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CAST ALUMINUM STRUCTURES TECHNOLOGY (CAST) *Phase* VI.
TECHNOLOGY TRANSFER.
SUMMARY TECHNICAL REPORT

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James W. Faber

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The Boeing Company
Seattle, Washington 98124

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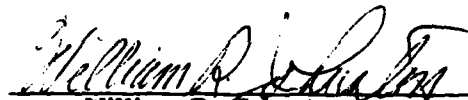
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This technical report has been reviewed and is approved for publication.

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

The objectives of CAST were to establish the necessary structural and manufacturing technologies and to demonstrate and validate the integrity, producibility, and viability of cast aluminum primary airframe structures.
This report summarizes efforts involved in the six phases of the program:
Phase I - Preliminary Design, Phase II - Manufacturing Methods, Phase III - Detailed Design, Phase IV - Fabrication of Demonstration Articles and Production Hardware, Phase V - Structural Test Evaluation, and Phase VI - Technology Transfer.

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FOREWORD

This report was prepared by the Boeing Military Airplane Company, Advanced Aircraft Branch, Seattle, Washington under USAF Contract No. F33615-76-C-3111. The contract work was performed under project 486U under the direction of the Flight Dynamics Laboratory, Advanced Metallic Structures/Advanced Development Program Office, Wright-Patterson AFB, Ohio. A significant portion of the contract was funded by the Metals Branch of the Manufacturing Technology Division of the Materials Laboratory. The Air Force Project Engineer was John R. Williamson of the AMS Program Office, Structural Mechanics and Dynamics Division, Flight Dynamics Laboratories (AFWAL/FIBAA).

The Boeing Military Airplane Company, Advanced Aircraft Branch, was the contractor, with Donald E. Strand as program manager and Donald D. Goehler as technical leader. Boeing management of the specific phases and other aspects of the program was provided as follows:

o	Phase I--Preliminary Design	Richard C. Jones
o	Phase II--Manufacturing Methods	Richard G. Christner
o	Phase III--Detailed Design	Richard C. Jones
o	Phase IV--Fabrication of Demonstration Articles and Production Hardware	Richard G. Christner
o	Phase V--Structural Test and Evaluation	Christian K. Gunther
o	Phase VI--Technology Transfer	James W. Faber
o	Business Manager	Dean H. Scovell
o	Program Coordination	William L. Slosson

The contractor's report number is D180-25725-1. This report covers work from June 1976 through April 1980. Previous work performed on the CAST program was reported in:

- o AFFDL-TR-77-36, Final Report (Phase I) for period June 1976-February 1977
- o AFFDL-TR-78-62, Final Report (Phase II) for period August 1976-March 1978
- o AFFDL-TR-78-7, Final Report (Phase III) for period February 1977-December 1977
- o AFFDL-TR-79-3029, Final Report (Phase IV) for period June 1977-March 1979
- o AFWAL-TR-80-3021, Parts I, II, and III, Final Report (Phase V) for period February 1977-January 1980

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The above five reports and the Technology Transfer (Phase VI) activities are summarized herein.

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SECTION I

INTRODUCTION

This report summarizes the work conducted and the results achieved in the Cast Aluminum Structures Technology (CAST) program.

The CAST program was another part of a long-term effort, the Advanced Metallic Structures-Advanced Development Program (AMS-ADP), being conducted by the Air Force Flight Dynamics and Materials Laboratories at Wright-Patterson Air Force Base, Ohio.

The purpose of the CAST program was to demonstrate that the use of premium-quality aluminum alloy castings in airframe construction could be extended to large primary structural components. The program goal was to demonstrate a minimum of 30% acquisition cost savings with no weight penalty and with no increase in maintenance cost. Specific objectives of the program were to establish necessary structural and manufacturing technologies, realistic production cost data, and realistic design allowables; to eliminate the use of any casting factor; and to demonstrate and validate improved structural integrity, reliability, producibility, and reproducibility of material properties and mechanical properties of cast aluminum airframe components. The end product of the program was the technology, including engineering specifications, transferred to the DoD/aerospace community.

The baseline airplane selected for the CAST program was the YC-14 prototype AMST (Advanced Medium STOL Transport) airplane. The baseline component selected to demonstrate structural casting capability was the YC-14 body/nose landing gear support bulkhead.

Figure 1 shows the YC-14 airplane and the location of the body/nose landing gear support bulkhead. This bulkhead provides forward support for the nose landing gear and nose gear door, carries cabin pressure on the upper segment, and provides support for the nose radome. A design for a sand-cast version of the bulkhead was established. The casting is 90 inches wide by 53 inches high, and a major portion of the part contains web areas and channels with 0.100-inch-thick walls. Figure 2 shows the nose of the YC-14 with the baseline fabricated sheet-metal bulkhead and the one-piece cast bulkhead standing on the floor. Figure 3 shows the aft side of the cast bulkhead.

1

STA. 170 LWR. BODY BULKHEAD
INCLUDING FWD NOSE GEAR SUPPORTS. (BASELINE)

Figure 1.   Boeing YC-14 AMST Prototype Airplane Showing Location of Baseline
Component Bulkhead

2
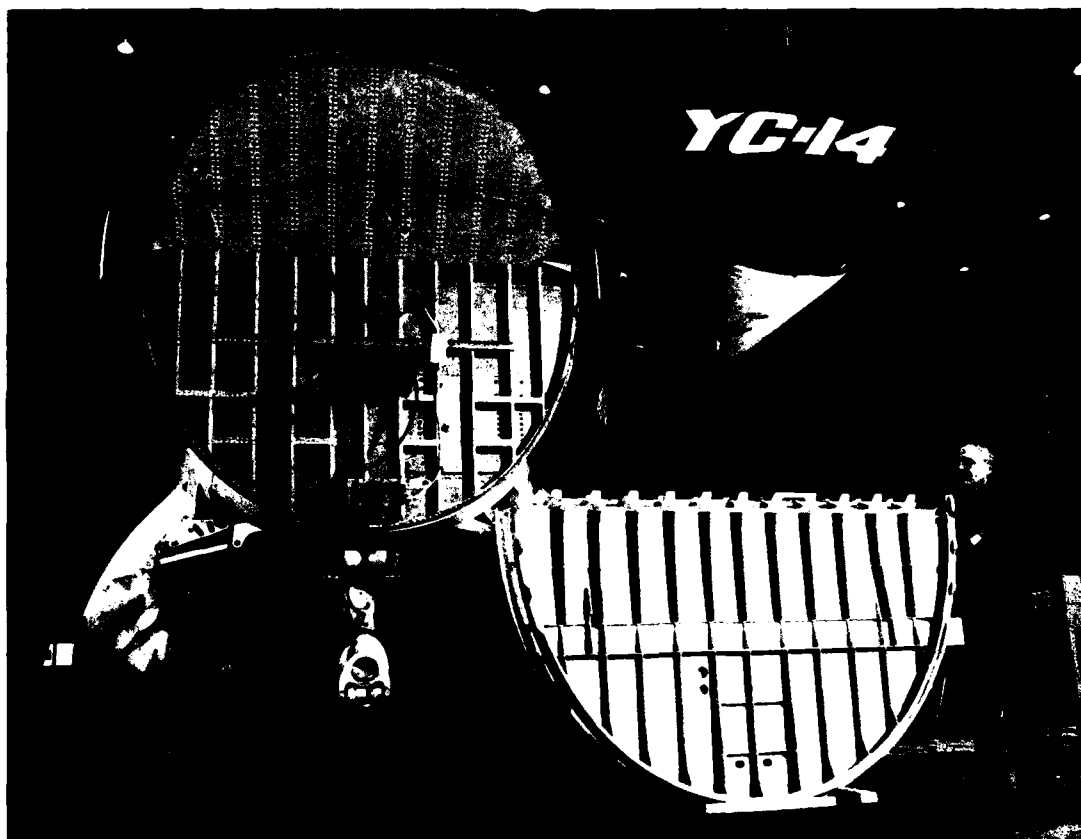
Figure 2.   Baseline Fabricated Sheet-Metal Bulkhead on YC-14 Airplane—CAST
Program Bulkhead on Floor
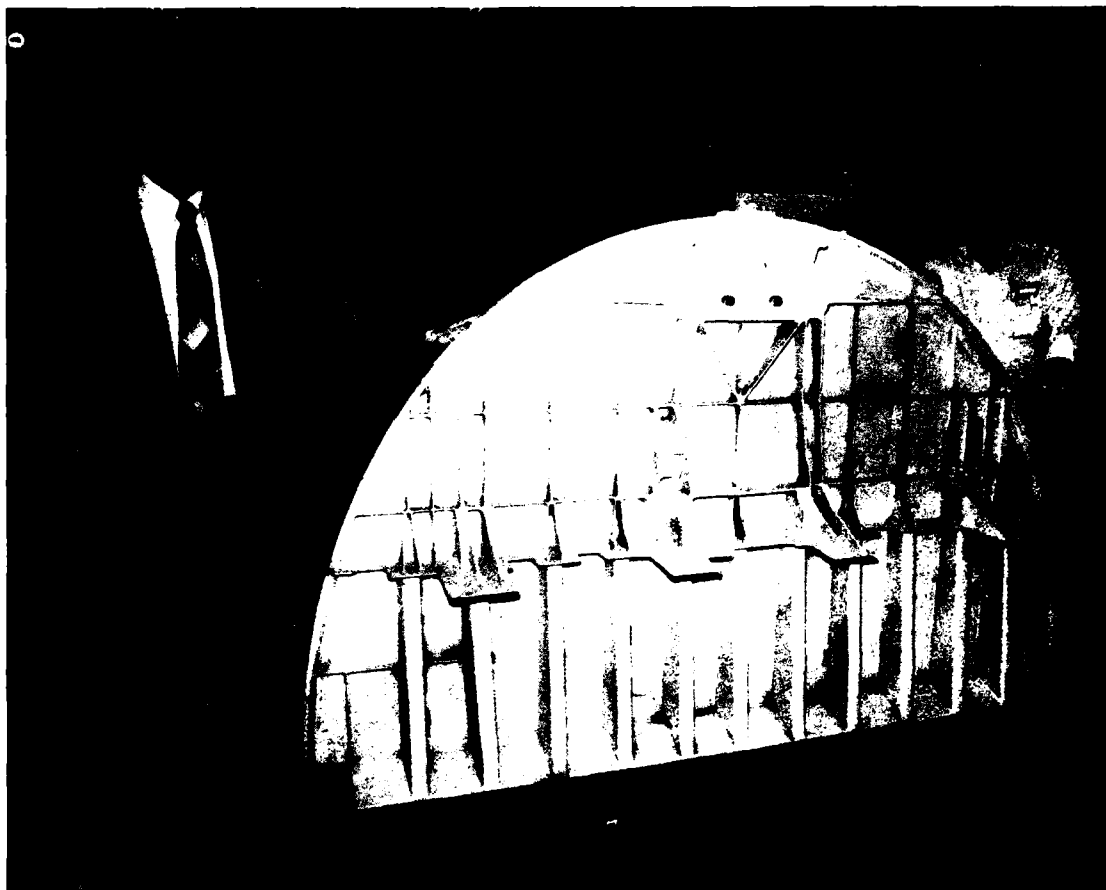
Figure 3.   YC-14 Body/Nose Landing Gear Support Bulkhead Casting—Aft Side

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The finish machined casting weight was estimated to be 181 pounds, which is comparable to the fabricated sheet-metal bulkhead weight. Production drawings for the bulkhead casting and bulkhead assembly are presented in Appendix A.

The aluminum casting alloy selected for the CAST program bulkhead was the age-hardenable silicon-magnesium alloy A357. This alloy is characterized by excellent castability, good response to heat treatment, high resistance to corrosion, and good weldability. A357 is similar to A356, but has a slightly higher magnesium content and controlled amounts of titanium and beryllium added to increase the strength. Table 1 shows the chemical composition limits established by the program material and process specification, M-XXXX, "Castings, Aluminum Alloy A357, Primary Aircraft Structure." This alloy was used in the solution-heat-treated and aged condition. Table 2 presents the nominal heat treatment. A typical microstructure of heat-treated A357 shows that solid solution dendrites of primary aluminum form the matrix, with an interdendritic eutectic network of alpha aluminum and silicon particles (Fig. 4). Extremely fine particles of the intermetallic phase, Mg_2Si, precipitate out of solid solution during aging; however, these are not visible at the magnification of Figure 4.

The CAST program was a six-phase effort. The six phases included the following specific activities:

Phase I: Preliminary Design
Phase II: Manufacturing Methods
Phase III: Detailed Design
Phase IV: Fabrication of Demonstration Articles and Production Hardware
Phase V: Structural Test and Evaluation
Phase VI: Technology Transfer

Complete details relative to any part of the work performed during the program can be found in the final report for each phase. These reports are listed in Section VII of this report.

Table 1.   A357 Chemical Composition

ELEMENTS	PERCENT, MINIMUM	PERCENT, MAXIMUM
COPPER	——	0.20
SILICON	6.5	7.5
IRON	——	0.10
MANGANESE	——	0.10
ZINC	——	0.10
MAGNESIUM	0.55	0.65
TITANIUM	0.10	0.20
BERYLLIUM	0.04	0.07
OTHERS, EACH	——	0.05
OTHERS, TOTAL	——	0.15
ALUMINUM	REMAINDER	

Table 2.   A357 Nominal Heat Treatment

SOLUTION HEAT TREATMENT	QUENCH DELAY	QUENCHANT	NATURAL AGING	PRECIPITATION HEAT TREATMENT (AGING)
$1010^{\circ}F \pm 10^{\circ}F$ FOR 16 HRS. MIN. $\boxed{1}\!\!>$	10 SEC. MAX.	$175^{\circ}F \pm 35^{\circ}F$ WATER	ROOM TEMP. FOR 16-24 HRS.	$325^{\circ}F \pm 25^{\circ}F$ FOR 8 HRS. $\pm$ 4 HRS.

$\boxed{1}\!\!>$ FOR CASTINGS WITH 1 INCH MAXIMUM THICKNESS. ADD 2 HOURS SOAK FOR EACH ADDITIONAL 1/2 INCH THICKNESS.
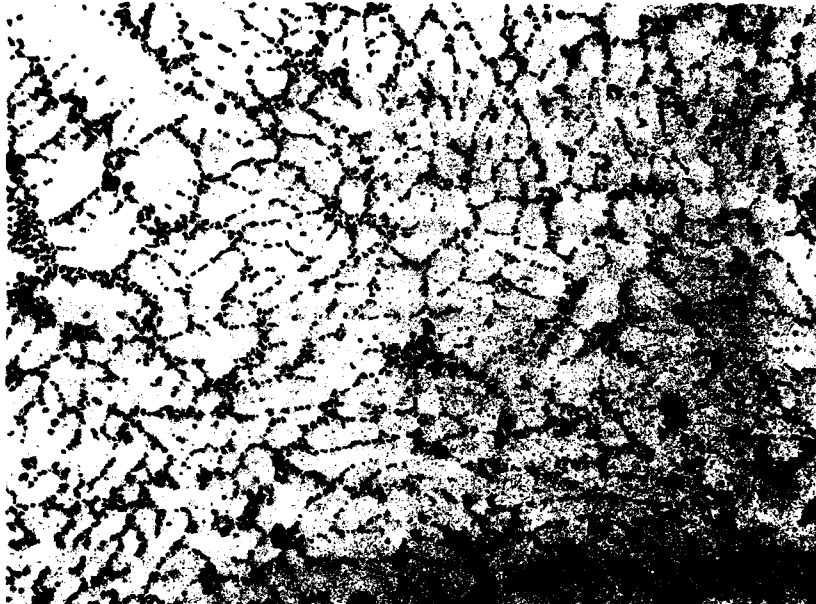
Figure 4.   Typical Microstructure of A357-T6. Mag.: 100X.

SECTION II
PHASE I—PRELIMINARY DESIGN

A. INTRODUCTION

The objectives of Phase I were to establish the design configuration to be continued in Phase III, Detailed Design, and to provide preliminary data and criteria for all following phases of the program.

The Preliminary Design phase consisted of the following items:

o   Baseline component selection from YC-14 candidate components and compilation of baseline component data for comparison purposes

o   Establishment of design criteria to be used throughout the program, including design strength, fatigue, durability, and damage tolerance criteria

o   Development of preliminary design allowables data for the A357 aluminum casting alloy to be used for design until completion of allowables testing

o   Design of a minimum of three conceptual configurations with supporting cost and weight data compiled for selection of the design configuration to be used in Phase III, Detailed Design

o   An on-site design review covering Phase I activities, plus a recommended selection and customer approval of the design configuration

This phase of the program was conducted by Richard C. Jones, assisted by Carlos J. Romero, Christian K. Gunther, Cecil E. Parsons, and Donald D. Goehler; and by Walter Hyler of Battelle Columbus Laboratories, subcontractor for allowables work.

Complete details of the Phase I work were reported in reference 1.

B. PRELIMINARY DESIGN

The Phase I Preliminary Design efforts were directed toward determination of conceptual casting configurations for testing and possible detail design application and compilation of preliminary design criteria, allowables data, damage tolerance methodology, and test plans.

The Phase I goals were accomplished as a result of full consideration of the peculiar problems, opportunities, and challenges by the individual CAST team members (Design, Materials, and Foundry). The foundrymen helped design the casting.

1. **Baseline Component**

At the beginning of Phase I, the YC-14 structural assembly candidates for baseline component were reviewed and selections were made, based on the following requirements:
o   Primary airframe structure
o   Large complex structure with both heavy and thin sections to provide casting challenge
o   Good potential for cost reduction
o   Potential for no weight penalty
o   Cost-effective structural test capability
o   Potential for near-term application
o   Accessibility for inspection in airframe

The component assemblies selected for final comparison were:
o   Station 170 body bulkhead (Fig. 5)
o   Wing box nacelle rib (Fig. 6)
o   Fin tip rib, including stabilizer support assembly (Fig. 7)
o   Aft body bulkhead-lower segment (Fig. 8)

A trade study chart was prepared to provide the basis for a comprehensive analytical comparison of the candidate component assemblies with the characteristics and criteria for the casting application. These characteristics and criteria were:
o   Structural application
o   Size
o   Casting technology challenge
o   Existing component cost (including tooling) and comments on potential cost reduction
o   Component weight and potential weight change
o   Structural test complexity

ENVELOPE SIZE: 89.6" x 57" x 16.5"

W.L. 150

748-141203-1 ⟁1

WL 130

₵ LDG GEAR FITTING ATTACH

748-141480-4*

748-141843-28

W.L. 105.02

748-141202-42 (2 PLACES)

B.L. 0

748-141209-2 ⟁2
748-141209-4 ⟁2

748-141707-8*
748-141710-2*

DOOR ACTUATOR SUPPORT

748-14120-17

748-141202-3

A

A

748-141840-3*
748-141843-27
748-141839-2*

748-141209-5 ⟁2
748-141209-6 ⟁2
(2 EACH)

748-141209-1
748-141209-3*

748-141707-7*

LBL 7.0

A-A

*INSTL: 748-141837 (REF)
INSTL: 748-141709 (REF)
⟁1 BULKHEAD INSTALLATION: SOME PARTS TO BE DELETED FOR SEPARATE INSTALLATION

⟁2 CALLED OUT ON 748-141203-1 BULKHEAD INSTALLATION

Figure 5. Station 170 Body Bulkhead

10
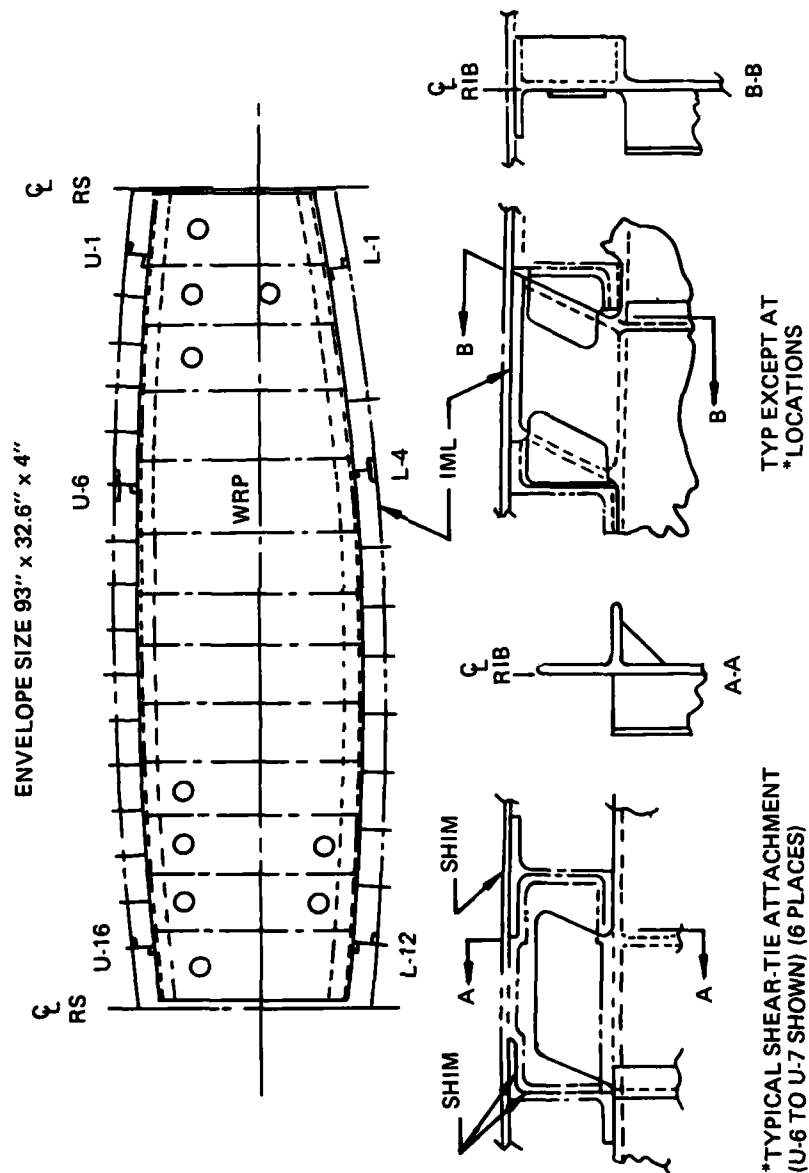
Figure 6. Rib Installation, BL 213, Inspar, Wing

