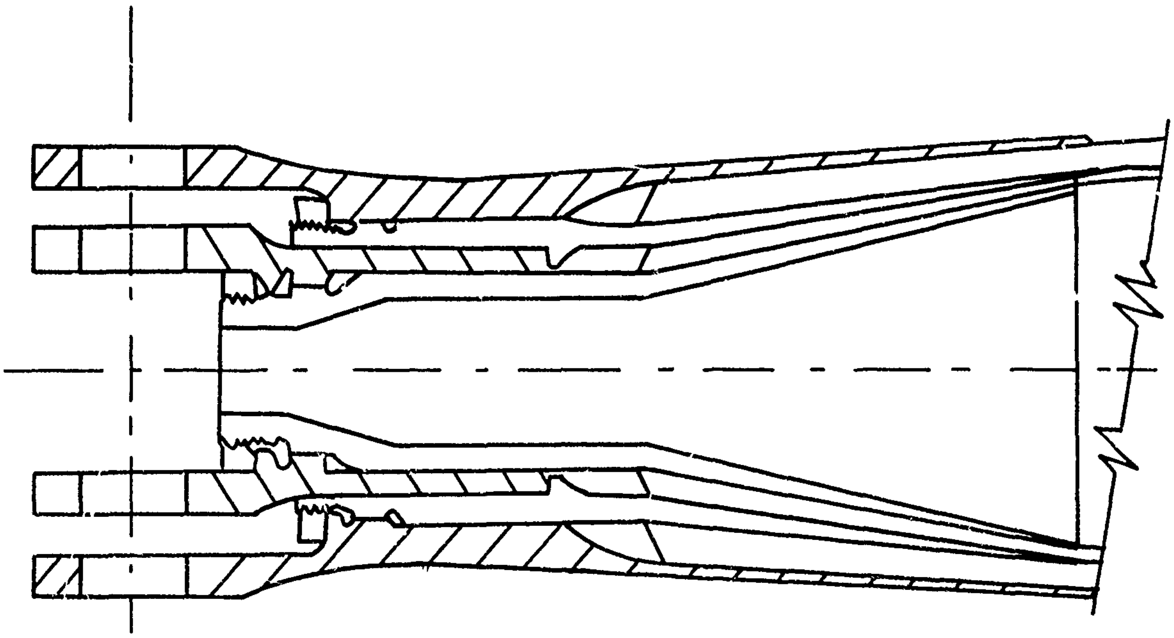


Figure 12. Root End Configurations Evaluated



DOUBLE COKE BOTTLE CONCEPT (SHOWN AS CURED)



DOUBLE COKE BOTTLE FITTING (ASSEMBLIED WITH OUTER SOCKETS)

Figure 13. Double Coke Bottle Fitting

pulled to produce a solid mandrel suitable for laying up the fiberglass details. Figure 14 illustrates buildup of the bean bag mandrel. Vacuum on the bag must be maintained during the full lay-up period and until the specimen is placed in the curing tool.

The coke bottle concept required that the titanium fitting be located outboard approximately 1 inch during lay-up and pulled to its true position during the cure cycle. This was required for applying pressure to the fiberglass laminate in the area around the fittings. In the case of a double coke bottle fitting, both fittings must be pulled independently and at different times, requiring tooling capable of operating at a temperature of 350° at 100 psi and being controlled from outside the autoclave. Hydraulics were not permitted due to possibility of contamination. A dual air plenum was therefore designed to operate with the autoclave pressure. During the cure, 100 psi was applied to the inside of the bean bag to cure the lamination. The specimen was successfully fabricated. However, the autoclave concept proved to have significant restrictions:

1. Insufficient length for a full scale rotor blade (estimates were obtained for adding ten feet to the existing autoclave).

2. Problems encountered in moving large and heavy fixtures in and out of the autoclave.

3. Difficulty in maintaining fixtures on a level plane during cure cycle.

4. Lack of adequate control.

Due to the above restrictions, it was decided to investigate integrally heated, self-contained tools.

While the coke bottle root end configurations were ultimately eliminated from further development, two significant conclusions were derived from these efforts:

1. The coke bottle concept proved that it was feasible to compact and cure large fiberglass structures using mechanical presses rather than fluid pressure.

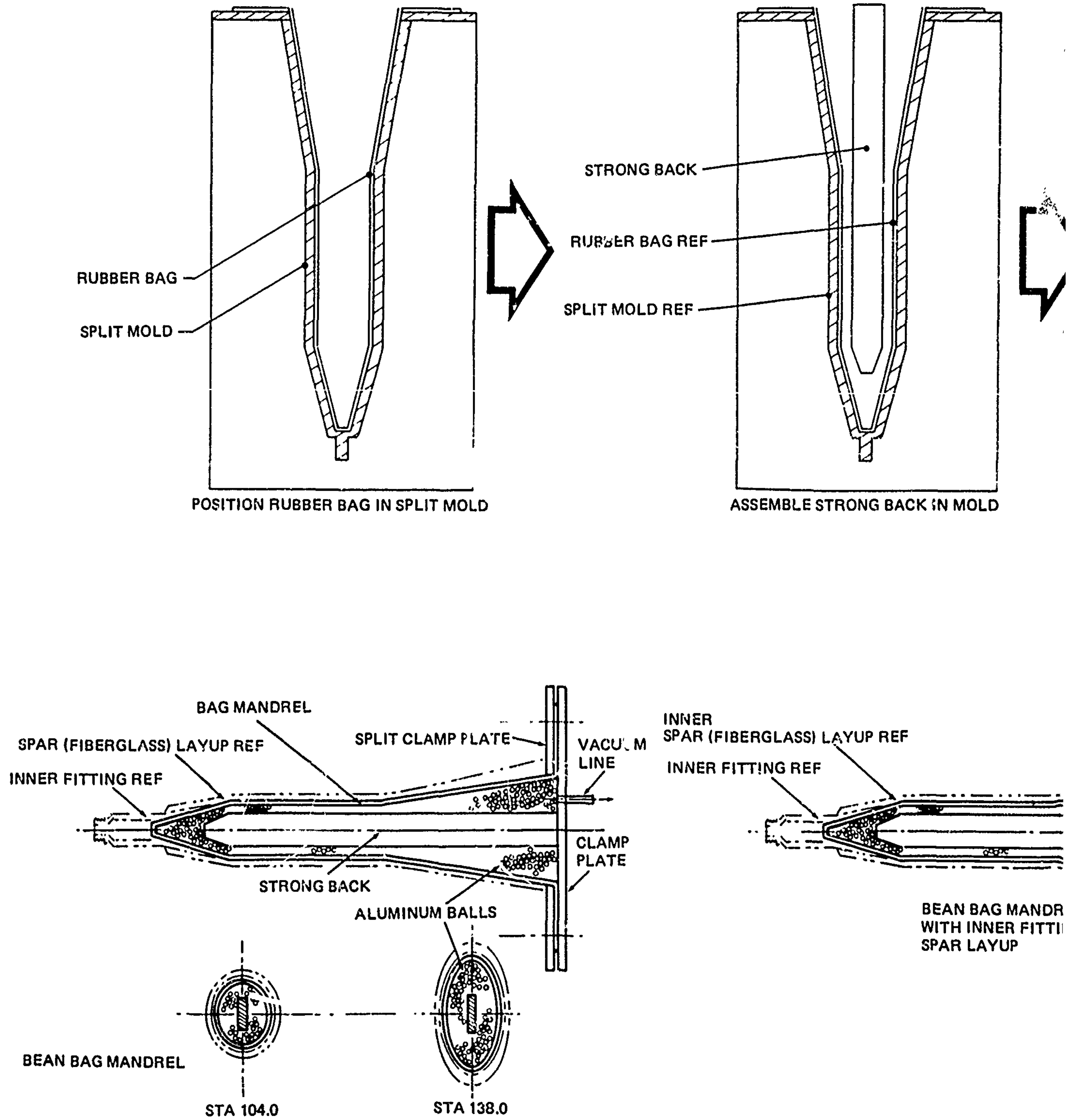
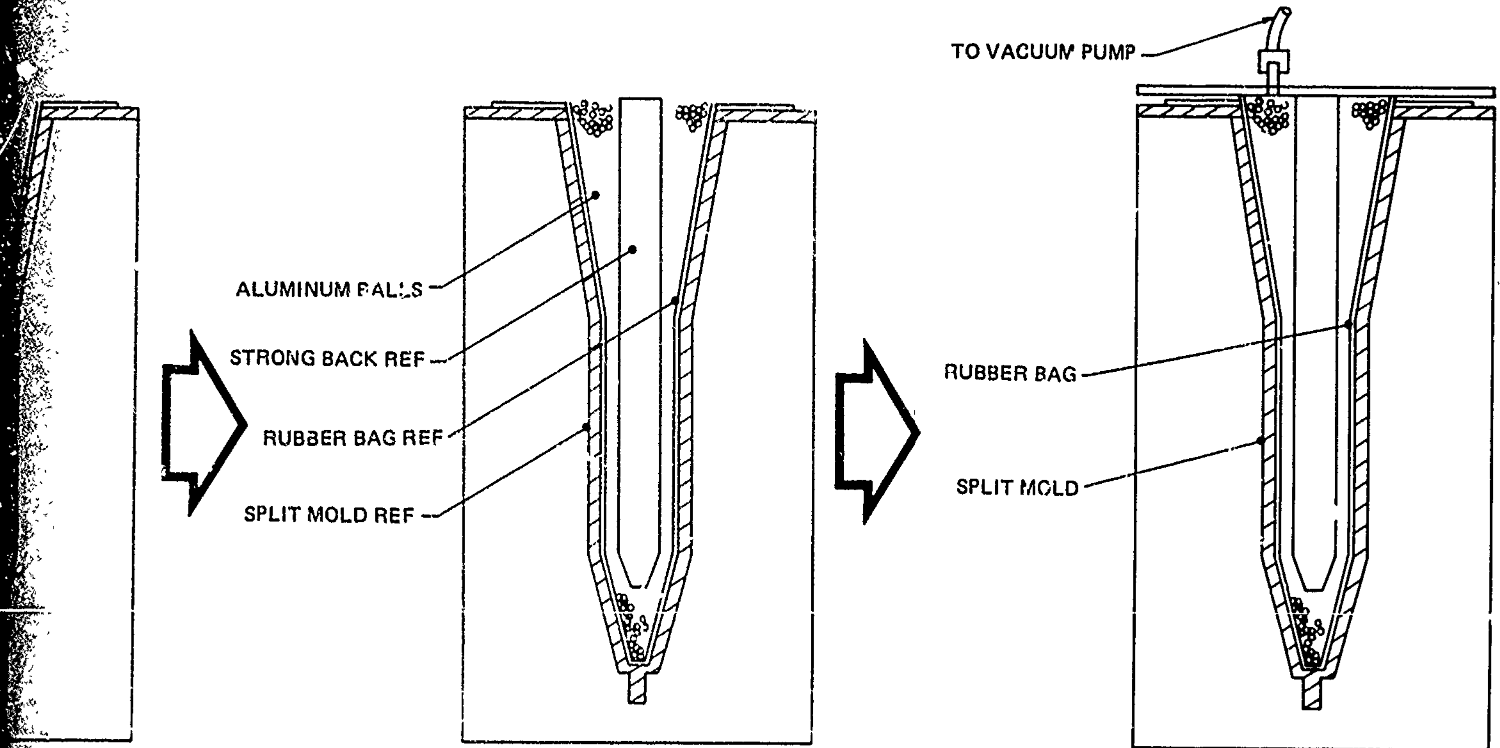


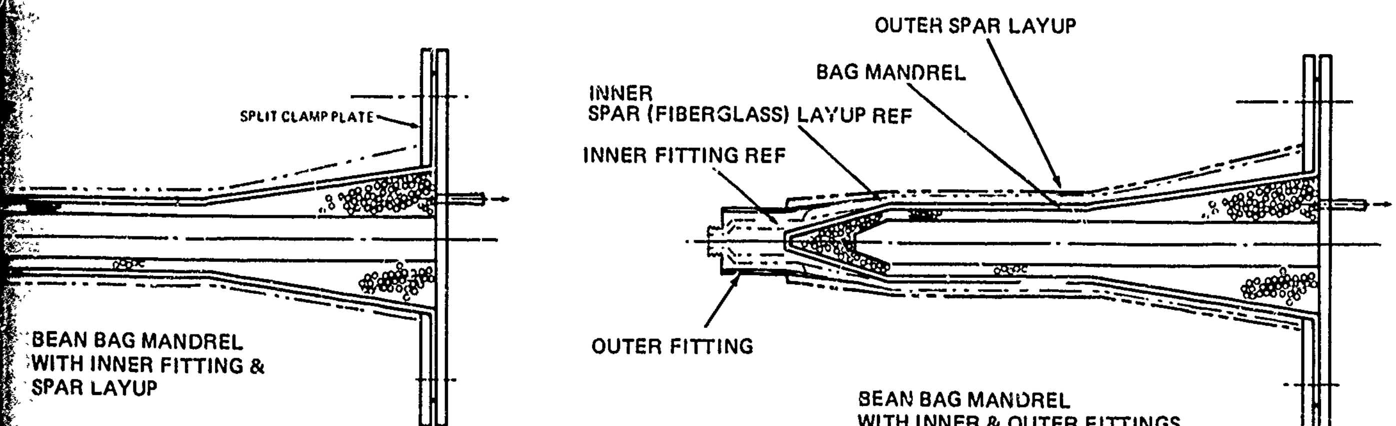
Figure 14. Fabrication and Buildup of Internal Bean Bag Mandrel



CK IN MOLD

FILL WITH ALUMINUM BALLS

VIBRATE TO COMPACT BALLS
ASSEMBLE CLAMP PLATES
PULL VACUUM
REMOVE SPLIT MOLD
(MAINTAIN VACUUM)



BEAN BAG MANDREL
WITH INNER FITTING &
SPAR LAYUP

BEAN BAG MANDREL
WITH INNER & OUTER FITTINGS
& INNER & OUTER SPAR LAYUP

2

2. Bleeder cloth layers with vacuum were necessary for degassing polymer resins during the cure cycle.

Integrally Heated Steel Tools

The second root end specimen was produced in a steel mold heated in a platen press and was intended to prove the integrally heated, self-contained tool concept. But by using it in the platen press, the high cost of adding heaters and controls was eliminated. The specimen was successfully fabricated.

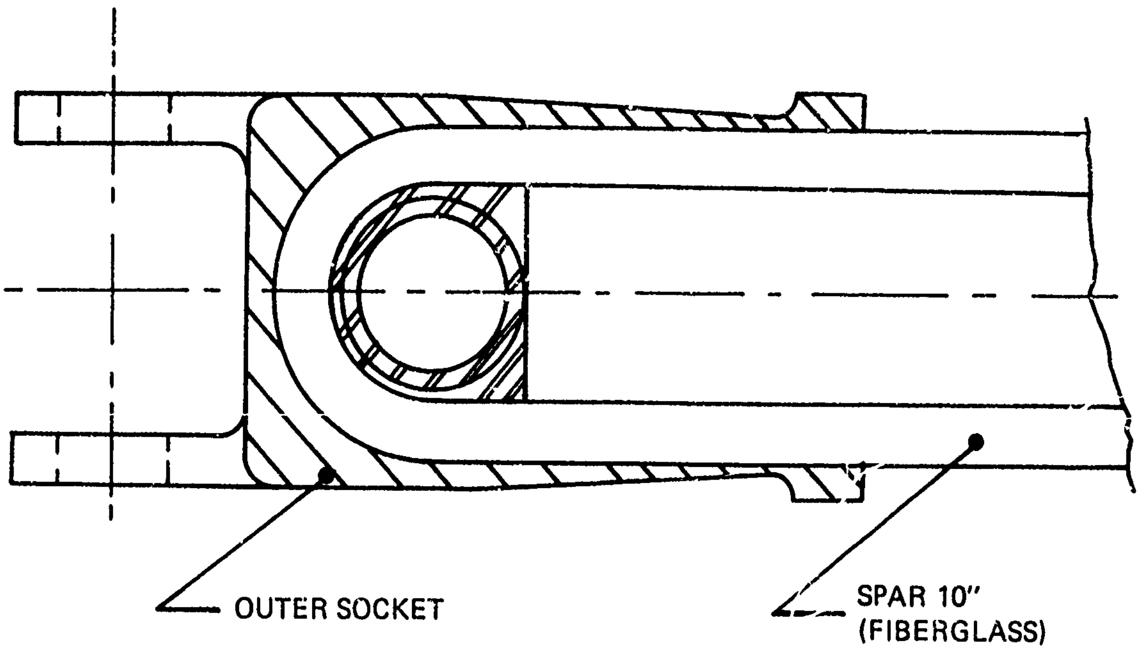
Another concept for a root end using steel tools and the platen press was evaluated. This concept was known as the "Ten-Inch Wraparound Fitting". The tooling effort on this concept (Figure 15) was limited to designing and fabricating a tool that would prove the feasibility of lay-up, compacting and curing of 10-inch wide by 1-inch thick Uni-Fiberglass material around a 2.5-inch radius.

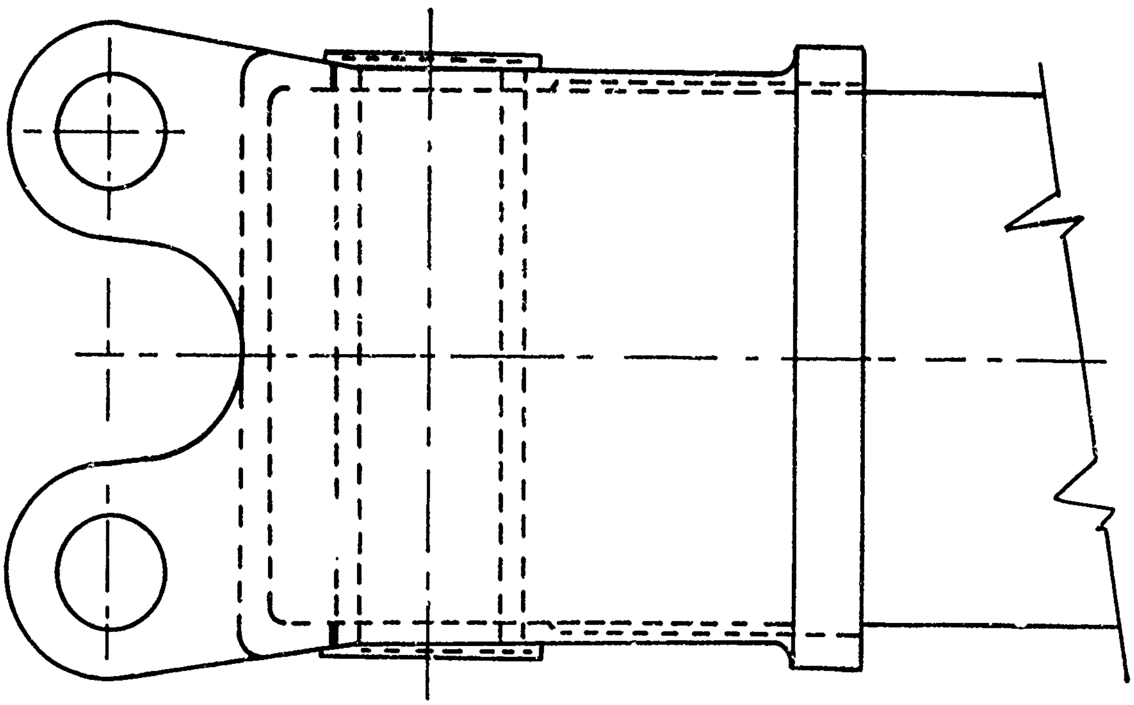
The tool was designed with a controlled or fixed outside radius (to simulate the OML of the blade) and employed an inner expanding mandrel.

The part was fabricated with good results; however, to use this type of tool with the bean bag for the outboard section would have created additional problems not encountered in the other configurations.

Integrally Heated Aluminum Tools

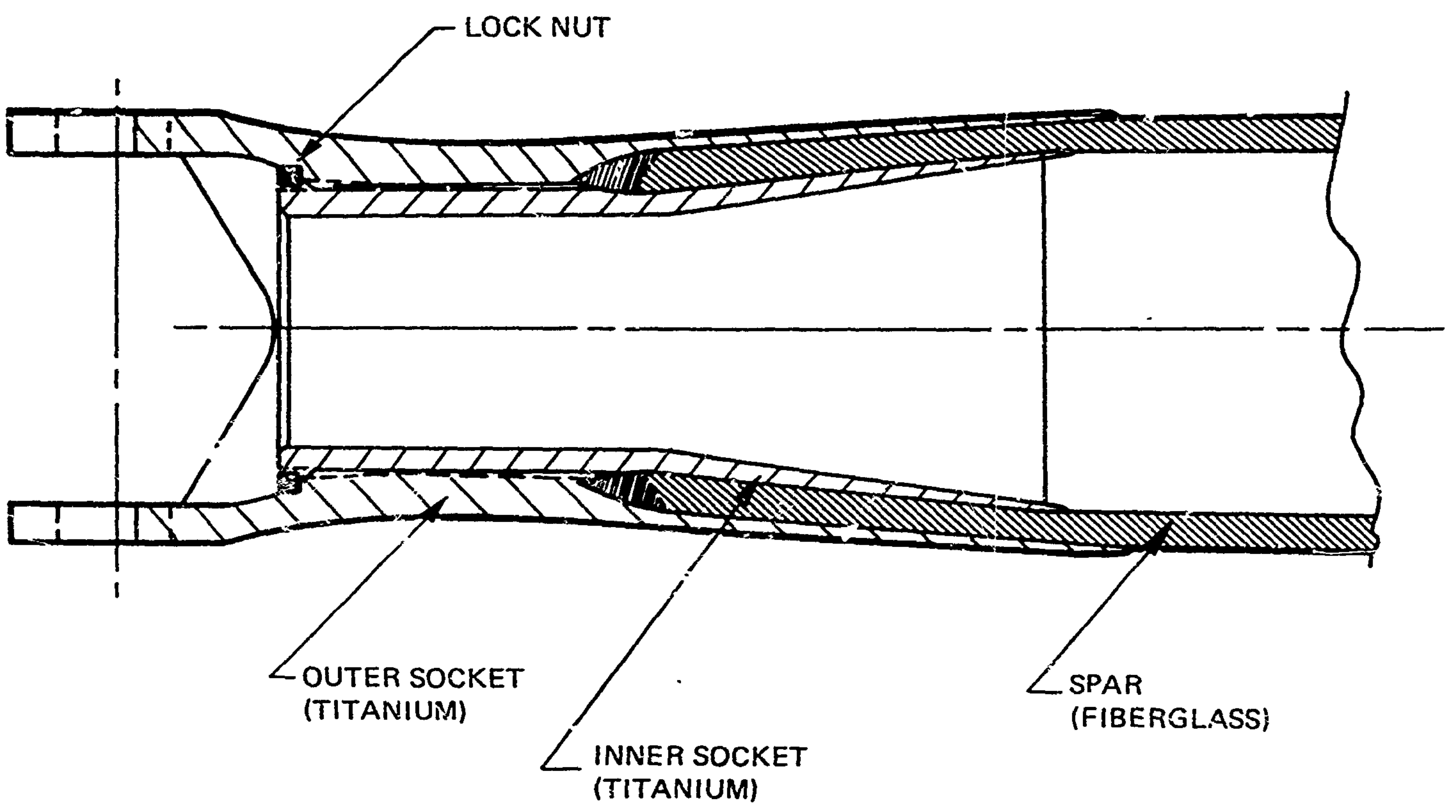
Since aluminum is a more suitable material for heating and significantly lower in cost to machine, it was selected for use in the blade molds. The disadvantages of aluminum are its softer tool surface, more subject to abuse during use, and its high coefficient of expansion relative to the fiberglass spar and titanium cap. It was preferred that a root end specimen be produced in an aluminum tool to evaluate the problems of expansion. The tool was made with the capability of producing the Double and Single Coke Bottle fitting specimens (Figure 16). The specimens were made identical to the specimen in the steel tool and were also heated in the platen press. The part showed some marking or wrinkling at Station 104 (approx) which was thought to be caused by unequal expansion. This was one of the contributing factors for later eliminating aluminum tooling.





10" WRAP-AROUND CONCEPT

Figure 15. Ten-Inch Wraparound Fitting



SINGLE COKE BOTTLE FITTING (ASSEMBLED WITH OUTER SOCKET)

Figure 16. Single Coke Bottle Fitting

Final Tooling Selection - Integrally Heated Steel Tools

Using data for the previous root ends that were produced (Figure 17), the decision was made to produce an integrally heated steel tool to the new engineering design capable of making the test piece and, upon completion, being adapted to a full length tool. It was at this stage of the program that the fittingless root end configuration (Figure 18) was designed. The part was cured, and the design proved successful; Engineering, however, re-evaluated the design and minor changes were made that eliminated some detail parts resulting in changes to the outer mold line. The fittingless root end, or "wraparound" root end concept, with integrally heated steel tools was selected in the first quarter of 1972 for full-scale blade tool fabrication.

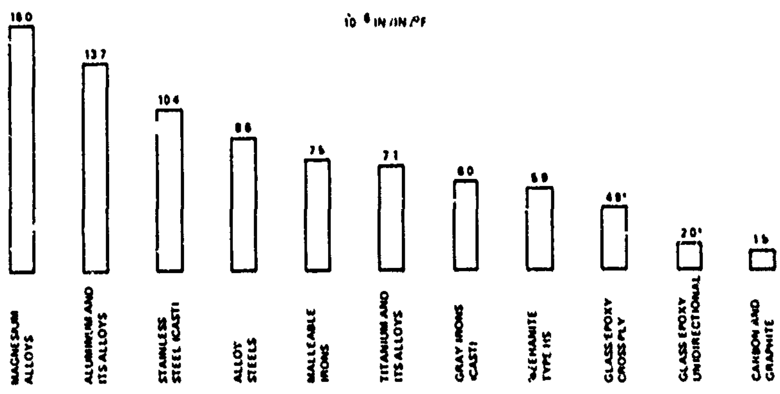


Figure 17. Coefficient of Thermal Expansion Comparisons

Methods of Heating

Throughout this period, numerous layouts and studies were performed, and evaluations from all areas were considered to determine the most efficient means of heating the two major bonding fixtures required for producing the HLH Rotor Blade. They were:

1. Spar Bonding Assembly Jig, BAJ SK301-11173-1 with a gross weight of 16,000 lb and dimensions of 20 in. by 24 in. by 42 ft. See Figure 36, Spar BAJ.

2. Final Assembly Bonding Fixture, BAJ SK301-11171-1 with a gross weight of 32,000 lb and dimensions of 20 in. by 50 in. by 42 ft. See Figure 50, Main BAJ.

Some of the heating systems considered were:

1. Liquid: Hot oil, Dow Therm, etc.

2. Steam: Super heated - high pressure

3. Electric: Strip heater, calrods, radiant vs. conductive, heat blankets, quartz lamps

Liquid Heating Systems

The major obstacle in employing an oil or oil base liquid for heating bonding tools is contamination. Unless tools can be designed so that the lines do

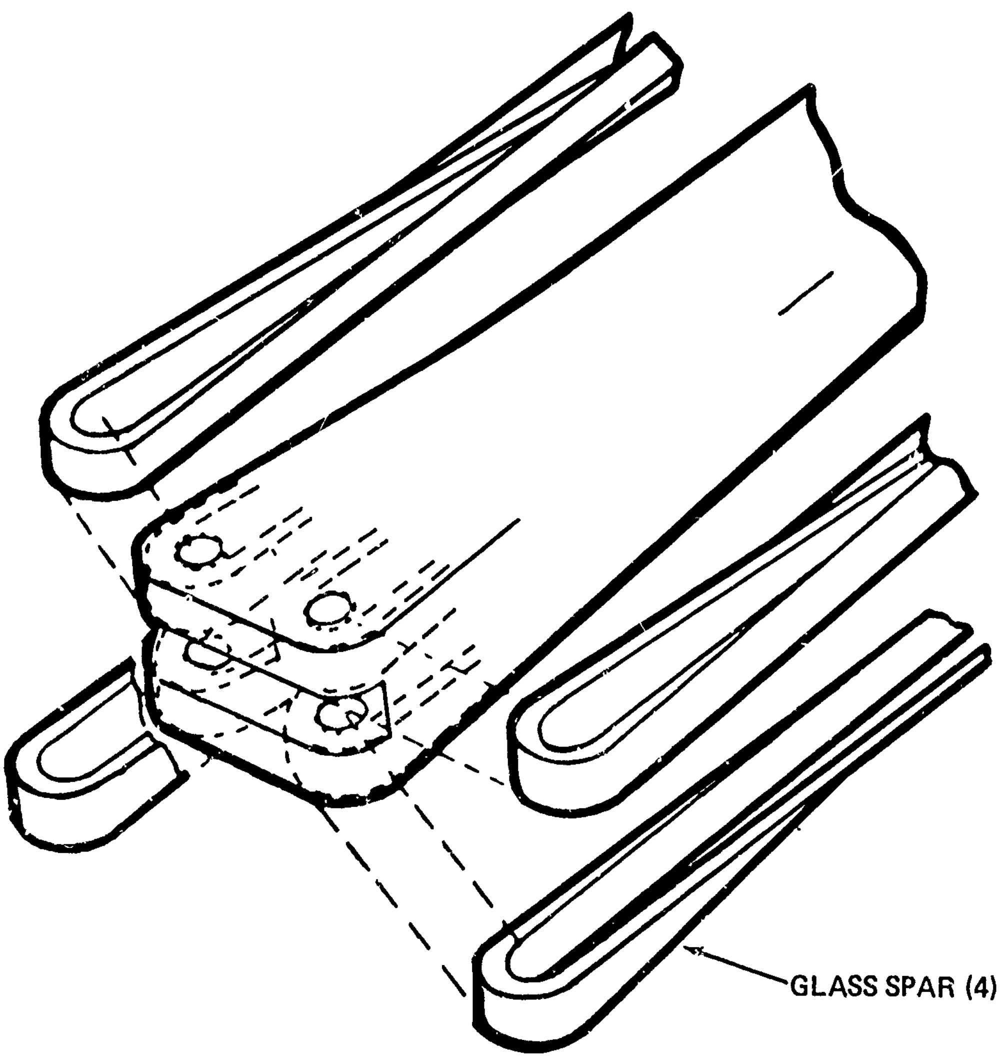


Figure 18. Fittingless Wraparound

not require disassembly for loading or unloading of the parts, there is always a high risk of part contamination which could cause bond voids. A good example for use of oil heat is the platen press (Figure 19); the oil is circulated through a closed loop within the platens and through flex lines (which are never disassembled) to and from the heater and pump. The tools (normally less than 6 ft long with essentially constant sections) are placed in the press, and heat is applied to the tool from both top and bottom. The platen press concept was considered for the HLH blade fixtures; however, the large overall size and weight of these rendered mechanization of this concept impractical. It should be noted that, for platen press tools to be most efficient, full contact should be made with the platens to conduct heat into the tool, thereby eliminating any coring or ribs that result in a much heavier tool. It should also be noted that zone control (higher or lower heat in specific areas of the tool) in the platen press requires special plumbing and incurs additional costs. The HLH blade spar changes shape from a 9-in. by 12-in. section (approx) with a 0.5-in. wall thickness at the root end (Station 66) to a 3-in. by 16-in. section (approx) with a 0.18-in. wall thickness at the tip end (Station 552). See Figure 20.

With unknown exothermal problems created in the curing of plastics, there was a greater need for more zone control than was practical with the platen press concept. This type of tool weighs approximately 2-1/2 times more than a cored or ribbed type tool and also requires more energy to both heat up to the required temperature and to cool down to the handling temperature.

Using a liquid heat device other than the platen press requires casting or machining the heating coils into the bonding fixtures. This results in better zone control; however, the cost of doing this, if practical, would be excessive. Tools of this type are not as mobile as others and require a more exotic mechanism for opening and closing without breaking oil lines to eliminate the contamination factor. In any of the foregoing concepts, a special facility for heating the oil and a heat exchanger for cooling the oil are required.

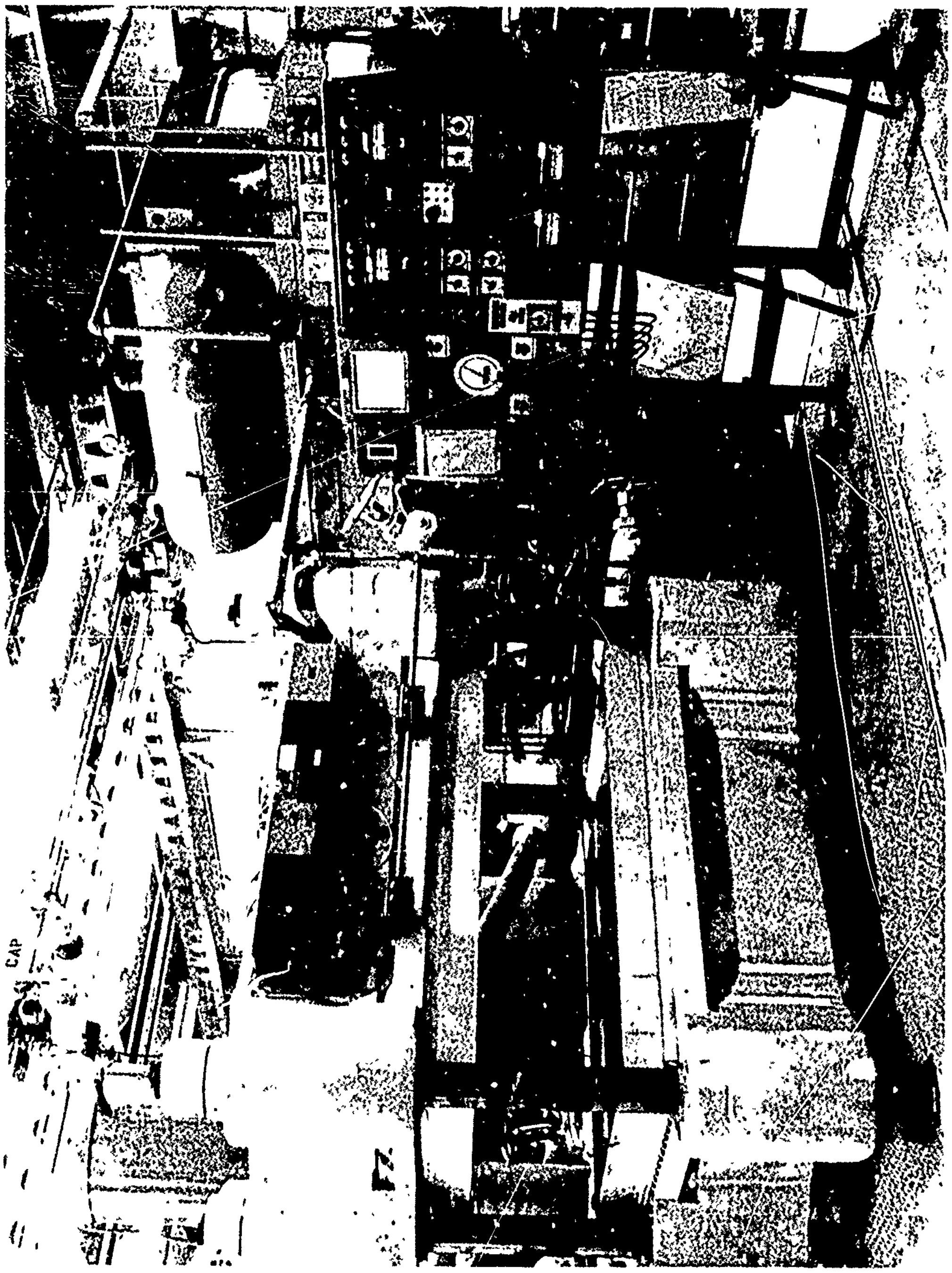
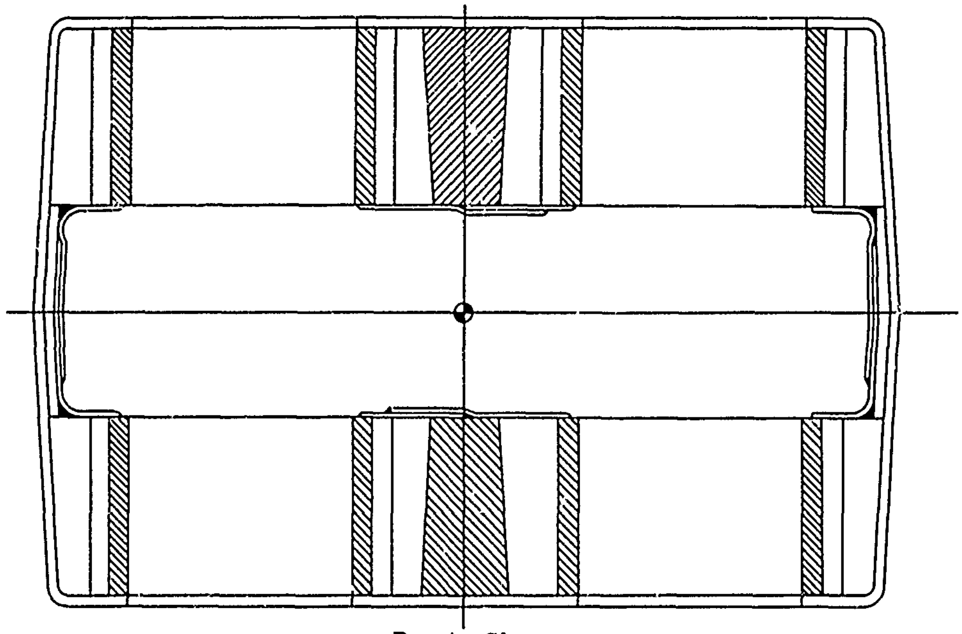
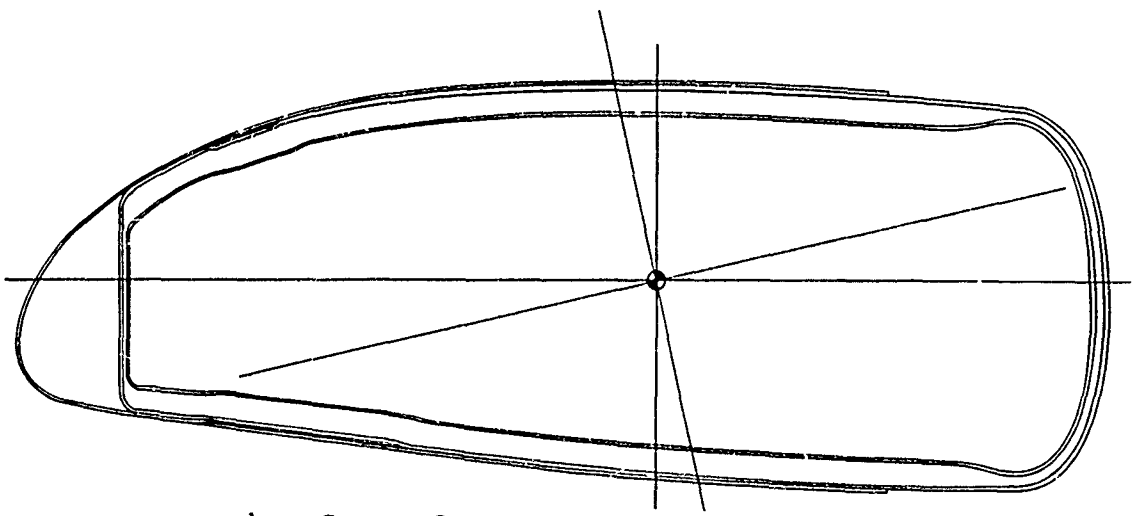


Figure 19. Platen Press



a. Root Shape.



b. Spar After Transition to 'D' Section

Figure 20. HLH Blade Spar Shape Transition

Steam Heated Systems

Steam heated systems are basically the same as oil or liquid heated types with the following exceptions: (1) steam systems do not have the contamination problem; and (2), due to high pressure requirements, safety becomes a problem. Acquisition of a boiler and the possibility of having to obtain a licensed operator resulted in rejection of this concept.

Electrically Heated Systems

Several types of electric heaters were investigated before selection of strip heaters for use in the major tools. The airfoil shapes and sections (tooling), required to withstand 80 to 100 psi, were more adaptable to a flat strip type of heater that could be formed to the tool as required. (Figure 20).

Heater Control System

Reviewing the control systems that were used over the past twenty years for self-contained blade bonding fixtures for CH-46, CH-47, and some experimental programs, a definite pattern of refinement could be seen. With each new model or program, the type of controls advanced with the state of the art. For example, early blade fixtures were designed with variable transformers to regulate the voltage to each zone of heaters. A thermocouple was placed in each zone to sense the temperature, and a readout was obtained on a recorder. This required a skilled operator to regulate or control the variable transformers in relation to the recorder. It is basically a simple procedure until multiple circuits are used (which is normally the case). Maintaining all the zones at the same temperature ($\pm 10°F$) then becomes hard. It should be noted that, with most of the adhesives and resins used in rotor blades, a controlled heat-up and cool-down is also requisite, adding to problems encountered by the operator.

As time went on, more equipment became available that would allow the operator to preset a control to some predetermined temperature; the equipment would then turn the heater on and off in response to a thermocouple. Although this was an improvement, the sensitivity of some of these controls was not fine enough to maintain the $\pm 10°F$ tolerance required.

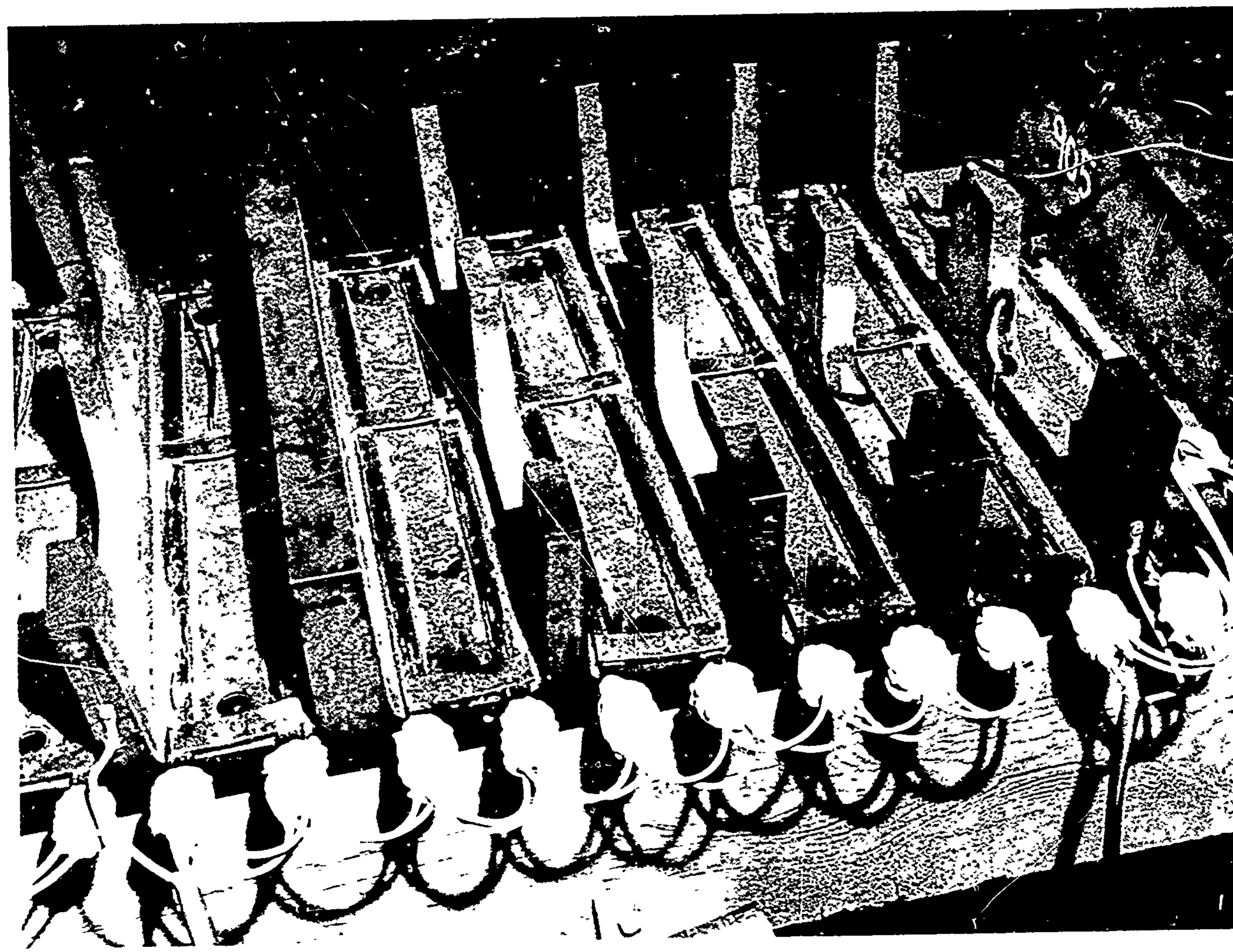


Figure 21. Strip Heater

The cost of providing this type of control system for the HLH rotor blade tooling, estimated to require sixty control zones per fixture, would have far exceeded the proposed budget.

The current state of the art for controls is the use of a fully computerized system, employing direct digital control techniques. This type of control was considered requisite for the large, complex type of tools used in our program; the cost of this system, however, was prohibitive.

After a complete review of the schedule for producing HLH blades and because of the limited quantity (9), it was determined that, by providing a common base to be used for all major bonding fixtures, tooling costs could be reduced with only a minimal increase in production time.

It was then decided to purchase a 60-zone computer-controlled ON/OFF switching control system as a facility item; the control system could be used for any program of this type, such as the UTTAS, ATB, etc. See Figure 22, computer controlled switching control system.

During the cure of the first tool proving spar, computer control system operation proved that it was capable of automatically controlling zone temperature to within engineering's specification limits, as shown in the heat chart, Figure 23.

At the beginning of the ATC Program, it was decided by Engineering and the Material Groups that the maximum heatup and cool-down rate would not exceed 6°F per minute. All the major bonding jigs were designed with heaters capable of meeting the 6°F heat-up, and the universal restraining fixture was designed and built with a forced-air cooling system.

The only restriction to curing the blade at the 6°F heat-up rate was the ability of the blade to absorb the heat at this rate. Because of this, the thick sections in the root end area became the controlling factor.

The common base, or as it is better known, the universal restraining fixture FMIT SK301-10167 (Figures 24 and 25), was designed with power plugs and thermocouple jacks wired into the control unit so that any fixture could be heated. The base was built with a system of T slots for mounting various size fixtures and maintaining them in a plane through the cure cycle. A cover was provided over its full length to eliminate heat loss and also to give more uniform heat to the fixtures (Figure 23).

Figure 22. Computer Based Heat Cycle Controller

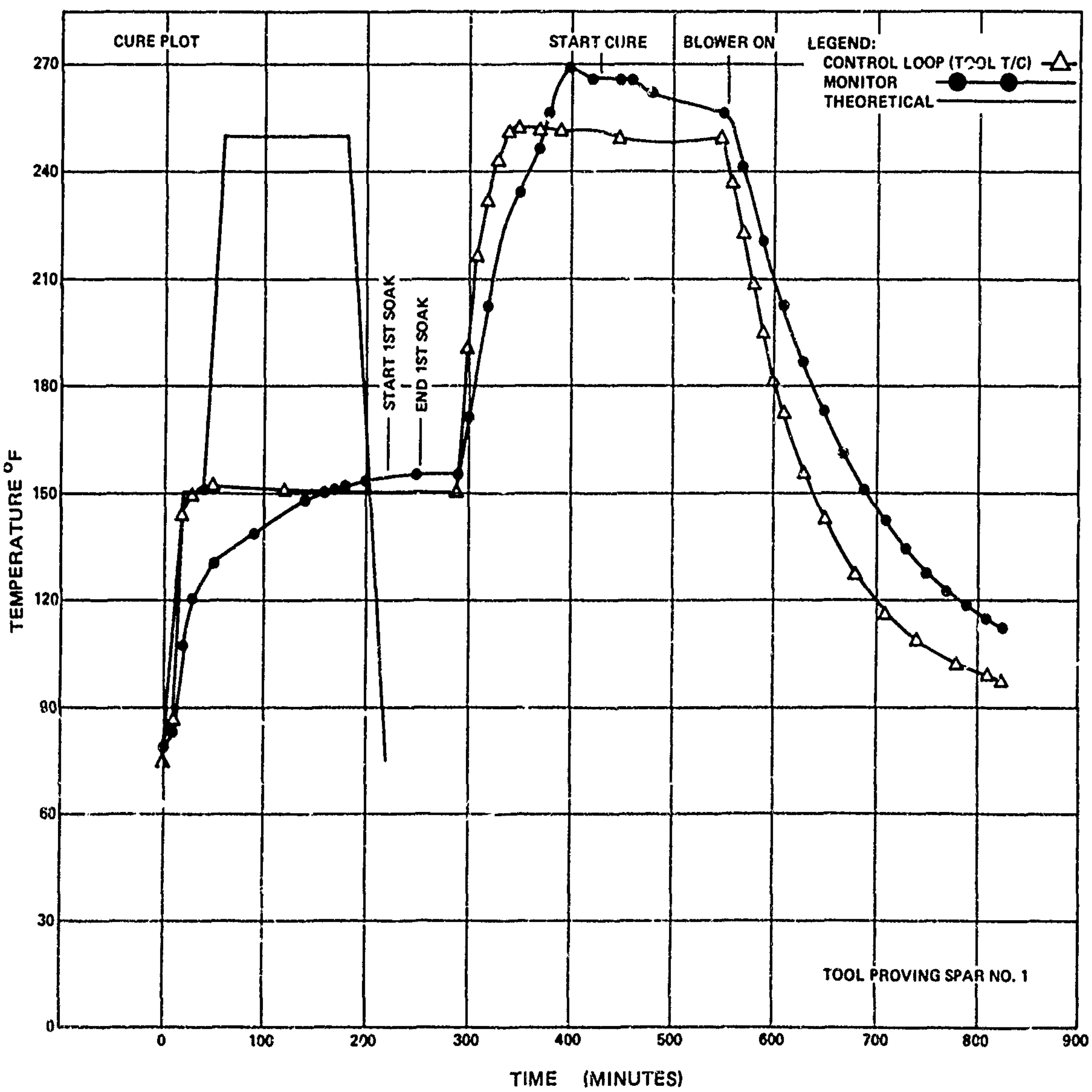


Figure 23. Spar Curing Operation Heating Cycle

The restraining base also has an integral air system used for cooling the fixtures at the end of a cure cycle. The base and the control unit performed as they were designed to do; the only problems encountered were some malfunctions of the computer unit. Replacement of some units was made, and the system performed well for the remainder of the program.

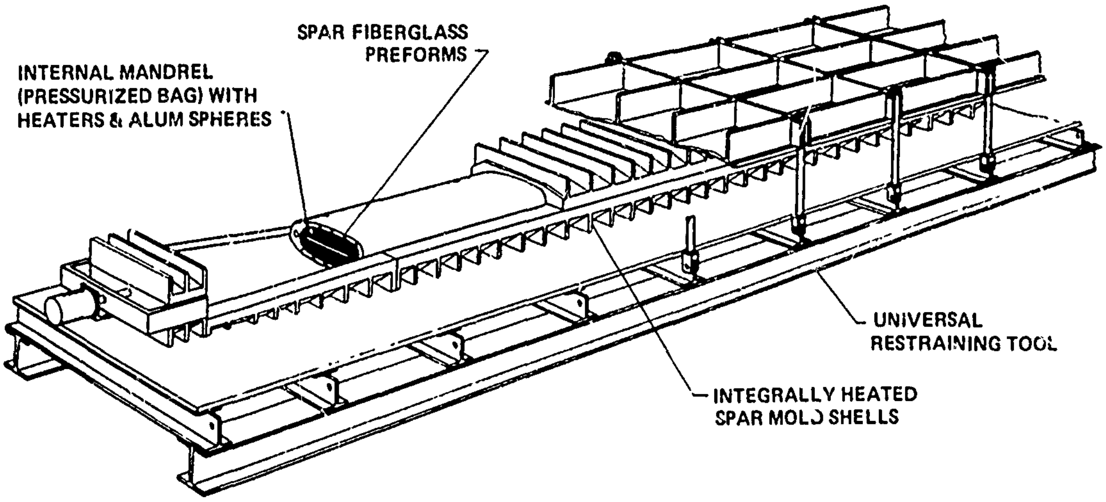


Figure 24. HLH Blade Spar Curing

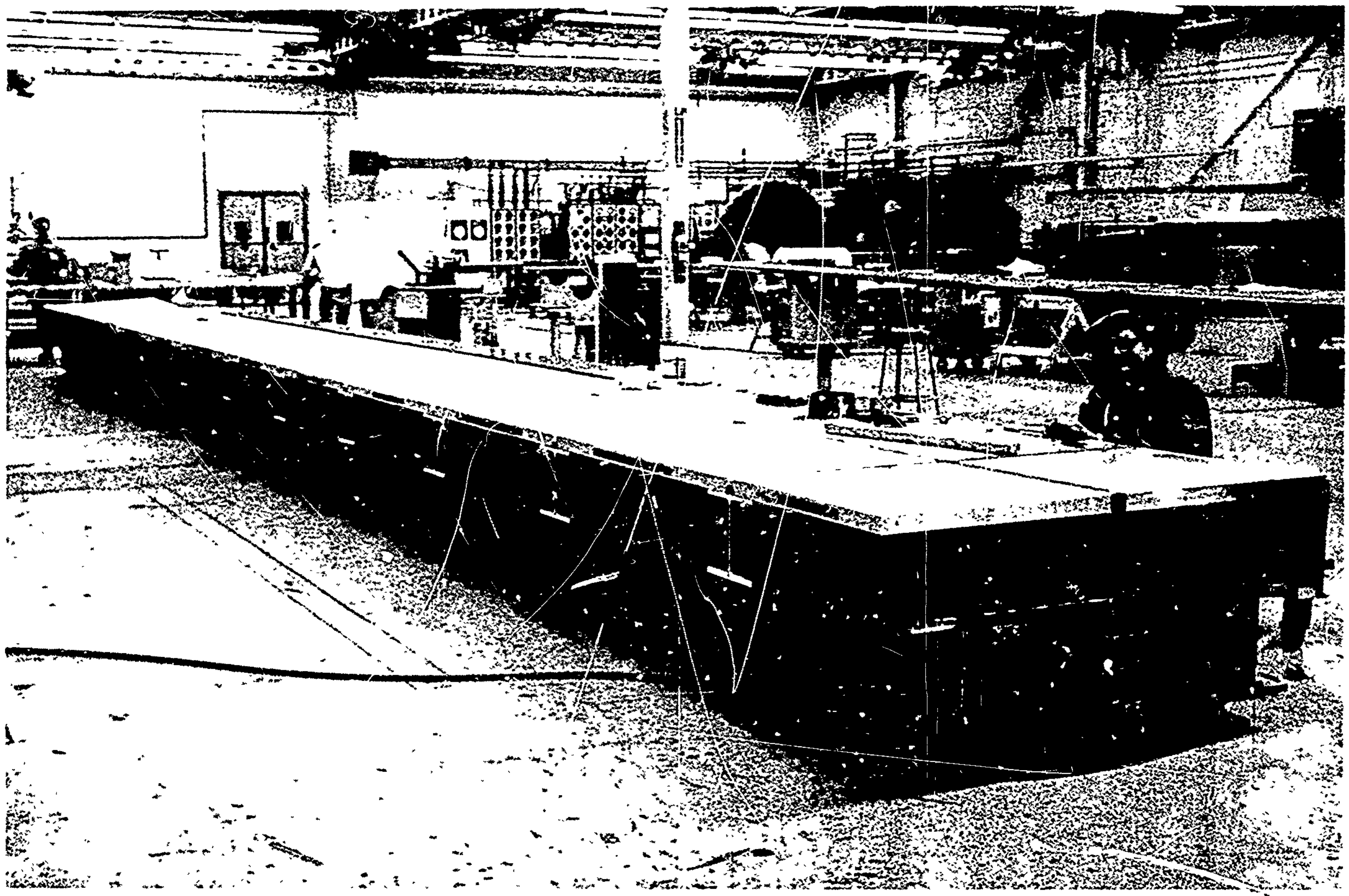


Figure 25. Fabrication of Universal Restraining Base

Forming Titanium Leading Edge

The HLH Rotor Blade is designed with a titanium cap 0.05 in. thick and extends from the leading edge of the blade back 13.47 in. toward the trailing edge and spanwise from Stations 104 to 552.

It is formed to the true OML of the blade and later is cured along with the spar. Forming of this part became a problem for several reasons; the most significant of which was the lack of experience throughout the industry for forming titanium. The OML of the blade has a changing airfoil that, along with twist, made the task even more difficult. The changing airfoils require stretching in some areas and shrinking in others throughout the 40-foot length. The best results for forming titanium have been achieved by forming the part at elevated temperatures (1400° to 1600°F).

Several pieces of titanium were formed at Boeing Vertol during early stages of the ATC Program. These pieces were approximately 0.016 in. thick by 3.0 in. from L.E. to T.E. and 3 ft long. Pieces were manufactured to develop the method of forming and to be used at a later date for blade samples.

The parts were produced by first preforming the leading edge radius on a brake using a conventional punch and die. Ceramic dies (male and female) were then made to finish-form the part in an oven. The female die (upper portion of the tool) was made to the OML of the part, and the male die (lower section), to the OML minus the material thickness. The titanium part was located on the male die with the female die suspended over it. At this time the upper die (female) did not touch the titanium part. The ceramic dies and the part were then placed into a furnace and brought up to heat (1450°F). Both the dies and the part were heated to 1450°F. At this time, the upper die was lowered onto the part and the lower die; guides were provided in the die for alignment. The upper die was designed so that it would have sufficient weight to form the hot titanium part over the male tool. The dies and part were then allowed to soak at this temperature and then allowed to cool to room temperature before removing the part from the dies. Inhibiting material was applied to the titanium preformed parts before final forming to prevent scaling. The results of forming the parts were good;

however, the ceramic dies developed cracks toward the end of the program and would not have been acceptable for producing any additional parts.

Boeing Wichita was selected to form the titanium caps since they had a furnace large enough to handle the full length titanium cap, thereby eliminating the cost of developing such a facility.

Using information gained through our test program and knowledge they acquired on previous programs, Boeing Wichita designed and built a male tool (CFF SK301-11174, Figures 26 and 27) made from Inconel 802 material. The major differences between Boeing Vertol's test tooling and Boeing Wichita's tooling is choice of material and elimination of the female die. The Inconel 802 material is one of the better materials for use at high heat. The tool was NC machined for contour from the blade MDI (Master Dimension Information). The base portion of the tool was core drilled to reduce mass (less mass, less cost to heat, etc.), and the tool was fabricated in sections to allow for expansion.

Forming of the titanium leading-edge cap was performed by placing the titanium sheet material over the forming tool and attaching weights along both edges. The weights applied amounted to 7-1/2 lb/inch/side. This tended to wrap the material over the mandrel. An additional 1200 lbs in the form of a weighted nose blanket was added to the outboard end of the cap. The tool and cap were then loaded into the furnace, and the temperature was raised to 1500°F. They were then allowed to soak for a little less than two hours. This time and temperature kept scaling to a minimum, and the phosphate flouride etching required was kept in the region of 0.008 inches.

Figure 27 shows the formed titanium cap with weights attached after removal from the furnace.

For the short time allotted to the development of full length tooling, results were good. The major defects in the eight titanium caps produced for the ATC program were:

1. Form of radii at L.E. was oversize
2. Outboard section from Station 469.2 to the tip (Station 552) had a chordwise bow.
3. Buckles and caves in the outboard area

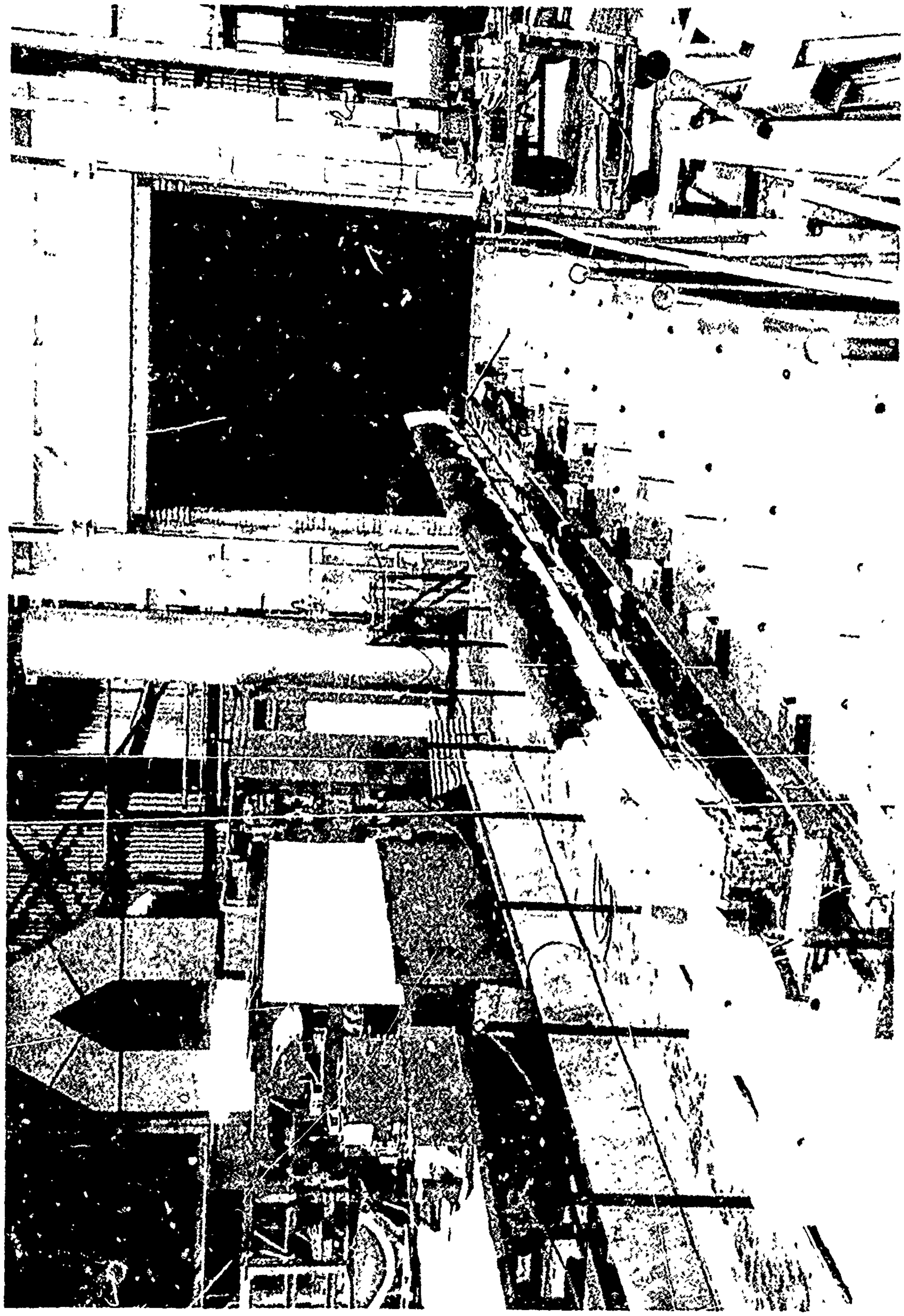


Figure 26. Titanium Cap Forming Tool with Base

Work to eliminate the above problems is continuing; the conclusion at this time is that any additional caps to be fabricated will be within engineering drawing tolerances.

The leading edge radius of the Inconel mandrel will be reduced to correct the oversize condition on the cap. The outboard section of the mandrel is to be moved chordwise approximately 0.150 inches to correct the bow; better control of expansion (part vs. tool) should help remove the buckles and caves.

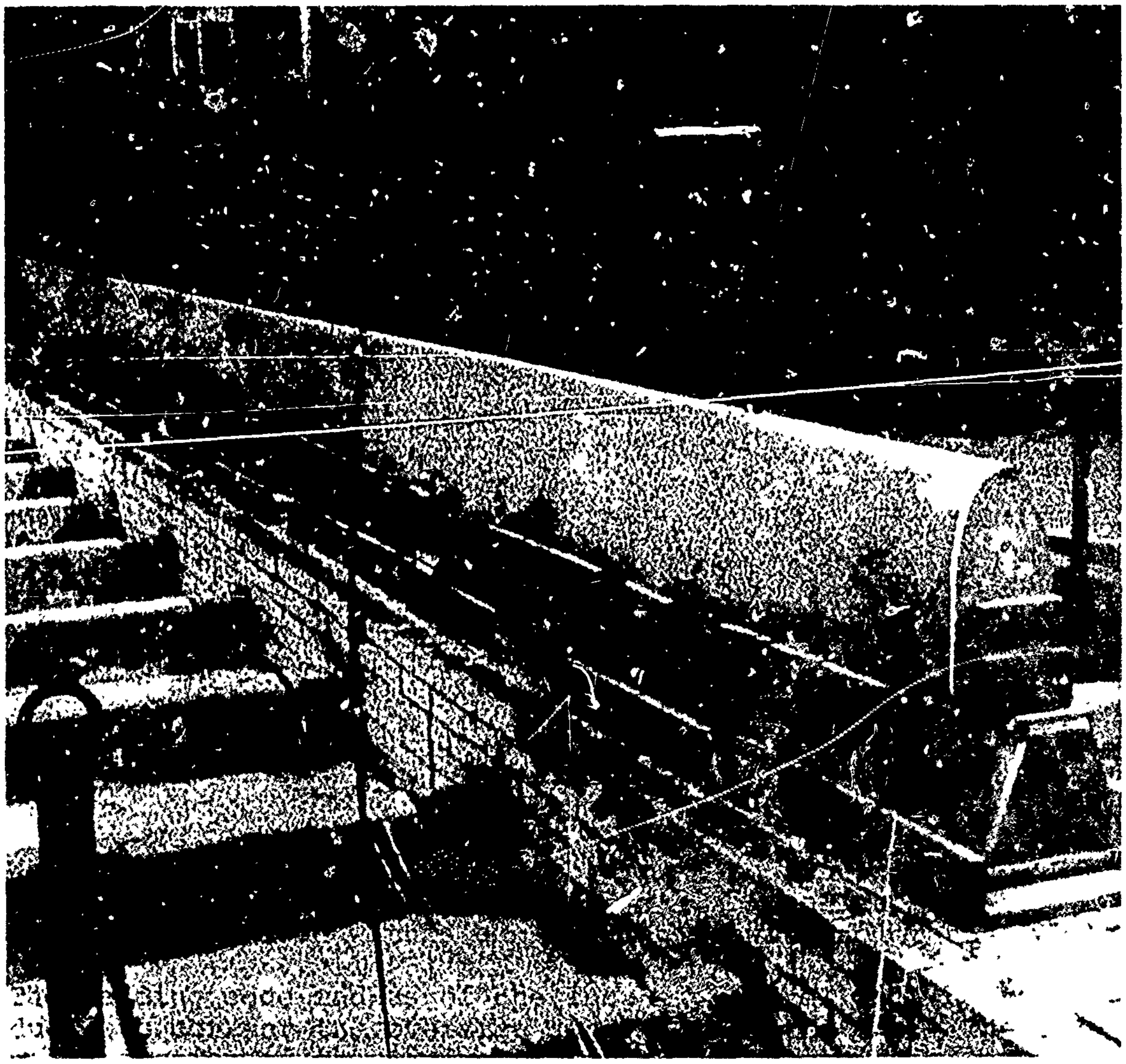


Figure 27. Formed Titanium Cap

Lay-Up Tools for Composite Details

For any composite product to be successful, the lay-up operation is the key. To ensure using the proper number of plies and and their correct orientation, tools of minimum complexity were provided to the shop. Tools were made for the following parts: leading-edge spar fillers (2), spar straps (4), and trailing-edge wedge (1). These parts are relatively flat; the prime purpose of the tool, therefore, was to control width, number of plies, and ply drop-off or location. It should be noted that the spar straps and leading-edge fillers each contained approximately 95 plies of Uni-Fiberglass. This was done so that, in addition to controlling plies, the tools also provided a means for the mechanic to compact the material, with Teflon rollers, to eliminate as much of the trapped air as possible. It also reduced the overall mass of material, which aided in the next assembly and cure operation. See Figure 28.

The spar nose block required a more elaborate tool than those described above, due to airfoil shape and the requirement to locate the leading edge weight rods (Figure 29). This was accomplished by making a two-stage tool which produced the first half of the nose block (to the centerline of the weight rod) and then the aft portion using a second compaction tool. Refer to Figure 30 for nose block tooling details.

Other details, such as the spar inner torsion wrap, the blade skins and others that did not have too many plies or were simple in configuration, were controlled by use of templates. One exception is the tool for outer torsion wrap; it consists of eight plies at the root end and reduces to one ply at the tip. Since it is the outer member of the spar, it is the last item to be assembled to the spar lay-up prior to installation of the titanium cap. If contour and overall size of the outer torsion wrap is not held during lay-up and installation on the spar, location of the complete uncured spar into the bonding fixture then becomes a difficult task and could cause wrinkles or voids in the cured spar. The outer torsion wrap for the first spar was laid-up using both halves of the spar BAJ. This method was acceptable; however, it required additional time spent in the BAJ which was already overloaded. In addition, it was found to be more desirable for shop personnel to lay-up the fiberglass on a male tool rather than on a female tool such

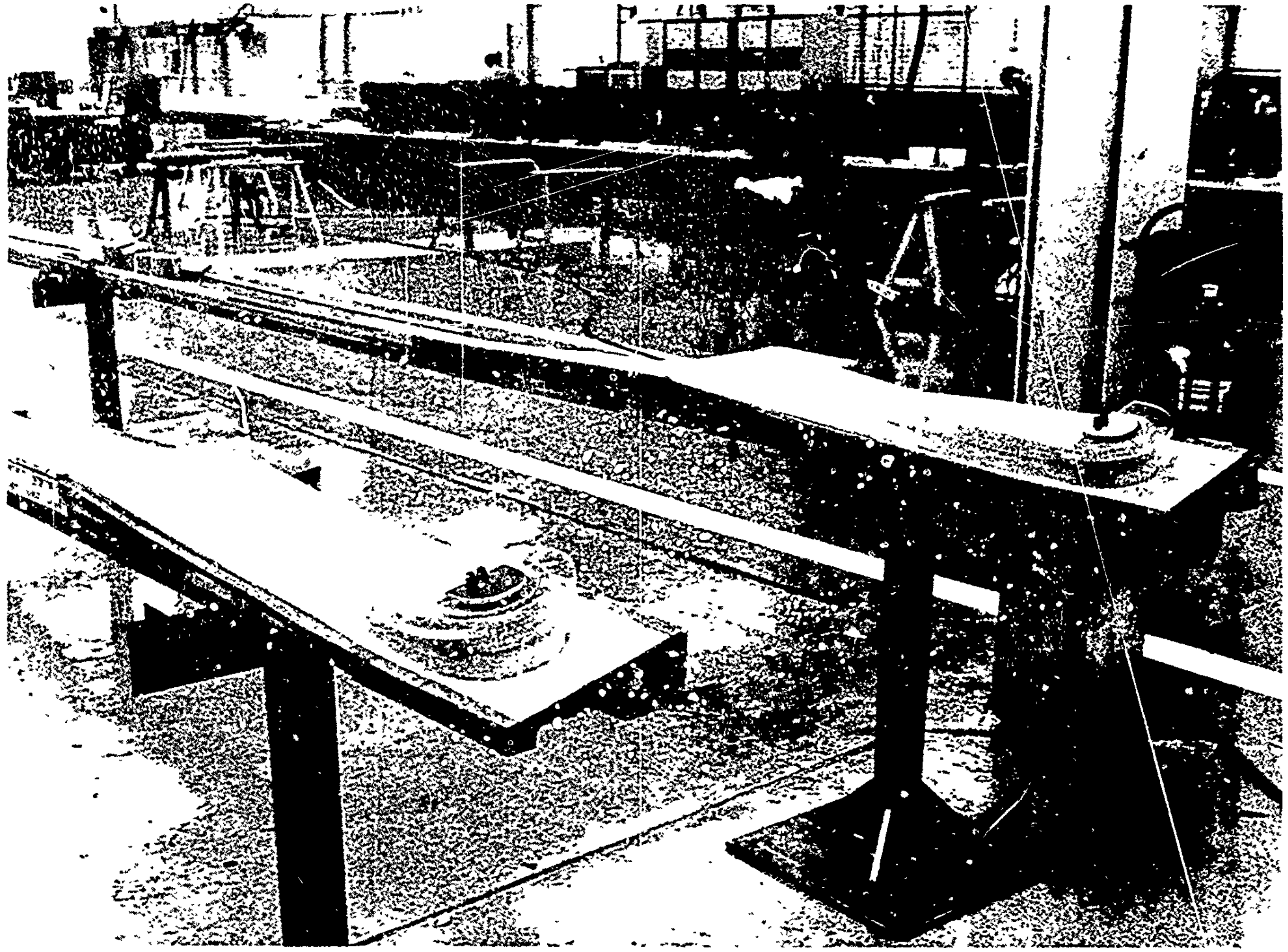


Figure 28. Two of Four Spar Strap Subassemblies

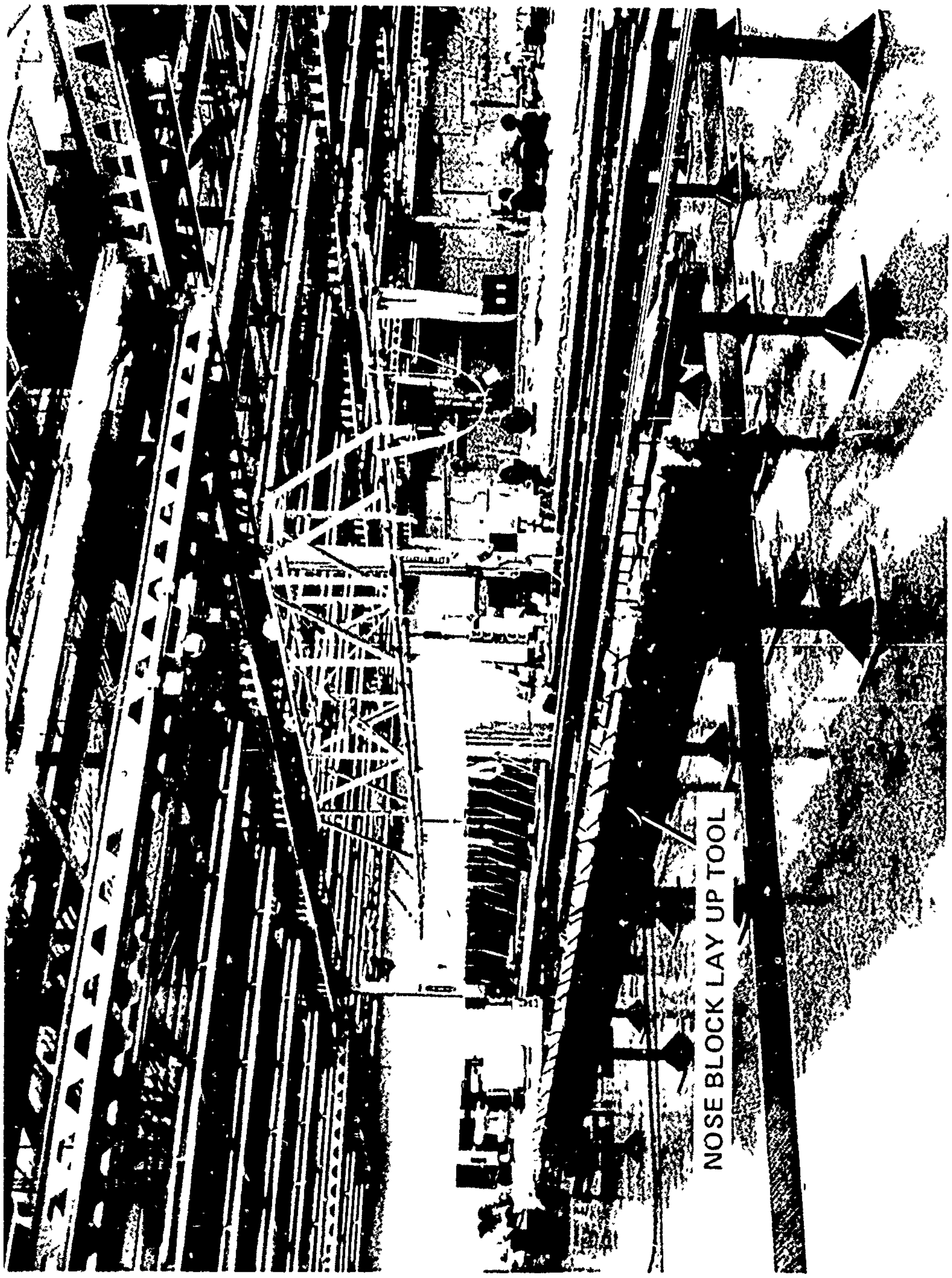


Figure 29. Nose Block Lay-Up Tool

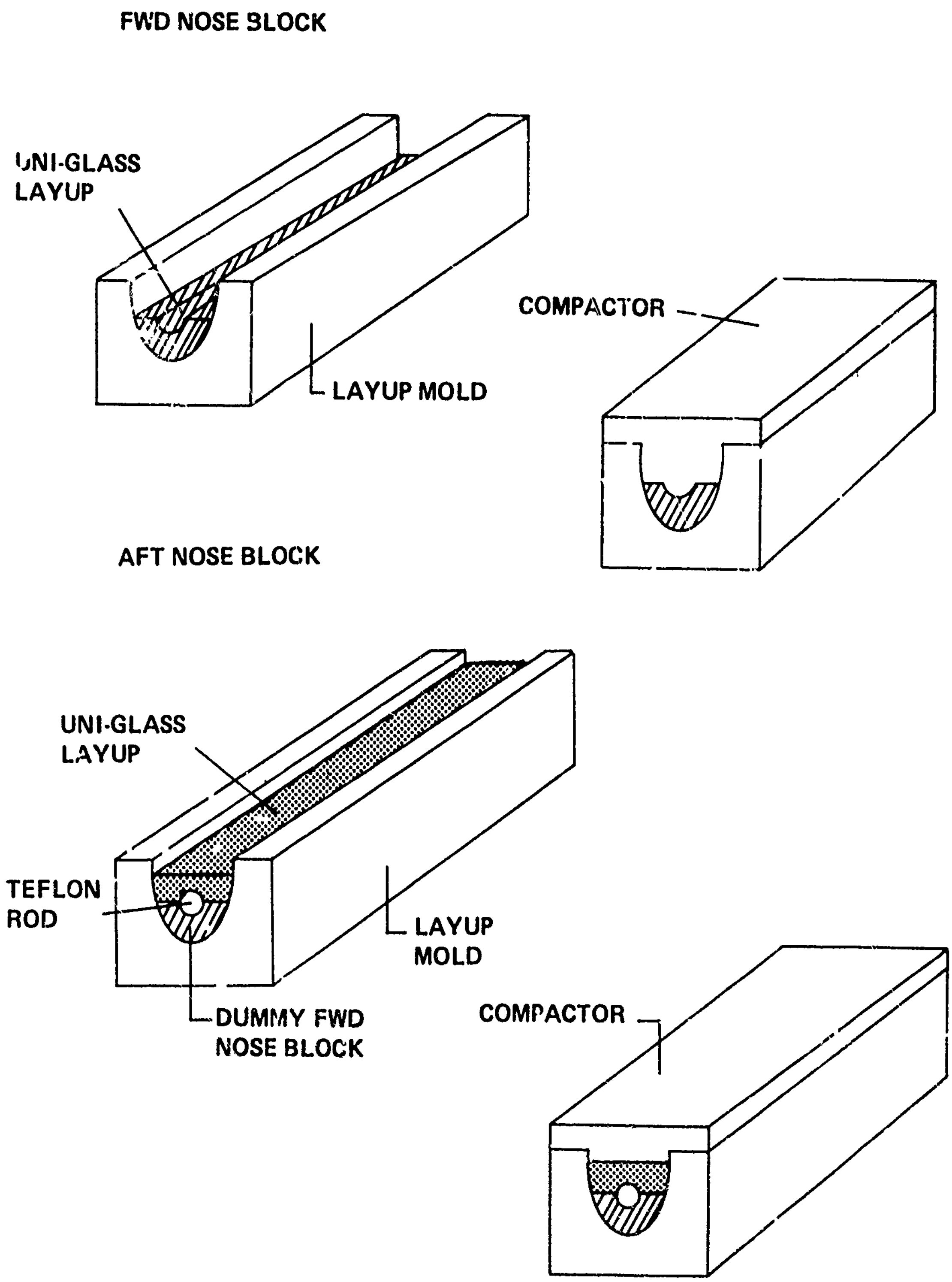


Figure 30. Nose Block Tooling

as the BAJ. A male mandrel (two-piece upper airfoil and lower airfoil) was made from a foam material, mounted on a common base, and covered with plastic coating to give a hard working surface. This is illustrated in Figure 31.