ENVELOPE SIZE: 144" x 44" x 17.5"   & 26.5" x 38" x 29"
(2 SEPARATE CASE COMPONENTS WOULD BE REQUIRED)

748-172161-2

748-172161-1

B-B

748-172610
STABILIZER SUPPORT
FITTING

748-172504-2 ASSY

RIB WITH FAIRING SUPPORTS

748-179120-9-10 OPP

748-179120-7-8 OPP

748-179210-7-8 OPP

748-170210-1 & -5
-2, -6 OPP

A-A

A

B

B

A

A

€ RS

€ RIB

LE
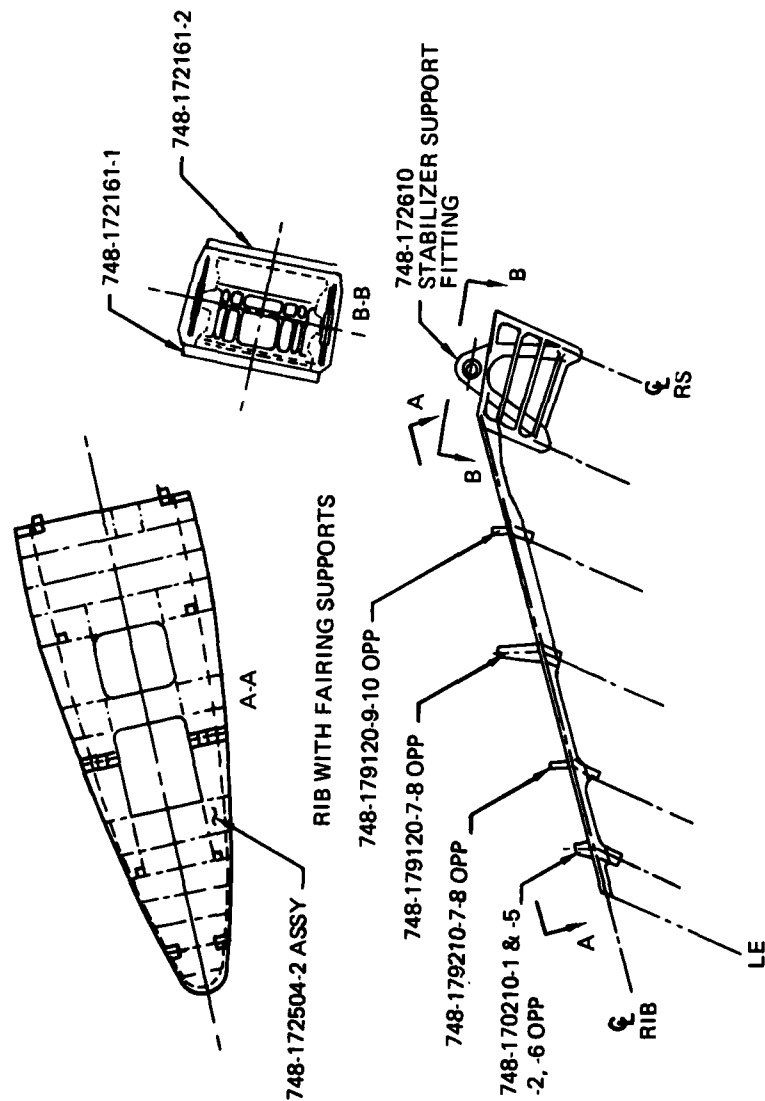
Figure 7.   Rib Assembly—Upper Closure, Vertical Fin

o   Possible near-term implementation

o   Inspection and maintenance access

This analysis clearly showed that the station 170 body bulkhead was the best choice for the baseline component. This component had the best potential for meeting the cost and weight objectives, possible near-term implementation, and ease of inspection access. The wing box nacelle rib was the first alternate choice, with a good rating except for structural test complexity and poor accessibility for inspection. The aft body bulkhead-lower segment and the fin tip rib were judged consecutively lower in meeting the baseline component criteria.

2.   Design Criteria

Preliminary design criteria for the CAST component included:

o   All applicable military specifications: MIL-A-008860A, MIL-A-008861A, MIL-A-008866B, MIL-A-83444, MIL-STD-1530A

o   Design allowables verification test requirements

o   Applicable YC-14 airplane requirements and objectives

o   Design loads requirements per YC-14 Airplane Strength Analysis

o   Repeated loads derivation from design usage as noted in the YC-14 Damage Tolerance Assessment Document

o   CAST design service life requirements (same as C-14 design service life requirements)

o   General requirements including deviation from MIL-A-008860A—no casting factu

o   Reliability requirements, durability, and damage tolerance criteria

A damage tolerance and durability control plan identified and defined the tasks necessary to ensure compliance with damage tolerance and durability requirements of MIL-STD-1530A, MIL-A-83444, and MIL-A-008866B. Included in this plan were:

o   The plan for fatigue and fatigue characterization testing of the A357 casting alloy

o   The fracture control specification for the station 170 bulkhead in the event it would be declared fracture-critical

o A detailed description of the flight-by-flight loads spectrum for the bulkhead

o A description of the damage growth prediction and durability methodology

o A plan for sensitivity studies to be performed in Phase III

3. **Preliminary Design Allowables Data**

Preliminary design allowables were developed for A357-T6 aluminum alloy castings procured to MIL-A-21180. The allowables were developed from data collected and analyzed by Battelle Columbus Laboratories under subcontract to the CAST program. Preliminary allowables were established for the four strength/elongation classes of MIL-A-21180 with the same distinctions regarding designated areas or total casting. These classes are designated as:

o Class 1—45/35/3

o Class 2—50/40/5

o Class 10—38/28/5

o Class 11—41/31/3

The values for F_{cy}, F_{su}, F_{bru}, and F_{bry} were developed from the F_{tu} and F_{ty} values using derived property ratios determined from the values shown for A357.0-T61 in Section 3.13.16 of MIL-HDBK-5B as follows:

o $F_{cy} = F_{ty}$

o $F_{su} = 0.7 \, F_{tu}$

o $F_{bru} = 1.4 \, F_{tu}$ (e/D = 1.5)

o $F_{bru} = 1.8 \, F_{tu}$ (e/D = 2.0)

o $F_{bry} = 1.6 \, F_{ty}$ (e/D = 1.5)

o $F_{bry} = 1.8 \, F_{ty}$ (e/D = 2.0)

The values for E, E_c, G, and   are the same as those in Section 3.13.6 of MIL-HDBK-5B for A357.0-T61.

The preliminary design allowables developed for the CAST program are shown in Table 3.

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Table 3.   "CAST" Preliminary Design Allowables

ROOM TEMPERATURE MECHANICAL PROPERTIES								
Program CAST Preliminary Design Allowables								
Alloy	A357							
Specification	CAST-XXXX							
Form	Castings							
Temper	T6							
Class ①	1		2		10		11	
Basis	A	B	A	B	A	B	A	B
Mechanical properties:								
F_{tu} ksi	42	46	47	51	35	40	38	43
F_{ty} ksi	35	37	40	42	29	31	31	34
F_{cy} ksi	35	37	40	42	29	31	31	34
F_{su} ksi	29	32	33	36	24	28	27	30
F_{bru} ksi								
(e/D = 1.5)	59	64	66	71	49	56	53	60
(e/D = 2.0)	76	83	85	92	63	72	68	77
F_{bry} ksi								
(e/D = 1.5)	56	59	64	67	46	50	50	54
(e/D = 2.0)	63	67	72	76	52	56	56	61
Elong Percent	2.5		2.5		2.5		2.5	
E 10^3 ksi	10.4							
E_c 10^3 ksi	10.5							
G 10^3 ksi	3.9							
μ	0.33							

① Class designations represent strength classes from MIL-A-21180

Program CAST	MIL-A-21180
Class 1	Class 1 (45/35/3)
Class 2	Class 2 (50/40/5)
Class 10	Class 10 (38/28/5)
Class 11	Class 11 (41/31/3)

Classes 1 and 2 represent properties of specimens cut from designated areas

Classes 10 and 11 represent properties of specimens cut from any area of a casting

4.   Casting Concept Configurations

Three different cast concepts of the station 170 bulkhead were completed to obtain cost, weight, casting method, and structural comparisons. The three concepts with design approach rationale were:

o   Stiffened Web Concept (Fig. 9)—This configuration was chosen for study on the basis of being the most direct design approach, physically matching the existing bulkhead structure as closely as possible.

o   Hybrid Concept (Fig. 10)—This concept was chosen to provide a cast framework, including all the heavy structure and fittings, with a sheet web mechanically fastened to the cast frame because of doubt that large areas of thin web could be cast.

o   Truss Concept (Fig. 11)—This design concept was chosen to take advantage of the thick cross-section members to transfer loads through tension and compression only, deleting the requirement for a web in the nonpressurized area. It also reduced the requirement for a thin cast web.

Layout drawings of each of the three cast concept configurations were distributed to Structures Staff and Foundry for analysis, comments, and required revisions. The layout drawings were subsequently completed and sent to Manufacturing and Weights for cost and weight analyses, respectively.

Cost, weight, advantages, and disadvantages were evaluated and compiled for each of the three concepts (Tables 4, 5, and 6).

The weight shown was derived as follows: weight of casting concept, plus weight of baseline components not included in cast structure, plus weight of additional built-up structure, if required, minus weight of any additional structure not originally included in the baseline concept.

The projected cost to a 300-airplane production run was estimated for each concept. The percent savings from baseline cost are noted for each concept.

16
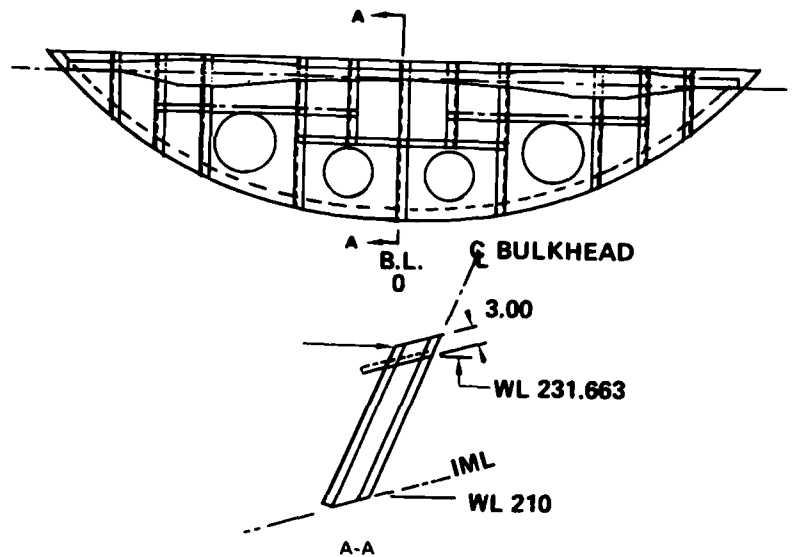
Figure 8.   Aft Body Bulkhead—Lower Segment
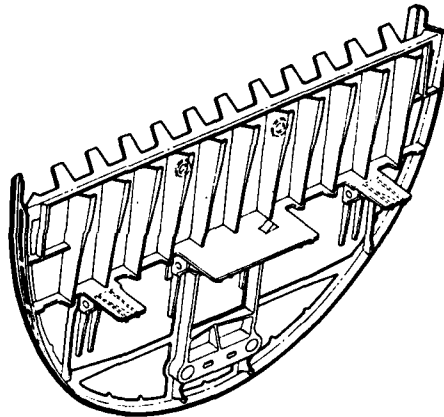
Figure 9.   Concept No. 1, Stiffened Web
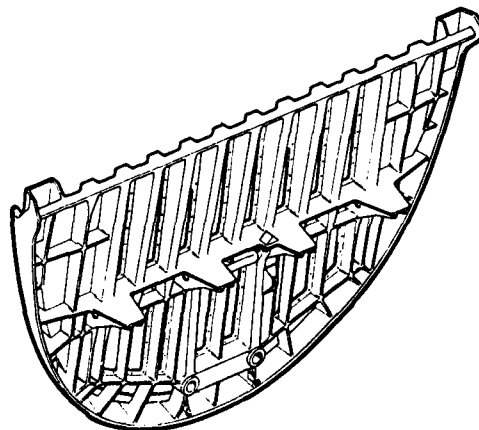
Figure 10.   Concept No. 2, Hybrid

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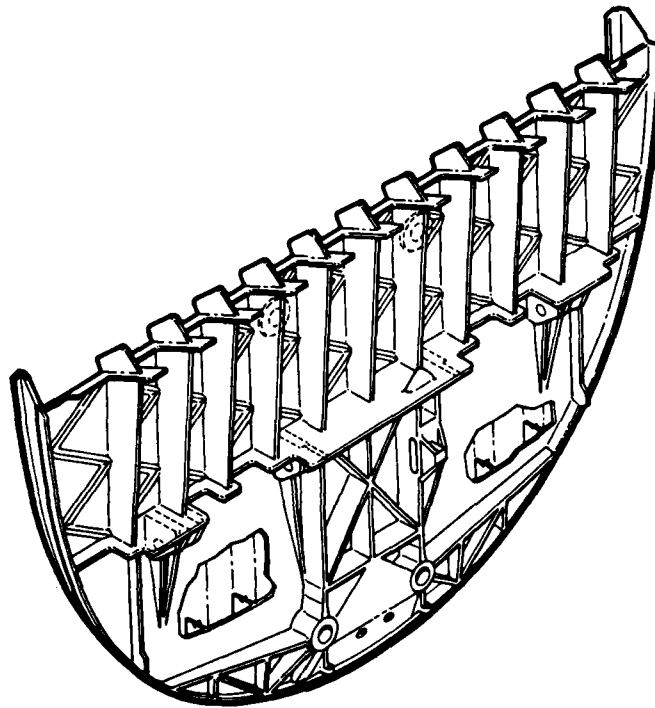
Figure 11.   Concept No. 3, Truss

Table 4. Evaluation Chart, Concept No. 1

	WT. (LBS)	COST 1 of 300 SHIPSETS	ADVANTAGES	DISADVANTAGES
CONCEPT No. 1 Cast - L/0-004 (Similar to As-Built)	172.9	$7948 (27% SAVINGS)	• Under Target Wt: Can Absorb Reduced Allowable for Fatigue, Etc., if Required • No Revision to Adjacent Struct. • Includes all Parts of Baseline Component	• Difficult Areas to Cast • High Flanges at W.L. 130 • Beam Flanges Require Coring • Outer Chord Requires Coring • Core Required Across Top at W.L. 150 • Large Areas of Min. Gage Web
BASELINE	184.6	$10,900		

Table 5. Evaluation Chart, Concept No. 2

	WT. (LBS)	COST 1 of 300 SHIPSETS	ADVANTAGES	DISADVANTAGES
Concept No. 2 Cast - L/0-002 (Hybrid)	209.4	$6393 (41% SAVINGS)	• Casting Simplification • Outer Chord is Open Angle (No Core Required) • No Beam Flanges (Reduced Coring) • Concept Includes Slanted Beam at W.L. 150	• Difficult Areas to Cast • High Flanges at W.L. 130 • Core Req'd across top W.L. 150 • More Fastener Holes - Possible Crack Growth Problem • More Difficult to Inspect (NDT) • Heavy Wt. • Does not include Radome Attach Parts, requires revised (heavier) Seal Retainer (to be used as edge stiff.)
BASELINE	184.6	$10,900		

Table 6. Evaluation Chart, Concept No. 3

	WT. (LBS)	COST 1 of 300 SHIPSETS	ADVANTAGES	DISADVANTAGES
Concept No. 3 Cast - L/0-003 (TRUSS)	210.8	$7154 (34% SAVINGS)	• Casting Simplification • No Beam Flanges (Reduced Coring) • Web Trusses (Diamond Shape) Aids Web Flow During Casting. • Lowered Flange Height at WL.130	• Difficult Areas to Cast •Outer Chord Requires Coring • Heavy Wt. • Requires New Built-up Intercostals at W.L. 130 • Does not include attach angle for slanted bulkhead.
BASELINE	184.6	$10,900		

The pertinent advantages and disadvantages were compiled from Manufacturing, Quality Control, Structures Staff, and Structures Design inputs.

5.   Preliminary Design Structural Analyses

Preliminary static strength analyses were performed on the three candidate bulkhead concept configurations.   Structural sizing on all elements was accomplished to support weight and cost comparisons. The design loads used were those for the YC-14 existing bulkhead design. Detailed strength analyses were made for the following major elements of the recommended bulkhead configuration:

o   Critical lug (landing gear support)

o   Bulkhead webs

o   Critical vertical stiffener

o   Actuator hinge backup structure

The nose gear attachment detail was selected for damage tolerance analysis, because the four details are common to the three bulkhead concepts (Fig. 12). They are a critical item for damage tolerance consideration, and the unit load solution for these points was already available. Other details must also be considered, but the detail stress analysis of the bulkhead to be performed in Phase II was required before a meaningful analysis could be performed.   For the purpose of this study, the cast bulkhead was classified as slow-crack-growth structure and in-service noninspectable. Items analyzed in this study were initial flaw assumption, material crack growth property, stress-intensity factor solution, plane-strain fracture toughness, and repeated loads.

The two outer nose gear attachment details (Fig. 12) were considered the most critical relative to durability analysis. They are common to all three bulkhead concepts. Detail design S-N curves were derived for A357. Such curves are expressed by the two parameters, detail fatigue rating (DFR) and slope ratio (S). The slope ratio was kept constant at 2.0, and the DFR for the details under consideration was calculated to be 8.

The economic life of the cast bulkhead was predicted for the design usage as represented by the mission mix noted in the Damage Tolerance and Durability Control Plan for the CAST program. The relative damage due to the five different flights within the mission mix consisting of 16 total flights was calculated. The economic life was predicted to be 40,380 hours.

C. CANDIDATE DESIGN SELECTION

1. Contractor Evaluation and Recommendation

A comparison chart (Table 7) was prepared listing the weight, cost with percent differential, primary advantage, and primary disadvantage for each of the three concepts, with the baseline weight and cost also noted. None of the three concepts met both primary criteria—equal or less weight and a minimum of 30% cost reduction.

A composite concept (Fig. 13) was established that had an estimated weight of 9.8 pounds less than baseline and an estimated cost reduction of 38% (Tables 8 and 9). This concept was based primarily on concept #1 with minimum gage webs, angled tee outer chord, and vertical beams matched to existing structure. The first revision, inclusion of the slanted beam at WL 150, was very efficient in that the beam could be simply cast-in and replaced approximately 158 separate parts, reducing both weight and cost. The second revision, deleting outstanding flanges and adding draft to the aft beams, added weight but reduced cost through reduction of coring requirements. Further refinement in detail design was assumed with no weight credit assigned.

This composite concept was established as the contractor-recommended cast concept bulkhead to be carried into Phase III, Detailed Design.