Spar Bonding Fixture BAJ SK301-11173-1 and Spar Mandrel 3LM 301-11173

After successfully producing the spar root end sections in the test program, the basic tooling concept was established. Changes by HLH Engineering to reduce the number of foam parts in the root end and to improve the method of applying pressure through chopped fiber fittings to the spar straps required some changes to the full length tooling. The major problem of producing a composite spar or any part that has a taper and/or "locked in" contours, is to provide a mandrel firm enough to allow for lay-up of the spar without distortion and still enough to allow movement of the mandrel and lay-up without damage, and still to be able to apply pressure to the spar during the cure. The mandrel must also be capable of removal from the spar after cure, such as the bean bag, wash out paraplast or break away type. Removal of the mandrel from the spar can be more hazardous in terms of damage to the spar and more costly than any other operation on the spar. The bean bag concept used in the root end program was the first selection; however, operations that were not considered a problem in a 6-foot length became a major handling problem with a 42-foot length. The first of these was filling of the bag with the "beans" (aluminum balls). The short length was done in a vertical position with little or no special equipment required. To do this with a 42-foot length would not be practical or, at best, would be very costly. Removal of the balls from the full length spar and storage were also concerns. However, it should be noted that the balls were reusable, which added to its favor. A method was devised to fabricate the bean bag in two halves in a horizontal position, thereby reducing some of the drawbacks listed above, but in so doing, created other hardships and high-risk operations. Maintaining a vacuum on both halves of this type of mandrel throughout the entire time of mandrel fabrication, spar lay-up and assembly was not too desirable. This being the only proven method at this time, it was pursued in conjunction with other methods.

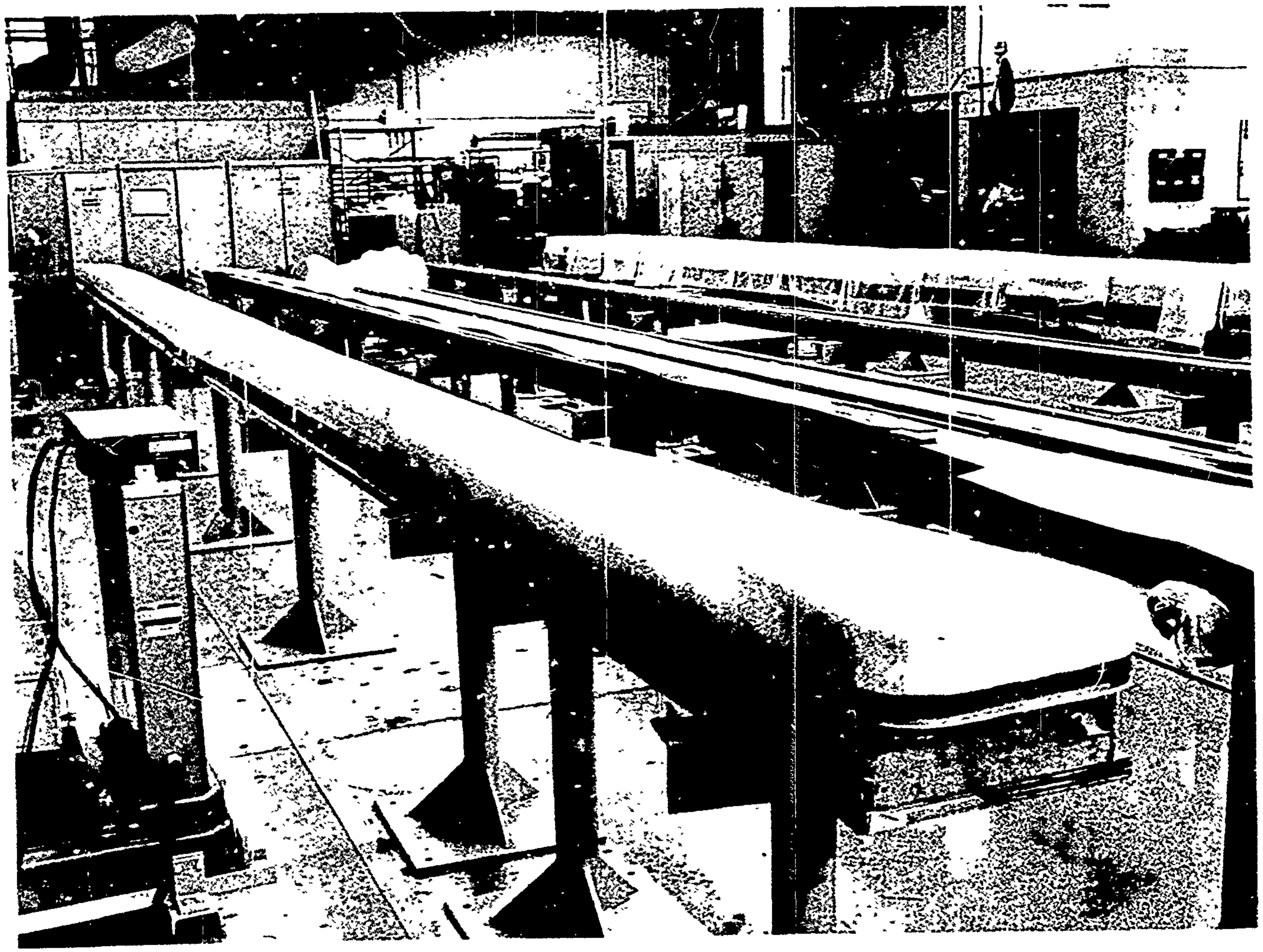


Figure 31. Outer Torsional Wraps – Lay-Up and Trimming Operations Completed and Ready for Use on Spar

After an analysis of other methods, the only other type of mandrel that merited consideration was one using styrofoam as a filler in place of the aluminum balls. In this type of mandrel, the foam blocks which are approximately 16 in. long are cut using a template at each end to produce the correct contour. (See Figure 32.) A "hot wire" cutting tool is used to cut the foam, which produces a smooth surface. The foam blocks are then assembled on a strongback which maintains their alignment and permits handling the finished mandrel without excessive bending. Two silicone rubber bags are then fabricated on the foam blocks or reassembled on the foam blocks if they have been used before. Two bags are used, each 0.06 in. thick and one on top of the other, thereby giving a safety factor should one bag fail during the cure. In past programs of this type, bag failures were quite common and costly, so every effort was taken to try to improve on bag design. It should be noted that throughout the eight-blade ATC Program no spars were lost due to bag failure. After assembly of the rubber bags over the foam blocks and strongback (Figure 33), the bags were sealed and a vacuum was pulled.

The vacuum is pulled between the inner bag and the foam blocks, and also between each of the two rubber bags. This removes any slack that may have been in the bags and provides a good surface for the lay-up of the inner torsion wrap. Pressure in excess of 5 PSI could result in crushing the foam blocks. The mandrel was then ready for lay-up of the spar. During curing of the spar, the foam will be subjected to 250°F, which will shrink the foam to approximately 1/3 its original size, allowing for its removal from the cured spar.

Cognizant of the high risks involved with a mandrel of this type and the detrimental effect a failure would have on the overall program, it was decided to investigate both types of mandrels (bean bag and foam) until further testing could be accomplished. After testing various types of foams, it was determined that Styropour, purchased from U. S. Mineral Products, Stanhope, N.J., was best suited for our purpose. It should be noted that this material is nontoxic: toxicity was a concern because of the method of venting the tool during the curing operation.

Due to design configuration and long length of the spar, the handling of the spar and mandrel throughout lay-up and assembly presented a critical problem. The Tooling group provided a fixture (8MIT SK301-11173-1) that would perform

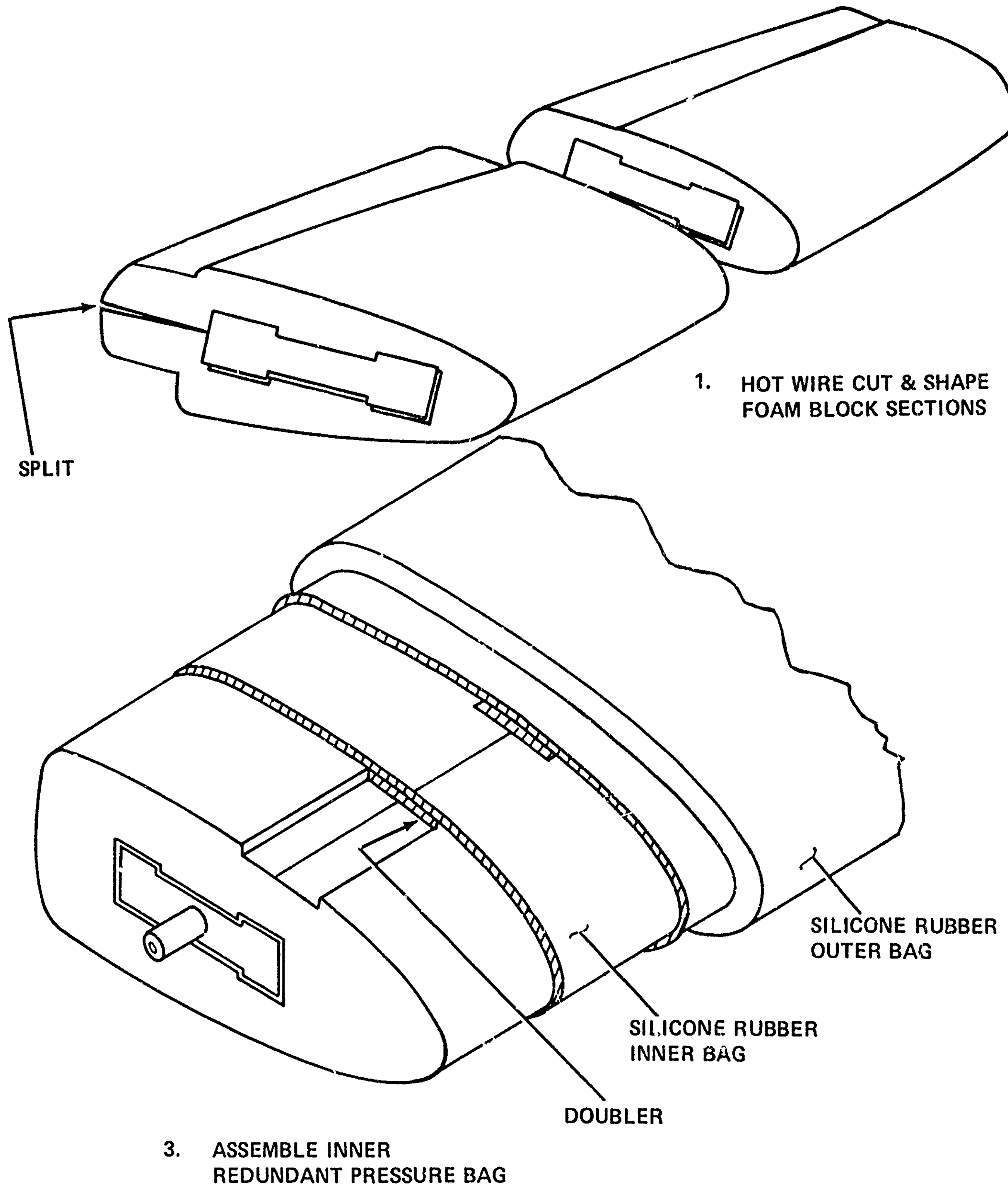
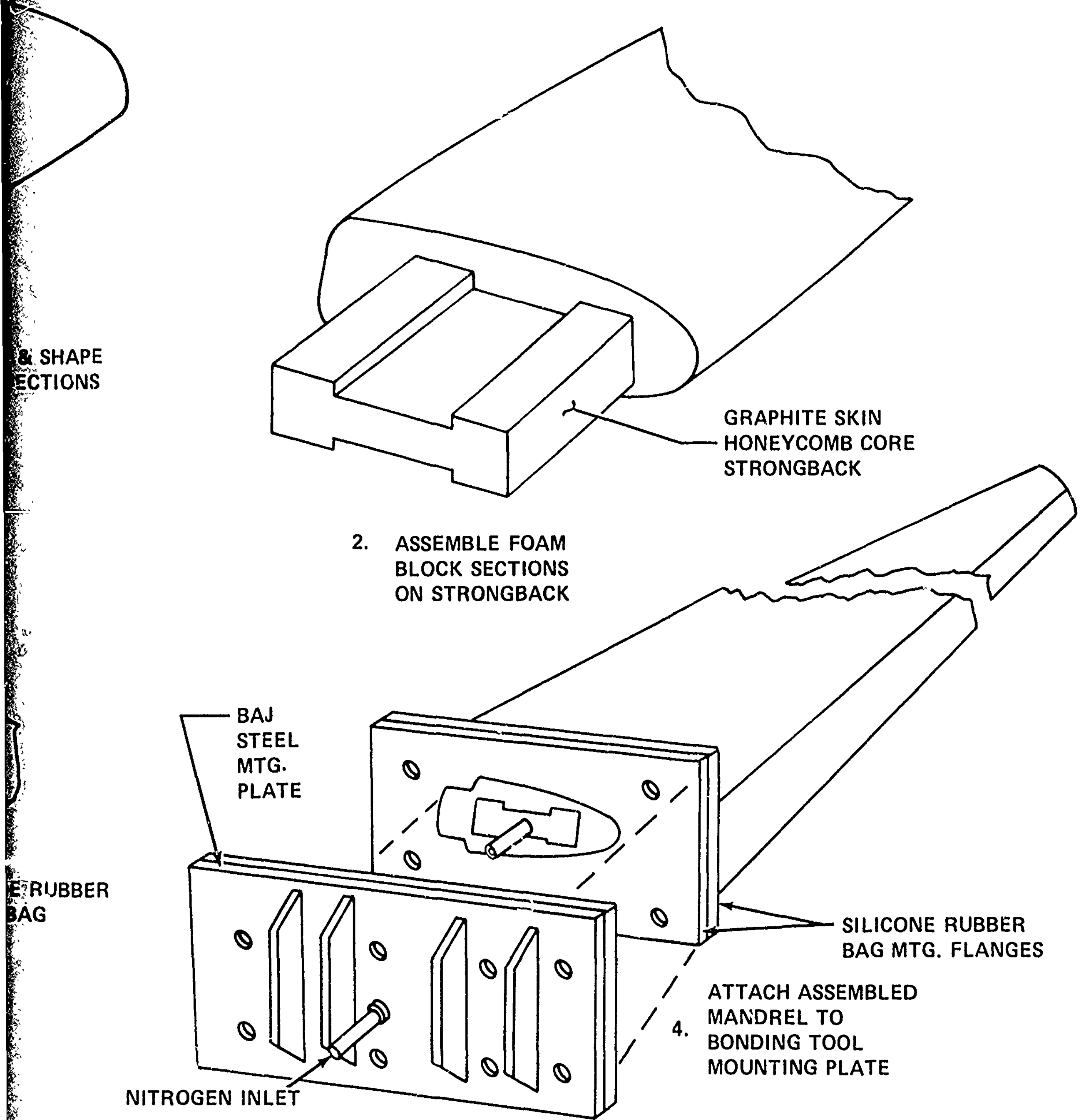


Figure 32. Internal Bag and Mandrel Fabrication Concept


& SHAPE
ECTIONS
GRAPHITE SKIN
HONEYCOMB CORE
STRONGBACK
2. ASSEMBLE FOAM
BLOCK SECTIONS
ON STRONGBACK
BAJ
STEEL
MTG.
PLATE
E RUBBER
BAG
SILICONE RUBBER
BAG MTG. FLANGES
4. ATTACH ASSEMBLED
MANDREL TO
BONDING TOOL
MOUNTING PLATE
NITROGEN INLET

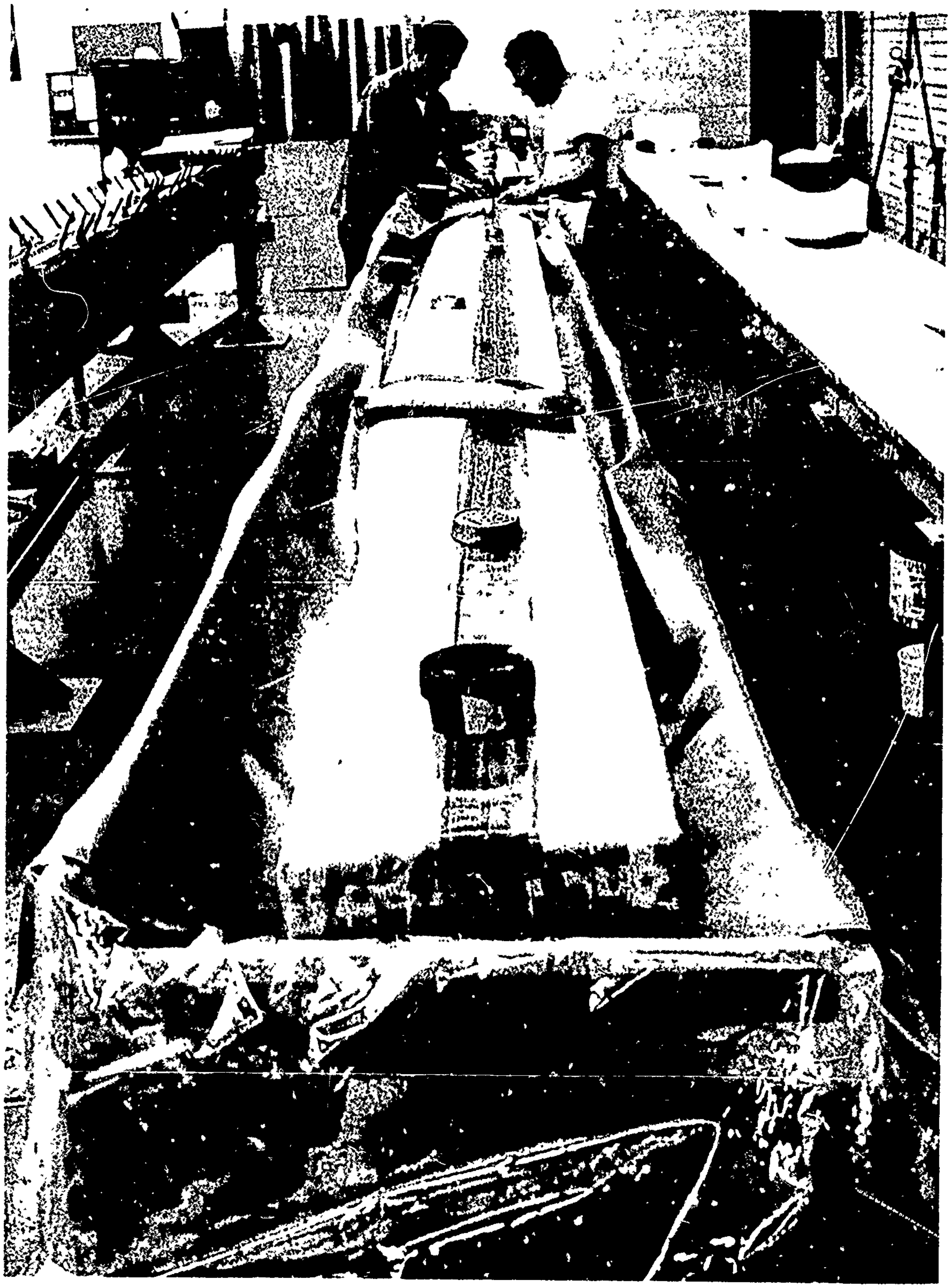


Figure 33. Bag Fabrication – Outer Bag Being Prepared for Seaming Operation

the following functions. Refer to Figures 34, 35, and 36.

1. Locate spar mandrel

2. Support mandrel at proper working height

3. Allow lay-up and mandrel to be rotated to any of three positions.

It was the conclusion of those associated with this program that lay-up of the spar would not have been possible without a fixture such as the 8MIT Spar Lay-up Tool.

After the spar lay-up has been completed (Figure 34), the titanium nose cap is located on the spar assembly, and the complete assembly is installed into the lower half of the Spar Bonding Fixture (BAJ SK301-11173-1). Refer to Figures 37, 38, and 39. The design of the spar bonding fixture used six castings; the lengths of these castings were determined primarily by the airfoil changes. (See Figure 40.) It could be seen that this would provide the greatest flexibility for change if, in the future, airfoil changes would be required. The casting breaks occur at Stations 66, 138, 220.8, 276, 372, 469.2 and 565.8; this allows 13.8 inches excess at the tip for quality control test pieces. The material selected for castings was Meehanite Type HS since it compares favorably from a strength standpoint with any heat resisting metal and is recommended for application at temperatures far above the HLH 250°F requirement under conditions of both cyclic and continuous heating without thermal shock. It machines easily and provides maximum resistance to scaling and growth. Thermal expansion of Meehanite HS is more compatible with fiberglass than most metals. Meehanite would also minimize distortion of the mold during repeated heating and cooling. Castings were selected for use rather than weldments or hogouts since layouts indicated that all five outboard sections could be machined from castings made from one basic pattern with removable inserts, resulting in a cost saving. A special pattern and casting was required for the root end section (Stations 66 to 138).

The spar assembly was located in the lower half of the BAJ. The upper sections were then assembled section by section starting with the root end section, taking care not to pinch any fibers or distort the spar in any way. The tip

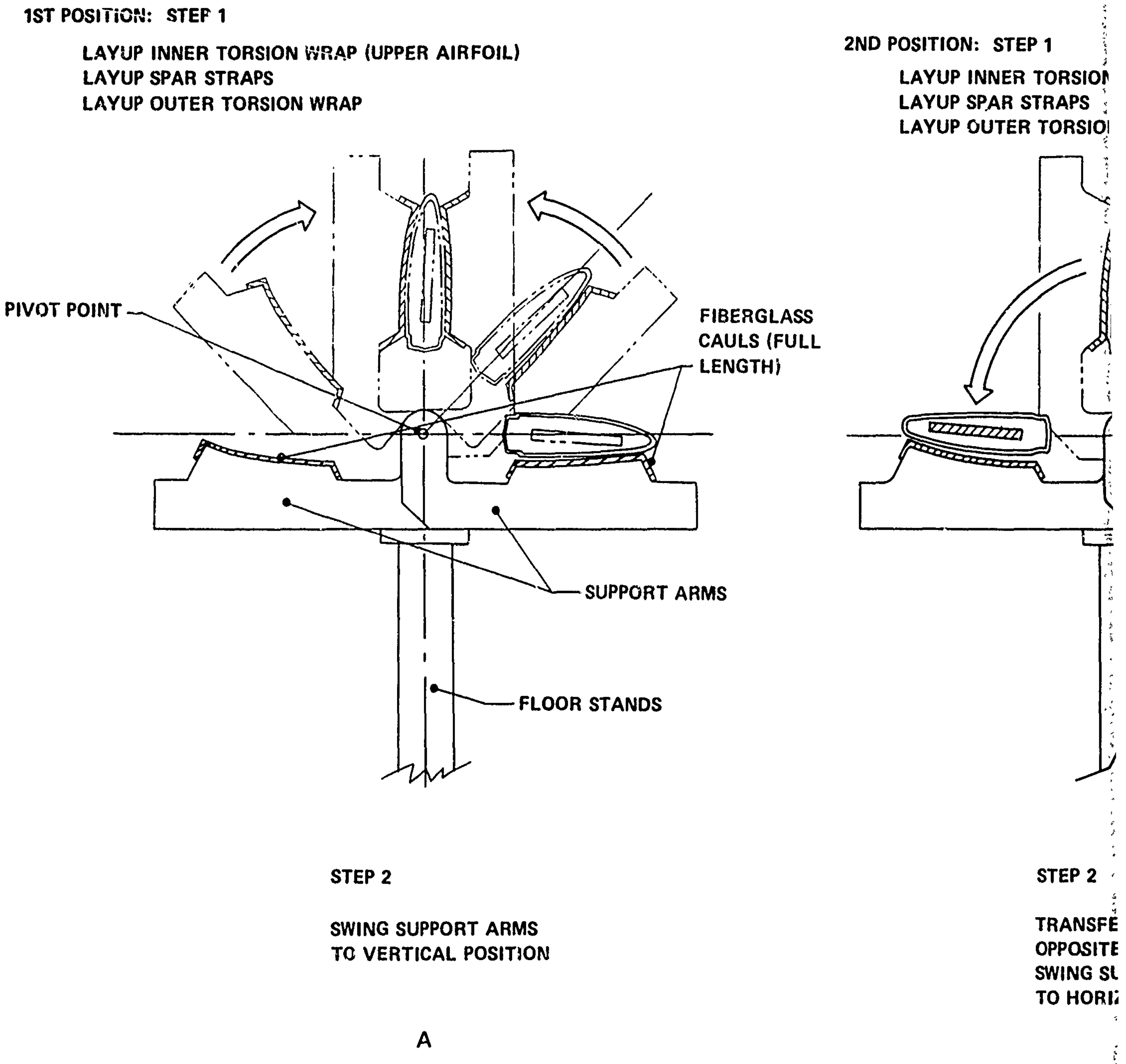
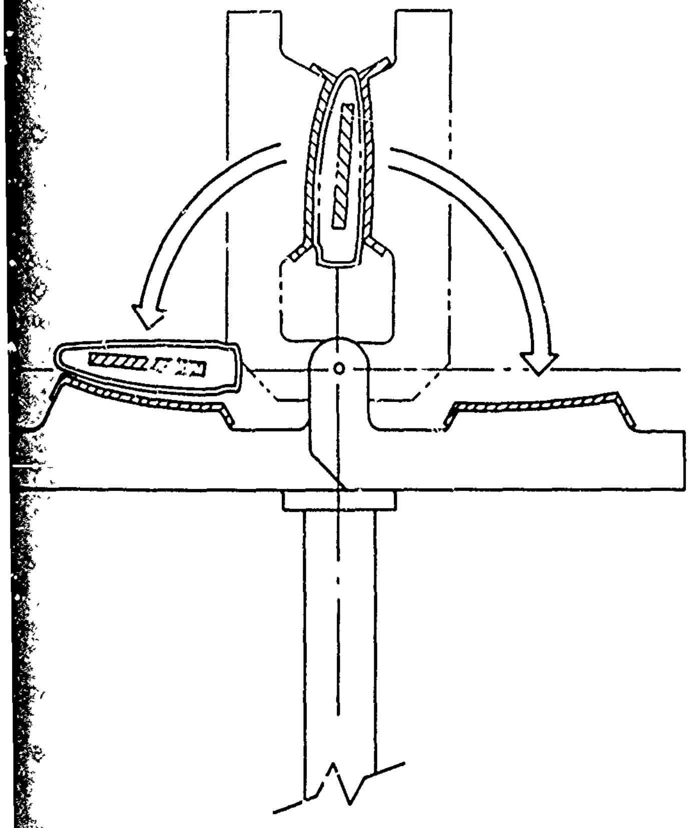


Figure 34. Operation of Spar Assembly Support Stand

POSITION: STEP 1

LAYUP INNER TORSION WRAP (LOWER AIRFOIL)
LAYUP SPAR STRAPS
LAYUP OUTER TORSION WRAP



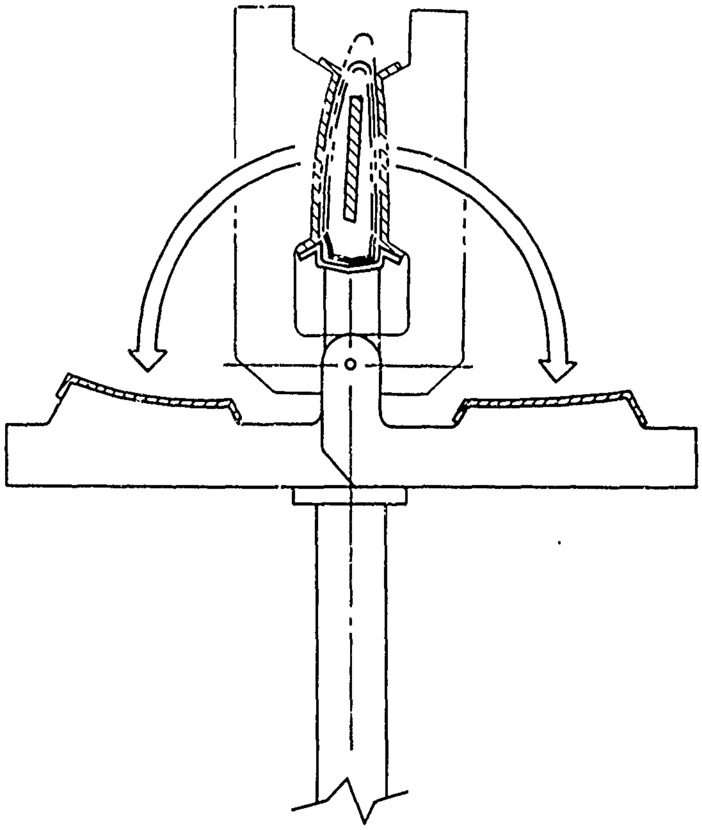
STEP 2

TRANSFER LAYUP TO
OPPOSITE SIDE AND
SWING SUPPORT ARMS
TO HORIZONTAL

B

3RD POSITION:

ASSEMBLE TITANIUM CAP
AND NOSE BLOCK ASSEMBLY



C

2

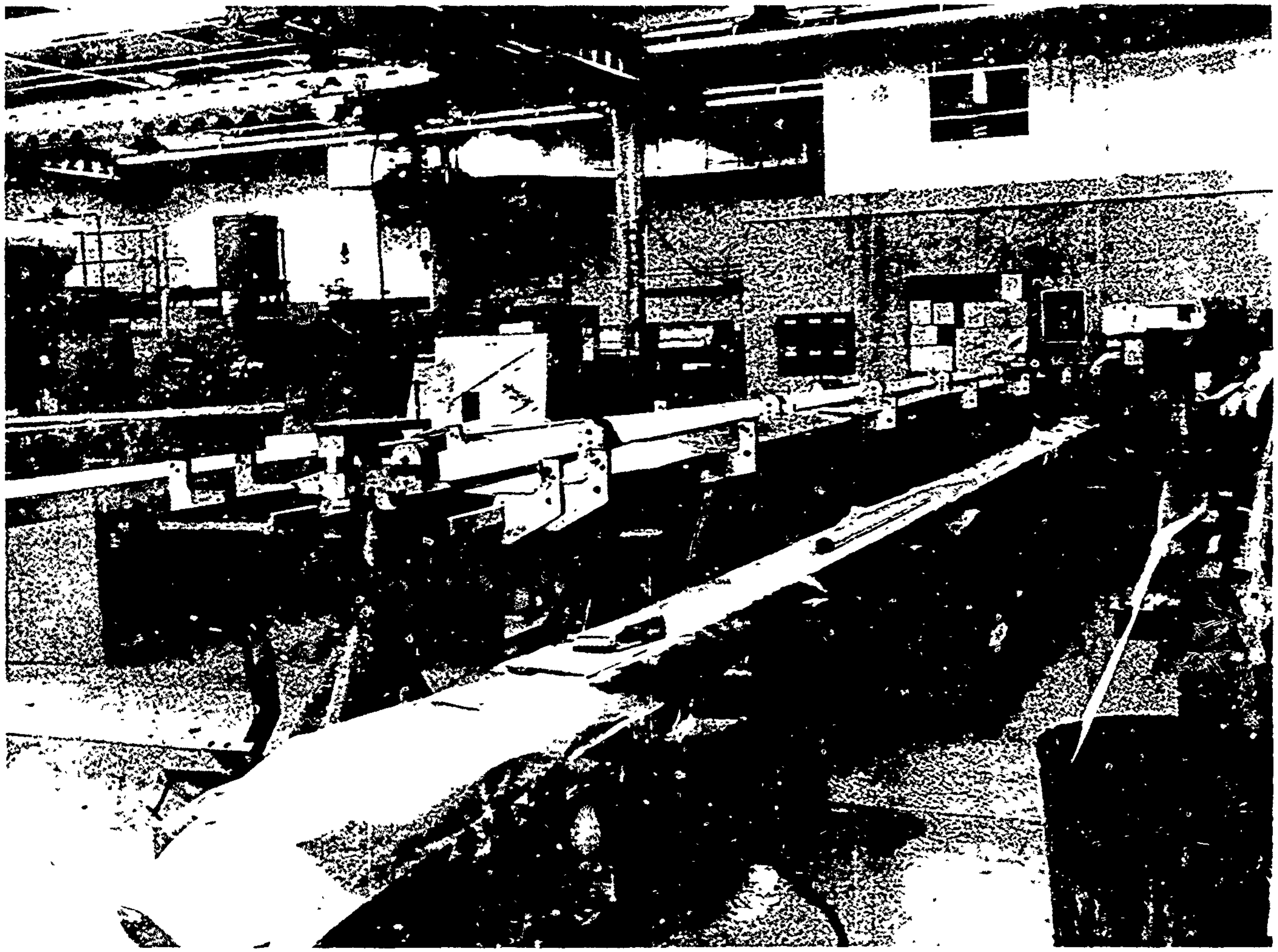


Figure 35. Spar Assembly Stand – Original Configuration Used for Spar No. 1

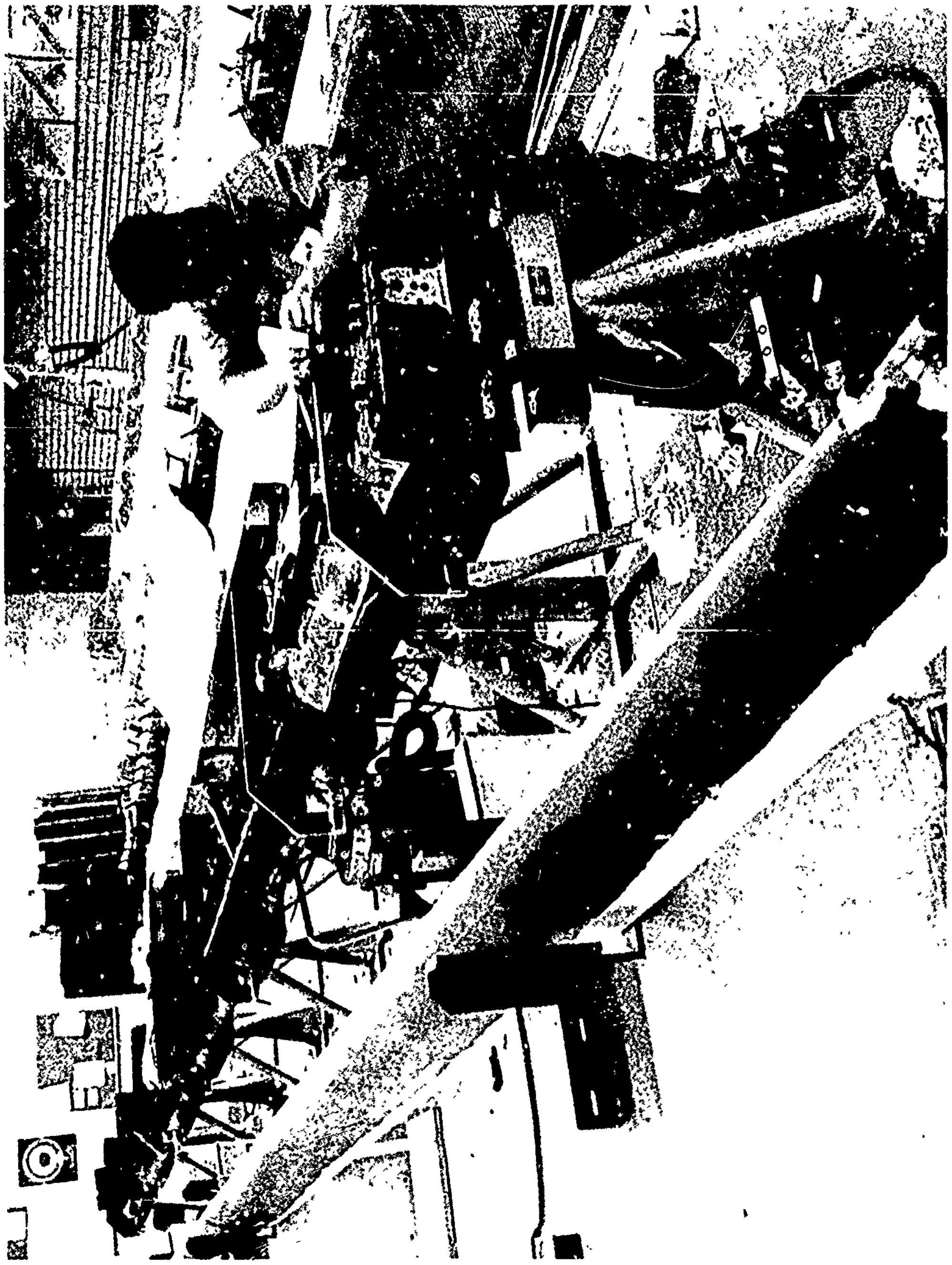


Figure 36. Spar Assembly Stand – During Modification after Use on Spar No. 1

Figure 37. Spar Bonding Fixture

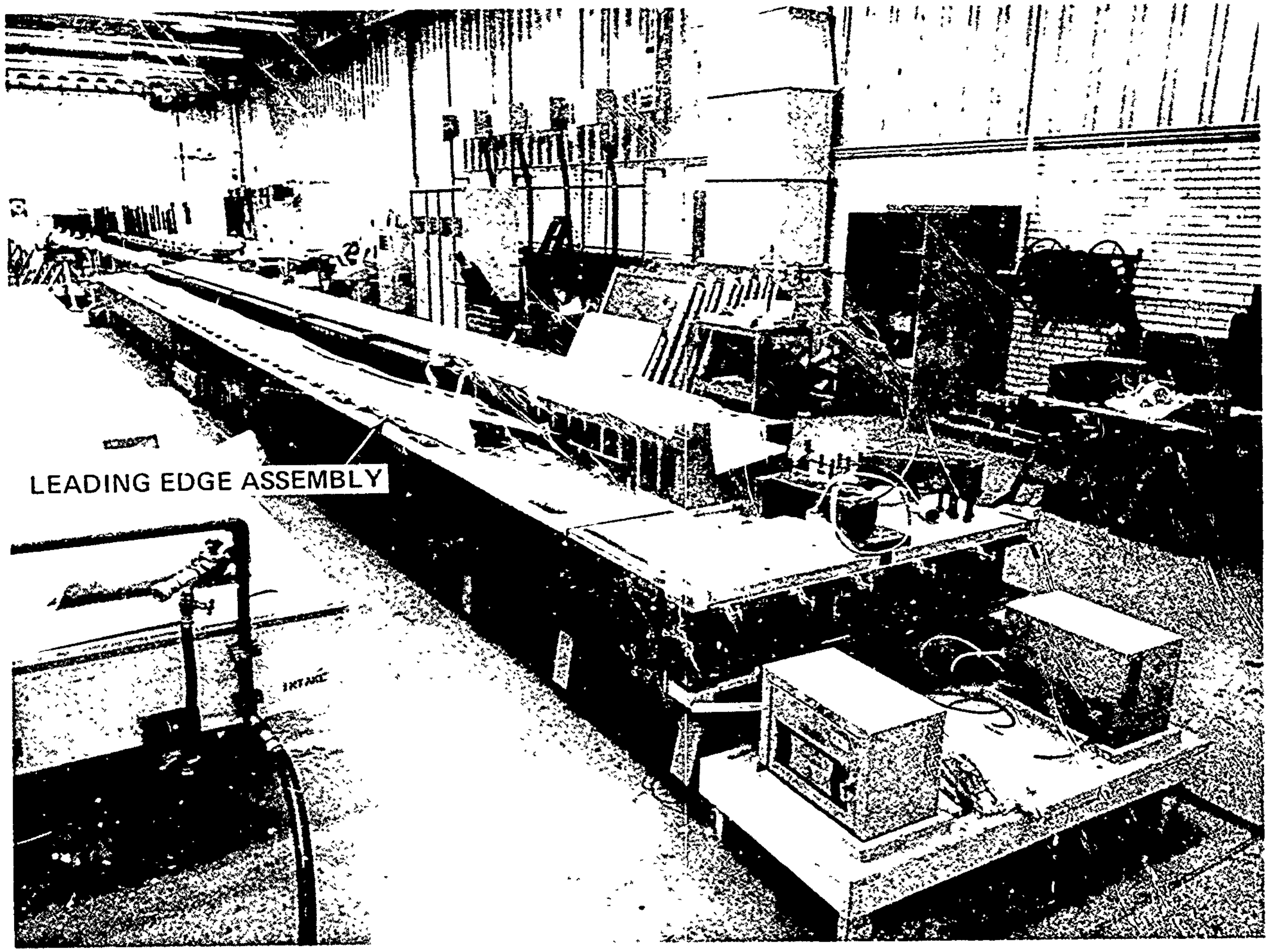


Figure 38. Leading Edge Assembly No. 1 Unloaded from Curing Tool

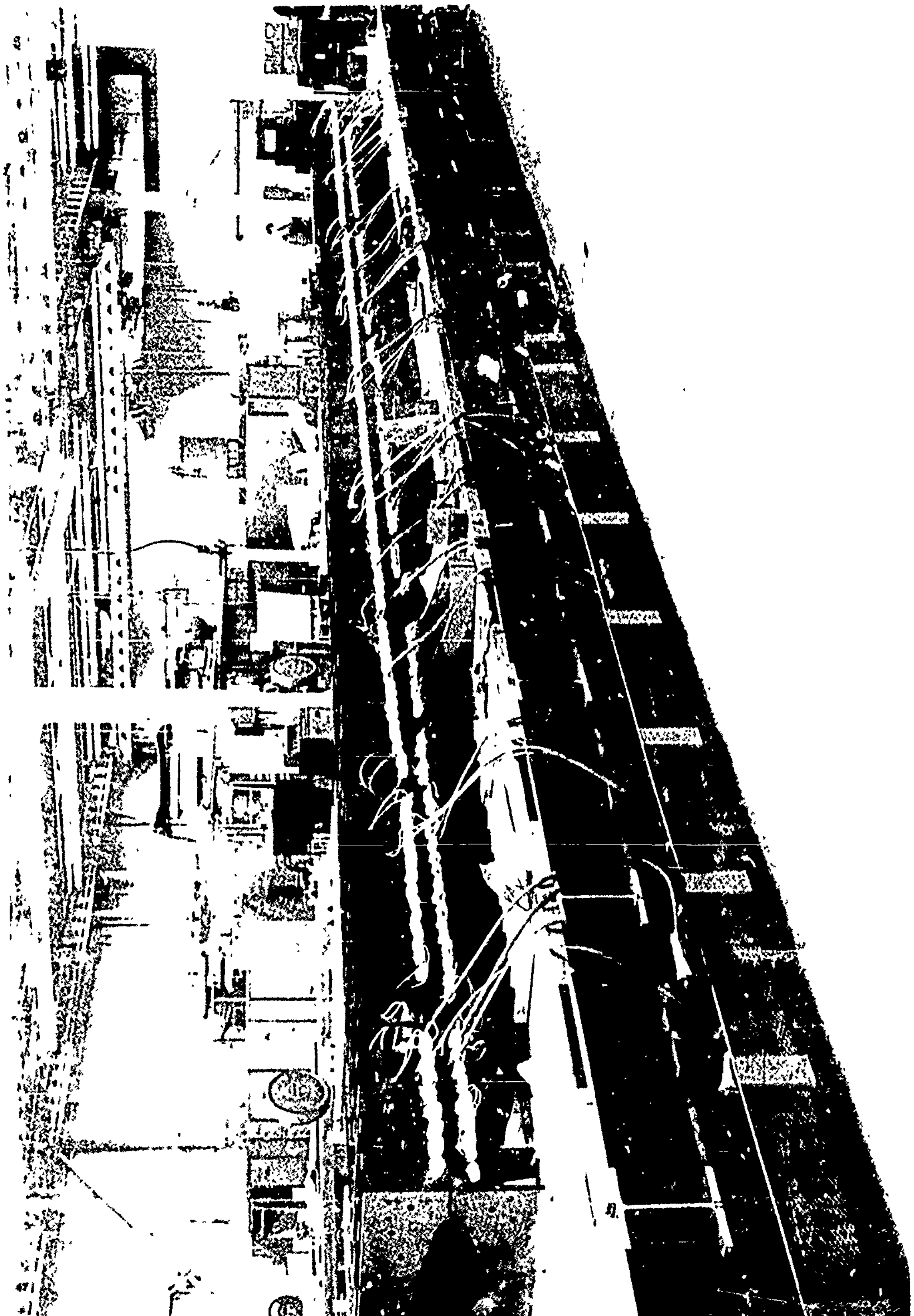


Figure 39. Checkout of Spar Curing Tool on Universal Base

end and root end hardware were then assembled, the power and thermocouple lines connected, and the spar was ready for cure. It should be noted that the spar castings were machined to the true OML of the spar using the MDI system provided by engineering and numerically controlled tapes and machines at both Boeing Wichita and Boeing Vertol (Figure 41). Some hand work was required after machining to remove tool marks and produce a good surface finish, suitable for curing; this was minimal, however, and this method of machining produced the best (least amount of deviation from true OML) contour for a mold of this size.

The basic premise of the spar tool application is to control the OML with the tool and to apply fluid pressure (80 to 100 psi) through the bag mandrel to the inside of the spar. Refer to Figure 42.

Assembly and disassembly of the six upper BAJ castings is time consuming; however, the cost to automate this would not be cost effective for a low-quantity program of this type. If, in the future, larger quantities of blades are to be built, it is recommended that some built-in type of opening and closing mechanism be incorporated.

Vacuum Forming Mold (VFM) SK301-11179-1

The honeycomb core assembly that will be bonded to the spar was fabricated using the following steps:

1. Using the VFM (Figure 43), special adapters were installed at the trailing edge area in which the T.E. wedge was to be layed up and cured (Figure 44).

2. Removing the special adapters, the VFM was then used to bond the honeycomb core blocks to the T.E. wedge.

3. The one skin (lower airfoil skin) was layed up, cured, and bonded to the T.E. and core assembly (Figure 45).

A second VFM tool was built for machining of core assemblies machined by a vendor. The only difference between this second VFM tool and the first was that the second unit had a vacuum system built into it for holding the core while it was being machined. (Figure 46)

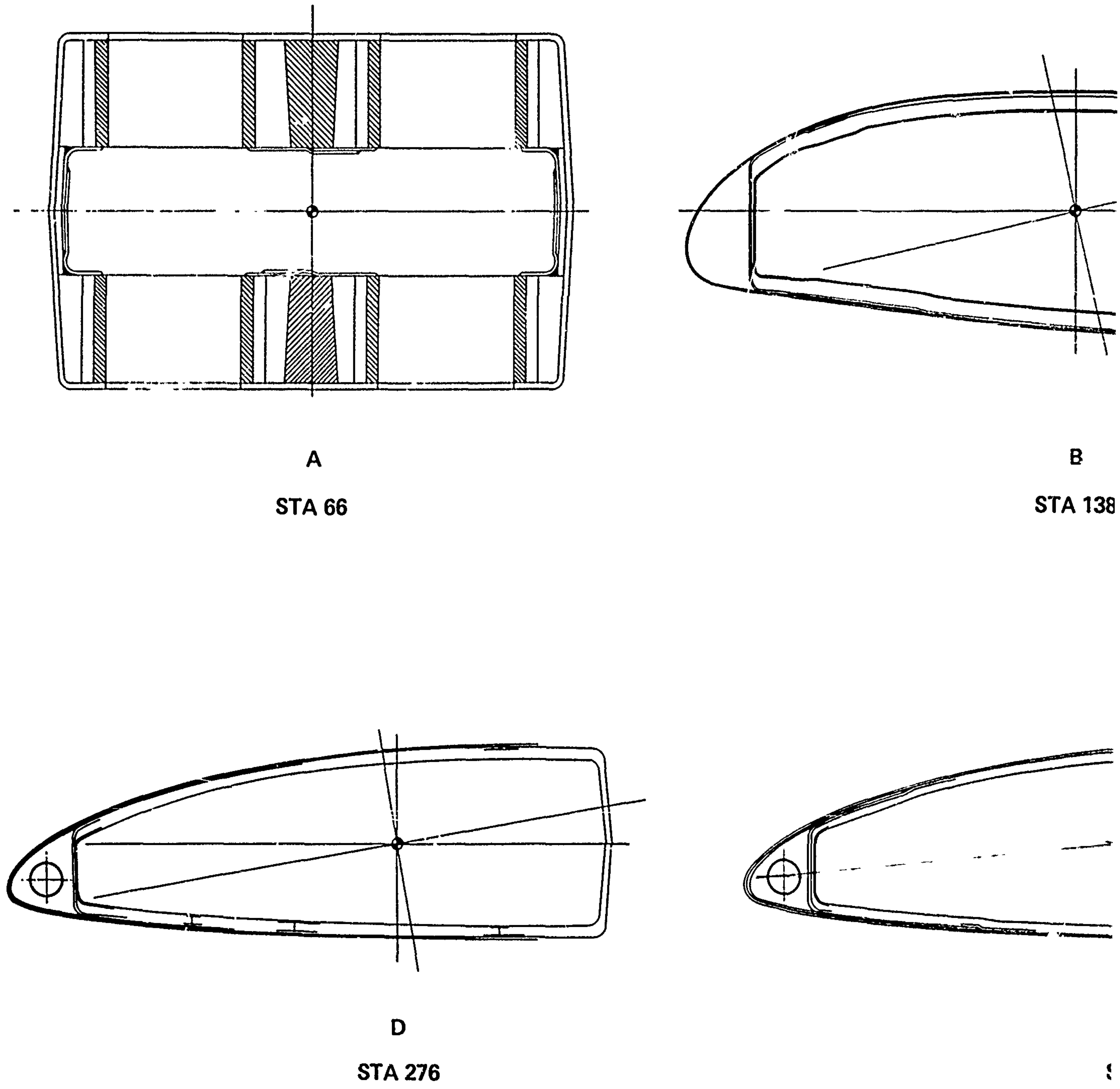
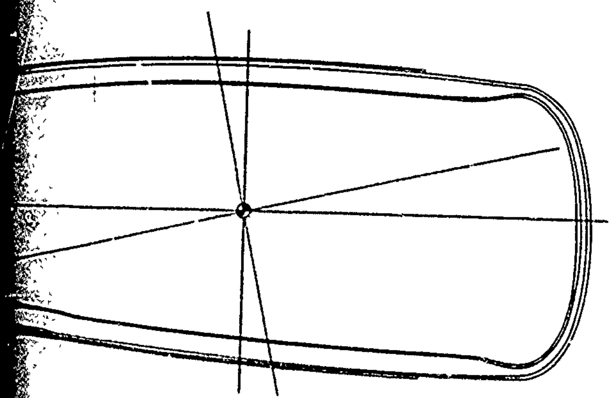


Figure 40. Spar Section Airfoil Transitions



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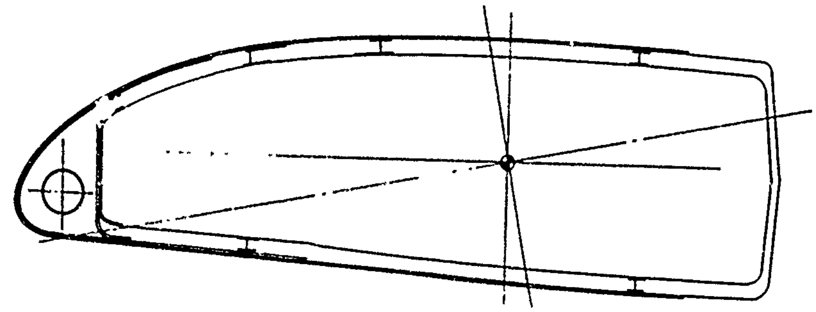

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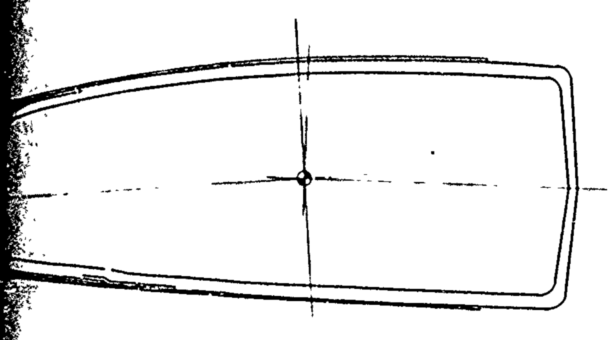
STA 220.8



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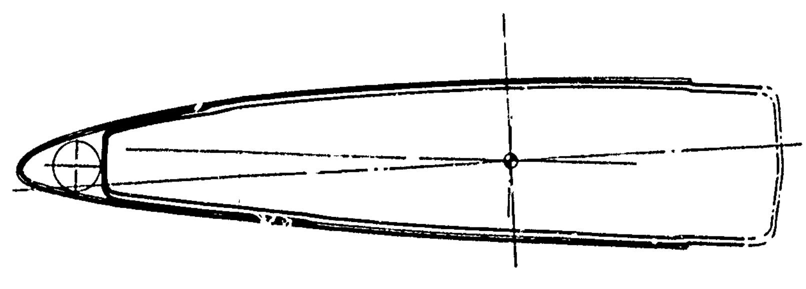
STA 372



F

STA 469 AND OUTBOARD

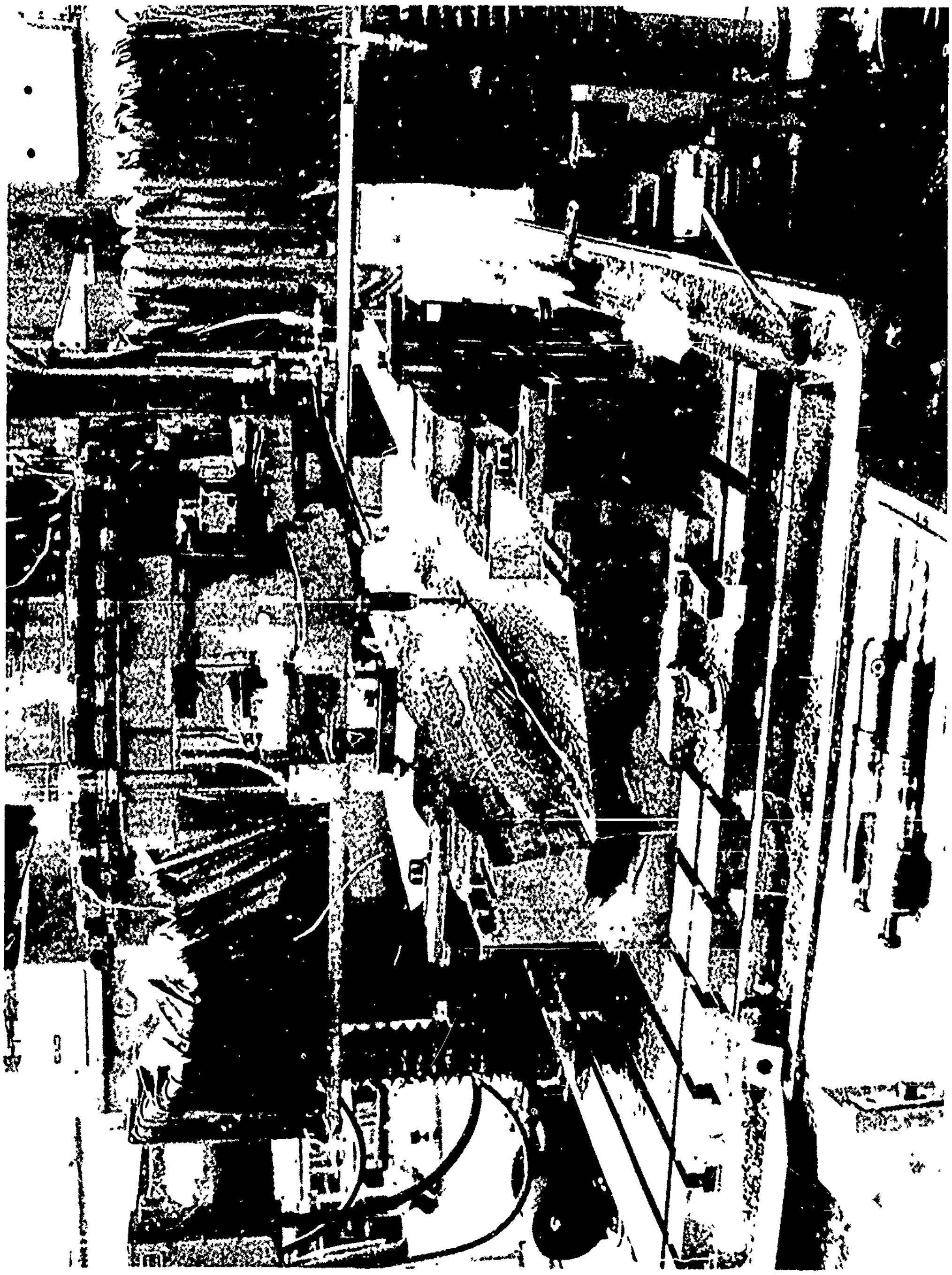


Figure 41. Numerically Controlled Milling Machine

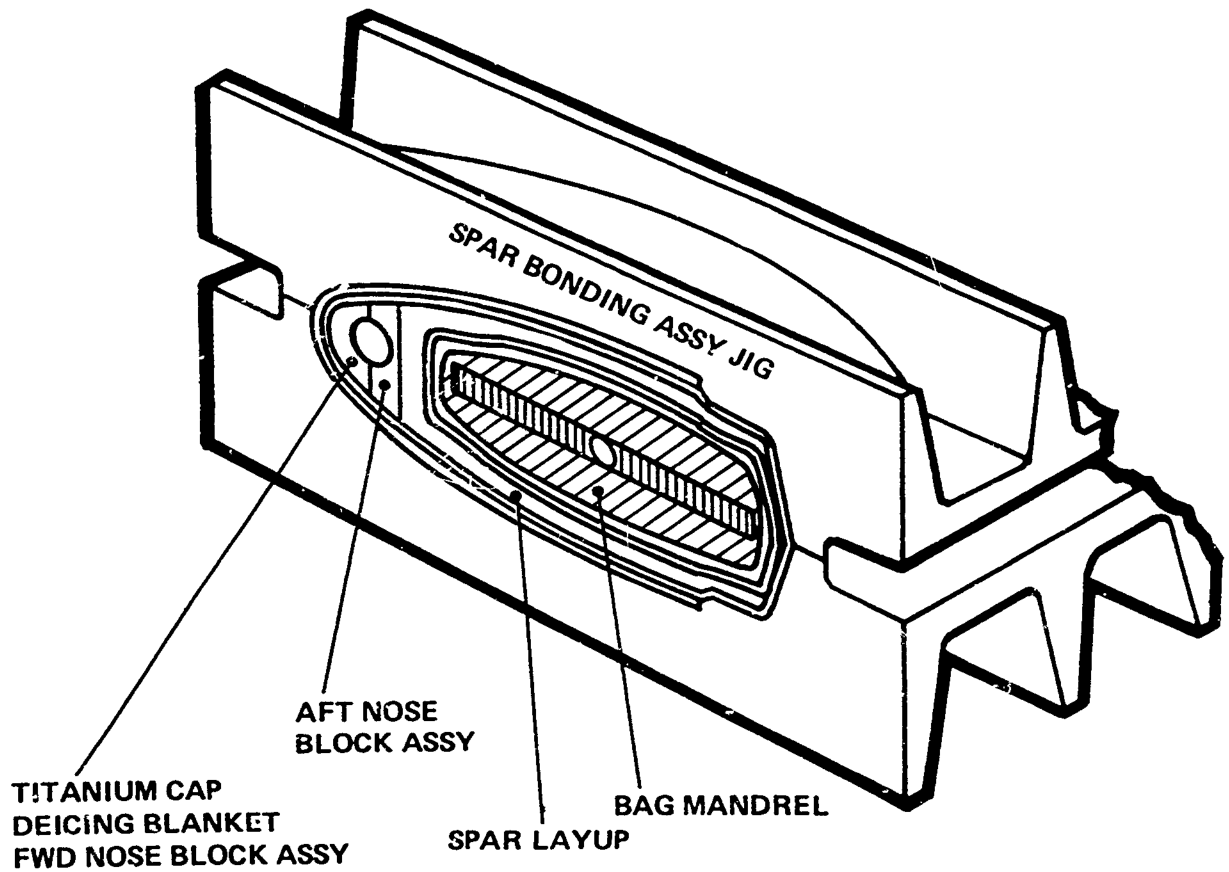


Figure 42. Spar BAJ Basic Theory Illustration

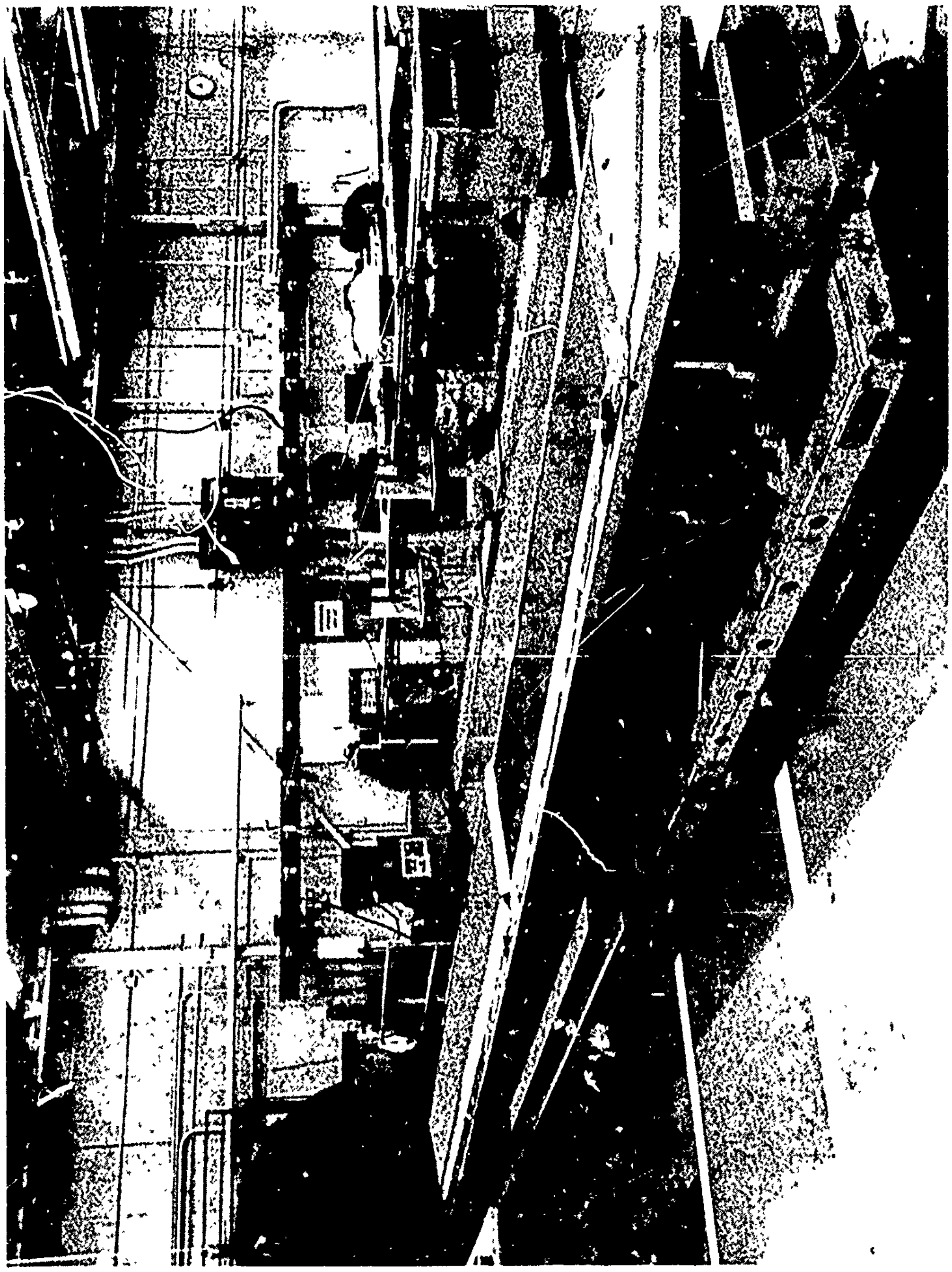


Figure 43. Vacuum Forming Mold, SK301-11179-1

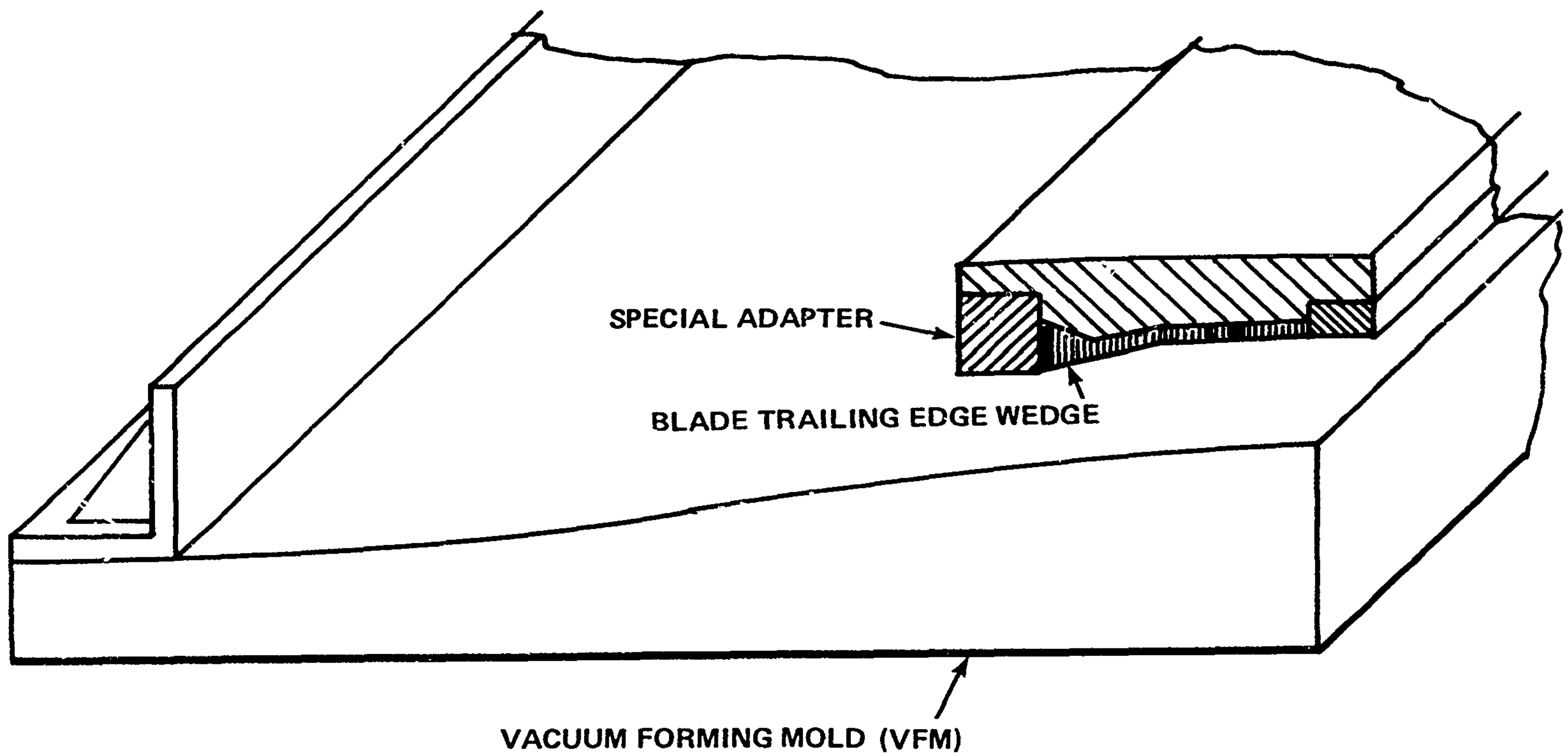


Figure 44. Special Adapter for VFM Used During Trailing Edge Wedge Fabrication

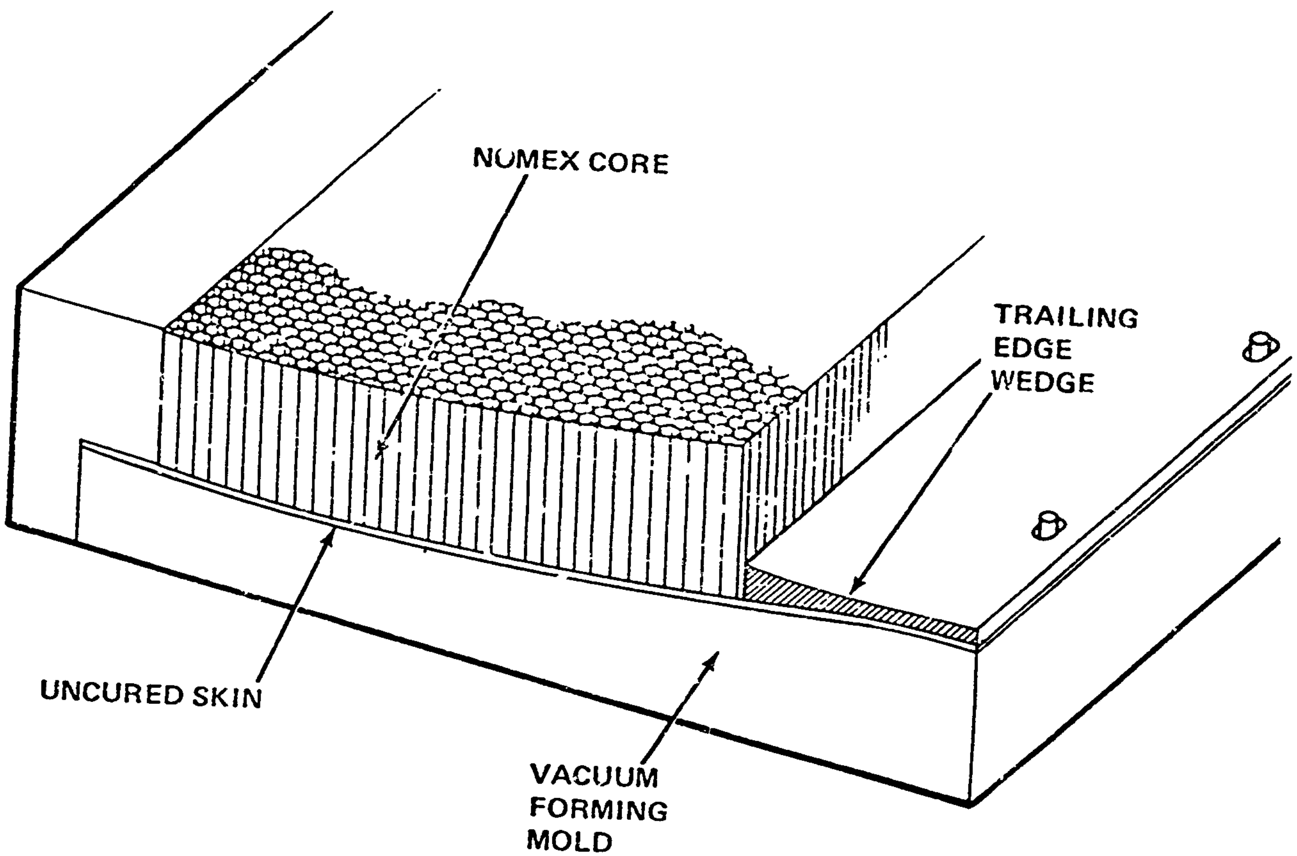


Figure 45. Lay-Up, Cure, and Bonding of Lower Skin to T.E. and Core Assembly

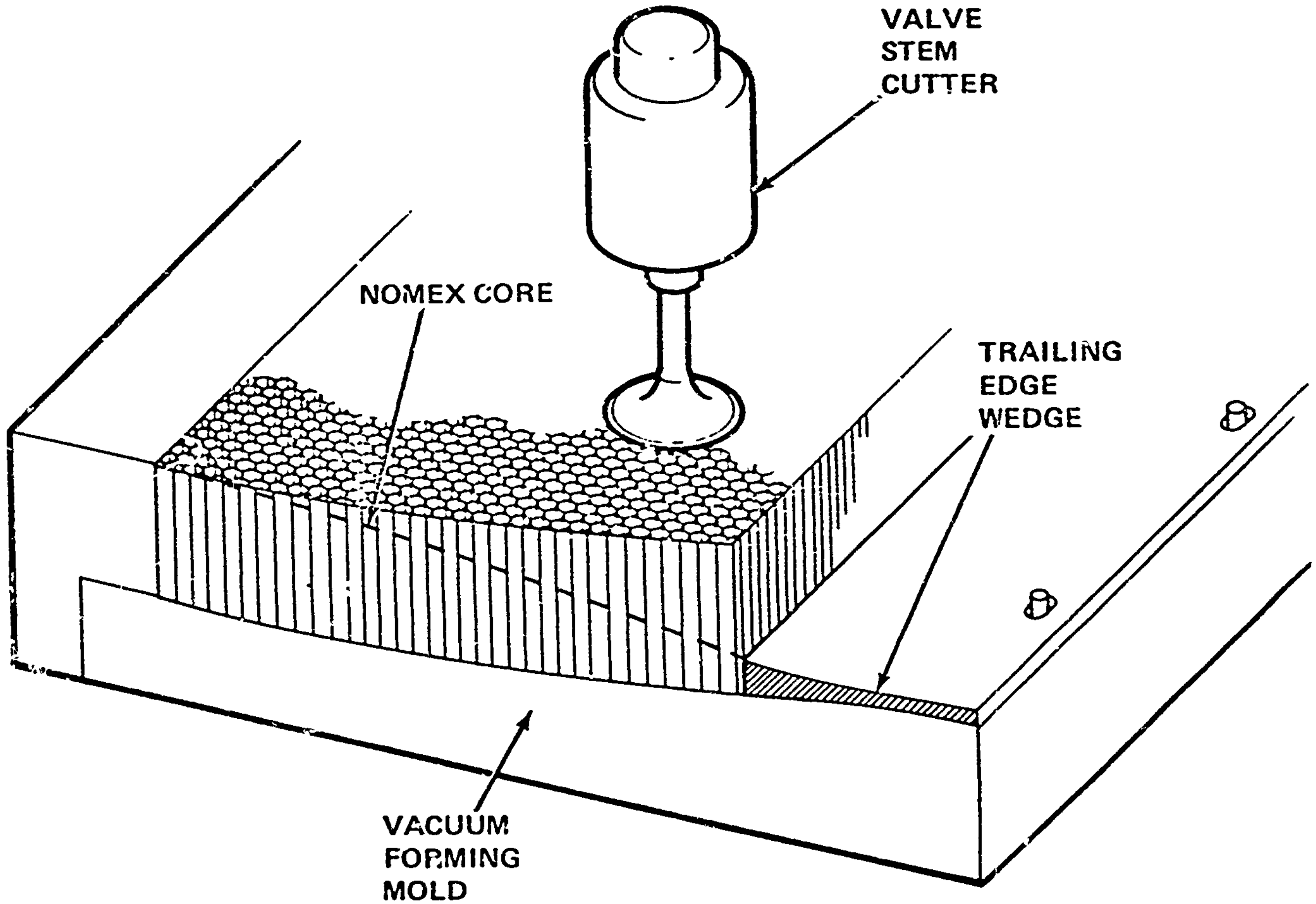


Figure 46. VFM Tool with Built-In Vacuum System Used for Machining Core

4. The upper airfoil surface and the V-cut at the L.E. of the core were machined at Boeing's subcontractor, Hexcel Corp., Graham, Texas, and returned to Boeing Vertol for assembly into the blade. The final BAJ (lower airfoil surface) and the two VFMs were all machined using identical MDI information, resulting in good coordination of the tools.

Compression-Molded Fiberglass Fittings

The rotor blade designed for the ATC program employed eight details that were made from chopped fiber (3M Co. SP 1157). This material requires 350°F and 1500 to 2000 psi pressure during cure to obtain the maximum rated strength properties.

The first engineering design of the fittingless blade (root end test section) used four such details. The parts were cured in an aluminum mold using the platen press for heat and closing pressure. The mold was designed with fixed stops to control part size and was constructed with four sets of inserts for four different part configurations. Several pieces were made before the required amount of material (SP 1157) was established, and due to the thin sections of the part, precompaction of the material was critical.

The aluminum mold produced the parts for the test piece, but the tool itself was not satisfactory. Since the tool was soft, it was subject to damage (tool marks, etc.) in loading and unloading; tapped holes for inserts were easily stripped; and because of the high cure pressure, the mold had deflection problems.

On the full length blade, the Engineering group made changes which required a completely new mold for the molded fiberglass fittings.

The new design was a much simpler configuration, and only two different type parts were required.

A kirksite die (MDSK301-11204, Figure 47) was made which incorporated all the features found to be lacking in the original aluminum tool. Some of these things were chrome plating of all mold surfaces, knockout pins and improved methods of handling.

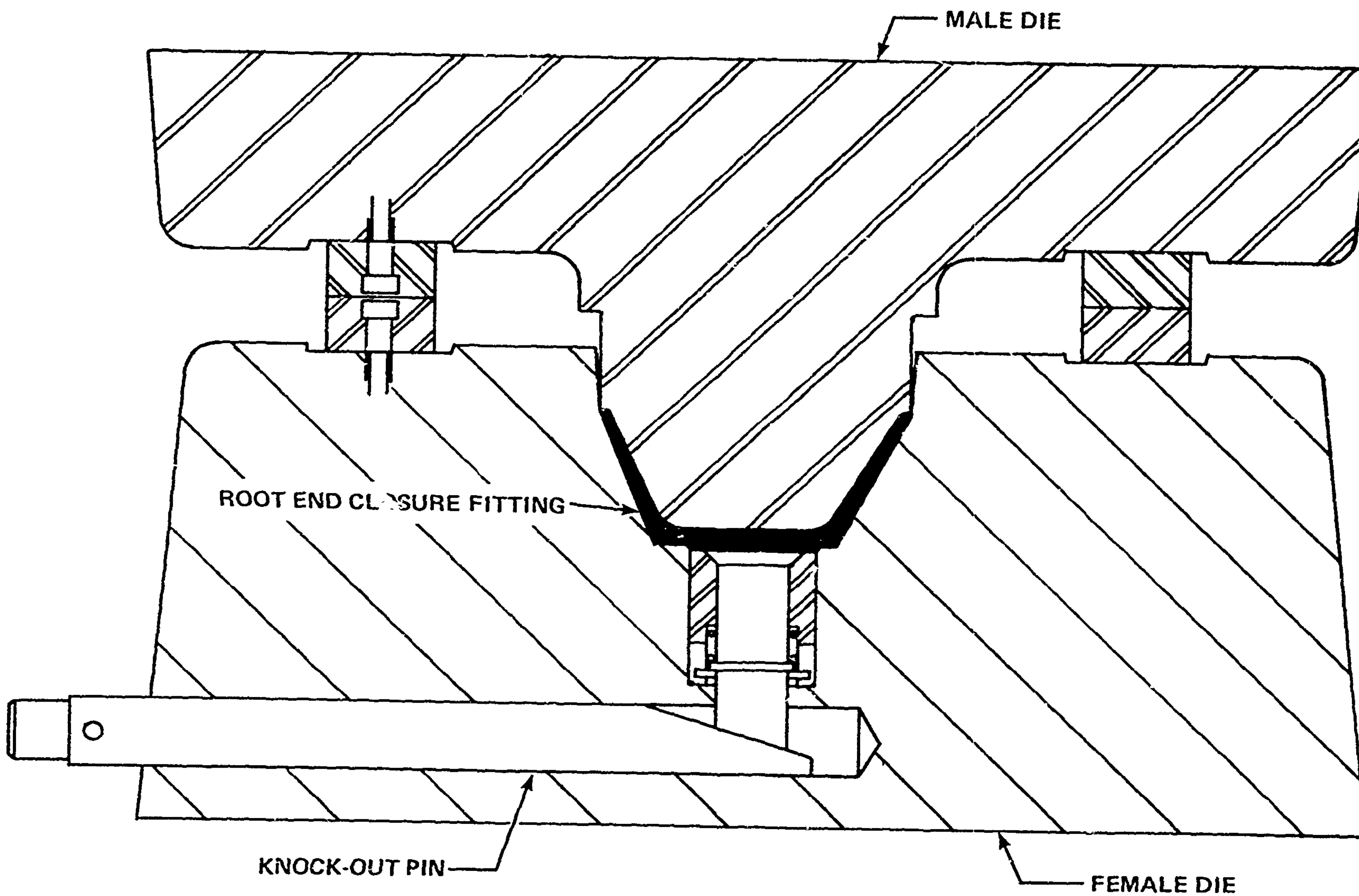


Figure 47. Kirksite Die, MD SK301-111204-1, for Chopped Fiber Compression Molded Part Fabrication

The results of this die were very good, and parts were produced with a minimum of additional development.

The tip balance weight fittings, 301-11184-1 and 301-11186-1, are made from the same chopped fiber material (SP 1157) as the root end fittings. They are, however, more complex in that they have metal tubes and plates built into them for retaining the weights. Because of the design, each of the fittings had to be molded in two halves and then bonded together with the tubes in a separate operation. Each half fitting then required a separate mold. See Figures 48, 49, and 50.

Due to the complexity of the molds and Boeing Vertol shops being at a peak at this time, machining of these tools was subcontracted to an outside vendor, Stokes-Trenton.

Final Bonding Fixture BAJ SK301-11171-1

Most comments made for the spar BAJ are also applicable to the final BAJ (fixture which bonds the aft fairing to the spar) with the exception that it is much wider and heavier. See Figures 51 and 52. The pressure required for this operation is derived from oversize machining of the honeycomb core and machining the fixture to the proper OML of the blade. Because of this, as in the spar BAJ, the castings were machined using the MDI method, which closely controls the contour, twist and other parameters.

Within the Boeing Co. there are approximately 250 NC machines that have maximum part size capacities ranging from a few inches to well over 100 feet and with part weights over 50 tons. Making use of some of the larger NC machine equipment at the Boeing Wichita Division, the large final BAJ castings were machined as one unit, thereby eliminating costly coordination and extra setups.

When the upper and lower sections of the final BAJ are assembled and bolted together to fixed stops, the inner mold contour is the true OML of the blade. There is no additional pressure applied to the part. It is therefore mandatory that the machining of all the tools be held within close tolerances to ensure the production of a good part. This was done most efficiently by using the NC method derived from the Master Dimensioning data.

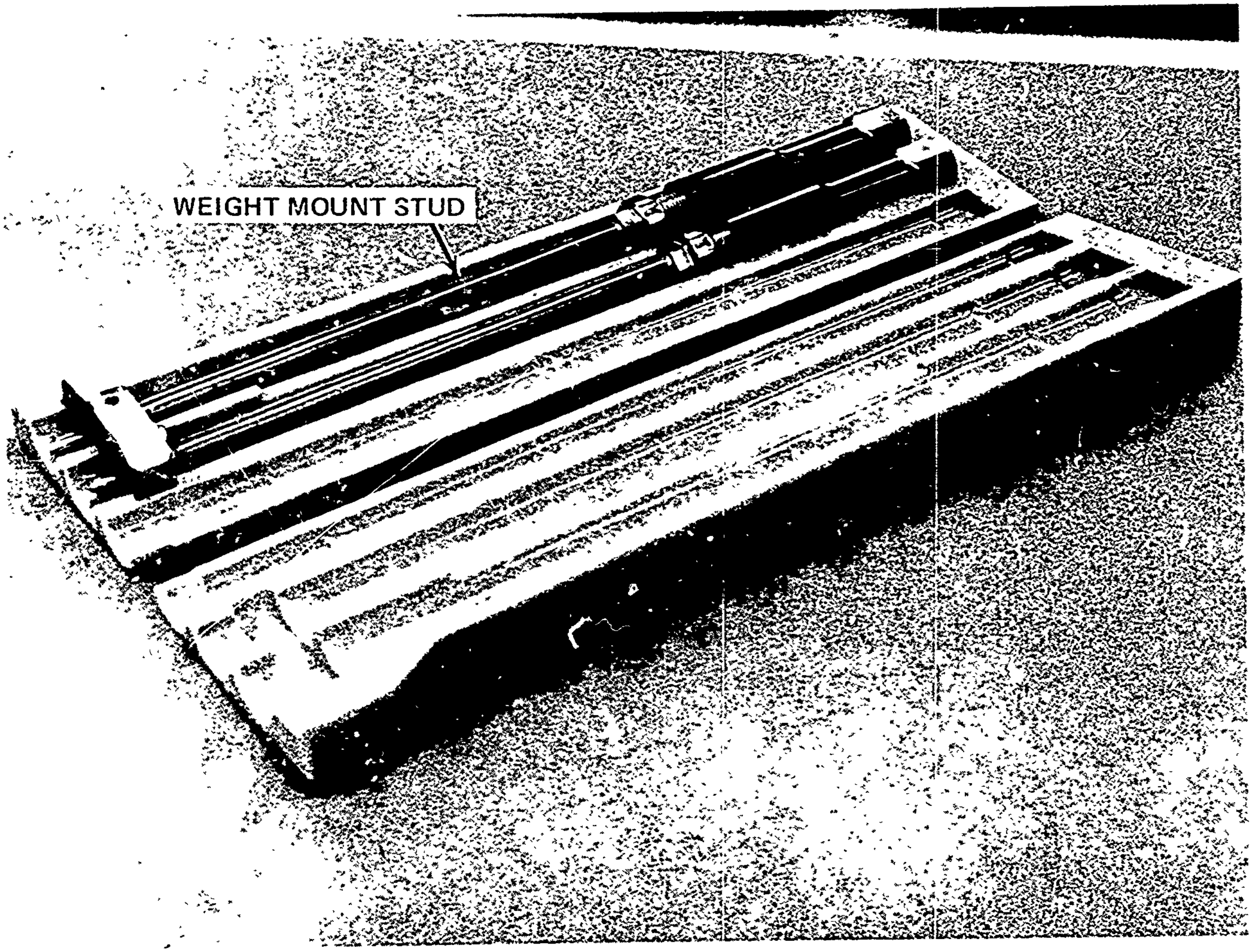


Figure 48. Forward Weight Fitting – Showing Upper and Lower Molded Halves, Internal Tubes and Blocks, and Studs Used for Mounting Balancing Weights

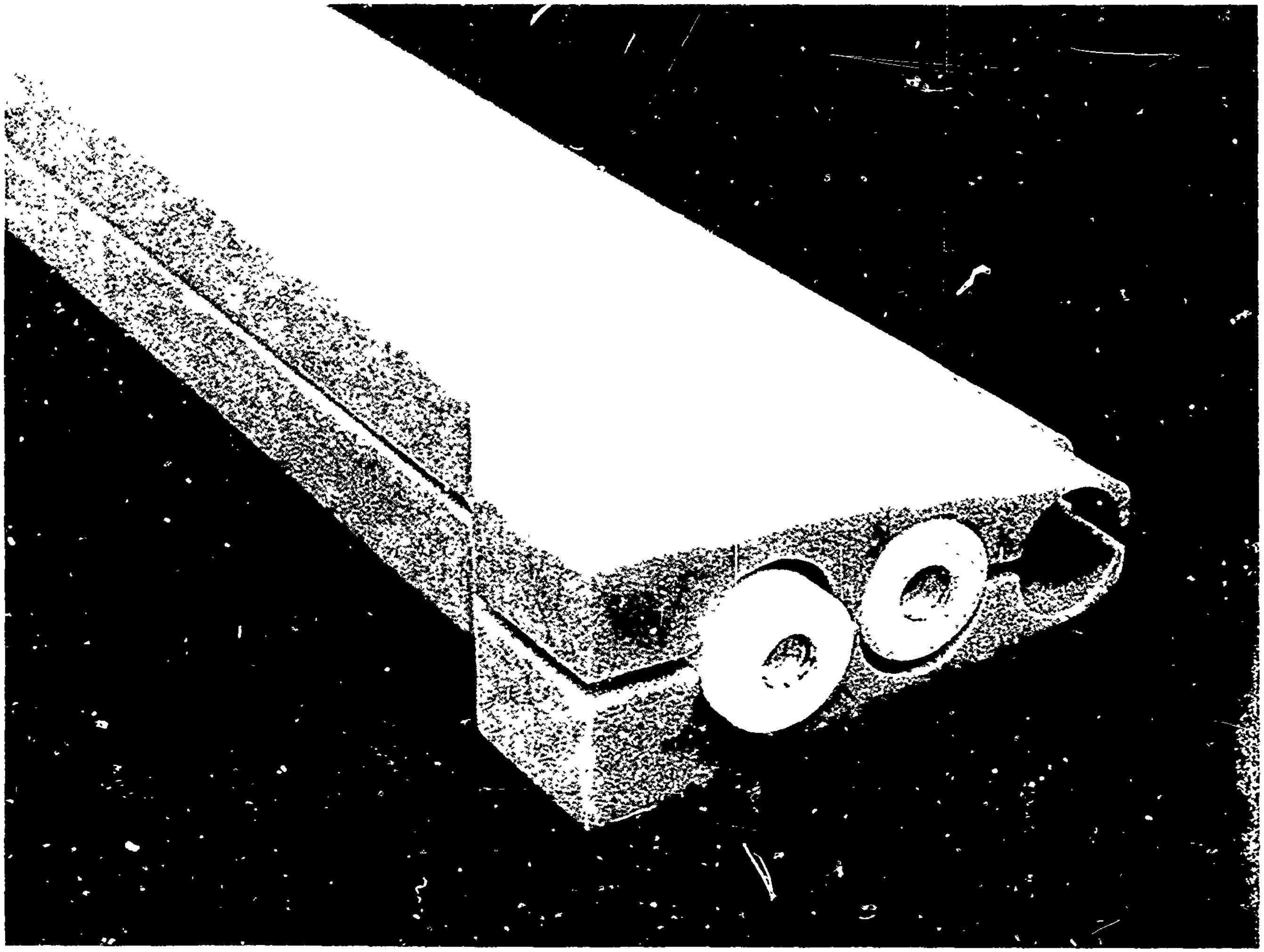


Figure 49. Forward Weight Fitting Subassembly – In Preparation for Bond Operation

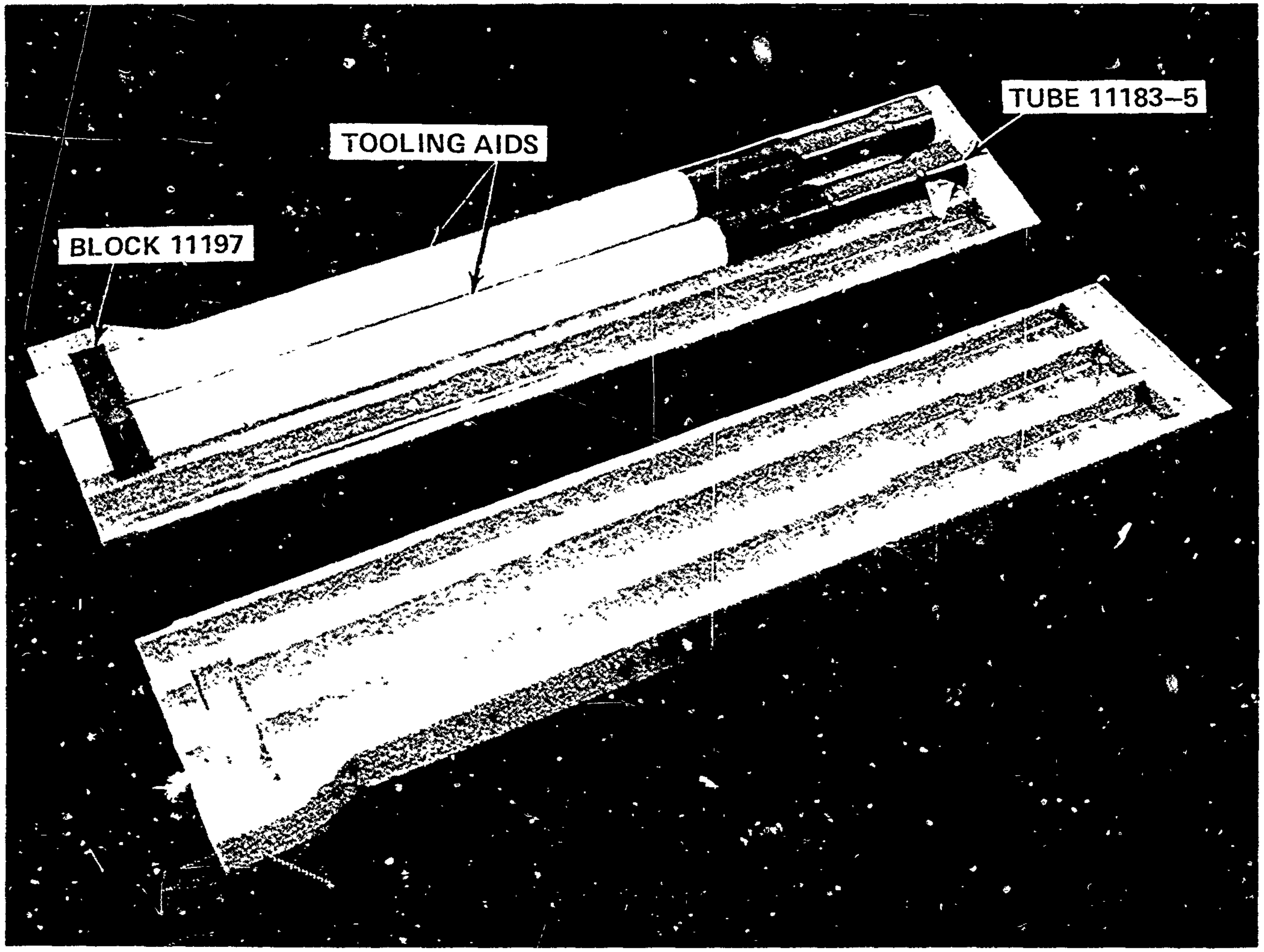


Figure 50. Forward Weight Fitting in Preparation for Bonding

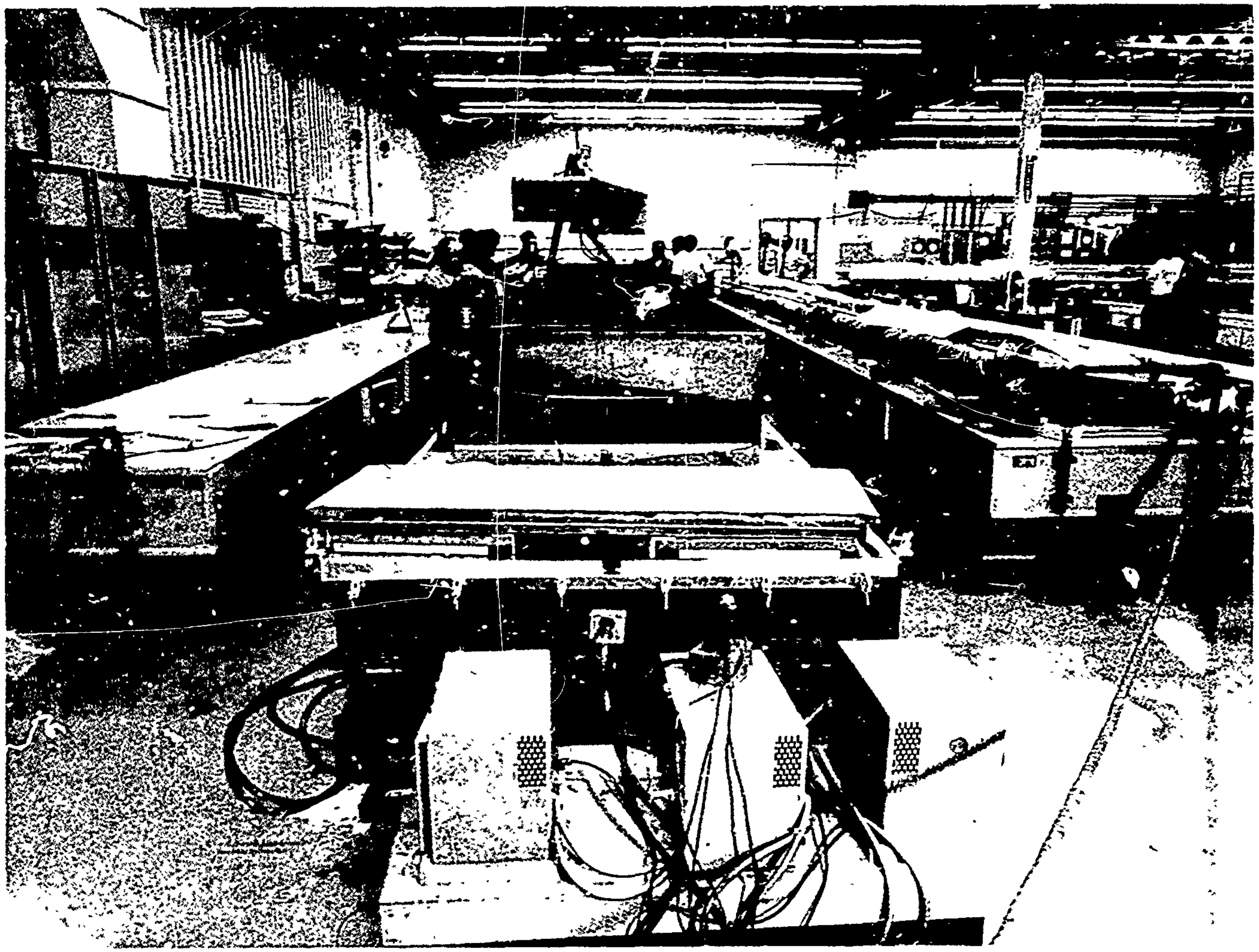


Figure 51. Closing Main Bond Tool for Bonding of First Blade

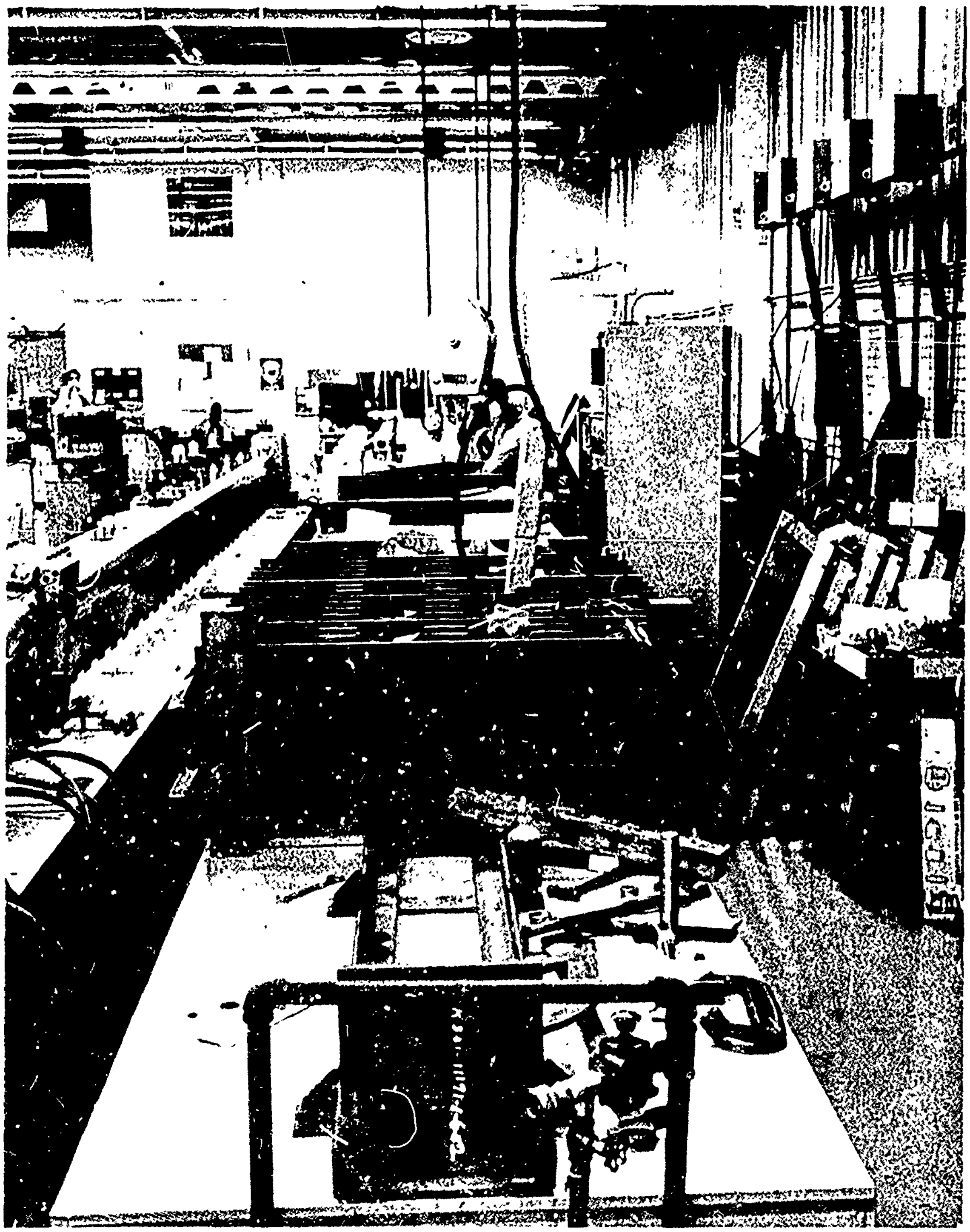


Figure 52. Simulation of Prefit Operation Prior to Actual Use of Final Bonding Fixture

During the bonding of fairing to blade, a special mandrel (MIT SK301-11175, Figure 53) is inserted into the spar. This mandrel applies an internal pressure of 80 psi at the spar heel to ensure a good bond of the skin fairing to the spar. In addition, both ends of the spar are capped, and the entire spar is pressurized from 8 to 10 psi to prevent any delamination of the previously cured spar.

Root End Boring

Following completion of bonding operations, trimming and machining of the root end is the next step in fabrication of an HLH Rotor Blade. The root end throat (opening between upper and lower straps) at the inboard end is opened to accept the lag damper; attaching holes are bored to their finished size and, more important, dimensionally held in relation to one another (7.000 ± .001 inches) and in relation to the outboard blade section (Station 414.0). A slight deviation at the root end of the blade would cause serious changes to blade lead/lag, angle of attack and mating with the rotor hub assembly.

Boring fixture BOF SK301-11171-1, Figure 54, was specifically designed and built to properly locate the blade using a special outboard stand at Station 414 and locating pads in the root end area. The machine was designed to use a twin-spindle boring head to maintain hole spacing; special boring bars and cutters were supplied to complete the operation.

Design of the boring fixture also provided for installing the lag damper arm, sleeves and washers that are assembled and bonded into the blade.

One of the problems encountered was the procurement of cutters best suited for machining cured fiberglass. The material is very abrasive, and unless a good cutting edge is maintained, delamination of the fiberglass will occur; maintaining part size then becomes a problem. The cutters used for boring the holes were made of Wildex-Carbide Grade E6 with a 12° positive rake angle. The cutters used for spotfacing the holes were Kennametal Grade 68, also with a 12° positive rake angle. All machining was done at slow speed and feed. It was also necessary to incorporate dust collection equipment due to the type of material being machined.

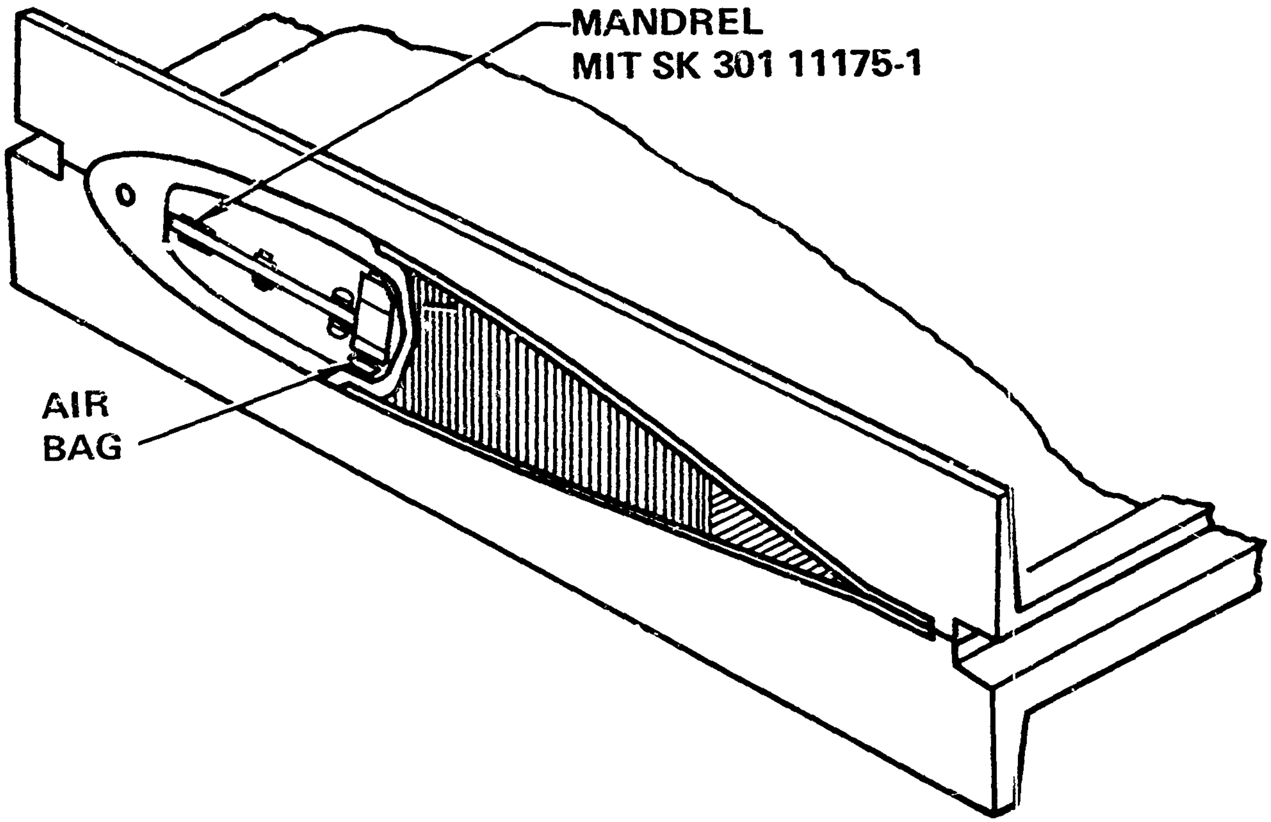


Figure 53. Special Mandrel Used to Support Spar Heel During Final Blade Bonding Operation

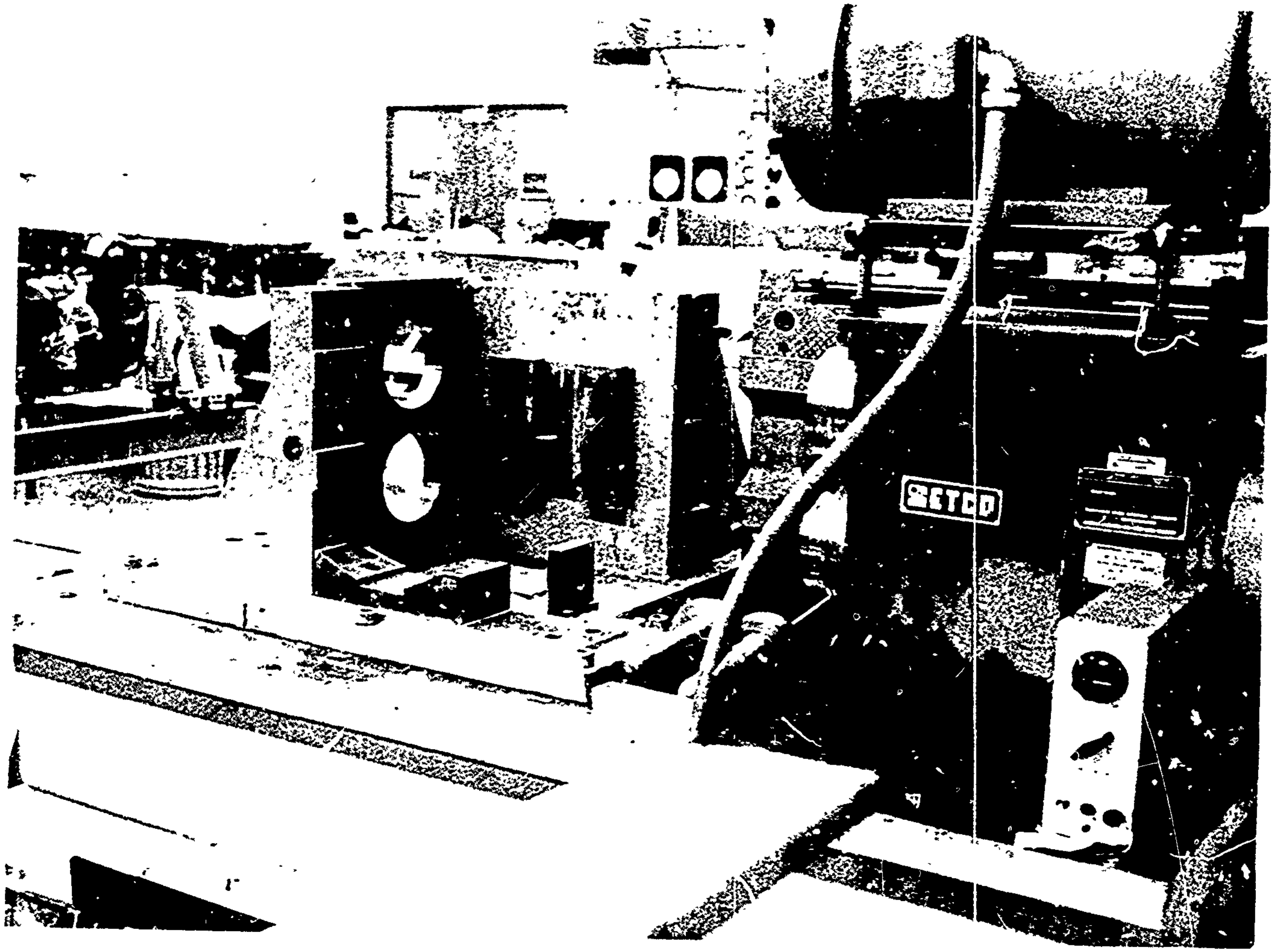


Figure 54. Root End Boring Fixture BOF SK301-11171-1

Erosion Cap

The HLH Advanced Composite Rotor Blade design concept required an electroformed nickel airfoil shape bonded to the outboard leading edge of the blade for erosion protection.

Electroformed nickel erosion caps unique to the industry were developed by HLH Design Engineering Tooling and Processes by a patented process covering the electroform technique.

The erosion caps are 82 inches long and have a tapering wall thickness. In addition to critical blade contour, the design of the cap requires controlled deposition of plating to produce airfoils that are tapered in both chord and spanwise planes. The selective deposition and distribution of heavier plating at the leading edge and outboard tip area provides maximum erosion protection. See Figure 55 for erosion cap details.

The desired plating requirements were achieved after a plating mandrel (SK301-11189, Figures 56, 57, and 58) was made. Development was conducted by varying the tooling mandrel/plating anode relationship in the electroform process, using existing facilities at Boeing Vertol Company (Figure 59).

Trimming of electroformed nickel erosion caps is necessary due to the nature of electroforming itself. Electroformed edges are typically irregular, show thickness variations, and include nodulation or bead-like growths of extensive proportions (Figure 60). As an aid in removing the crust-like nodule formations, the electroform mandrel is masked in such a way as to produce an easily-fractured line from which the noduled edges are broken off. This leaves a fractured edge (Figure 61) which must be trimmed to dimensional size and dressed to the required surface finish requirements. The fracture line (Figure 62) location is determined by the masking tape position and generally is ¼ in. to ½ in. outside (larger than) the net part dimensions to allow for trimming/finishing that satisfies engineering and manufacturing considerations.

Rough trimming is done using hand routers (air driven) with ¼-in. diameter high-speed straight-fluted bits. Finishing is performed with an orbital hand sander used with 240 grit aluminum oxide cloth discs to remove router tool marks and burrs (Figure 63). This is followed with crocus cloth discs

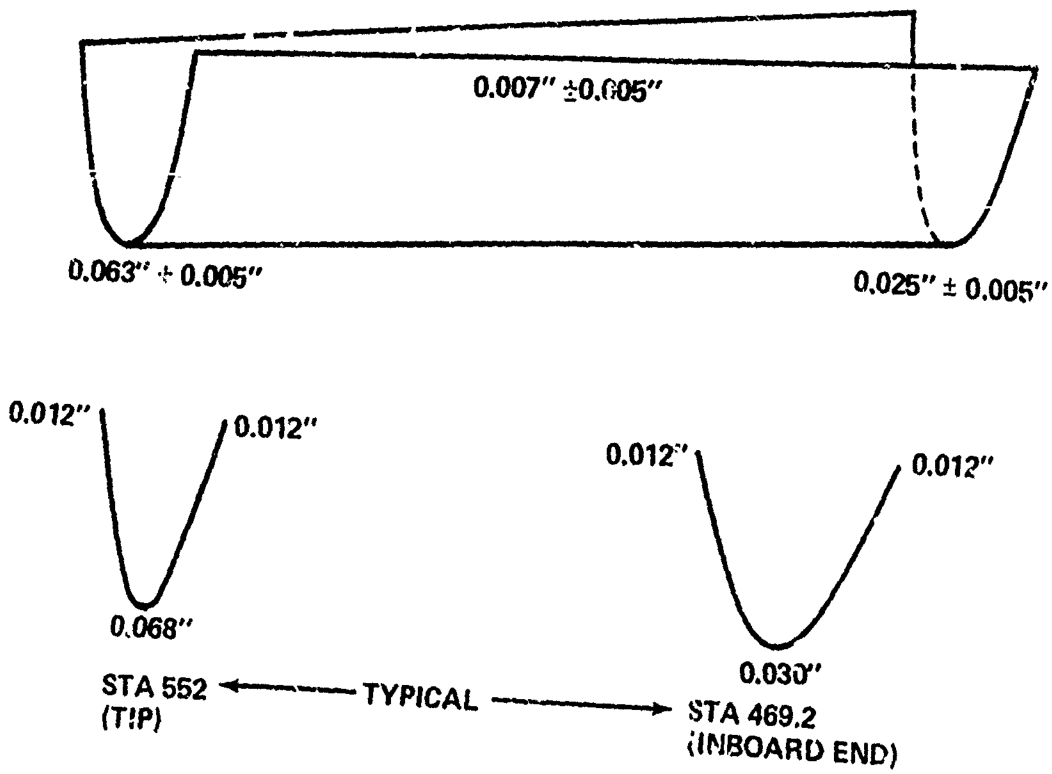


Figure 55. Typical Nickel Erosion Cap

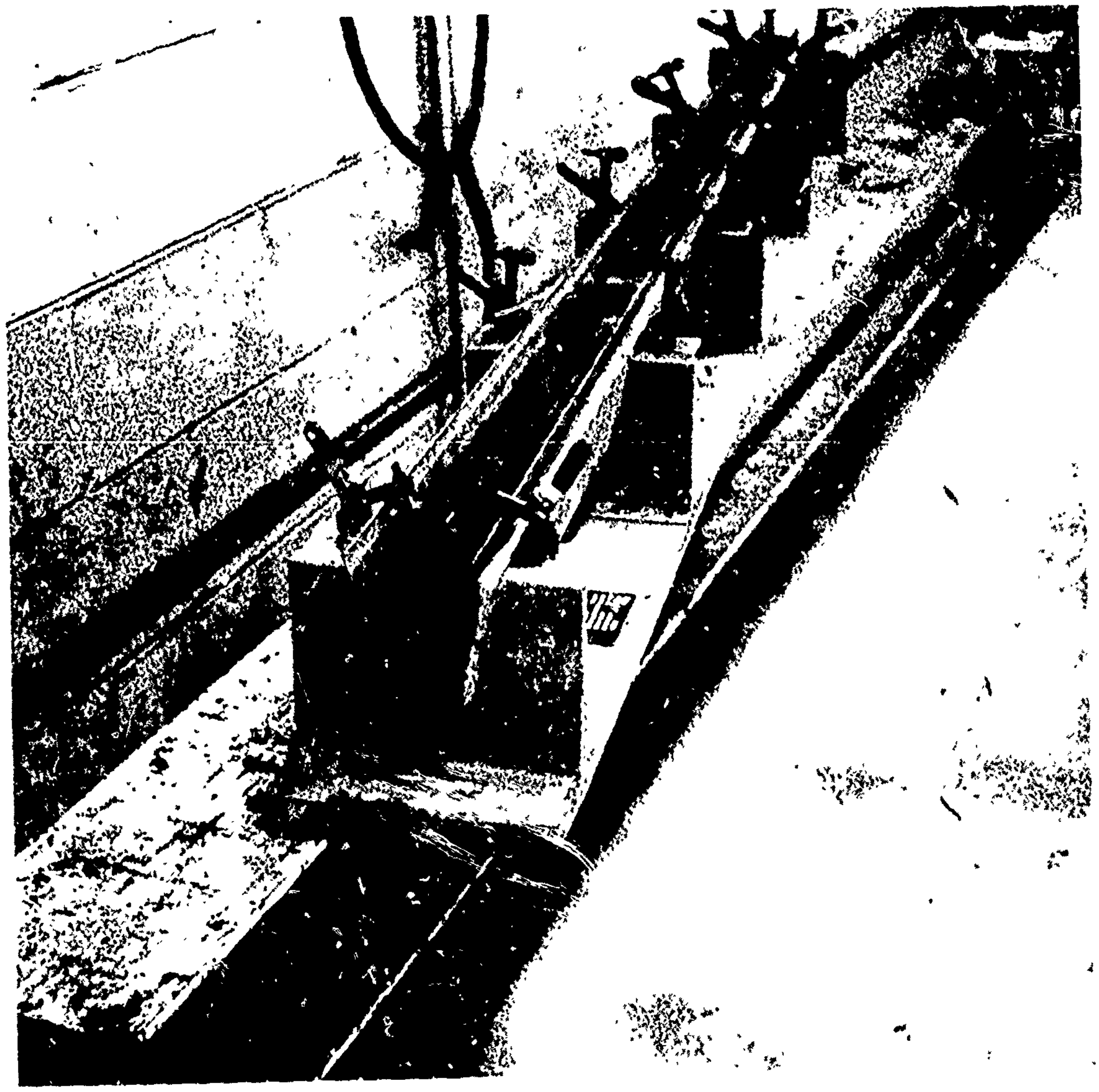


Figure 56. Nickel (Electroform) Cap in Trim Fixture

Figure 57. Erosion Cap Plating Mandrel Mounted and Ready for Use

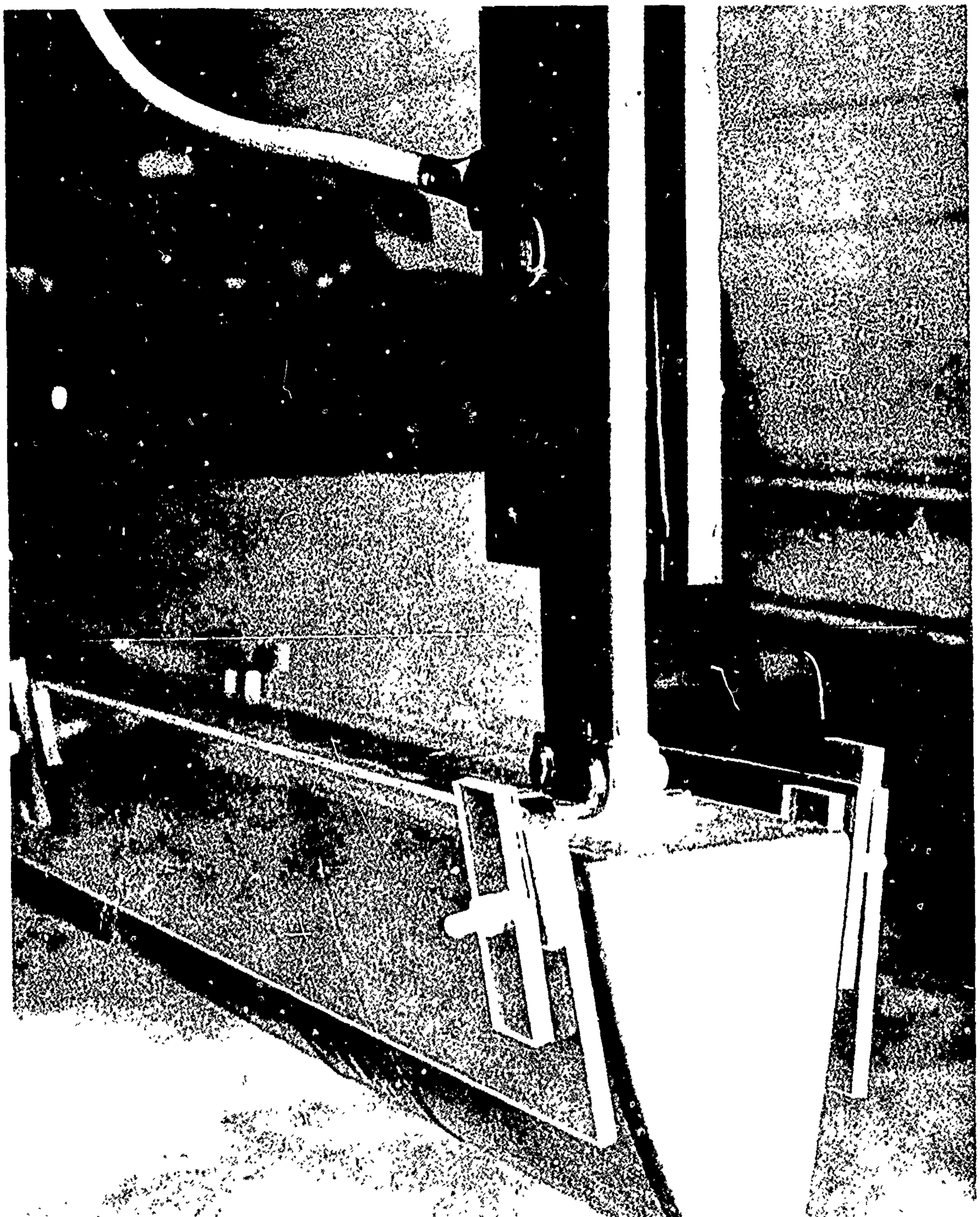


Figure 58. Details of Erosion Cap Plating Mandrel

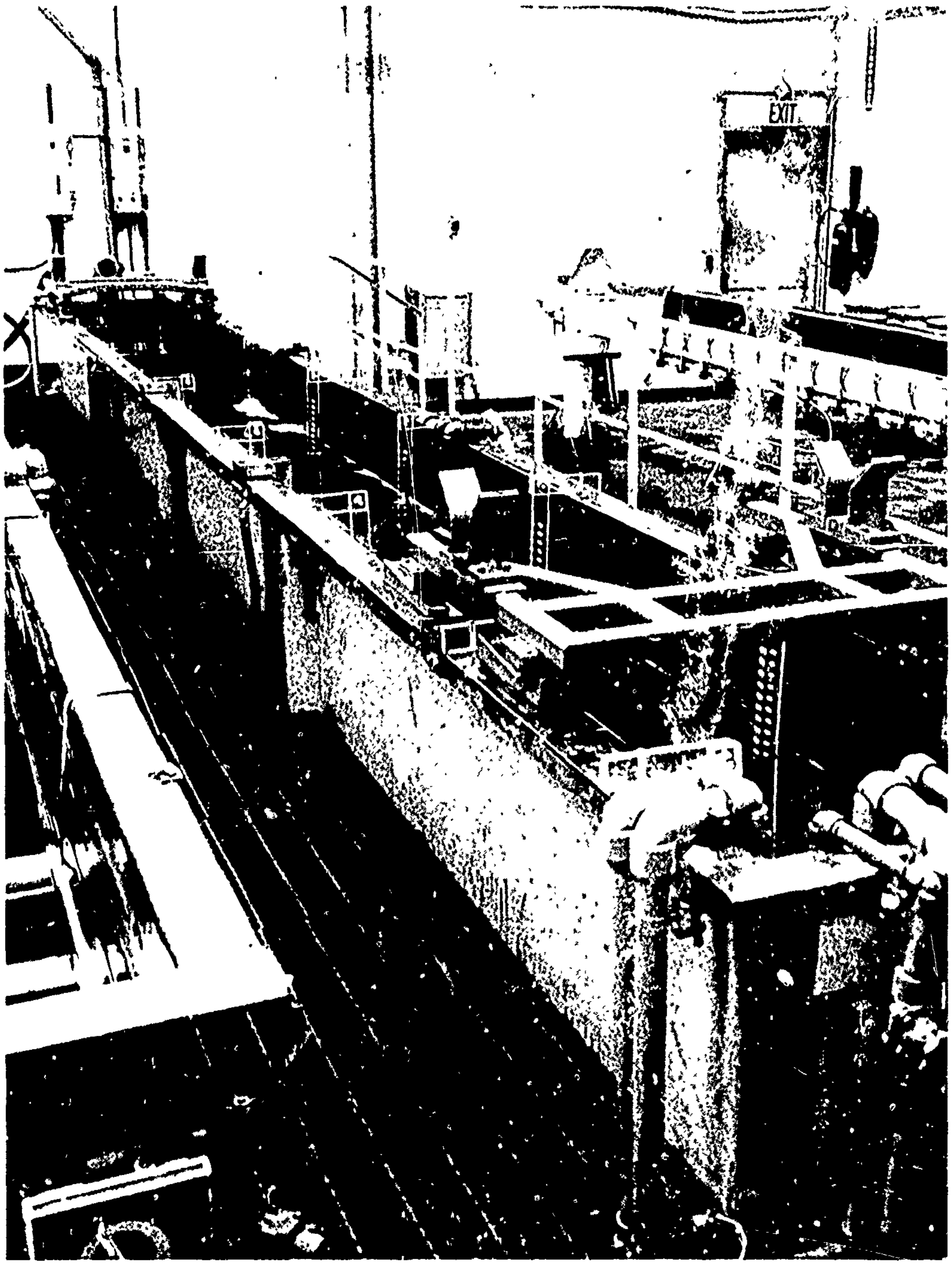


Figure 59. Plating Facility for Nickel Electroforming Erosion Cap

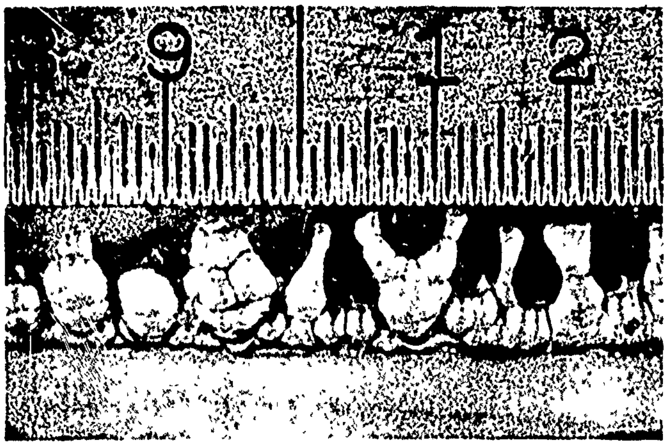


Figure 60. Edge Nodulation on Electroformed Part

Figure 61. Edge Resulting from Breaking Off Noduled Strip

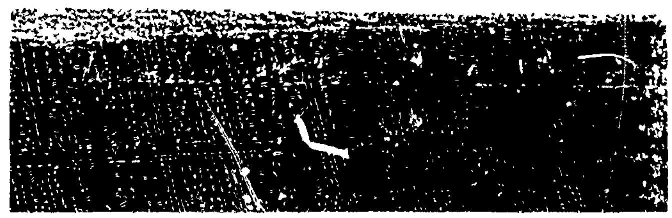


Figure 62. Edge Meeting Requirements

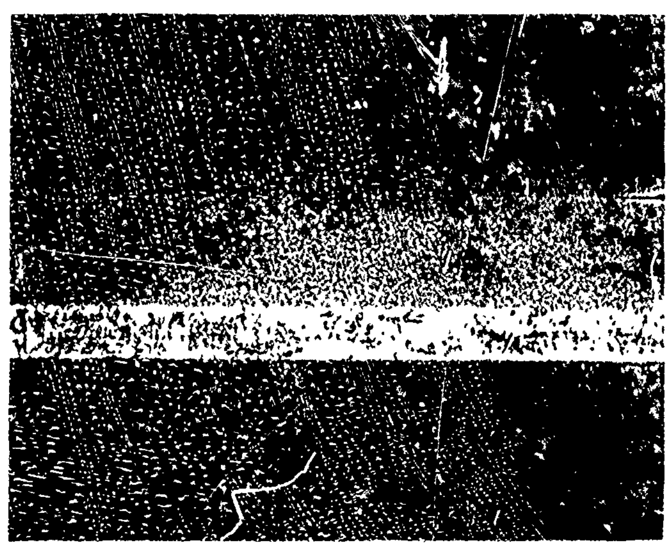


Figure 63. Edge with 240-Grit Orbital Sanding

in the sander to remove the 240 grit marks.

The final steps to complete the HLH Rotor Blade (listed below) were performed with a minimum of tools and were not intricate in nature.

1. Trim the T.E. (trim jig)

2. Bond trim tabs (2) (bonding tool)

3. Bond rib closures (bonding tool)

4. Bond R.E. doublers (shop aid)

5. Bore R.E., install lag damper and sleeves (boring fixture, Figure 53)

6. Bond L. E. erosion strip (shop aid)

7. Assemble tip hardware and tip cover

8. Paint

9. Teeter balance (teeter balance fixture, 7MIT SK301-11171-1, Figure 64).

Teeter Balance Fixture

For most of the HLH Rotor Blade operations, the tooling could be considered standard except for the Teeter Balance Fixture (Figure 64). Due primarily to its large size and weight, the teeter fixture created new problems. A blade is balanced against a known weight to ensure that all blades have the same total span moment. Adjustment is made by adding or subtracting tip weights in the blade.

All existing teeter stands for the CH-46 and CH-47 models employ a shaft at Station 0.0 going through the balance head and pivoting in bearings. The arc through which the shaft rotates is very small, and only a small section of the bearing is used. Friction, dirt, and other factors affect rotation of the shaft, resulting in poor balance. To overcome this condition, bearings were not used and the balance head was suspended by straps. Because of their availability, four tension/torsion straps used in the Chinook CH-47 aircraft were adopted for this purpose. This method worked very

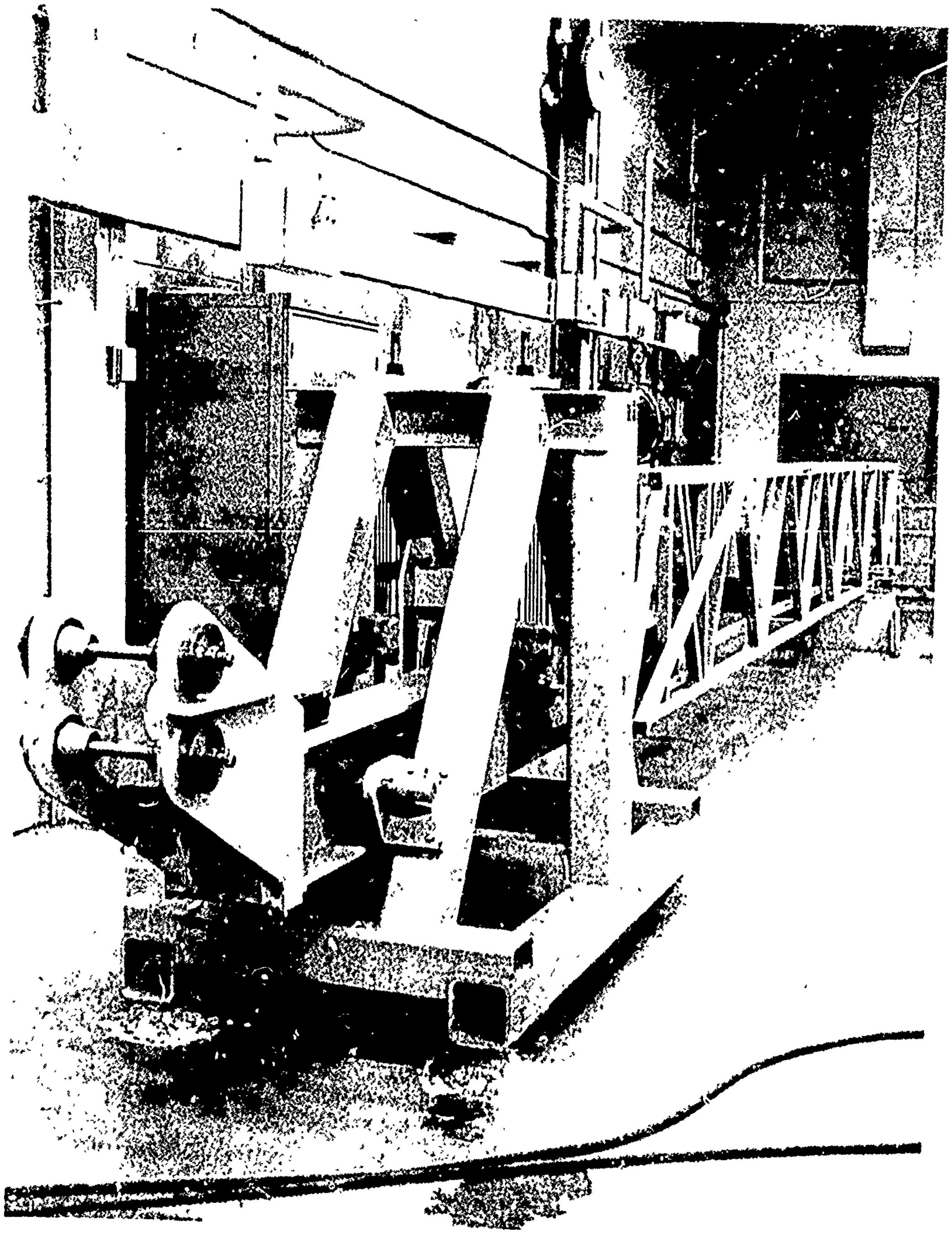


Figure 64. Teeter Balance Fixture

well and all HLH ATC blades were teetered satisfactorily.

Handling Equipment

The HLH Rotor Blade and its associated tooling created handling problems not normally encountered in the fabrication of rotor blades. The CH-47 rotor blade, with a chord of 23 inches, a 25-foot length, and weighing approximately 350 pounds, is the largest blade presently produced at Boeing Vertol. A blade of this size can still be manually moved from one work station to another or with the aid of a simple spreader bar, can be handled with existing overhead equipment. The HLH blade, weighing in excess of 700 pounds, requires that all moves be made with overhead equipment using a specially designed beam (2OHME SK301-11173-1, Figure 65). The beam is 40 feet long with a sufficient number of adjustable nylon straps to give full support to the blade, the spar, or any of the long detail parts. This was most important when moving the uncured spar assembly.

The fabrication concept of using one common base and control unit requires movement of the spar BAJ and final BAJ on and off the base for each operation. The weight of full spar BAJ is 16,000 pounds; the final BAJ weighs 32,000 pounds. The three-ton limit of the overhead equipment available in Boeing Vertol's Blade Shop made it mandatory that other systems be developed.

The method chosen was to make two tables each with ten 28-inch diameter air cushions on the bottom (PME SK301-11171-1, Figure 66) and with an "Air Off" height to match the restraining base. With this system, the complete fixtures could be moved from one area to the other with minimum effort. Note that each of the BAJs had clearances (slots) milled into them to accept 16-inch diameter air cushions to permit moving the tools from table to restraining base or vice versa.

A special sling (OHME SK301-11171-1) was designed and built for assembling the blades to the hub assembly at the Whirl Tower and at the test stand.

A special dolly (FME SK301-11171, Figure 67) was also fabricated for interplant movement of completed blades.

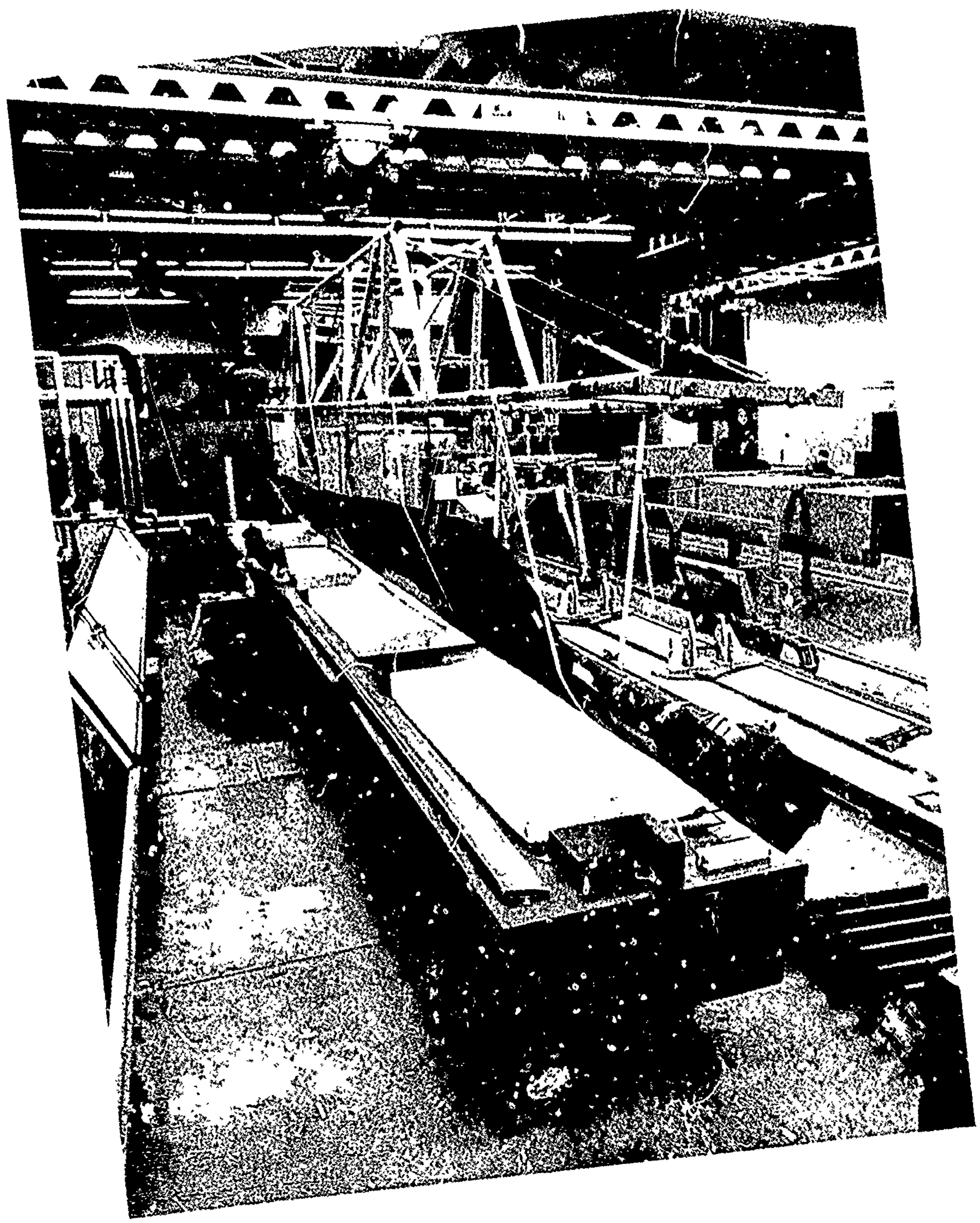


Figure 65. Unloading Blade from Bonding Operation

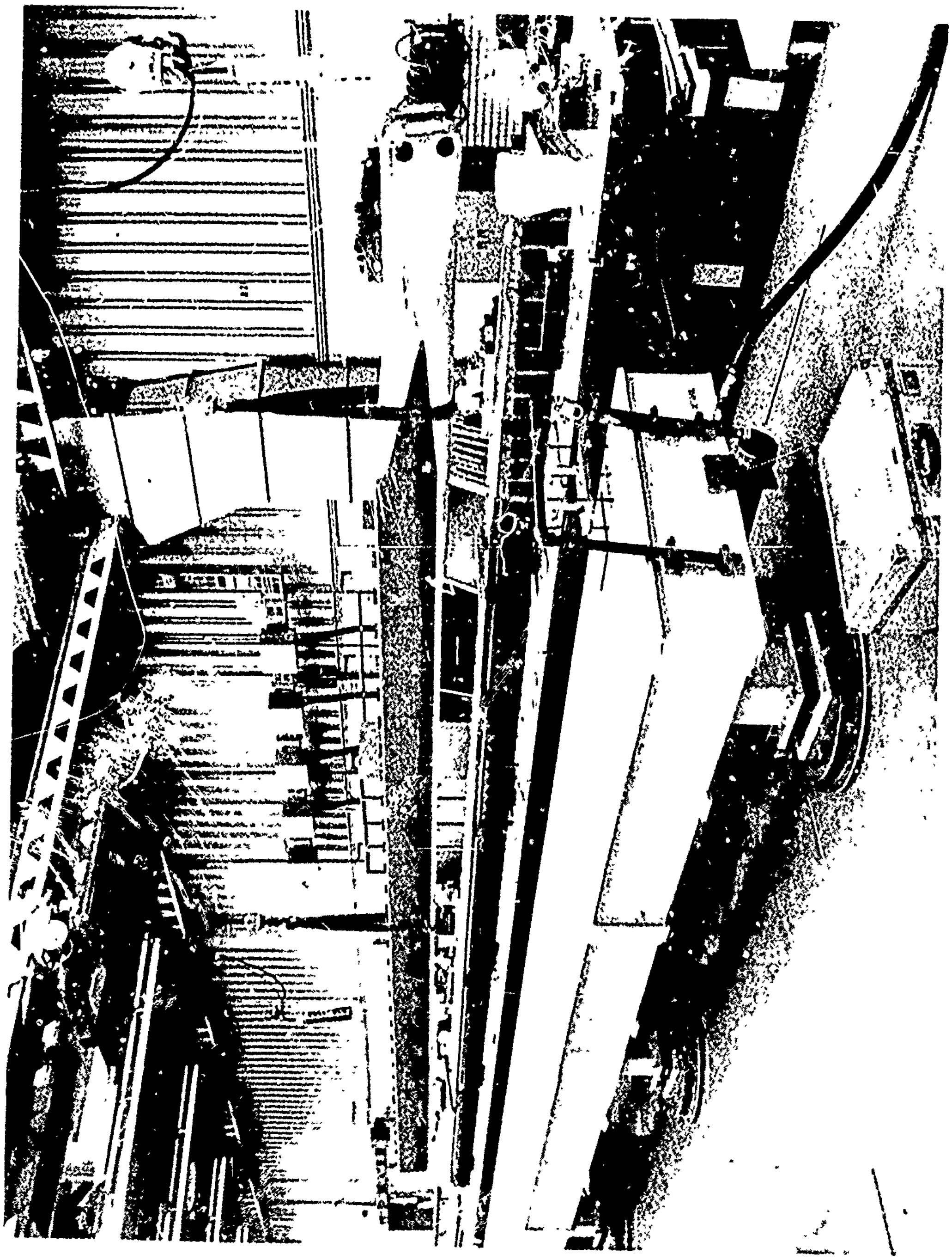


Figure 66. Unloading Spar No. 1 from Cure Tool

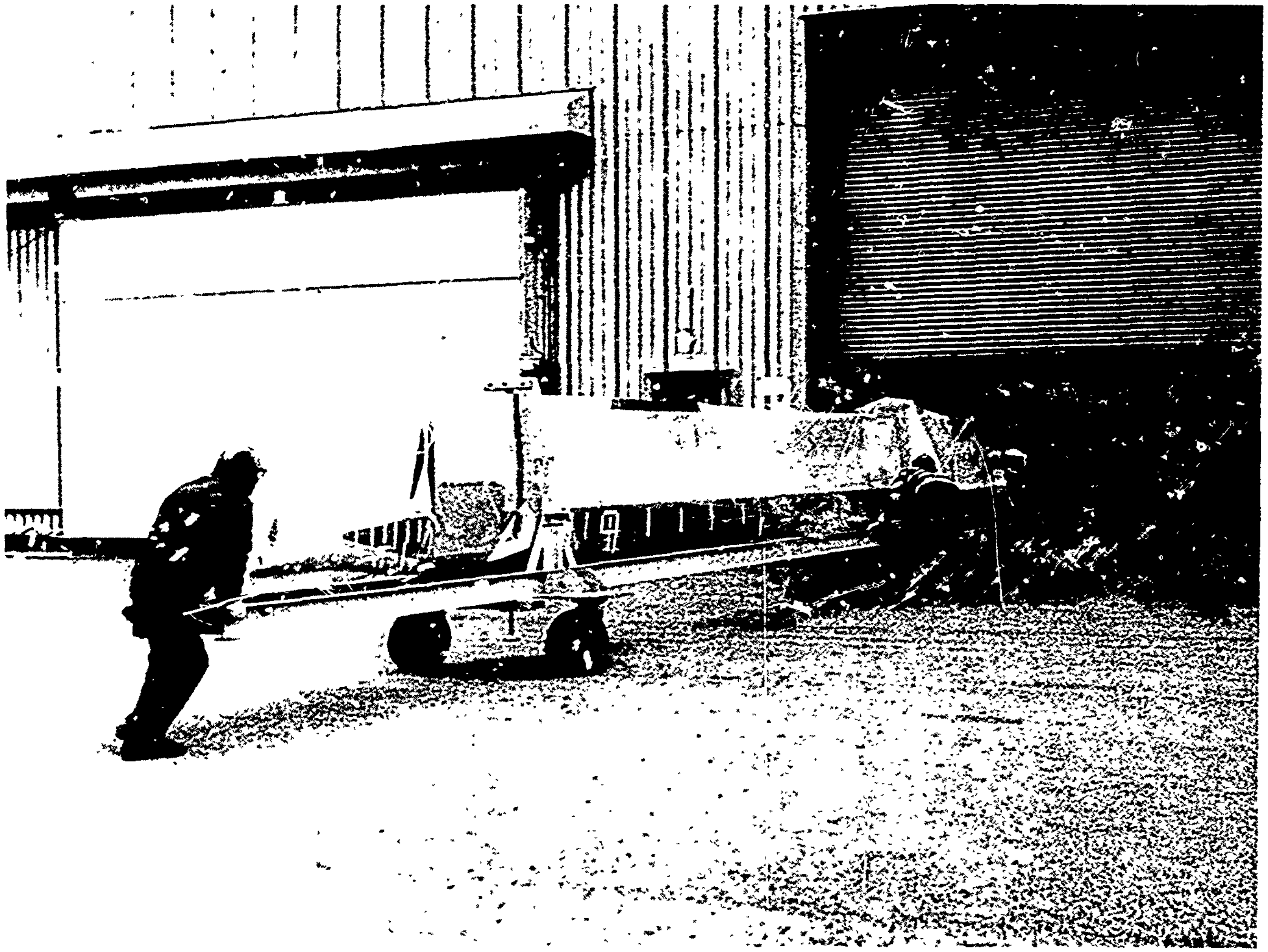


Figure 67. Transporting Blade No. 3 to Instrumentation Laboratory

3.0 ROTOR BLADE FABRICATION

The information in this section documents the HLH ATC rotor blade fabrication program process and results. Included are a separate summation on each assembly function, describing the basic factors leading to the assembly's creation, and a brief outline of the work involved. The major problems encountered and the actions taken to achieve permanent resolution of these problems are also included. Finally, as a result of this experience, any judgements or conclusions reached are noted with appropriate comments.

The fabrication portion of this section is divided into two basic rotor blade components: spar and fairing. (Refer to Figure 68.) The fabrications of the blade detail parts are considered sufficiently simple and do not warrant separate coverage. However, to show the quantity of details and other particulars, a series of charts has been prepared and included at the end of the section.

SPAR FABRICATION

The following paragraphs describe the essential elements of the spar and the spar assembly operations.

Cap and Heater Subassembly

To cure the titanium nose cap primer and prepare it for subsequent bonding, the cap and heater subassembly was created. This subassembly includes positioning of the AF30 adhesive and the simulated heater blanket on the cap interior surface, which are then covered with a peel ply. The subassembly is next bagged and placed in the autoclave for curing. The cured piece is removed from the autoclave, is cleaned up to remove excess resin, has its edges trimmed, and is prepared for the next operation.

Fabrication

Overall, fabrication of this subassembly was successful as planned; however, several problems were encountered. The following is a brief outline of those problems:

o Bag Failure. During the initial autoclave heat cycles, leaks developed in the film bag on the earlier units. The resolution of this problem involved double bagging the subsequent units.

- Adhesive Repair. During the curing operation, the adhesive moved on some units, resulting in a cap without adhesive along the edge. The interim "fix" during the ATC program was to add adhesive strips and to cure them with strip heaters. The final resolution for prototype units is to let the adhesive be oversize to allow for movement and shrinkage. A subsequent trim operation will then be performed as part of the post-cure operation.

- Peel Ply Removal. Prior to use on the next assembly, the peel ply must be removed. Considerable difficulty was encountered with the peel ply breaking and coming off in threads rather than in a full sheet as desired. An investigation was launched to ascertain the source of this problem, which proved to be the material itself. Based on a series of tests, an improved material was selected and will be used on the HLH Prototype blades.

Leading Edge Subassembly

To simplify the spar assembly task, the down stage leading edge subassembly was created (Figure 69). Included in this subassembly are the titanium leading edge and simulated heater blanket, the nose block detail, and the tip block subassembly. Fabrication involved assembling the compacted glass blocks (tip and nose) with the titanium cap and the heater subassembly. With a mandrel for internal pressure, the part was cured in the spar bonding fixture. After the cured part was unloaded and the mandrel removed, a trim operation was performed, and excess resin and peel ply were removed.

There was a major concern in the preplanning stage that the different thermal coefficients of expansion of the titanium and glass materials would cause a warpage problem with this subassembly. A series of meetings were held to identify methods of optimizing the tooling to minimize this condition. It was concluded that a warpage test specimen would be run to fully understand the problem prior to fabrication of the full scale spar. The specimen was 12 feet long, with a nose block and titanium leading edge, and was built to simulate the actual fabrication sequence. (Refer to Figures 70 and 71). Based on test results of that specimen and the tool concept utilized, it was determined that warpage was not a problem.

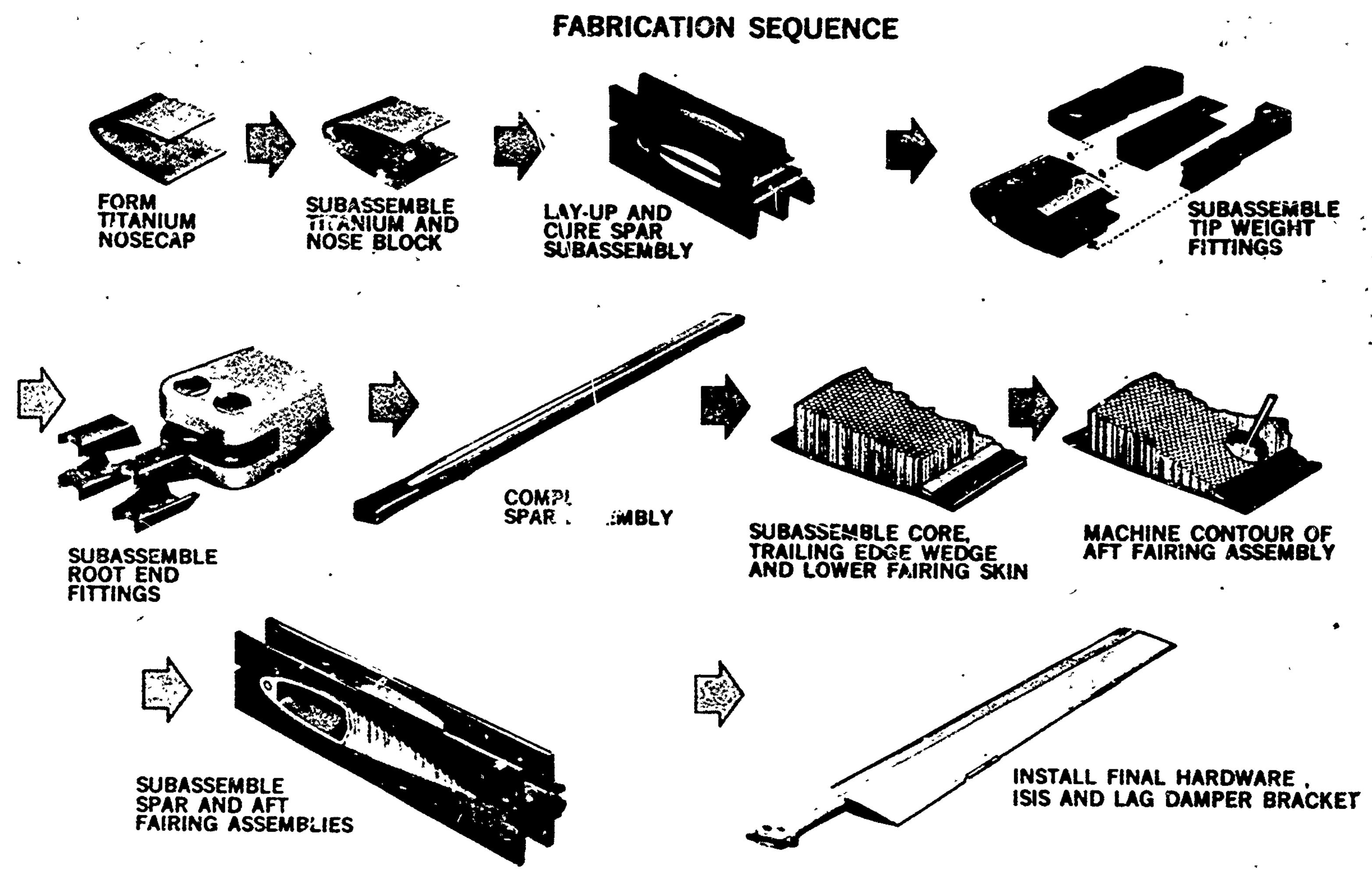


Figure 68. Blade Fabrication Sequence

ATC Experience

Other problems with this subassembly were encountered and resolved, including:

- Leading Edge Trim. Several units had to be reworked to correct the trim dimension along the skirt of the cap. The problem was noted when the leading edge was loaded in the spar bonding fixture and the cap skirt extended beyond the spar heel joggle. This discrepant condition required a trim operation for correction. As a permanent resolution, the drawing dimension was changed, and the fixture was revised to provide the proper trim.

- Leading Edge "Clamshelling". Blade numbers 4 and 5 were received with a severe "clamshell" condition on the outboard end. These blades required cutting along the nose to open the cap. After the cut, edge treatment was added along the cut edge, and a graphite doubler was placed between the titanium and the glass in the tip block. The problem was identified, and the titanium creep forming tool was modified. On subsequent blades, the problem was significantly reduced.

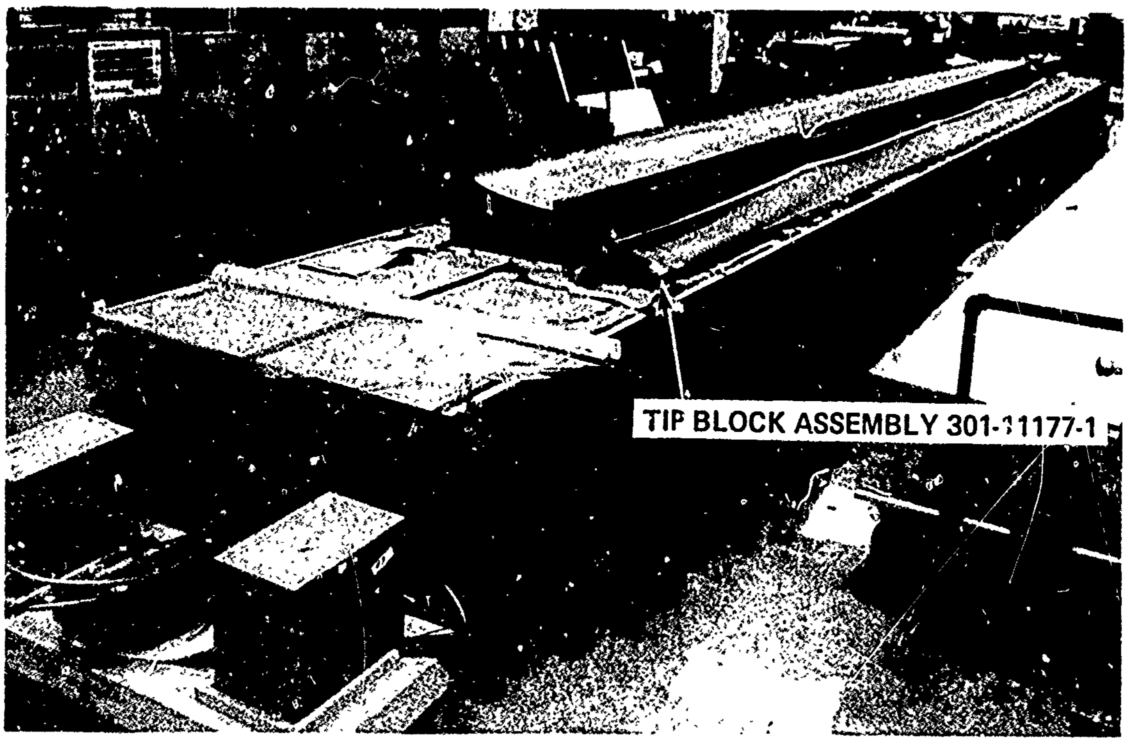


Figure 69. Leading Edge No. 1, Showing Tip Block Cured in Place

Figure 70. Warpage Test Article – Full-Scale Leading Edge (12 feet)

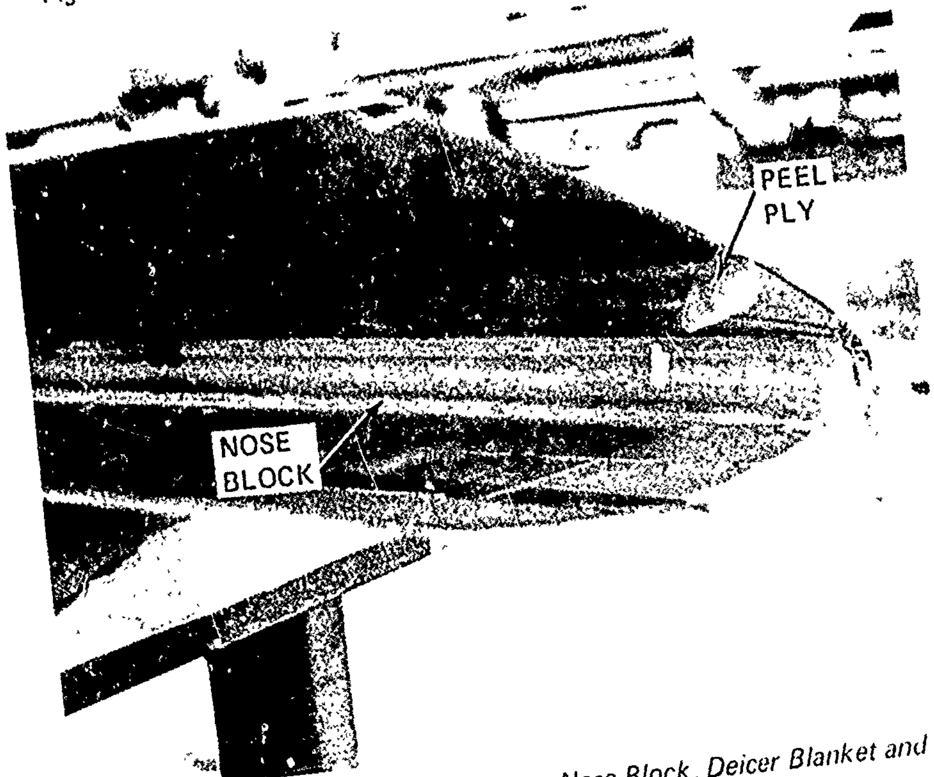


Figure 71. Warpage Test Article – Showing Nose Block, Deicer Blanket and Peel Ply

o Discrepant Spanwise Tube Location. After the cure of the leading edge, it was noted that the tip block tube had moved, resulting in the tube location being too far outboard. The interim "fix" was to cut off the tube end. The permanent fix consisted of a stronger, more positive locator being added to the spar bonding fixture and the addition of a positive locator on the internal mandrel.