2. On-Site Review

An on-site review was held on February 7 and 8, 1977, at Boeing with the USAF, AMS ADP representatives and second-source supplier representatives in attendance. A complete review of the program to date was

NOSE GEAR ATTACH POINTS
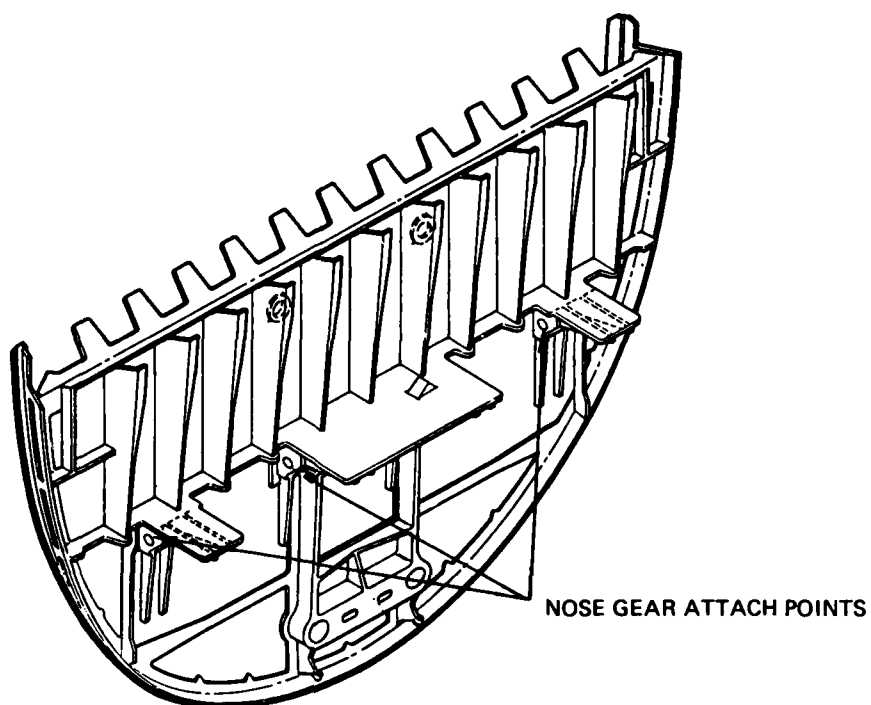
Figure 12.   Nose Gear Attach Points

Table 7.   Concept Comparison

Concept no.	Weight (lb)	Cost 1 of 300 shipsets	Primary advantage(s)	Primary disadvantage(s)
1	172.9	$7,948 (-27%)	Lowest weight: under target weight	Highest cost due to casting complexity
2	209.4	$6,393 (-41%)	Least cost due to casting simplicity of outer chord and inclusion of beam at WL 150	Approximately 25 pounds over target weight
3	210.8	$7,154 (-34%)	Less cost than no. 1 due to deletion of beam flanges and lower flange height, WL 130	Approximately 26 pounds over target weight. Requires additional built-up structure (WL 130)
Baseline	184.6	$10,900	—	

22
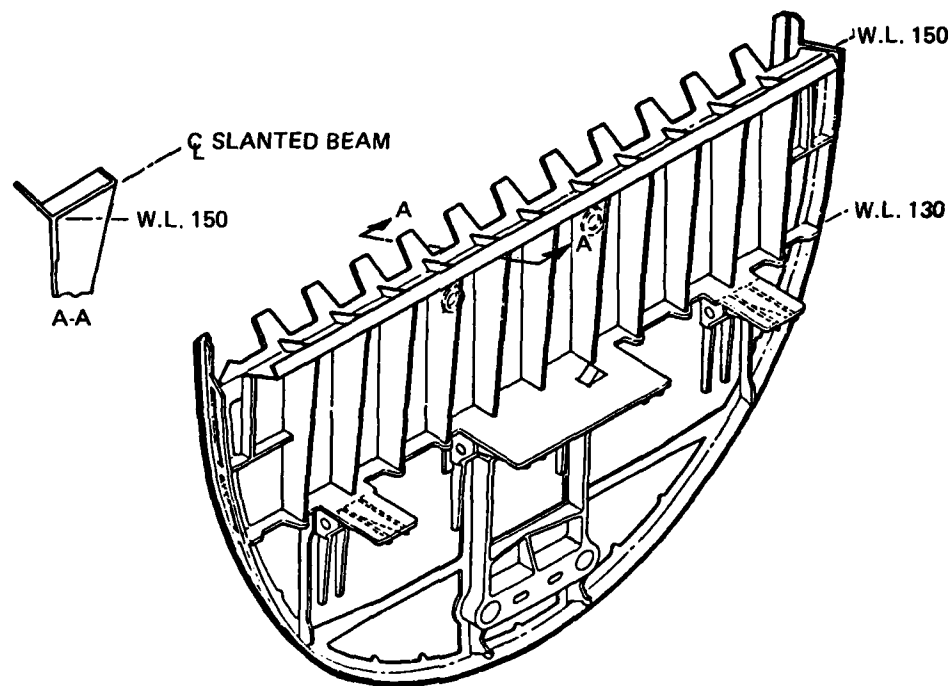
Figure 13. Recommended Cast Concept for Detail Design: Station 170 Body Bulkhead

Table 8.   Cost and Weight Increments to Concept No. 1

Concept no. 1 (Cast-L/O-004) revised as shown:	Estimated Δ weight	Estimated Δ cost
● Include slanted beam at W.L. 150: Similar to concept no. 2 (Cast-L/O-002) Adds beam assy (748-141202-1 to baseline component)	-10.5 lb	$-840./unit
● Delete beam flanges - aft side only Note: Forward beam flanges to be retained along with closed angle chord - deletion of all coring requirements on aft side of bulkhead will be design goal	+12.4 lb	$-355/unit
● Tailor all beams in height and thickness to match final refined load requirements	—	—
	+1.9 lb	$-1,195/unit

Table 9.   Recommended Casting Cost and Weight Summary

	Weight (lb)	1 of 300 cost
Concept no. 1	172.9	$7,948
Revisions	+1.9	-1,195
Recommended concept	174.8	$6,753
Baseline component	184.6	$10,900

Δ weight = -9.8 lb (provides allowance for weight increases during detail design for fatigue damage tolerance, and revisions for further cost reduction)

$$\Delta \text{ cost} = \frac{10,900-6,753}{10,900} \ (100) = 38\% \text{ reduction}$$

439 parts + fasteners replaced by one casting

presented, ending with the recommendation of the composite concept for detail design as noted above.

The customer review team requested further study of the recommended concept for detailed design. This further study consisted of evaluating a corrugated upper web in the cast bulkhead to facilitate casting operations.

3.   Final Design Selection

A design layout of the revised CAST concept for detailed design was completed. This concept had the outer chord, upper beam, and landing gear fittings similar to the concept recommended by the contractor for detailed design. The upper web was corrugated with a transition to stiffened web below WL 130 (Fig. 14).

The revised concept resulted from the comments of the Air Force program manager during the on-site review. There was concern that the return flanges and web-to-stiffener junctions of the previously recommended concept would be a source of casting defects such as shrinkage and dimensional mismatch. The corrugations of the revised concept avoided these junctions and backdrafts, while being fairly easy to cast.
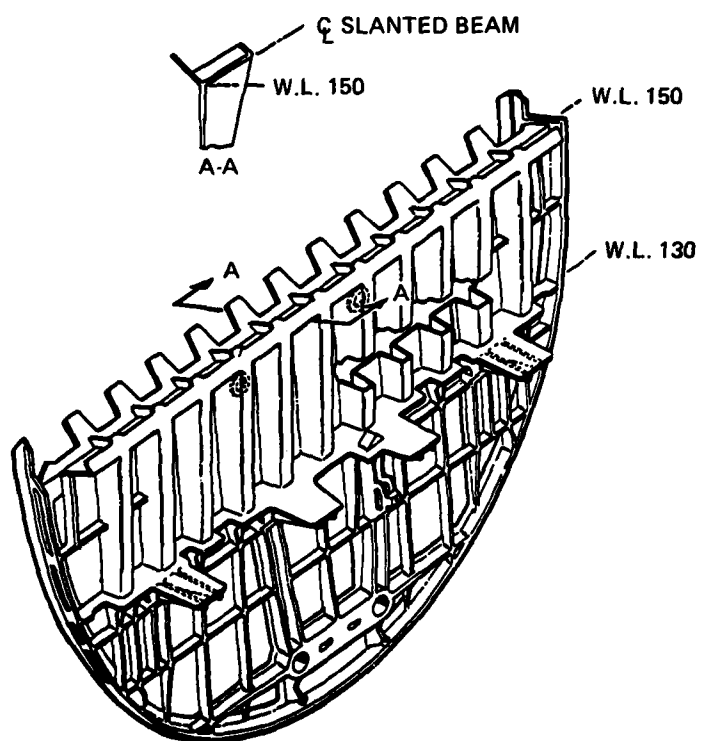
Figure 14.   Revised Cast Concept for Detail Design: Station 170 Body Bulkhead

SECTION III
PHASE II—MANUFACTURING METHODS

A. INTRODUCTION

The objective of Phase II was to develop and establish necessary casting foundry practices and related manufacturing technologies to support all design and fabrication efforts.

In accomplishing the above objective, trial-and-error methods of casting were minimized and a more scientific approach was taken. This approach aided in ensuring higher and more consistent mechanical properties. This effort involved extensive characterization of each step of the casting process to define acceptable limits of process parameters and incorporation of them into the development by producing subsized components representing the preliminary design configuration. This technology subsequently was used during the fabrication of the demonstration components during Phase IV.

This phase of the program was conducted by Richard G. Christner assisted by Calvin R. Belden, James W. Faber, Frederick J. Feiertag, Jerry E. Ginn, L. Arne Logan, Robert C. McField, Dale L. McLellan, Cecil E. Parsons, Howard L. Southworth, and Andrew S. Tam.

Complete details of the Phase II work were reported in reference 2.

B. METAL MELTING AND POURING TECHNIQUES

1. Spectrographic Analysis

Close control of alloy composition throughout the casting process, critical for optimization of mechanical properties, can be accomplished only if the method of determining alloy composition is reliable. Vacuum emission spectrographic analysis was used to determine alloy composition in this program. This analytical method is fast, convenient, and produces reliable results.

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2. Fluidity Tests

Fluidity is the property of molten metal that allows it to flow through the mold gating system and ultimately fill the mold cavity to produce a casting. The fluidity of a given metal is measured with standard fluidity test molds. One fluidity test mold configuration is the single spiral in which the width of the part decreases as the length of the spiral increases (Fig. 15). This test configuration did show the effect of nonuniform section thickness in molds on the fluidity characteristics of the molten metal, but it did not provide reliable data for estimating the fluidity in a mold of uniform section thickness. The determination of fluidity obtained in molds of uniform section thickness was made by casting parts in the form of a double spiral, as shown in Figure 16.

The double-spiral test casting was used to evaluate the effects on fluidity of pouring temperature, silica sand grain size (AFS 53, 70, and 140), sand type (silica, chromite, and zircon), and mold coating (amorphous carbon, hexachloroethane, or none). Figure 17 is an example of the type of data obtained.

The effect of alloy composition on fluidity also was evaluated by modifying the silicon, magnesium, and beryllium contents of A357 within their given ranges. This evaluation showed no significant difference in fluidity resulting from chemistry variation.

These data offer a comparison of the relative effects that some of the foundry parameters have on fluidity. The following general conclusions were drawn from these tests:

o   Amorphous carbon coating enhances the fluidity of thin-wall castings.

o   AFS 70 sand offers improved fluidity over AFS 53 sand.

o   Variation in the chemistry of A357 does not affect fluidity.
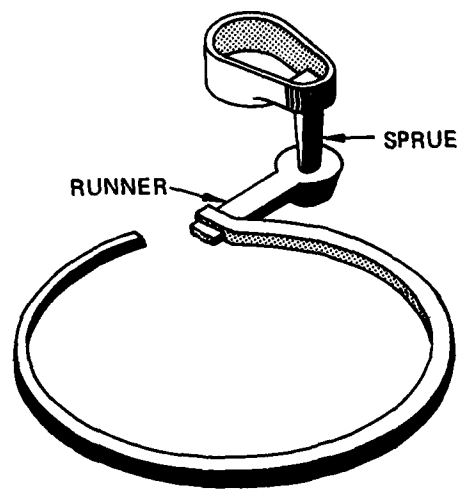
Figure 15. Single Spiral Casting for Fluidity Testing
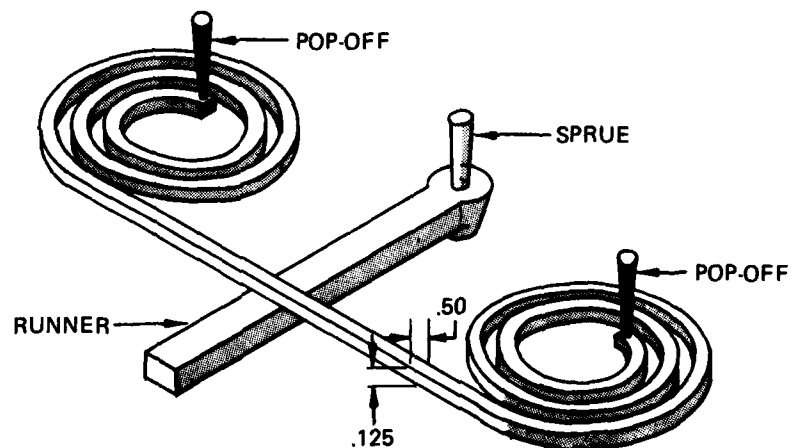
TOTAL LENGTH ONE SIDE: 31.5 IN.

Figure 16. Double Spiral Casting for Fluidity Testing

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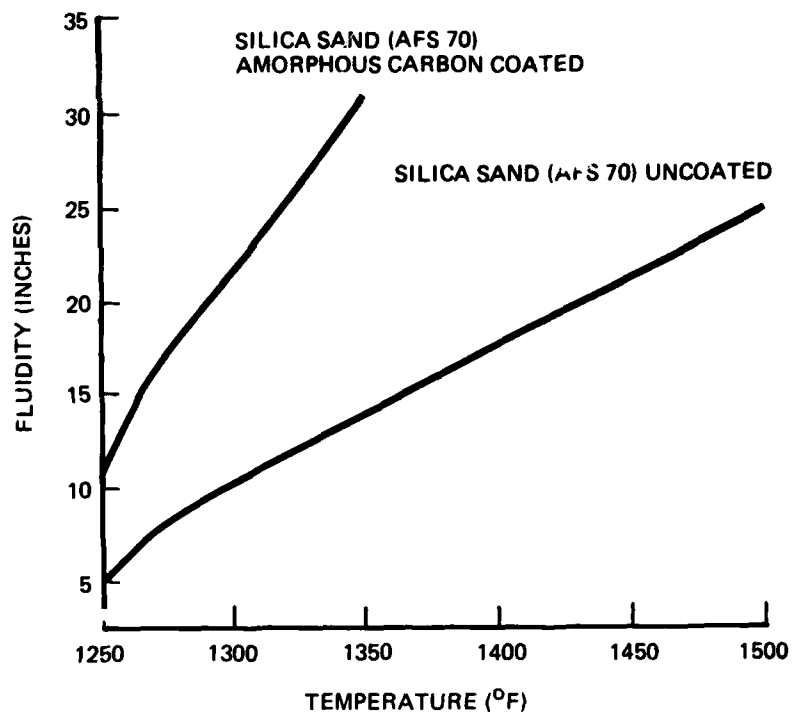
Figure 17. Effect of Temperature on Fluidity of A357 Cast in Coated and Uncoated
Double Spiral Molds

3. Holding Temperature

A charge of metal is typically held at a temperature between the melting point and the pouring temperature until preparations for pouring and degassing operations are complete. For aluminum alloys, this temperature is generally between 1300 and 1400°F. The length of time that the metal remains at the holding temperature depends upon the time required for degassing operations and/or mold and pouring preparations.

The effect of melt holding temperature and time on the stability of A357 was evaluated at 1250, 1300, 1350, and 1450°F for holding times ranging from 0 to 24 hours. At each of the prescribed test temperatures, the alloy composition (Si, Mg, and Be) was adjusted to the maximum allowable for the A357 alloy range (7.5, 0.70, and 0.070%, respectively). When the temperature of the melt had stabilized at the desired holding temperature and correct chemistry was obtained, metallurgical and gas test samples were taken at prescribed intervals up to and including 24 hours. The metallurgical samples were subjected to spectrographic analysis and the gas samples were evaluated by solidifying a molten specimen in a vacuum chamber, sectioning, and observing gas-hole formation at the interior surfaces of each specimen.

The effect of holding the melt at 1300°F on alloy stability as a function of time is shown in Figure 18. The results show that the length of time the melt is held at temperature has relatively little effect on the silicon, magnesium, and beryllium contents.

Visual examination of the gas test specimens revealed that the amount of hydrogen gas present in the melt increased as the holding temperature was increased. This increase in hydrogen present at the higher holding temperature is due to the increased solubility of hydrogen at elevated temperatures.

The effect of holding time on the amount of hydrogen present in the melt at 1300°F is shown in Figure 19. In this evaluation, the charge was degassed with a 95% nitrogen/5% chlorine gas mixture at 1300°F for 20
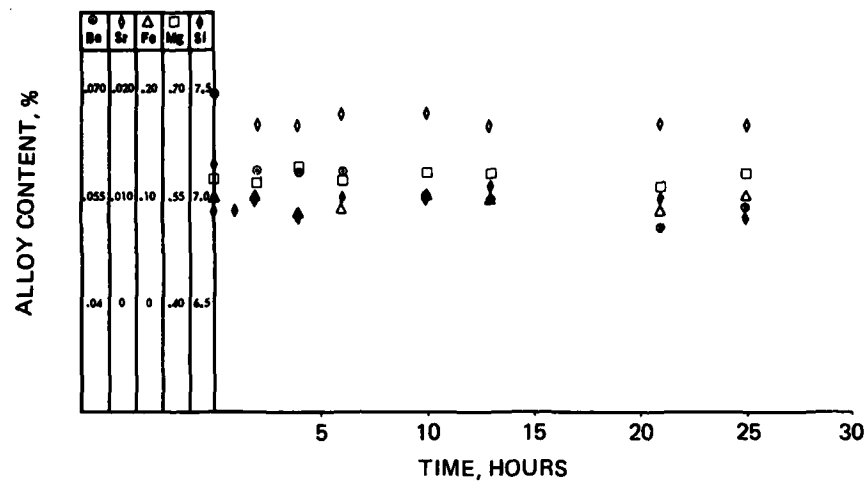
Figure 18.   Alloy Stability of A357 when Melt Held at 1300°F
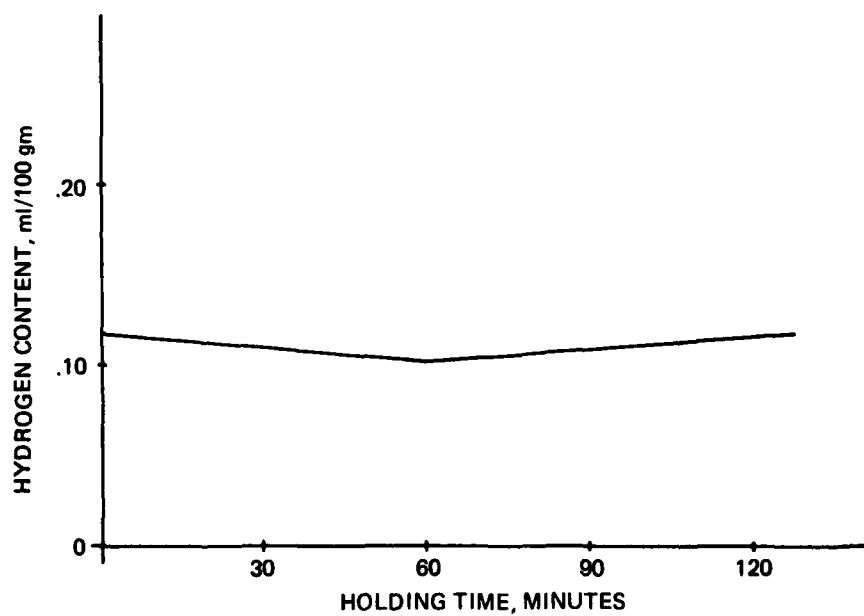
Figure 19.   Effect of Holding Temperature at 1300°F on Hydrogen Content of A357

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minutes and then held for 2 hours. Measurements of the hydrogen present in the melt after degassing were taken with an Alcoa "Telegas" hydrogen analyzer. The data show a constant decrease in the amount of hydrogen present in the melt from 0 to 60 minutes, and then an increase in gas content from 1 to 2 hours at the holding temperature. The initial decrease in hydrogen content is believed to be due to residual nitrogen-chlorine gas still in the melt, acting as a deoxidizing agent.

Based upon the results of this investigation, the holding temperature for A357 aluminum prior to degassing operations may be considered arbitrary, but should be between 1250 and 1325°F. The holding temperature of the melt for degassing operations is discussed in Section 6 below.

4.   Pouring Temperature

The pouring temperature for aluminum alloys generally is dependent upon the size and configuration of the casting. Aluminum castings consisting of heavy sections may be poured at lower temperatures than castings with thin sections. The pouring temperature range for aluminum castings is usually between 1325 and 1450°F. As the pouring temperature is increased to the upper end of the range, the molten metal becomes more fluid and will flow more readily into thin sections of the mold cavity. Other variables that determine the pouring temperature include alloy composition, molding materials, and type and ratio of the gating system. Each of these variables was discussed at length in the Phase II final report (ref. 2). In general, these variables are predetermined during casting and mold design and taken into consideration when determining the optimum pouring temperature. After the optimum pouring temperature for a casting has been established, it must be controlled by monitoring the molten bath at frequent intervals with immersion-type pyrometers.

To determine the optimum pouring temperature for large, thin-wall aluminum castings, subsized component parts were cast of the configuration shown in Figure 20. Section thicknesses on the casting ranged from 0.1 to 1.5 inches and included both copper and aluminum chills. Parts were cast with A357 at 1425 and 1450°F and inspected for

casting defects. Test parts cast at 1450°F displayed shrinkage defects. Castings poured at 1425°F displayed fewer shrinkage defects.

The results of this investigation showed that the pouring temperature for large, thin-wall aluminum castings must be (1) high enough to provide sufficient fluidity for complete filling of the mold cavity and to avoid casting defects such as misruns, cold shuts, and shrinkage, and (2) low enough to minimize coarse grain structure, porosity, shrinkage, and oxide formation. It was concluded that the optimum pouring temperature range for large, thin-wall aluminum castings is between 1400 and 1450°F.

5. Melting and Pouring Techniques

Contamination of the melt via iron and hydrogen pickup and oxide formation is generally controlled by good shop practices. Cleaning and preheating the charge, use of clean, nonferrous handling equipment, and proper stirring and skimming techniques all are considered standard foundry practice. Good melting and pouring techniques must include (1) good material control and storage procedures, (2) use of handling and skimming equipment that will not contaminate the melt, (3) proper control of metal temperature in the furnace and pouring ladle, (4) good pouring basin design to permit only clean metal to enter the sprue and mold gating system, (5) good pouring techniques, and (6) the use of screens and/or filters in the gating system to minimize dross or slag defects in the casting.

6. Degassing

Hydrogen dissolution and oxide formation in molten aluminum alloys can cause degradation of mechanical properties of the casting. As shown in Figure 21, temperature exerts a profound effect on the solubility of hydrogen in aluminum. When the melt cools to the melting point, a rapid decrease in solubility occurs that subsequently will cause porosity defects in the casting. Therefore, it is essential to have low-hydrogen-content metal before pouring to avoid a high casting rejection rate.

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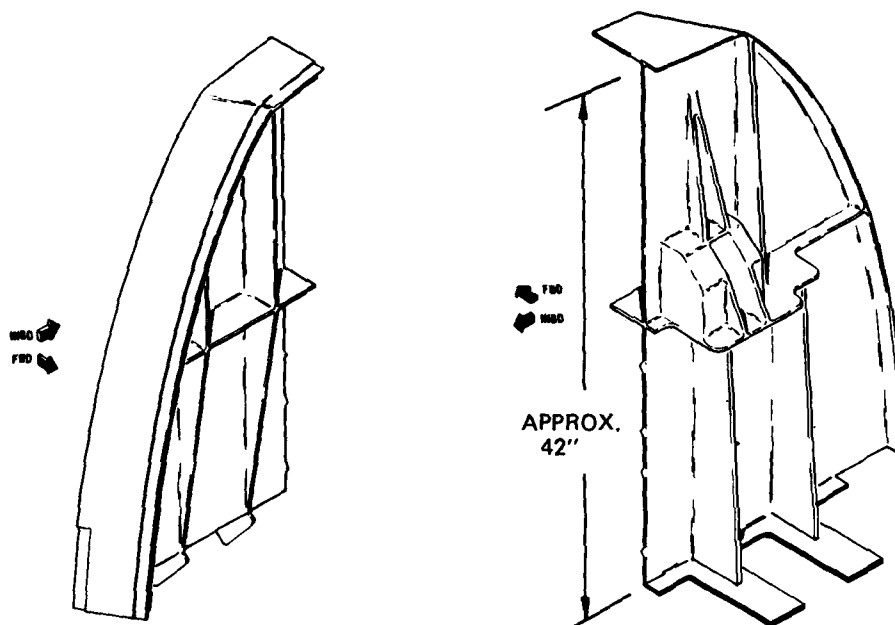
Figure 20.   Part "A" Test Section of YC-14 Station 170 Body Bulkhead
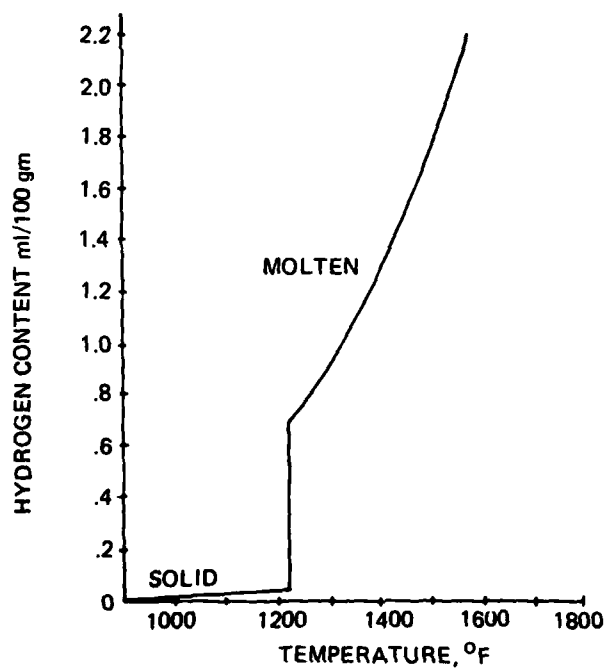
Figure 21.   Solubility of Hydrogen in Aluminum at One Atmosphere Hydrogen Pressure

Three different degassing media—nitrogen gas, 95% nitrogen/5% chlorine gas mixture, and solid hexachloroethane tablets (C_2Cl_6)—were evaluated for their ability to remove hydrogen and oxides from molten aluminum. The gaseous media were examined by varying the flow rate, flow time, and melt temperature. The solid hexachloroethane was examined by varying the amount and the melt temperature.

Based upon the test results obtained in this part of the program, the following degassing recommendations can be made for producing high-quality aluminum castings:

o   The hydrogen content of the melt must be held to a minimum and in no case should be greater than 0.15 ml/100 g of aluminum.

o   The hydrogen content of a melt should be determined by observing a solidifying sample of degassed melt under a vacuum of 27 inches of mercury. If no bubbles break the surface during the latter stages of solidification, the metal can be considered hydrogen-free.

o   The maximum holding time between degassing and pouring should be 2 hours, after which the metal should be rechecked.

o   · Of the gases analyzed, the optimum degassing conditions are a mixture of 90–95% nitrogen/5–10% chlorine at a melt temperature of 1300–1325°F. Degassing intervals should be at least 30 minutes apart.

o   A holding time of 15 to 20 minutes between degassing and taking a vacuum gas sample should be observed to ensure an accurate determination.

7.   Grain Refinement and Eutectic Modification

To achieve good mechanical properties in a casting, close control of the grain size and shape of the silicon constituents must be exercised. This is accomplished with the use of grain refiners, eutectic modifiers, and controlled solidification of the casting.

Grain size control in A357 castings is accomplished by the addition of titanium, a grain growth inhibitor, which is an alloying constituent.

Replenishment of the melt with titanium was accomplished with an Al-5Ti-1B master alloy.

Modification of the silicon particles is necessary to achieve good strength and ductility. The two eutectic grain modifiers investigated were sodium and strontium. The use of either sodium (as pure sodium) or strontium (as Al-15Si-10Sr master alloy) resulted in an increase in the hydrogen gas content of the melt.

Considering the problems experienced with sodium and strontium modification, the decision was made to use unmodified A357. When casting thin sections and heavily chilled thick sections, the solidification rate is fast enough that the silicon constituents showed good modification without the use of modifiers.

C. MOLD AND CORE MAKING

Boeing's experience in making molds for large, high-strength aluminum castings dictates that to maintain consistently close dimensional tolerances, sound castings, and good surface finishes, it is necessary to use a moisture-free, chemically bonded sand. In addition, close control over the design and fabrication of molds for large castings is essential if the aforementioned characteristics are to be achieved. Because all molding variables are interdependent, an extensive test program was conducted. Variables investigated included the effects of sand types and sizes, binder types, mixing times, and storage times and temperatures on the mechanical and physical properties of molding sand. Other items investigated were venting, parting agents, mold leveling, and mold shakeout.

These investigations showed that molding sand to be used for producing large aluminum castings should have the following specific characteristics: good flowability, permeability, tensile strength, and compressive strength; high hot strength; low retained strength; and low thermal expansion and gas evolution. Good mold and core sand should be strong enough to withstand handling and resist deterioration by the molten metal at elevated temperatures; have good permeability to allow the passage of gas; be flowable and display good compaction and surface finish characteristics; hold dimensional tolerances at

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elevated temperatures; and provide ease in shakeout after cooling to room temperature.

In general, the results of this investigation showed that after sand type and method of mixing have been established, the required properties of a molding sand depend upon binder type and amount. The choice of binder type depends upon: (1) obtainable mold properties, (2) applicability to required molding procedures, and (3) availability. In summarizing the results of tests conducted to determine the effect of storage time on mold properties with respect to binder type, the following conclusions were drawn:

o   Although sands bonded with sodium silicate-CO_2 and sodium silicate airset binders displayed good mold properties, the strengths obtained showed rapid deterioration after relatively short storage intervals. This decrease in strength is due to the hygroscopic nature of the binders.

o   Molding sands bonded with synthetic resin binder displayed generally lower mold properties than obtained will all other binder types. In addition, the short work and strip times of molding sand using this type of binder are considered unfavorable for the production of molds for large aluminum castings.

o   Sands bonded with oil-urethane binders continued to display good mold properties after prolonged storage intervals and offered flexible work and strip times.

Because of the length of time required to construct a mold for a large aluminum casting, a binder that displays good mold properties after prolonged storage and provides flexible work and strip times is required. These characteristics were displayed by the oil-urethane binder (Linocure). This binder met each of the aforementioned criteria for binder selection and displayed favorable results in each of the tests described in this section.

In conclusion, the results of this investigation showed that optimum mold properties for the examined systems were obtained from a molding sand consisting of AFS 53 or 70 (depending upon application) silica sand bonded with about 1.1% Linocure when large, thin-wall aluminum parts are to be cast.

D. CHILLING AND/OR INSULATION REQUIREMENTS

1. Chill Material, Size, and Location

The function of chills in a mold is to promote directional solidification and produce a microstructure with fine dendrite arm spacing (DAS). Directional solidification is the control imposed upon the liquid-to-solid transition from a solidifying section toward a molten metal reservoir (riser). The influence of the chill on cooling rate is related to the volumetric heat capacity of the chill material. Fine DAS is dependent upon rapid solidification of the cast material and is typically finest in the areas adjacent to the chill.

Chill materials evaluated in this investigation included copper, iron, aluminum, and graphite. Tests were conducted on parts cast in the configuration of Figure 22 (T = 0.5 inch), and specimens were removed to evaluate the effects of chills on the mechanical properties of A357. The effects of chill material, mass, and configuration were evaluated.

In summary, these investigations showed that the use of chills is essential in casting large, thin-wall aluminum parts requiring good "as-cast" properties. To obtain maximum properties in a cast part, a rapid solidification rate is required. This is best achieved with copper chills because of the high thermal conductivity of copper. However, the cost of copper makes it economically impractical to use it for all chills. Hence, a combination of copper chills in the heavy (greater than 1.0 inch) sections and aluminum chills in lighter sections (0.2 to 1.0 inch) may be used to reduce costs. Both types of chills will promote directional solidification and enhance the mechanical properties of the casting. The configuration of the chills will be dictated by the shape of the area to be chilled. Based upon Boeing's experience and that of other foundries, the total thickness of the chill should equal 1 to 2 times the thickness of the section being chilled.

Although the results of this investigation show that mechanical properties in localized areas may be enhanced through the use of chills, the primary function of chills is to promote directional solidification. In molds for

large, thin-wall aluminum castings that incorporate complex gating systems and numerous risers, chills should be used extensively to ensure proper control of metal solidification. Proper use and positioning of chills in the mold will reduce the possibility of casting defects such as shrinkage, misruns, and cold shuts.

2. Insulation Material, Size, and Location

Insulating materials such as plaster, ceramic, and fibrous material are used by the casting industry to provide improved fluidity and/or decrease the solidification rate of molten aluminum. These materials are commonly used to insulate risers or thin sections of aluminum sections, which are susceptible to cold shuts or misruns.

Risers feed molten metal to the casting as it solidifies and minimize the occurrence of shrinkage porosity. To ensure proper feeding, the riser must remain in the molten state until the casting passes through the solidification range and becomes solid. This molten state of the metal in the risers may be controlled by insulating the riser cavity from the molding sand. Preformed riser sleeves consisting of a fibrous material composite and cast plaster risers were evaluated in this investigation. Parts were cast in the configuration shown in Figure 23, with composite and plaster riser sleeves, and the cooling rate of each monitored with thermocouples. Because of the inherently hygroscopic nature of the plaster sleeve even after prolonged drying, gas defects were noted in areas of the part fed by that riser.

Because insulation of mold sections results in a reduction in the solidification rate, insulation materials may be used to induce the feeding of sections that are susceptible to misruns or cold shuts. This theory was evaluated by casting parts in the configuration shown in Figure 24 and placing plaster or ceramic foam block pads at the middle of each test plate. The results indicated that there is not much difference between the insulation characteristics of ceramic foam block and plaster. However, because of the hygroscopic nature of plaster, the plaster insulation

outgassed when molten metal contacted it. This resulted in localized warpage of the casting.

In summary, it was concluded that plaster displayed unfavorable results when used as a riser sleeve material or insulating material for thin sections. When used as a riser material, it showed no significant improvement over the paper-fiberglass composite material tested and also caused gas defects in the cast test part. As an insulating material for thin-section castings, plaster displayed the same insulating properties as ceramic foam block and outgassed when contacted with molten aluminum. Based upon the results of this investigation, the optimum material for the riser sleeves was paper-fiberglass composite, and the best insulating material for casting thin sections was ceramic foam block. The thickness of the insulating material used should be held to the minimum required to obtain good feeding characteristics.

E. GATING AND RISERING TECHNIQUES

1. Gating Techniques

The gating technique used to get metal into the mold cavity is one of the most important contributors to the production of sound castings. Improper gating practice can result in a wide variety of casting defects. Various gating techniques were analyzed to consistently ensure the promotion of directional solidification, adequate mold filling, proper riser feeding, and minimum turbulence. The gating parameters considered in this investigation were gating ratio, sprue height and shape, straining materials, and riser size and location. It was the purpose of this investigation to evaluate different gating systems and assess their effectiveness to consistently produce high-quality aluminum castings.

One of the first concerns in designing a gating system is to determine if the part should be cast vertically or horizontally. Horizontal gating is the most commonly used technique because it generally is less complicated to mold, has less hydrostatic pressure, and produces less metal turbulence. However, large, thin-wall castings are impractical to cast in a horizontal

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position because of nonuniform directional solidification and the potential for mold sag. When parts are cast in the vertical position, however, directional solidification is promoted because the metal is gated into the casting only when and where metal is required. Solidification then can be controlled by judicious placement of chills, thus allowing the metal to solidify toward each riser/ingate combination. The main disadvantage of vertically gating large, thin-wall castings is a large sprue height that will cause metal turbulence if not properly designed.

Two test sections (Figs. 25 and 26), representing portions of the YC-14 station 170 body bulkhead, were selected for evaluation of gating techniques. A vertical gating system was selected for evaluation. The next step is selection of a gating ratio. At the start of this investigation, a 1:4:4 gating ratio was used. The metal flow in a vertical gating system such as shown in Figures 25 and 26 is down the sprue into the horizontal runner, through the ingates to one of a number of vertical runners, and into the casting through a series of step gates. The gating ratio does not take into account cross-sectional areas of the vertical runners and step gates. It was determined from this investigation that as long as the cross-sectional area of the vertical runner was larger than the area of an ingate and the total areas of two step gates were larger than the area of an ingate, metal flow would not be restricted.

After pouring the Figure 25 part at 1450°F, radiographic inspection revealed the presence of dross and porosity throughout the part. The poor quality of this part was attributed to the 1:4:4 gating ratio. It was suspected that this gating ratio, coupled with a large sprue height, resulted in a high metal velocity at the ingates, causing turbulent flow of metal into the mold. To overcome this problem, a 1:8:8 gating ratio was evaluated. Another casting was poured under similar circumstances except with the larger gating ratio. The internal quality of this casting was better, but unacceptable gas porosity, dross, and small misruns still persisted. The gating ratio then was changed to 1:6:8. The overall radiographic quality of this part was better than those previously cast; however, some gas porosity was present in the part. The gas porosity was found not to be attributed to the gating system, but rather to the strontium modifier used in the A357.

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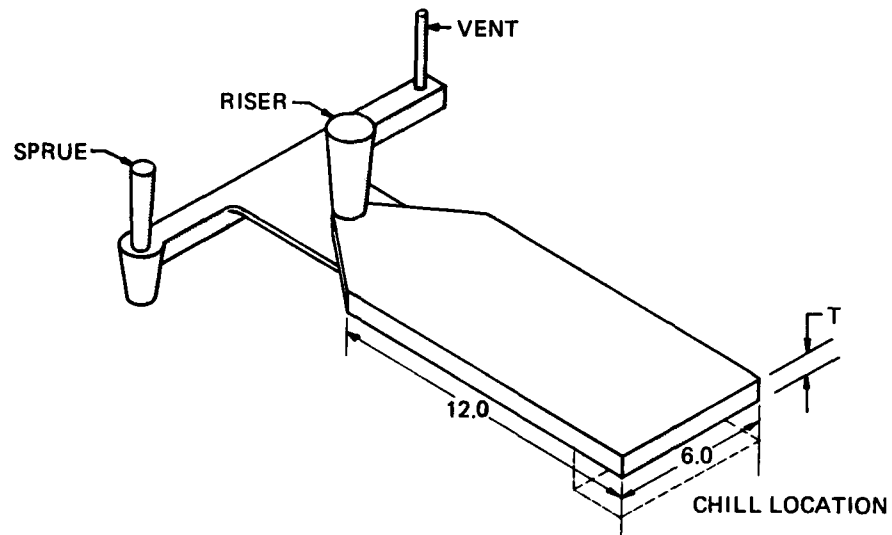
Figure 22.   Test Plate Configuration for Chilling Tests
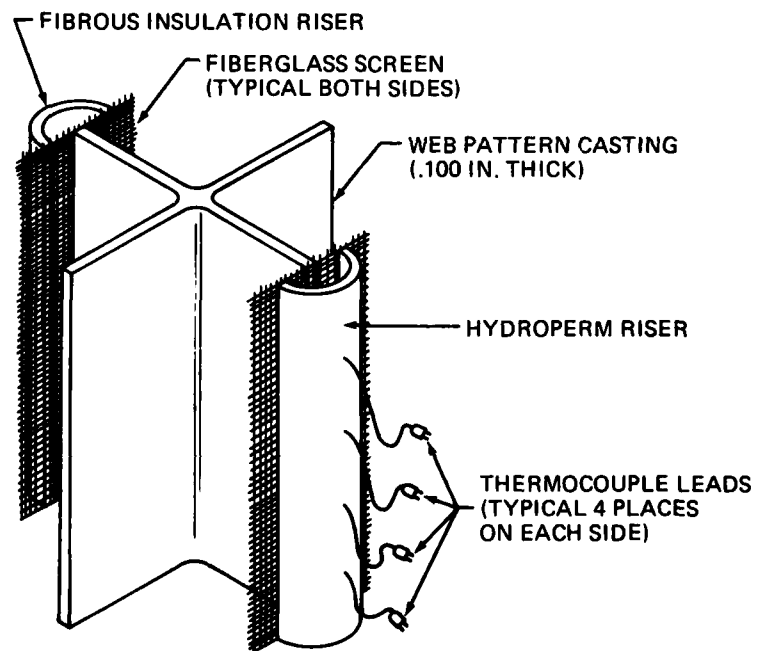
Figure 23.   Test Configuration for the Evaluation of Vertical Runner Insulation Material
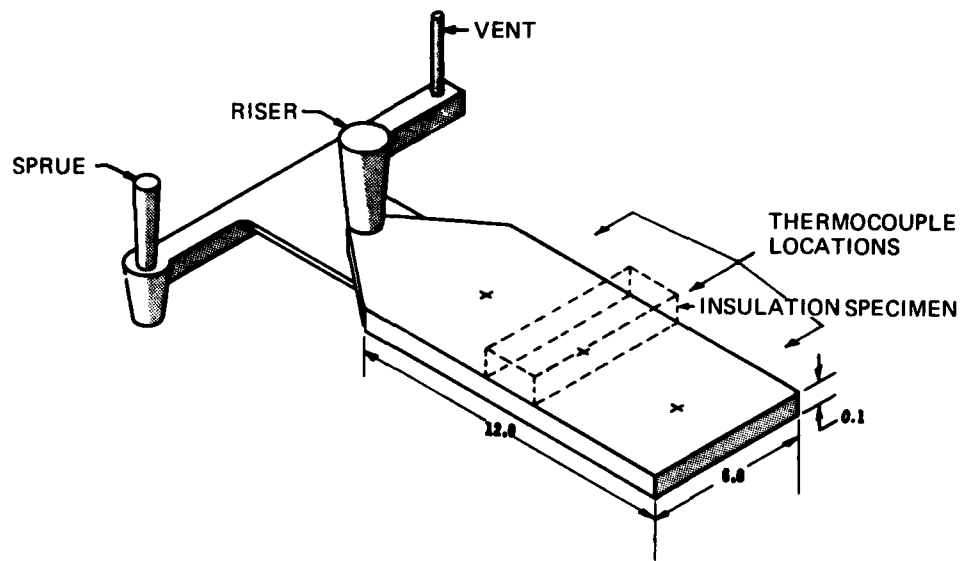
Figure 24.   Configuration of Test Plate for Insulation Tests
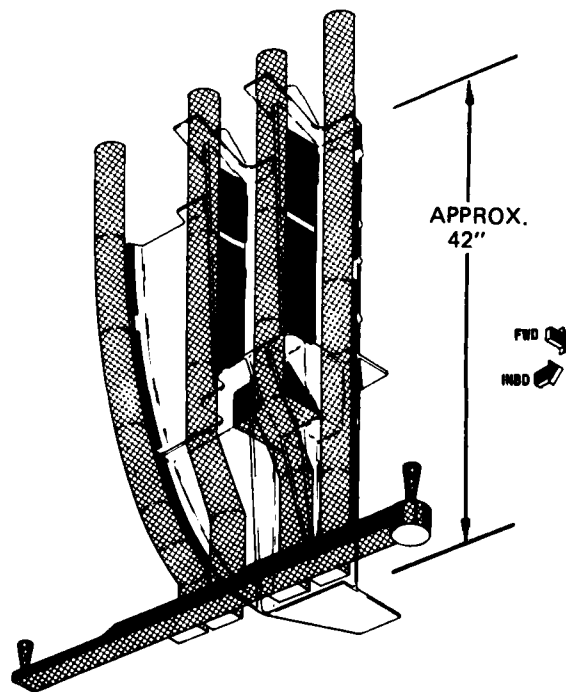
Figure 25.   Part "A" Configuration with Gating System Attached
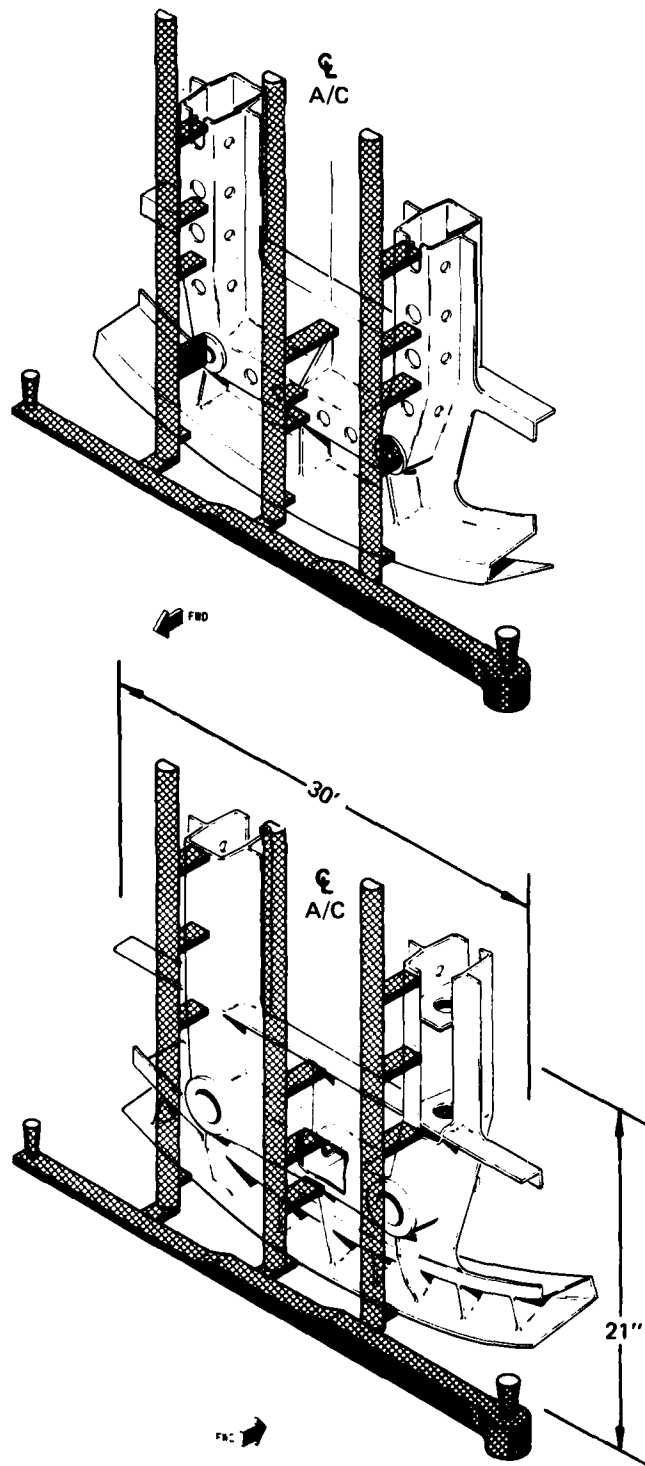
Figure 26.   Part "B" Configuration with Gating System Attached

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It was concluded that a 1:6:8 gating ratio provided optimum metal flow characteristics. It is recommended from the results of this work that a 1:6:8 gating ratio be used for large, thin-wall structural parts cast in the vertical position.