Strap Subassemblies

The spar strap design was developed with the concept in mind of eventually making the transition to automated tape lay-up during production. A strap subassembly consists of the inner strap, outer strap, uni-directional fiberglass wedge, wraparound strap, and the inboard torsional wrap. (Refer to Figure 72.)

There are four strap subassemblies on each spar: one upper forward, one upper aft, one lower forward, and one lower aft. Each subassembly is laid up separately on its own lay-up mandrel. The task begins by locating the tooling expander on the inboard end of the lay-up mandrel. The inboard inner torsional glass cross-ply is positioned over this; then, the wraparound strap detail is positioned against the tool expander

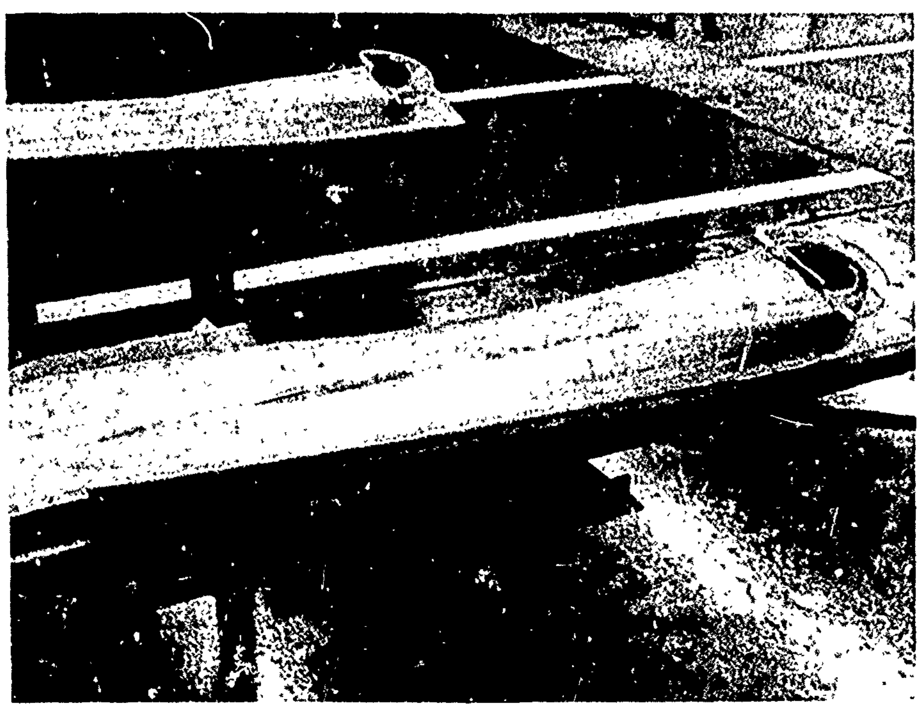


Figure 72. Completed Spar Strap Subassembly

and over the cross-ply. At that point, lay-up of the inner strap is made, one ply at a time, with each ply extending farther outboard than the previous ply. The outer strap is then laid up until the plies finally extend to the blade tip end. In the process of laying up the outer strap, the uni-directional fiberglass wedge is positioned between the straps at the point where they converge.

ATC Experience

The overall fabrication task was fairly simple and few problems were encountered, especially on the first several units. Briefly, those problems encountered were as follows:

- Strap Wrinkling in Wraparound Area. After the initial subassembly was completed, a wrinkling of the inner strap plies was observed. The source of the problem was identified to be the application of insufficient tension to the inner plies during the lay-up process. The wrinkling tended to be concentrated in the wraparound area and was generally on the inner plies. The problem solution included utilizing increased control and attention during the actual assembly by tending to apply increased tension on the layup of inner plies and reducing this tension as the wraparound radius increased. Training and careful control by the operator reduced this problem, and as an added precaution, only experienced personnel were used to perform this operation. One strap subassembly was scrapped due to this problem and a number of units required rework. The obvious long-term "fix" identified was to eliminate the "Human element" by going to an automated lay-up process.

- Tape Placement Discrepancies. The strap lay-up involves going through a transition area where each ply changes from a flat plane to a vertical plane. In that area, the location of each ply is critical in achieving a wrinkle-free shank on the cured spar. Through the transition area, proper tape placement is difficult to achieve and adequate tooling guides are not practical.

On spar number 3, shank wrinkling was encountered, and a portion of the wrinkle was attributed to inadequate control and placement of the tape lay-up through the transition area. Shank wrinkling is shown in Figure 73. An extensive effort placed on preventing further shank wrinkles by reducing bag mandrel size and tighter wrapping of outer cross ply material was successful. Tight monitoring of the strap lay-up process, coupled with a revised unidirectional wedge configuration, made a significant improvement in the quality of the spar straps produced.

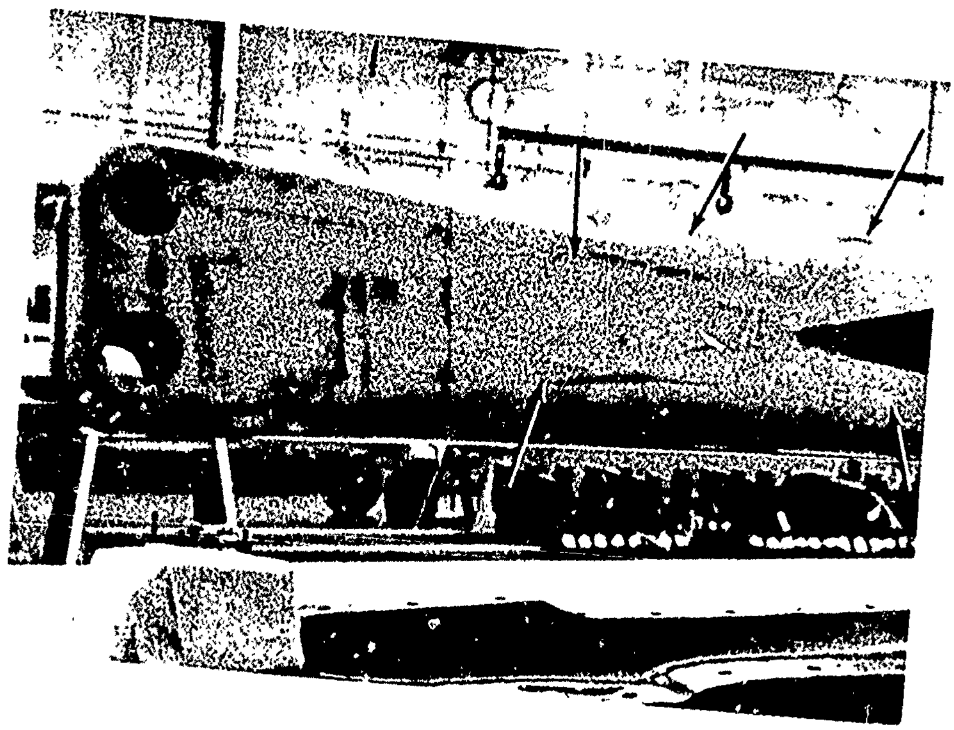


Figure 73 . Root End Shank Wrinkles

To achieve better control and minimize rework, additional lay-up shop aids will be provided on the HLH Prototype blades. A drawing will be developed to depict the "as laid up" configuration, and a series of templates will be provided for all control stations in the transition. Long range planning includes automated tape lay-up for the production program. This type of equipment can be precisely programmed for lay-up through the transition, and will provide repeatability from unit to unit.

Figure 74 shows one of the four spar straps used in the spar assembly. The sections depict the way the strap starts in a horizontal position at the tip end (Station 552.0), continues at this attitude to approximately Station 138.0, and then rotates 90° to a vertical position at Station 66.0. There it reverses and returns to the tip end of the spar. (Refer to Engineering Drawing 301-11173, Sheet 3 in Appendix B.) During the cure of the spar, the internal mandrel (pressure bag) 3LM-SK301-11173-1 (see Figures 31 and 32) applies the required pressure to the strap. A special tool was required in the root end area (Stations 66.0 to 104.0 approx.) where the strap goes through the major change from horizontal to vertical. This tool (9MIT-SK301-11173-1) was designed using an inner wedge which, when activated by the internal mandrel, applies pressure to the spar strap (see Figure 75). The inboard end of the 9MIT-SK301-11173-1 mandrel is also activated by the inner wedge by expanding the serrated end of the tool (see Figure 76).

Spar Assembly

The spar assembly, as the primary structural member of the blade, presented the greatest challenge in the fabrication of the HLH rotor blade. A number of technological advances were required before a "D" spar of the required size could be built. After many design reviews and meetings, the final designs, tool requirements, and fabrication techniques were selected. In many cases, a developmental program was initiated to finalize and try out a concept under consideration.

A good example of a successful program was the spar bag and mandrel development. Economics dictated the requirement for a redundant bag, since a bag failure could necessitate scrapping the entire spar. The "D" spar configuration added complexity because the assembly function required a firm mandrel that could be removed after curing. Handling of the uncured spar placed even greater demands on the design. The bag and mandrel were required to be sufficiently rigid to accommodate movement and transfer. The final design included a laminated graphite/honeycomb strong-back as the structural member within the mandrel (Figure 77). The development of the bag and mandrel assembly is described in the tooling section of this report.

While the spar represented the biggest challenge, it also represented the greatest success in the fabrication of the HLH blade. This achievement was largely due to the significant amount of preplanning devoted to the assembly. A number of problems were anticipated in the early stages, and action was initiated to avoid them and minimize the risks.

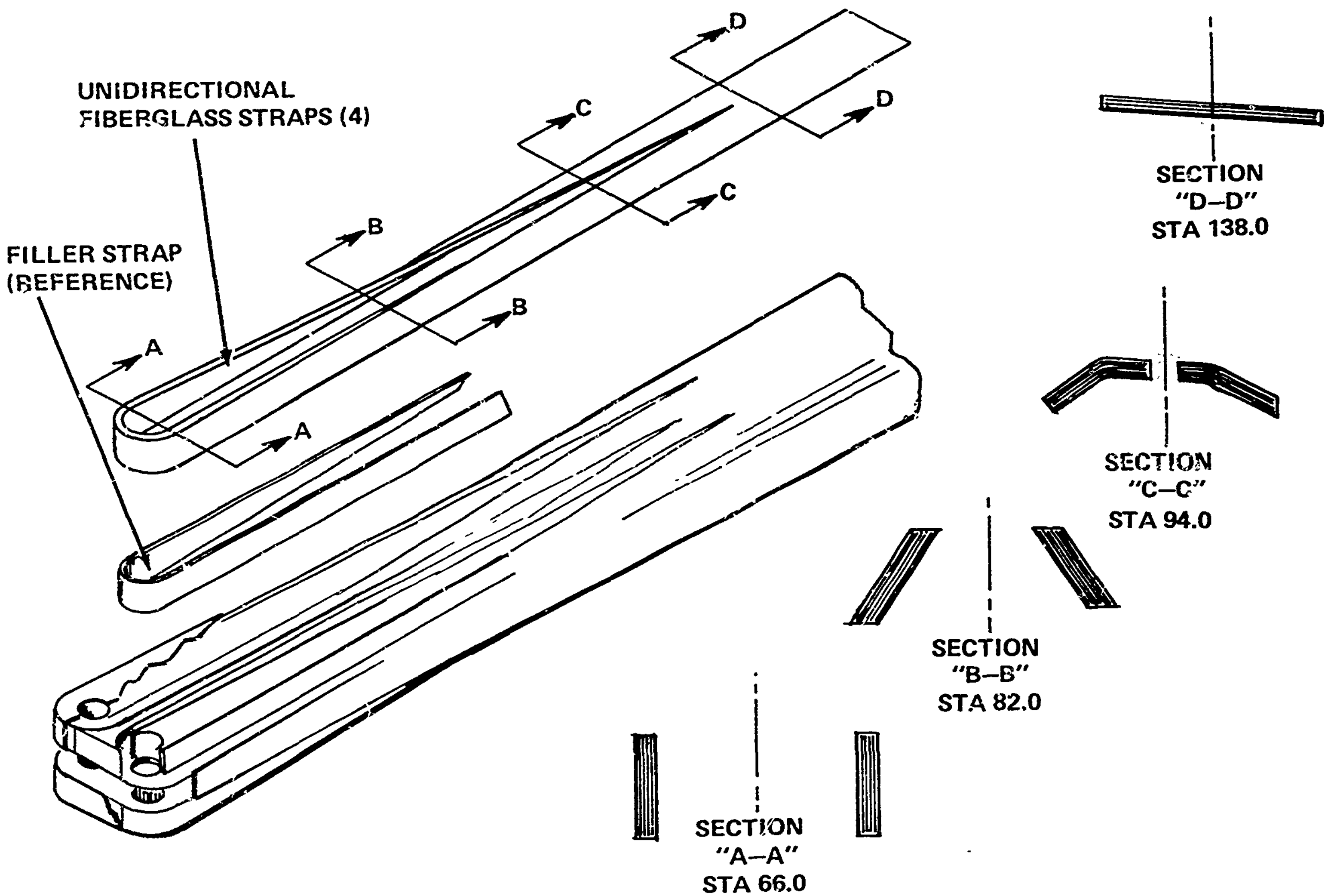


Figure 74. Typical Spar Strap Orientation

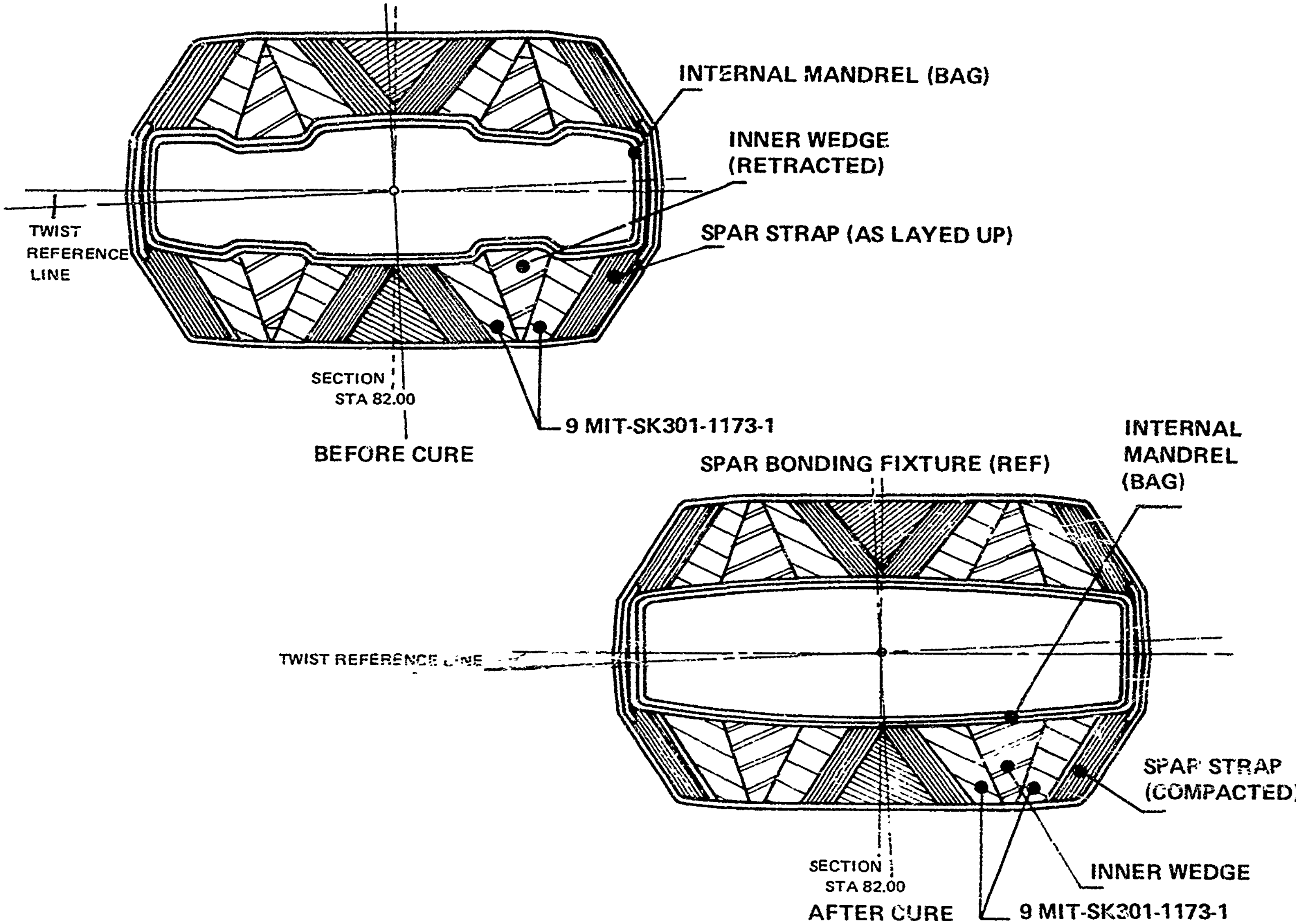


Figure 75. Root End Compaction, Station 66 to Station 109

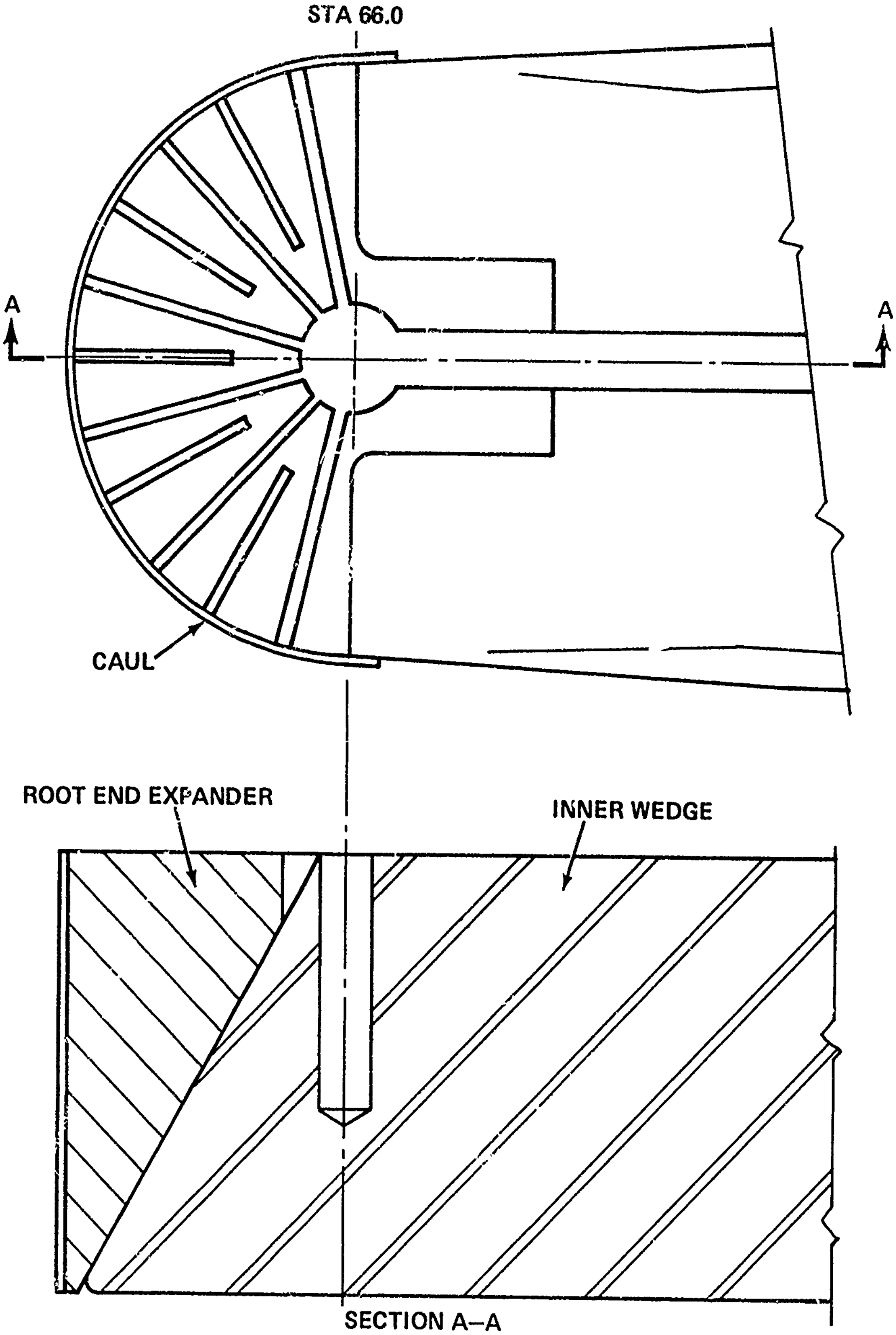


Figure 76. Root End Compaction, Station 66 Inboard

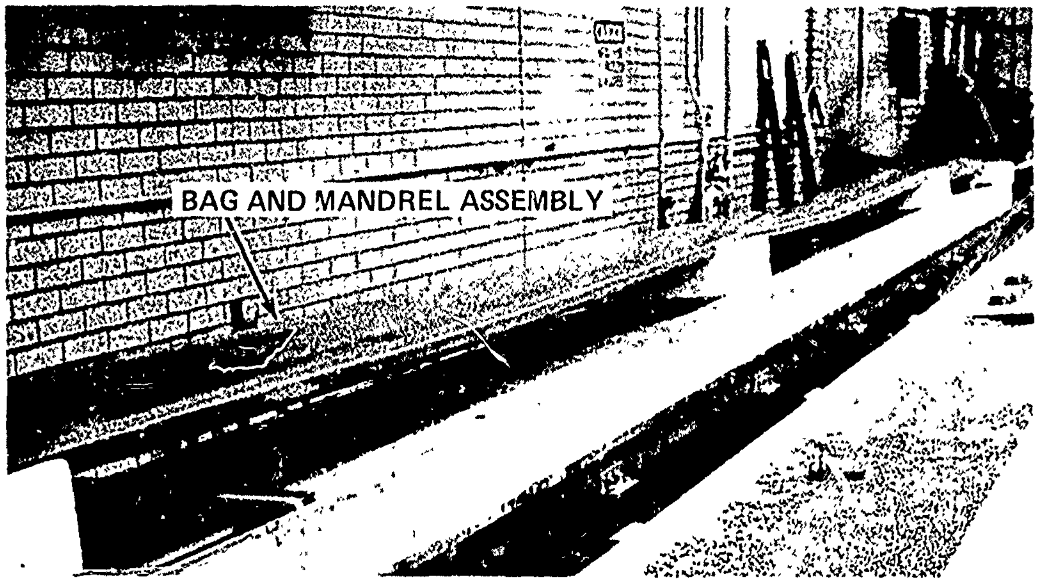


Figure 77. Bag and Mandrel Assembly Prepared for Assembly Stand

Spar Fabrication

The spar fabrication involves the assembly of details on a bag and mandrel, installation of the leading edge assembly, and the curing operation. The process begins by positioning the bag and mandrel on the 8MIT assembly stand. (Refer to Figures 33 and 78.) The upper end inner torsional skin is then laid up on the bag (Figure 79), followed by the chordwise stiffener graphite. On top of this, the strap subassemblies are positioned together with the "T" bone fillers and leading edge filler (Figure 80). The assembly is then flipped over, and the same operations are repeated for the opposite (lower) side. At that time, the outer torsional wrap is positioned over the lower side lay-up. The assembly is then flipped over once more, and the upper outer torsional wrap is applied (Figure 81) and tied in with the lower half. Following this operation, the spar is positioned on its heel, and a sheet of adhesive is draped over the entire unit. The leading edge assembly is next

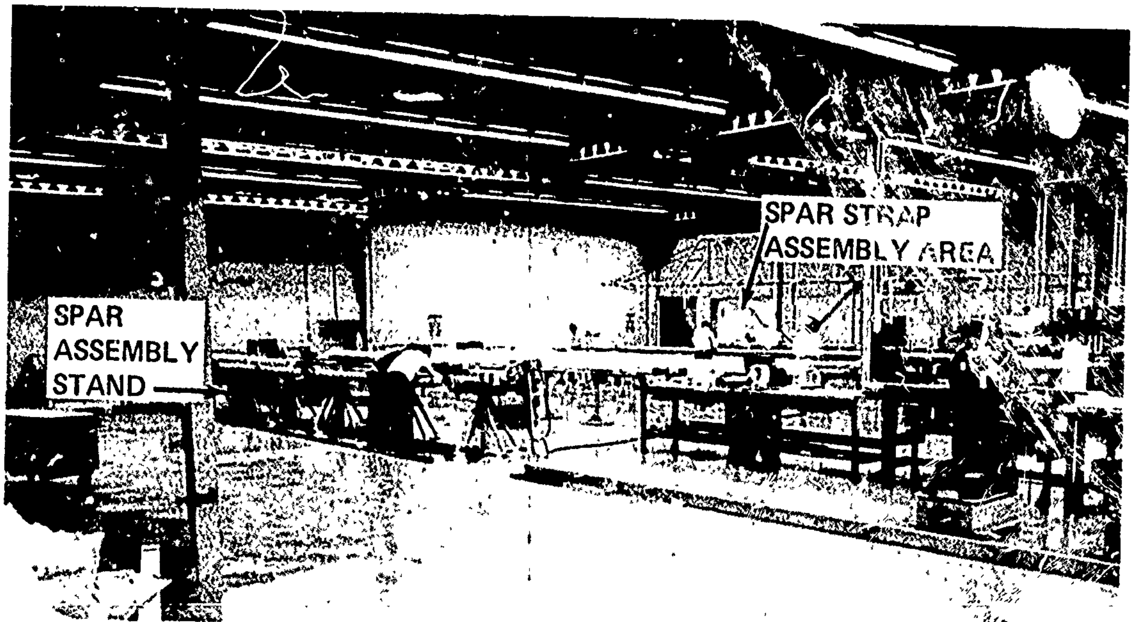


Figure 78. New Clean Room Area Showing Spar Strap Subassemblies and Spar Assembly in Background

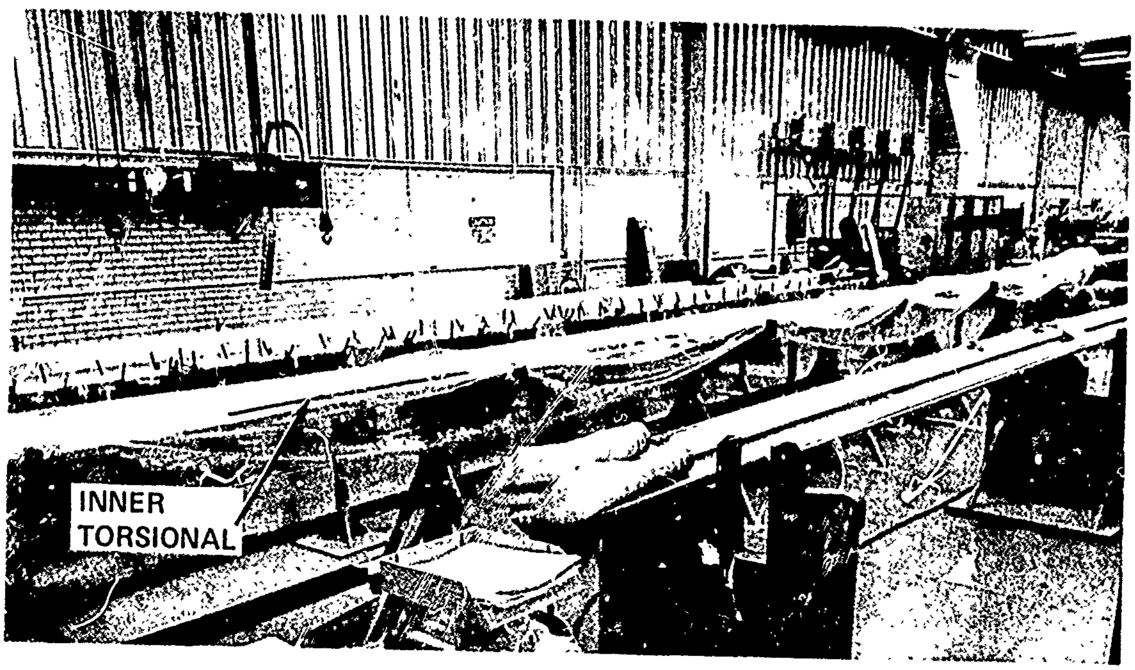


Figure 79. Spar No. 1 with Inner Torsional Skin Lay-Up on Bag Mandrel

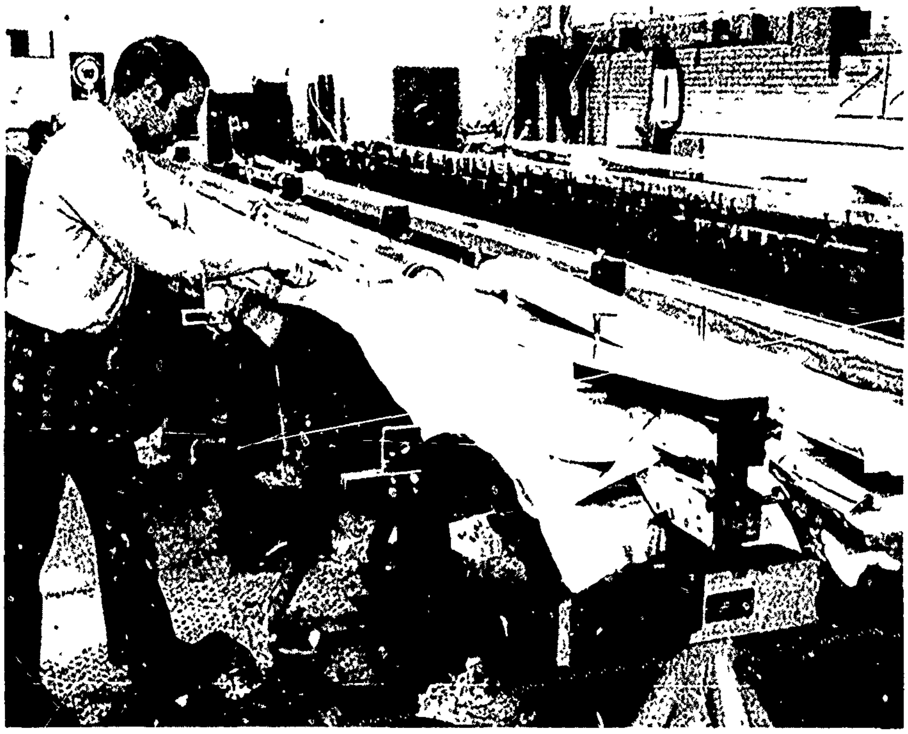


Figure 80. Spar Assembly Stand Showing Spar Strap Subassemblies Positioned on Inner Torsional Wrap

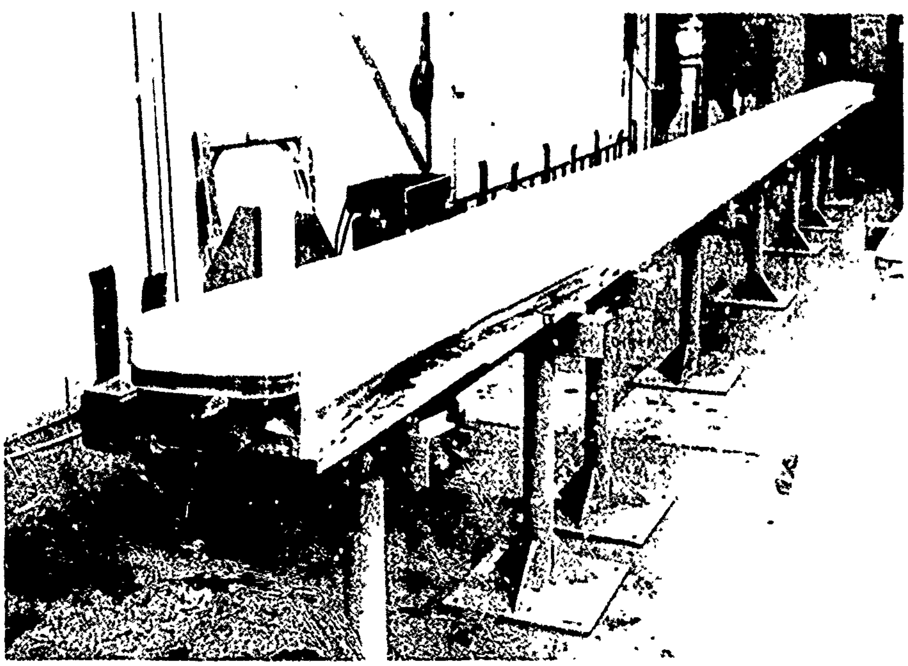


Figure 81. ⁻uter Torsion Wrap Ready for Installation

positioned over the spar and secured. Then the assembled spar is turned on its side, and the adhesive is trimmed. The spar bonding fixture (lower half) is installed on an air table and moved alongside the spar assembly stand. The spar is prepared for transfer and is lifted up and placed into the bonding fixture. The bonding fixture and spar are then transferred to the Universal restraining base, where the upper molds are positioned and bolts are installed (Figure 82). Finally, the tool root and tip ends are closed, the hoods are installed, and the curing operations are begun. (Refer to Figures 83 and 84).

Spar Fabrication Problems and Resolutions

The following paragraphs are brief outlines of the major problems overcome during the HLH/ATC spar fabrication operation.

Bag Damage During Removal. The bag (and mandrel) is removed from the cured spar while the spar is still supported in the lower half of the bonding fixture. The first item to be removed is the "strongback" which, being a flat plane (no twist) and a constant width, is easily removed from the tip end of the spar. The foam, having been shrunk by the 250° heat during the cure cycle (see Figure 85), fits through the small aperture at the tip end. It should be noted that during the assembly of the mandrel strips of nylon were bonded to the foam sections, which assists in the removal operation. The rubber bags are the last to be removed, and this is accomplished by first relieving the outer bag from the spar I.M.L. The outer bag, having been completely covered with teflon tape, is easily released; however, the friction must be broken, and this is done by inserting a long wedge (wood board) in the tip end between the bag and spar. This is repeated until the complete bag is free from the spar. The bag is then extracted from the tip end of the spar. As a precaution after the bags are removed, the teflon tape is removed from the outer bag and both bags are pressure checked and inspected for any damage (cuts, holes, etc.) and repaired as required before reusing. On the first spar, the redundant bag was extensively damaged during removal. The bag and mandrel development program included a bag removal operation on a short simulated spar. The general technique for removal was identified and was considered satisfactory. However, on a full length spar, the bag removal operation proved to be more difficult than originally envisioned.

On subsequent units, the bag removal operation was refined and performed satisfactorily, with a minor bag repair required on only two occasions during the fabrication of seven blade spars. The bag and mandrel fabrication, usage,

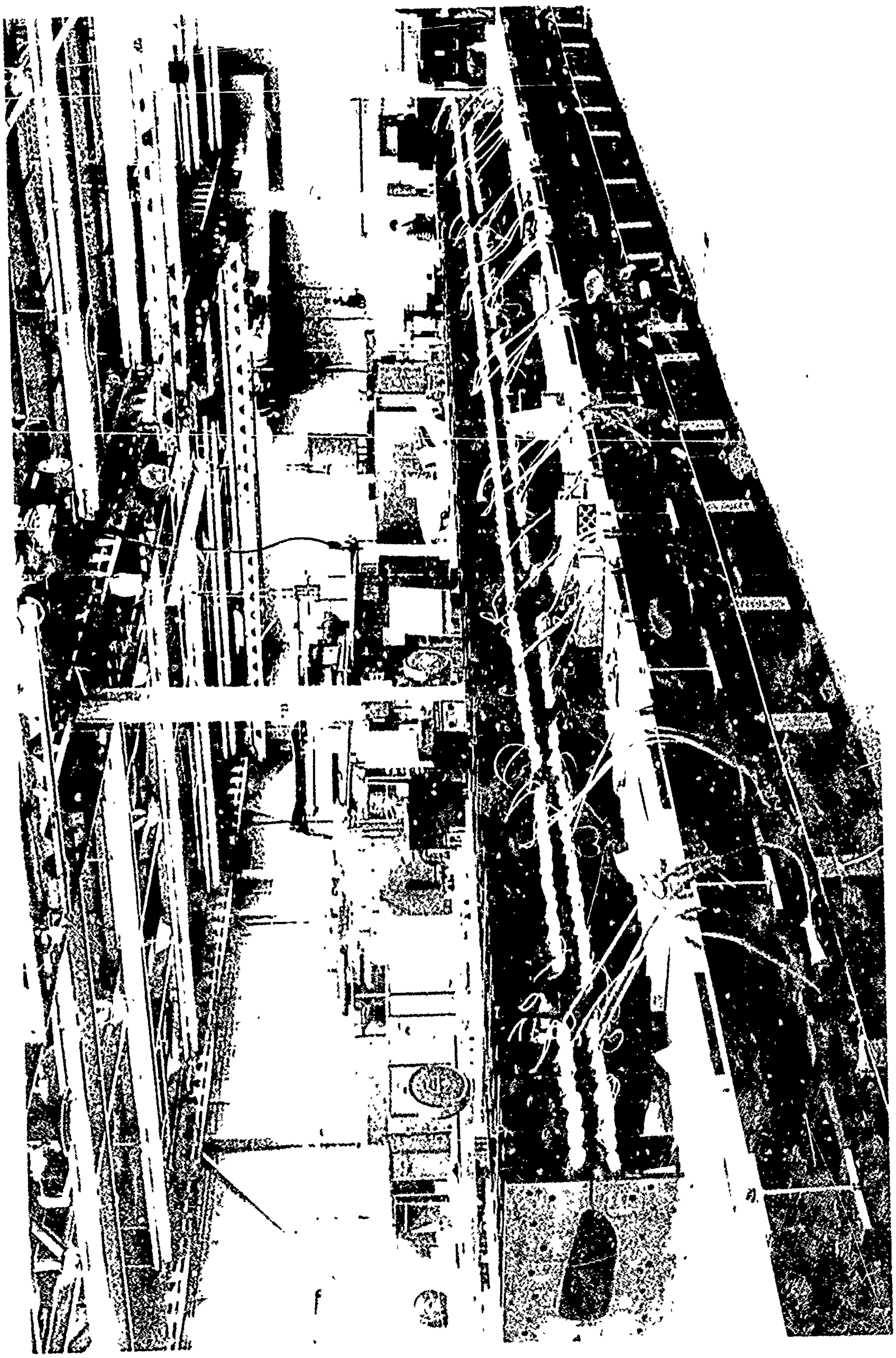


Figure 82. Spar Bonding Fixture Ready for Use

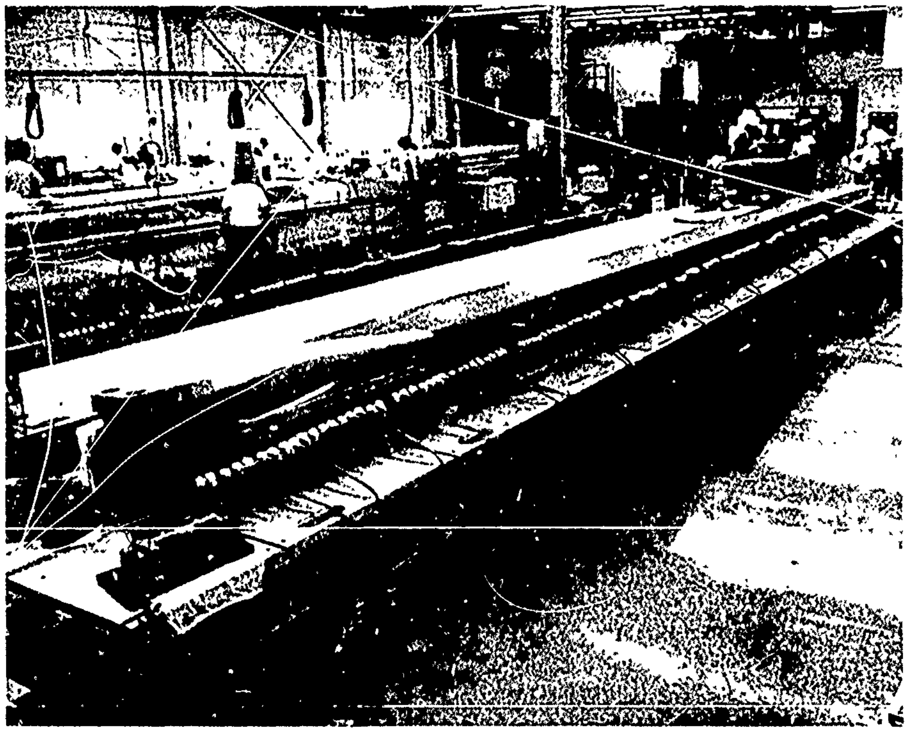


Figure 83. Ready to Unload Spar No. 1 After Curing Operation

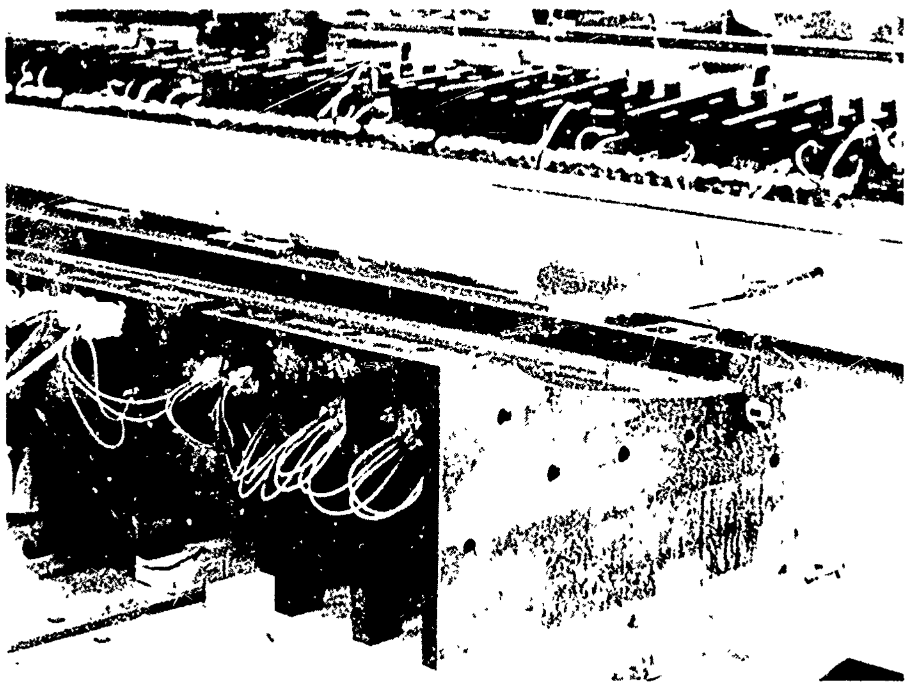


Figure 84. Spar No. 1 – Tip End View Showing Thermocouple Wiring

and removal process, as now developed, is a significant manufacturing achievement. This technique is satisfactory for an engineering development or limited production program; however, it would require further refinement and improvement for a production program, particularly from an economic viewpoint.

Spar Shank Wrinkling. On ATC spar number 3, excessive wrinkling in the shank was identified after the spar was cured. This condition was considered to be unacceptable and had to be eliminated. An investigation was launched and corrective measures were identified. At that time, spar number 4, nearly assembled, was reworked to add an interim fix. The straps were realigned to

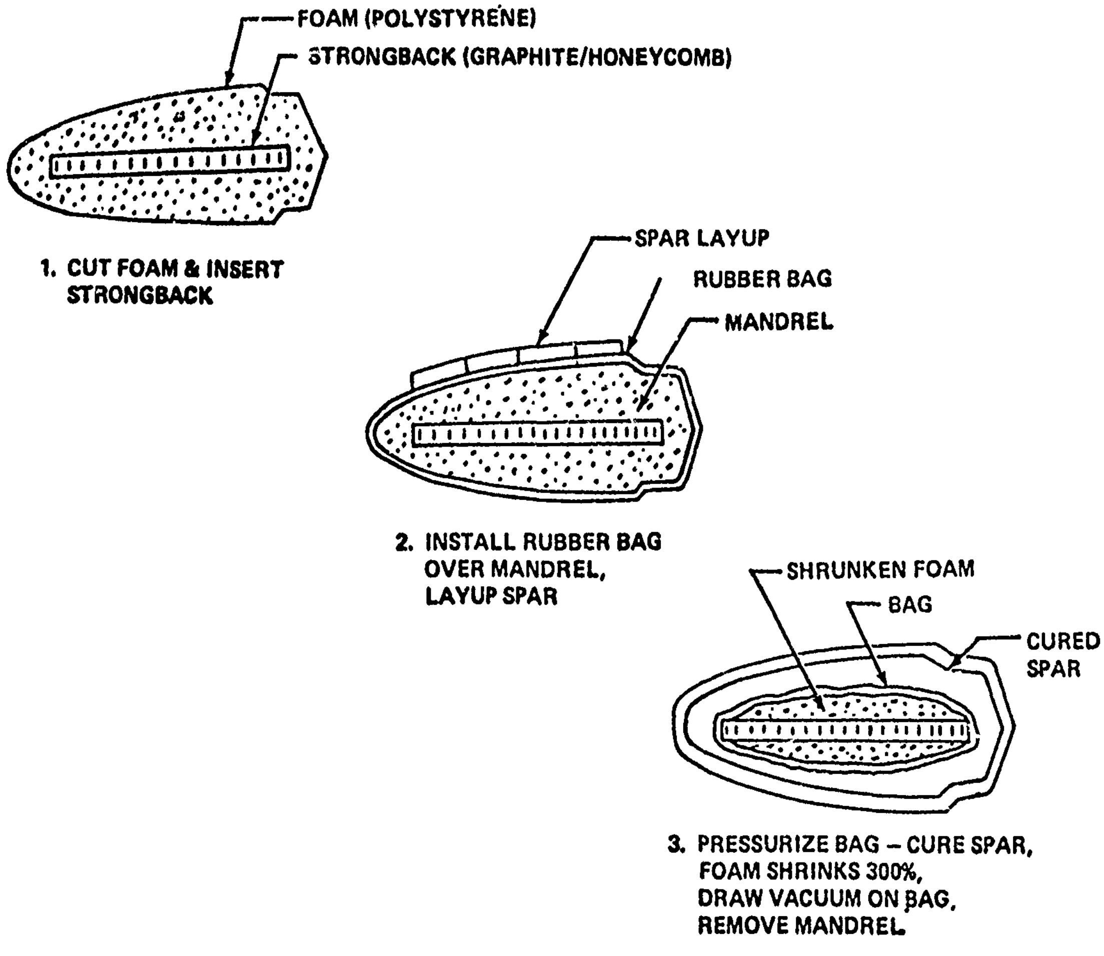


Figure 85. Foam Mandrel Concept and Bag Removal

give better contour through the transition area, and the uni-directional wedges were modified. The area over the wedge was filled in with uni-directional glass until it was flush with the strap upper edge.

On spar number 5 and on all succeeding spars, the permanent fix was incorporated, which included a new "uni-wedge" configuration. The wedge was made larger and longer, and more adequately filled the gap between the straps. The strap lay-up was monitored very closely, and overall, the details fitted together much better. In addition, the permanent fix included other changes in related operations: a reduction of the spar mandrel inside mold line (IML); maintenance of increased vacuum on the bag during spar assembly; and tighter control and tie-in of the upper and lower torsional wraps.

Wrinkling of Outer Torsional Wrap. After spar number 1 was assembled and cured, wrinkles were noticed in the outer torsional wrap. The wrinkling was concentrated primarily in the spar heel area. It was apparent that corrective measures were required prior to proceeding with spar fabrication. A major change was incorporated into the spar assembly stand (8MIT Tool) to provide improved contour control during the lay-up and assembly operations. (Refer to Figure 86.) The support arms were modified to include contour caul plates, which supported the spar on either side or on its heel.

Other items identified as requiring improvement were the method of fabrication and the handling of the outer torsional wrap. The spar bonding fixture was used for lay-up of the outer torsional wrap on spar number 1. The operation was slow and tedious and represented a program constraint since the fixture was also required for other blade operations. As a result, two new tools were fabricated to provide a male lay-up mandrel (Figure 87). After the tools were built and used (in spar number 3 and all succeeding spars), the lay-up task was improved, and transfer of the outer torsional wrap from the tool to the spar was simplified.

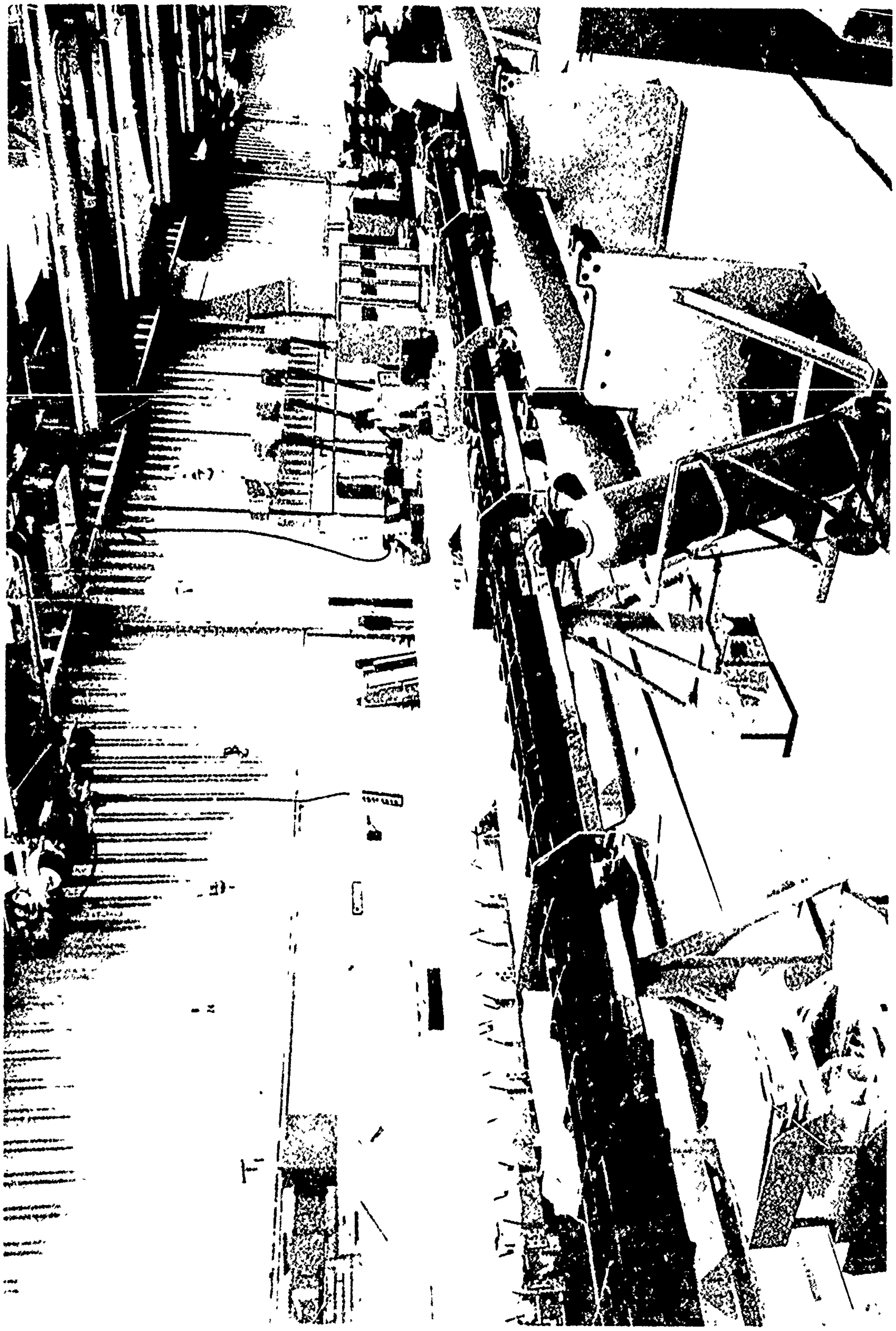


Figure 86. Spar Assembly Stand After Modification to Provide Contoured Caul Plates

Further refinement was achieved by minimizing the amount of time during which the uncured spar was supported on its heel. Briefly, this meant that the installation of the leading edge assembly had to be improved. The operation was refined by method improvements, and the elapsed time was reduced. However, additional improvement is desired and is being planned for use on the prototype blades. This includes new locator straps bonded to the exterior surface of the leading edge for handling and coordination purposes. The leading edge installation tool will also be modified to pick up the new locators. It is anticipated that better handling and seating of the leading edge on the spar can be realized with the improved tool.

Another factor associated with wrinkling was the spar handling and transfer in an uncured condition. The transfer from the assembly stand to the lower segment of the spar bonding fixture was particularly difficult and was a source of wrinkling. Ideally, the spar should be fully encapsulated during the transfer, but this interferes with lowering the spar into the tool cavity. A series of reviews has identified several potential solutions for the prototype blade fabrication, which are now being subjected to cost and feasibility exercises. One possible solution includes the use of an air bag that would roll out of the cavity as the spar is being lowered and its weight is felt.

In summary, spar wrinkling can be minimized but it is that type of problem which will require continued emphasis and control because of the spar's large size. Another design improvement has been developed to incorporate a pre-cured heel on the prototype blades. With the heel pre-cured, wrinkling is eliminated in the critical area and minimized elsewhere by providing structural support of the uncured spar during the transfer operation.

Chopped Fiber Fitting Installation

After spar fabrication and inspection, the cured chopped-fiber fitting installation is accomplished. This effort consists of a fit-up operation and a bond operation for each of eight fittings. Six fittings are installed on the root end, and two are installed on the tip end. The spar is cured in a "closed metal die" cavity which controls the outside mold line (OML), and the surface obtained is repeatable from unit to unit.

Those fittings which nest on the OML require a minimal "fit-up" operation, and their installation is fairly simple. The spar inside mold line (IML) is controlled by the redundant rubber bag. Due to the IML variation, five of the eight fittings must be "custom fitted" to achieve proper nesting and satisfactory bonding. Overall, the fit-up operations have proven to be complex and time consuming.

Root End Fittings

The root end fittings include the four closures which nest on the IML just forward of the pin holes. Early attempts to hot-bond these fittings were not successful, and the design was changed to a cold-bond adhesive. The configuration dictated that heat for hot bonding had to be driven through the fitting or spar into the bondline (Figure 87). The large mass in that area precluded this approach. The cold bond adhesive was incorporated and proved to be very successful when tested. As a result, the blade (number 1) that was hot bonded was modified using the cold bond adhesive. As a part of the design-to-cost program, the closure fitting design and fabrication is being studied. To eliminate the high cost of fit-up and bond, the "co-cure" approach has been selected for the prototype aircraft. The fitting becomes a "B" staged, semi-cured preform, which is cured during the spar cure. A sample fitting has been laid up and "B" staged with excellent results.

The other root end fittings are the two inserts located at Station 139, where the fairing leading edge blends into the spar (Figure 88). A minimum of fit-up is required, and bonding represents few problems.

Tip End Fittings

The tip end fittings include the two weight fitting assemblies: one forward and inside the spar, and one aft and outside the spar. The forward weight fitting required extensive fit-up effort and proved to be very difficult to bond. Because the spar tip is thin and has limited accessibility, the fit-up operation was

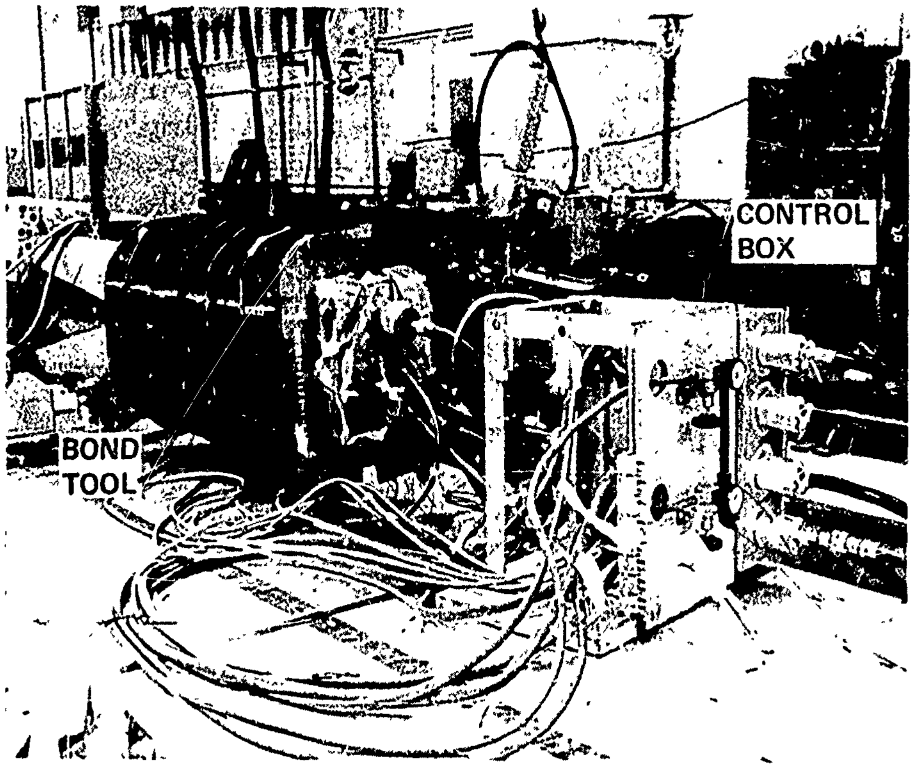


Figure 87. Spar No. 1 Showing Bond Tools in Use for Closure Fitting (11204) Bond

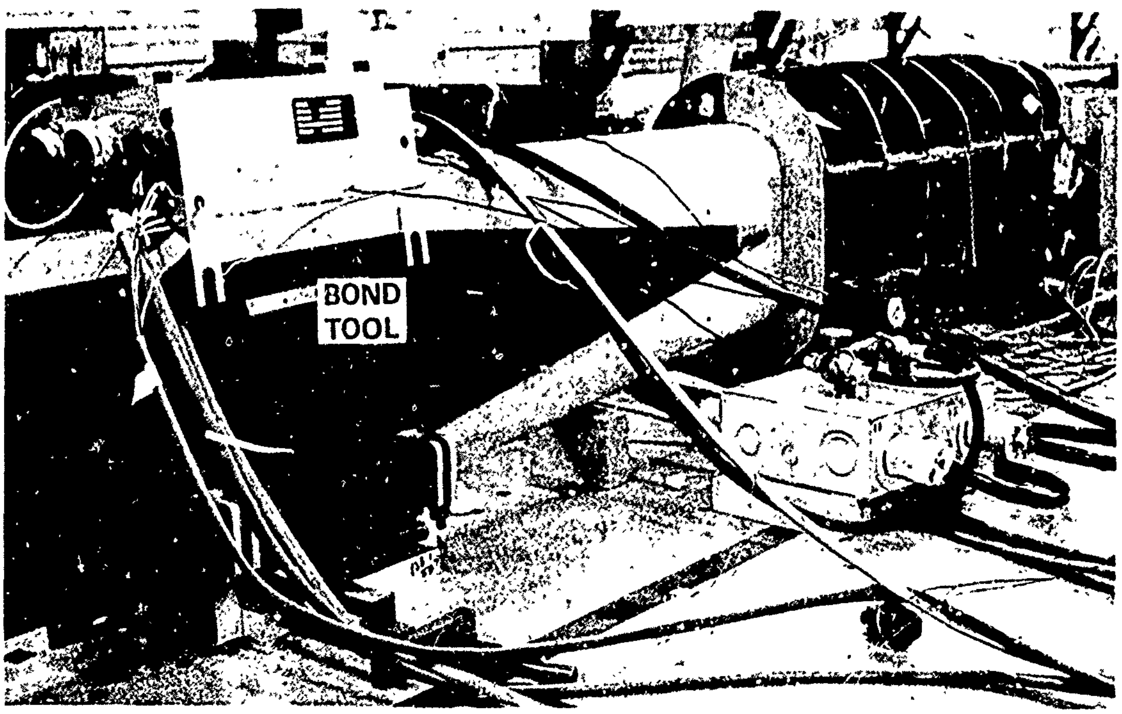


Figure 88. Spar No. 1 with Insert (11176) Bonding Tool Being Used

slow and costly. To achieve a good bond, a close fit had to be maintained over the entire length of the fitting (approximately 21½ inches).

An interim fix was incorporated for insurance purposes. The fix included the installation of roll pins to mechanically secure the forward weight fitting to the spar tip. The ATC configuration was tested on blade tip hardware specimen number 1 and proved to be satisfactory. However, the cost is considered to be excessive from a design-to-cost viewpoint. A design-to-cost project has been initiated to identify a product improvement and reduce the overall costs in this area.

The resultant change has been identified, and a trial installation has been made with excellent results. The improvement involves bonding the forward fitting during the spar cure. This technique is planned for all HLH Prototype blades. The cost reductions associated with this change are particularly significant since the requirements for a fitting bond tool and associated fit-up and bond operations are eliminated, as well as any rework and repair. The installations of retaining pins and the drill fixture required for locating the pin holes are also eliminated. Overall, the weight fittings of the prototype blade will have improved bondlines with slight reductions in weight. This is a classic example of design-to-cost in action, whereby a product deficiency was eliminated and an associated cost reduction was achieved in the early stages of a program, prior to production.

The other tip end fitting (aft weight) required a minor fit-up operation prior to being bonded to the spar. This bonding operation is also simple, with few problems. Both tip fittings are bonded to the spar concurrently to minimize flow time. (Refer to Figure 89.)

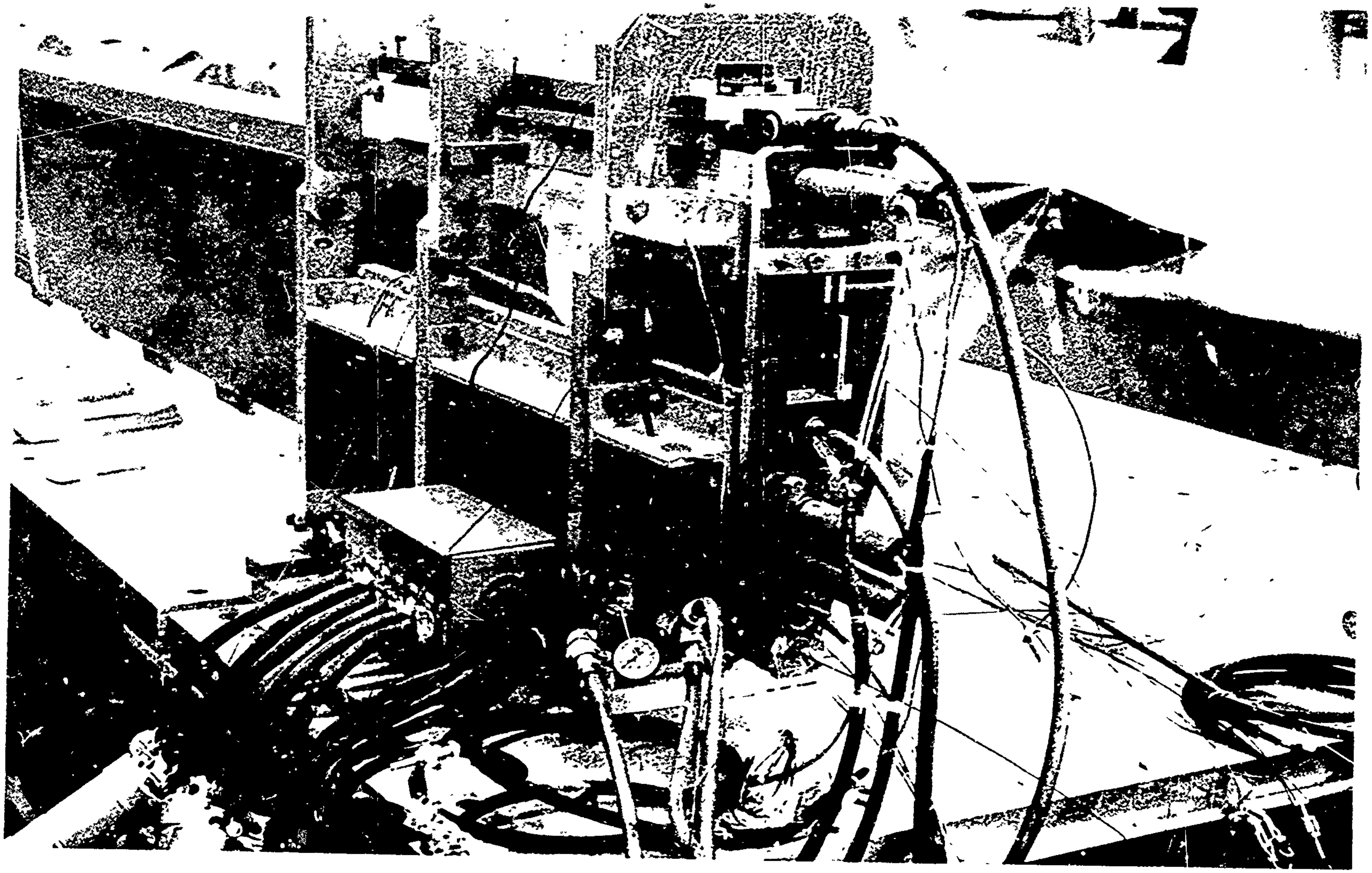


Figure 89. Tip Fittings Being Bonded to Spar

FAIRING FABRICATION

The following paragraphs describe the fabrication of the aerodynamic fairing, which is the second major component of the HLH rotor blade.

Fairing Fabrication Process Selection

Background

Prior to the HLH/ATC rotor blade program, fairing fabrication required machining of the honeycomb core on both sides. The core blocks were stabilized with a skin, or attached directly to a holding fixture for machining. With a stabilizer, vacuum was used for attachment; with direct attachment, bonding with various adhesives was the general practice. One airfoil surface was then machined, and the partially machined core was removed from the fixture. The machined surface was stabilized or bonded directly to a second holding fixture, and machine contoured. The remaining surface was then machined and removed from the holding fixture. An additional operation was required to remove the stabilizer skin or the adhesive residue. Overall, the process was slow and costly, and was therefore considered undesirable for a larger fairing such as that required by the HLH.

Improved Process Selected for HLH

A study was launched to identify a fairing fabrication process which would be more cost effective. The process selected has resulted in eliminating a number of operations and minimizing tool requirements.

Briefly, the process selected for the HLH blade is based on machinir he upper airfoil contour only. The honeycomb core block is procured in a pre-cut triangular shape. The honeycomb core is pre-assembled with the trailing edge wedge and then cured to the lower airfoil skin. The skin-to-core bond is accomplished in a vacuum form holding fixture that was built to the lower airfoil contour. The cured skin provides a means of stabilizing and retaining the honeycomb during machining.

The selected process for aft fairing fabrication produced excellent results. Since most of the resultant cost savings in the approach are on recurring cost items, its use on a production program is considered to be significant and will result in substantial cost savings. The major benefits of this concept include the following:

- Nonrecurring Cost Benefits

  Second holding fixture is not required.

- Recurring Cost Benefits

  Installation and subsequent removal of stabilizer skin is not required.

  Machining time is reduced by 50 percent.

  Total flow time required is drastically reduced.

  Part handling effort is appreciably less.

  Material costs are minimized in the areas of:

  - Stabilizer skin and adhesive

  - Better utilization of honeycomb core - two triangular pieces can be cut from one block of raw material.

Fairing Assembly

Fairing Assembly Fabrication

The fairing assembly includes a trailing edge wedge, a wedge-to-core subassembly, the core-to-skin operation, and the fairing machining.

Trailing Edge Wedge. The trailing edge wedge is fabricated with fiberglass and graphite laid up, and transferred to the fairing bond fixture (VFM) where it is bagged in an autoclave for curing. After the cure is completed, the trailing edge wedge is removed and trimmed, and the locator holes are added in preparation for the next operation.

Wedge-to-Core Subassembly. The wedge-to-core subassembly involves positioning the trailing edge wedge with the honeycomb core blocks and adhesive in the fairing bond fixture (VFM). The core is Nomex honeycomb that has been purchased pre-cut to a specified size. A special nodal bond adhesive (Hexabond) is used on the core-to-core bond (between the three segments), and a foaming adhesive (FM 37) is used between the core and trailing edge wedge. The subassembly is bagged and cured in the autoclave. After curing, the subassembly is inspected in preparation for the next operation (Figure 90).

Core-to-Skin Subassembly. In the fairing bond fixture (VFM), the lower airfoil skin material is laid up, and the wedge-to-core subassembly is positioned over the skin. The subassembly is bagged and cured in the autoclave. After curing, the completed part is removed from the tool, trimmed, and inspected. (Refer to Figure 91.) The fairing is then ready for shipment to the core machining vendor. In the ATC program, the vendor utilized for this operation was the Hexcel Corporation, Graham, Texas.

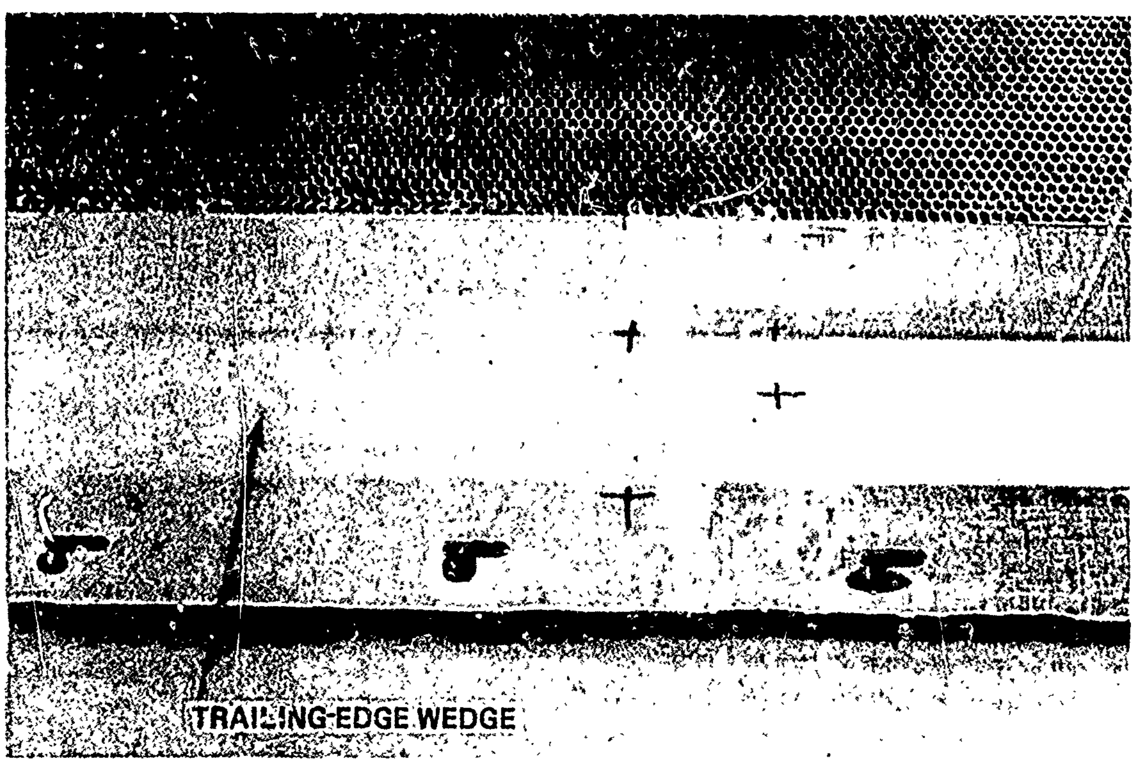


Figure 90. Trailing-Edge Wedge Assembly After Bond to Core

Core Machining Operation. The machining operation includes the upper contour and the leading edge cut, referred to as the "V notch". (Refer to Figure 92.) After machining, the upper surface requires hand sanding to blend the core and trailing edge wedge in a smooth transition. The size of the part, the variations in geometry, and the tolerances required made this one of the most difficult parts that we have attempted to machine for bonding.

ATC Experience

Processing the fairing through the various fabrication stages proved to be extremely challenging. The following paragraphs summarize the difficulties encountered and the solutions implemented.

Trailing Edge Bow. The first trailing edge wedge was bowed excessively and was not acceptable. An investigation of the problem resulted in a minor redesign of the wedge along the rear edge. The change included the lay-up of additional graphite in the trim area, which offset the inherent forces caused by differences in the coefficients of expansion of the graphite and fiberglass in the leading edge area. All subsequent units were built without bow and all were acceptable.

Trailing Edge Thickness Variation. The upper mold for the trailing edge was designed to "float" in order to compensate for differences in the bulk factor of the uncured material. The upper mold was positioned over the lay-up, and the entire assembly was bagged for curing. Once the trailing edge reached curing temperature, the bag pressure would then compact the trailing edge. However, with the mold location floating, variations in the trailing-edge thickness were encountered in each unit.

The condition was further aggravated by the various types of graphite material in the trim area. Since the area with the added graphite is trim material and not part of the blade, existing graphite on hand was used to avoid a program schedule impact.

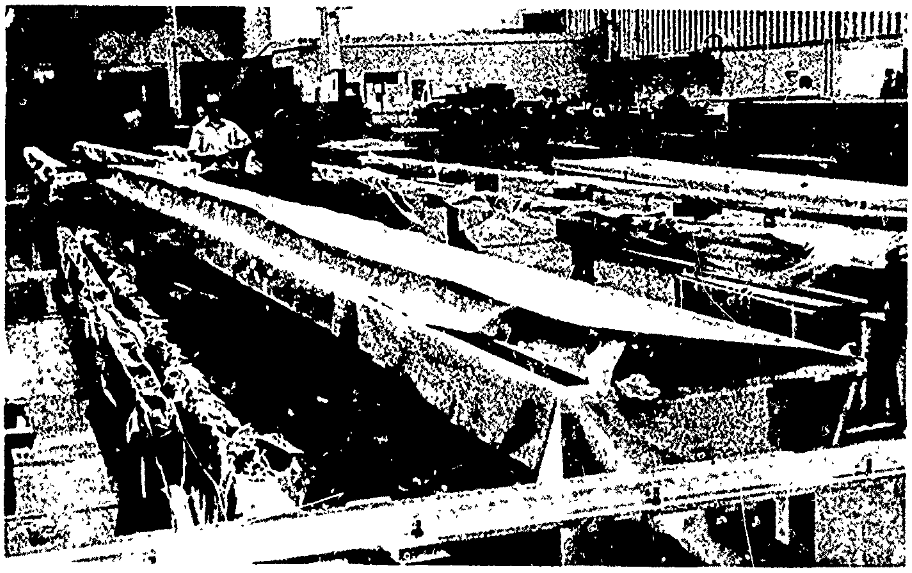


Figure 91. Inspection Being Performed on Fairing Assembly After Skin-to-Core Curing Operation

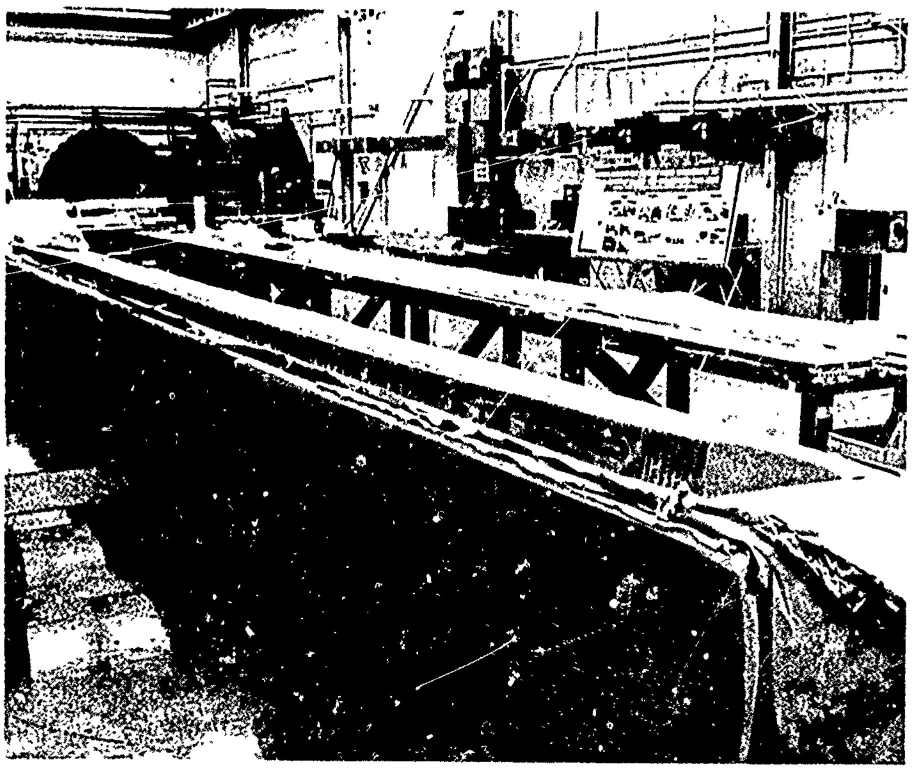


Figure 92. Fairing Assembly Machined and Ready for Bonding on Blade No. 1

The problem has been resolved on prototype blades by better containment of the upper mold, the addition of a series of fixed stops, and the procurement of uniform material.

Trailing-Edge Bag Failures. On two assemblies the bag film developed a leak during the curing cycle. On unit number 4, the failure resulted in a delamination on the inboard end, and the trailing edge was not usable. To resolve the problem, redundant bagging was utilized. This "fix" was used on unit number 5 and on all subsequent units with good results.

Core Slippage During Cure. On the first unit, the trailing edge and core slipped forward during the curing operation. As a result, the lower airfoil skin was wrinkled when the assembly was removed from the tool. This occurred because the skin is still flexible during the cure cycle and any movement of the Nomex honeycomb results in the skin being displaced accordingly. In turn, localized wrinkling or delamination will be experienced.

The honeycomb and trailing edge are contained by tooling pins which are located at spaced intervals along the aft edge. These pins extend into trailing edge holes and mate with an upper caul plate. With the basic fairing configuration being tapered, the bag pressure is downward but with a large component force in the forward direction. This force created the forward movement, or "lemon seeding" effect on unit number 1, which also distorted the pin holes within the tool. In addition, the pin holes in the trailing edge were elongated, or pulled to a degree, and localized crazing of the fiberglass and graphite occurred.

A tool modification was incorporated and the problem was resolved. The modification consisted of increasing the pin diameter, using longer pins that were recessed further into the tool, and a general reinforcement of the upper caul plate.

The wrinkling in unit number 1 was concentrated in the test panel area and the forward skin area. As a result, the assembly could be saved, since all of the major problems were in areas requiring trim. The fairing was then bonded to a non-flying blade which was to be cut up and tested.

Discrepant Leading-Edge Cut. The first fairing to be machined experienced a problem with insufficient material along the leading edge, resulting in a discrepant "V" notch cut spanwise along the fairing. After investigation the problem was identified to be occurring during the core-to-skin bonding operation. In effect, the assembly was bonded with the leading-edge forward location too far aft in relation to the trailing edge. There were a number of factors which contributed to this problem, and corrective action was initiated to resolve each one.

The tooling holes were the source of greatest concern. The crazing and pulling the holes experienced during the bonding of core to wedge and core to skin served to further aggravate the condition. The pin modification previously described was incorporated, and this made a significant improvement but did not permanently resolve the problem.

The concept of retaining the fairing by tooling pins is now considered to be marginal, and it has been decided that an improved concept is mandatory for the HLH prototype. Along the aft edge, a bulb or "dog's knot" will be molded into the wedge. This bulb will be used to locate the fairing assembly chordwise by its engagement in a mating slot in each tool.

Core-to-Core Bond Rework. On two units, the spanwise core-to-core bond was discrepant and had to be repaired. The problem was caused by insufficient pressure at the core splice. This was corrected by revising the tool loading technique and adding a small honeycomb core section. The new section with the existing three segments generated additional spanwise pressure. The increased pressure on the bond joint ensured a good bond.

Additional corrective action was implemented by revising the padding techniques prior to the bagging operation. Rubber pads are required at transition points to prevent a concentration of bag pressure which could locally crush the honeycomb. Careful placement of these pads results in the application of additional pressure to the bond joint and improvement in the quality of the resultant bond.

Trailing-Edge Coordination Holes. The cured trailing edge is drilled along the aft edge to provide coordination points for subsequent operations. The initial location was obtained from the trailing-edge bonding tool and then drilled out by hand. The result was a slight variation in hole location from unit to unit, which created difficuties in later operations.

The interim resolution for the remaining aft blades was to provide a drill fixture to eliminate the human element. The permanent fix has been established and will be used for all forward blades and for all aft blades subsequent to the prototype program. The solution involves the use of a bulb or "dog's knot" as an integral part of the aft edge for coordination purposes as previously described. The bulb will provide excellent location features and eliminate the entire drilling operation. The bulb is aft of the final trim line and is not included in final blade configuration.

Trailing-Edge Trim. The initial blades were fabricated with both ends contained, in an effort to minimize trim requirements. This created a trim problem, with insufficient material to permit the removal of the rough edge, and tended to induce the wrinkling of fibers. The permanent resolution implemented was to modify the tool, allowing the trailing-edge spanwise length to grow freely during cure and to provide sufficient material for trimming. On subsequent units, the ends were trimmed with no apparent problems.

Discrepant Airfoil Contours. The first unit to have the upper airfoil Nomex honeycomb machined was purposely bonded to a blade prior to machining any additional units. The airfoil height had been intentionally machined oversize to ensure that proper crush pressure in the honeycomb would be achieved.

After the first blade was bonded and inspected, a decision was made to proceed with the machining of the fairings. The honeycomb crush factor had been evaluated, and it was indicated that the normal airfoil height would give sufficient crush pressure.

The second unit was machined and then bonded to a blade. After inspection, it was suspected that a number of areas had improper crush pressure during bond. As a result, an investigation was initiated to determine the source of the problem. Fairing numbers 3, 4, and 5 were machined and on hand, ready for bonding to a blade. The fairings were inspected and found to have discrepant core heights (both high and low spots). The machining operation was terminated pending completion of the overall investigation and the identification of a solution. The corrective action that was established required the return of these discrepant units for remachining. A team was dispatched to the Hexcel Corporation, Graham, Texas, to review the core cutting operation and to implement those changes required to achieve the proper machining. The team reviewed the overall machining setup, with unit number 6 in place. The general conclusion of the team was that the fairings were being improperly positioned in the tool during the loading process. The fairing was repositiond and then machined. A subsequent inspection indicated an overall improvement, and and three discrepant fairings were then remachined.

Final disposition was to implement better and more stringent controls during the setup and machining operations. Additional contour templates were fabricated and provided to ensure better inspection of the completed operation.

<u>Aft Fairing "Lessons Learned"</u>

A number of changes were identified and will be implemented prior to beginning the prototype program. The fairing holding fixture (VFM) will be modified to provide positive location and facilitate improved inspection. Additional templates will be provided to check contour during core machining. The fairings will have a trim operation added to remove the rough edges along the skin.

The assembly will be inspected prior to shipment to identify and remove obstructions on the skin surface that could prevent the fairing from seating in the holding fixture.

The equipment used to machine the fairings utilizes a mechanical tracer which follows a machined tool pattern. On follow-on programs, the use of this equipment is considered to be undesirable. It is currently planned to utilize NC-controlled equipment that has a bed length adequate to machine the entire core system of the HLH prototype blades with a single setup. With such equipment, errors inherent with a tracer machine will be avoided, and more precise core machining will be attained.

BLADE BONDING

After installation of the spar fittings, the next major operation is bonding of the fairing subassembly and spar subassembly into a bonded blade assembly in the main blade bonding fixture (BAJ). The operation begins with a pre-fit check of the spar in the main bonding fixture. This is followed by a pre-fit of the fairing assembly. Measurements are taken at critical points to ensure proper closing of the tool. (Refer to Figure 93.) The main bond fixture is then unloaded, and the upper airfoil skin is laid into the bottom half of the fixture. An internal mandrel is positioned inside the spar, and both ends of the spar are sealed. The internal mandrel is required to provide positive support for the spar heel during the cure operation. The spar and fairing are then positioned in the fixture, together with the required adhesives (FM37 and EA9628). Next, the upper halves of the tool are placed over the assembly and secured. The computer-controlled heating elements are connected, and the curing cycle started. After the cure, the bonded blade is removed from the fixture, and the outboard end (test article) is trimmed off. The spar seals are removed, and the internal mandrel is extracted. At that time the trailing edge tool coordination holes are no longer required and the entire aft edge is routed off to the proper chordal dimensions. (Refer to Figures 94 and 95.)

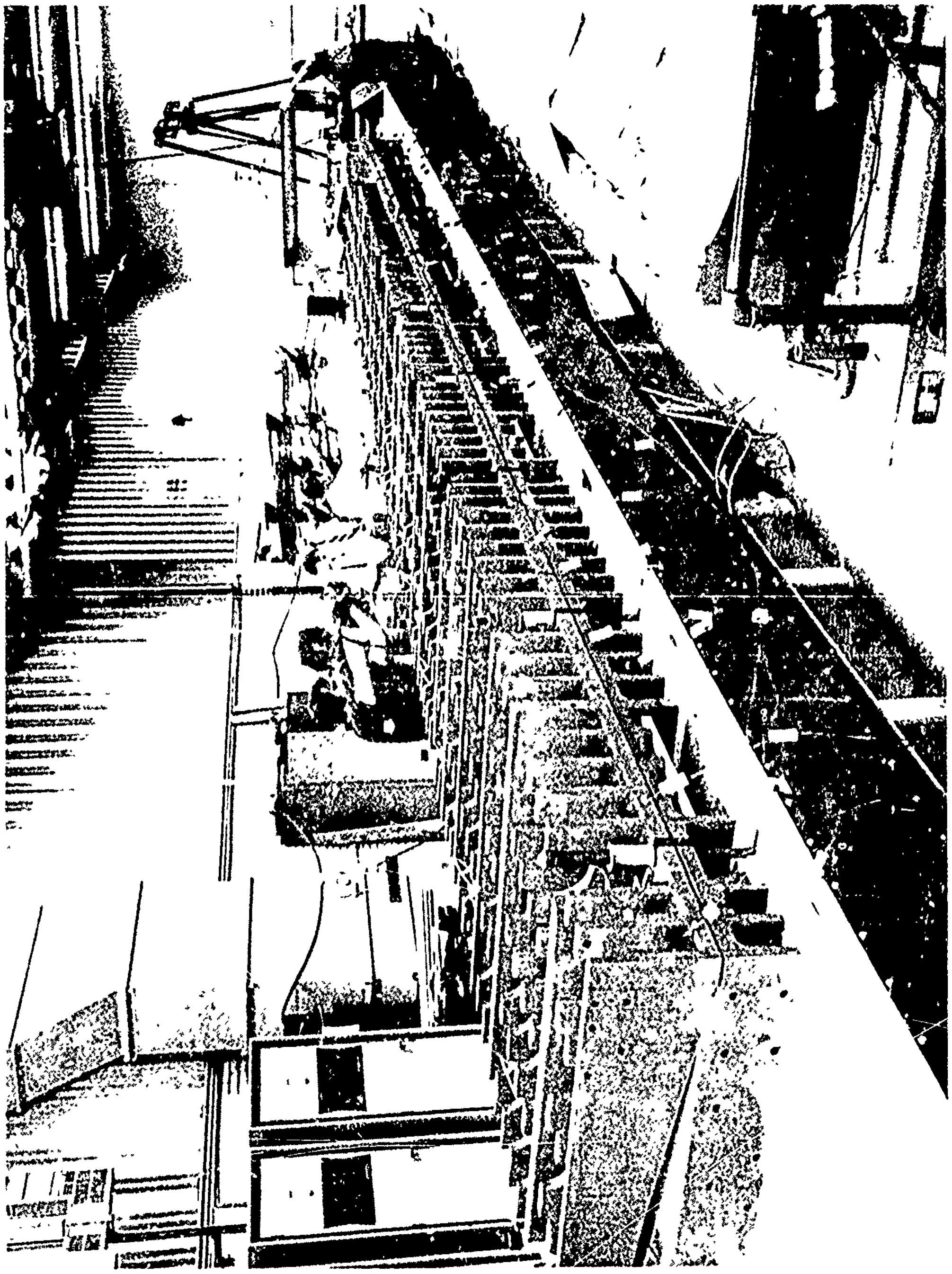


Figure 93. Main Bond Tool Being Closed

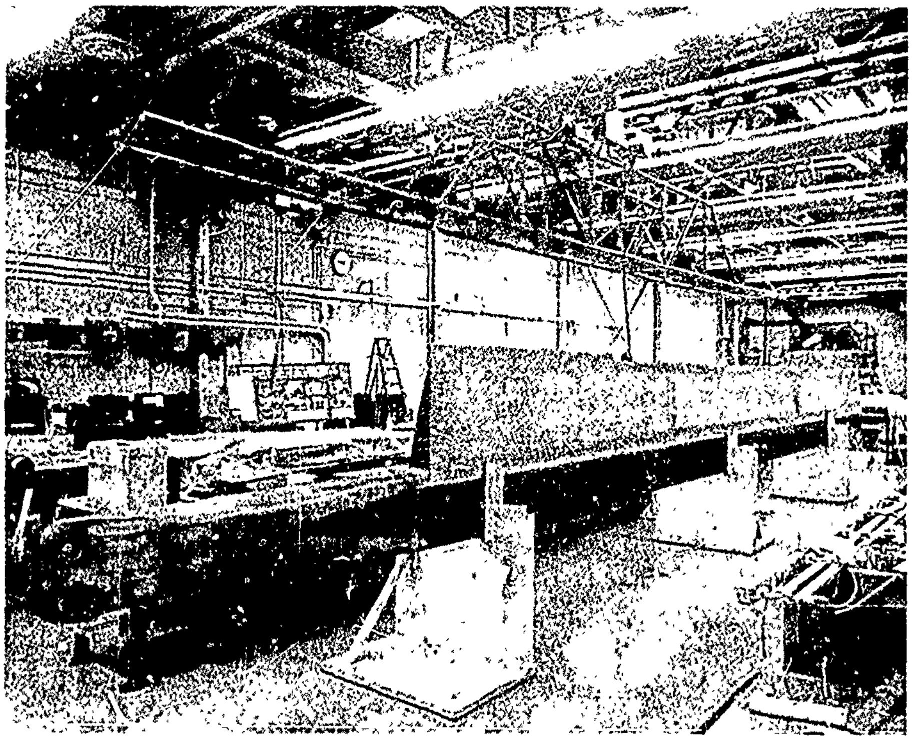


Figure 94. Blade No. 1, Just Unloaded from Bonding Operation

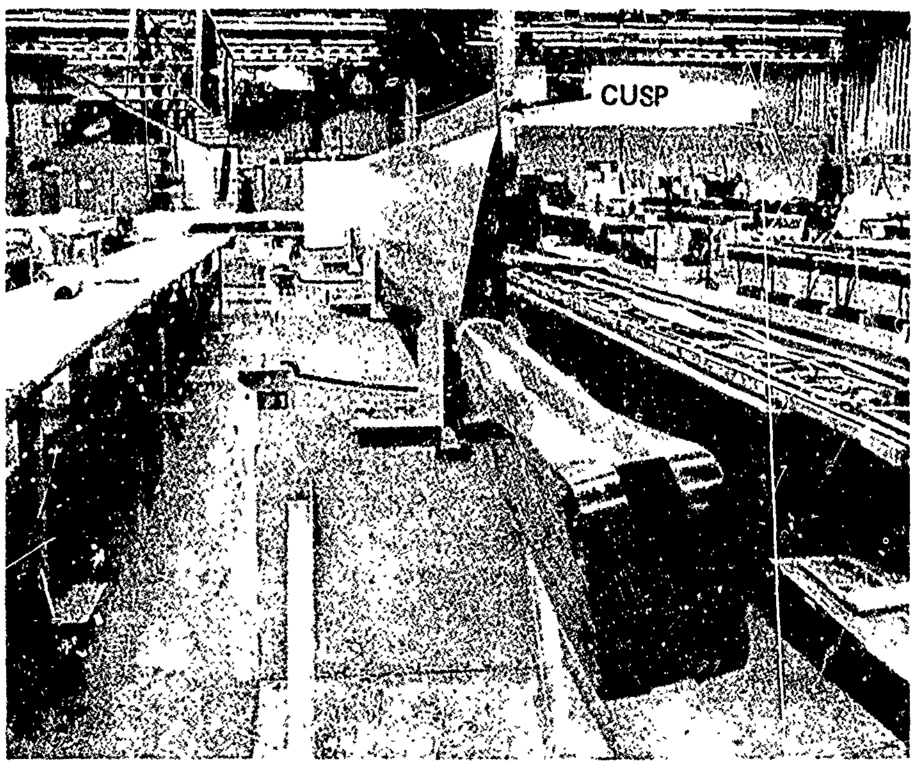


Figure 95. Blade No. 1, Showing Trailing Edge Cusp and Blade Twist

Blade Bonding "Lessons Learned"

The entire bonding operation was performed with excellent results, and the process will be utilized in follow-on programs. However, a number of developmental-type problems were encountered on the ATC program. The following paragraphs discuss these problems.

Localized Skin Cracks

On three of the seven blades fabricated, localized skin cracks were encountered. The fourth blade was the first that experienced severe cracking. However, during the resultant investigation, evidence of crack initiation was also noted on blade numbers 1, 2, and 3, but to a very minor degree. To resolve this problem, a number of the curing operations were changed on the next blades. In each case, the cracking was reduced but not eliminated. The problem source has now been identified, and a fix will be incorporated into the prototype blades.

Briefly, the cracking is caused by thermal pressure in the aft fairing region, where three separate forces are interacting. On cool down, the graphite force component is directly opposite those forces within the fiberglass. The condition is further aggravated by tool forces that are applied as a result of the tool cooling down and contracting at a rate faster than the blade. One of the changes implemented on the ATC program was to relieve the ball pressure on the upper and lower bond fixture castings. In effect, this reduced the forces that the tool applied to the fiberglass and minimized cracking.

The permanent fix includes bringing the inner blade skin all the way back and over the trailing edge wedge. On the ATC blades, the inner skin stopped approximately 6 inches forward of the trailing edge. This lay-up caused the skin to be weakest in the area exposed to thermal forces during cool down.

Bridging of Uncured Skin

After bonding blade number 2, a slight bridging condition was noted on the uncured skin. The bridging was localized between the core leading edge and the spar heel, in an area where the skin is unsupported and without pressure. The front edge of the skin is retained by the positive pressure applied to the spar heel. Similarly, all of the skin over the honeycomb core is properly contained with the exception of the small transition area along the spar heel. This area is not exposed to adequate pressure and is free to bridge.

The first attempt to resolve this problem included the use of a pre-cured glass shim that would provide the necessary support during cure. The concept was successful and eliminated the bridging condition; however, the shim proved to be difficult to retain in place during the cure cycle. The final resolution was to increase the shim width, providing better retention of the part during the cure cycle. The "new" bridge was used successfully on blade numbers 6 and 7.

BLADE FINAL ASSEMBLY

Final assembly of the blade includes boring the root end, installation of blade hardware, activating the Integral Spar Inspection System (ISIS), painting, and teeter balance. The blade hardware consists of the trim tabs, tie-down fitting, tip cover, inboard and outboard ribs, inboard ISIS bulkhead, teeter hardware, ISIS mount, ISIS indicator and valve, inboard bulkhead, damper fitting, sleeves, washers, erosion cap, lightning protection and tip targets. (Refer to Figures 96 and 97).

Blade Fabrication

The following paragraphs are brief descriptions of the final assembly operations, the problems encountered, and the corrective actions implemented.

Boring Operations

The boring and counter boring of the holes in the root end of the blade are performed in a special boring fixture designed for the HLH blade (Figures 54 and 98). This fixture is also used in aligning the lag damper fitting in the root end of the blade and the installation of the sleeves. In

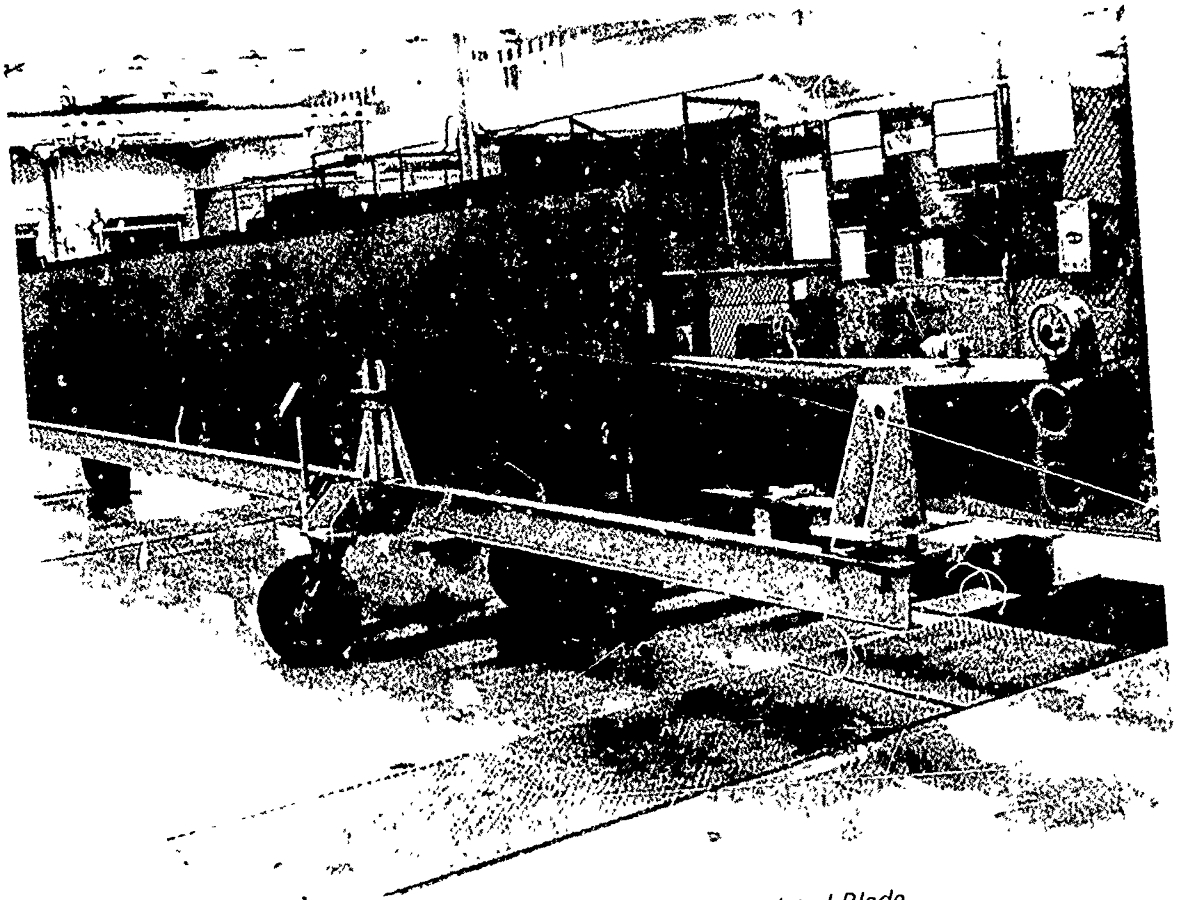


Figure 96. Root End View of Completed Blade

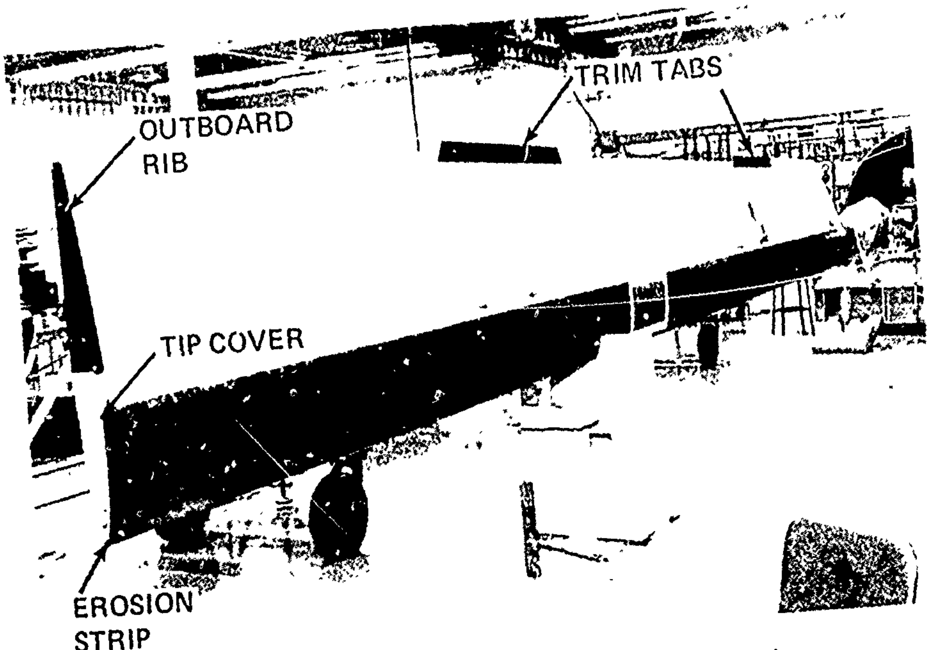


Figure 97. Blade No. 2 in Final Assembly Operation

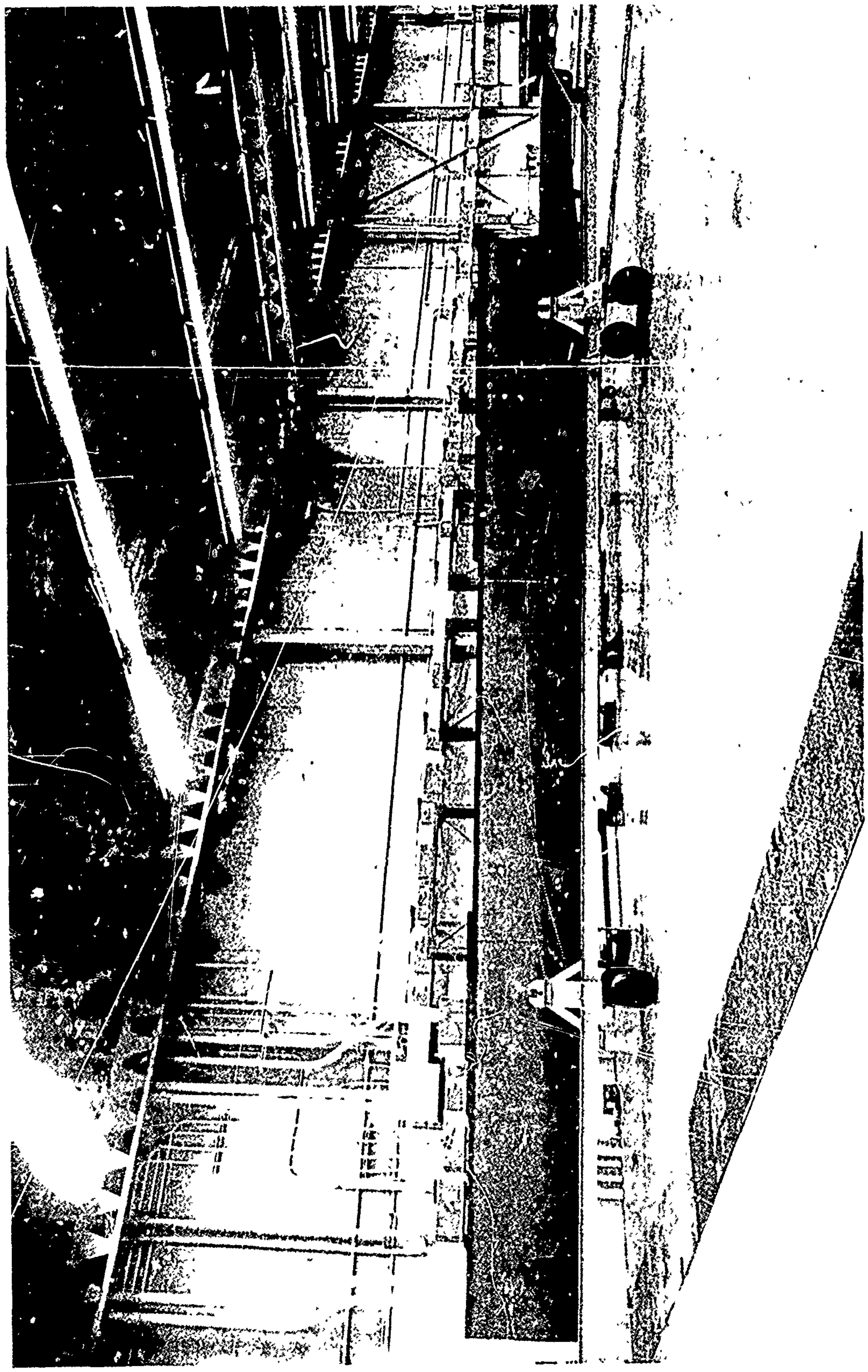


Figure 98. Blade No. 1 After Boring Operation Complete

boring these holes, a problem was encountered with the cutting tools not producing a smooth finish, and the counter bores tended to be oval shaped. With some experimentation, the ideal cutter configuration was identified and used with good results.

<u>ISIS Backing Plates</u> (see Figure 99)

Installation of the Integral Spar Inspection System (ISIS) involves six major steps. The first step is laying out and drilling the ISIS indicator mount hole in the spar shank. Next, the inside of the spar where the plates nest is prepared to receive the plates. The plates and areas in the spar are coated with adhesive, and the plates are then installed using a locator tool. When cured, the tool is removed and excess adhesive is cleaned off. On blade number 1, a teflon locator was used for this operation; however, the locator was not durable enough for repeated operations, and a metal locator was designed.

<u>ISIS Mount</u> (see Figure 99)

Ths ISIS mount is installed directly into the backing plates previously installed. The first operation is a dry fit and shimming operation to achieve proper positioning. Next, the surfaces of the parts are prepared with sealant, and the mount is installed and torqued. The last operation is to seal around the spar and mount, and then to cure.

<u>Indicator and Valve Assembly</u> (see Figure 99)

After the mount is cured, the surfaces of the mount and the ISIS indicator and valve are prepared and coated with sealant. The indicator and valve are then installed in the mount, torqued and sealed. When cured, the assemblies are cleaned and readied for the next operation.

<u>Inboard Bulkhead</u> (see Figure 99)

Before installing the inboard ISIS bulkhead, the inside of the spar at Stations 76 through 82 must be prepared for sealant. The sealant is applied where the bulkhead seats, and the bulkhead is positioned in the sealant and pressed against the two bulkhead backing plates. The bulkhead is held in place with a shop aid tool. When the sealant is cured, it is inspected prior to more fillets being applied to the bulkhead. After a 24-hour cure, the tool is removed, and the bond area is cleaned.

Outboard Bulkhead (see Figure 99)

The outboard blade inside mold line (IML) is prepared by sanding, cleaning and priming. When the primer is dry, a sealant is applied to each of the four corners inside the spar. The bulkhead is installed 1/8 inch back from the final location, a bead of sealant is applied around the bulkhead, and the bulkhead is pulled into place with a locating tool. After this initial cure, two more applications of sealant (BMS-544) are applied, each having a 24-hour cure time. When the last application of sealant has cured, the tool is removed and the blade is ready for the next operation.

ISIS Activation and Test (see Figure 99)

At this point, the ISIS system is leak-checked as described in the Quality Assurance section, since the inboard bulkhead becomes inaccessible after the lag damper fitting is installed. The spar cavity is pressurized to 2.0 psig with helium, and the entire spar is checked with a leak detector. Any discrepant conditions are reworked and the spar is then evacuated to 7.5 psia. After evacuation, the ISIS valve is closed, capped and torqued. The ISIS system is monitored for a specified period to ensure against any minute leaks.

Lag Damper Fitting Installation

This operation begins with filling in the grooves and clevises in the root-end opening. The lag damper fitting is then installed in the root end to ensure proper fit. Next, the root end lag damper fitting is prepared and reinstalled with temporary locating tools. The blade is then installed in the boring fixture, where the damper arm is aligned and cured. The lag damper is shown in Figure 100.

Sleeves and Washers

While the damper fitting is curing, the sleeves are prepared for installation. The sleeves are shrunk with a freezing agent (e.g., liquid nitrogen) and installed

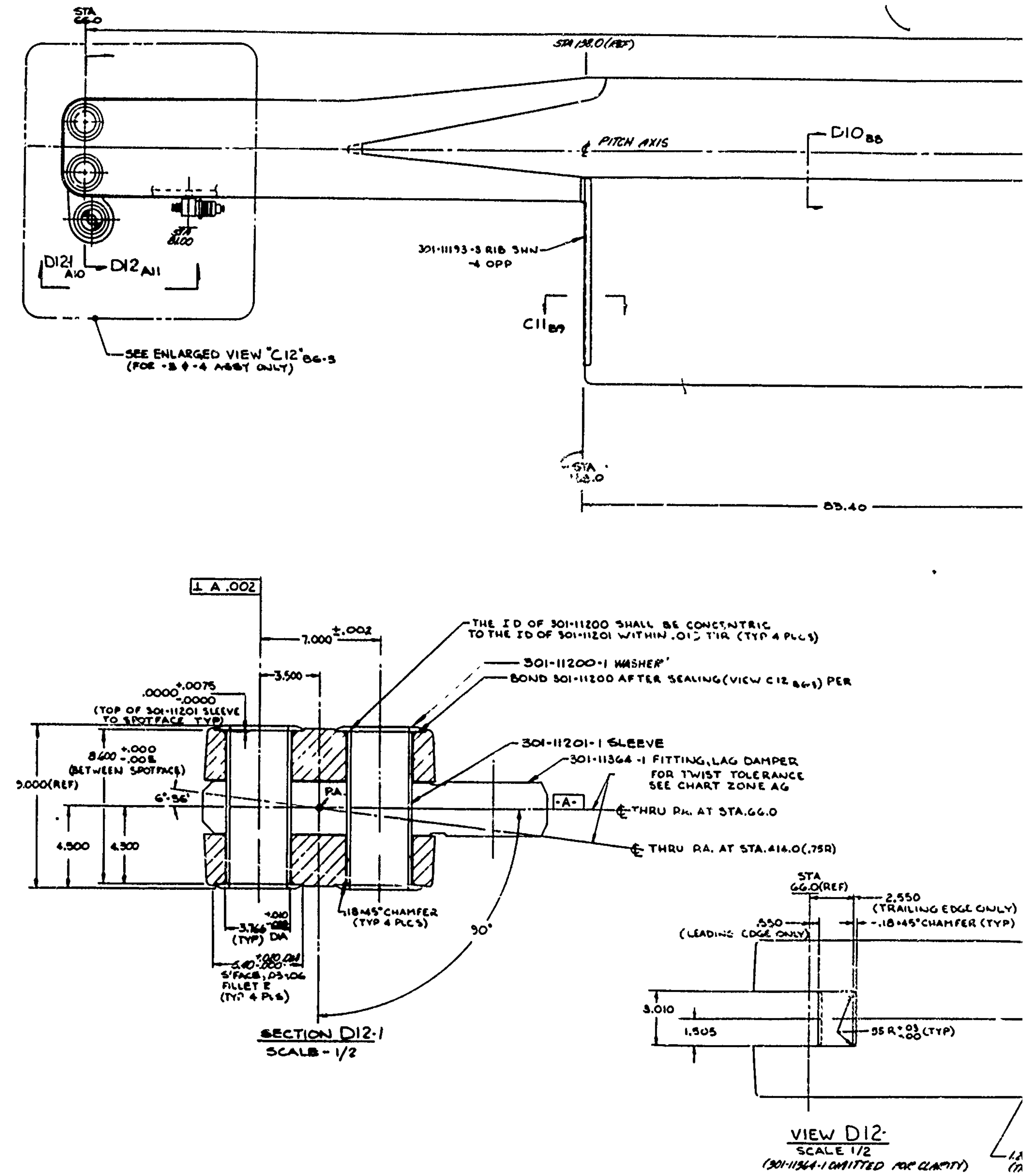
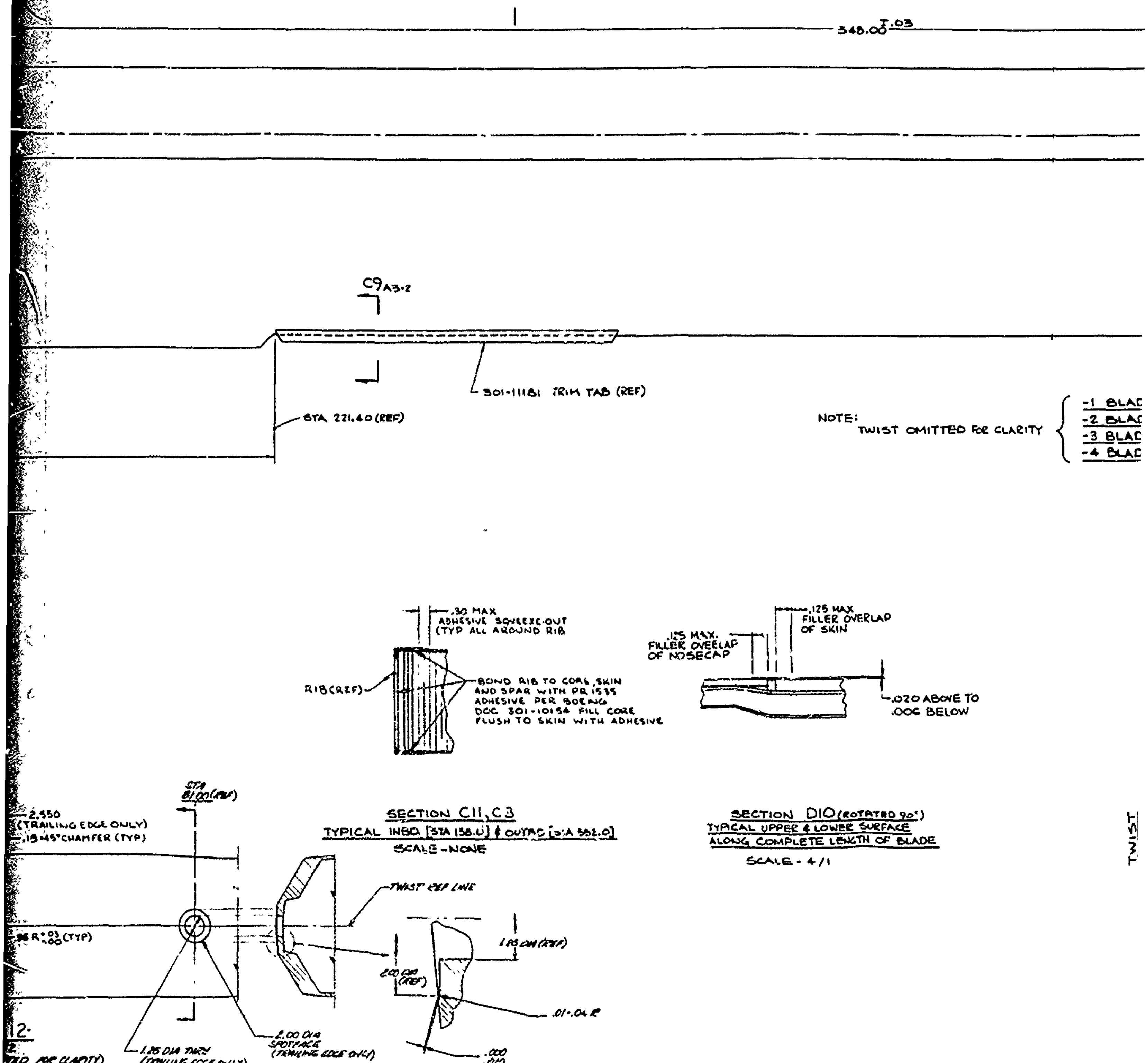
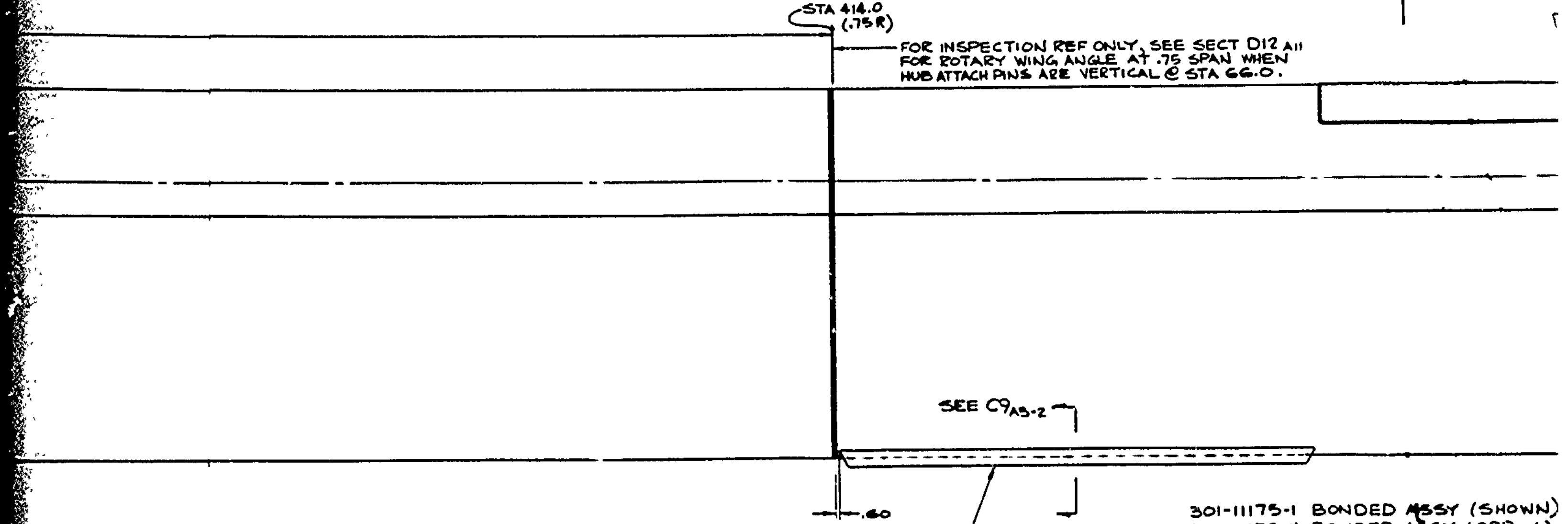


Figure 99. HLH Rotor Blade Assembly (Sheet 1 of 3)



348.00 ±.03
C9 A3-2
301-11181 TRIM TAB (REF)
STA 221.40 (REF)
NOTE:
TWIST OMITTED FOR CLARITY
-1 BLAD
-2 BLAD
-3 BLAD
-4 BLAD
.30 MAX
ADHESIVE SQUEEZE-OUT
(TYP ALL AROUND RIB
RIB (REF)
BOND RIB TO CORE, SKIN
AND SPAR WITH PR 1535
ADHESIVE PER BOEING
DOC 301-10154 FILL CORE
FLUSH TO SKIN WITH ADHESIVE
.125 MAX
FILLER OVERLAP
OF SKIN
.125 MAX.
FILLER OVERLAP
OF NOSECAP
.020 ABOVE TO
.006 BELOW
STA
81.00 (REF)
2.550
(TRAILING EDGE ONLY)
.19 x 45° CHAMFER (TYP)
SECTION C11, C3
TYPICAL INBD [STA 138.0] & OUTBD [STA 352.0]
SCALE - NONE
SECTION D10 (ROTATED 90°)
TYPICAL UPPER & LOWER SURFACE
ALONG COMPLETE LENGTH OF BLADE
SCALE - 4/1
TWIST
TWIST REF LINE
1.85 DIA (REF)
2.00 DIA (REF)
.01-.04 R
1.25 DIA THRU
(TRAILING EDGE ONLY)
2.00 DIA
SPOTFACE
(TRAILING EDGE ONLY)
.000
.010
12-
ED FOR CLARITY)

2



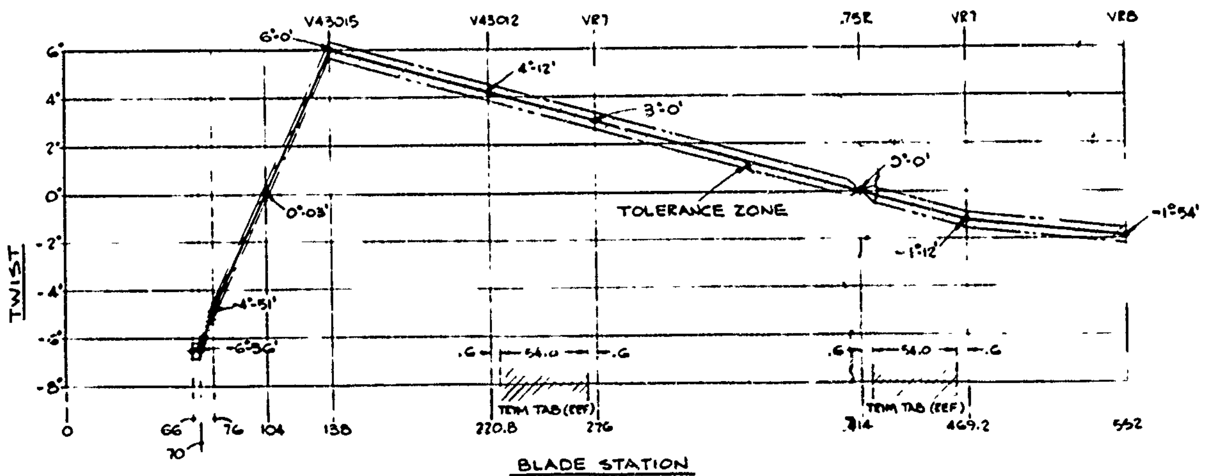
301-11175-1 BONDED ASSY (SHOWN)
301-11175-2 BONDED ASSY (OPP. -1)

OMITTED FOR CLARITY
-1 BLADE ASSEMBLY, AFT (SHOWN)
-2 BLADE ASSEMBLY, FWD (OPP-1)
-3 BLADE ASSEMBLY (SAME AS -1 EXCEPT DETECTION SYSTEM INSTALLED)
-4 BLADE ASSEMBLY (SAME AS -2 EXCEPT DETECTION SYSTEM INSTALLED)

O ABOVE TO
S BELOW

E)

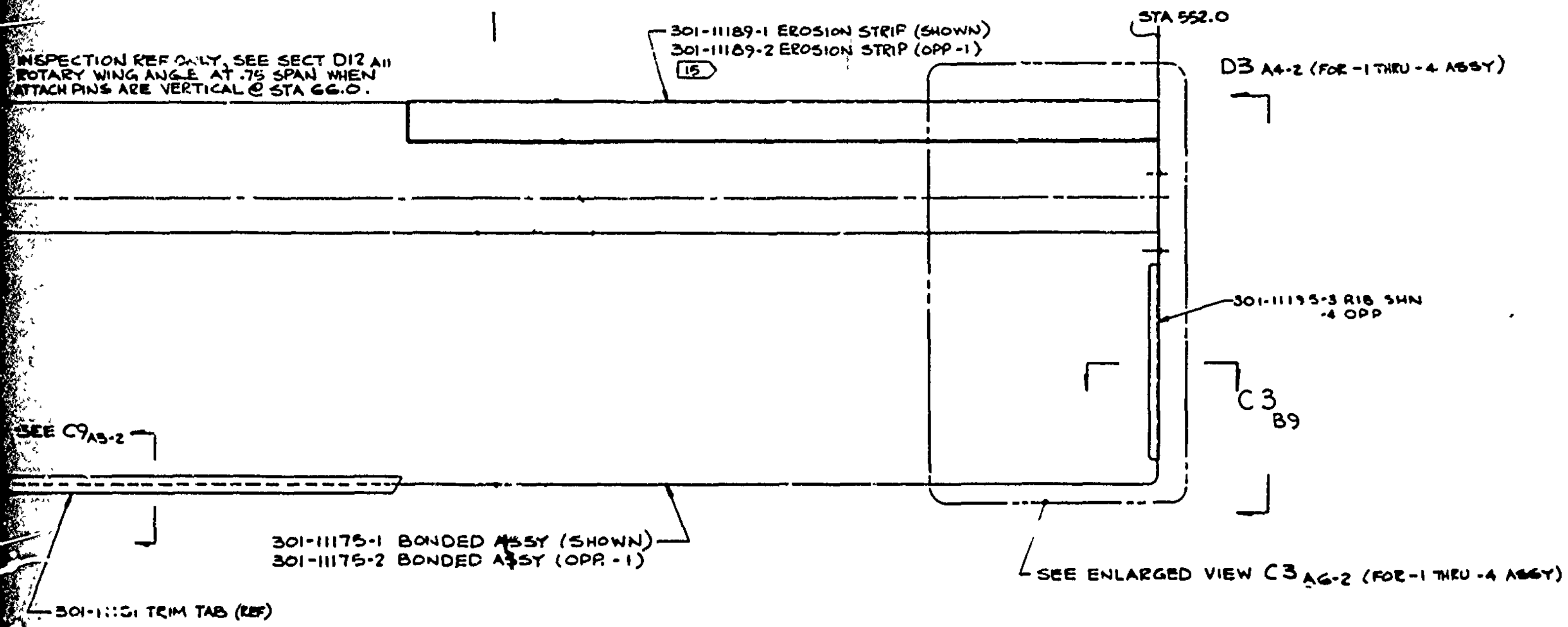
LADE

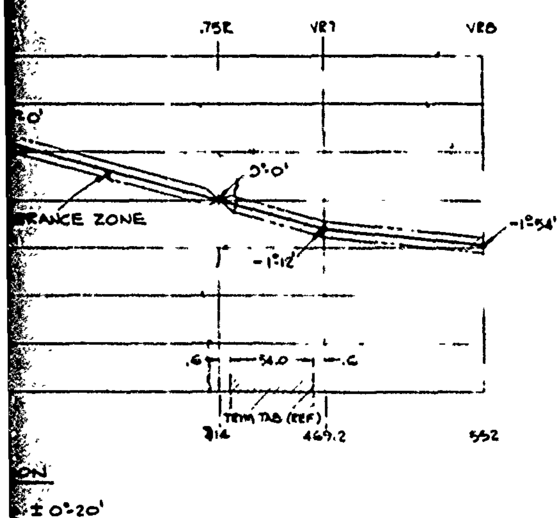


BLADE STATION

TWIST TOLERANCE = ± 0°-20'

3


STA 552.0
301-11189-1 EROSION STRIP (SHOWN)
301-11189-2 EROSION STRIP (OPP -1)
15
INSPECTION REF ONLY, SEE SECT D12 A11
ROTARY WING ANGLE AT .75 SPAN WHEN
ATTACH PINS ARE VERTICAL @ STA 66.0.
D3 A4-2 (FOR -1 THRU -4 ASSY)
301-11195-3 RIB SHN
-4 OPP
C3
B9
SEE C9 A5-2
301-11175-1 BONDED ASSY (SHOWN)
301-11175-2 BONDED ASSY (OPP. -1)
SEE ENLARGED VIEW C3 A6-2 (FOR -1 THRU -4 ASSY)
TRIM TAB (REF)


.75R
VR7
VR8
5°0'
RANCE ZONE
-1°54'
-1°12'
.6
54.0
.6
TRIM TAB (REF)
469.2
552
ON
± 0°20'

4

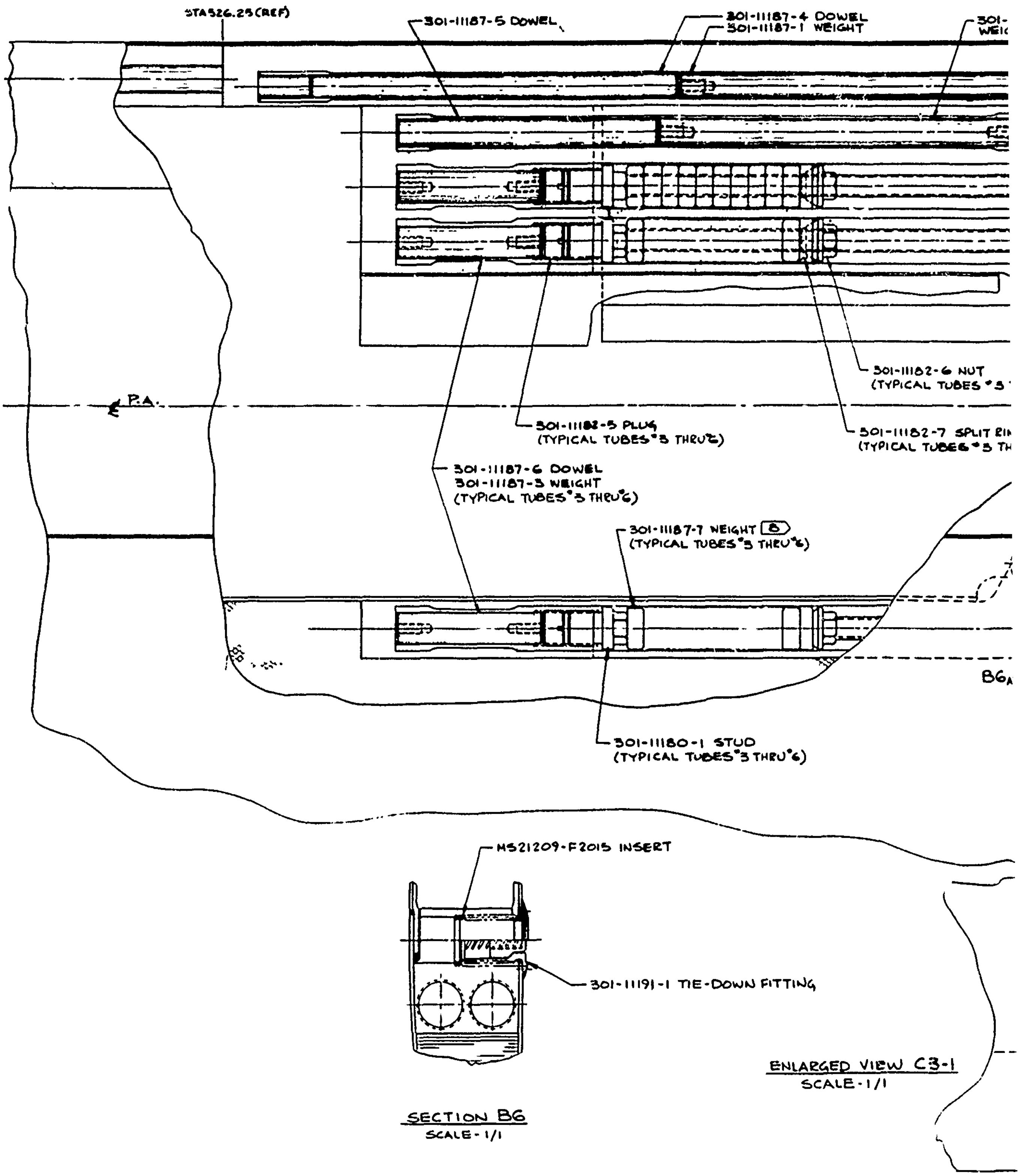
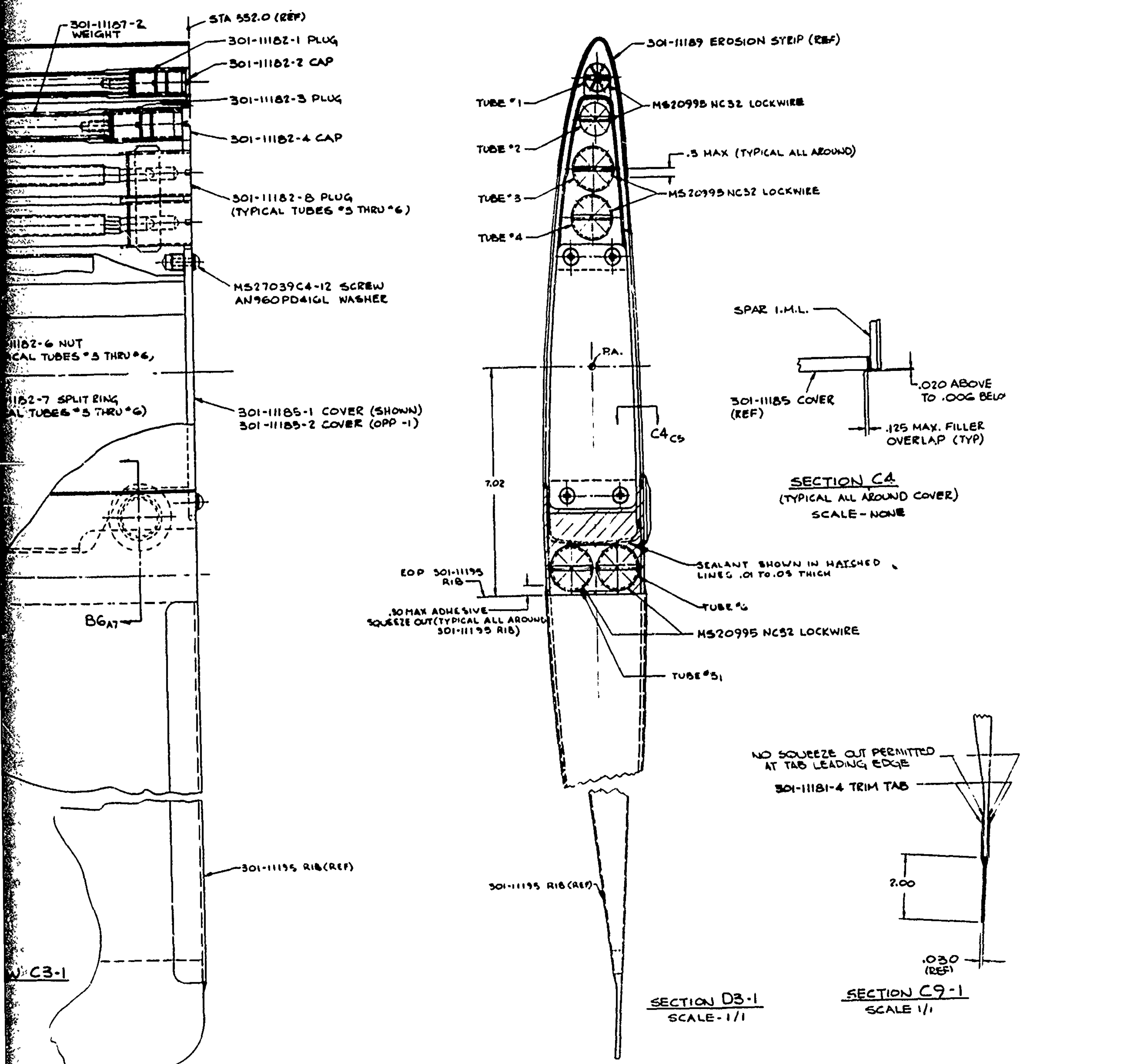


Figure 99. HLH Rotor Blade Assembly (Sheet 2 of 3)



SECTION C4
(TYPICAL ALL AROUND COVER)
SCALE - NONE

SECTION D3-1
SCALE - 1/1

SECTION C9-1
SCALE 1/1

2

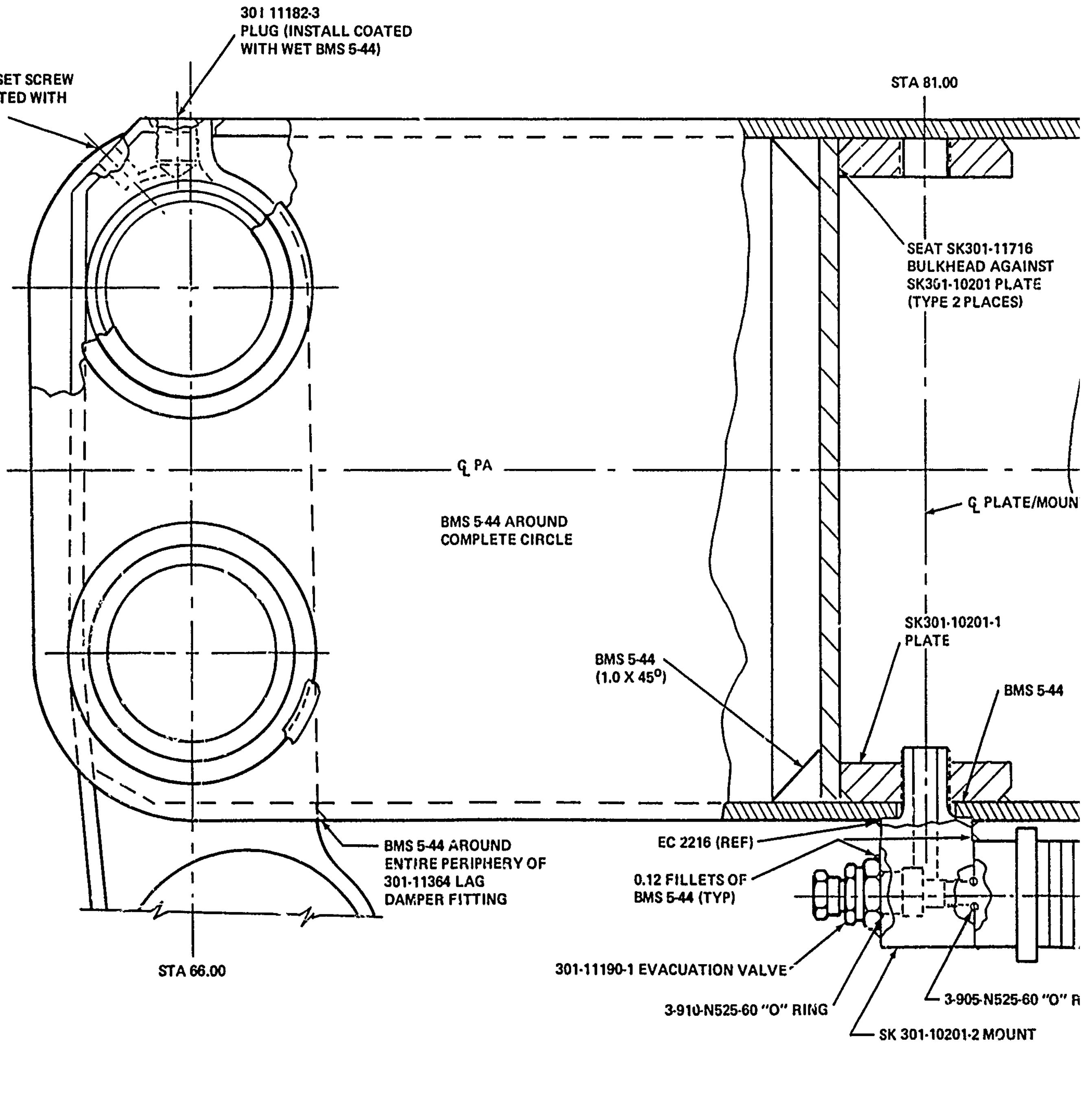
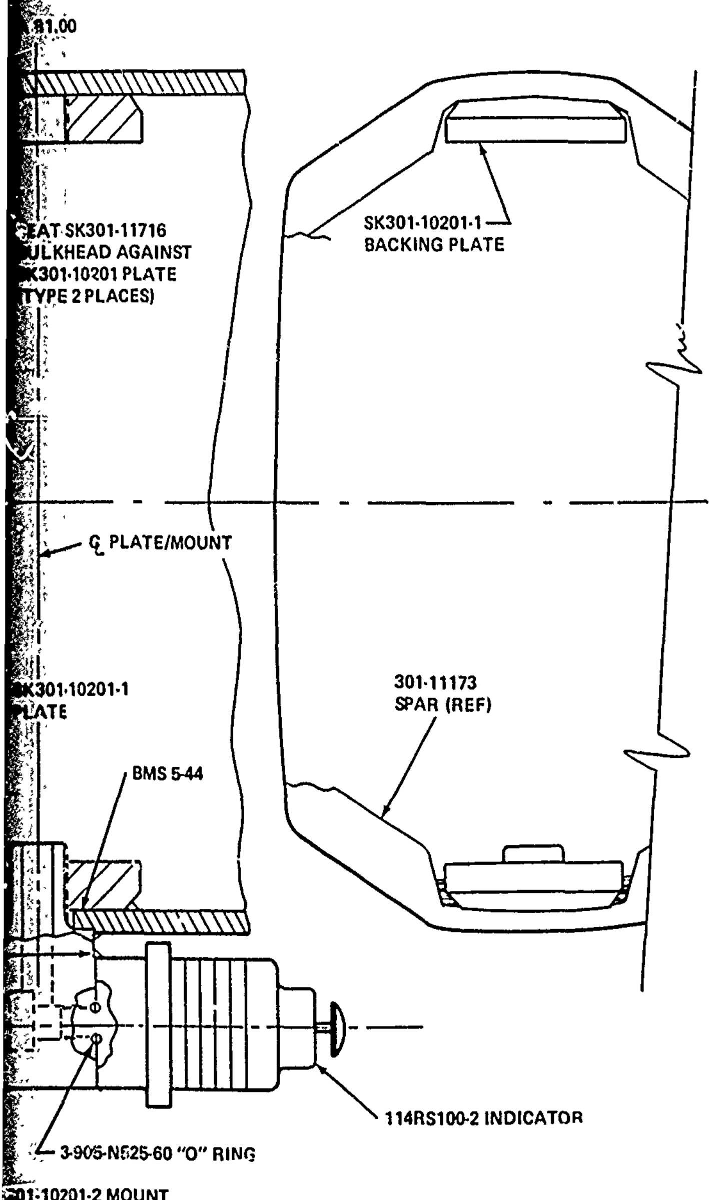
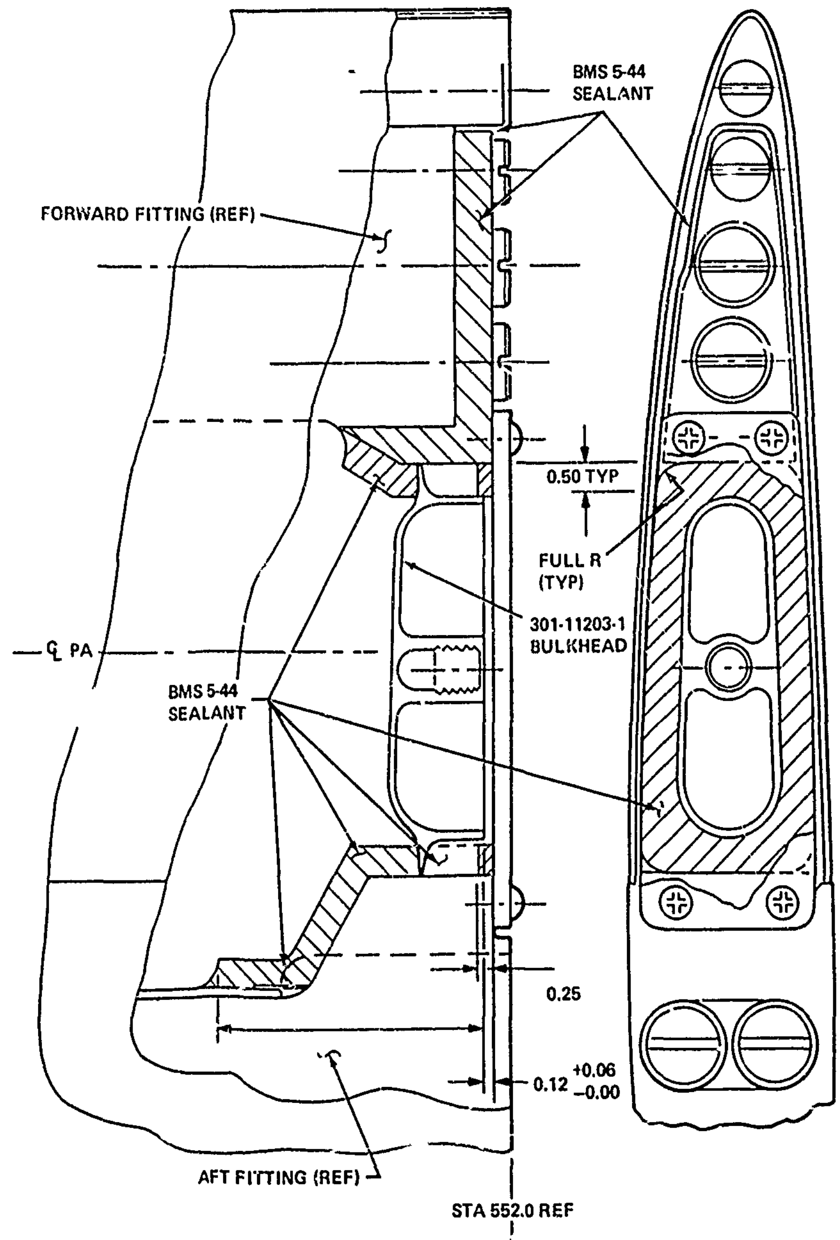


Figure 99. HLH Rotor Blade Assembly (Sheet 3 of 3)





TIP END ISIS INSTALLATION

2

using mandrels and an adapter to pull the sleeves into place. At this point, the moisture is dried from the sleeves, using heat lamps, and the blade is removed from the boring fixture. Filler is injected between the root end bores and the O.D. of the sleeves. The washers are prepared, and a sealant is applied to the counter bores on the root end of the blade. The washers are then installed in the sealant, the holding tools are installed, and a bead of sealant is applied over the edge of the washers. After a 24-hour cure, the tools are removed, and the blade is ready for the next operation.

Trim Tabs

This operation consists of bonding four sheetmetal tabs to the trailing edge of the blade, using a cold bond adhesive system. The trim tabs are located and clamped in place with a tool designed for this operation. After cure, the tools are removed, and the trim tab areas are

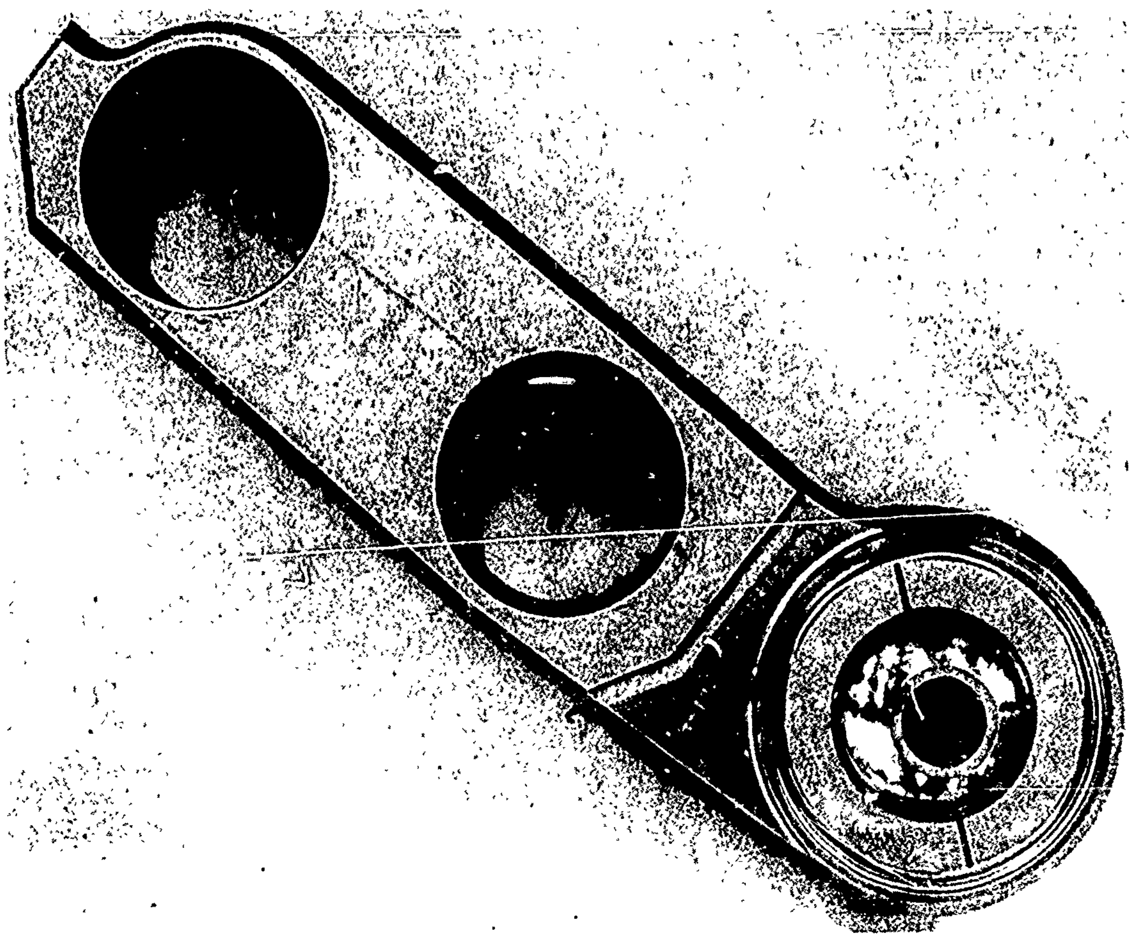


Figure 100. Lag Damper Fitting

cleaned and trimmed. On the first blade, a voided area was found during inspection. This problem was resolved by additional clamping.

Tie-Down Fitting

Installation of the tie-down fitting includes step-drilling a series of holes using a drill jig locator tool. The tie-down fitting is primed with a sealant and installed on the outboard end of the blade, using four mounting screws.

Lightning Protection

Lightning protection consists of four strips of aluminum foil and a brass strap with approximately four feet of wire brazed to it. The aluminum foil is bonded under the inboard and outboard ribs on each side of the fairing and runs from the trailing edge to the titanium cap. The brass strap is bonded on the root end overlapping the titanium cap, and the wire is attached to the lag damper fitting.

Inboard and Outboard End Ribs

The ribs are molded synthetic rubber and are bonded to the ends of the fairing with cold bond adhesive. During the initial installation, problems were encountered with the ribs being distorted after bond. This was corrected by covering the exposed core cells on the ends of the fairing with a filler and sanding to a smooth surface prior to installing the ribs.

Nickel Erosion Strip

This installation includes preparing the area on the blade leading edge and applying adhesive to both the blade and the erosion strip. The erosion strip is then positioned, holding blocks are applied, and the entire assembly is bagged. A vacuum is held for 24 hours, and the bag and blocks are then removed. The erosion strip and leading edge are cleaned and prepared for inspection.

Painting

Because it is a matched molded blade, the preparation for paint becomes a much simpler task than that for conventional blades currently in production. Only minor rework is required to eliminate surface irregularities prior to painting. Application of paint is similar to that of conventional blades except for the conductive coating. The conductive paint system requires careful monitoring during application to ensure that proper resistances are maintained.

Weight Control and Teeter Balance

To develop weight and balance data for the completed blade, each subassembly is weighed prior to being assembled into a major component. The major components are weighed by using a two-point scale system.

The blades are balanced to a specified span moment, developed by Engineering, using the heaviest blade as a master. To balance each blade to the specified span moment, weights are added to the tip weight fittings.

The overall operation experienced very few problems, and the teeter stand functioned very satisfactorily. A problem was encountered with installation of weights, where threads tended to bind on the fitting cavity. The problem was severe enough to stimulate a design improvement, which will be incorporated into the prototype blades.

Tip Cover and Tracking Targets

After painting and teeter balancing the blades, the tracking hardware is secured, and the tip cover is installed. A special tracking target is installed over the tip cover, picking up two of the four tip cover mount screws.

Blade Assembly Summary

With the installation of the tip cover and tracking targets, the final assembly operations of the HLH rotor blade are complete, and the finished product is ready for final inspection, tracking and end-item use. Weight control during the detail fabrication and subassembly operations was extremely successful. Of the seven ATC blades produced to date, all achieved the specified weight of 765 pounds (excluding the damper arm).

The variation of weight between the lightest and heaviest blade was 5 pounds after teetering or less than 1% of the specified blade weight. Figure 101 is a size comparison between the HLH and CH-47 rotor blades.

BLADE DETAILS

The data in Table 1 is presented to provide some visibility of the detail parts included in the HLH blade. The list of detail parts has been compiled numerically by part number and includes the drawing nomenclature and other pertinent data. In the remarks column is a brief description of the part, the part's intended function, the process used for fabrication, or miscellaneous other information which aids in identifying the part. For additional specific information, refer to the applicable drawing.

FABRICATION SCHEDULING AND CONTROLS

To accomplish the blade fabrication program on schedule, each of the many tasks was closely monitored and controlled. To facilitate the monitoring, detailed schedule charts and plans were established concurrent with the fabrication concept development. The charts were further refined and revised as the program progressed. Examples of these charts, and other charts used to provide detailed visibility, are shown in Figures 102 through 110. The overall program schedule is shown in Figure 102. Figures 103 through 106 depict the anticipated flow for each major work task. Detailed schedules developed to outline daily requirements and sequencing are shown in Figures 107 through 108.