Further evaluation of gating techniques was conducted using the same part configurations and gating ratio. The parts were gated in the inverted position (Fig. 27) to simulate a possible method of pouring the full-scale station 170 body bulkhead. Pouring the part in the inverted position would allow the thin areas to fill first since the hydrostatic head pressure is greatest and provides better feeding of the thick sections that are in the upper portion of the part.

The key to a good gating system is to have a properly designed sprue system. The important aspects of sprue design that affect metal turbulence are sprue height and shape, and the base diameter of the sprue, which controls the flow rate. The first consideration in the design of a sprue system is to determine the height of the sprue. Large sprue heights cause metal turbulence. During this investigation, test parts (Figs. 25 and 26) were poured with sprue heights of 30 and 52 inches. Parts cast with sprue heights greater than 30 inches had poor radiographic quality thought to be caused by increased turbulence.

The sprue system used for these parts was a cascading design (Fig. 28). The purpose of this system was to eliminate metal turbulence while maintaining the hydrostatic head. The advantage is that the metal does not make a continuous drop from the pouring basin to the pouring well, but a series of smaller drops. The height of each cascade step was 30 inches. The bottom sprue had a 0.5-inch base diameter, and the top sprue had a base diameter of 0.7 inch. Several castings poured with this gating system exhibited radiographic quality better than those cast with a single sprue. There was still a small amount of gas porosity dispersed through the casting. Since the metal quality was satisfactory prior to pouring, the dispersed gas porosity was assumed to be caused by the gating system.

INBD
FWD

FWD
INBD
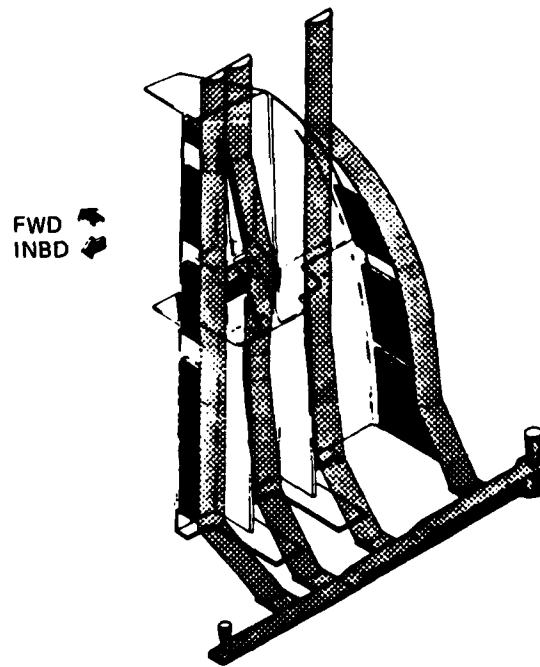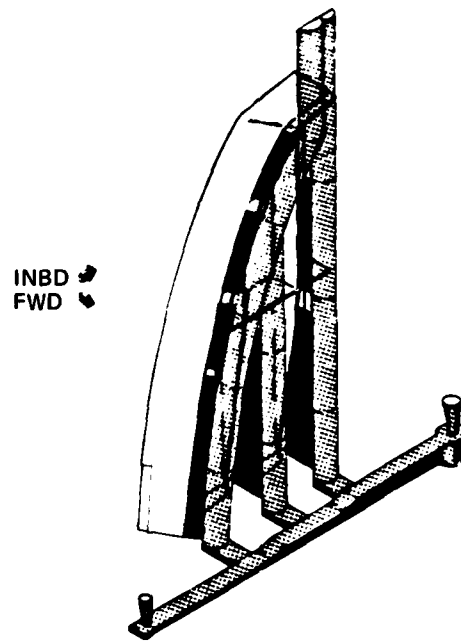
Figure 27. Part "A" Configuration Cast in Inverted Position with Gating System
            Attached

All sprues were tapered to prevent entrapment of air in the metal as it flowed down the sprue. The two sprue shapes evaluated in this investigation were conical (round) and rectangular. The configuration shown in Figure 27 was cast with both conical and rectangular sprues. The cascading sprue system was used in both cases. The relative radiographic results of those parts poured using the rectangular sprues were better than those those poured with the conical sprues. The rectangular sprues produced less dispersed gas porosity in the casting, which indicated less metal turbulence.

Another important consideration in the design of a gating system is the runner and ingate configuration. The optimum runner shape was found to be square. The shape of the pouring well is important to control metal flow entering the runner. The optimum shape was found to be cylindrical with a flat bottom.

The ingate configuration found most suitable was that shown in Figure 29. There should be generous radii in the transition from the runner to the ingate. Abrupt changes in metal direction will cause turbulence. The location of the ingate relative to the runner was found to be best placed on top of the runner. This facilitates mold fabrication and, most importantly, prevents dross from entering the mold cavity.

2.   Straining Materials

Straining materials in the horizontal runner are used to filter out dross that forms as the metal comes down the sprue. The use of straining material such as fiberglass screen in the vertical runners provides another means of ensuring metal quality. A fiberglass or metal screen can be placed between the vertical runner and the step gates (Fig. 30A). The advantage of screening the metal at this location in the mold is that the lower metal velocity in the vertical runners permits a more uniform filtering. However, the combination of the continually reducing hydrostatic head pressure and the resistance of the screen to metal flow may cause misruns. One way to overcome this problem is to place screening
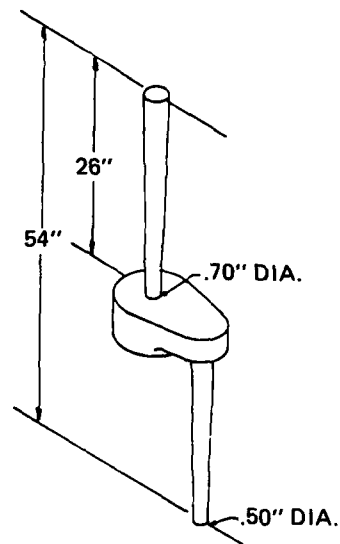
Figure 28.   Cascade Sprue System for Part "A" Configuration of Figure 27
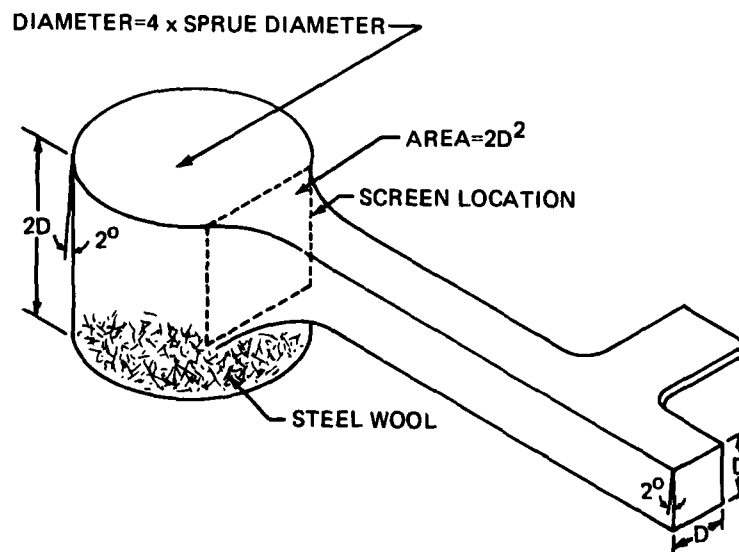
Figure 29.   Typical Runner, Pouring Well, and Ingate Configuration

material above the step gates at the location where the problem occurs. This technique is illustrated in Figure 30B.

Screening materials will reduce effective runner or ingate areas. The fiberglass screen used during this investigation had a 50% open area, which means that the runner area was reduced by half. The area of the runner must be enlarged by the amount the screen reduces it. The amount of area reduction that will occur as a result of the screen becoming filled with dross also must be considered. An additional 25% increase in area was used during this investigation.

3.   Risering Techniques

The promotion of directional solidification is the key to obtaining high-strength castings. To design such a risering system, information must be known about the effect of riser size, the distance metal will feed from a riser, and the feeding paths that transport metal through the casting. During this investigation, plates of the configuration shown in Figure 22 were used to determine the effect of riser size and the distance metal will feed from a riser. Tests also were conducted to determine the effect of chill size on the ability of the risers to feed the plates.

It was found to be important, when designing a risering system for a thin-wall casting, to use a large number of closely spaced risers to ensure adequate feeding of the thin sections. The larger, heavy wall sections do not require as many risers, but they do need to be larger. Another conclusion was that the distance from the chill to the riser affects mechanical properties. The shorter the distance between the chill and riser, the more uniform the mechanical properties will be. The feeding distance should not exceed 6 inches in section thicknesses less than 0.25 inch. In section thicknesses greater than 0.25 inch, a chill should be placed at the maximum distance from the riser. To produce consistently uniform properties, the chill-to-riser distance should be minimized.

The information gained from these tests was applied to the design of the risering system for the part shown in Figure 20. The vertical runners and

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ingates act as risers to feed the solidification shrinkage. The riser selected for the vertical runner was 2.5 inches in diameter, semicircular, and made of fibrous insulation. The size of the step gage feeding the ribs was dictated by the rib width and length. To eliminate as much cleanup after casting as possible, the step gate width was three times the width of the rib. The step gate covering the rib was 1/3 to 1/2 the height of the ribs. Tapered step gates were used to prevent the casting from feeding the vertical runners.

Radiography was used during this investigation to determine if the step gates were of the proper size and providing adequate feed to the casting. In areas that were suspected of inadequate feeding, step gates were removed and radiographed. If shrink porosity was evident in step gates near the casting, vertical runners were not providing enough feed metal, and the size of the vertical runners in this area was increased.

The techniques for designing a gating and risering system are not cut and dried. There are no magic formulas that will tell the riser placement and size and gating configuration. The gating and risering for each casting are unique. However, from the tests conducted in this investigation, a lot of the guesswork can be eliminated from the gating and risering design, and a more sophisticated, scientific approach can be taken.

F. DIMENSIONAL TOLERANCES AND STRAIGHTENING REQUIREMENTS

The purpose of this portion of the investigation was to define the dimensional tolerance requirements that could be achieved cost-effectively by sand casting. Shrinkage allowances were established, and straightening requirements and techniques for large, thin-wall A357 castings were developed.

1. Dimensional Requirements

Parts used for previous tests were dimensionally checked and compared with the pattern to determine the amount of shrinkage. Tests results are shown in Table 10. The area that can be cast with the 0.100 ± 0.010 inch section thickness is limited. The maximum distance from the center of the

51
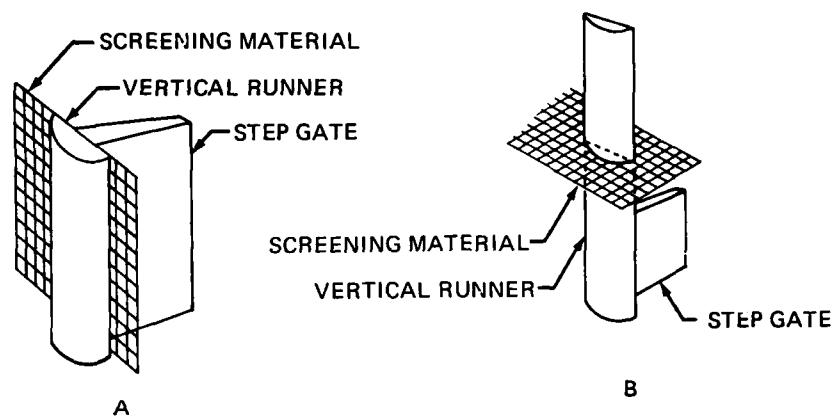
Figure 30.   Applications for the Use of Screening Material in Vertical Gating Systems

Table 10.   Dimensional Tolerances—A357 Sand Castings

DIMENSION	MINIMUM DIMENSION & TOLERANCE, IN.
DRAFT ANGLE	$\frac{1}{2}^{\circ}$
SECTION THICKNESS	.100 ± .010
OVERALL DIMENSION, IN. (GENERAL)	
0-1.0	± .010
1.1-10.0	± .030
10.1-20.0	± .050
20.1-40.0	± .10
40.1-60.0	± .15
60.1-100.0	± .25
MACHINING ALLOWANCE UP TO 100 IN.	+ .250
SHRINKAGE ALLOWANCE (GENERAL)	.125 IN./FT.

thin section to a riser is approximately 5 inches. This limits the dimensions of any one thin area to about 10 x 10 inches.

The dimensional requirements of A357 aluminum sand castings can be closely controlled if the shrinkage allowances are carefully selected. One possible means of selecting the proper shrinkage allowance is to section the part into small sections and determine the shrinkage characteristics of each section.

2.   Straightening Requirements

Straightening of A357 must be accomplished after solution heat treatment ("W" condition). This alloy begins to naturally age after quenching if it is not maintained at a temperature of -10°F or less. Because it is almost impossible to straighten a large, complex casting while maintaining it at -10°F, it was necessary to determine how long a part could be held at room temperature after quenching and still have enough ductility for straightening. It was found that the ductility of A357 is not affected appreciably by naturally aging up to 8 hours at room temperature.

The tools required for straightening consisted of various sizes of rubber mallets, clamps for straightening ribs and flanges, and backing blocks. All distortion except oil-canning could be removed. Oil-canning generally occurs in thin sections as the result of a severe quench. It is almost impossible to remove oil-canning once it has formed. Careful design of the part is required to ensure that it does not occur.

Straightening of parts cast form A357 can be easily accomplished in the "W" condition up to 8 hours after quenching. Standard foundry straightening tools are all that is necessary. Careful design of the part is necessary to prevent the formation of oil-cans during quenching.

G.   DISTORTION

1.   Design-Related Distortion

One of the major causes of distortion in castings is that resulting from improperly designed parts and/or molds. Nonuniform section thicknesses and solidification rates cause a buildup of stresses that act to distort the part. Distortion due to these inherent stresses is minimized by altering the mold design.

To evaluate this type of distortion, parts were cast in the configuration of Figure 22 (T = 0.1 and 0.5 inch) and Figures 25 and 26. Distortion resulting from solidification stresses was found to be negligible. However, if distortion due to these stresses should occur in large aluminum castings, it could be controlled by incorporating cast-on additions for part balance or using extra runners and gates to provide symmetry.

2.   Heat-Treatment Distortion

The second major cause of distortion is heat treatment. This distortion results when the parts are rapidly quenched from the solution heat-treatment temperature. Variations in the cooling rate throughout the part result in a buildup of stresses that, if large enough, will warp the part.

To determine the amount of distortion resulting from heat-treatment operations, parts of the configuration shown in Figure 22 (T = 0.1 and 0.5 inch) were cast, solution heat treated at 1010 $\pm$ 5°F, and quenched in either agitated (1) water at 160°F, (2) 20% glycol solution at 120°F, or (3) 28% glycol solution at 120°F. To simulate production heat-treatment operations, a 10-second delay was allowed between heat treatment and quenching. Parts of the configuration shown in Figure 22 (T = 0.1 inch) and Figure 31 were used to determine mechanical properties.

The parts quenched in water contained a far greater buildup of stresses than found in parts quenched in glycol; maximum distortion occurred in the parts quenched in 160°F water. Distortion in parts quenched in 20% glycol

VENT

RISERS

SPRUE

4"

8"

4"

CHILL LOCATIONS - - - - - - - - - -
(ENTIRE BOTTOM SURFACE ALSO CHILLED)
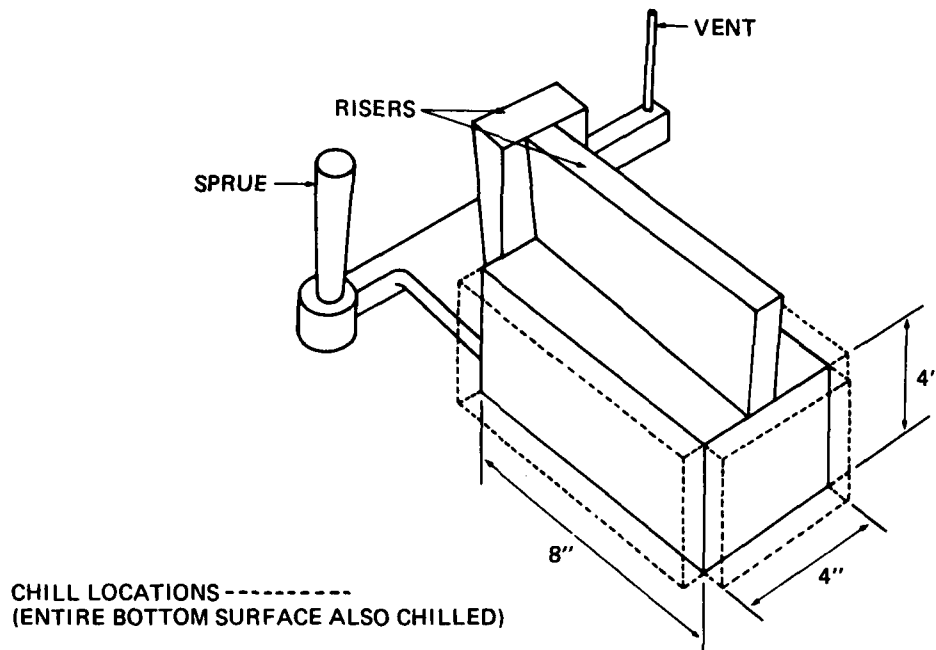
Figure 31.   Test Block Configuration

solution at 120°F was less than observed in the water-quenched parts, and parts quenched in 28% glycol solution at 120°F displayed the least amount of distortion.

Parts used in this investigation were packed in dry ice and held for 33 hours. The parts then were taken from cold storage, straightened, artificially aged at 325°F for 9 hours, and allowed to air cool. Tensile specimens then were machined from the test parts and used to determine ultimate tensile strength, yield strength, and percent elongation.

Optimum overall mechanical properties were obtained by quenching in water at 160°F. For parts quenched in water, round specimens were (1) about 3.0% higher in yield strength and 7.5% higher in tensile strength than round specimens taken from parts quenched in 20% glycol at 120°F, and (2) slightly higher in yield strength (about 0.5%) but 5.0% higher in tensile strength than round specimens taken from parts quenched in 28% glycol at 120°F. Flat specimens of parts quenched in 160°F water were (1) about 1.0% higher in yield strength but about 3.0% lower in tensile strength than specimens quenched in 20% glycol at 120°F, and (2) about 4.0% higher in yield strength but about 3.5% lower in tensile strength than specimens quenched in 28% glycol at 120°F.

Significant differences in the elongation of the test specimens were noted. Round test specimens quenched in 160°F water displayed average values about 50% higher than with 20% glycol at 120°F and about 44% higher than with 28% glycol. Flat specimens quenched in 160°F water displayed values about 12% lower than with 120°F-20% glycol solution and about 28% lower than with 120°F-28% glycol.

Considerable distortion was obtained in thin sections from quenching in each of the three quenching media. Although the distortion observed on the specimens quenched in 28% glycol at 120°F was significantly less than that observed on specimens quenched in 160°F water or 120°F-20% glycol, it merits concern with respect to dimensional control problems. In large, complex aluminum castings, distortion in thin sections between ribs or thicker sections may result in buckling or oil-canning. This distortion is

very difficult and often impossible to correct. However, this type of distortion may be avoided by minimizing the size of the thin section with respect to distance between ribs or by adding ribs or supports to the thin sections.

During quenching, heat-treated parts tend to move about in the quench tank because of agitation of the bath. This movement may result in nonuniform cooling of the part and/or damage to the part if it strikes other quenched parts or quench tank walls. To avoid these problems, a fixture should be used to restrict movement. Design of such a fixture should include provisions for holding the casting in place to minimize movement during quenching, but also allow expansion/contraction of the part during heat treatment and cooling to room temperature.

H. NDE PROCEDURES AND VERIFICATION OF RESULTS

The primary nondestructive evaluation (NDE) methods evaluated and used in Phase II were fluorescent penetrant for surface discontinuities and X-radiography for internal soundness. Ultrasonic techniques demonstrated a potential capability to reveal fine porosity in heavy sections where the ability of radiography is deficient. This capability was further investigated during Phase IV.

1. Surface Inspection Methods

Initial inspection for surface irregularities, discontinuities, and finish was accomplished visually. Surface irregularities below drawing tolerances, such as underflush parting lines, core or chill impressions, pits, inclusions, and open gas holes, were sought. Discontinuities such as cracks, misruns, cold shuts, and other linear, propagating-type flaws also were noted. Surface finish was compared with NAS 823, "Cast Surface Comparison Standards," after final cleanup of the castings.

Fluorescent penetrant inspection procedures were evaluated, and materials and techniques considered optimum were designated. Water-washable and post-emulsifiable systems were investigated. The investigation of these

various techniques was conducted in a laboratory on relatively small cast panels.

Based upon the laboratory tests, available facilities, and other practical considerations, a penetrant system using a highly self-developing, water-washable penetrant with no developer was selected for the program. This system is considered to have a sensitivity equivalent to Group V materials per MIL-I-25135, "Inspection Materials, Penetrant." Proper preparation of parts prior to inspection is very important. Sawing, grinding, and sand blasting exert a smearing action that can completely close tight defects to the entry of even the most sensitive penetrants. Therefore, a requirement was imposed on the program castings that 0.0002 to 0.0004 inch be chemically removed from all surfaces.

2.   Determination of Dendrite Arm Spacing

Dendrite arm spacing (DAS) measurements provide a nondestructive means of determining mechanical properties likely to be attained in local areas of a casting. It was necessary to develop suitable methods for the microscopic measurement of DAS on designated areas of the full-size castings, as well as on the mechanical test specimens for the design allowables study, and to aid in the preparation of engineering specification D-XXXX, "Aluminum Alloy A357 Castings, Dendrite Arm Spacing, Process for Determination of." A mechanical method for metallographic polishing of the local area of the casting surface was chosen for development. The resulting simple and rapid technique used a flexible-shaft motor-tool for rough and fine grinding with three grades of rubber-bonded abrasive wheels. Polishing was accomplished with cotton laps and both 6- and 1/2-micron diamond paste. After polishing, the surface was etched with 0.5% HF solution. Then a plastic replica of the etched surface was prepared and examined in the laboratory. The replica was retained as a permanent record.

3.   Casting Soundness

A uniformly sound casting is critical to the achievement of consistently high mechanical properties. X-radiography was the primary inspection

method chosen for evaluation of internal soundness. Radiographic inspection techniques were refined during foundry control development to provide consistently high-quality radiographic practices. However, the application of the ASTM E155-76 radiographic standards is definitely subjective and requires experienced, skilled film interpreters. The task of film interpretation becomes more difficult and less accurate if the thickness of the material being evaluated differs significantly from that of the reference standard. A high proportion of the program casting design consists of thicknesses of 0.100 to 0.125 inch, and the lesser proportion contains critical areas with sections several inches thick. These must be radiographically compared with standards representing 0.25- and 0.75-inch thicknesses.

Dispersions of very fine porosity become increasingly difficult to detect radiographically as section thickness increases. The maximum thickness of the bulkhead casting is 4 inches. In an attempt to improve inspection capabilities in the heavy sections of the casting, ultrasonic methods were evaluated. Ultrasonic comparison tests were made on 5- and 6-inch-thick cast material with and without porosity (equivalent to radiographic quality grades A and C). Three approaches to porosity estimation were evaluated:

o   Pulse-echo multiple back reflection loss

o   Pulse-echo direct porosity detection

o   Through-transmission

All three methods were successful with direct contact coupling and a promising ability of ultrasound to detect porosity in aluminum castings was demonstrated. The pulse-echo method of direct porosity detection is the more practical approach, as the inspection can be conducted from one surface and the back surface need not be parallel.

I.   WELD CORRECTION OF CASTING IMPERFECTIONS

Imperfections in A357 sand castings frequently can be corrected by fusion welding. Casting defects such as porosity, shrink, misruns, and cracks usually can be corrected, but each casting must be evaluated on its own merit. Consideration must be given to such factors as the number, size, and location of

individual imperfections, working access, distortion produced by weld shrinkage, weld restraint conditions, rework and reinspection costs, and monetary investment in the particular casting.

1.   Welding Process Selection

Weld correction of casting imperfections can be accomplished successfully by gas tungsten arc welding (GTAW) in the alternating current (AC) or direct current (DC) modes, or by gas metal arc welding (GMAW). Process selection is dependent upon such factors as material thickness, available welding equipment, and availability of suitable weld filler material.

GTAW-AC usually is used for single-side corrections in materials up to 1/8 inch thick without a prepared weld cavity and up to 1/4 inch thick with a cavity. Thicknesses up to 3/8 inch can be welded successfully using GTAW-AC by grooving and welding both sides. The GTAW-AC mode provides excellent cathodic surface cleaning and good visibility due to the high arc intensity. The GTAW-DC mode is used for heavier material sections and produces deep, narrow weld penetration.

2.   Welding Equipment

Although manual AC/DC GTAW power sources can be used to produce acceptable weld corrections, consistently better results were obtained using solid-state, square-wave, variable-polarity duty cycle equipment. Such a power source completely eliminated the problem of tungsten spitting and produced a substantial reduction in the incidence of porosity in the weld deposit during test welding in the AC mode. This equipment also provides excellent arc stability and smooth weld tailouts in the DC mode.

3.   Weld Tests and Mechanical Properties

Tests were conducted to evaluate the relative suitability of various welding processes and to determine the mechanical properties of the weld deposits and adjacent base metal. Cast A357 test panels (Fig. 32) were used in the evaluation. Simulated weld corrections were made using the
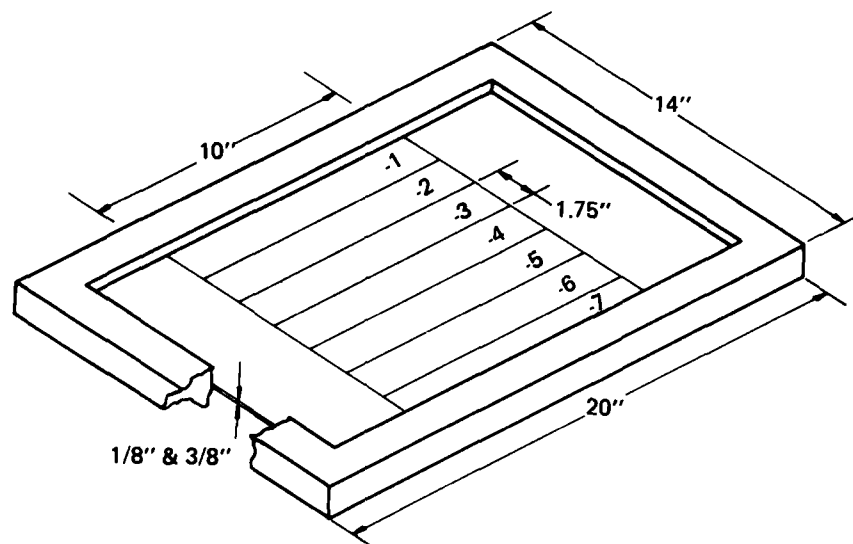
ODD DASH NUMBERS - WELDED SPECIMENS
EVEN DASH NUMBERS - PARENT METAL

Figure 32.   Weld Test Panel Configuration

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GTAW-DC and GTAW-AC modes, A356 and A357 filler materials, and preheat and no preheat, on 1/8- and 5/8-inch-thick test panels in the as-cast and heat-treated conditions.

Evaluation of the test data indicated that the various combinations of welding modes, filler materials, and preweld temperatures produced no significant differences in mechanical properties of test specimens welded in the as-cast condition and heat-treated after welding. There also was no significant difference between the mechanical properties of the welded and base metal specimens in the as-cast condition.

However, as predicted, there was a substantial reduction in the tensile and yield strengths of welded specimens that had been heat-treated prior to the simulated weld corrections and not re-heat-treated after welding.

4. Weld Correction Procedures

In general, the procedures and techniques required to accomplish weld correction of A357 sand castings are identical to those commonly employed for weldable wrought alloys. The experience gained during this test program demonstrated that high-quality weld corrections can be produced consistently by employing reasonable care and standard industry practices. Detailed procedures required to accomplish weld correction of typical casting defects were documented in Appendix A of reference 2.

J. PRELIMINARY MATERIAL AND PROCESS SPECIFICATION

A preliminary material and process specification, covering A357 aluminum alloy castings produced for use as primary aircraft structural components, was prepared during Phase II of the program. This preliminary specification, M-XXXX, "Castings, Aluminum Alloy A357, Primary Aircraft Structure," formed the basis for the final material and process specification completed in Phase VI.

K.   ALLOWABLES TEST CASTINGS

Two casting configurations were established in Phase II for allowables testing. Each configuration represented a full-scale region of the station 170 bulkhead. These configurations, designated allowables parts A and B, are shown in Figures 88 and 89 in Section VI (Phase V—Structural Test and Evaluation).

Fourteen allowables test castings were produced during Phase II. Four parts A and five parts B were produced by the Boeing foundry, and five parts A were produced by Hitchcock Industries, Inc., Minneapolis, Minnesota, the second-source foundry. A summary of the allowables test program is presented in Section VI.

L.   METALLURGICAL STUDIES

During Phase II, extensive work was conducted to gain an understanding of the metallurgical structure of A357-T6 and its relationship to foundry variables, such as chilling. An important part of this work involved the study of dendrite arm spacing (DAS) in the casting microstructure.

1.   Measurement of DAS

By definition, DAS is the distance between secondary dendrite arms in the cast metal microstructure (Fig. 33). Typical casting macrostructures and microstructures, and method of DAS measurement, are shown in Figures 34 and 35. DAS also could be determined by drawing two diagonal lines connecting opposite corners of each photomicrograph shown in Figure 35 and counting the number of intercepting dendrite arms. The latter method, however, resulted in DAS averages that were 10 to 20% higher than those determined by the illustrated procedure.

2.   Mapping of DAS

A metallographic procedure was developed for mapping the changes in DAS from chill to riser locations. The resulting "contour map," showing lines of constant average DAS, was a very useful tool for studying the progression

of solidification. Such maps are particularly helpful during the preproduction phase of a casting.

In this procedure, a section was cut through the selected portion of the casting, and the section was ground, polished, and etched. Grid lines were lighly scribed on the etched surface and, using a metallurgical microscope, DAS measurements were made at approximately 1/8-inch intervals along each grid line. The resulting DAS data were plotted versus distance along each particular grid line, and an average curve was drawn through the points. Points then were taken from the average DAS curves and plotted on a sketch of the cut section, so that "contour" lines of constant average DAS could be constructed. The cutting, polishing, etching, and measuring were conducted on several planes through the selected casting section to provide a detailed analysis. An example of the DAS mapping procedure is shown in Figure 36.

Figure 36 shows a cast lug through which three sections were cut for investigation. Planes D and E were not actually sectioned, but are reference planes only for cross-plotting contour line data. Figure 36 also illustrates six grid lines scribed on each plane section. Figure 37 shows the DAS measurements along the six grid lines on plane A. This illustrates the typical procedure for recording DAS measurements on all planes. Figure 38 shows the resulting DAS contour maps constructed from the average DAS curves for the three planes A, B, and C. DAS contour maps for planes D and E (Fig. 39) were constructed by cross-plotting the data from Figure 38.

Figure 39 also shows the attachment hole and beveled surface (dashed lines) that subsequently would be machined on the lug. The contour maps revealed that the largest dendrite arm spacings, and therefore lower mechanical properties, occurred in the critical ligament area between the hole and the beveled surface. Also, the worst porosity was found in the critical area. Therefore, two corrections were made in the tooling to reduce DAS and porosity in this area. The corrections were:
o   The step-gate was relocated to the left side of the lug.
o   A copper chill was added on the beveled surface.

DAS = DISTANCE BETWEEN SECONDARY DENDRITE ARMS

PRIMARY DENDRITE

$$DAS = \frac{L}{N}$$

WHERE
L = LENGTH OF INTERCEPT LINE
N = NUMBER OF INTERCEPTING DENDRITE ARMS
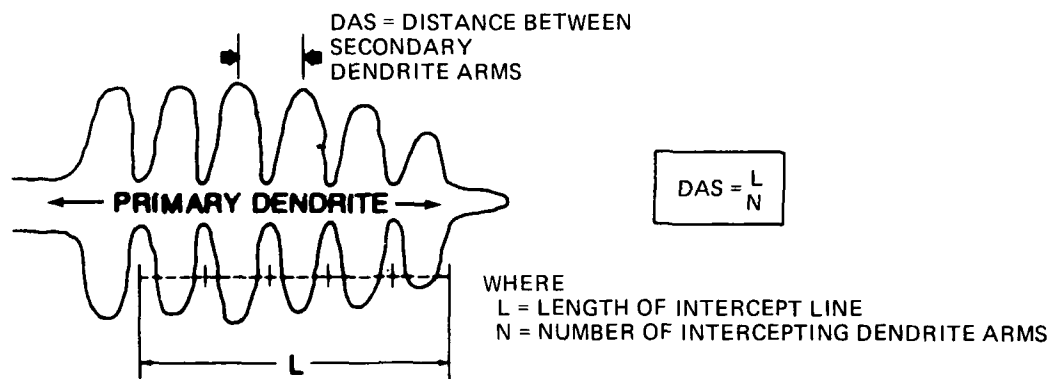
Figure 33. Schematic Sketch Defining Dendrite Arm Spacing

CHILLED SURFACES

CHILLED SURFACE A   SURFACE B
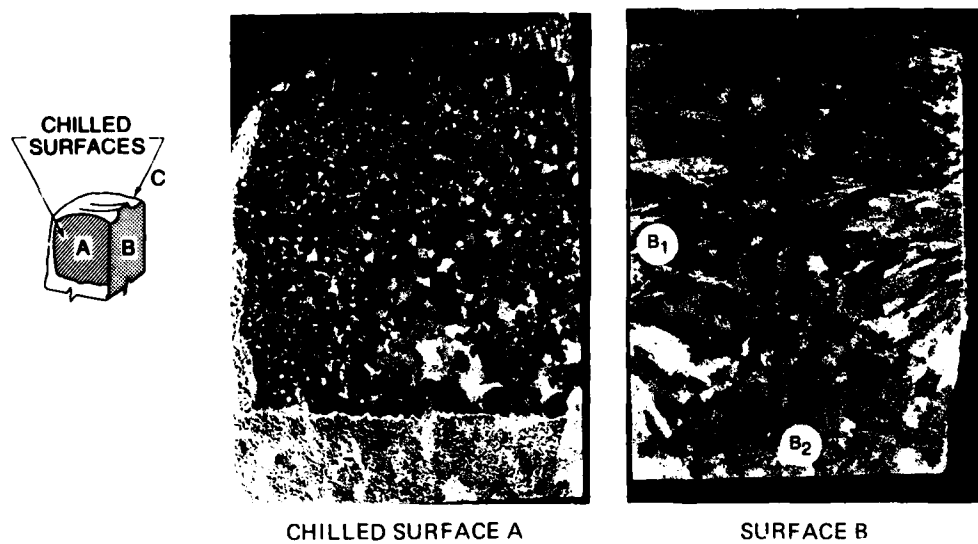
Figure 34. Sections through a Small Lug Showing Macrostructure. Mag.: 2X.

65

$$DAS = \frac{\substack{\text{LENGTH OF}\\ \text{INTERCEPT LINE}}}{\substack{\text{NO. OF INTERCEPTING}\\ \text{SECONDARY}\\ \text{DENDRITE ARMS}}} \times \frac{1}{\text{MAG}}$$
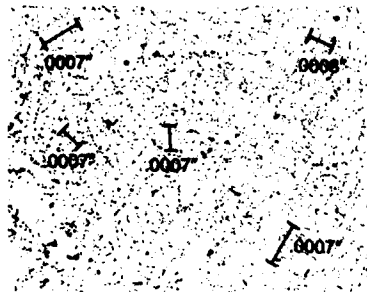
LOCATION B_1
AVERAGE DAS = .0007"
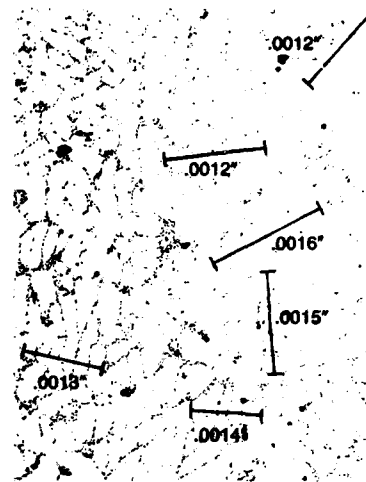
LOCATION B_2
AVERAGE DAS = .0014"

Figure 35.   Microstructure at Two Locations, B_1 and B_2, Shown in Figure 34, Illustrating Method of DAS Determination. Original Mag.: 100X.
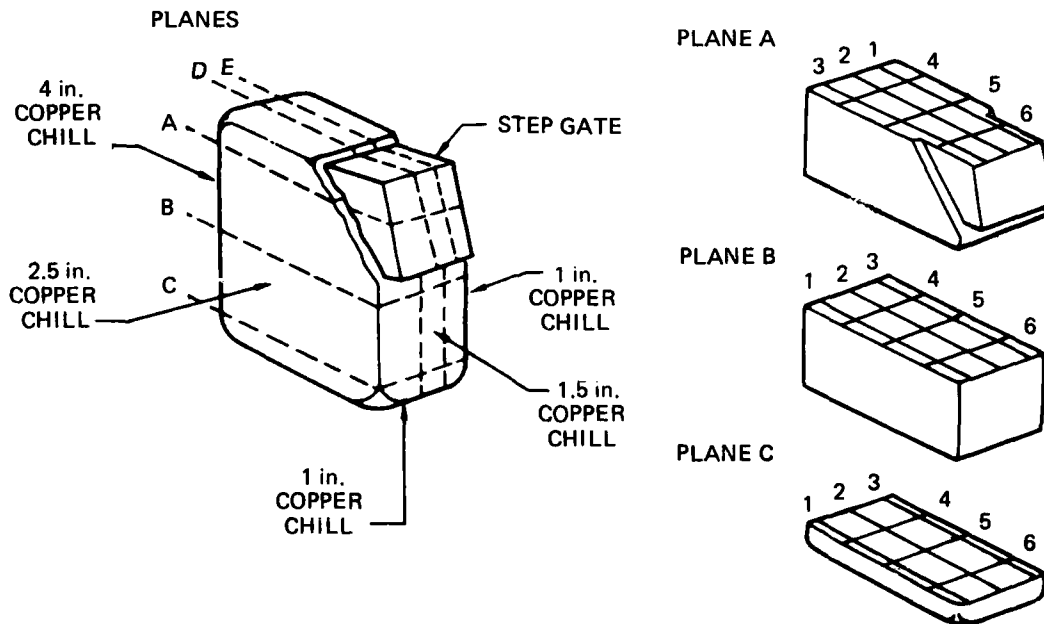
Figure 36.   Cast Lug, Approximately 2 x 4 x 5 inches, Showing Three Planes A, B, and C That Were Investigated, and Grid Lines 1 through 6