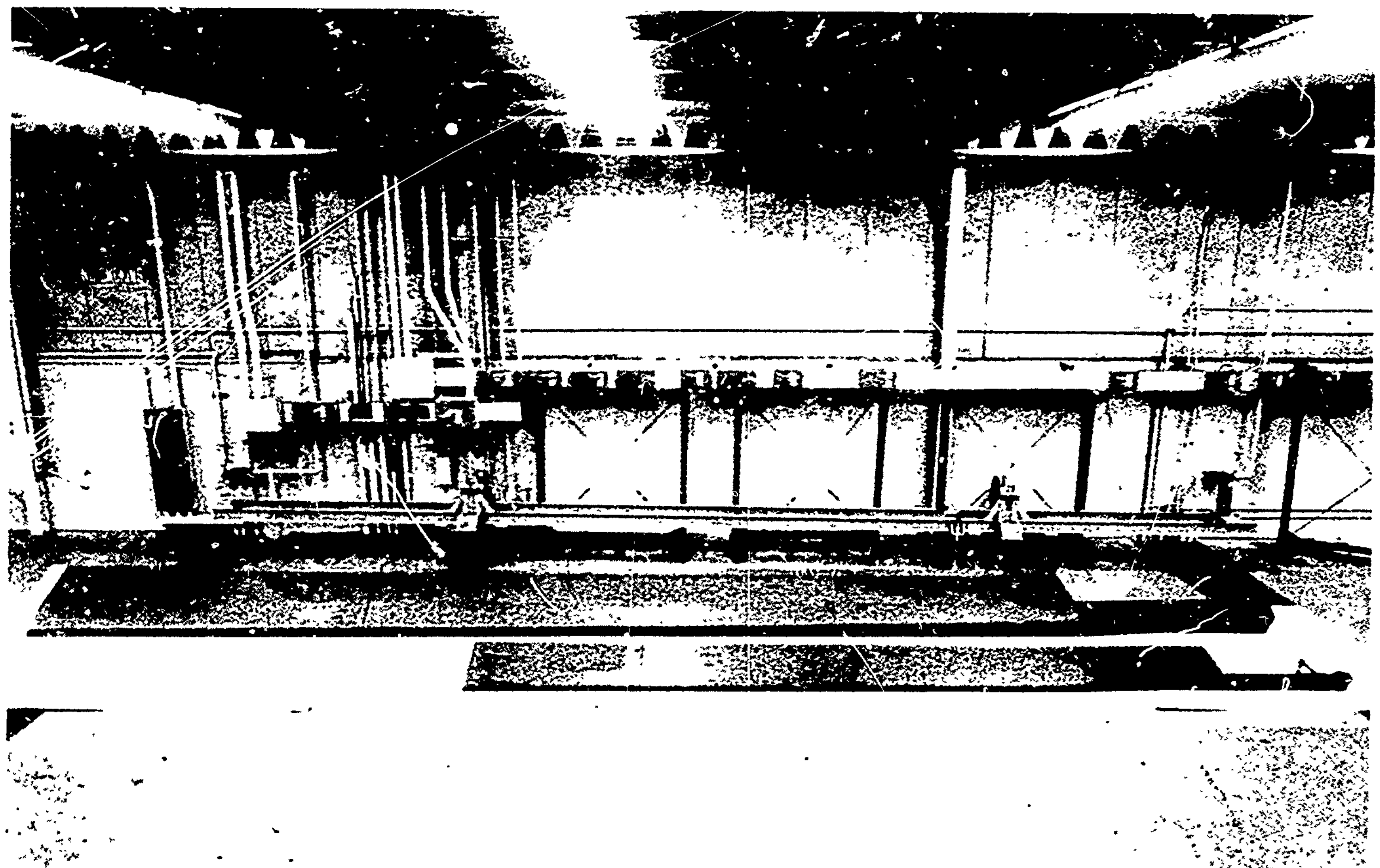


Figure 101. Size Comparison Between HLH Blade No. 1 and CH-47 Production Blade

TABLE 1. HLH ROTOR BLADE DETAIL PARTS

PART NUMBER	NOMENCLATURE	QTY PER BLADE	MATERIAL USED	SOURCE MAKE	SOURCE BUY	REMARKS
301-11173-11	Outer Skin - Upper	1	Glass (Cross Ply) BMS8-164	x		26" Wide Cross Ply - Top of Spar
11173-13	Outer Skin - Lower	1	Glass (Cross Ply) BMS8-164	x		26" Wide Cross Ply - Bottom of Spar
11173-15	Inner Skin - Upper	1	Glass (Cross Ply) BMS8-164	x		26" Wide Cross Ply on Spar
11173-17	Inner Skin - Lower	1	Glass (Cross Ply) BMS8-164	x		26" Wide Cross Ply on Spar
11173-19	Wrap Around	4	Glass (Cross Ply) BMS8-164	x		2.62" Wide Cross Ply Lay Up "U" Shaped
11173-20	Uni Strap Wedge	4	Glass (Uni) BMS8-164	x		4" Wide Uni Cut & Laid Up Chordwise
11173-21	Spar Strap Upper Fwd	1	Glass (Uni) BM8-164	x		2.62" Wide Uni Laid Up Spanwise
11173-23	Spar Strap Upper Aft	1	Glass (Uni) BMS8-164	x		2.62" Wide Uni Laid Up Spanwise
11173-25	Spar Strap Lower Fwd	1	Glass (Uni) BMS8-164	x		2.62" Wide Uni Laid Up Spanwise
11173-27	Spar Strap Lower Aft	1	Glass (Uni) BMS8-164	x		2.62" Wide Uni Laid Up Spanwise
11173-29	Filler Strap Upper Fwd	1	Glass (Uni) BMS8-164	x		2.62" Wide Uni Laid Up Spanwise
11173-31	Filler Strap - Upper Aft	1	Glass (Uni) BMS8-164	x		2.62" Wide Uni Laid Up Spanwise
11173-33	Filler Strap - Lower Fwd	1	Glass (Uni) BMS8-164	x		4" Wide Uni Laid Up Spanwise
11173-35	Filler Strap - Lower Aft	1	Glass (Uni) BMS8-164	x		4" Wide Uni Laid Up Spanwise
11173-37	Web - LE (Root End)	1	Glass (Uni) BMS8-164	x		4" x 10" Wide Uni Laid Up Into Web
11173-39	Web - TE (Root End)	1	Glass (Uni) BMS8-164	x		4" x 10" Wide Uni Laid Up Into Web
11173-41	Stiffener Chordwise	1	Graphite XBMS8-164	x		3" Wide Graphite Laid Up Chordwise
11173-43	Stiffener Chordwise	1	Graphite XBMS8-164	x		3" Wide Graphite Laid Up Chordwise
11173-49	Filler Strap LE Upper	1	Glass (Uni) BMS8-164	x		4" Wide Uni Laid Up Into a Strap
11173-51	Filler Strap LE Lower	1	Glass (Uni) BMS8-164	x		4" Wide Uni Laid Up Into a Strap
11173-53	Spacer (Heat Blanket)	1	Glass (Cross Ply) BMS8-164	x		26" Cross Ply 38' Long Cut Into 2 Pcs 13" x 38' Makes 1 Heat Blanket
11173-55	Wedge Lower	1	Glass (Uni) BMS8-164	x		4" Wide Uni Retangular Shaped Wedge
11173-57	Wedge Upper	1	Glass (Uni) BMS8-164	x		4" Wide Uni Rectangular Shaped Wedge
11173-61	Inb'd Inner Skin Fwd Upper	1	Glass (Uni) BMS8-164	x		26" x 15' Uni Laid Up Under Strap at RE
11173-62	Inb'd Inner Skin Aft Upper	1	Glass (Uni) BMS8-164	x		26" x 15' Uni Laid Up Under Strap at RE
11173-63	Inb'd Inner Skin Aft Lower	1	Glass (Uni) BMS8-164	x		26" x 15' Uni Laid Up Under Strap at RE

TABLE 1. HLH ROTOR BLADE DETAIL PARTS (Continued)

PART NUMBER	NOMENCLATURE	QTY PER BLADE	MATERIAL USED	SOURCE MAKE	SOURCE BUY	REMARKS
301-11173-64	Fnb'd Inner Skin Fwd Lower	1	Glass (Uni) BMS8-164	x		26" x 15' Uni Laid Up Under Strap at RE
11174-3	Nose Cap	1	Titanium (6AL-4V)	x		Continuously Rolled & Annealed Titanium
11175-4	Skin	1	Glass (Cross Ply) BMS8-164	x		36" Cross Ply Used On Upper Airfoil
11175-5	Skin	1	Glass (Cross Ply) BMS8-164	x		36" Cross Ply Used on Upper Airfoil
11175-7	Filler	2	Honeycomb BMS8-124	x		Filler Between Joggle in Ftg & Outside Skin
11175-9	Doubler	1	Glass (Uni) BMS8-164	x		10" Wide Uni in Upper Airfoil Skin
11175-10	Strip	2	Glass (Uni) BMS8-169	x		Top Skin Tear Strip
11175-12	Shim	1	Glass (Uni) BMS8-164	x		Shim Used Over Aft Wt Ftg & Spar
11175-13	Shim	1	Glass (Uni) BMS8-164	x		Shim Used Over Aft,Wt,Ftg & Spar
11175-14	Channel	1	Glass (Cross Ply) BMS8-164	x		Channel Used to Hold Fwd Wt Ftg in Place
11176-1	Insert	1	Chopped Glass Fibers/Epoxy	x		Compression Molded Part
11176-2	Insert	1	Chopped Glass Fibers/Epoxy	x		Compression Molded Part
11177-3	Nose Preform	1	Glass (Uni) BMS8-164	x		L/U Preform & Compacted
11177-5	Heel Preform	1	Class (Uni) BMS8-164	x		L/U Preform & Compacted
11177-7	Nose Preform	1	Glass (Uni) BMS8-164	x		L/U Preform & Compacted
11178-5	Rod	A/R	Tungsten Bar	x		Machined & Processed Part
11178-6	Rod	A/R	Steel Bar SAE 1018 QQ-S-633	x		Machined & Processed Part
11179-12	Core Block	1	Core Per BMS8-124 Type 1		x	Honeycomb - Pre cut by Vendor
11179-13	Core Block	1	Core Per BMS8-124 Type 1		x	Honeycomb - Pre cut by Vendor
11179-14	Core	1	Core Per BMS8-124 Type 5		x	Honeycomb - Pre cut by Vendor
11180-1	Stud	4	4130 Steel Bar		x	Machined Stud with External Threads
11181-4	Trim Tabs	4	Cres Sht Type 301 1/2 Hard	x	x	Formed Sheet Metal, Processed for Bond
11182-1	Plug	1	17-4 PH Stainless Steel		x	Threaded Plug
11182-3	Plug	2	17-4 PH Stainless Steel		x	Threaded Plug
11182-5	Plug	4	17-4 PH Stainless Steel		x	Threaded Plug

FORM 46280 (12/69)

TABLE 1. HLH ROTOR BLADE DETAIL PARTS (Continued)

PART NUMBER	NOMENCLATURE	QTY PER BLADE	MATERIAL USED	SOURCE MAKE	SOURCE BUY	REMARKS
301-11182-6	Nut	4	4130 Steel Bar	x		Machined, Chamfered & Threaded Nut
11182-7	Split Ring	4	17-4 PH Stainless Steel	x		Machined & Chamfered Ring
11182-11	Cap	1	Aluminum Rod 6061-T6		x	Machined, Threaded & Drilled Cap
11182-13	Plug	4	Aluminum Rod 6061-T6		x	Machined, Threaded & Drilled Plug
11183-2	Tube, Overbalance	1	Cres. Tubing Type AISI 304	x		Machined & Internal Threaded Tube
11183-3	Plug, Tube	1	Cres. Bar Type AISI 302	x		Machined & Threaded Plug
11183-4	Tube - Overbalance	1	Cres. Tube Type AISI - 304	x		1" x 20.5" Tube Machined & Internal Thread
11183-5	Tube Tracking Wt	4	Cres. Tube Type AISI - 304	x		1¼" x 6" Tube Machined & Internal Threads
11184-3	Fitting	1	Chopped Glass Fiber/Epoxy	x		Molded in 2 Halves, Lower is 3L, Upper is 3U
11185-1	Cover	1	Aluminum Plate 7075-T6	x		Machined & Processed for Bonding
11186-3	Fitting	1	Chopped Glass Fibers/Epoxy	x		Molded in 2 Halves - Lower is 3L, and Upper is 3U
11187-1	Weight	AR	Tungsten Bar	x		Tracking Weight
11187-2	Weight	AR	Tungsten Bar	x		Tracking Weight
11187-3	Weight	AR	Tungsten Bar	x		Tracking Weight
11187-4	Dowel	AR	Spruce Dowel	x		Filler
11187-5	Dowel	AR	Spruce Dowel	x		Filler
11187-6	Dowel	AR	Spruce Dowel	x		Filler
11187-7	Weight	AR	Tungsten Bar		x	Tracking Weight (1/4 Pound)
11189-1	Erosion Strip	1	Nickel Electro Plated	x		Nickle Electro Form with Spanwise & Chordwise Taper in Thickness
11190-1	Valve Assembly	1	Cres. Steel		x	Vendor Item - Source Controlled
11191-1	Tie Down Receiver Ftg Assy	1	Aluminum 6061-T6		x	Vendor Item - Source Controlled
11193-3	Rib Closure LH	1	Per MIL-R-83397 Type II Grade 90		x	One Piece Flexible Molded Part

FORM 46289 (12/69)

TABLE 1. HLH ROTOR BLADE DETAIL PARTS (Continued)

PART NUMBER	NOMENCLATURE	QTY PER BLADE	MATERIAL USED	SOURCE MAKE	SOURCE BUY	REMARKS
301-11195-2	Rib Closure RH	1	Per MIL-R-83397 Type II Grade 90		x	One Piece Flexible Molded Part
11197-1	Block Wt Ftg	1	Cres Bar Type AISI 303	x		Machined Part & Processed for Bond
11197-2	Block Wt Ftg	1	Cres Bar Type AISI 303	x		Machined Part & Processed for Bond
11199-1	Wedge Trailing Edge	1	Glass (Uni) BMS8-164 Graphite XBMS 8-189 Type II	x		Glass & Graphite Laminate
11200-1	Washer	4	Cres.Plate 17-4 PH	x		Machined & Processed Part
11201-1	Sleeves	2	Cres. Steel 17-4 PH	x		Machined & Processed Part
11203-1	Bulkhead Outb'd	1	Per MIL-R-83397 Type II Grade 90		x	Molded Part - 1 Piece
11204-1	Insert	1	Chopped Glass Fibers/ Epoxy	x		Compression Molded with -3
11204-3	Insert	1	Chopped Glass Fibers/Epoxy	x		Compression Molded with -1
11207-2	ISIS Indicator	1	-		x	Vendor Item - Source Controlled
11208-1	Pigtail Assembly	1	Naval Brass Comp. 1 1/2 Hard	x		Lightning Protection Lead from TI Cap to Damper Arm
11209-1	Doubler	1	114R1549-2 Skin	x		Glass Box Skin Bonded to HLH Blade at Root End
11211-1	Target	1	Aluminum Plate 7075-T6	x		Flat Plate with Machined Target Slots
11211-2	Target	1	Aluminum Plate 7075-T6	x		Flat Plate with Machined Target Slots
11211-3	Target	1	Aluminum Plate 7075-T6	x		Flat Plate with Machined Target Slots
11211-4	Target	1	Aluminum Plate 7075-T6	x		Flat Plate with Machined Target Slots
11349-1	Liner	1	Cres. Bar 17-4 PH	x		Machined & Processed Part
11364-1	Fitting Assy	1	Titanium Alloy 6AL-4V	x		Machined & Processed Part
SK301-10168-18	Filler Preform Center	1	BMS 528 Type II Mold Compound	x		Molded Part 1 Piece
SK301-10168-19	Filler Preform Center	1	BMS 528 Type II Mold Compound	x		Molded Part 1 Piece
SK301-10201-1	Backing Plate	2	Aluminum Bar 7075-T6	x		Machined & Processed Part
SK301-10201-2	ISIS Mount	1	Aluminum Bar or Sheet 7075-T6	x		Machined & Processed Part
SK301-11716-1	Backing Plate	1	Aluminum Alloy 6061-T6	x		Machined & Processed Part Trimmed to Fit IML of Spar
SK301-11716-14	Block	4	Aluminum Alloy 6061-T6	x		Machined & Processed Part

FORM 46285 (12/68)

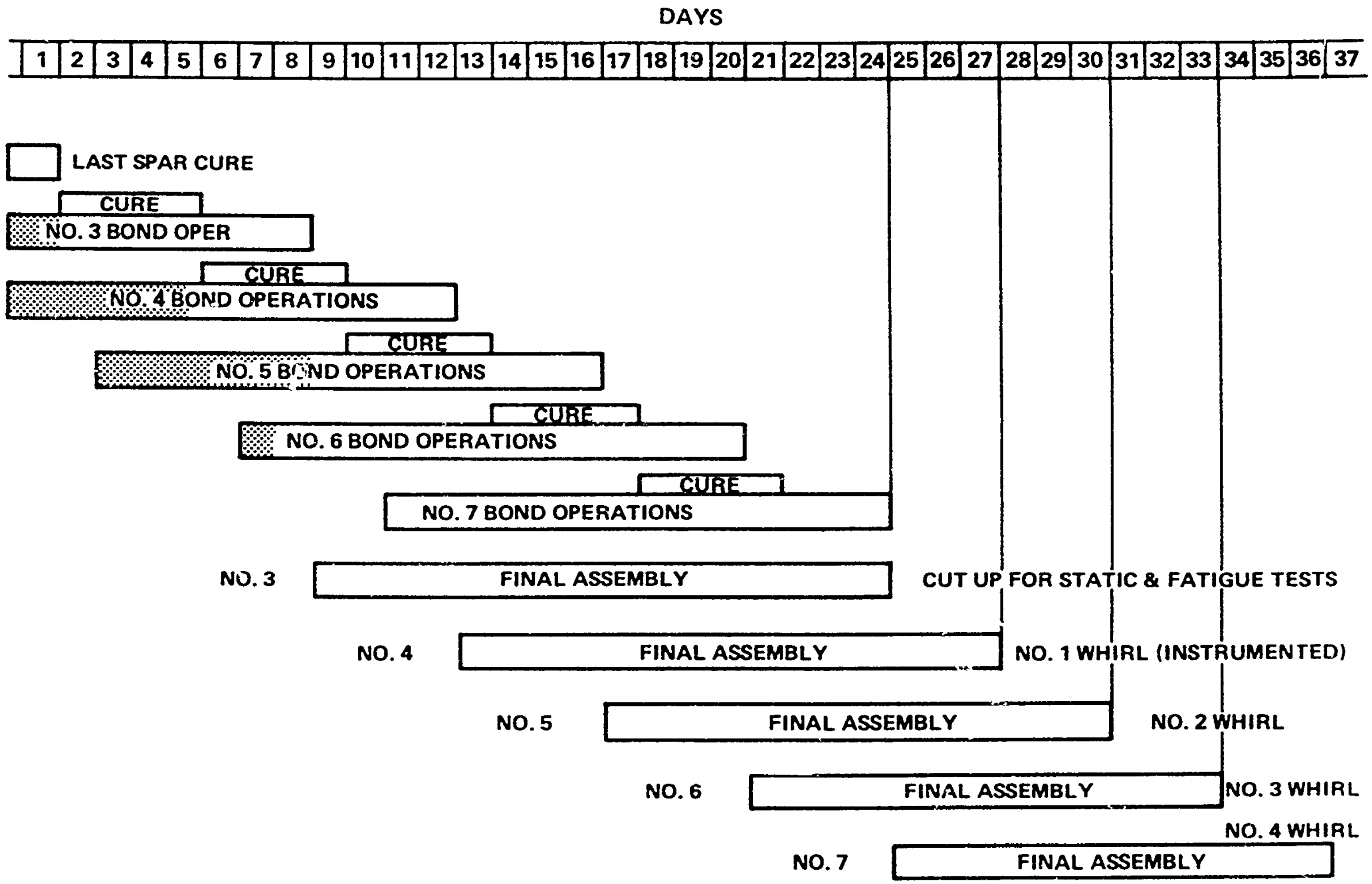


Figure 102. HLH/ATC Blade Fabrication Schedule

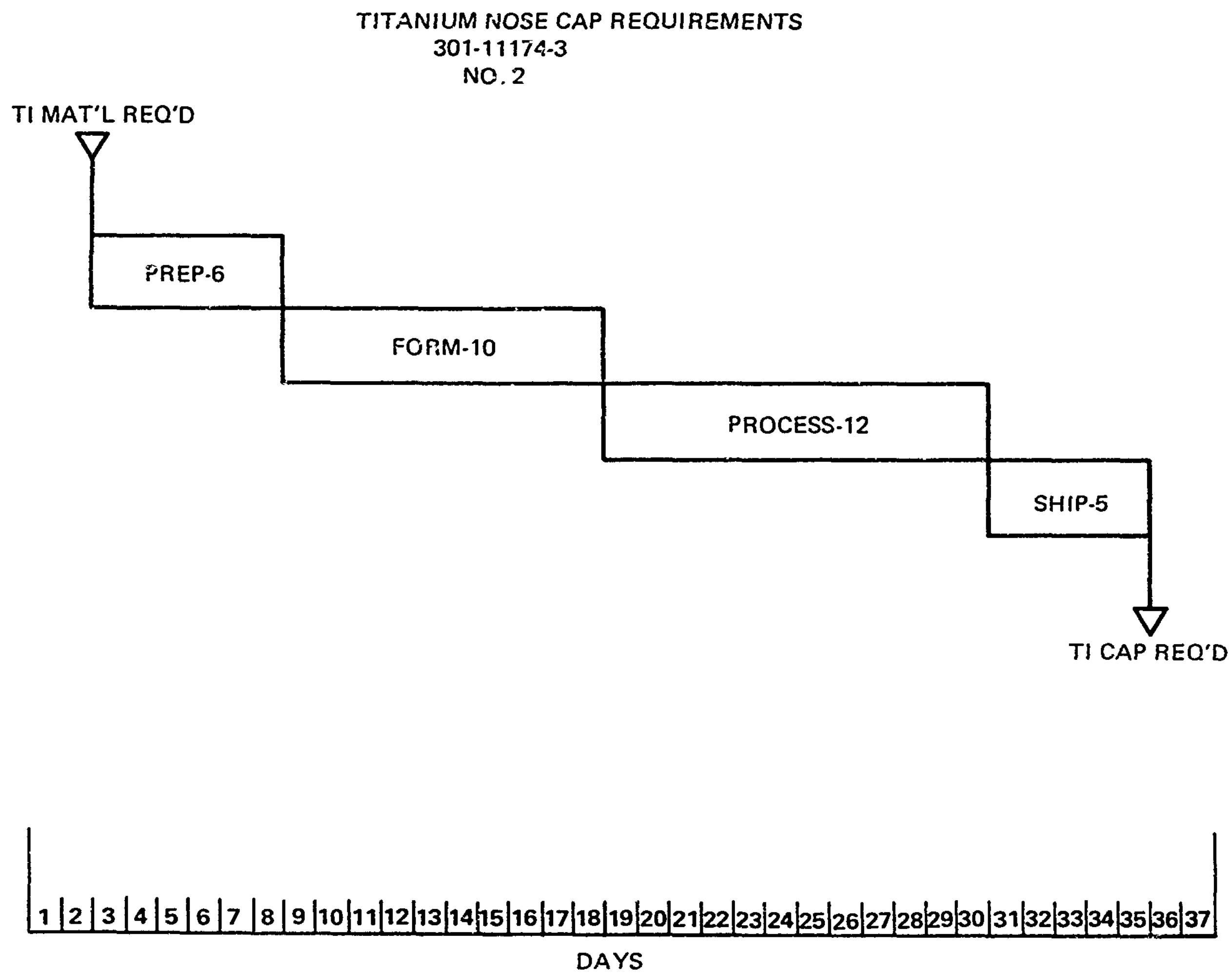


Figure 103. Titanium Nose Cap Requirements (301-11174-3, No. 2)

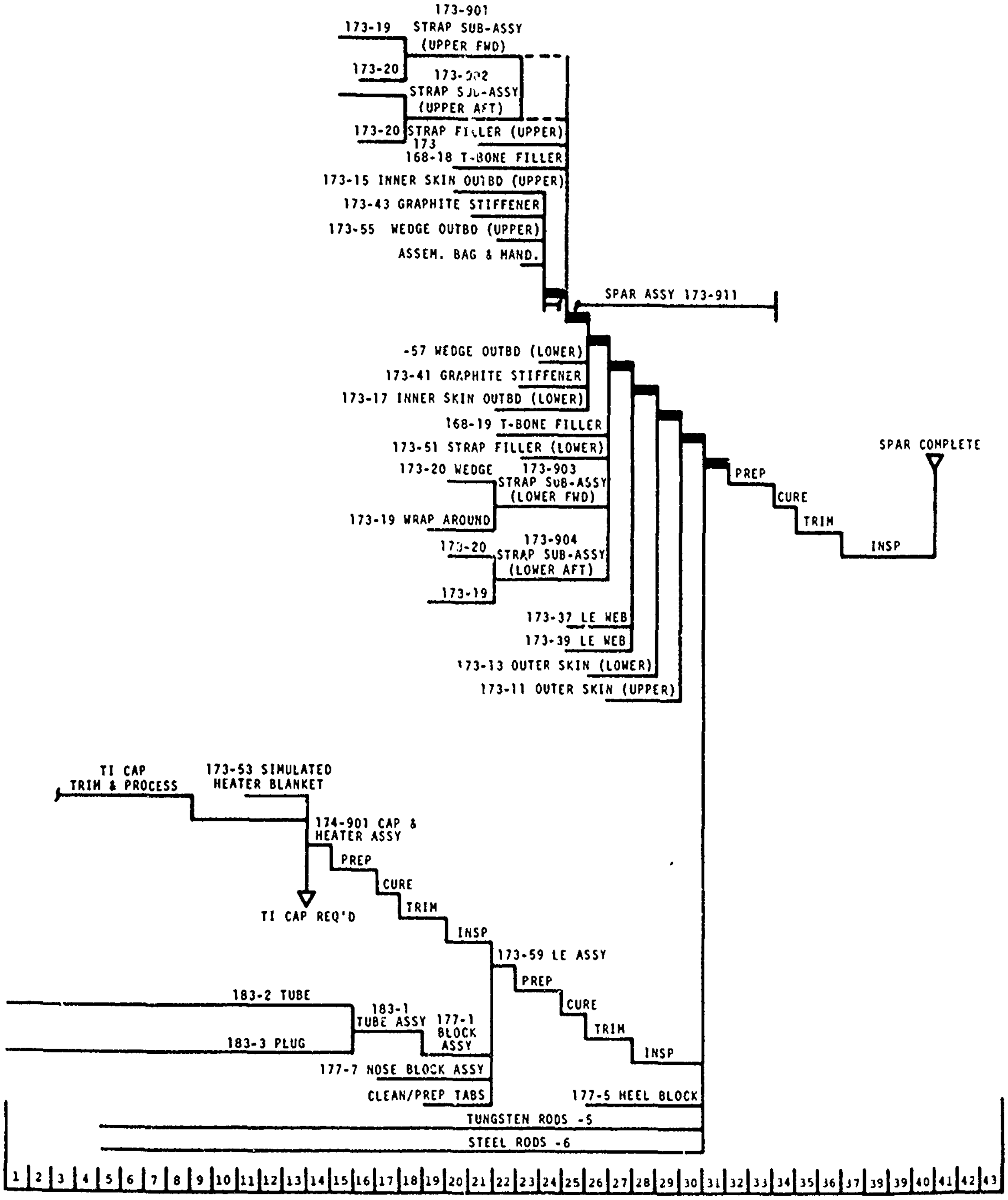


Figure 104. Spar Assembly Detail Schedule

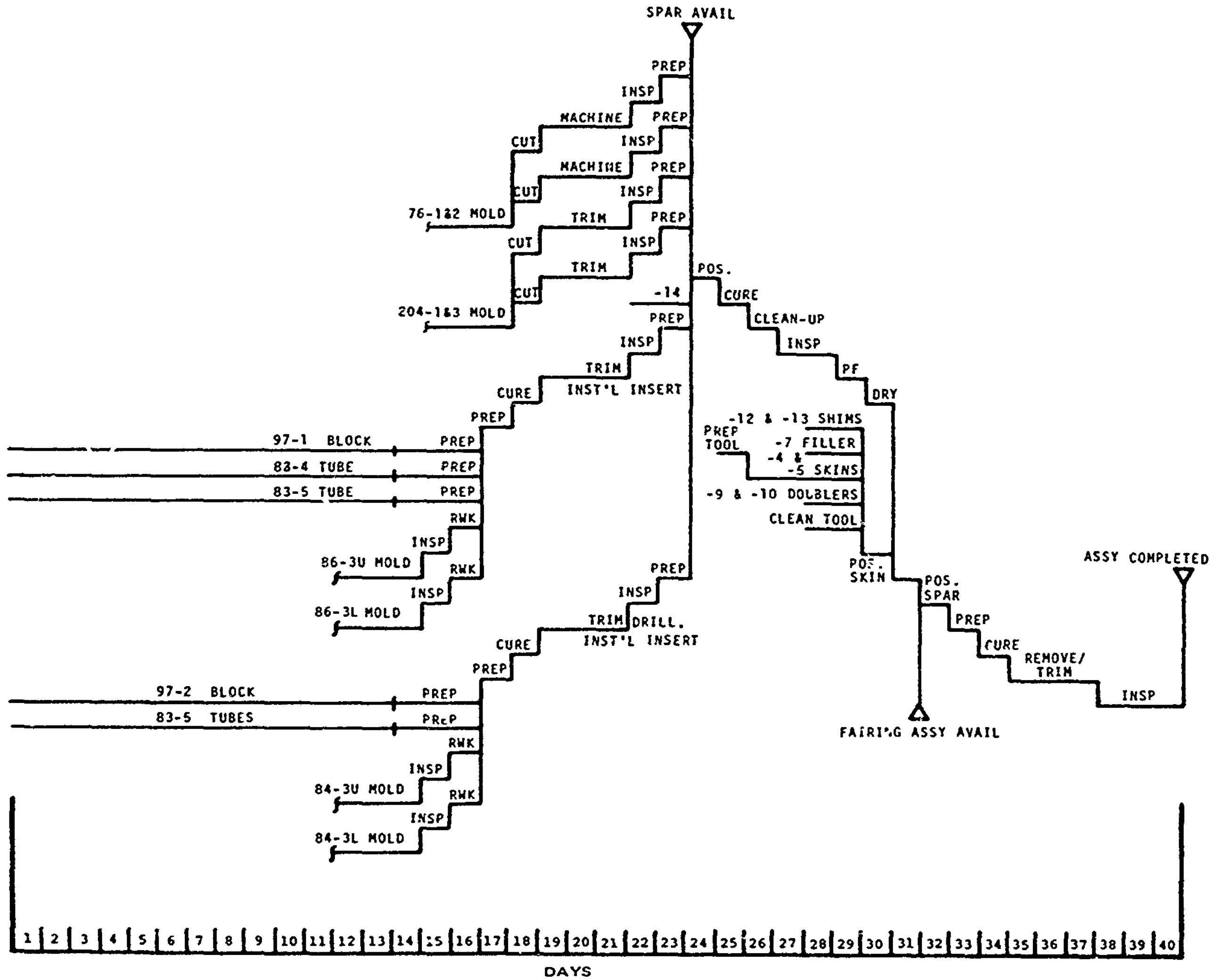


Figure 105. Blade Bonding and Related Operations Detail Schedule

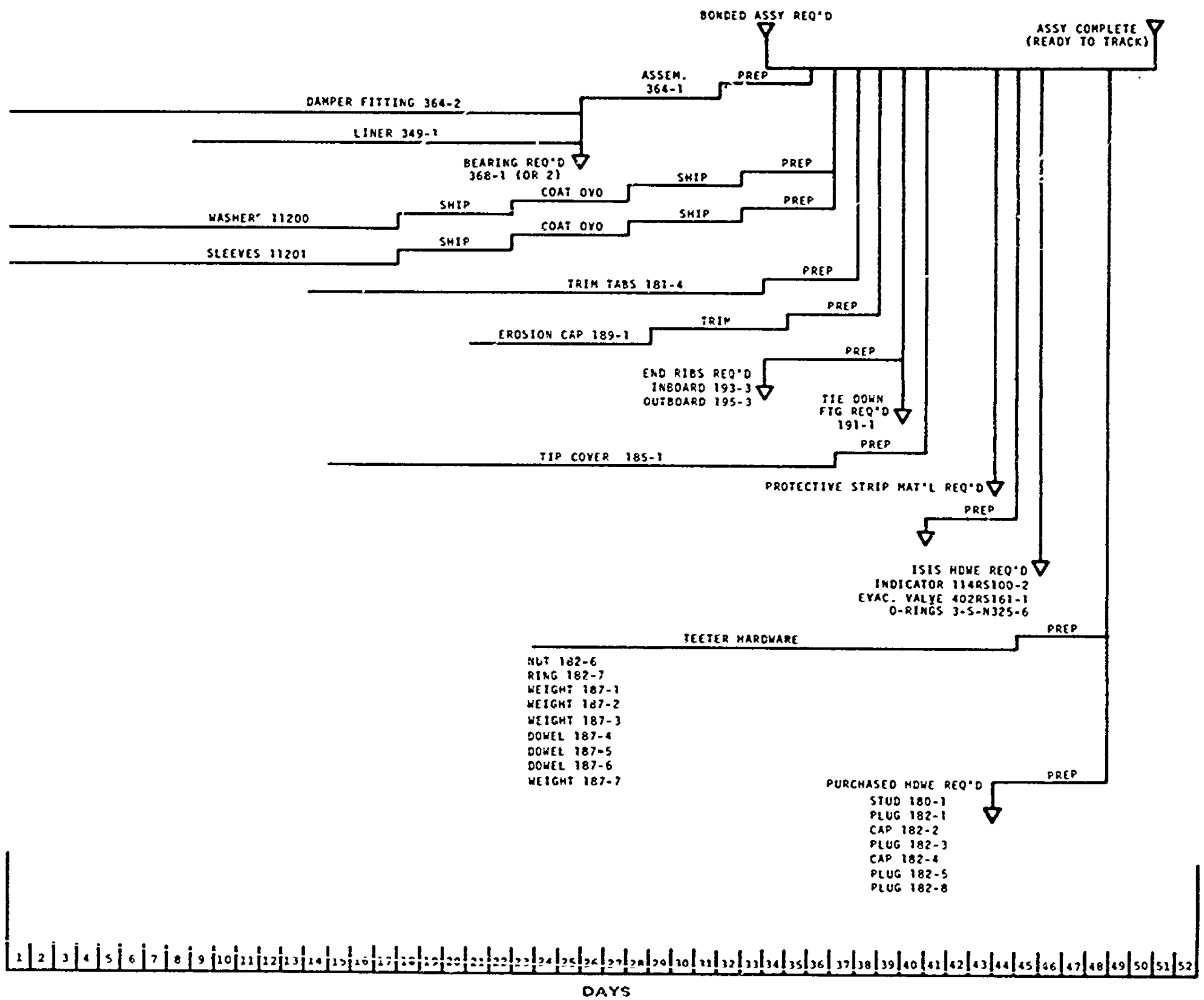


Figure 106. Final Assembly and Related Operations Detail Schedule

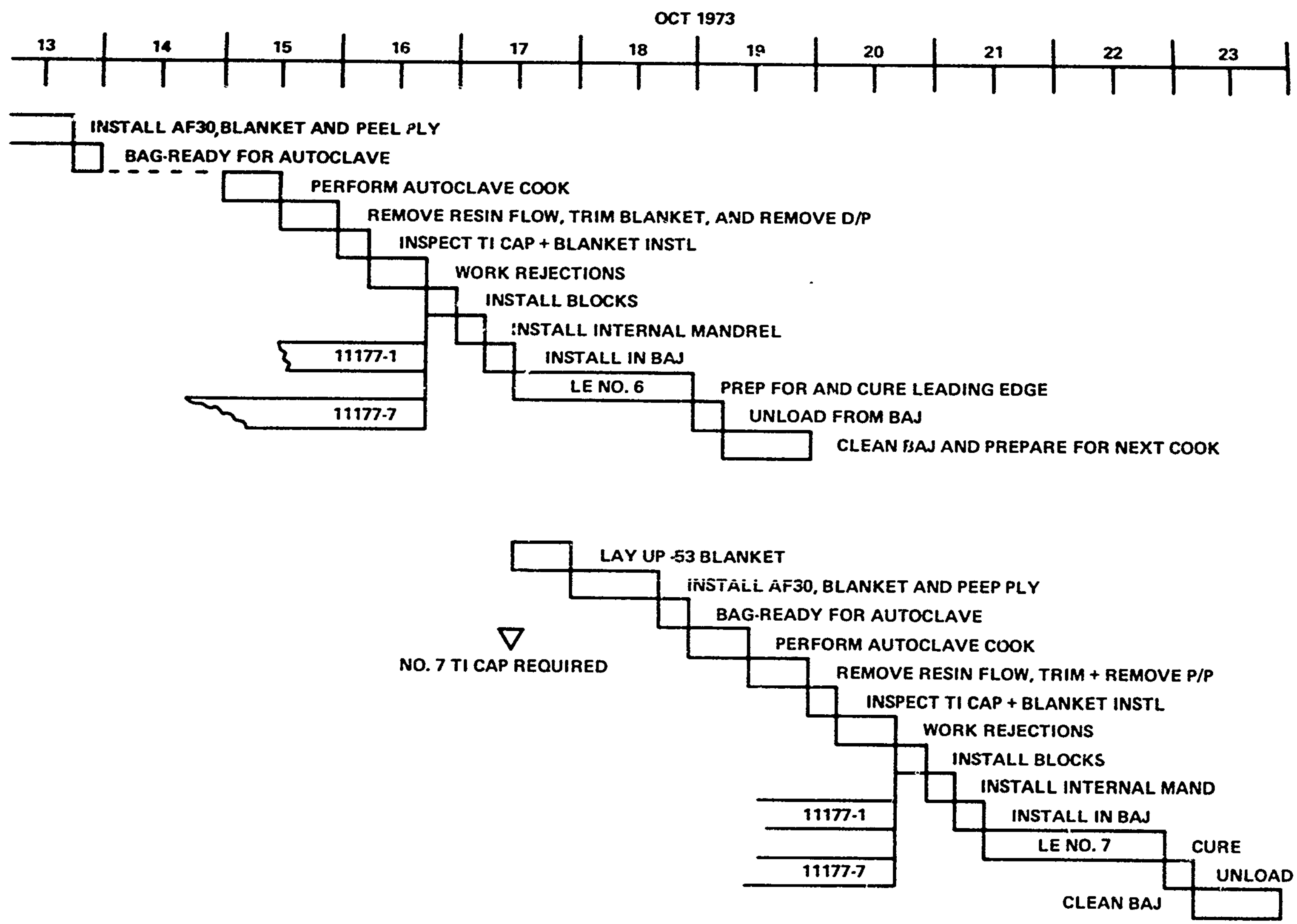


Figure 107. Leading-Edge Fabrication Plan

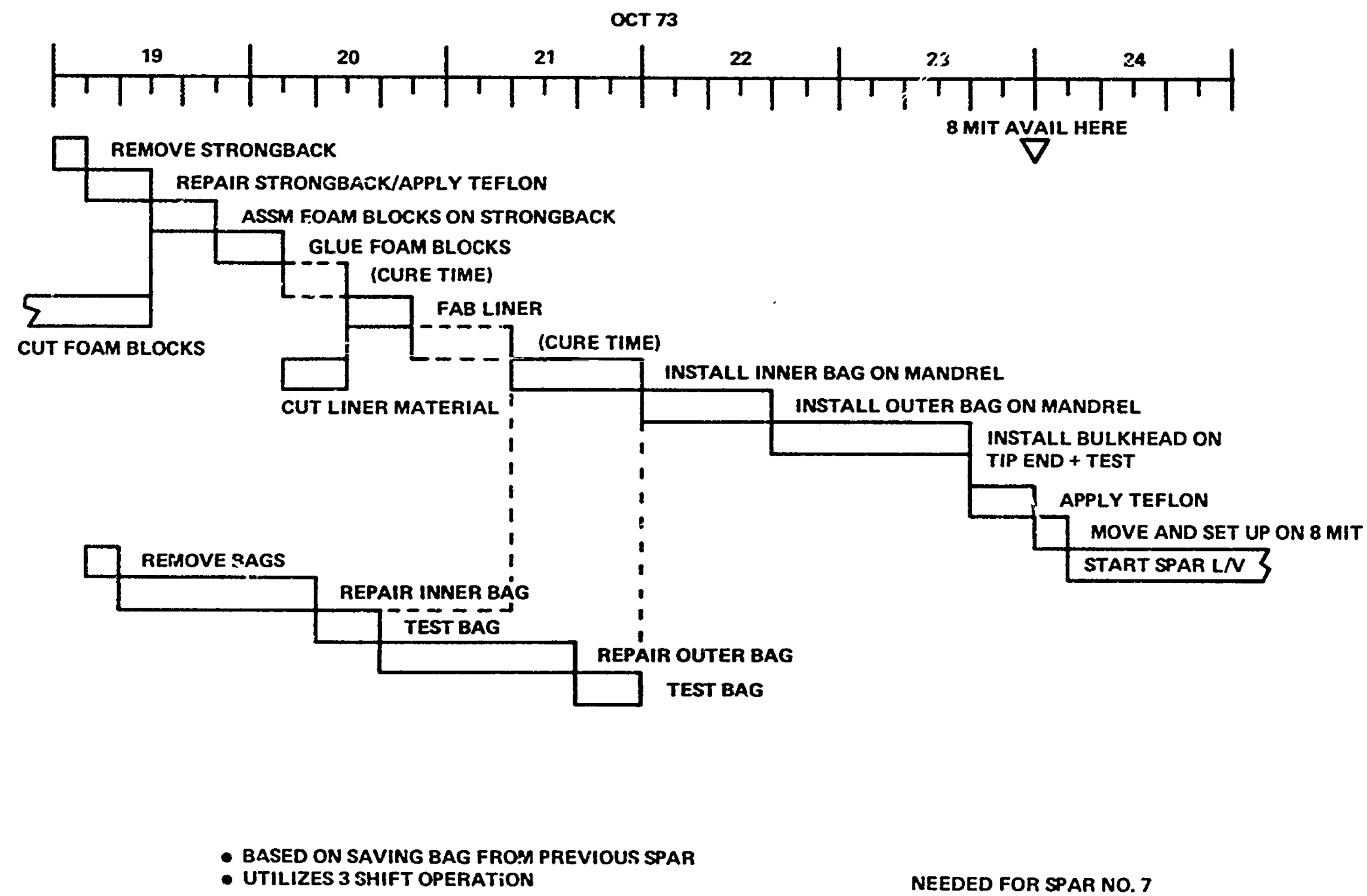


Figure 108. Mandrel and Bag Assembly Work Plan

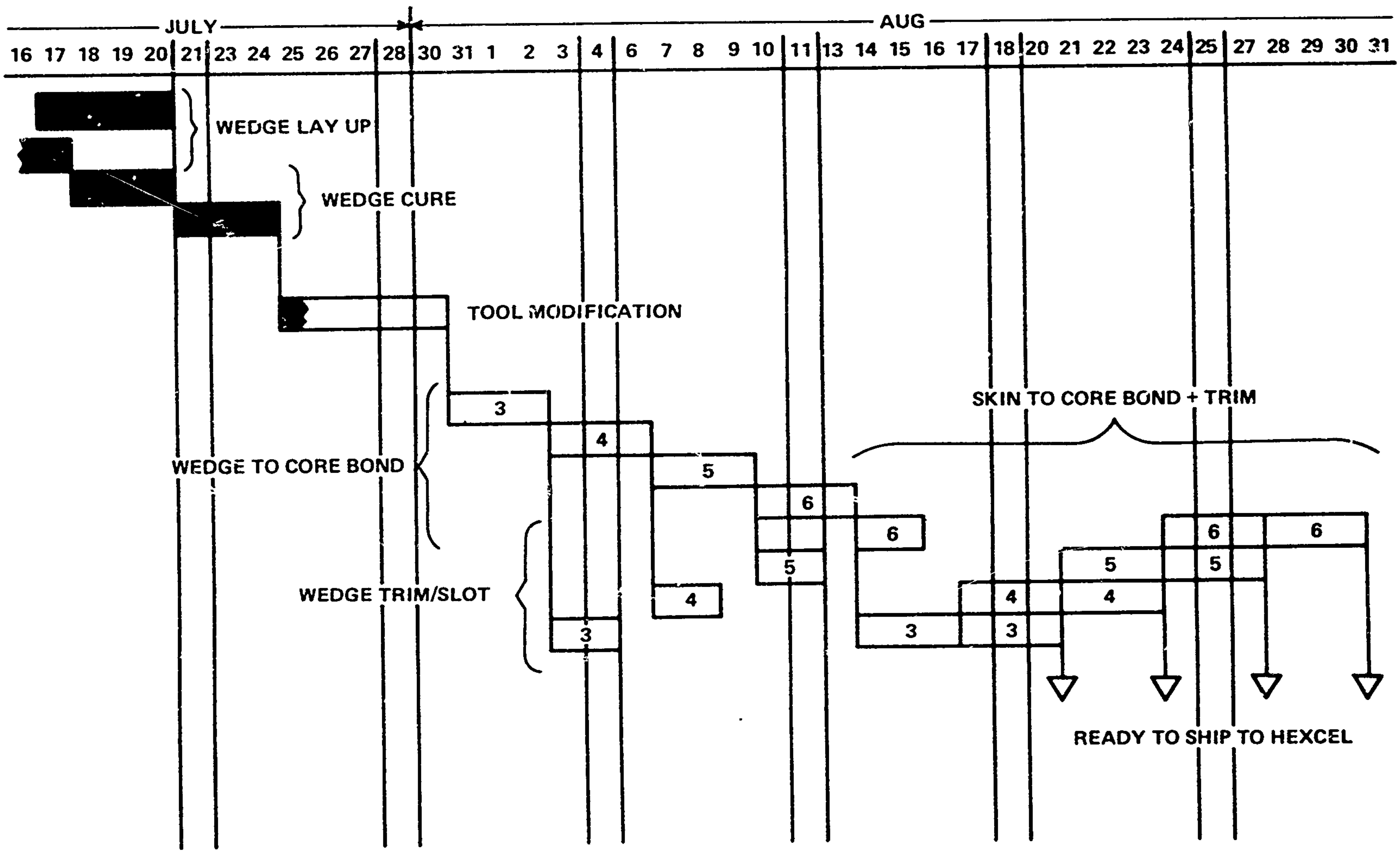


Figure 109. Fairing Fabrication Plan

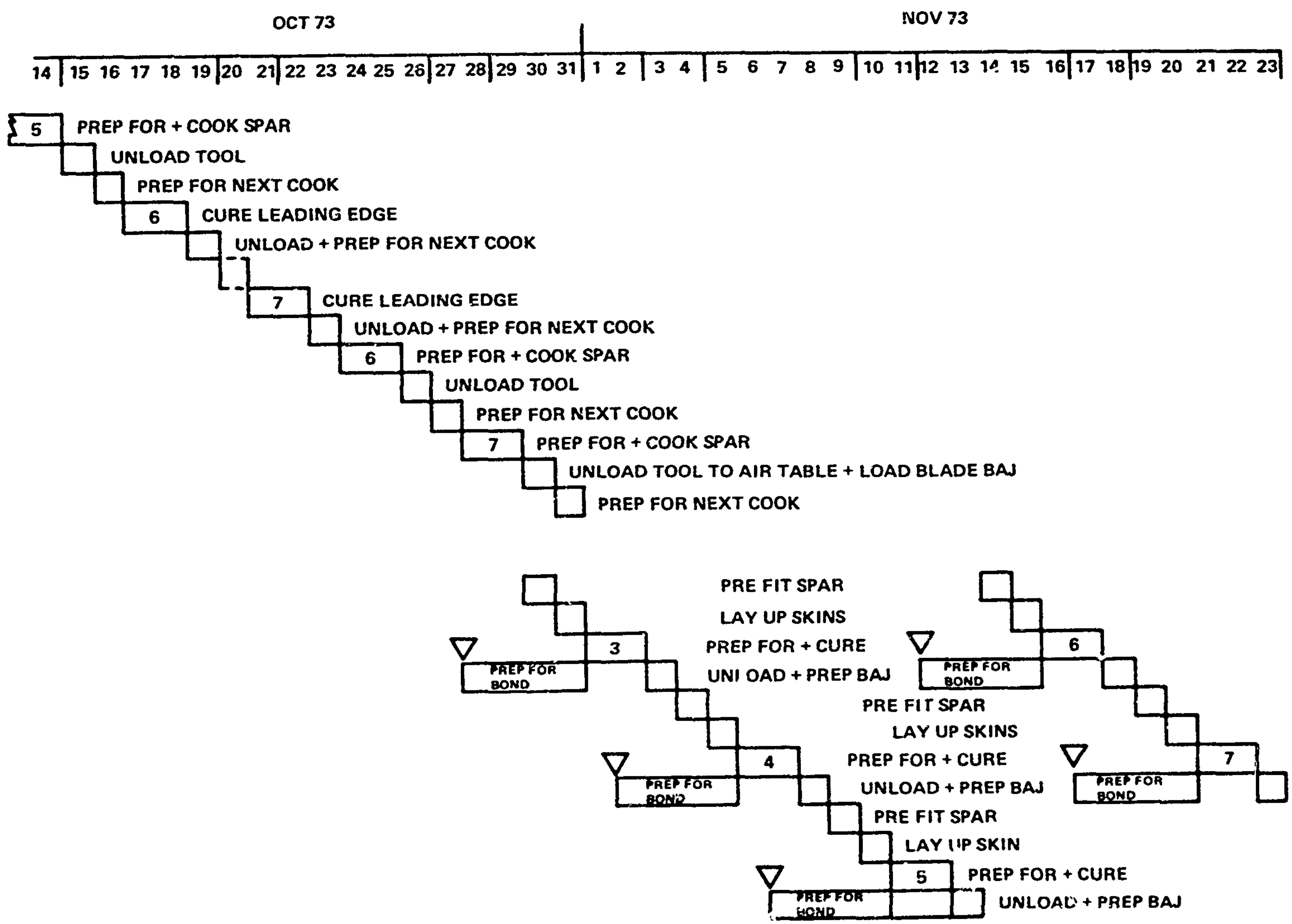


Figure 110. Spar and Blade Fabrication Plan

4.0 QUALITY ASSURANCE APPROACH

INTRODUCTION

The quality level of the HLH/ATC rotor blades was achieved through the control of processes used in blade development and by thorough inspections of details, subassemblies, and the finished product. Specimens were fabricated from the materials used in blade construction to check the validity of inspection techniques. These techniques, which were later used to inspect the rotor blade itself, gave a high degree of confidence in the quality of materials and processes.

The critical characteristics of each blade subassembly were inspected during fabrication, after assembly into the blade, and after blade component specimen tests. Final inspection of the assembled blades was performed to assure compliance with design requirements. In addition, four of the blades were subjected to ultrasonic, visual and dimensional checks following 33 hours of whirl test, as described in the paragraph titled Post Whirl Test Inspection.

QUALITY ASSURANCE CAPABILITY ANALYSIS

To assure the quality of the HLH/ATC rotor blade, it was necessary to inspect the critical characteristics of its components at appropriate stages of fabrication and assembly. Processes used in the fabrication and assembly were also important factors in the development of a quality end-item. Rigid control of these processes was required. A Quality Assurance Capability Analysis was made to ensure that component characteristics were measured and processes adequately controlled during development of the blade.

The basic element of the Capability Analysis was the Quality Assurance Flow Chart, Figure 111, which shows schematically the processes involved from the receipt of materials to final assembly of the blade. Each major block in the flow represents a step in the fabrication sequence at which controls and inspections are required. Figure 112 shows the details and physical relationships of the blade components.

Detailed lists of measurement characteristics and inspection procedures were evolved from an analysis of the fabrication flow and the design requirements. These lists comprised the Inspection Plan for the blade development program. Figure 113 is a typical example of a list of characteristics and procedures extracted from the HLH/ATC Rotor Blade Inspection Plan.

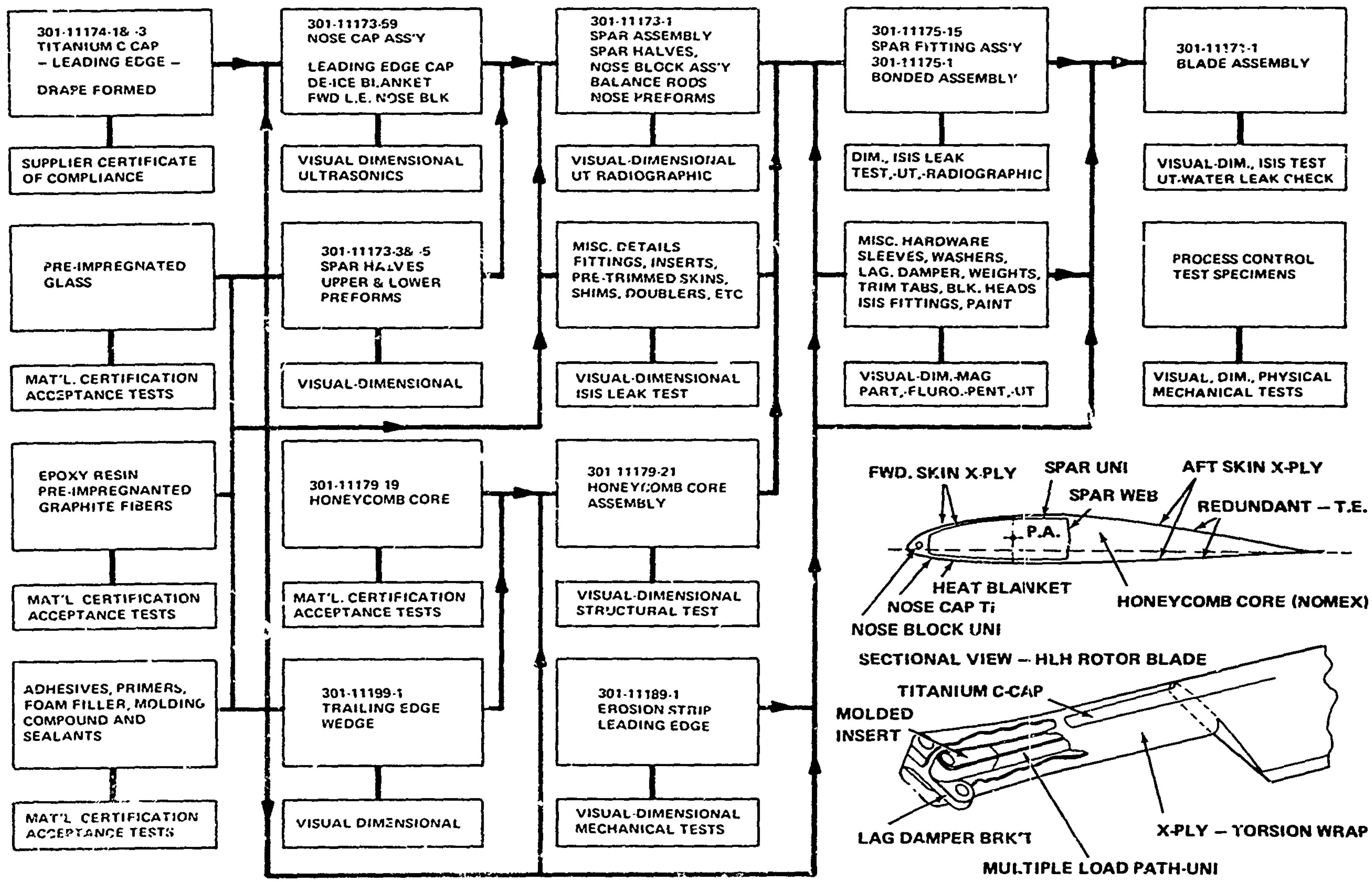


Figure 111. Quality Assurance Flow Chart

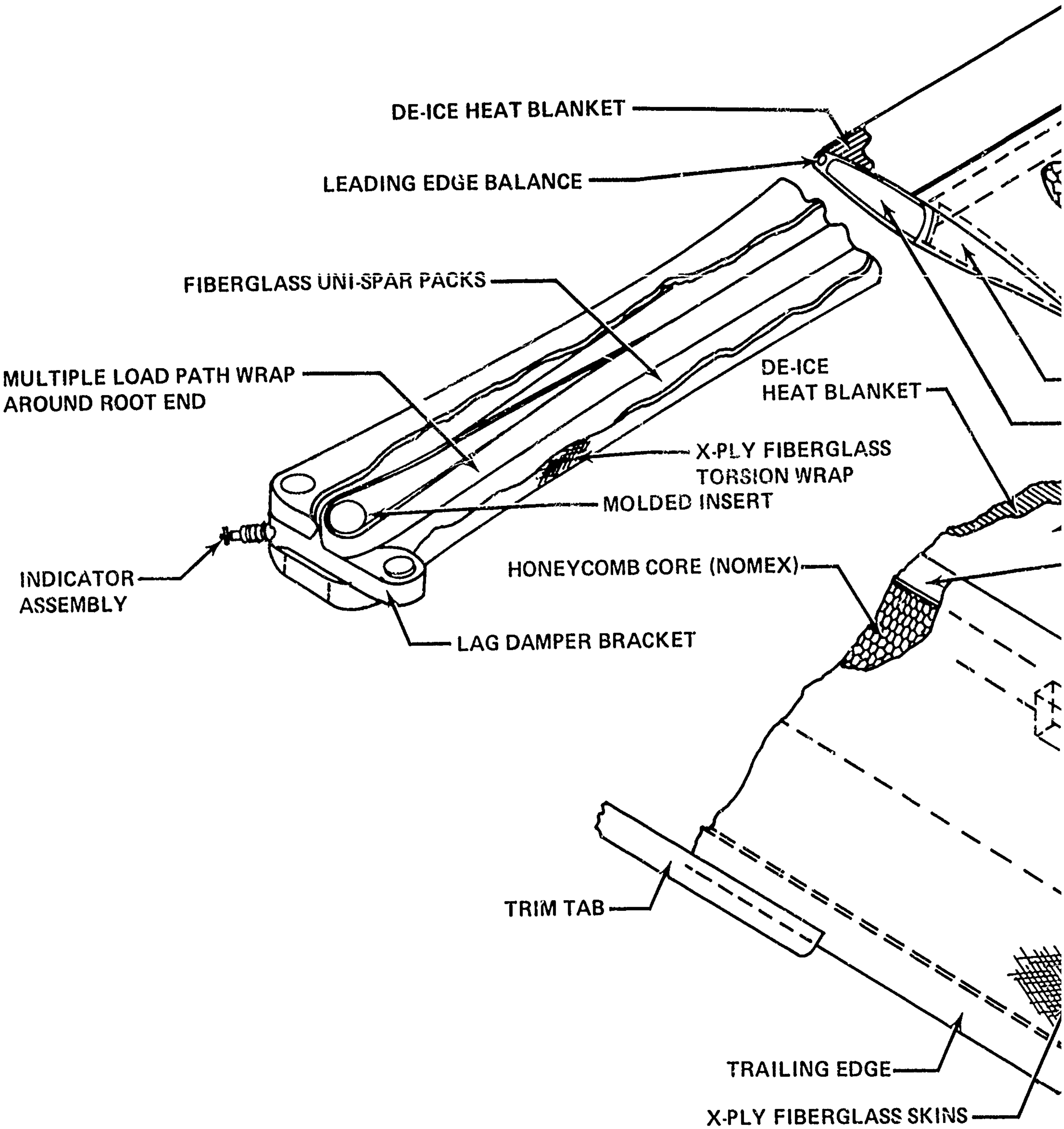
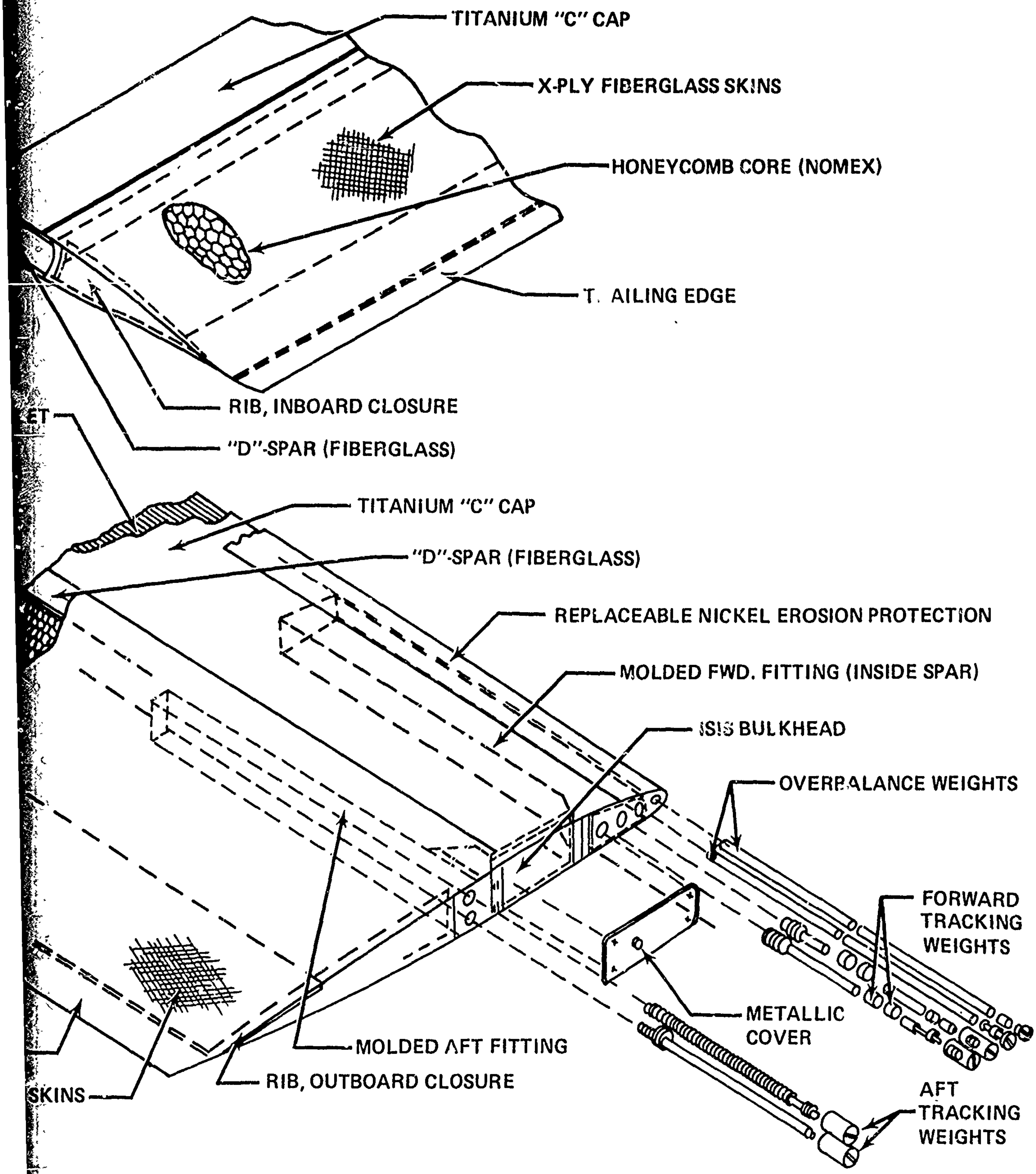


Figure 112. HLH Rotor Blade Components


TITANIUM "C" CAP
X-PLY FIBERGLASS SKINS
HONEYCOMB CORE (NOMEX)
T. AILING EDGE
RIB, INBOARD CLOSURE
"D"-SPAR (FIBERGLASS)
ET
TITANIUM "C" CAP
"D"-SPAR (FIBERGLASS)
REPLACEABLE NICKEL EROSION PROTECTION
MOLDED FWD. FITTING (INSIDE SPAR)
ISIS BULKHEAD
OVERBALANCE WEIGHTS
FORWARD TRACKING WEIGHTS
METALLIC COVER
MOLDED AFT FITTING
RIB, OUTBOARD CLOSURE
SKINS
AFT TRACKING WEIGHTS

301-11173-1
SPAR ASSEMBLY

NOTE: CLEAN, WHITE GLOVES SHALL BE WORN AT ALL TIMES WHILE HANDLING CLEANED AND/OR SURFACE TREATED PARTS

301-11173-3 SPAR HALF UPPER
-5 SPAR HALF LOWER
-37 WEB L/E ROOT END PER BMS8-164 CLASS A TYPE I
-39 WEB T/E ROOT END PER BMS8-164 CLASS A TYPE I
-59 NOSE BLOCK ASSEMBLY
301-11178 BALANCE RODS
301-11177-5 PREFORM, HEEL
EA-9628 ADHESIVE

301-11178 - BALANCE RODS SHALL BE WRAPPED WITH ONE (1) LAYER OF EA 9628 ADHESIVE BEFORE INSTALLATION

CHARACTERISTIC	INSPECTION PROCEDURE
GENERAL	
LAY-UP REQUIREMENTS TEMPERATURE, HUMIDITY & CONTAMINATION CONTROL	WITNESS PER D301-10154-1
CERTIFICATION OF PERSONNEL	WITNESS PER O.P. 800.33
MOLD CONDITION	VISUAL PER D301-10154-1 AND COMPLIANCE TO TOOL ASSEMBLY PROCEDURE
MOLD RELEASE	VISUAL PER D301-10154-1
WEIGHT OF TOOLS (MANDREL CAULS, ETC.)	WITNESS AND RECORD
WEIGHT OF COMPONENTS AND PRE-FORMS	WITNESS AND RECORD
PROPER POSITIONING OF TI CAP ASSY IN VACUUM SPREADING FIXTURE	VISUAL PER D301-10154-1
REMOVAL OF PEEL PLIES FROM NOSE BLOCK, SPACER, AND CURED AF-30 BONDING AREAS	WITNESS PER D301-10154-1
INSTALLATION OF NOSE BALANCE BARS	WITNESS LOCATION AS DETERMINED BY WEIGHT REQUIREMENTS PER D301-10155-1 REF. C
APPLICATION OF ADHESIVE	VISUAL AND DIMENSIONAL CHECK FOR BUTT JOINTS, GAPS AND OVER-LAP AREAS PER REQUIREMENTS OF D301-10154-1
PROPER POSITIONING OF -5 HALF OF NOSE BLOCK	VISUAL PER DWG AND D301-10154-1

Figure 113. Typical Quality Capability Analysis Inspection Procedure

301-11173-1 (Continued)

CHARACTERISTIC	INSPECTION PROCEDURE
PROPER POSITIONING OF -37 WEB L/E ROOT END, AND -39 WEB T/E ROOT END TO PREFORM ASSEMBLIES, 301-11173-3 AND -5	VISUAL PER DWG. AND D301-10154-1
PROPER POSITIONING OF OUTER TORSION WRAP	VISUAL PER DWG
APPLICATION OF PEEL PLY	VISUAL PER D301-10154-1
PROPER INSTALLATION OF TI CAP ASSY TO PREFORM ASSEMBLIES, 301-11173-3 AND -5	VISUAL AND DIMENSIONAL PER DWG
WEIGHT	WITNESS AND RECORD
PROPER POSITIONING AND ALIGNMENT OF ASSY TO BOTTOM HALF OF BAJ	VISUAL AND DIMENSIONAL PER DWG
PROPER ALIGNMENT AND CLOSING OF TOP HALF OF BAJ	VISUAL CHECK
PROPER ALIGNMENT OF BAJ ON RESTRAINING TOOL	VISUAL CHECK
TEMPERATURE, PRESSURE AND CURE CYCLE	WITNESS AND RECORD PER D301-10154-1
DIMENSIONS (TRIM SIZE, CONTOUR TWIST AND CHORDWISE BOW)	GEN. Q.C. PRACTICE PER DWG AND MDI DATA PER D301-10136-1 - BLADE GEOMETRY PER DWG 301-11172
TI CAP TO GLASS BOND, ACCEPTANCE VALUES (PROCESS CONTROL PANEL)	VERIFY PER D301-10154-1 REQUIREMENTS
HARDNESS (GLASS SURFACE ONLY)	HARDNESS TESTER (BARCOL IMPRESSOR) PER D301-10154-1
DELAMINATION AND VOIDS (TIP END ONLY)	ULTRASONICS PER D301-10154-1
INTERNAL VOIDS, ALIGNMENT OF FIBERS AND LOCATION OF DETAILS	RADIOGRAPHIC PER D301-10154-1 AND DWG
UNIT SERIAL NUMBER	WITNESS AND RECORD
WEIGHT	WEIGH AND RECORD
PROPER PACKAGING	WITNESS PER D301-10154-1
PROPER STORAGE	WITNESS PER D301-10154-1

Figure 113. Typical Quality Capability Analysis Inspection Procedure (Continued)

The most important contribution of the Capability Analysis was that it ensured design inspectability. The analysis was made concurrently with the design of the blade, enabling coordination between HLH Quality Engineering and HLH Design Engineering. The joint effort resulted in a design which permitted adequate inspection throughout the fabrication and assembly of the blade.

SPECIMEN EVALUATION

Root End Specimen Inspection

Two rotor blade root end specimens were made to establish fabrication methods and to provide test specimens for the development program. The required quality level of the root end specimens was maintained by monitoring the types and conditions of materials, and by accurately controlling temperature, pressure, and cure cycle during material lay-up. The completed specimens were dimensionally inspected to make certain that the cross-sectional contour and the spanwise twist met the requirements of the Master Dimension Identifier (MDI); i.e., to verify that the Y-Y and Z-Z coordinates of the contour were as specified by the MDI at several blade stations. Figure 114 shows the MDI coordinate system used in making the dimensional measurements.

Nondestructive Inspection (NDI)

Two nondestructive test techniques were validated through laboratory investigations involving the root end specimens. The capabilities of penetrating radiation (X ray) and ultrasonic inspection to detect discontinuities in the root end were investigated. It was determined that both methods yielded data pertinent to the structural integrity of blade components. Both inspection methods were subsequently used to provide detailed inspection of the blade components. Investigation of the two methods was made as described in the following paragraphs.

Penetrating Radiation (X-Ray) Evaluation

Various X-ray techniques utilizing existing equipment were used to assure the capability of achieving the inspection requirements. The work was conducted on the SK301-10168 HLH root end test specimens, before and after the fatigue test program. Special emphasis was placed on developing techniques for inspecting the following areas: the blade attachment holes at Station 66; the fiberglass spar straps, starting at Station 66 through Station 94; and the foam filler preforms bonded between the fiberglass spar straps from Station 66 through Station 94.

To obtain the maximum amount of information in these areas, a number of single wall radiographic exposures were obtained by placing the film in the internal cavity of the specimen. Since the configuration of the full length spar did not allow easy access to the internal cavity, double wall exposures were obtained to compare their sensitivity to those of the single-wall exposures. Comparison of the double wall and single wall results revealed that either method is capable of detecting the presence of fiber distortion and delaminations in the spar straps, as well as cracks in the foam filler preforms. Figures 115 and 116 illustrate typical alignments of the X-ray beam, root end specimen and film location.

In addition to the fiber conditions detected in these areas, the radiographic inspection of the root end test specimens revealed several material anomalies. For example, areas of greater material density were noted around Station 66, Station 95, and Station 135. The source of these dense inclusions was not determined since a destructive sectioning of the root end specimens was not performed. Also, station areas 75 through 140 showed random evidence of distorted and broken lead silicate strand material.

It was concluded from this study that penetrating radiation (X-ray) techniques are capable of determining variations in the material lay-ups. Specifically, delaminations, distorted fibers, broken lead silicate strands, material density changes and cracked foam preforms can be detected in the root end area of the blade.

Ultrasonic Evaluation

The purpose of the ultrasonic evaluation was to develop techniques for adapting existing equipment for the inspection of the HLH blade. Ultrasonic evaluation of the two root end specimens was performed using both low frequency (30 kHz) and normal frequency (2.25 MHz) ultrasonic instrumentation.

A low frequency Zetec "Sondicator", employing a dual (pitch/catch) air-coupled contact probe, was used to determine the quality level of the cross-ply outer torsion wrap to the uni-packs. Measurable surface defects were used as references for calibrating the Sondicator responses. On the basis of the responses from these areas, the entire outside surface of each specimen was inspected. All specimen areas indicating an ultrasonic response equal to or greater than those of the referenced areas were outlined on the root end specimen and are plotted in Figures 117 and 118. Ultrasonic test data taken after

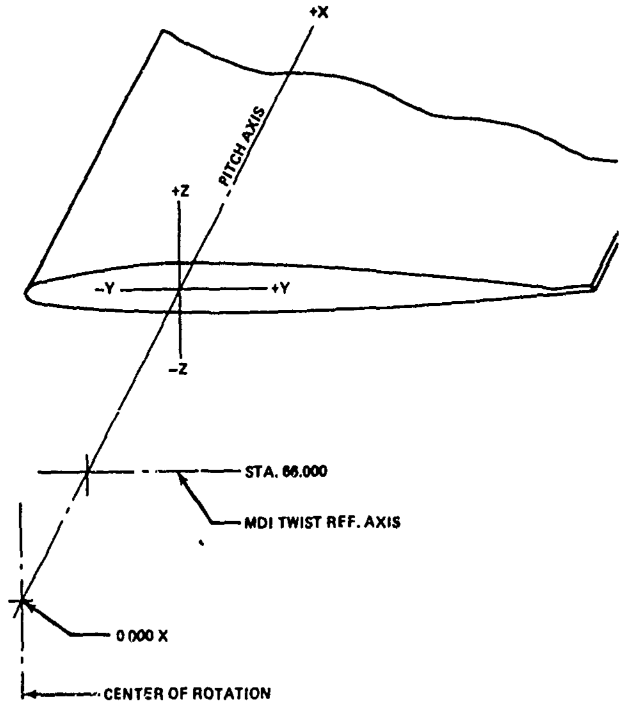


Figure 114. MDI Coordinate System and Axes Orientation

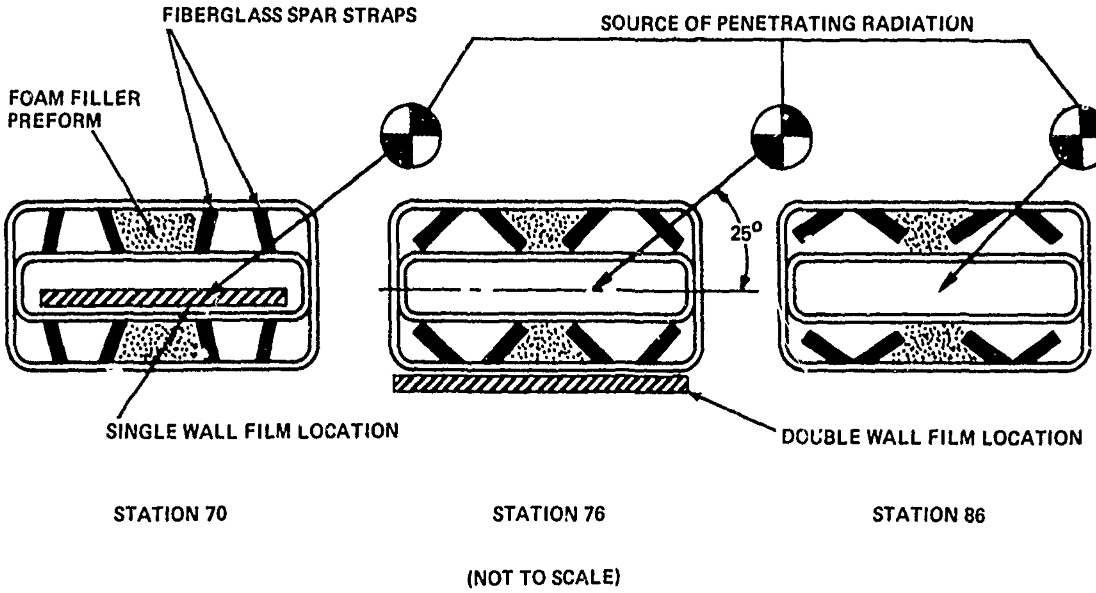


Figure 115. Typical Relationship of Fiberglass Spar Straps to Penetrating Radiation

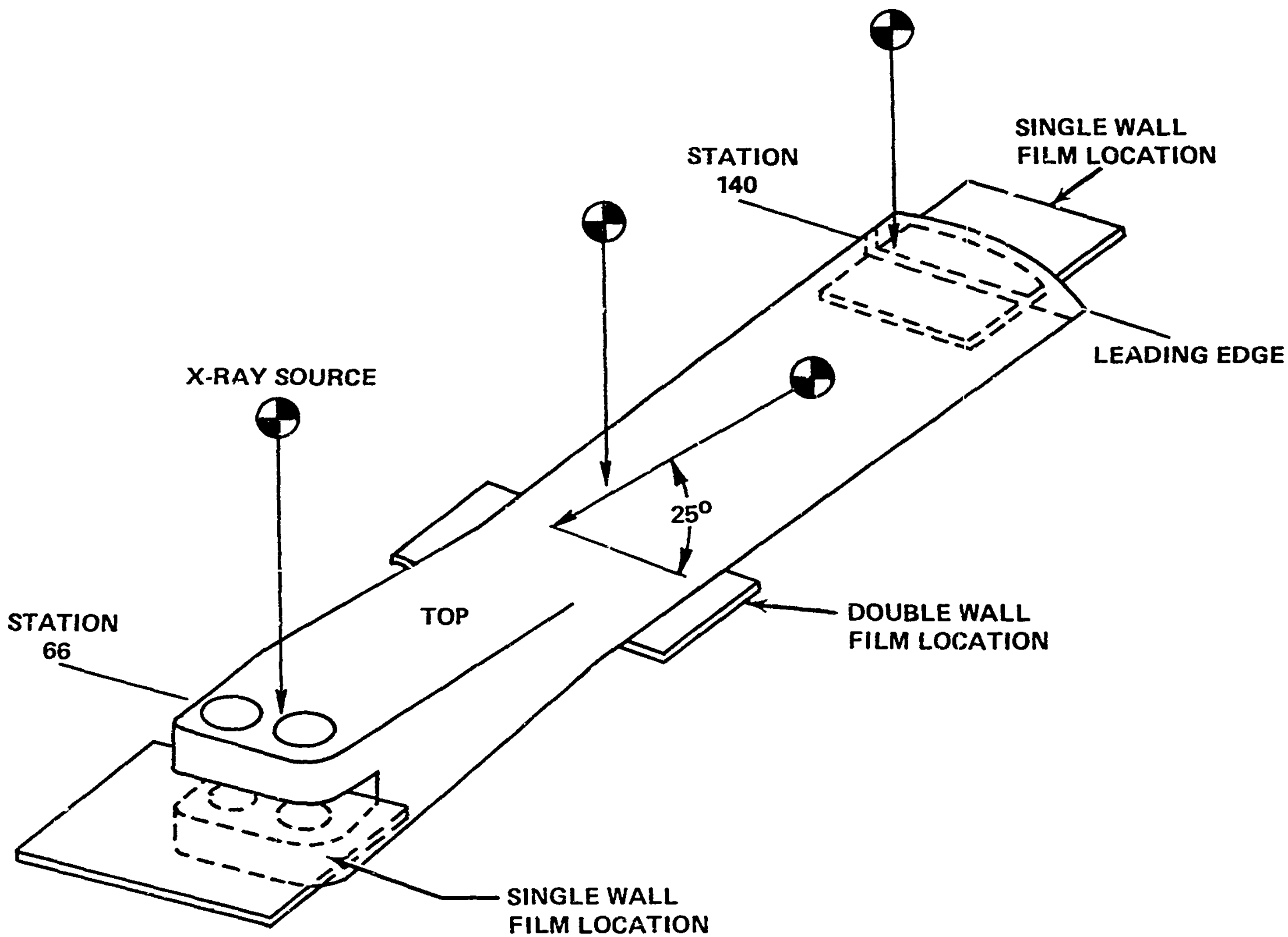


Figure 116. Typical Alignments of X-Ray Beam to Root End Specimen

the structural test program are also shown i Figures 117 and 118. Ultrasonic test data taken after the structural test program are also shown in Figures 117 and 118.

A normal frequency ultrasonic evaluation was performed at a frequency of 1 MHz using an Automation Industries Reflectoscope UM-721, with a 3/4-inch-diameter contact search unit and a liquid couplant (glycerine). The evaluation was limited to the area between Stations 103 and 140 due to the configuration of the specimen. No ultrasonic responses were received in this area.

An evaluation of other accessible areas of the spar specimen surface was also performed, using a modified immersion, through-transmission method. However, due to the fixturing required to manipulate the search unit and contour problems, discrepant areas could not be defined. (This through-transmission evaluation required that the root end specimen be filled with water and the search unit be manipulated manually.)

BLADE INSPECTION

Raw Materials

General Requirements

Procured materials were source-inspected in accordance with Boeing Vertol purchase requirements. Supplier inspection data was submitted with the procured material. In addition to the source inspections, verification tests were performed by the Quality Control Materials and Processes Laboratory when required. To avoid the use of materials with degraded quality due to age and/or use, all materials were marked to indicate the remaining useful life. Data was recorded and maintained in accordance with Boeing Vertol procedures.

Additional Requirements for Ti6Al-4V Sheet

Ti6Al-4V continuously rolled sheet was inspected to BMS 7-197B and additional drawing requirements. Source inspections were made to verify that the material met the drawing requirements in the following areas: chemistry, mechanical properties, heat treatment, surface finish thickness and flatness. Problems were encountered specifically in the surface finish and thickness requirements. These problems were resolved.

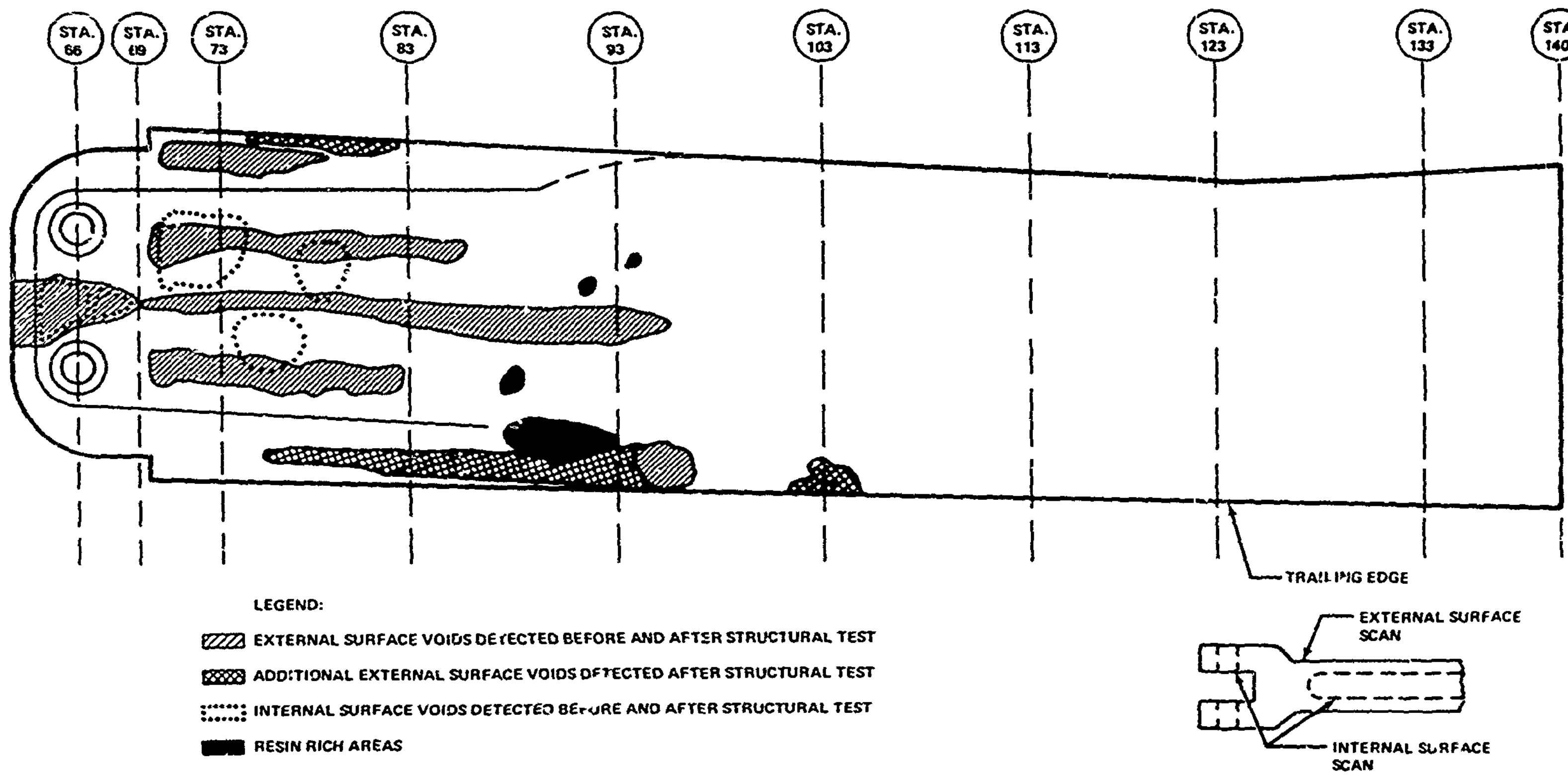


Figure 117. HLH/ATC Root End Test Specimen No. 1 (Upper Surface)

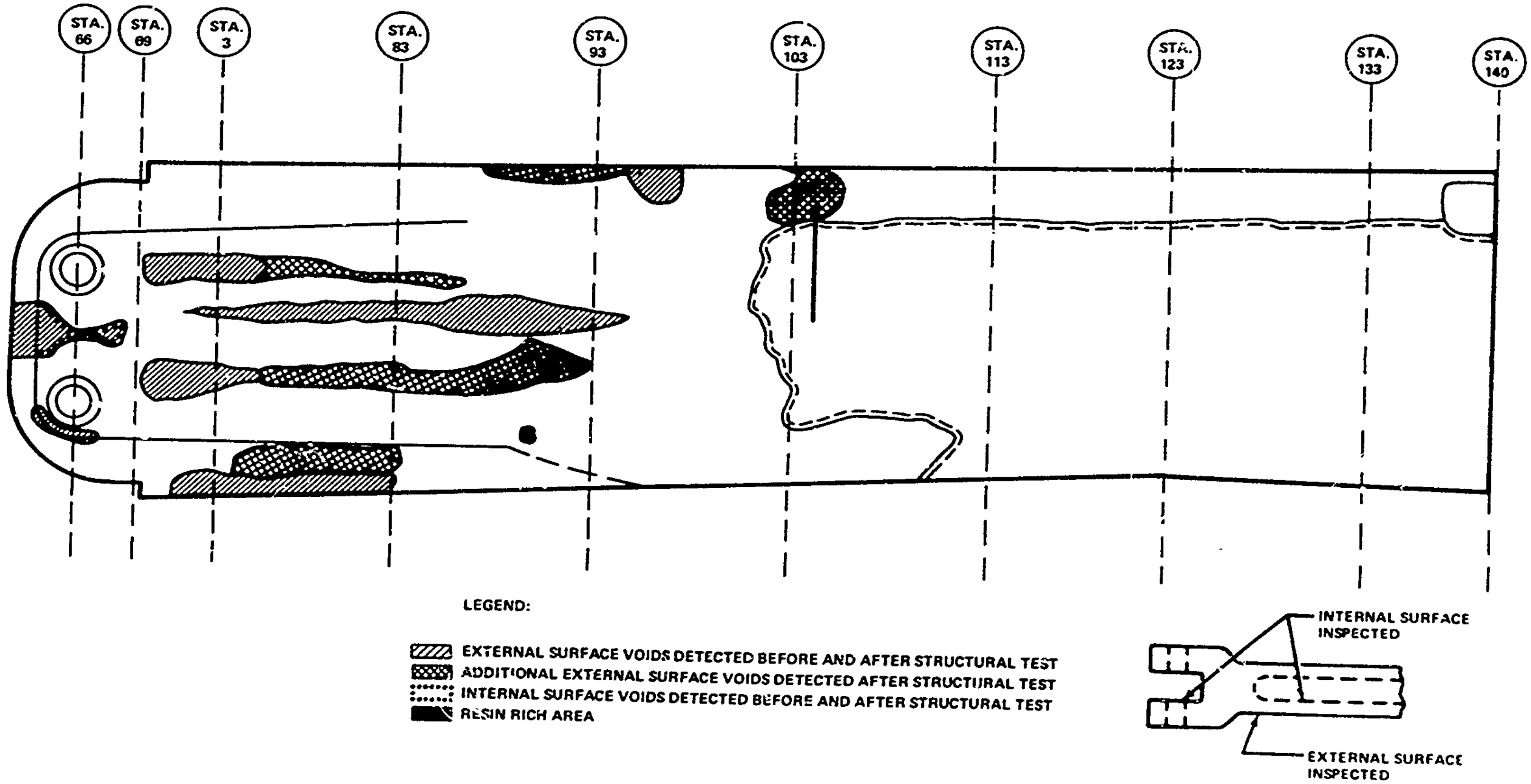


Figure 118. HLH/ATC Root End Test Specimen No. 1 (Lower Surface)

Inspection Controls

Titanium 'C' Cap

The forming and processing of the titanium 'C' cap were performed at the Boeing Wichita Division. The forming operations were controlled in the following manner:

- o Digital measurement of thickness was made before and after each etching operation.
- o Hydrogen analysis was performed during each etching operation.
- o Time and temperature were controlled during the forming operations.
- o Bell peel specimens were made to verify the cleaning cycle prior to bonding.
- o Contours were checked at control stations by use of offset templates and also by a comparison of contour casts with mylar printouts.