66
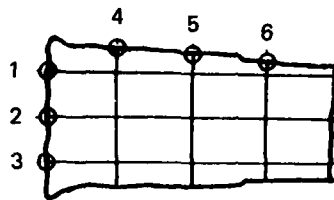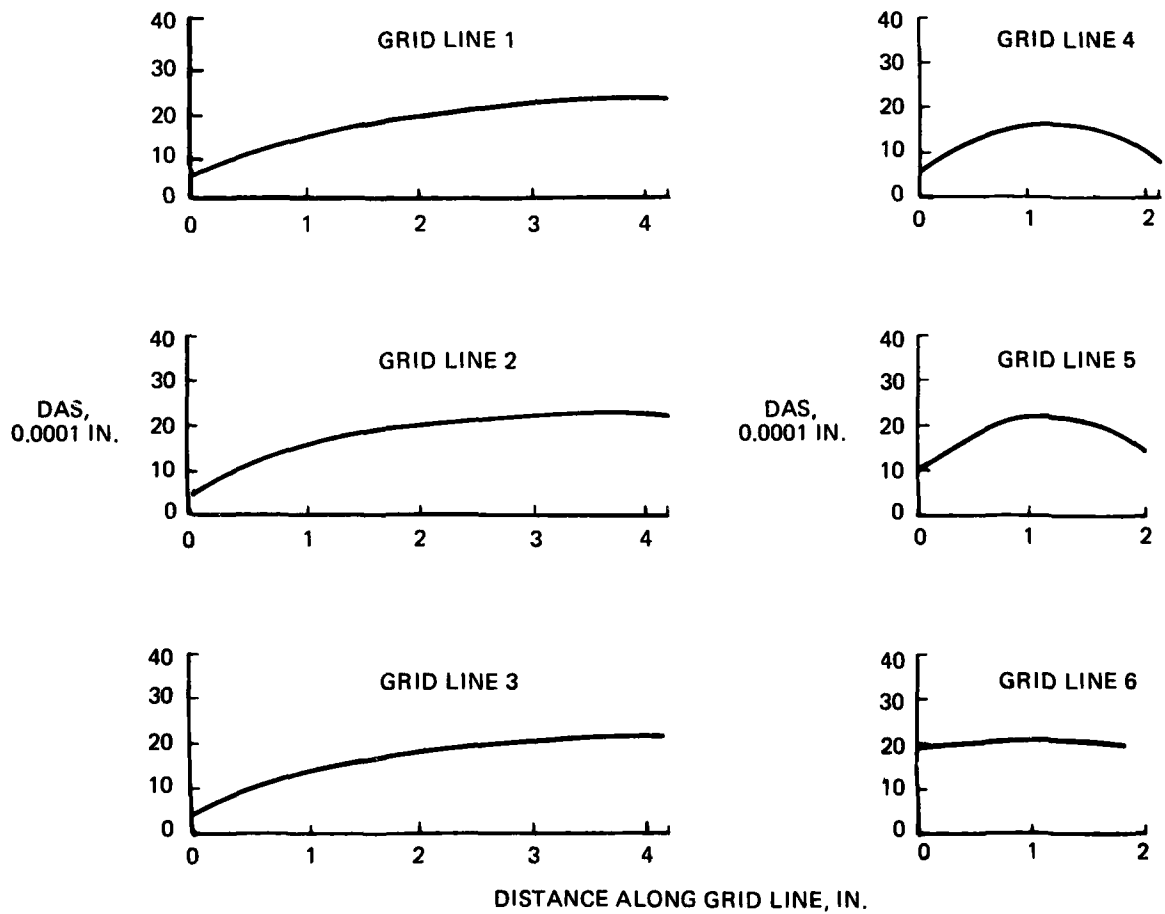
Figure 37. DAS Average Measurements Along Six Grid Lines on Plane A
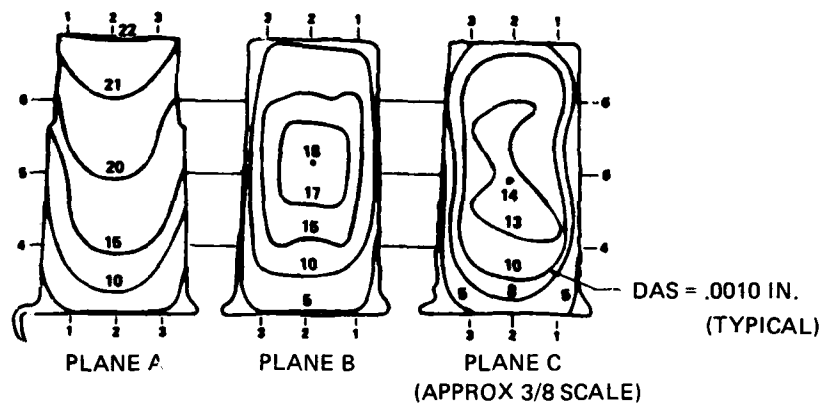
Figure 38. DAS Contour Maps Constructed from Data Like That in Figure 37
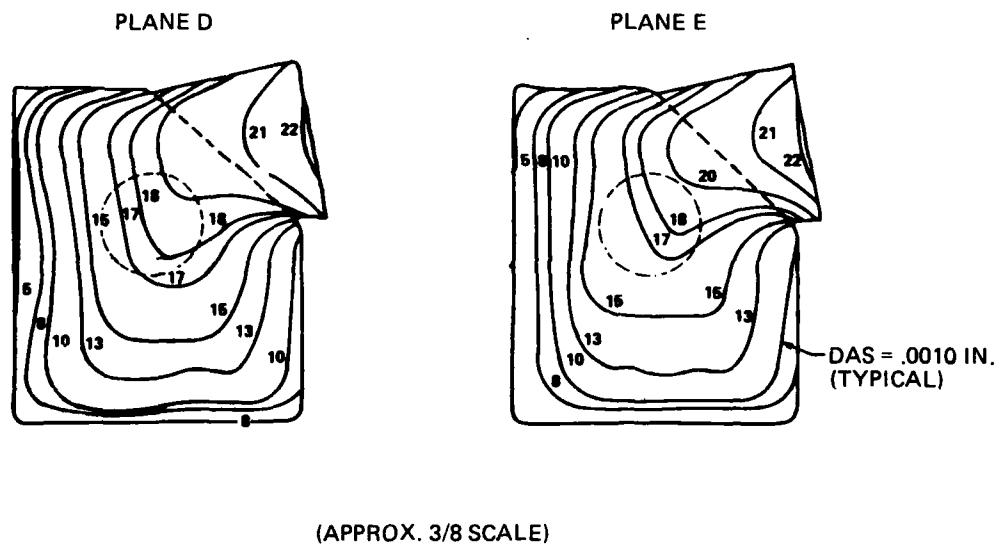
Figure 39. DAS Contour Maps for Planes D and E in Figure 36

3. Summary

This DAS technology application provided an extremely useful tool for studying the progression of solidification and other metallurgical factors concerning casting development and production control. Also, a direct relationship between DAS and porosity was found: as DAS increases, both the amount of porosity and the pore size increase.

M. MANUFACTURING PLAN

At the conclusion of Phase II, a manufacturing process plan was prepared for the fabrication of the YC-14 station 170 body bulkhead. The manufacturing concepts used in this plan were based upon the results of the work conducted during this phase. The plan incuded the manufacturing concepts and major tool requirements needed to cast the bulkhead. It was used by both Boeing and Hitchcock foundries in Phase IV to fabricate the bulkhead castings. The manufacturing plan, presented in full in Appendix A to reference 4, contained the following major topics:

o Material storage
o Sand preparation
o Mold and core making
o Mold preparation for pouring
o Metal preparation
o Ladle fill
o Pouring
o Mold shakeout
o Casting cleanup
o Inspection
o Weld correction
o Heat treatment and straightening
o Mechanical property testing
o Machining and inspection of casting

N. FOUNDRY CONTROL PROCEDURES

To extend the use of aluminum castings to large primary airframe structures, close control of the foundry process must be exercised. In Phase II, an approach to foundry process control was outlined that will ensure the consistent, reproducible fabrication of large primary airframe structural castings. Foundry process control was divided into four categories: personnel qualification, critical operations within the casting process, process plans, and record keeping.

1. Personnel Qualifications and Critical Skills

The use of properly trained people for a specific operation is vital to achieve consistency in the foundry process. Because the production of castings is a very labor-intensive process, the skill level of the foundry personnel will determine the quality of castings produced. Personnel should have experience in their specific job descriptions. This experience, depending upon the sophistication of the job and employee, may be a short, on-the-job training program or an intensive apprentice program.

Several operations in the foundry process were identified as requiring the attention of skilled personnel. The foundry operations judged critical are the following:

o Metal Preparation—This operation includes metal melting and alloying, degassing, checking the gas content, and preparing the pouring ladles for use.

o Pouring—This operation normally is left to the experienced foundryman.

o Mold and Core Making—This is probably the most important step in the successful casting of a part.

o Heat Treatment and Straightening—Correct heat treatment is essential to provide the required mechanical properties. Straightening is necessary to ensure that the casting will meet the specified dimensional tolerances.

Other foundry operations require semiskilled labor. No prior foundry experience is necessary. However, it is the responsibility of every foundry

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supervisor or foundry engineer that all foundry personnel understand their job functions as they relate to the overall casting process. If these steps in foundry personnel qualification procedures are practiced, consistency of the casting process will follow.

2. Critical Operations

Critical operations are those steps of the casting process that, if done improperly, will cause rejection of the casting. Large primary airframe structural castings are generally complex and costly to produce. To keep costs down and to ensure consistent, reproducible castings, control over the following critical operations is mandatory:

o Metal Preparation
    o Chemical analysis
    o Hydrogen content of the melt
    o Pouring temperature
o Mold Fabrication
    o Sand fineness and type
    o Binder quantity and type
    o Chill/insulation locations
    o Riser locations
    o Core alignment
    o Mold alignment
o Mold Shakeout
    o Sand removal
    o Gate and riser removal
o Heat Treatment/Straightening
    o Fixturing techniques
    o Dimensional accuracy after straightening

Each of the above operations should be approved by the foundry supervisor, engineer, or inspector prior to the start of the next sequential operation.

3. Process Plans

Each primary airframe structural casting should have a manufacturing plan that includes the manufacturing steps and major tool requirements. The purpose of this plan is to provide foundry personnel with detailed instructions on how to fabricate the particular casting. Constant updating of the plan must be accomplished as required during fabrication of the tool tryout castings. After the casting process has been perfected, the plan then is released to the foundry for the production phase. The applicable material and process specification must be a part of the manufacturing plan. The plan also must outline the NDE inspections required to ensure the production of consistent, reproducible castings.

In addition to the manufacturing plan, each specific job should have supplemental shop aids. These aids should describe in detail the specific tasks to be performed and provide a checklist to ensure completion of each. Supplemental shop aids would typically include instructions to metal preparation personnel outlining what metal to use, chemistry limits, degassing media and time, and pouring temperature. Mold- and core-making personnel require diagrams specifying the chill/insulation and riser locations and instruction sheets outlining sand type and fineness, binder type, and quantity required. Heat-treatment personnel need to have instructions on how to fixture the part and sketches showing locations where straightening will be required.

4. Record Keeping

An important aspect of the casting process is what was done in the past. Record keeping is necessary to ensure a repeatable process. If the foundryman does not know what he did in the past, he will not know what to do in the future. An unrecorded casting process will result in inconsistent and nonreproducible results. Detailed records should be kept on all aspects of the casting process. Typical record forms were presented in reference 2. Photographic recording of what has been done is a useful technique. Information must be recorded as soon as it is available so that it will not be lost in the confusion of generating more data. It should be

the responsibility of every foundry supervisor or engineer to record all pertinent data and to be responsible for its retention.

SECTION IV
PHASE III—DETAILED DESIGN

A. INTRODUCTION

The objectives of Phase III were to complete and release a detailed design of the cast bulkhead and the machined bulkhead assembly that met or exceeded the CAST program goals.

This phase consisted of the following items:

o   Production drawing preparation to include design layouts for review, analysis, and completion of final production drawings

o   Strength and stability analysis

o   Fatigue and damage tolerance analysis

o   Effects of defects analysis

o   Detailed design weight analysis

o   Preparation of detailed projected cost estimates

o   Final review, approval, and release of the production detailed design bulkhead

o   An update of the baseline component data originally released in Phase I

o   An on-site review covering Phase III activities

This phase of the program was conducted by Richard C. Jones assisted by Carlos J. Romero and Christian K. Gunther. Throughout Phase III, Mr. Jerry Ginn coordinated the foundry and pattern maker's comments with the design activities to ensure optimum casting producibility.

Complete details of the Phase III work were reported in reference 3.

B. DETAILED DESIGN

The Phase III detailed design efforts continued on from Phase I, Preliminary Design. The detailed design of the production cast bulkhead was based upon the final cast bulkhead concept and the preliminary design criteria established in Phase I.

1.   Design Layout

The first design layout of the body station 170 cast bulkhead was an update
of the final aproved concept from Phase I (Fig. 14, Sec. II).   Design
features of this concept included the following:

o   Close physical match to existing bulkhead structure, especially in
     areas of interface with adjacent structure—to provide continuity of
     existing load paths; no revision to adjacent structure required.

o   Single casting replaced all parts of original baseline component plus
     crosswise slanted beam at WL 150.

o   Machining of casting required only for close-tolerance contour at skin
     IML and at nose gear fitting interface locations.

o   Bulkhead webs of minimum castable thickness and upper pressurized
     section in corrugated form replaced original stiffened web.
     Transition section to the lower stiffened web segment located
     between WL 124.6 and 130.

o   Below WL 124.6, web stiffeners extend both fore and aft of web.
     Reduced height of stiffeners from web provided better castabilitiy
     and reduced amount of draft material.

o   No outstanding zee flanges on web stiffeners—reduced requirement
     for coring to outer angled tee chord, upper beam at WL 150, and
     lower torque box.

o   Material located and shaped to provide most direct load path from
     load application to reaction. Primary load application points are four
     nose gear attach points and two door actuator pivot locations.
     Reactions are floor at WL 130 for horizontal and outer skin at each
     side for vertical.

o   Casting draft held to 1/2 degree with concurrence of Manufacturing
     Research and Development, except in selected areas.

The cast bulkhead layout was completed in detail, sized to preliminary
design loads, and released to Manufacturing, Allowables, and Structures
Staff for checking, coordination, and comments.

2. Design Coordination

The initial cast bulkhead drawings were studied and analyzed by Manufacturing, Materials Technology, Allowables, and Structures Staff, with the following changes or additions recommended in the production drawing:

o   Web gages, beam flange thickness, and fitting lug thickness checked and revised as required to match structural loads derived from stress computer model.

o   Added integral cast-on test coupons for mechanical property testing. Located preproduction test coupons to be excised and tested for mechanical properties.

o   Chord casting configuration revised to remove step in parting plane around periphery of bulkhead. This reduced cost of pattern with no increase in machining cost.

o   Cross beam extending outboard and upward from lower boss for door actuator pivot to outer chord revised to be horizontal. This beam would have crossed from one mold flask to another at a very flat angle, requiring extremely close tolerance in mold assembly. Revision located beam entirely within one flask.

o   Recesses were added in large boss at approximately RBL 8.7 and WL 120. These were added for reduction of casting thickness in an area of low stress.

3. Drawing Release

After completion of drawing revisions resulting from design coordination, the drawings were rechecked and approved by Stress, Design, and Project. Copies of the drawing then were released to Manufacturing organizations, Structures Test, and Structures Staff groups including Stress, Fatigue, Weights, and Allowables.

4. Production Drawings

The production bulkhead casting drawing, 162-00017, sheets 1 through 4, is a drawing on mylar with a half-size rear view and full-size section views.

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The production bulkhead assembly drawing, 162-00018, sheets 1 through 4, is a drawing made from "brown line" reproducible copies of the bulkhead casting drawing. This drawing deletes the basic casting dimensioning and adds machining dimensions, bushings, inspection requirements, and finishes.

These drawings, reduced to document size, are presented in Appendix A for reference only.

5.   Baseline Component Data

The initial baseline cost data were derived during Phase I, Preliminary Design. The first unit YC-14 bulkhead total cost was estimated to be $122,000 and the projected unit cost of the bulkhead, based upon a 300-airplane production run, was $10,900. These costs were derived primarily from actual records and were for the built-up baseline component bulkhead prior to release of the updated baseline data.

The initial baseline component weight was 184.6 lb. This weight was the actual weight of the YC-14 baseline component bulkhead and did not reflect a reduction for nonoptimum prototype structures.

A baseline component revision was released September 30, 1977. The revised baseline component included the original YC-14 bulkhead components plus that portion of the slanted beam assembly at WL 150 between LBL 41.0 and RBL 41.0. The updated cost summary, shown in Table 11, gives both the first unit cost and the projected unit cost based upon a 300-airplane production run. The $12,484 figure replaced the $10,900 previously used for a cost comparison of the cast concept versus the baseline component.

The revised baseline component weight was 187.6 lb. This weight was for the YC-14 component parts plus the WL 150 slanted beam between LBL 41.0 and RBL 41.0, and also includes the deletion of nonoptimum weight items that would not be required on a production YC-14 bulkhead.

Table 11. Updated Baseline Component Cost Summary—Conventionally Fabricated
Station 170 Bulkhead Costs

	No. 1 A/P cost	300 A/P cost
Raw material	$ 1,228	$ 384,000
Labor:		
Detail tools	45,450	302,577
Assembly tool	55,325	366,345
Detail fabrication	45,250	1,701,120
Sub-assembly	9,750	743,505
Section installation	– –	247,680
Total	$157,003	$3,745,227
Cost per unit	$157,003	$ 12,484

C. ANALYSIS

1. Static Strength Analysis

The YC-14 design loads were used to structurally size the cast bulkhead and transition structure. A finite-element computer model was used to calculate the internal loads. The exploded computer model geometry of the cast bulkhead and transition structure (Fig. 40) is shown in Figures 41 and 42. Detailed sections of the computer model showing nodes, rods, beams, and plates were prepared. Loads were applied at specific nodes to simulate landing gear loads and loads due to a jammed landing gear door actuator.

Detailed stress analysis of major critical components included:
o   Analysis of lug at BL 28
o   Critical webs
o   Stiffener at BL 28
o   Horizontal beam at WL 150
o   Bulkhead perimeter chord
o   Backup structure for landing gear door actuator
o   Lug backup structure at BL 8.7

Table 12 summarizes the margins of safety of the critical components. The least margins of safety were found for the lug at BL 28 and for the perimeter beam at WL 150. The lug exhibits a positive 9% margin of safety for the maximum tensile force and the perimeter beam also shows a 9% positive margin of safety for combined bending and axial loads.

Complete details of the finite-element model used to determine the internal loads and of the critical components stress analysis were presented in reference 3.
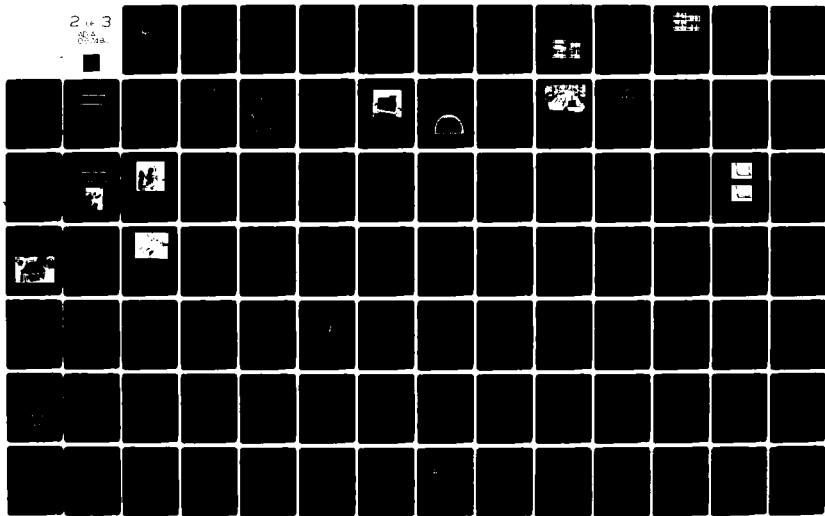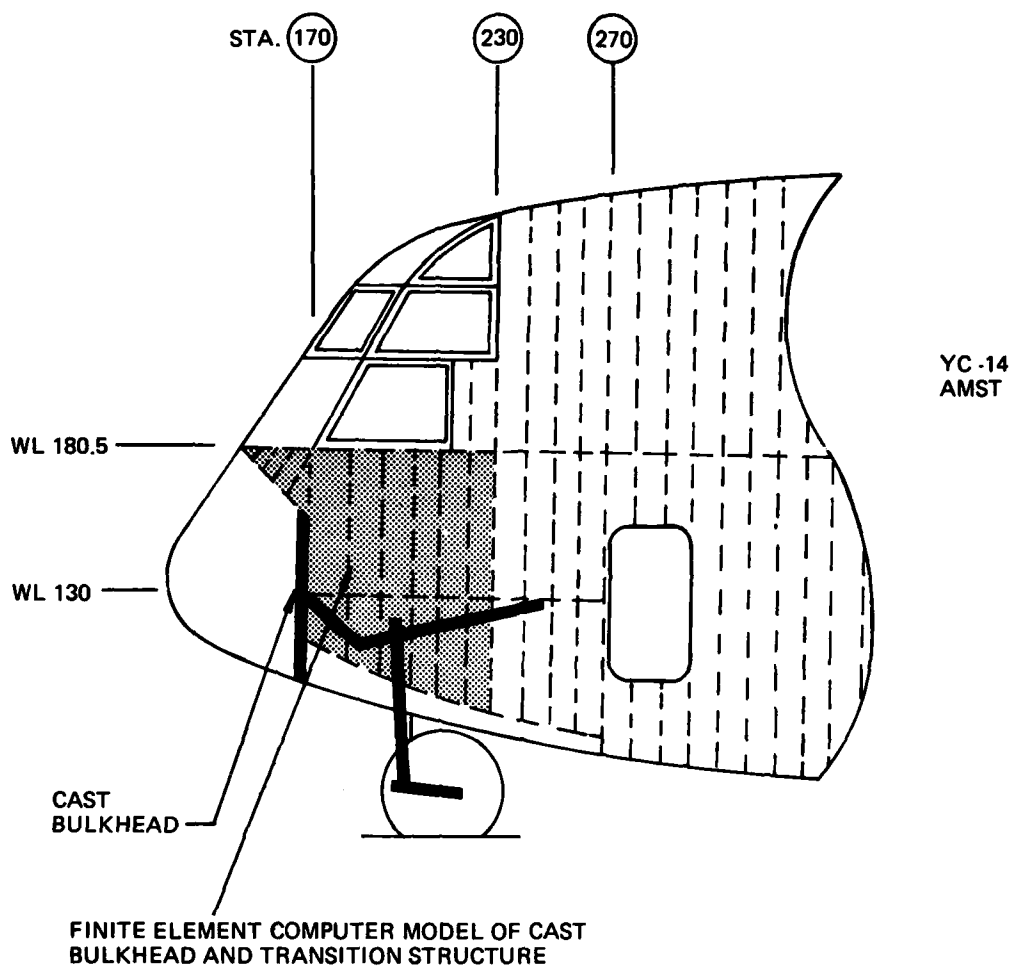
Figure 40.   CAST Bulkhead and Transition Structure

UP

FWD.