Figure 119 shows the titanium 'C' cap on the check fixture.

'D' Spar

Standard Quality Control inspection procedures and non-destructive inspection techniques were used for the objective evaluation of the quality and uniformity of the 'D' spar.

Process Control. The bond strength between the titanium 'C' cap and fiberglass 'D' spar was determined by performing a lap shear test using specimens taken from the Quality Assurance process control panel, which was an extension (outboard of Station 552) of the 'D' spar (Figure 120). The lap shear test was accomplished by applying a load along an imaginary straight line passing through the center of the bonded area and through the points of suspension of the specimen. Lap shear strength was obtained by dividing the applied load by the area of the overlap joint measured to the nearest 0.01 square inch. The area and the maximum stress in lbs/sq. in. of actual bond area were recorded.

Inspection Controls

Titanium 'C' Cap

The forming and processing of the titanium 'C' cap were performed at the Boeing Wichita Division. The forming operations were controlled in the following manner:

- o Digital measurement of thickness was made before and after each etching operation.
- o Hydrogen analysis was performed during each etching operation.
- o Time and temperature were controlled during the forming operations.
- o Bell peel specimens were made to verify the cleaning cycle prior to bonding.
- o Contours were checked at control stations by use of offset templates and also by a comparison of contour casts with mylar printouts.

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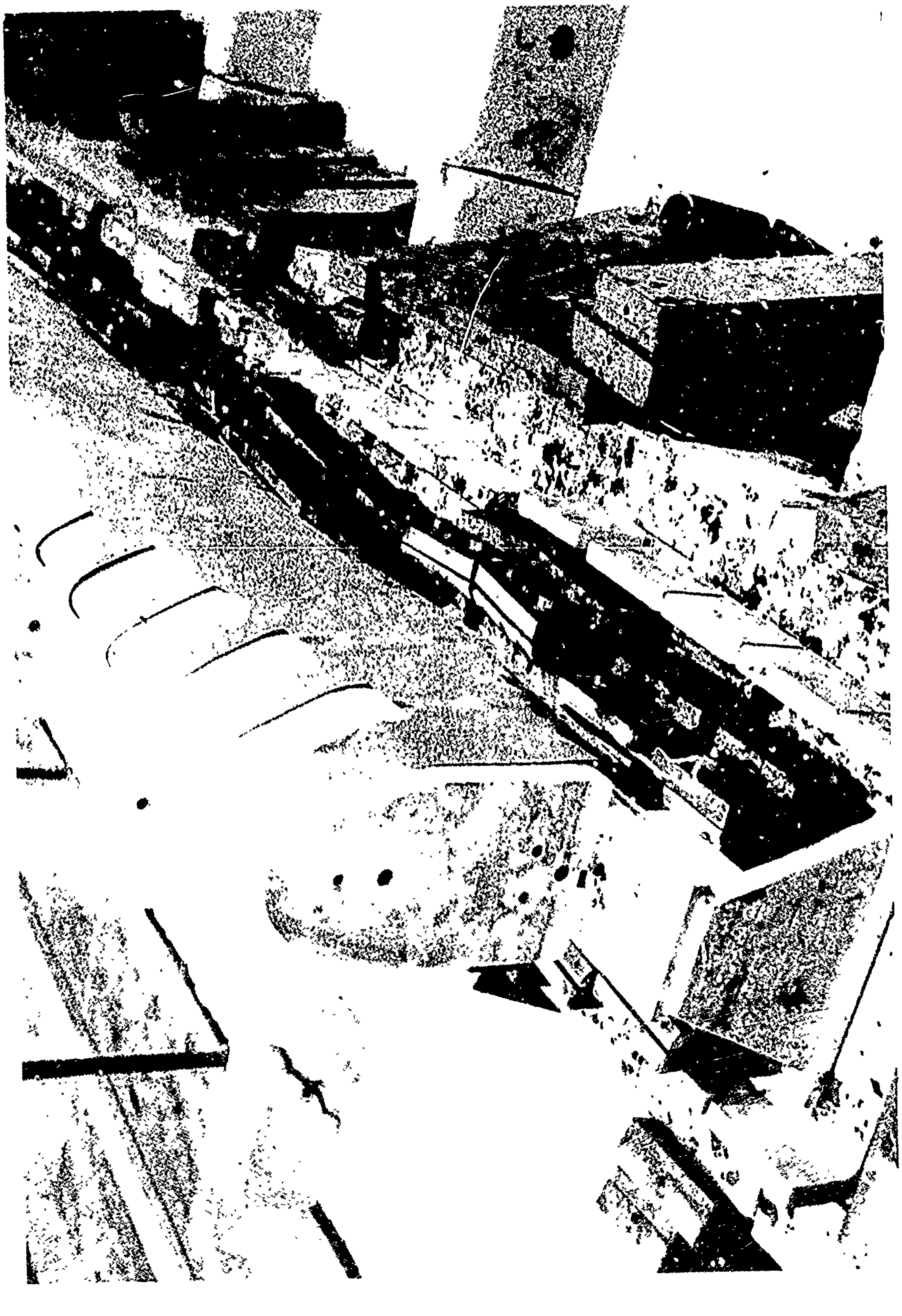


Figure 119. Titanium "C" Cap on Check Fixture

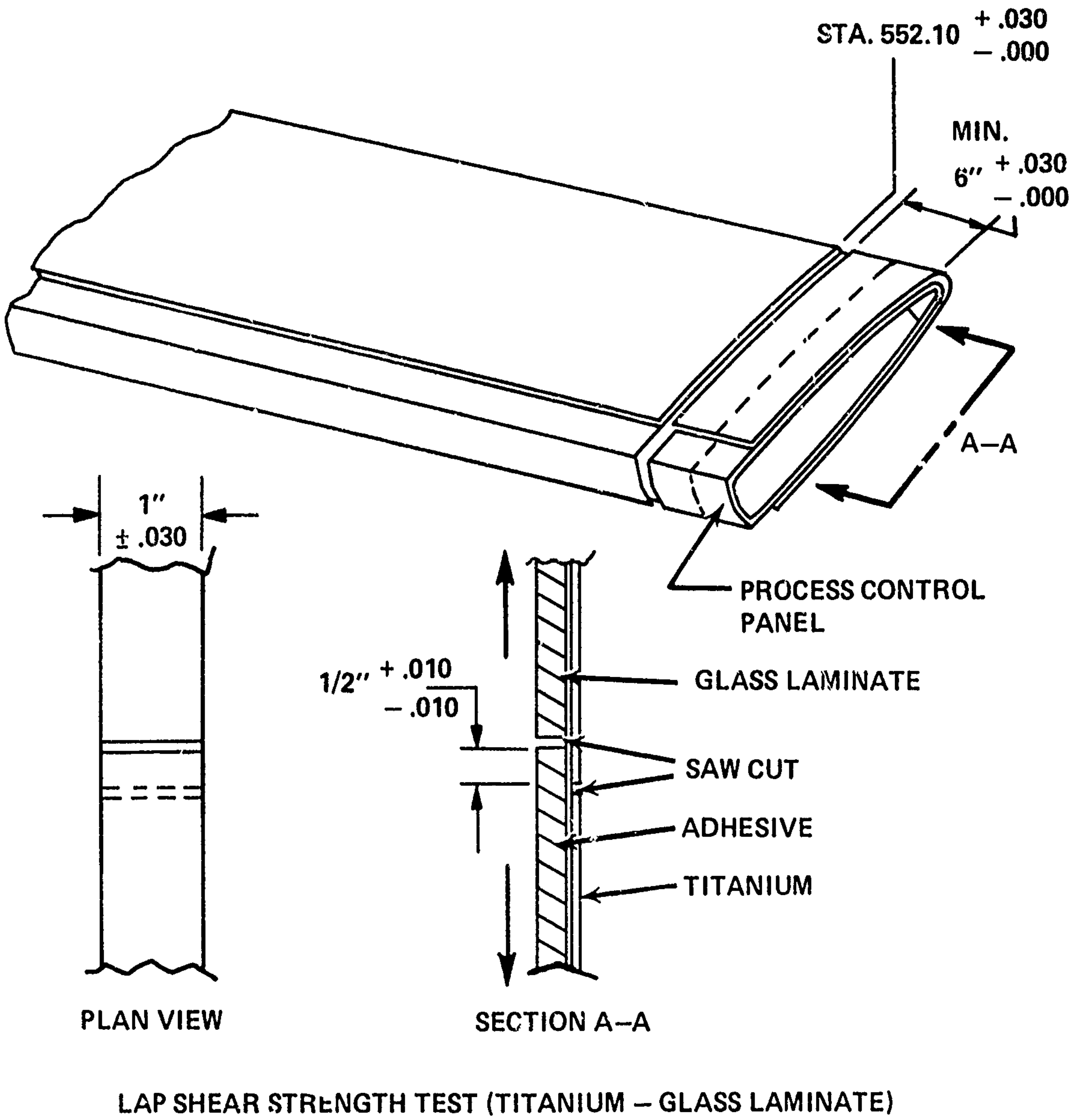


Figure 120. Process Control Panel

Major Dimensional Inspections. All blade components and bonded assemblies were dimensionally inspected during blade fabrication. This included major and minor characteristics as defined in the Quality Capability Analysis and typical components as shown in the HLH Spar Assembly diagram (Figure 121) and in the HLH Rotor Blade Fabrication Sequence diagram (Figure 122).

Major emphasis was placed on the 'D' spar. The blade Master Dimension Identifier (MDI) describes the outer contour of the 'D' spar, which in turn is machined into a two-part mold (spar bonding assembly jig) to be used to form the 'D' spar. The same MDI data used in making the mold contour serves as the basis for dimensional measurements of the spar itself. Figure 123 is a simplified sketch illustrating the reference lines and coordinate systems used to obtain raw data. The spars were positioned in a fixture and aligned optically relative to the pitch axis and root end control station.

Chordwise bow (measured in the Y-Y direction) refers to the amount of bow in the 'D' spar when compared to the design MDI data. Similarly, flapwise bow is measured in the Z-Z direction. The raw data is recorded at various stations. The data for spar number 5 is shown in Figure 124. This data is converted into flapwise and chordwise bow measurements, and summarized for spars 1 through 7 in Figure 125. The first number in parentheses under each column heading is the design drawing tolerance as defined by HLH Engineering. It should be mentioned that these measurements represent worst-case conditions; in general, smaller errors were predominant over large areas of the spars. The errors represent the repeatability and types of tolerances that can be expected using a match-molded fabrication concept. Figure 125 also summarizes the twist measurements and the ultrasonic and X-ray inspections for the 'D' spars.

A dimensional comparison of the four fiberglass/titanium D-spars used in the whirl test blades is shown in Figure 126. The graph shows deviations from the MDI requirements over the full span for each blade. The difference in the scale factors for the two axes of the graph should be noted; the horizontal axis represents the 486-inch blade span, while the vertical axis gives dimensional deviations in thousandths of an inch. The graph illustrates the general trend of dimensional errors over the entire span and indicates that these errors fall within a narrow band over the 40.5-foot blade span. Grouping of the Y-Y and Z-Z measurements at the various stations indicates good process repeatability from blade to blade.

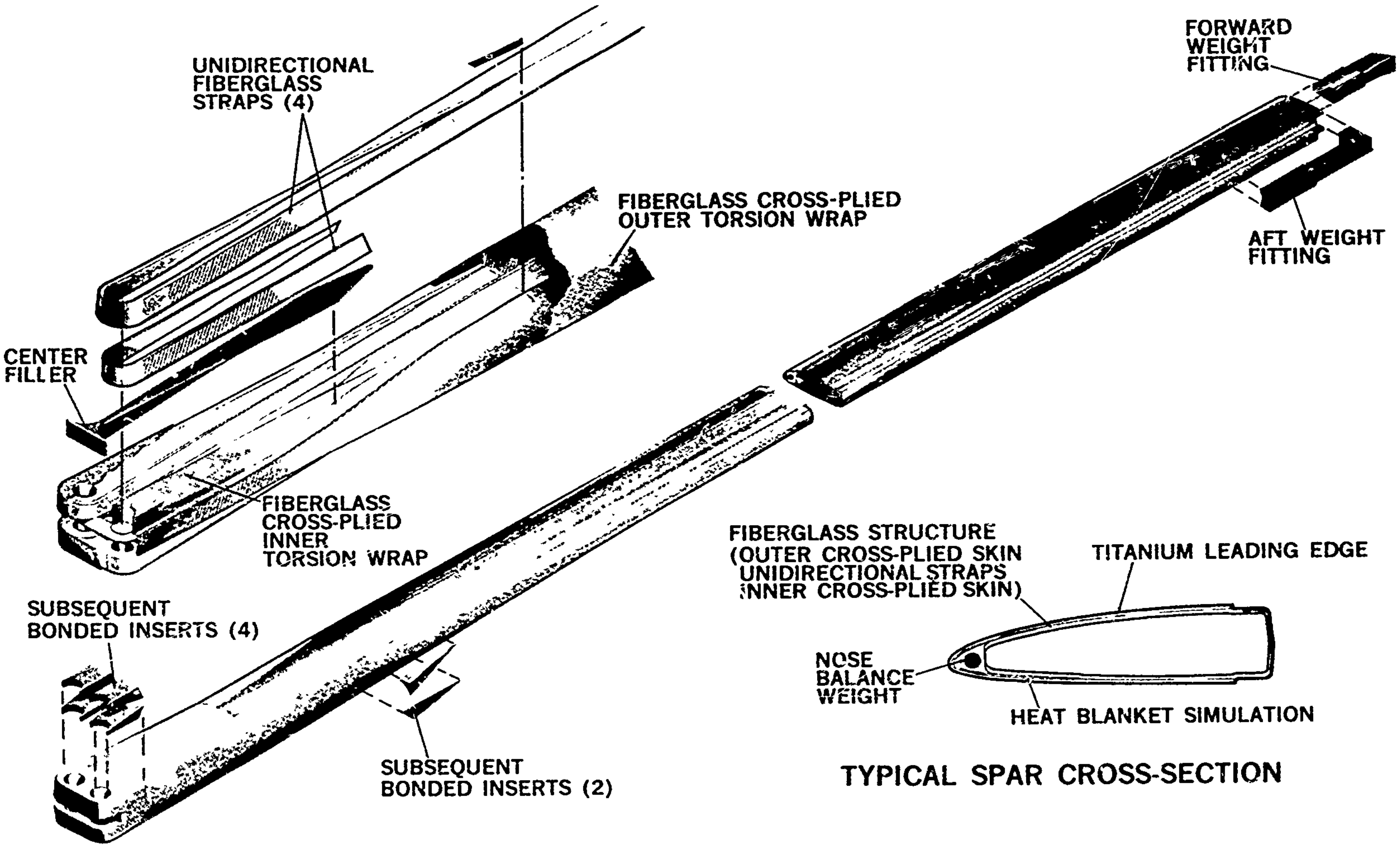


Figure 121. HLH Spar Assembly

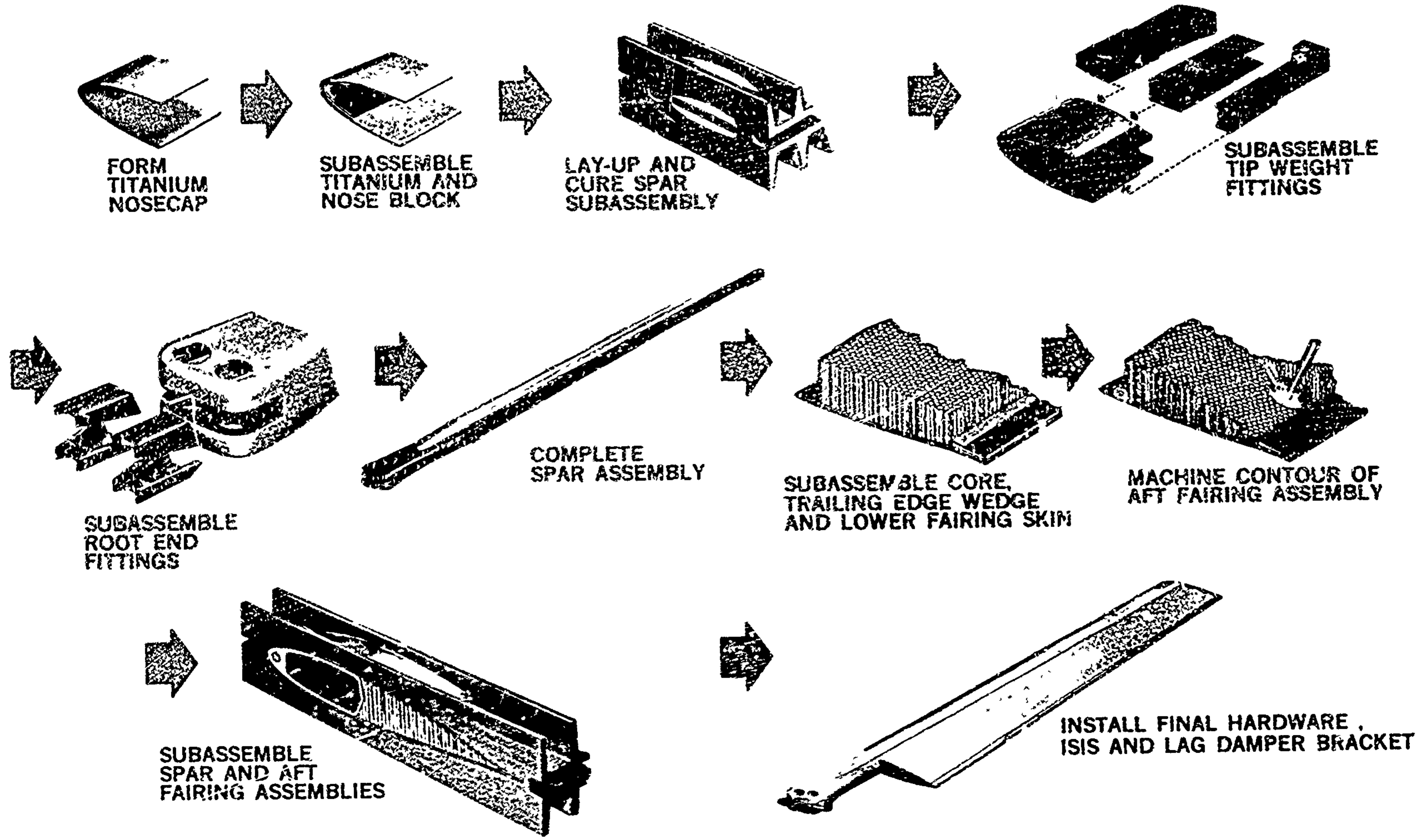


Figure 122. HLH Rotor Blade Fabrication Sequence

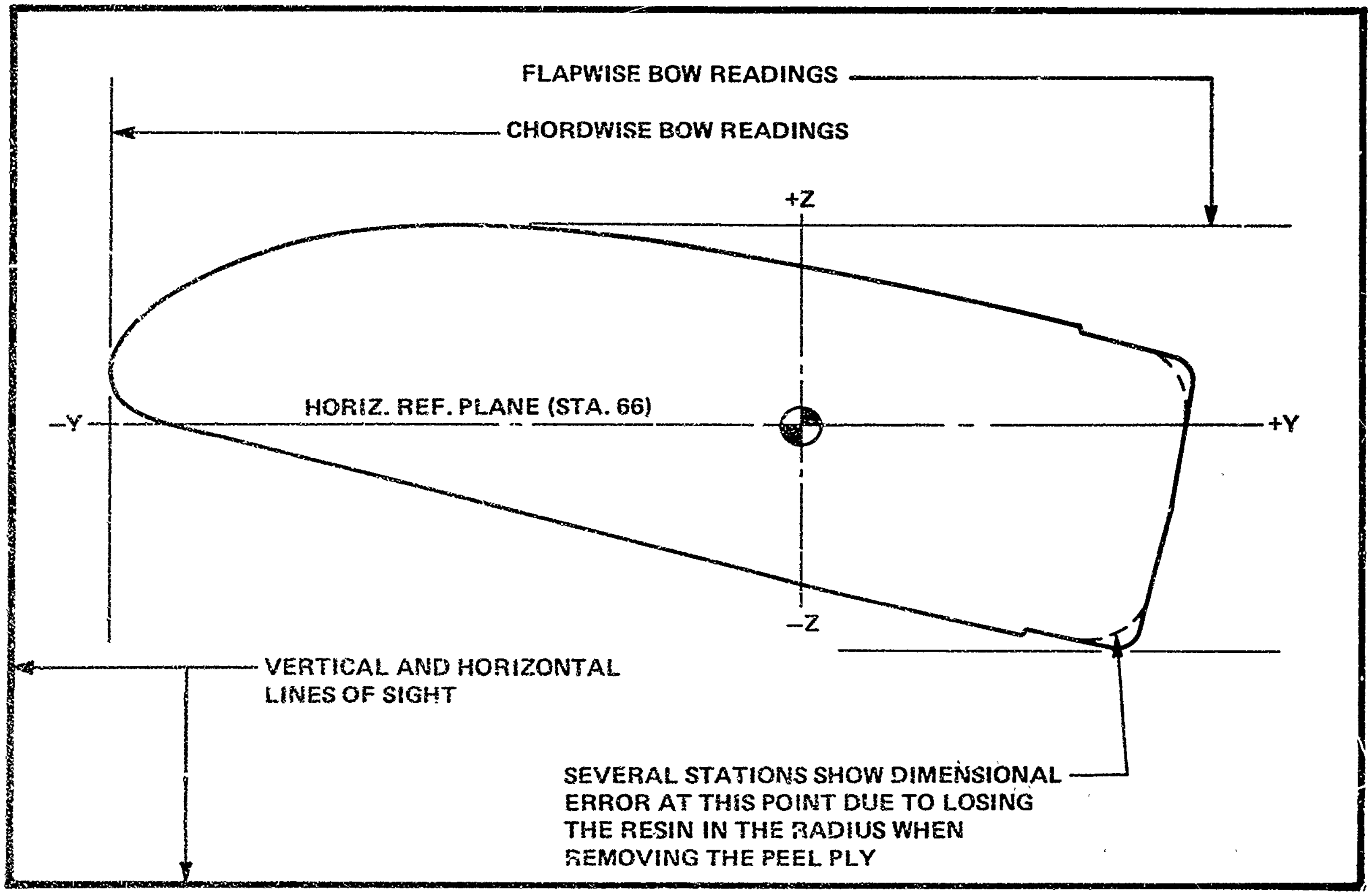


Figure 123. Spar Data Reference Lines and Coordinate Systems

SPAR NUMBER 5

1. Record dimensions at stations listed

		MDI DATA		ACTUAL	ERROR
STA 66	Z-Z	8.700	Z-Z	8.750	+.050
	Y-Y	13.500	Y-Y	13.441	-.051
STA 138	Z-Z	7.951	Z-Z	7.935	-.016
	Y-Y	16.911	Y-Y	16.877	-.034
STA 220.8	Z-Z	6.469	Z-Z	6.440	-.029
	Y-Y	15.592	Y-Y	15.530	-.062
STA 275	Z-Z	5.591	Z-Z	5.573	-.018
	Y-Y	15.634	Y-Y	15.503	-.131
STA 371	Z-Z	5.341	Z-Z	5.319	-.022
	Y-Y	15.603	Y-Y	15.490	-.113
STA 414	Z-Z	5.242	Z-Z	5.225	-.017
	Y-Y	15.581	Y-Y	15.445	-.136
STA 469.2	Z-Z	5.111	Z-Z	5.073	-.038
	Y-Y	15.548	Y-Y	15.416	-.132
STA 552	Z-Z	3.545	Z-Z	3.541	-.004
	Y-Y	15.487	Y-Y	15.392	-.095

Remarks:

All readings above were taken with spar lying vertical with leading edge down in ultrasonic machine saddles, reference plane at Sta. 66 in vertical position.

Figure 124. Spar No. 5 Raw Data

INSPECTION SUMMARY - SPARS

SPAR NO.	CHORDWISE BOW CRITERIA (1.0"MAX)	FLAPWISE BOW (.035"/FT)	SPANWISE TWIST ± 20'0" LIMIT	ULTRASONIC	X-RAY
1	0.168"	0.026" /FT	± 0°16'2"	All D-spars showed no void indications (Ti-cap-to-spar) over almost 100% of surface area.	One mislocated Leading Edge Balance Weight
2	0.301"	0.020" /FT	± 0°9'46"		No mislocated parts
3	0.294"	0.016" /FT	∓ 0°3'27"		No mislocated parts
4	0.457"	0.028" /FT	∓ 0°8'8"		No mislocated parts
5	0.340"	0.016" /FT	∓ 0°5'54"		No mislocated parts
6	0.383"	0.015" /FT	∓ 0°10'3"	Each D-spar showed several small, isolated void indications, but no recurring pattern from spar-to-spar.	No mislocated parts
7	0.352"	0.052" /FT	∓ 0° 8'9"		Two weights away from Leading Edge at Sta. 323 (0.100") Sta. 250 (0.050")

Figure 125. Inspection Summary for Spar Nos. 1 Through 7

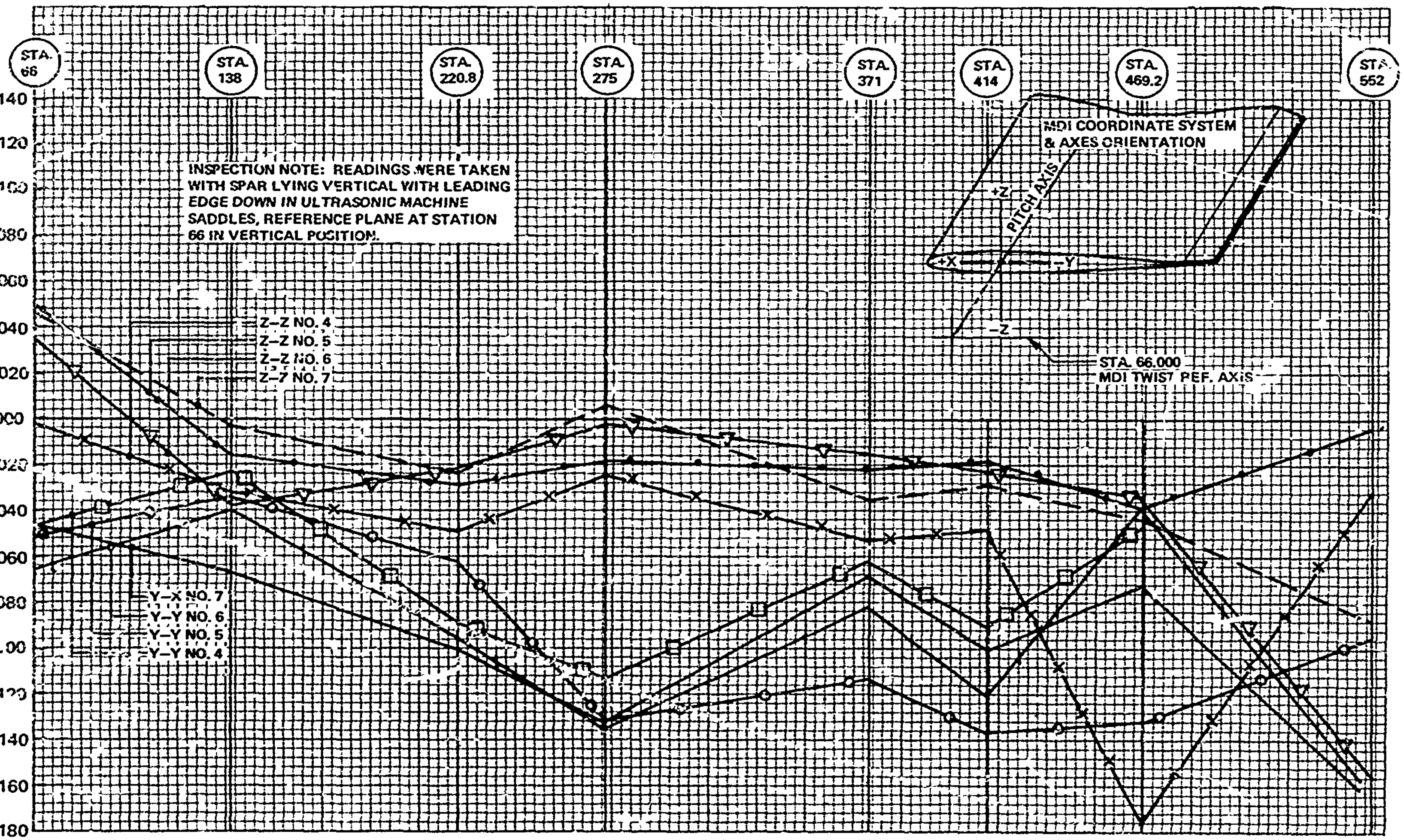


Figure 126. HLH/ATC Spar Dimensional Inspection Error Comparison Plot

The 'D' spar contour was measured using micrometer and/or plaster casts; however, such measurements were obtained only for additional information or confirmation during the assembly operations since formed 'D' spars were checked for contour conformity in the bonding assembly jig itself.

Cross-sectional 'D' spar thickness measurements were obtained at several stations using an ultrasonic digital thickness gauge. The measurements correlated well with actual thickness measurements obtained from spar number 1 after it was sectioned for test specimens. The nondestructive test method was then used on the remaining spars. From a manufacturing standpoint, the cross-sectional thickness can be held to within 10 to 15% of the actual drawing dimensions. The variations are most likely caused by resin flow during cure and human factors during hand lay-up of the various plies. Other measurements on the spars in the root area showed good repeatability; for example, the root end attachment holes were all within tolerance with respect to location, diameter, concentricity, and taper.

In summary, the important exterior contours and dimensions were shown to be repeatable.

Nondestructive Testing (NDT). Both ultrasonic and penetrating radiation (X-ray) techniques were used to determine the presence of voids, delaminations, unbonded areas and fiber orientation. The ultrasonic inspection was performed on the 'D' spar using a Sondicator Bond Tester at the root end and heel areas, and then using the Custom Machine semi-automatic scanning system to inspect the upper and lower airfoil sections. The size and location of all detected indications equal to or greater than ¼ inch diameter were recorded and kept on file.

Leak Inspection. Leak testing at the spar level was performed. See paragraph entitled "Leak Testing of Blade Components," below, for a complete description of the operation.

Fairing Assembly

The fairing assembly consists of a honeycomb core, lower skin, and trailing edge bonded together and machined to the required airfoil contour. The quality of the completed assembly is dependent upon bonding integrity, component alignment, and airfoil contour dimensions. Visual inspections were made during bonding to verify the correct positioning of components and to ensure that no bondline voids or node-to-node unbonds were present. Destructive tests were conducted on specimens taken from the process control panel (see Figure 127) to ensure adequate bond strength. Flatwise tensile tests resulted in core failures rather than bond failures, indicating that the bond strength was adequate.

The bonded assemblies were sent to the Hexcel Company for machining of the honeycomb core to the airfoil contour. The assemblies were held in place by a Vacuum Form Mold (VFM) during machining. Dimensional inspection of the contours was made before removing the assemblies from the VFM. Contour dimensions were verified by the tracer method using MDI-controlled airfoil patterns as masters.

Spar-to-Core Assembly Bonding

The spar-to-core bond was accomplished in the main bonding fixture after prefit and alignment inspection of the spar and honeycomb fairing subassemblies. A dimensional inspection of the bonded assembly was made using mechanical and optical checks at the Z-Z and Y-Y coordinate points at the control stations, in the same manner described for the spar in the paragraph entitled "Major Dimensional Inspections", above. A through-transmission ultrasonic technique using a semi-automatic scanning system was used for inspecting the upper and lower fairing sections of the blade. The skin-to-spar bond was inspected by hand scan pulse echo ultrasonics. Figure 128 shows the semi-automatic scanning system with a blade in place.

Indications of defects equal to or greater than .50 inch in the skin-to-core area were recorded, and indications equal to or greater than .25 inch in the skin-to-spar and skin-to-trailing edge wedge were recorded. The size and location of all detected indications were recorded and are on file. Figure 129 summarizes the inspection results for blades 1 through 7.

Evidence of distortion and chordal movement of the core skin assembly relative to the spar molding was found after cure of the assemblies. Small cracks were present in the skin along the trailing edge at the outboard end. The addition of spray adhesive on the surface of the main bonding fixture and enlarged trailing edge pins in the tool helped to hold the assembly in position, thereby alleviating this problem.

Destructive tests were performed on specimens taken from the process control panel. The panel was an integral part of the assembly. The following tests were performed:

FLATWISE TENSILE TEST

$$S = \frac{P}{A}$$

* MINIMUM EXPECTED VALUES = 200 PSI

SYMBOLS:

S = ULTIMATE FLATWISE TENSILE STRENGTH, PSI
P = ULTIMATE LOAD, LBS.
A = CROSS-SECTIONAL AREA, $INCH^2$

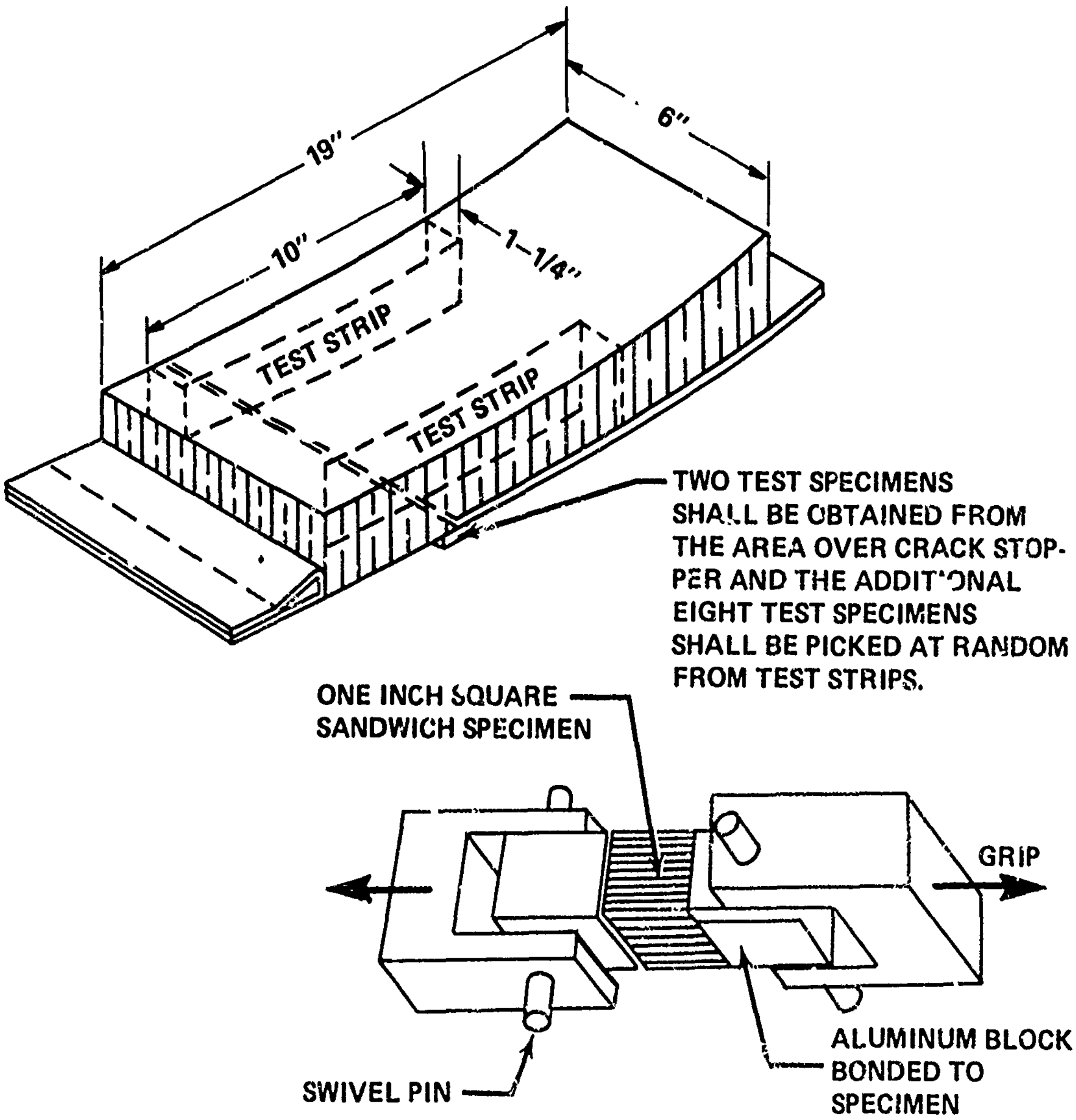


Figure 127. Section of Process Control Panel

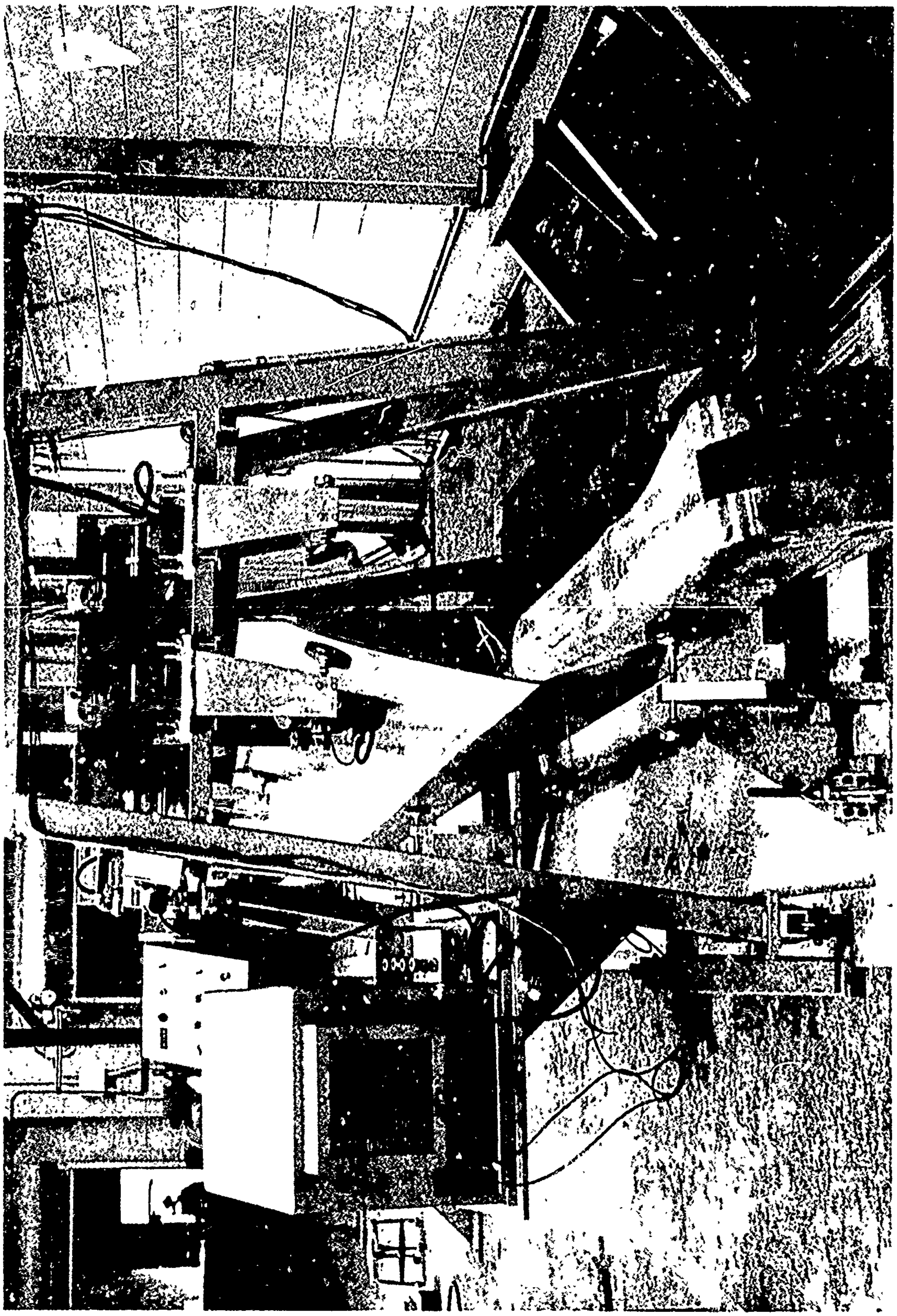


Figure 128. Semi-Automatic Scanning System with Blade in Place

BLADE NO.	ULTRASONIC SKIN-TO-SPAR	ULTRASONIC SKIN-TO-CORE	ULTRASONIC SKIN-TO-T.E.	X-RAY (HONEYCOMB CORE) AND CORE-TO-SPAR BOND
1	Sporadic bond quality both sides	Overall bond quality excellent. Each blade showed no ultrasonic indications over more than 99% of the surface area. Each blade showed several small isolated void indications, but no recurring pattern from blade-to-blade.	Skin-to-T.E. unbond Station 485 to Station 550	Some localized core crushing at root end. Small delaminations in skins.
2	Much improved bond quality; isolated ultrasonic indications present on both sides		No unbonded areas	No significant core crushing evident. No gaps (core-to-spar bond).
3	Isolated ultrasonic indications; random, no recurring pattern		Excellent; one or two localized ultrasonic indications	No gaps (core-to-spar bond).
4	"		Much improved bond quality; no recurring pattern	Slight gap at bondline Sta. 138.4 to Sta. 142.
5	"		"	Slight gap at bondline Sta. 504 to Sta. 511.2.
6	"		"	No gaps (core-to-spar bond).
7	"		"	Change in density Sta. 387.7 to Sta. 389.

Figure 129. Blade Nos. 1 Through 7 Inspection Summary

flatwise tensile - skin-to-core; tensile shear - glass skin-to-D-spar bond; and cell-to-cell liquid migration test of the honeycomb core. Figure 130 is a sketch of the process control panel showing flatwise tensile, bond shear strength, and liquid migration specimens, and Figure 131 lists typical test values.

Final Inspection

Final inspection of the blades included the visual inspection for surface defects; dimensional inspection to ensure drawing compliance on final hardware only; and ultrasonic inspection of trim tabs, doublers and the nickel erosion strip.

The ultrasonic tests revealed a number of unbond discrepancies. These and other final inspection data were recorded in the Quality Control Inspection Record. In addition to a complete inspection history for each subassembly, the inspection record also includes data on weight and balance, and surface finish.

Leak Testing of Blade Components. The final assembly was leak tested to ensure proper function of the Integral Spar Inspection System (ISIS). Simply stated, ISIS on HLH blades is primarily an evacuated 'D' spar connected to an indicator. Since the system must retain vacuum over extended periods of time, it was necessary to develop leak testing methods in order to avoid false indications due to causes other than the intended fail-safe function.

NOTE

> In the following discussion, "high sensitivity" implies the ability to detect very small leaks, while "low sensitivity" implies ability to detect gross leakage. Also, the term "qualitative" refers to the ability of a method to determine the location of a leak, while "quantitative" refers to the ability to measure leakage rate.

Various leak-testing methods were investigated: halogen detectors, bubble testing, high-sensitivity pressure gauges and others. These methods proved generally inadequate because of low sensitivity or the inability to test both qualitatively and quantitatively. It was decided to utilize a helium mass spectrometer because of its very high sensitivity and its qualitative and quantitative capabilities.

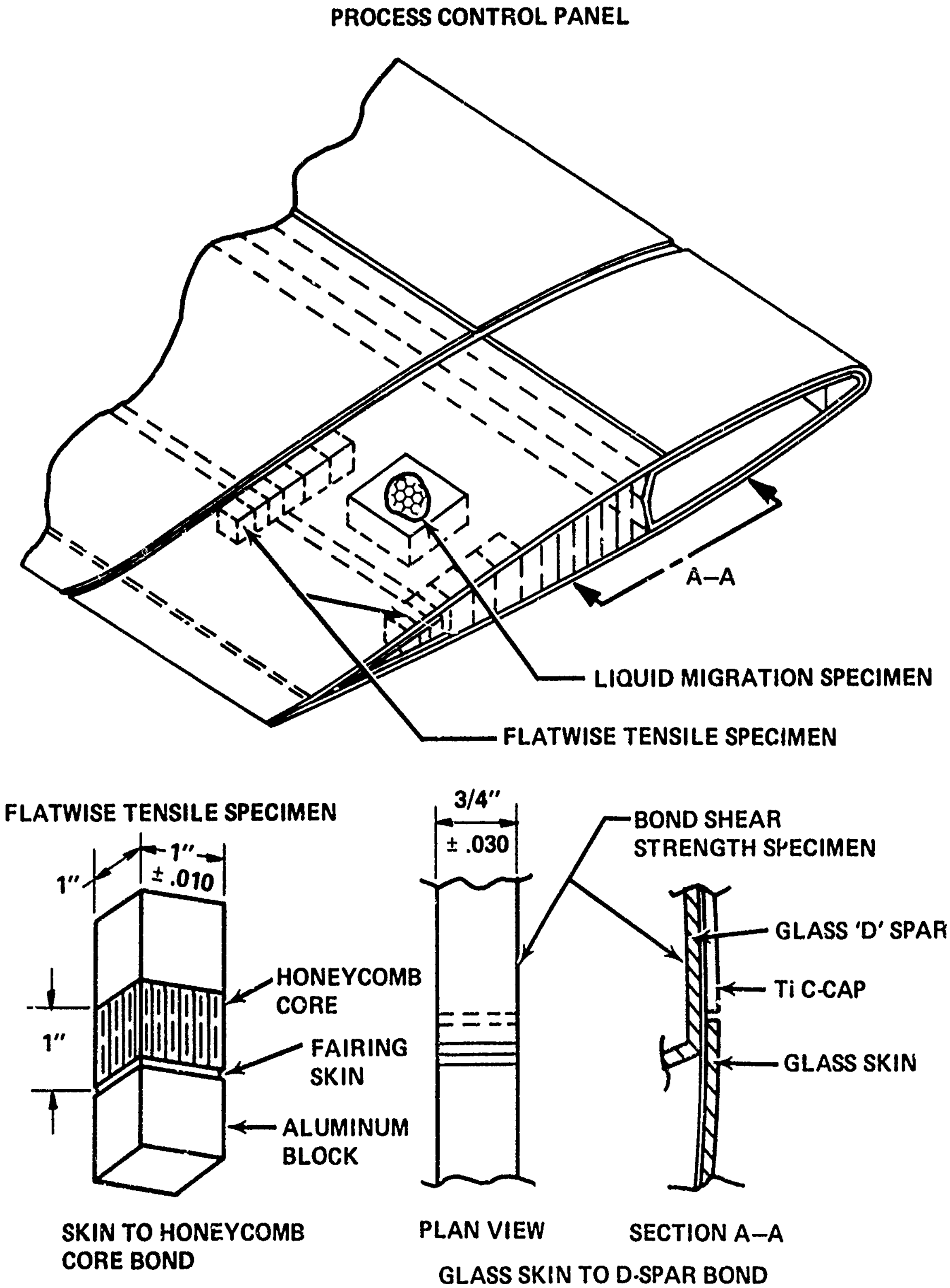


Figure 130. Flatwise Tensile, Liquid Migration, and Bond Shear Strength Specimens of Process Control Panel

The results of tests performed in accordance with D301-10154-1 are given below:

FAIRING ASSEMBLY FLATWISE TENSILE TEST

Specimen No.	Tensile Failure Point (psi)	Minimum Reqd. Tensile Strength (psi)	Failure Type
1	350	200 (core failure) 300 (bondline failure)	Core
2	355	↓	↓
3	322		
4	320		
5	335		
6	390		
7	385		
8	420		
9	415		
10	385		
Avg.	367.7		

FAIRING ASSEMBLY & SKIN/SPAR ASSEMBLY TESTS
FLATWISE TENSILE

Specimen No.	Tensile Failure Point (psi)	Minimum Reqd. Tensile Strength (psi)
1	285	200
2	280	↓
3	275	
4	280	
5	280	
6	290	
7	280	
8	295	
9	275	
10	270	

LAP SHEAR - TI CAP TO GLASS 'D' SPAR

Specimen No.	Shear Failure Point (psi)	Minimum Reqd. Shear Strength (psi)
1	2720	2200 (Individual) 2500 (Average)
2	1840	↓
3	3040	
4	2760	
Avg.	2590	

LAP SHEAR - GLASS SKIN TO GLASS SPAR

Specimen No.	Shear Failure Point (psi)	Minimum Reqd. Shear Strength (psi)
1	1604	3000 (Individual) 3500 (Average)
2	1808	↓
3	1480	
4	1781	
Avg.	1669	

LIQUID MIGRATION TEST

No migration beyond first row of inspected cells.

Figure 131. Adhesive/Liquid Migration Test Results for HLH/ATC No. 7 'D' Spar and Blade Fairing Assembly.

Two basic test methods, a pressure mode and an evacuation mode, were used on ISIS blade components. The left side of Figure 132 represents a simplified sketch of the pressure mode in which the component to be tested is pressurized with helium tracer gas. A special probe is attached to the helium mass spectrometer. Any helium escaping from the test object is drawn through the probe into the detector. This qualitative method can be made quantitative (as shown in the right portion of Figure 124) by placing the pressurized test object in a chamber and measuring the amount of tracer gas which accumulates in the chamber over a fixed period of time. The amount of helium measured by the detector probe is proportional to the leakage rate of the test object. This method is capable of detecting leaks smaller than 1×10^{-8} atmospheric-cubic centimeters/second (atm-cc/sec) of helium and is dependent on accumulation chamber volume, test time and helium pressure in the test object. The smallest rate required by any blade component is 1×10^{-5} atm-cc/sec.

The evacuation mode using the helium mass spectrometer leak detector is essentially a quantitative test, as shown in Figure 133. In this mode, the test object is evacuated by the pumping system of the leak detector, and then the exterior of the test object is exposed to helium. Any helium which penetrates the test object is drawn into the detector and ionized, thereby producing a current which in turn is converted into a leakage rate. The sensitivity of this method is approximately 1×10^{-7} atm-cc/sec helium. If the exterior helium spray is concentrated locally to the exterior of the test object, the method also has qualitative capability. All ISIS blade components ('D' spar, evacuation valve, system indicator, seals, etc.) were subjected to these types of tests.

Post Whirl Test Inspection

Four blades were nondestructively evaluated after whirl testing. The data was compared with nondestructive test data taken during fabrication and at final assembly. The comparison was made to measure the effect of whirl testing on the structural integrity of the blades. Only one significant change was noted in the post-test inspection: blade number A-2-0005 developed a ripple approximately ten inches long in the upper airfoil skin. Ultrasonic inspection of the area revealed a slight progression of the original void indications. No other significant changes were detected in the whirl-test blades.

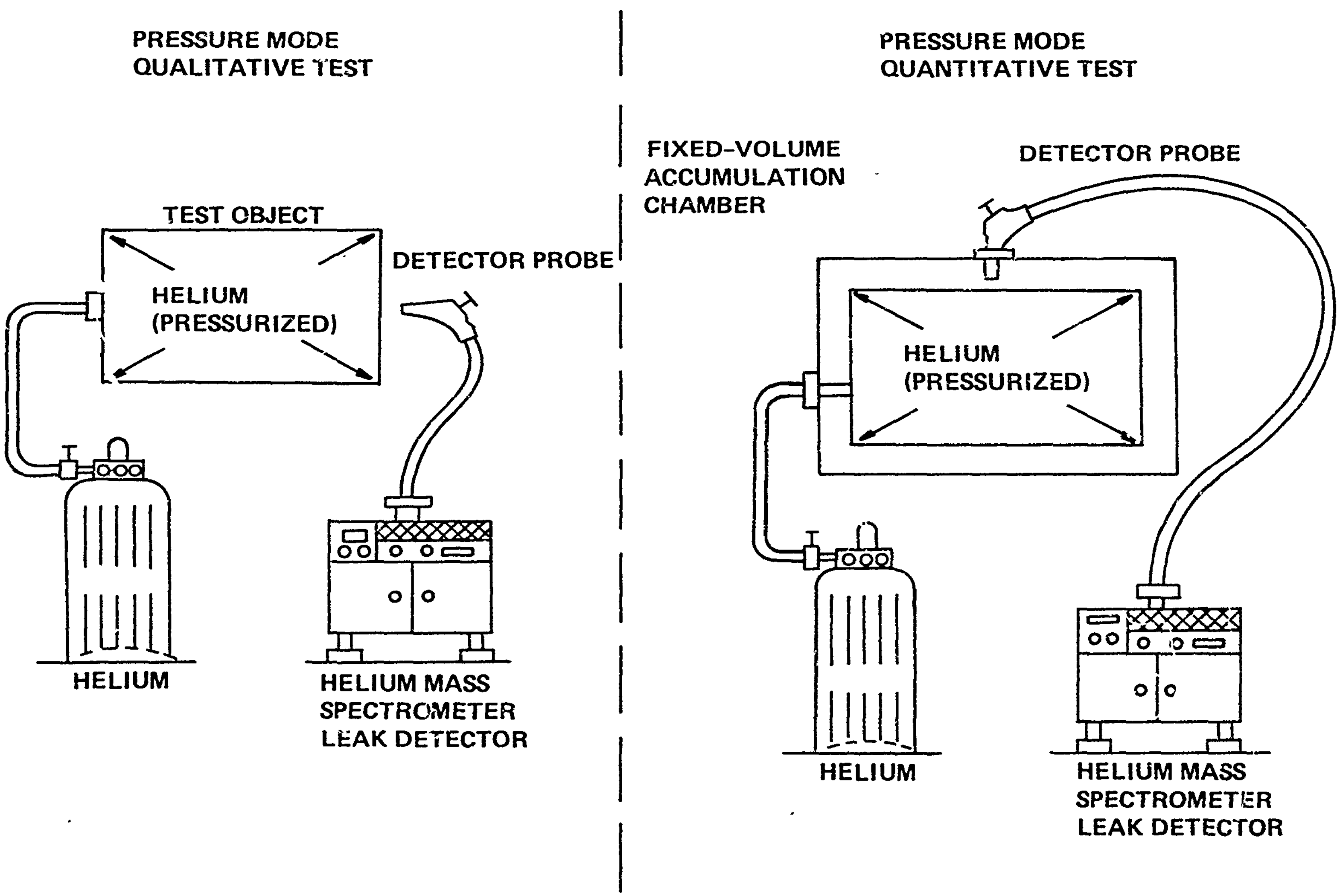


Figure 132. Qualitative and Quantitative Pressure Mode Tests

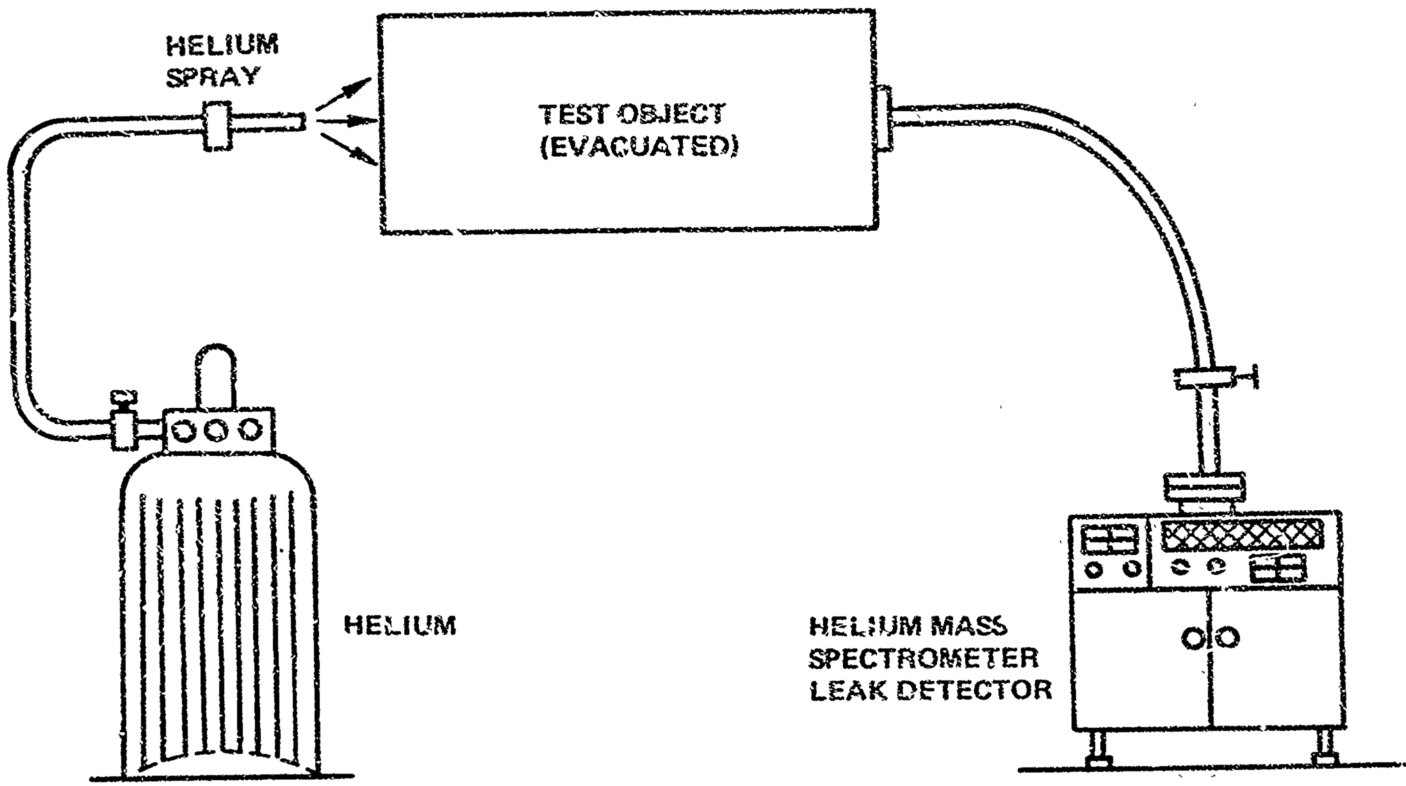


Figure 133. Evacuation Mode Quantitative Test

Blade Weight Summary

A weight summary breakdown of the HLH/ATC blades is given in Figure 134. Calculated weights and actual weights are given for major details of each blade, as well as for the total blade. Process changes were considered in the calculations which reflect the as-fabricated blades.

Differences in actual and calculated weight values are due to variation in laminated densities, resin content, and noseblock weights. Total blade weights averaged 796.8 pounds (including the damper area). This differs from the calculated value of 800.87 pounds by 4.07 pounds, or approximately 0.51%. The small difference indicates good repeatability in composite blade construction.

ITEM	SHOP THEORETICAL WEIGHT	ACTUAL WEIGHTS							REMARKS
		BLADE 1	BLADE 2	BLADE 3	BLADE 4	BLADE 5	BLADE 6	BLADE 7	
Ti Nose Cap	99.81		97.15			102.75	105.35	98.35	Spars 1 & 2 - No tungsten nose balance
-59 Assy Sub	140.51		143.25	136.00	140.29	141.34		137.9	
-59 QC+	3.71	**	**	**	**		**	**	
-59 Assy Final	136.80	(with tabs) 132.27	139.54	132.29	136.58	137.63		134.15	
-901 Strap Assy		37.59		44.78	47.20	46.75	46.81	47.55	See sheet 2 for legend
-902 Strap Assy		40.79		46.43	47.22	46.80	46.09	50.15	
-903 Strap Assy		41.05		44.78	48.92	48.40	46.15	46.85	
-904 Strap Assy		38.84		46.43	48.27	47.65	47.55	47.70	
-49 Filler		27.89		18.2	17.75	17.85	18.20	17.75	
-51 Filler		15.73		16.85	16.45	16.25	16.25	17.45	
Uni Glass	210.36	201.89		217.47	225.[illegible]	223.70	221.00	227.45	
11177-5 Preform	34.32			34.05	33.25	33.70	33.45	33.25	
11173-11 Upper OTW	39.12	**	**	**	**	**	**	**	
11173-15 Upper ITW	15.17			11.68	12.22		11.15	10.8	
11173-41 Stiffener	2.61			2.83	3.0		2.75	2.65	
11173-55 Upper Wedge	.45	.45	.44	.45	.46	.44	.44	.44	
SK-18 Filler	2.42	2.45	2.42	2.44	2.44		2.40	2.40	
11173-13 Lower OTW	39.12	**	**	**	**	**	**	**	
11173-17 Lower ITW	15.17			11.74	10.40		11.10	11.50	
11173-43 Stiffener	2.61			3.06	2.50		2.83	2.40	
11173-57 Lower Wedge	.12	.27	.27	.26	.26	.27	.25	.25	
11173-37 L.E. Web	3.69	4.08		4.25	4.10	3.85	3.95	3.85	
11173-39 T.E. Web	4.35	4.84		4.65	4.60	4.40	4.45	4.25	
SK-19 Filler	2.36	2.35		2.35	2.45		2.40	2.40	
Glass Spar - Hub	371.89			333.45	380.03		374.41	379.69	
Glass Spar - Q.C.+	3.48	**	**	*	**	**	**	**	
Glass Spar Final	368.41			363.97	376.55		370.93	376.21	
Balance Weights	63.48	48.00	48.00	65.27	63.48	63.48	63.48	63.48	
SPAR ASSY	568.69			567.53	576.51			573.84	
Actual SPAR ASSY	--	(with tabs) 558.5	563.51	578.22	574.88	574.92	577.17	569.40	
Tungsten Delta	15.48		0	17.27	15.48	15.48	15.48	15.48	
Wy - Spar				161,873	161,130	159,971	162,344	159,208	

Figure 134. HLH Blade Weight Summary.

ITEM	SHOP THEORETICAL WEIGHT	ACTUAL WEIGHTS							
		BLADE 1	BLADE 2	BLADE 3	BLADE 4	BLADE 5	BLADE 6	BLADE 7	
Fairing Assy *	100.65	96.40	96.75	94.60	91.9	89.05	92.45	91.55	Blades 1 & 2 - No tungsten nose balance
Fairing Excesses + Top Skin & Adhesive	16.52 37.23 (20.71 net)	** **	** **	** **	** **	** **	** **	** **	Blade 2 - Not painted
Fairing Assy-Final	121.4	--	117.46	115.31	112.61	109.76	113.16	112.26	
Fittings	32.56	**	**	**	**	**	**	**	Blade 4 - Instrumented
11175 Bonded Assy *	722.65	--	713.53	726.09	720.05	717.24	722.89	714.22	Blade 6 - Used as teeter master
Actual Bonded Assy	--	--	701.95	723.00	717.45	720.25	719.80		
All Misc Hardware	40.22	--	**	**	**	**	**	**	
Total Blade	762.87	--	753.75	766.31	760.27	757.46	763.11	754.44	
Lag Damper	35.0	--	**	**	**	**	**	**	
<u>Total Blade</u>	797.87	--	788.75	801.31	795.27	792.46	798.11	789.4[illegible]	
<u>Actual Blade</u>	--		774.8		797.63	797.55	799.75	790.15	
Track Weights	3.0		--	--	6.37	5.0	3.0	9.75	
<u>Final Blade Actual Weight</u>	800.87	--	774.8	--	804.0	802.55	802.75	799.90	

<u>LEGEND</u>

\+ Weight of tooling and Q.C. excesses

* Weight includes peel ply

** Theoretical weight used - actual weights not available

Figure 134. HLH Blade Weight Summary (Continued)

5.0 ROTOR BLADE TEST RESULTS AND IMPACT ON TOOLING/FABRICATION

The experience gained in producing the HLH ATC rotor blades and the testing that has been accomplished verified the basic tooling methods and engineering design concept. Appendix A presents a description of the ATC Rotor Blade Test Program. The test program, however, highlighted areas in blade construction and design that were potential items for improvement.

PROBLEM AREAS AND REMEDIAL ACTION

Following is a summary of these problems, together with corrective action being taken.

Honeycomb Core

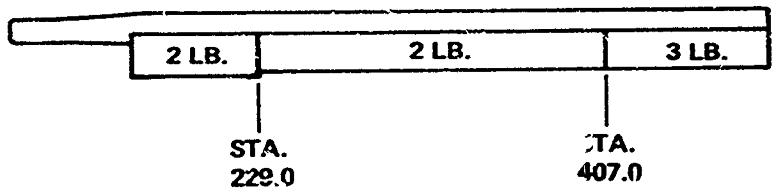
Chordwise airload fatigue testing of rotor blade sections indicated a premature failure of the Nomex core at the heel of the spar. After evaluation of the problem, HLH Engineering changed the design to include a heavier core in certain areas of the blade. In addition, a splice or stiffening member has been added on the chord centerline as shown in Figure 135.

The foregoing changes will not affect the basic tooling concept of bonding and machining the core assembly. It will, however, require handling of additional pieces. The profile template used for contour machining the core will require modification.

Spar

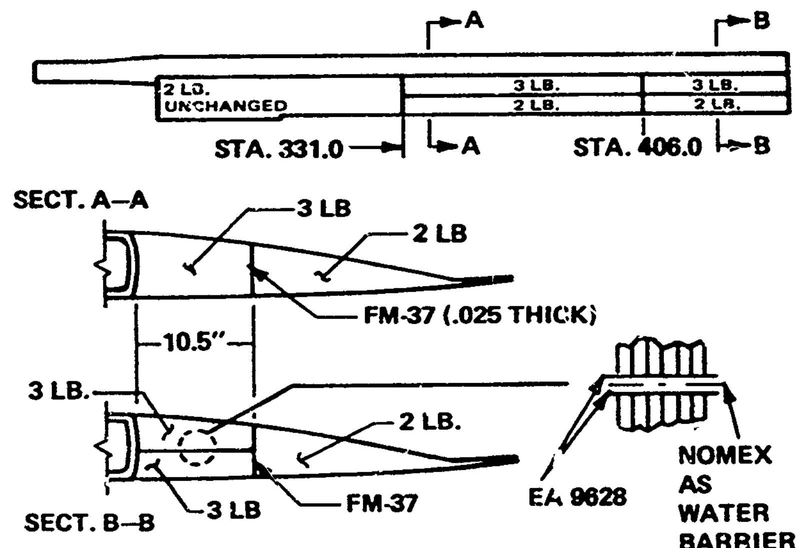
ATC testing has revealed that the spar wall in the outboard area (Stations 569 to 552) requires additional stiffening. The modified design adds more fiberglass material to the spar straps and extends the graphite lay-up to the outboard section.

Tooling mylars and templates will be altered to reflect the changes shown in Figure 136.



PROTOTYPE CONFIGURATION

- Coupon program defined strength of 2# and 3# core at required height; defined beneficial effect of stabilizer.
- Based upon testing, outboard section is marginally acceptable as is; intermediate section required beef-up.
- Vertical splicing provides weight efficient method of introducing beef-up. (7.5# total/blade)



ATC CONFIGURATION

- The intermediate and outboard sections of the honeycomb core failed in shear during testing of air load specimens. This failure was attributed mainly to the core height. Test set-up was also contributory.
- Test program of real size coupon verified effect height; effects of heel notch, cure temperature and crush exist but are within scatter of height effect.

Figure 135. Nomex Honeycomb Core Changes for HLH Prototype

ATC CONFIGURATION

- Outboard spar wall (86 to 96% radius) deflected beyond criteria limits when spar cavity was evacuated for ISIS due to insufficient stiffeners of local spar wall.
- As a near term solution for the ATC blades – a honeycomb insert was added to act as stiffener.

PROTOTYPE CONFIGURATION

- Increase spar wall thickness with 2 ply of cross-plied S-glass and 4 ply transverse graphite (4 pounds per blade).
- Build-up replaces the honeycomb bulkhead (1.5 pounds per blade).
- Change from bulkhead to lay-up reduces fabrication cost and complexity.

OUTBOARD SPAR WALL

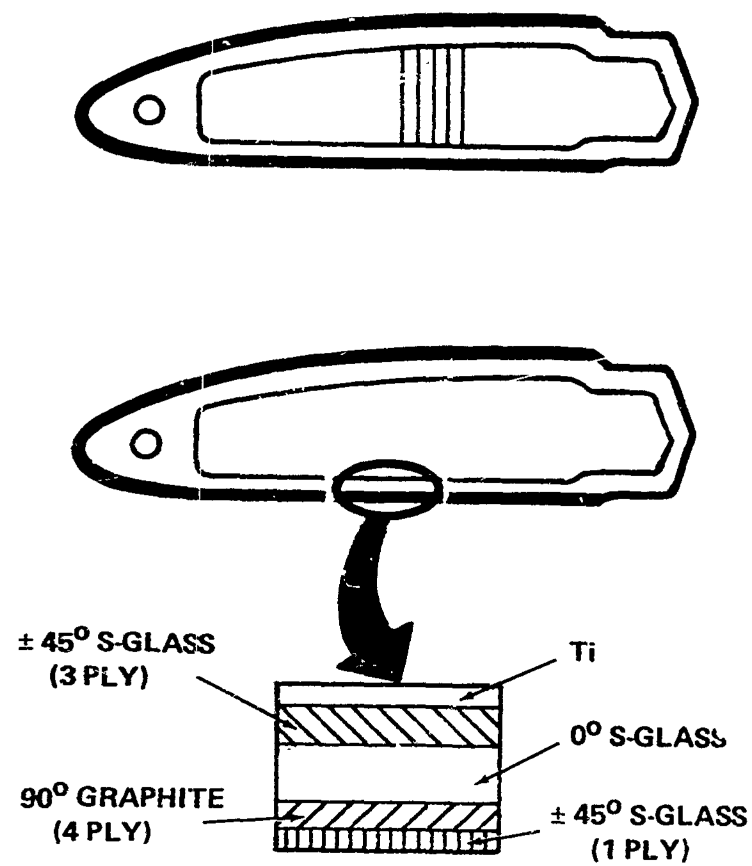


Figure 136. Spar Improvements

Aft Fairing Skin

Cracks occurred in the skin at the outboard section of the blade trailing edge during the final bonding operation.

HLH Engineering has recommended increasing skin thickness in this area and extending the additional material to the trailing edge. Modification of the tooling mylar and deviations from the core machining pattern will be made to accommodate these changes. Refer to Figure 138.

The first blade to be bonded developed a wrinkle in the skin at the leading edge of the core on the upper airfoil side (the skin is cured during this operation). The wrinkle was eliminated by adding a cured shim as shown in Figure 139. The prototype blades will have a larger shim to extend onto the spar joggle.

Tooling will provide a shim in the spar BAJ to allow for this shim.

Titanium Nose Cap

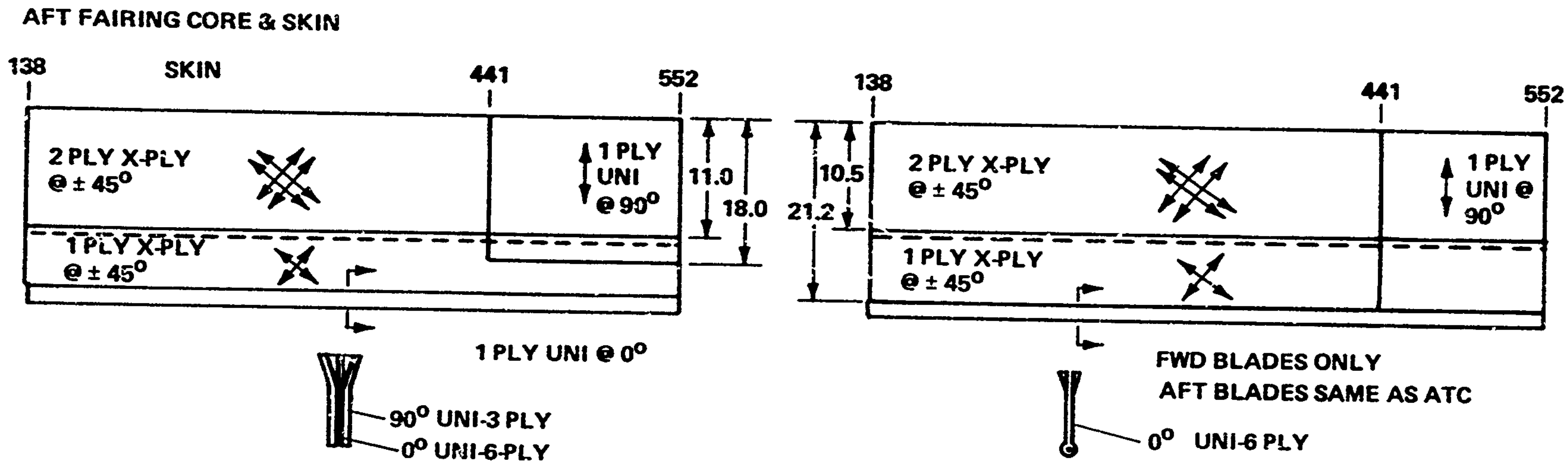
During fatigue testing of the intermediate blade section, a crack developed in the trailing edge of the titanium cap; the crack progressed toward the leading edge. Note that this failure occurred in a cap that had been retrimmed prior to bonding to the spar; the retrimming may have contributed to the failure of the cap in this area. However, a joint Engineering, Tooling, and Manufacturing Development effort was initiated to investigate this problem, and it was found that this crack had not been caused by the trimming or edge finishing. Instead, it was discovered that the failure had been caused by a shear crack at the edge of the material. Microscopic examination of the titanium material indicated that it had subsurface shear cracks. This was eventually traced to the rolling process used by the mill in production of the sheet. Examination of the material supplied by another manufacturer indicated that this problem did not exist in their product.

Root End Lag Damper Fitting

Fatigue testing of the root end specimen indicated that the lag dampers required modification to achieve desired life limits. A modified lag damper (Figure 139) has been designed, fabricated, and installed in the ATC whirl tower/DSTR (Dynamic System Test Rig) blades no's 4, 5, 6 and 7.

Anti-Fretting Inhibitor

As a result of the ATC root-end fatigue tests and other rotor/drive system tests, a decision was made to change the anti-fretting inhibitor application on the root-end sleeves from



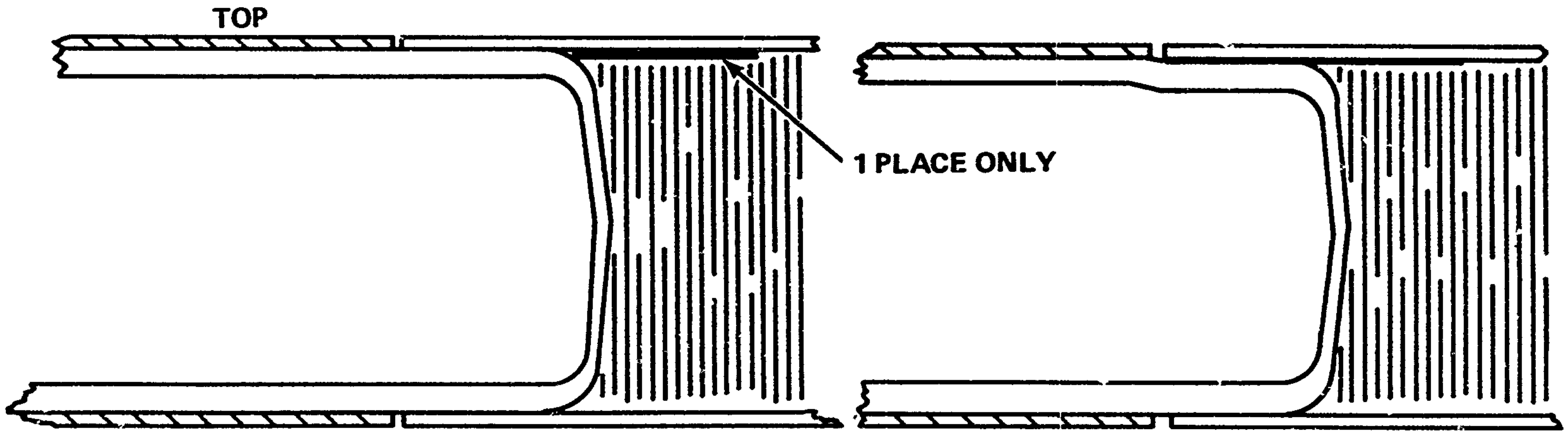
ATC CONFIGURATION

- Skins cracked during final cure due to:
  - Thermal condition
  - Pressure necessary to deform core
- Cracks only occurred in 3 lb/ft^3 density region where 90° material terminated.
- All 90° material in T/E wedge is cured with basic wedge. Voids occur during subsequent operations if tolerances shift beyond expected range.

PROTOTYPE CONFIGURATION

- Extended 90° uni to T/E wedge.
- Shorten inner skin by 0.5" to have core splice and uni 0° rip strip coincide.
- T/E wedge will have all 90° material added to fairing in subsequent assemblies for additional tolerance (fwd only)

Figure 137. Aft Fairing Skin Changes



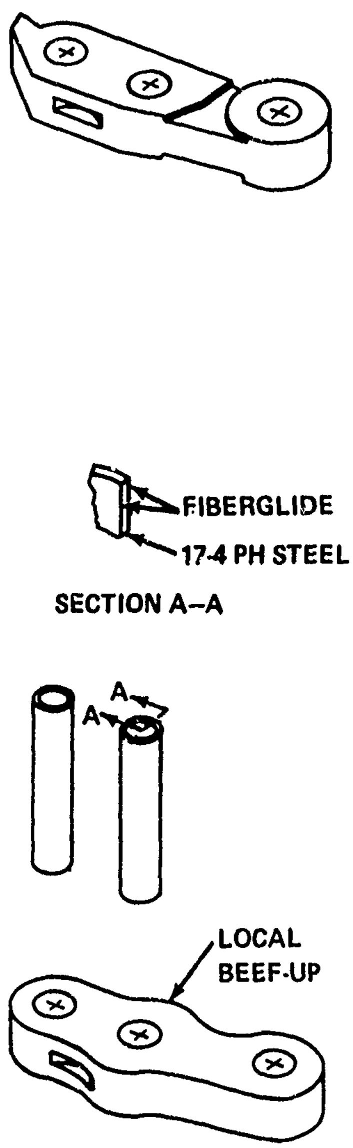
ATC CONFIGURATION

- Cured shim was defined as a necessity to avoid wrinkling of top airfoil skin during final bond in main BAJ.
- Because spar BAJ did not have the joggle depth necessary, the cured shim had to butt against the heel (inconsistent) or the second skin had to be cut and spliced with the shim (undesirable).

PROTOTYPE CONFIGURATION

- Cured shim will be brought up on the spar.
- Spar BAJ will be modified to accommodate increased thickness at joggle.

Figure 138. Elimination of Wrinkle in Aft Fairing Skin



ATC CONFIGURATION

- High stress levels
- Failure at trailing pin hole during root end test (loads improperly applied contributed to failure)
- Fretting occurred between steel sleeve and titanium damper arm.

  Sermetal coating on inner diameter surface of sleeve showed wear through and fretting.

PROTOTYPE CONFIGURATION

- Beef-up lag damper arm in critical area of trailing pin hole to reduce stress levels (2.1 lb per arm).
- Apply fiberglide coating to inner and outer diameter surfaces of steel sleeve.
- Fiberglide proven in service at comparable operating, bearing stresses (CH-47 Socket).

Figure 139. Root End Lag Damper

0.007-inch (nominal) Sermetal to 0.015-inch thick Fiberglide Teflon/Dacron weave. Blades of this configuration have been installed on the DSTR, Ft. Dix, N. J., for 200 hours of endurance testing.

PROTOTYPE TOOLING IMPROVEMENTS

While not a direct result of ATC testing, the changes listed below have been or are being implemented to:

1. Improve quality of rotor blade components produced.
2. Ensure repeatability between blades.
3. Reduce manufacturing costs of prototype rotor blades.

Trailing Edge Wedge

The ATC Trailing Edge Wedge was fabricated with 2 inches of excess material or selvage on one side; a series of ¼-inch diameter tooling holes were drilled in the selvage (Figure 140). The holes were used primarily for locating and holding the wedge in proper chordwise location during wedge-to-core and core-to-skin bonding operations, and final bonding of fairing to spar. The tool locator holes, in addition, were also used for locating the Nomex honeycomb core during machining of the upper airfoil contour.

For the HLH Prototype, the trailing edge wedge will be fabricated with a molded graphite tube or "dogs knot" (Figure 142) at the wedge's trailing edge running the full span. The VFM core tools and final bonding fixture have been modified with a similar groove milled into them to accept the diameter of the trailing edge's graphite tube. This modification will provide more precise location of the aft fairing during subsequent assembly operations and also prevent the forward movement or "lemon seeding" effect of the aft fairing experienced on early ATC blades. All tooling modifications to the VFM and main blade BAJs have been coordinated through computerized Master Dimension Identifiers.

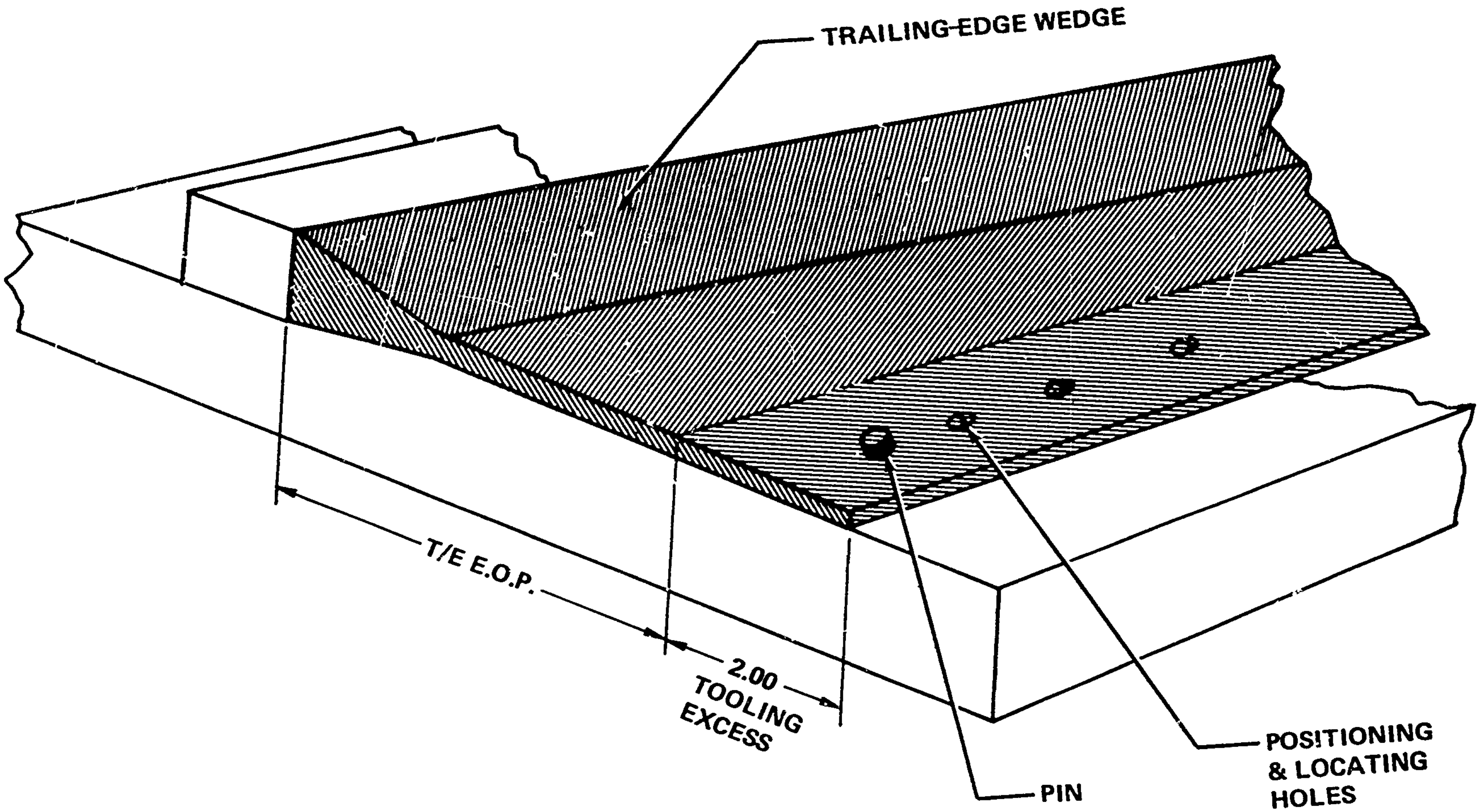


Figure 140. ATC Trailing-Edge Wedge

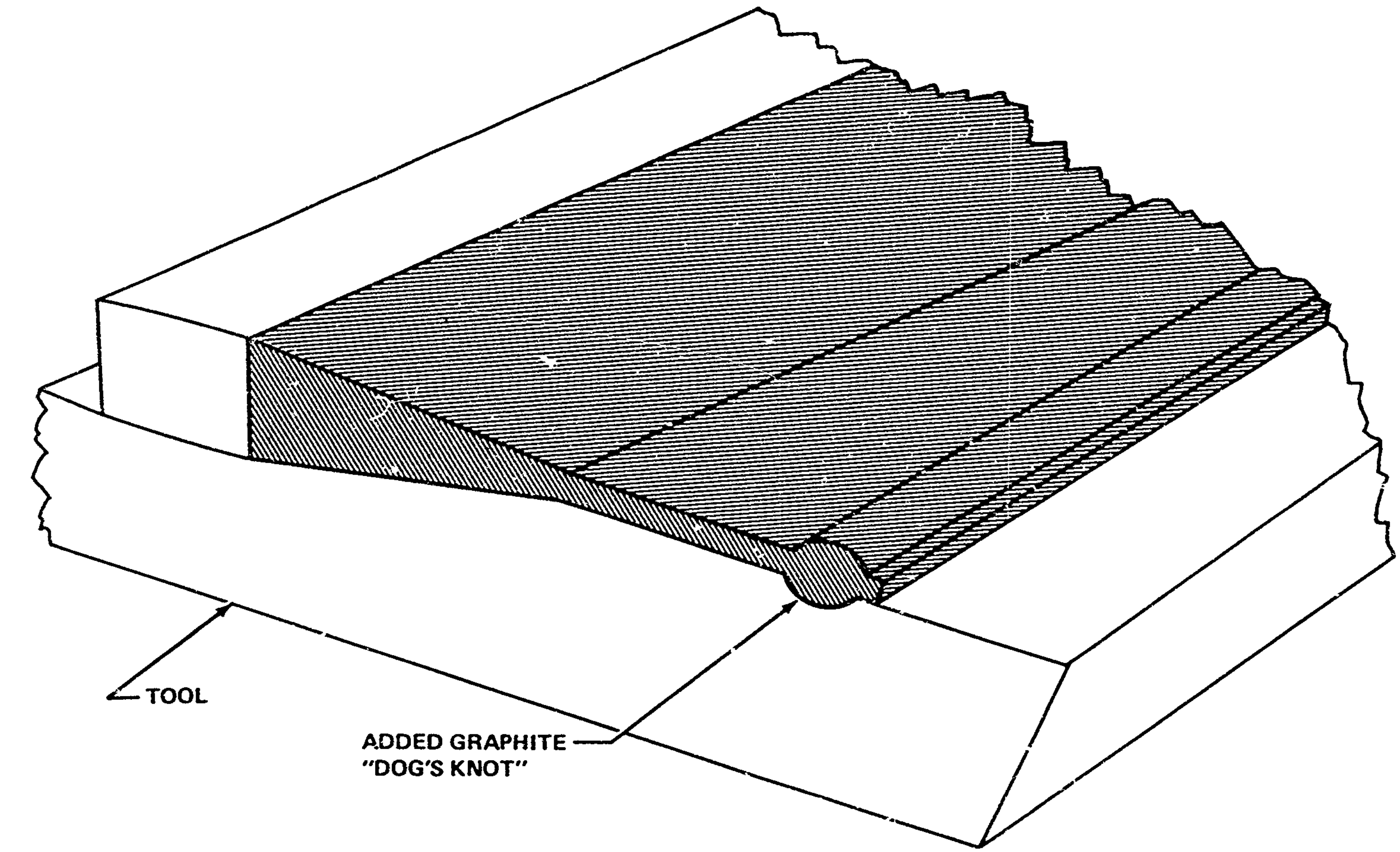


Figure 141. Prototype Trailing Edge Wedge

Titanium Nose Cap

Experience on the ATC blade program provided background for improving certain areas in the fabrication of subsequent titanium nose caps for the HLH Prototype Program. Areas for improvement included:

1. Radius of leading edge
2. Chordwise bow of outboard blade section

Titanium nose caps for the Heavy Lift Helicopter have been formed at Boeing-Wichita. Changes in titanium forming are being made at the Wichita Division to correct the foregoing conditions. Refer to Figure 142. For example, 3000 pounds of additional weights have been added to improve the forming of the leading edge radius. A cap made of refrasil, a refractory silicone blanket material, is being used on the cap's leading edge during the forming operation to help control cool-down of the part. A ceramic female upper cap has been added to approximately 10 feet of outboard blade section to improve nose radius forming.

Pre-Cured Heel

The heel of the spar (section aft of the titanium nose cap) is subject to distortion during lay-up and loading into the spar BAJ. Care must be exercised to prevent or eliminate any wrinkling of the fiberglass material. To eliminate wrinkling experienced on ATC blades and to provide an improved, lower cost manufacturing approach, a pre-cured heel test spar (Station 372 to 469) has been made. Refer to Figures 143 and 144). The heel of the spar is cured as a separate detail and then bonded into the spar during spar cure. This test specimen was successfully formed.

The decision was then made to produce a second test specimen of the tip section (Stations 469 to 552) using a new mandrel configuration (Figure 145) which would:

1. Be a mandrel for spar heel lay-up
2. Bond nose block assembly into the titanium cap
3. Bond de-ice blanket into the titanium cap

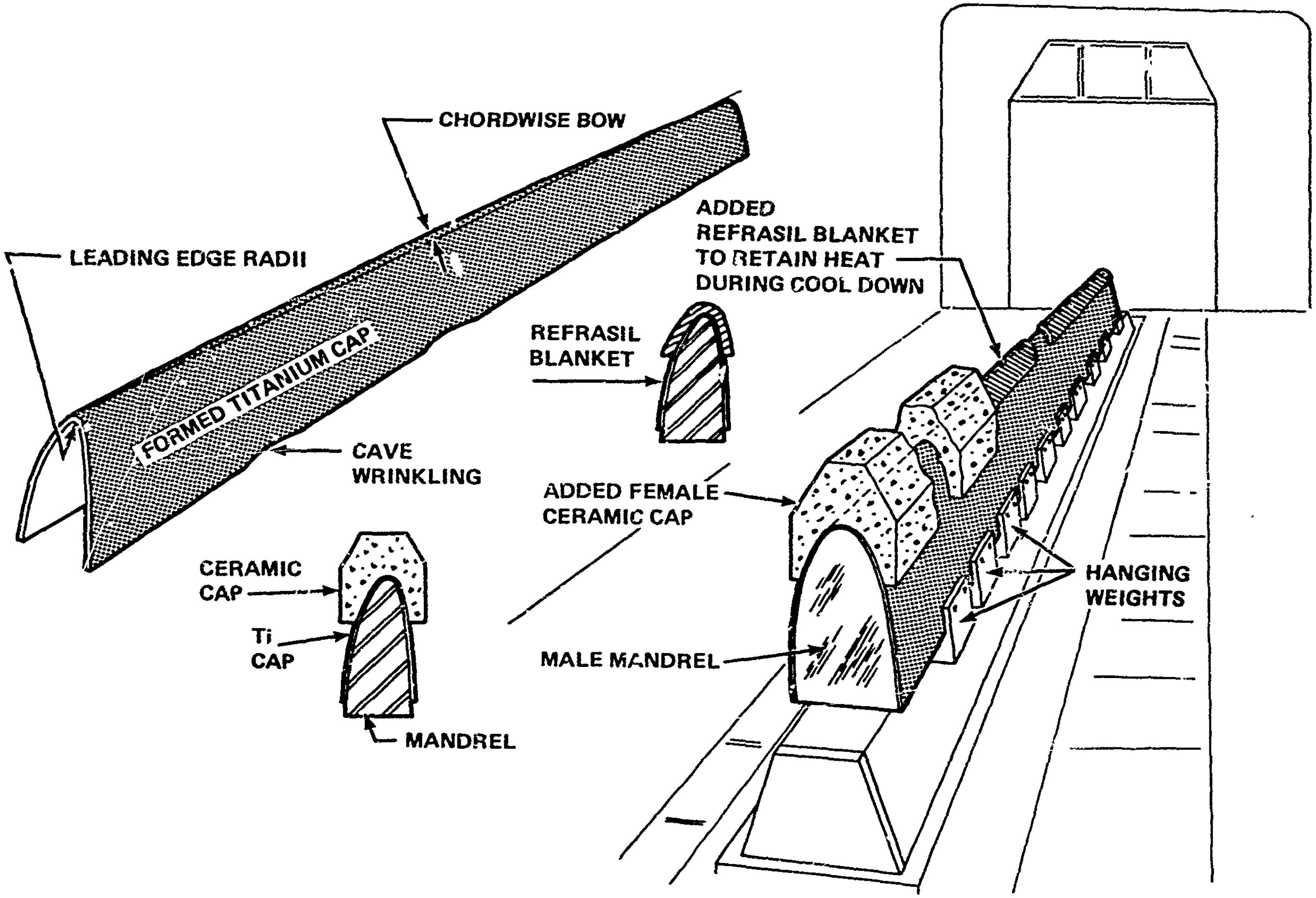


Figure 142. Tooling Improvements for Titanium Nosecap

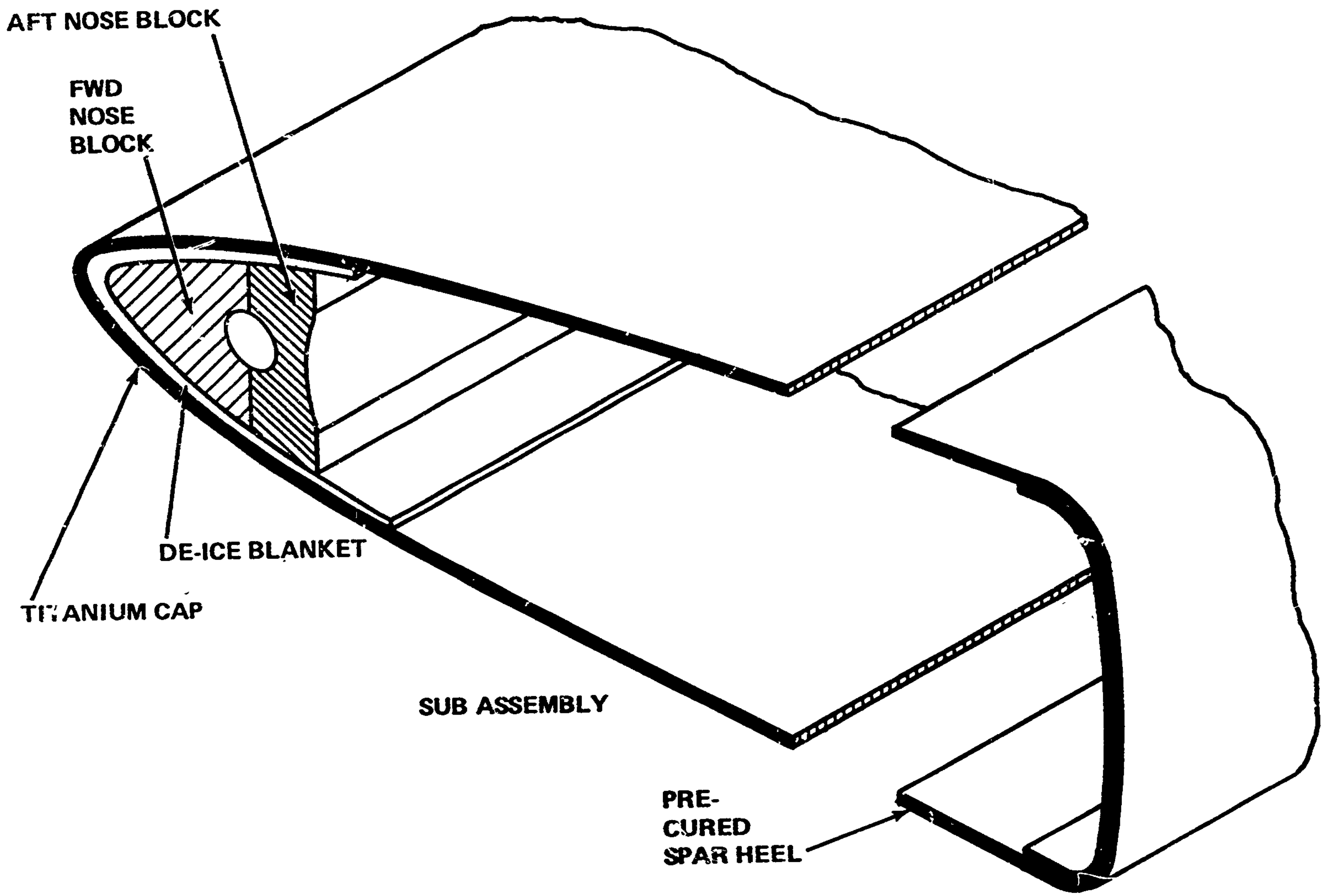
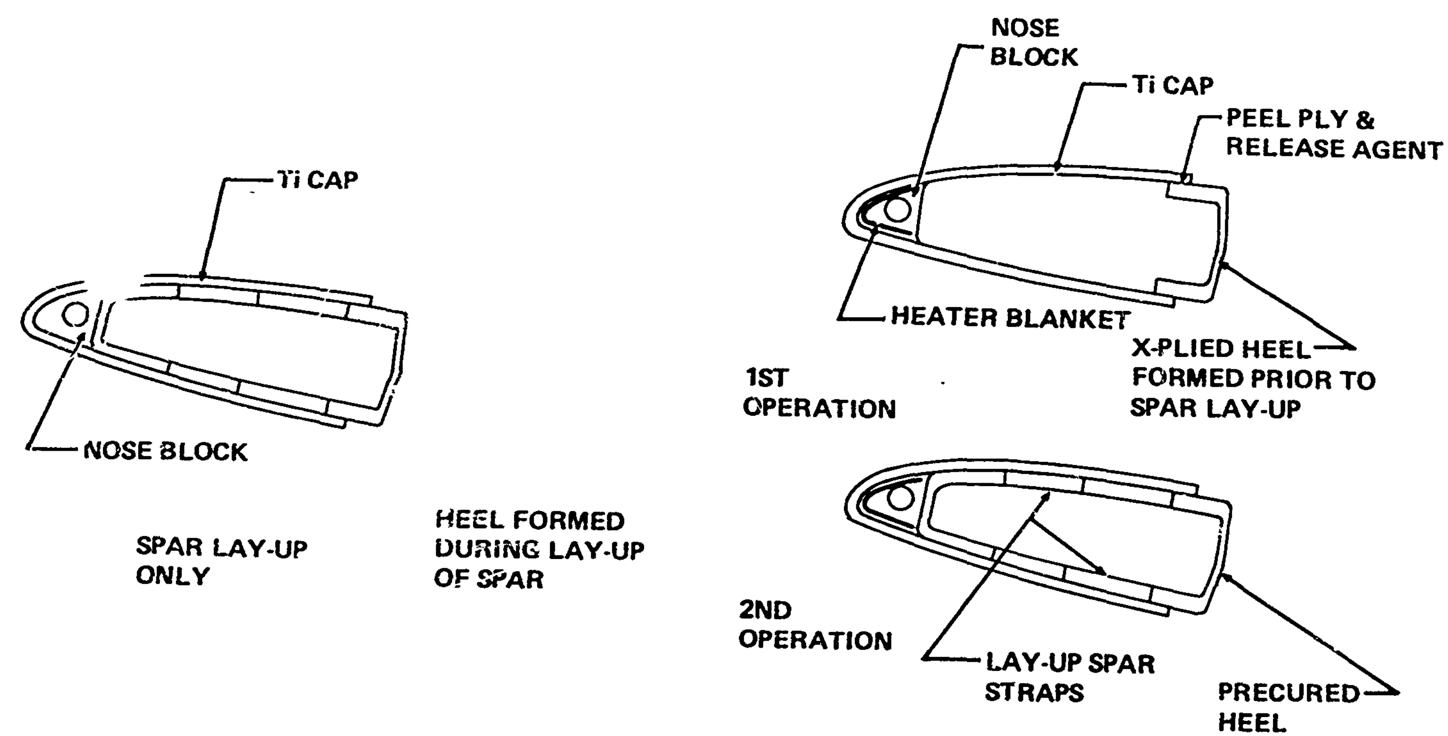


Figure 143. Pre-Cured Spar Heel



ATC CONFIGURATION

- Lay-up of spar and assembly for a single co-cure of titanium and glass can result in wrinkles in spar heel which may be unacceptable for flight aircraft.
- ISIS leaks originate from apex of heel and require a secondary sealing operation.

PROTOTYPE CONFIGURATION

- Pre-cured heel which simplifies the spar assembly and insertion into the tool, eliminates the potential of any skin wrinkling at the critical heel.
- Eliminates the possibility of ISIS leakage due to resin starvation.

Figure 144. Pre-Cured Heel Lay-Up

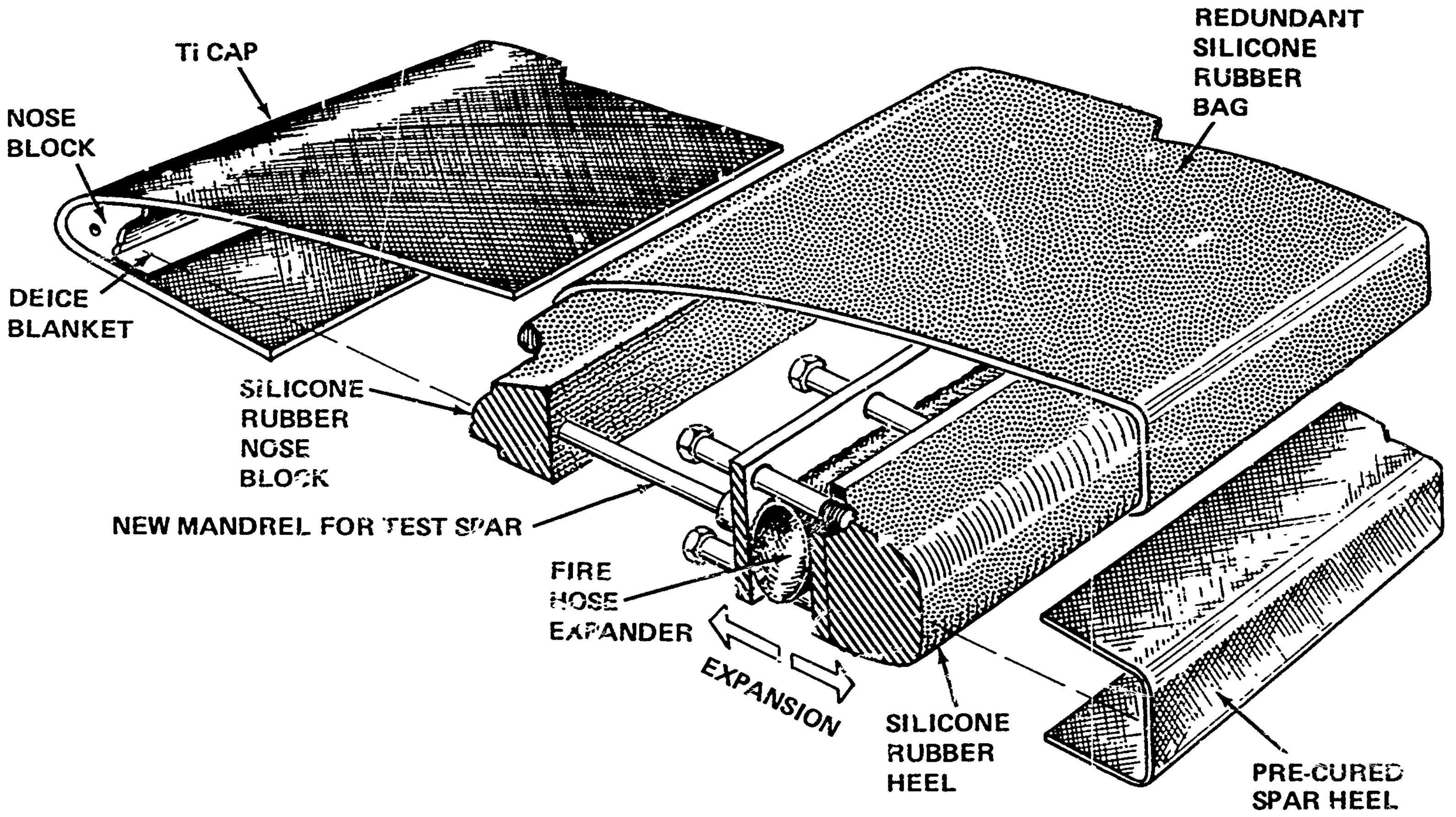


Figure 145. Simultaneous Cure of Nose Block and Spar Heel Results in Reduced Fabrication and Assembly Manhours

4. Bond AF30 adhesive into the titanium cap

5. Provide for bonding tool tabs to the outside of the titanium cap

6. Cure the spar heel.

Following complete evaluation of this 8-foot specimen, it is currently planned to develop a full-length mandrel to perform the same operations for the entire blade.

Co-Cured Forward Tip Weight Fittings

ATC experience had indicated that bonding the forward weight fittings (301-11186-1) into the spar was time consuming and produced bond lines that, in certain cases, were marginal. With the ATC method, the spar is cured using special cauls located on the foam bag mandrel to control inside spar contour in the tip fitting area. Using the silicone rubber bag to apply pressure, variations in IML contour were experienced from spar to spar. A hand sanding operation was therefore required to match the weight fitting to the spar prior to bonding. The fitting was then bonded into the spar with another tool in a separate operation.

To improve the weight fitting bond line and reduce cost, a test part has been produced with a modified mandrel (Figure 146) which permits installation of the weight fitting on the spar mandrel during lay-up of the spar. The weight fitting was then bonded or co-cured to the spar at the same time the spar was cured. This technique proved successful and will be incorporated on the prototype blades.

Droop Stop Fitting

The four 301-11204 Droop Stop Fittings (Figure 147), located in the root end of the spar, were also very difficult to hand-fit prior to bonding. A similar approach to that described for the forward weight fittings is under evaluation to improve this installation.

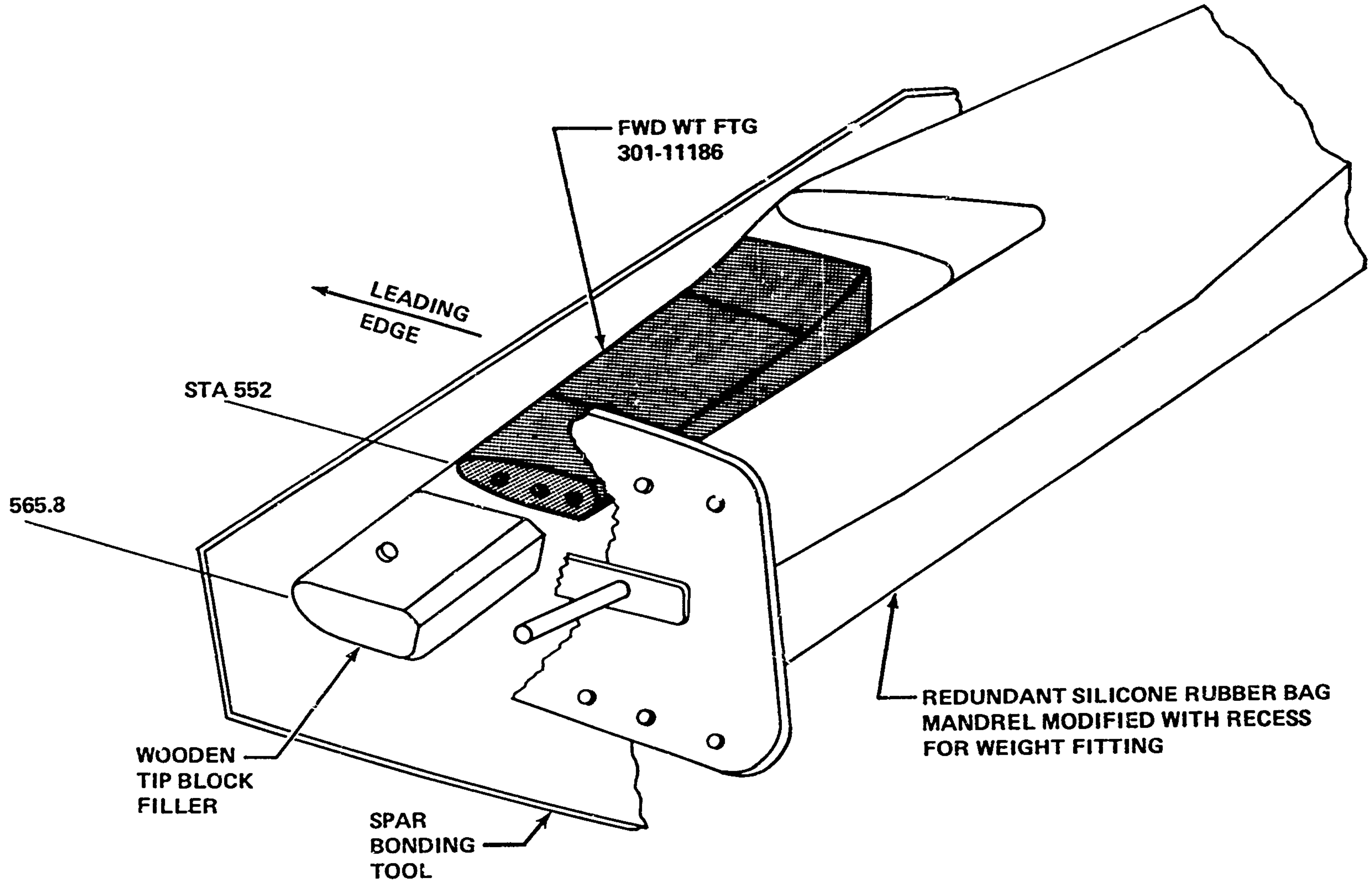
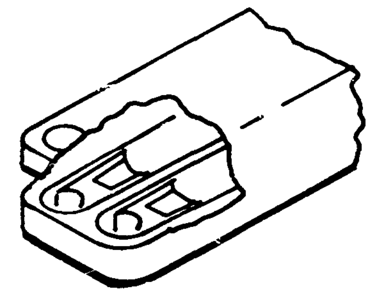


Figure 146. Improved Forward Weight Fitting Mandrel

PROTOTYPE CONFIGURATION

- Droop fittings cured in place during spar cure. No separate fabrication required.
- Design to cost savings.



ATC CONFIGURATION

- Four (4) fittings hot bonded to root end.
    - Fittings are all different due to internal blade contour - high cost for hand fitting.
    - Hot bonding of fittings was unsuccessful and development was deemed to be not cost effective.
    - Therefore fittings were cold bonded for ATC Program.
    - Strength of cold bond questionable at temperature extremes and would require increased fitting size for Prototype.
    - Bonds hard to inspect and unrepairable.

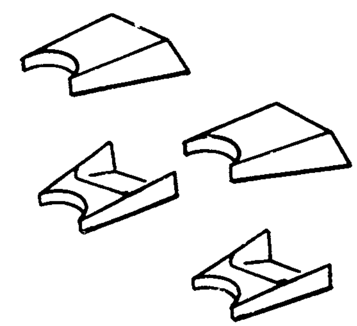


Figure 147. Droop Stop Fittings

6.0 CONCLUSIONS

The HLH/ATC Rotor Blade Program successfully accomplished its original design objectives and evolved an advanced composite blade that promises significant performance and operational advancements over conventional rotor blades. This blade, in addition, has demonstrated that it is a cost-effective, producible design consistent with the overall HLH design-to-cost philosophy.

Significant manufacturing technology breakthroughs for the HLH rotor blade include:

- The first advanced composite blade fabricated with electrically heated, zone temperature controlled, matched metal dies using internal fluid pressure.

- The first rotor blade to be constructed with a fiberglass spar, Nomex aft fairing, and titanium leading edge.

- The largest titanium part successfully preformed for an aerospace primary structure (over 37 feet in length and approximately 3 feet wide prior to forming).

- The first co-cure of a composite spar with a titanium nose cap.

It should be noted that the initial "tool proving" root end article was of sufficiently good quality to be subjected to engineering fatigue tests and exceeded the specified test requirements.

The following significant conclusions can be drawn from the HLH/ATC rotor blade development:

1. The tooling and manufacturing approach utilized was verified through extensive testing of full-scale rotor blade hardware.

2. The HLH rotor blade design possesses many inherent features directed toward the use of automated tooling for high rate production which will result in reductions in unit cost.

3. Precise weight control of the blade can be achieved with a minimum of effort.

4. The matched metal tools assure airfoil surfaces and blade physical properties that are consistent and repeatable from unit to unit.

5. Nondestructive test techniques have been developed and are now available to provide the high level of quality assurance needed for production of composite rotor blades.

6. The use of computer-based Master Dimensioning Information was extremely successful in coordinating the fabrication of the various tools required and ensuring that the advanced aerodynamic rotor blade contours were attained.

7. Excellent raw material utilization was experienced through techniques such as the use of constant-width tapes, coiled titanium sheets, precut Nomex honeycomb core wedges, and chopped fiber match-molded detail fittings.

8. Additional work is being done, and should be continued to augment capability in the areas of:

   a. Titanium cap fabrication

   b. Honeycomb machining

   c. Improvement of parting agents

   d. Improvement of bag materials and fabrication techniques

   e. Automation and semiautomation of fiber polymer lay-ups.

APPENDIX A
BLADE TEST PROGRAM

INTRODUCTION

The blade test program was initiated early in the ATC program with a series of tests to accumulate basic design development data. Later, another series of tests was conducted to support the design and prove out critical components and concepts prior to being committed to the final tooling approach and fabrication of the full scale hardware. Upon completion of blade fabrication, another series of full scale specimen tests was required to demonstrate the final properties of the actual hardware. This appendix identifies those tests, including a brief description of the effort involved and other appropriate comments.

DESIGN DEVELOPMENT TESTS

Test Program	Title	Brief Description
218001	Airfoil Development Test - 2D	A series of wind tunnel tests was conducted to support development of the basic airfoil. The tests included fabrication of sub-scale 2D models of selected candidate airfoils.
220000	Dynamic Airloads Evaluation	A series of 220 programs was initiated to conduct a dynamic airloads evaluation. A number of sub-scale blades were fabricated and then tested in the wind tunnel. The blades were fabricated in match molds, similar to the process used for the full scale blades. A noteworthy accomplishment was the machining technique used for fabricating the molds. Using the blade MDI data, NC tapes were created, and the molds were NC machined. Previously, this was accomplished using conventional machining and included extensive hand finishing to achieve the desired airfoil. Significant savings were realized and subsequent program molds will be NC machined whenever MDI data is available. The test was conducted using the Dynamic Rotor Test Stand (DRTS), which was reconfigured with simulated HLH hub and upper controls.

DESIGN DEVELOPMENT TESTS - Continued

Test Program	Title	Brief Description
238001	UHM Hover Test	A wind tunnel hover test was conducted to investigate means of eliminating tandem rotor blade bang. The Boeing Vertol Universal Helicopter Model (UHM) was used with blades modified to a candidate configuration.
623000	Airfoil Development Tests - 3D	To support development of the blade basic airfoils and twist schedule, a series of 3-dimensional tests was conducted. A number of model sub-scale blades were fabricated using selected airfoils and advanced blade geometries. The blades were then tested to gather performance data and to select the optimum configuration. The test was conducted with the blades mounted on the Boeing Vertol Rotor Test Stand (RTS), which was positioned in the Boeing Vertol V/STOL wind tunnel.
625002	Stall Flutter Load Determination	The stall flutter wind tunnel program was planned to determine blade damping requirements and to provide correlation data and design criteria for the full scale HLH lag damper actuators. The program was initiated but was not completed because of the wind tunnel model's inability to duplicate conditions of the scaled control system.

DESIGN SUPPORT TESTS

Test Program	Title	Brief Description
511001	Core and Seal Development	The core and seal development test included the fabrication and test of small simulated fairing coupons. Also included were static test, fatigue test of sealants, and moisture absorption.
520001 (Part "A")	Impact Tests	The impact tests included the fabrication of a sub-scale specimen, complete with a formed titanium leading edge. Specimens were built with the various materials planned for use in the HLH blade. The tests consisted of whirling each blade and subjecting it to an impact with a simulated small tree.
520001 (Part "B")	Erosion Tests	The erosion tests included the fabrication and test of specimens with various types of erosion protection. The specimens were mounted on the whirling arm test fixture and exposed to various types of erosion.
615001	Materials Evaluation Phase I	Materials and processes associated with the "coke-bottle" blade concept were tested in Phase I of the program. Process variables were simulated by fabrication of coupon type specimens.

DESIGN SUPPORT TESTS - Continued

Test Program	Title	Brief Description
615002	Materials Evaluation Phase II	Materials and processes associated with the "wraparound" blade concept were tested under Phase II of the materials evaluation program. The wraparound concept was completely new; therefore, this phase of the program was more comprehensive than the testing done under the Phase I evaluation.
616003	Outboard Section Tests	This program fabricated and tested several simulated outboard spar specimens. Long (180-inch) "D" spar specimens were fabricated using glass and titanium cured in a matched mold die. In addition, a series of oval tubes were fabricated with different configurations. The oval tube specimens were used to develop ISIS data, proving that pneumatic type ISIS systems were compatible with failure detection in glass composite structures.

DESIGN SUPPORT TESTS - Continued

Test Program	Title	Brief Description
617001	Root End Tests	These root end tests included the fabrication and testing of a full scale root end specimen built to the dual "coke-bottle" concept. The initial unit was a "tool prover" article made of steel fittings and fiberglass. Another article to be tested used titanium in the dual "coke-bottle" metal details and fiberglass and graphite for the composite details. One specimen was fabricated with plastic molds; one was fabricated with aluminum molds; and a third was specimen was fabricated using steel molds. An integral part of this program was an investigation of various tooling concepts. Selection of the final tooling concept was based on the data developed during the program. Included as a part of this program was the fabrication of the tooling required to fabricate the root ends.

DESIGN SUPPORT TESTS - Continued

Test Program	Title	Brief Description
617002	Root End Tests	These root end tests included the fabrication and testing of two full scale root end specimens built to the wraparound blade concept. The first specimen tested proved to be very successful and negated the necessity of testing the second specimen. The original test was then extended over a longer time period, and the specimen continued to carry the loads until the test was concluded. Failure was ultimately induced by cutting one spar strap at a time until 3 of the 4 straps had been cut.
		Fabrication of a dummy damper arm fitting and retrofitting the root end to simulate the selected blade root end configuration was included as a part of the test extension.
629001	Titanium Thread Evaluation	The initial HLH blade design included the redundant "dual coke-bottle" root end fittings, which were fabricated from titanium forgings. The purpose of the titanium thread evaluation test was to understand the thread fretting inherent in that design. A number of specimens were fabricated using various fretting inhibitors, and were then tested. The existing blade design eliminates the need for the titanium thread data.

DESIGN DEMONSTRATION TESTS

Test Program	Title	Brief Description
224001	Lightning Test Program	Sections of blade No. 1 were prepared and shipped to an offsite test facility for lightning evaluation. A post test cut up and evaluation of the tested articles was also included in this test.
627001	Static Test Program	Static testing of the full scale specimens was performed under this program. In addition to static tests of the sectional fatigue specimens, a full blade was static tested, including blade properties identification (natural frequency, etc.).
628002	Fatigue Test Program	All of the full scale blade fatigue tests were conducted under this program. The various types of specimens were tested for root end fatigue, intermediate bending fatigue, outboard bending fatigue, outboard torsional fatigue, chordwise airload fatigue, and tip hardware fatigue. The program also included test fixture fabrication and modification. Test hardware was also fabricated as a part of this program, which in total represented a significant work package.

DESIGN DEMONSTRATION TESTS - Continued

Test Program	Title	Brief Description
290001	Whirl Test	The four whirl blades were installed on the whirl tower, together with the hub and upper controls. A test of more than 33 hours duration was performed to identify blade flying qualities and to subject the blades to an overspeed condition. Overall, the blade performance was excellent.
730001	DSTR Test	The Dynamic System Test Rig (DSTR) was fabricated to provide an integrated test bed for the entire dynamic system. The four whirl blades will undergo further flight evaluation during the course of this program.

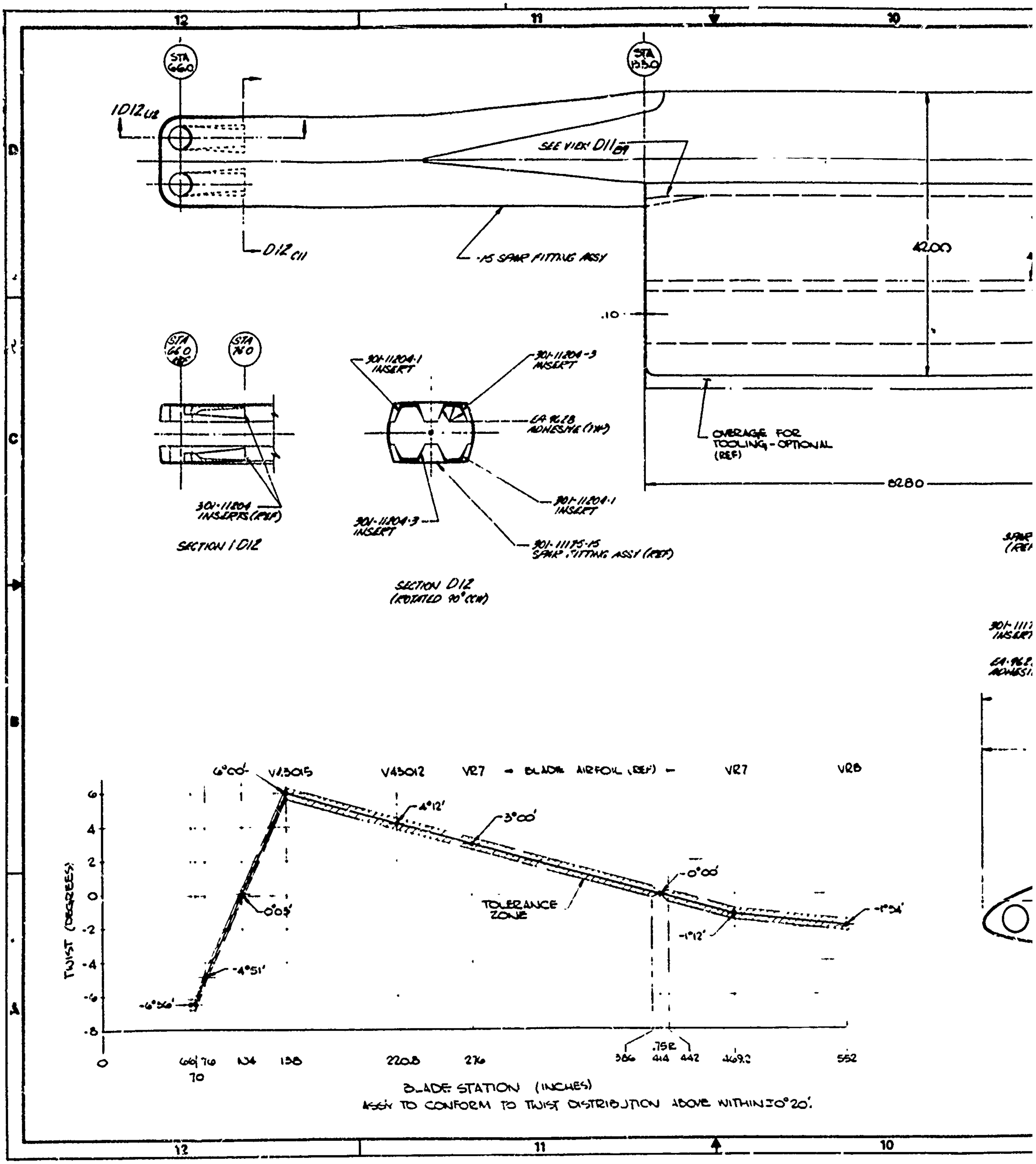
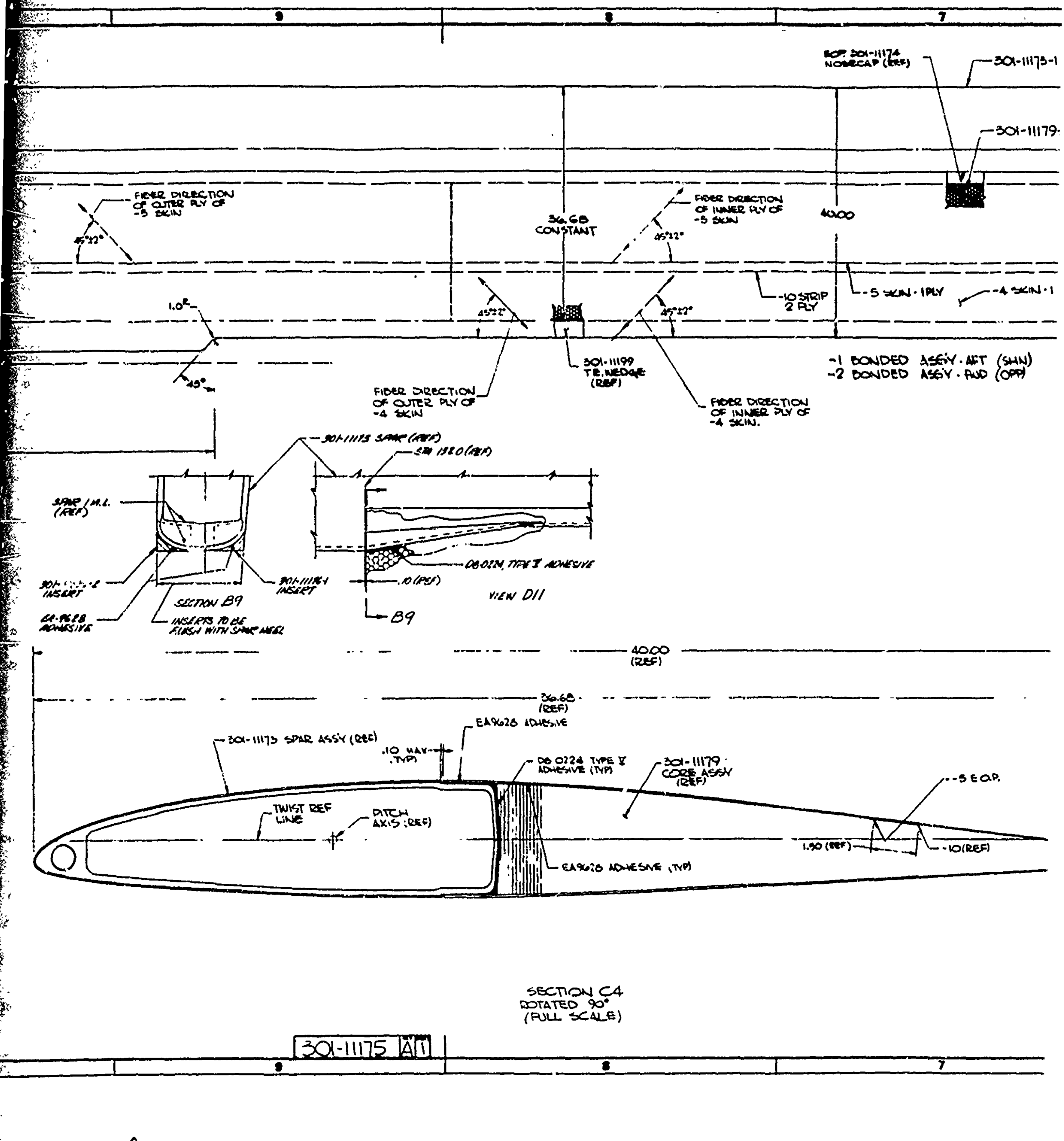
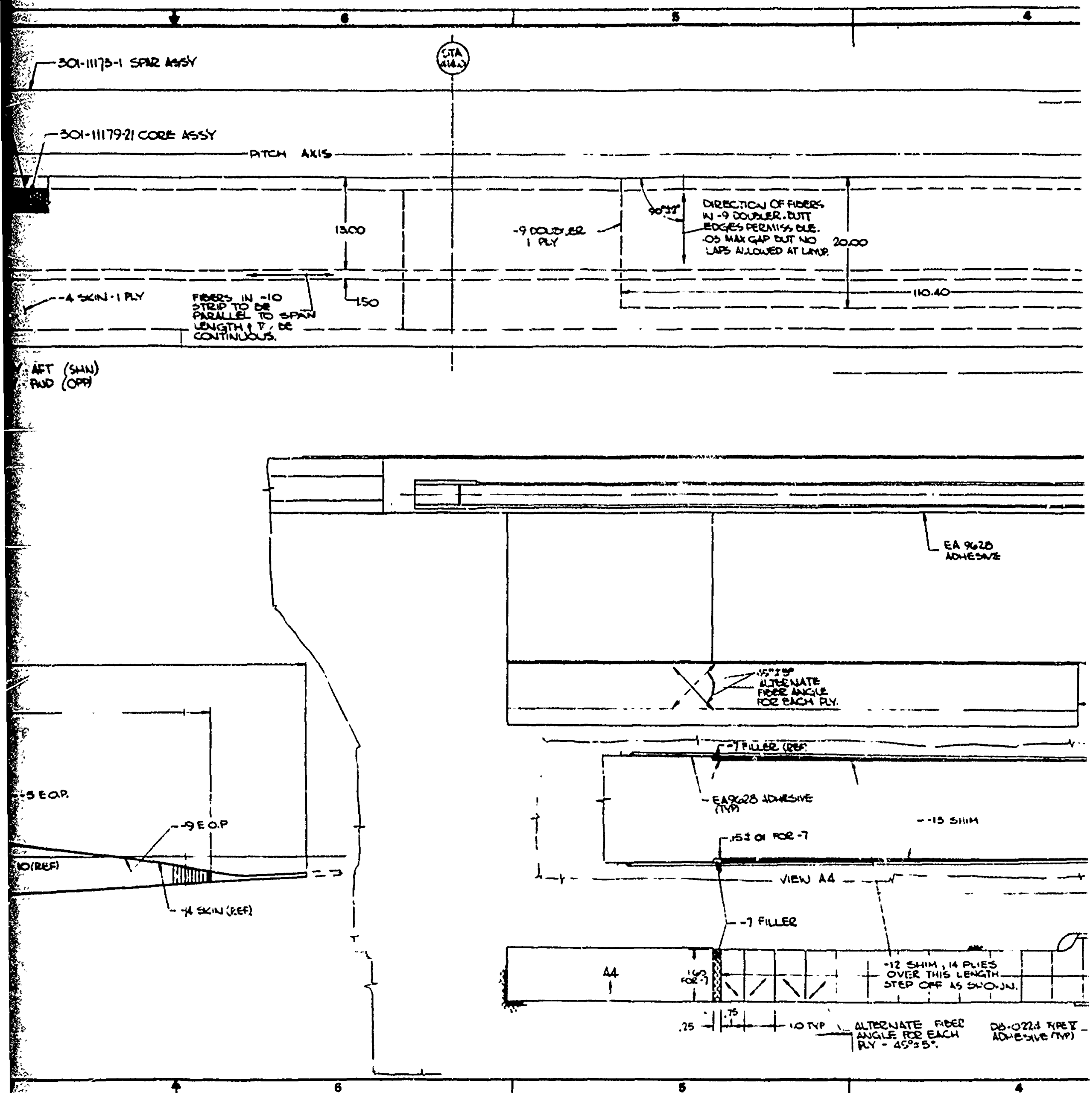


Figure B-1. Bonde·' Assembly 301-11175


9
8
7
REF 301-11174 NOSECAP (REF)
301-11175-1
301-11179
FIBER DIRECTION OF OUTER PLY OF -5 SKIN
45°±2°
36.68 CONSTANT
FIBER DIRECTION OF INNER PLY OF -5 SKIN
40.00
-10 STRIP 2 PLY
-5 SKIN · 1 PLY
-4 SKIN · 1
1.0R
45°
301-11199 T.E. WEDGE (REF)
FIBER DIRECTION OF OUTER PLY OF -4 SKIN
FIBER DIRECTION OF INNER PLY OF -4 SKIN.
-1 BONDED ASSY · AFT (SHN)
-2 BONDED ASSY · FWD (OPP)
301-11175 SPAR (REF)
STA 192.0 (REF)
SPAR I.M.L. (REF)
DB 0224, TYPE V ADHESIVE
.10 (REF)
INSERT
301-11184-1 INSERT
SECTION B9
VIEW D11
EA-9628 ADHESIVE
INSERTS TO BE FLUSH WITH SPAR MOLD
B9
40.00 (REF)
36.68 (REF)
EA9628 ADHESIVE
301-11175 SPAR ASSY (REF)
.10 MAX (TYP)
DB 0224 TYPE V ADHESIVE (TYP)
301-11179 CORE ASSY (REF)
-5 E.O.P.
TWIST REF LINE
PITCH AXIS (REF)
1.50 (REF)
-10 (REF)
EA9628 ADHESIVE (TYP)
SECTION C4
ROTATED 90°
(FULL SCALE)
301-11175 A1
9
8
7

2



301-11175-1 SPAR ASSY
STA 414.0
301-11179-21 CORE ASSY
PITCH AXIS
13.00
-9 DOUBLER 1 PLY
90°±3°
DIRECTION OF FIBERS IN -9 DOUBLER. BUTT EDGES PERMISSIBLE. .05 MAX GAP BUT NO LAPS ALLOWED AT LAYUP.
20.00
-4 SKIN - 1 PLY
FIBERS IN -10 STRIP TO BE PARALLEL TO SPAN LENGTH & TO BE CONTINUOUS.
1.50
110.40
AFT (SHN)
FWD (OPP)
EA 9628 ADHESIVE
45°±5° ALTERNATE FIBER ANGLE FOR EACH PLY.
-7 FILLER (REF)
-5 E.O.P.
EA9628 ADHESIVE (TYP)
-15 SHIM
-9 E.O.P
.15± .01 FOR -7
-10(REF)
-4 SKIN (REF)
VIEW A4
-7 FILLER
A4
.163 FOR -7
-12 SHIM, 14 PLIES OVER THIS LENGTH STEP OFF AS SHOWN.
.25
.75
1.0 TYP
ALTERNATE FIBER ANGLE FOR EACH PLY - 45°±5°.
DB-0224 TYPE II ADHESIVE (TYP)

NOTES: CONTINUED

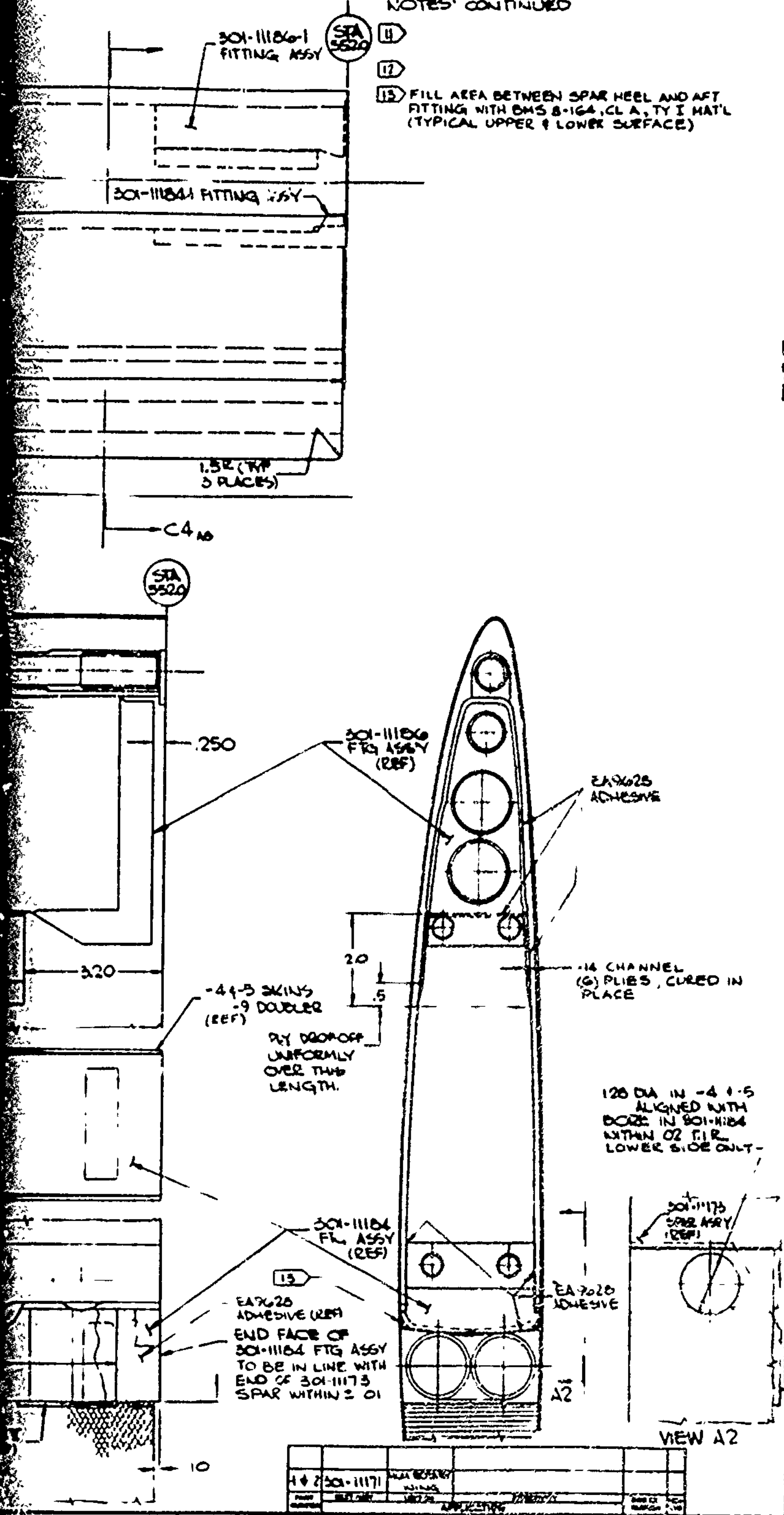
11

12

13 FILL AREA BETWEEN SPAR HEEL AND AFT FITTING WITH BMS 8-164, CL A, TY I MAT'L (TYPICAL UPPER & LOWER SURFACE)

2 FABRICATE PER BOEING DOC. D301-10154-1
3. CHORDWISE BOW OF ASSY TO BE MAX. OF .50 FWD OR AFT MEASURED BETWEEN STATION 138 & 552.
4. OUTSIDE CONTOUR OF ASSY TO MATCH BLADE BASIC OML DEFINED BY BOEING DOC. D301-10136 WITHIN ± .015.
5. FLAPWISE BOW OF ASSY MEASURED WITH ASSY STANDING ON ITS LEADING EDGE TO BE .50 MAX IN EITHER DIRECTION BETWEEN STATION 138 & 552.
6. BONDED ASS'Y TO BE INSPECTED PER BOEING INSPECTION PROCEDURE DOC D301-10157.
7
8
9

10 THIS IS A CRITICAL PARTS ASSEMBLY & REQUIRES ALL TESTS & RECORDS SPECIFIED IN BOEING PROCESS SPEC MS 14.00



	-16	-15	-2	-1	Part No.	Nomenclature	Zone	Material and Specification
	3				301-11204-4	INSERT		
		2			301-11204-3	INSERT	C11	
	2				301-11204-2	INSERT		
		2			301-11204-1	INSERT	C11	
			-	-	MS 14.00	CRITICAL PARTS SPEC	NOTE 10	
	-	-	-	-	D301-10157	INSPECTION DOCUMENT	NOTE 6	
	-	-	-	-	D301-10136	MDI DOCUMENT	NOTE 4	
	-	-	-	-	D301-10154-1	PROCESS DOCUMENT	NOTE 2	
					D8-0224	ADHESIVE SPEC		
			A/R	A/R	D8-0224, TYPE V	ADHESIVE		(FM 37)
	A/R	A/R	A/R	A/R	EA 9628	ADHESIVE		PER D301-10154-1
	1				301-11186-2	FITTING, - FWD		
		1			301-11186-1	FITTING - FWD	D3	
	1				301-11184-2	FITTING - AFT		
		1			301-11184-1	FITTING - AFT	D3	
	X		1		-16	SPAR FTG. ASSY		
		X		1	-15	SPAR FTG ASSY	D11	
	1	1			-14	CHANNEL	B3	BMS 8-164, CLASS 'A', TYPE III
			1	1	-13	SHIM	B4	(OPP -12)
			1	1	-12	SHIM	A4	BMS 8-164, CLASS A TYPE I
			1		301-11179-22	FAIRING ASSY		
				1	301-11179-21	FAIRING ASSY	D7	
	1				301-11173-2	SPAR ASSY		
		1			301-11173-1	SPAR ASSY	D7	
	1				301-11176-4	INSERT		
	1				301-11176-3	INSERT		
		1			301-11176-2	INSERT	D11	
		1			301-11176-1	INSERT	D11	
ADD			2	2	-10	STRIP	C8	BMS 8-164, CLASS A, TYPE I
[illegible]			1	1	-9	DOUBLER	D6	BMS 8-164, CLASS A, TYPE I
			2	2	-7	FILLER	A5	BMS 8-124, CLASS IV, TYPE 3, GRADE 4.0
[illegible]			1	1	-5	SKIN	C7	BMS 8-164, CLASS A TYPE III
301-[illegible]			1	1	-4	SKIN	C7	BMS 8-164, CLASS A TYPE III
			X		-2	BONDED ASSY	C7	(OPP -1 FWD BLADE)
				X	-1	BONDED ASSY	C7	AFT BLADE)

BONDED ASS'Y ROTARY WING HLH

J 77272 301-1117[illegible]

7540

4

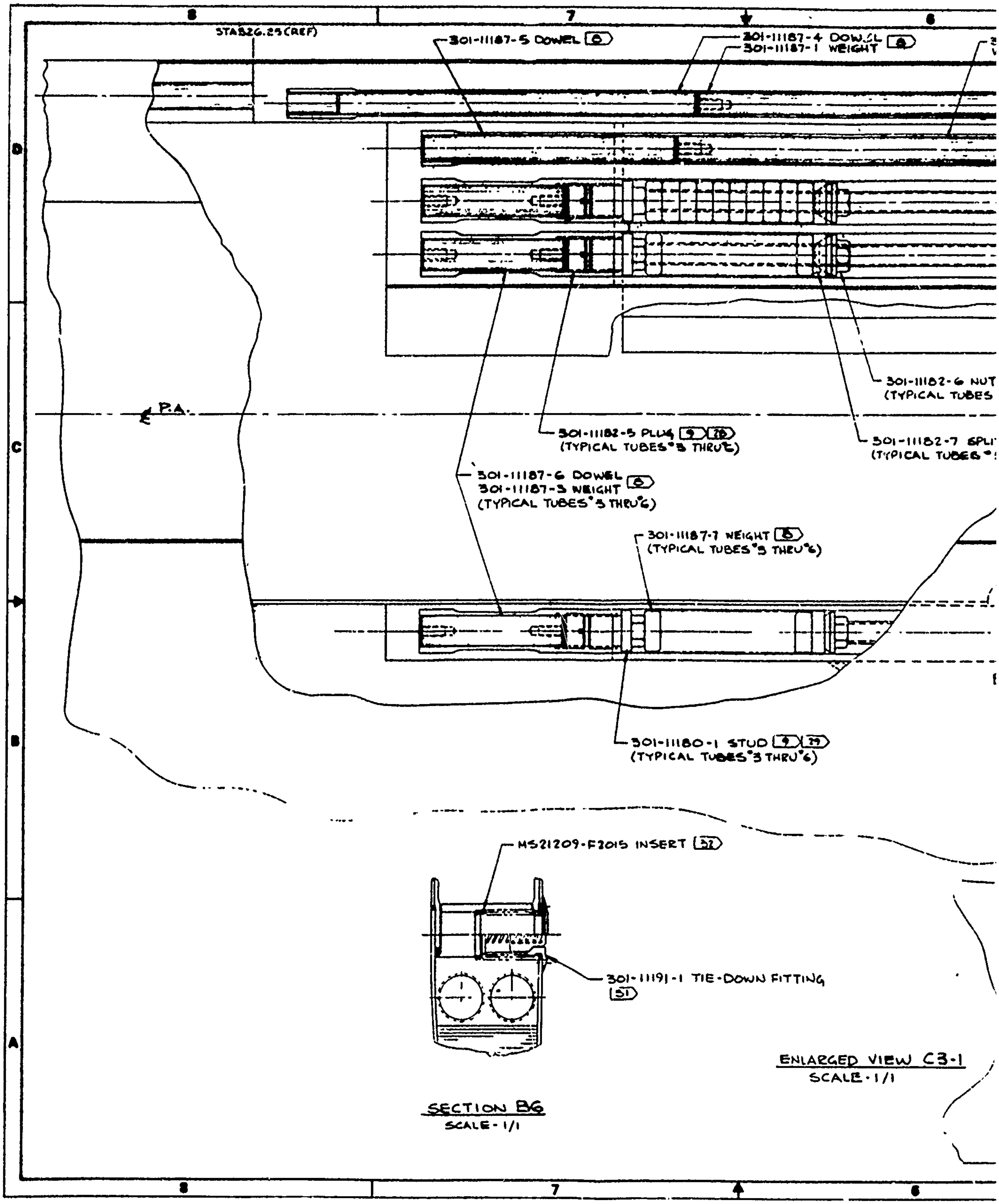
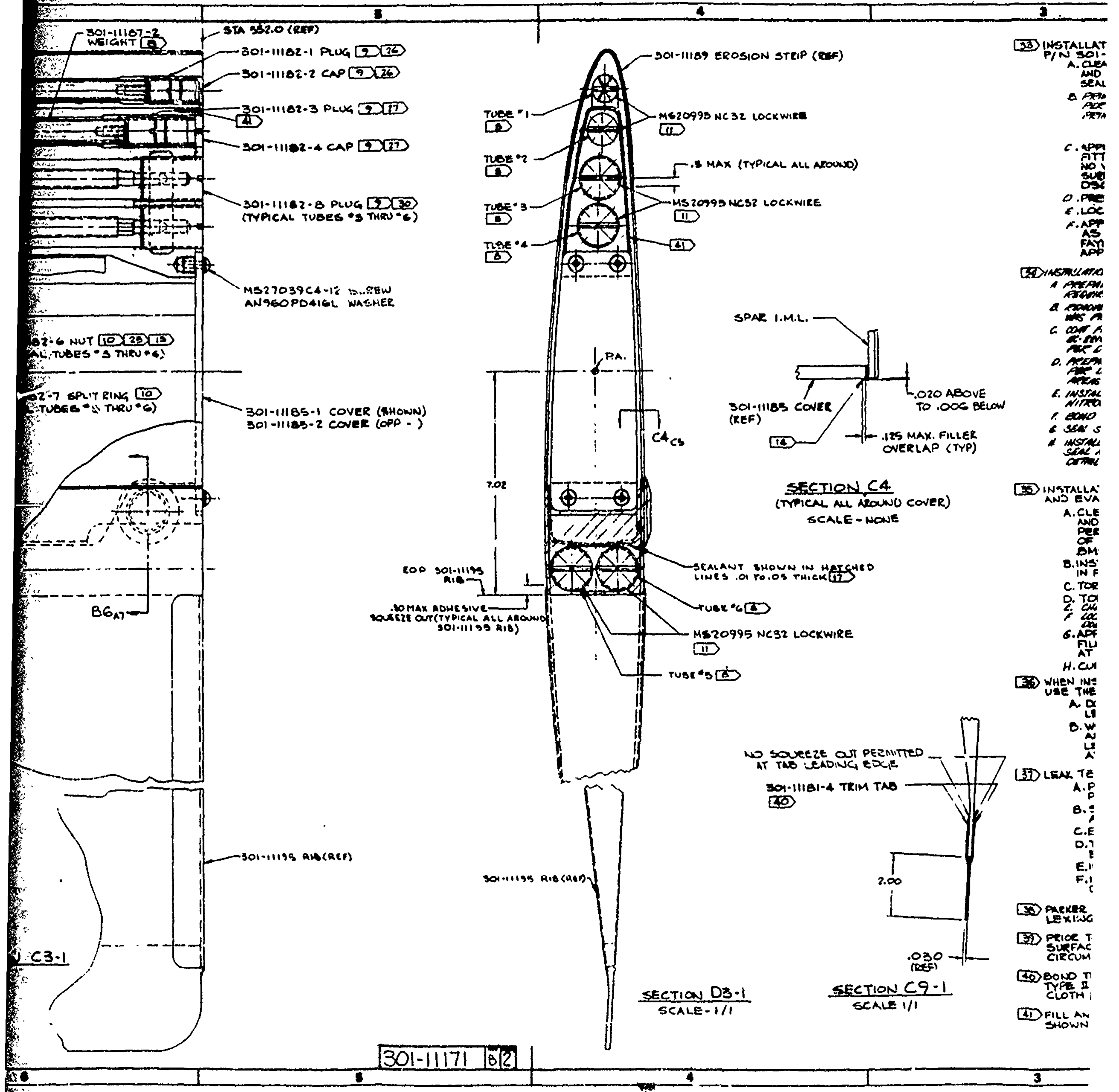


Figure B-2. Blade Assembly 301-11171 (Sheet 2)



301-11171 B 2

2

ABOVE
DOG BELOW
FILLER
(TYP)

NOTES - CONTINUED FROM SHEET 1

A	SEE DCN A		
B	SEE DCN B		

33 INSTALLATION OF OUTBOARD BULKHEAD P/N 301-11203:
- A. CLEAN SPAR I.D. (STA 546 THRU STA 552) AND ALL AREA'S WHICH WILL HAVE BMS 5-44 SEALANT APPLIED PER D301-10154-1.
- B. PRIME THESE AREAS WITH EC-1945 PRIMER PER D301-10154-1. APPLY A HIDING COAT OF PRIMER-NO RUNS OR THIN AREAS PERMITTED.
- C. APPLY BMS 5-44 SEALANT ALONG SPAR AND FITTINGS (FWD & AFT) JOINTS AS SHOWN NO VOIDS PERMITTED AT FAYING SURFACES. APPLY AND CURE PER D301-10154-1.
- D. PREPARE BULKHEAD PER D301-10154-1.
- E. LOCATE BULKHEAD IN SPAR AS SHOWN.
- F. APPLY BMS 5-44 SEALANT; FILLING CAVITY AS SHOWN. NO VOIDS PERMITTED AT FAYING SURFACES OF SPAR AND SEALANT. APPLY AND CURE PER D301-10154-1.

34 INSTALLATION OF 301-11364 DAMPER FITTING & SLEEVES:
- A PREPARE SPAR SURFACES FOR EC 2216 BOND PER REQUIREMENTS OF D301-10154-1.
- B REMOVE DAMPER FITTING FROM WRAPPER. (FITTING WAS PREVIOUSLY PREPARED FOR BOND)
- C COAT FAYING SURFACES OF SPAR AND FITTING WITH EC-2216 ADHESIVE AND INSTALL AS SHOWN. CURE PER D301-10154-1. USE SCRIM PER 24
- D. PREPARE 301-11201-1 SLEEVES FOR EC-2216 BOND PER D301-10154-1. PREPARE ONLY SLEEVE O.D. AREAS NOT COATED WITH SARMETEL 72.
- E. INSTALL SLEEVES PER BAC 5435, ONLY LIQUID NITROGEN IS TO BE USED AS A COOLANT.
- F BOND SLEEVES PER 18
- G SEAL SLEEVES PER 39
- H INSTALL WASHERS, 301-11200-1 INTO WET BMS 5-44. SEAL AROUND OUTER DIA OF WASHERS PER DETAIL C12.

35 INSTALLATION OF INDICATOR ASSY P/N 114RS100 AND EVACUATION VALVE ASSY P/N 301-11190.
- A. CLEAN AREA'S OF MOUNT , INDICATOR, AND VALVE WHERE "O" RINGS WILL SEAL PER BAC 5750. COAT FAYING SURFACES OF MOUNT , INDICATOR AND VALVE WITH BMS 5-44 (DO NOT CURE)
- B. INSTALL INDICATOR AND VALVE, WITH 'O' RINGS IN PLACE, TO THE MOUNT FITTING.
- C. TORQUE EVACUATION VALVE TO 100-140 IN LB.
- D. TORQUE INDICATOR TO 100-140 IN.LB.
- E. CHECK TORQUES AS [illegible] AFTER INITIAL INST'L.
- F LOCKWIRE INDICATOR TO VALVE PER BAC 5018, DOUBLE TWIST METHOD.
- G. APPLY BMS 5-44 SEALANT TO FORM A FILLET AROUND INDICATOR AND VALVE AT MOUNT FITTING JUNCTURE AS SHOWN.
- H. CURE BMS 5-44 PER D301-10154-1

36 WHEN INSTALLING THE INDICATOR ASSY P/N 114RS100 USE THE FOLLOWING PRECAUTIONS:
- A. DO NOT PERMIT SOLVENTS TO CONTACT LEXAN SURFACE.
- B. WHEN TORQUEING INDICATOR DO NOT AFFIX WRENCH TO RING AT BASE OF LEXAN COVER. USE ATTACHING POINTS AT BASE OF INDICATOR.

37 LEAK TEST OF DETECTION SYSTEM
- A. PERFORM A FINAL SYSTEM LEAK TEST PER D301-10154-1.
- B. SYSTEM LEAK RATE CRITERIA IS 7×10^{-5} ATMOS CC/SEC OF HELIUM.
- C. EVACUATE SPAR TO 3.0 TO 3.5 PSIA
- D. TORQUE VALVE JAM NUT TO 20 IN.LB AFTER EVACUATION AND WHILE PUMP IS ON.
- E. INSTALL VALVE CAP AND TORQUE TO 5-10 IN.LB.
- F. INSTALL LOCKWIRE PER BAC 5018 DOUBLE TWIST METHOD.

38 PARKER SEAL CO DIV OF PARKER HANNIFIN CORP LEXINGTON KY.

39 PRIOR TO INSTALLATION OF WASHERS, SEAL FAYING SURFACES OF SLEEVE & SPAR AROUND COMPLETE CIRCUMFERENCE USING BMS 5-44 PER D301-10154-1.

40 BOND TRIM TAB P/N 301-11181 TO BLADE PER D8-0224 TYPE II ADHESIVE BONDING SYSTEM (USING SCRIM CLOTH 24)

41 FILL AND FAIR CAVITY BETWEEN FITTING AND SPAR AS SHOWN USING DOW 92-018 SEALANT PER D301-10154-1

(NOTES CONTINUED ON SHEET 3)

10 APPLY MIL-L-23398 SOLID FILM LUB. TO TAPERED SURFACE PER BAC 5811, METHOD 2.

11 INSTALL PER BAC 5018.

12 INSTALL PER BAC 5435.

13 ANTI-SEIZE COMPOUND TT-A-580 TO BE USED ON THREADS WHEN INSTALLING NUTS P/N 301-11182. AFTER INSTALLATION OF NUTS REMOVE ALL EXCESS COMPOUND.

14 SEAL JOINT BETWEEN COVER P/N 301-11185 AND SPAR I.M.L. AS SHOWN USING DOW 92-018 SEALER PER BOEING DOCUMENT D301-10154-1. (SEE SECTION C4-2)

15 BOND EROSION STRIP P/N 301-11159 TO BLADE USING EC-2216 ADHESIVE PER D301-10154. (USING SCRIM CLOTH 24). FAIR EDGES ALL AROUND AS SHOWN IN ZONE C4-2.

16 FILL AND FAIR CAVITY BETWEEN TRAILING EDGE OF EROSION CAP AND LEADING EDGE OF FAIRING SKINS AS SHOWN USING EPON 934 ADHESIVE PER D301-10154-1. REMOVAL OF EXISTING RESIN OR ADHESIVE IN CAVITY NOT REQUIRED.

17 SURFACES TO BE FAIRED AS SHOWN USING DOW 92-018 SEALANT PER D301-10154. THERE SHALL BE NO DISCONTINUITIES GREATER THAN .06.

18 BOND SLEEVE P/N 301-11201 IN PLACE USING EC-2216 ADHESIVE PER D301-10154-1. DO NOT USE SCRIM. EC-2216 MAY BE THINNED TO FACILITATE INSERTION, PER D301-10154-1.

19 COMMERICAL ITEM

20 ADIPRENE - POLYURETHANE (POLYETHER BASE) HARDNESS SHORE "A" 65±5 TENSILE STRENGTH AT BREAK 2700 PSI MIN. ELONGATION AT BREAK 400% MIN MAY BE PURCHASED FROM:
QUANTUM INCORP.
BARNES INDUSTRIAL PARK
WALLINGFORD, CONN. 06492

21

22

23 VENDOR ITEM - SEE SPECIFICATION CONTROL DRAWING

24 SCRIM CLOTH NO. 655 DACRON
TRAVIS MILLS INC
N.Y., N.Y.

25 TORQUE TO 350 - 400 IN LBS
DO NOT USE POWER TOOL TO INSTALL NUT.

26 TORQUE TO 100 - 150 IN LBS

27 TORQUE TO 100 - 200 IN LBS

28 TORQUE TO 200 - 300 IN LBS

29 TORQUE TO 1400 - 1500 IN LBS

30 PLUG TO BE FLUSH TO .03 IN FROM BLADE TIP

31 INSTALL FITTING AND SEAL FITTING EDGES AS SHOWN USING EC-2216 ADHESIVE PER D301-10154-1

32 TAP WITH HELI-COIL STI TAP #8193-20H4 MIN. FULL THREAD DEPTH 2.00 INSTALL INSERT WITH HELI-COIL INSERTING TOOL NO. 535-20. INSERT TO BE .06 - .12 BELOW SURFACE REMOVE DRIVING TANG WITH LONG NOSED PLIERS BY BENDING TANG UP AND DOWN TO SNAP OFF AT NOTCH

DAAJ01 71-C-0401
R. BELLO
BLADE ASSEMBLY
HLH
ROTOR BLADE
J 77272 301-11171
SCALE 1/2
7540

301-11171 S