OUTB'R'D

TRANSITION STRUCTURE
(LEFT SIDE)

CAST BULKHEAD

TRANSITION STRUCTURE
(RIGHT SIDE)
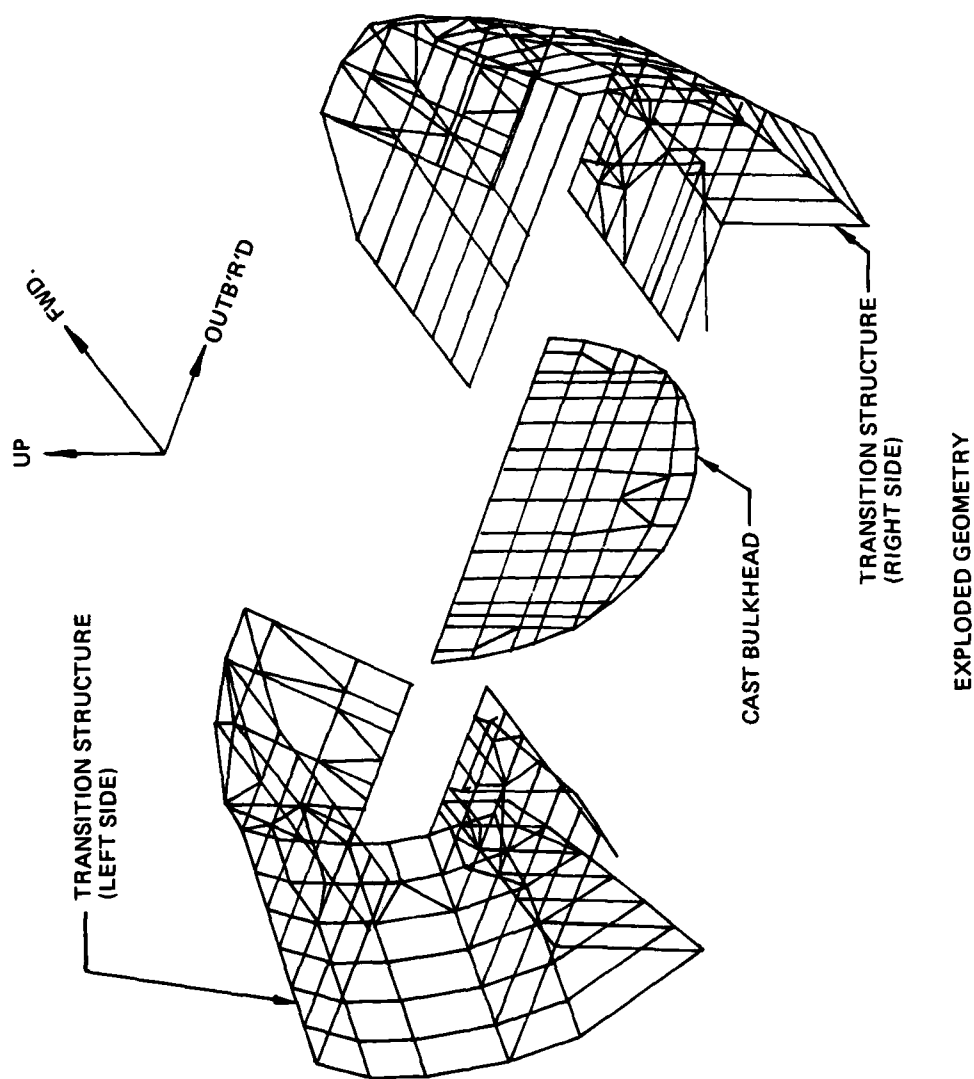
EXPLODED GEOMETRY

Figure 41.   CAST Finite-Element Computer Model, Exploded Geometry

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TRANSITION STRUCTURE

CAST BULKHEAD
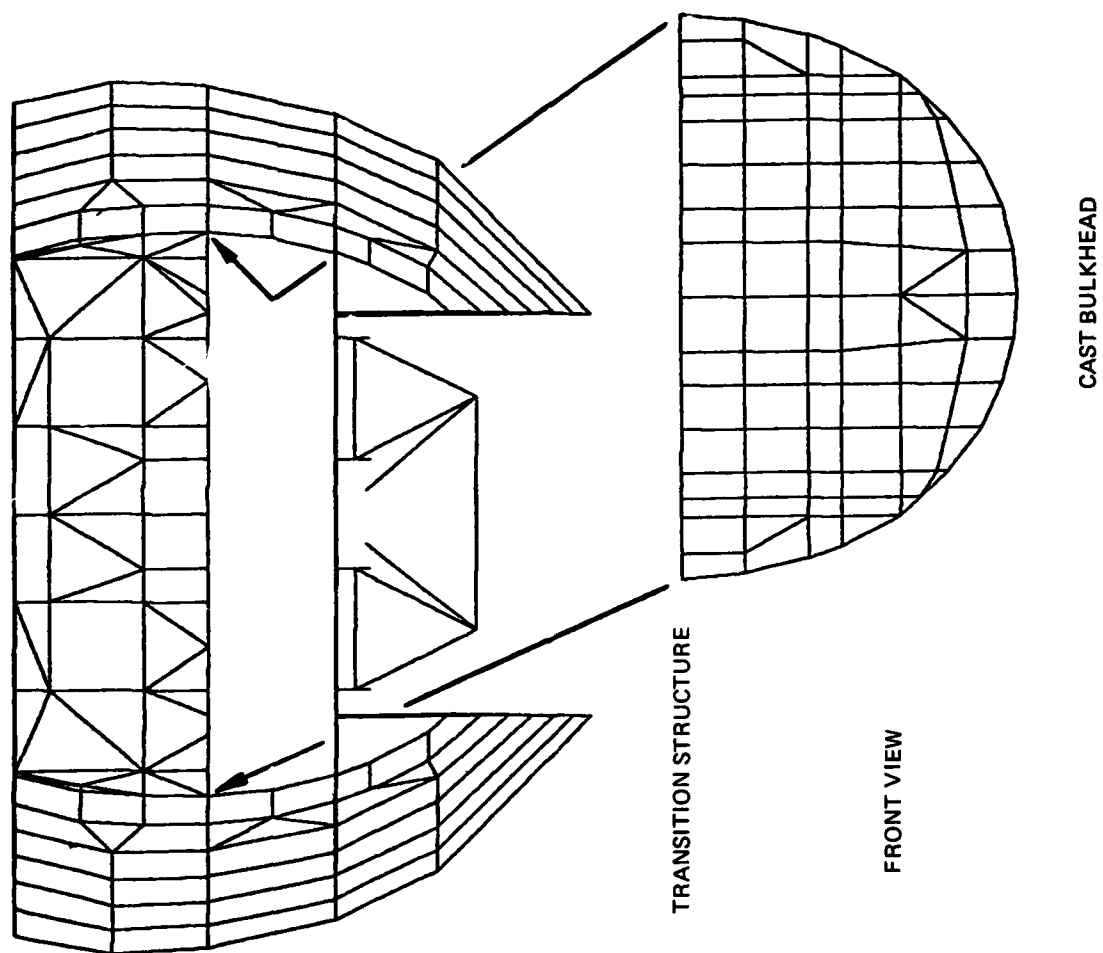
FRONT VIEW

Figure 42.   CAST Finite-Element Computer Model, Front View

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Table 12.   Summary of Margins of Safety for Critical Components

Critical Component	Margin of Safety

Critical lug at BL 28
    Shear-Bearing
    Tension
	
	+0.13
	+0.09

Critical webs
    t = 0.1
    t = 0.14
	
	+0.67
	+0.29

Critical stiffener at BL 28
    WL 150
    WL 140
    WL 130
 	
    WL 124.7
	
	+0.82
	+0.72
	+0.32
	+0.33
	+0.64
	+0.75
	High

Horizontal beam at WL 150
    Upper flange
    Web
	
	High
	High

Perimeter beam
    Inboard of BL 13.5
    Outboard of BL 13.5
	
	+0.09
	+0.22

Torque box at WL 105
    Tension
    Compression
	
	+0.50
	+0.10

Lug backup structure at BL 8.7	+0.24

2. **Damage Tolerance Analysis**

Bulkhead stresses obtained from finite-element computer runs were reviewed to determine which points would be considered damage-tolerance-critical. The details selected for this analysis were:

o   Outer load attachment point A (Fig. 43)

o   Shear web located between LBL 28-LBL 32 and WL 124.7-WL 130 (Fig. 43)

Damage tolerance analyses were performed on the respective details for the following flaw types:

o   Corner flaw at a clevis hole

o   Surface flaw in a shear web

A third detail/flaw combination consisting of a corner crack at a stiffener on the pressure web was considered; however, finite-element analysis showed detail stresses to be noncritical.

According to the requirements of MIL-A-83444, the cast bulkhead is classified as slow crack growth structure and in-service noninspectable.

Initial flaw assumptions were made in accordance with MIL-A-83444 requirements for slow crack growth structure:

o   0.05-inch-radius corner flaw at the side of a hole

o   Semicircular surface flaw with a length equal to 0.25 inch and a depth equal to 0.125 inch

Details relative to crack growth rate (da/dn), plane-strain (K_{IC}), and plane-stress (K_C) testing of A357 were presented in reference 3. Average crack growth rate was da/dn = $(4.76 \times 10^{-11}) (1 - R)^{3.70} (K_{max})^{4.70}$, where R = 0.06. Average K_{IC} was 17.55 ksi in.$^{1/2}$. Average K_C was 38.47 ksi in.$^{1/2}$.

Damage tolerance analysis results (Table 13) demonstrated that the requirements specified in MIL-A-83444 for in-service noninspectable slow crack growth structure were met for the two analyzed details; outer load attachment point A, and shear web between LBL 28-LBL 32 and WL 124.7-WL 130.
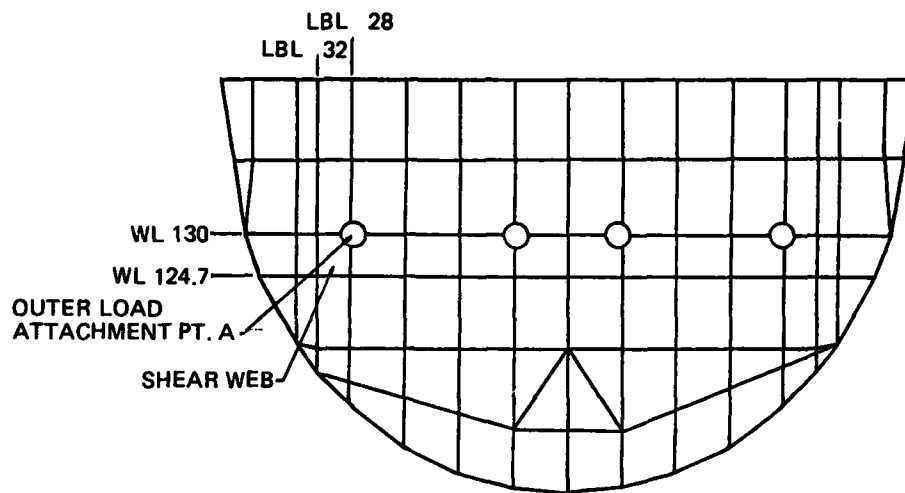
Figure 43. Damage Tolerance Critical Control Point Locations

Table 13. Flaw Growth Summary for Bulkhead Details

Detail	$a_{initial}$	$a_{1\ life}$*	$a_{2\ lives}$*	$a_{critical}$**
Load Attachment Point A	0.05"	0.050"	0.050"	0.10"
Shear Web (LBL 28-32/ WL 124.7-130)	0.125"	0.125"	0.125"	4.39"

* One service life consists of 1516 applications of the mission mix block

** $a_{critical}$ is determined using design limit load

Fatigue crack growth test results showed that little crack growth would be expected for either detail, since the spectrum stress intensities for cracks on the order of MIL-A-83444 assumed initial flaw sizes well below 10 ksi in.$^{1/2}$.

3.   Sensitivity Studies

Sensitivity studies were performed to identify the sensitivity of crack growth life predictions to material properties, aircraft usage, and the initial flaw size assumed to exist. The details used for the studies are those selected for the damage tolerance analysis:
o   Outer load attachment point A
o   Shear web located between LBL 28-LBL 32 and WL 124.7-WL 130
Detailed results of these studies were presented in reference 3. It was determined that:
o   MIL-A-83444 requirements could still be met using upper bound crack growth data and lower bound fracture toughness properties
o   The change in mission mix for this study had little effect on the crack growth
o   An equivalent initial flaw size much larger than that required by MIL-A-83444 would not grow to critical crack size in two service lifetimes for either detail

4.   Durability Analyses

Durability analyses were performed for the same details as were selected for the damage tolerance analysis:
o   Outer load attachment point A
o   Shear web located between LBL 28-LBL 32 and WL 124.7-WL 130

S-N data for A357, developed from fatigue test data for both smooth and open-hole fatigue test specimens, are shown in Figure 44. The design S-N curves for each detail were derived from test data by applying appropriate factors to achieve 95% confidence and 95% reliability. Detail design S-N curves for smooth and open-hole specimens are presented in Figures 45 and 46, respectively.
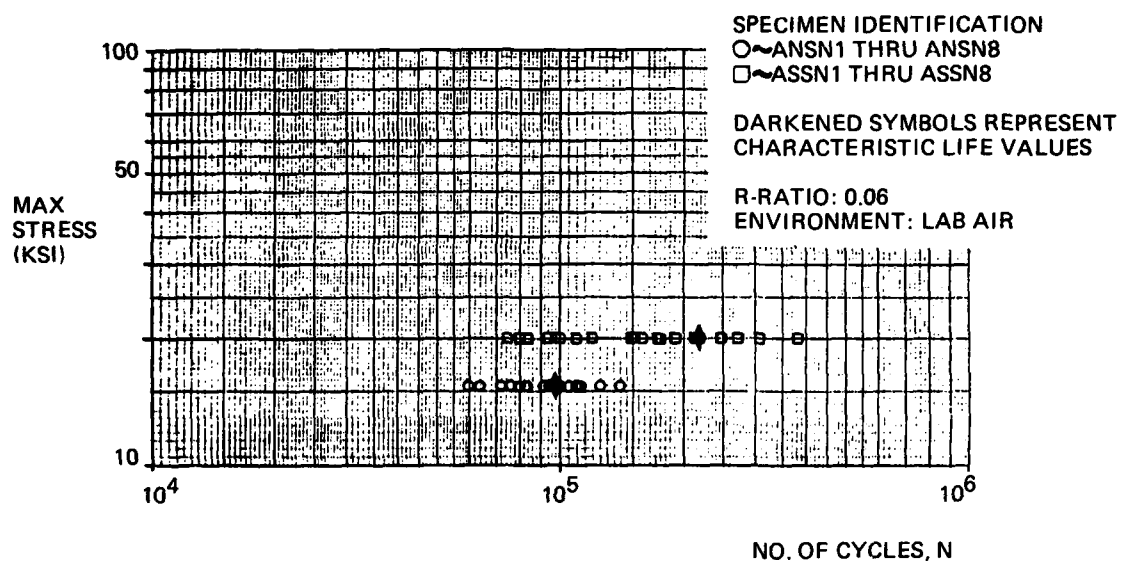
Figure 44. A357 S-N Data for Smooth and Open-Hole Specimens
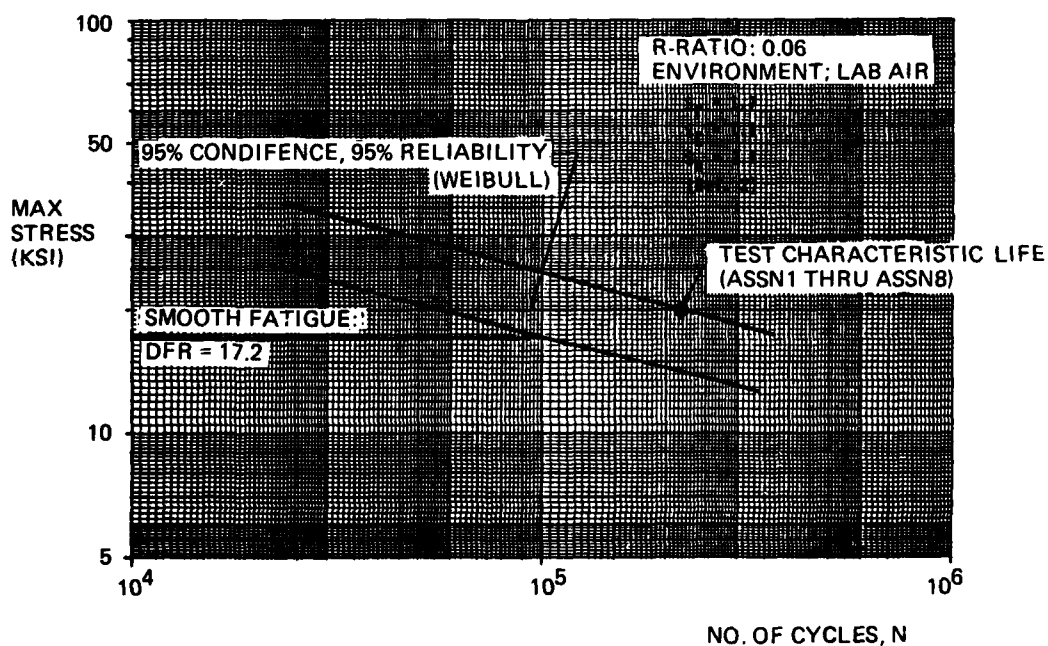
Figure 45. Detail Design S-N Curves for Smooth Fatigue Specimens

Detail design S-N curves are expressed by two parameters: a detail fatigue rating, DFR, and slope ratio, S. The slope ratio is generally constant at 2.0 for aluminum alloys. The geometric severity of a particular detail considering its fatigue performance is therefore expressed by the DFR.

The economic life of the cast bulkhead was analyzed for both the load attachment point A and shear web details. It was determined that the economic life for load attachment point A exceeded the design life by 8%, and that the economic life for the shear web detail exceeded the design life by a large margin.

5.   Weights

The calculated weight of the bulkhead casting was 205.2 lb. This weight resulted from a detailed weight calculation of the bulkhead and included a +2.5% increment for manufacturing tolerance. The 2.5% represented half the drawing tolerance over nominal (+0.005) on web and flange thickness. Past experience with aircraft parts calculated at nominal dimensions versus actual part weight showed this approach to be satisfactory. The density of A357 was assumed to be the same as for A356: 0.097 lb/in.^{3}.

The weight of the finished machined bulkhead including bushings was 181.1 lb. This weight resulted from machining the periphery to contour and machining the interfaces for the nose gear and door actuator fittings. The finished bulkhead weight of 181.1 lb resulted in a 6.5-lb weight reduction when compared to the updated baseline component weight of 187.6 lb.

6.   Cost

The cost summary for the YC-14 station 170 cast bulkhead is shown in Table 14. These cost figures were based upon the CAST bulkhead assembly, 162-00018, using the final detail design of the station 170 bulkhead casting, 162-00017, as the major part.
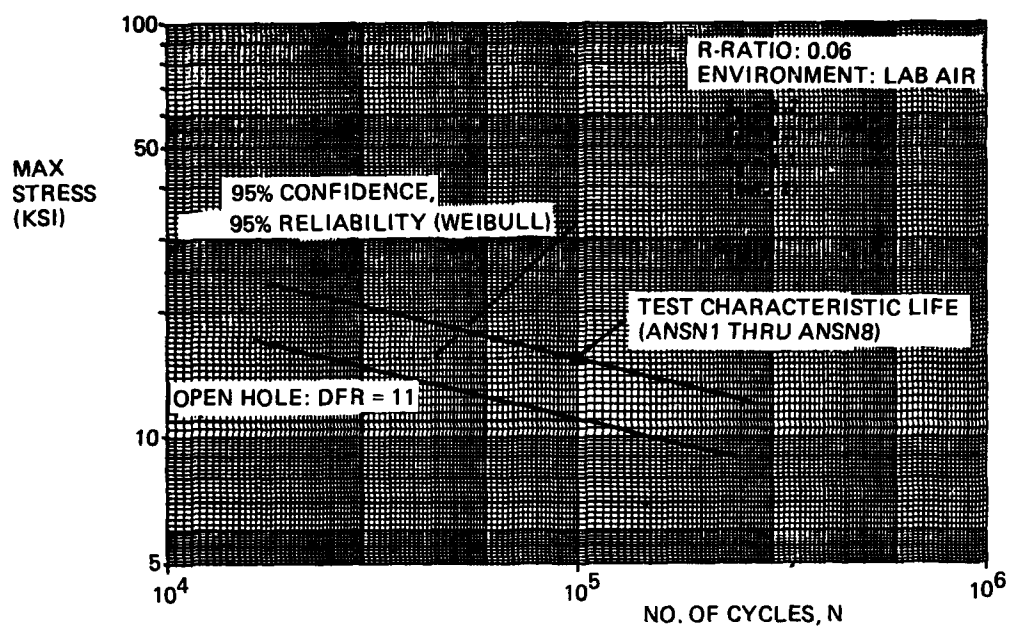
Figure 46. Detail Design S-N Curves for Open-Hole Specimens

Table 14. Station 170 Cast Bulkhead Costs

	No. 1 A/P cost	300 A/P cost
Raw material	$ 1,870	$ 309,000
Labor:		
Detail and assembly tools	200,018	200,018
Foundry tools	95,000	95,000
Fabrication	10,003	1,482,313
Section installation	– –	247,680
Total	$306,891	$2,334,011
Cost per unit	$306,891	$ 7,780

The raw material figure covers aluminum, sand, and binder. The item for detail and assembly tools covers only the initial hard production tooling costs. The foundry tool costs cover the pattern, special mold flask tooling, and chills. Fabrication costs for the 300-unit production run include a factored cost increment for tool maintenance and refurbishment. The section installation costs shown are the same as shown on the updated baseline component. Engineering costs are not included here, because for a 300-unit production run, the unit cost for engineering is relatively small.

The cost comparison between the udpated baseline component and the detail designed cast bulkhead is:

$$\text{Cost} = \frac{12484 - 7780}{12484} (100) = 37.7\% \text{ reduction}$$

7.   *Effects of Defects*

The occurrence of discontinuities in the castings produced during the development of foundry manufacturing procedures (Phase II) did not result in a wide variety of discontinuity types or sizes from which to test the effects of defects. Also, few defects were found in locations having sufficient material for specimen fabrication. The most common discontinuities encountered were gas and shrink porosity, sponge and shrinkage cavities, and less dense inclusions. Crack-like discontinuities were almost completely absent.

The analytical approach to the effects of defects consists of accounting for defects in crack growth and fatigue analysis by using the equivalent initial flaws and detail fatigue ratings (DFR) for the various types of defects and X-ray grades. Testing to determine the effects of defects was done in Phase V and is reported in Section VI.

SECTION V
PHASE IV—FABRICATION OF DEMONSTRATION ARTICLES
AND PRODUCTION HARDWARE

A.   INTRODUCTION

The principal objective of Phase IV was to fabricate full-scale castings of the YC-14 station 170 body/nose landing gear support bulkheads to demonstrate producibility of the process, based upon manufacturing procedures developed in preceding activities on the program.

The required work was accomplished by two different qualified casting vendors, under separate tasks, as follows:

o   Task 1—Fabricate 10 full-scale bulkhead castings at The Boeing Company Foundry, Seattle, Washington.

o   Task 2—Fabricate 10 full-scale bulkhead castings at Hitchcock Industries, Incorporated Foundry, Minneapolis, Minnesota.

This phase of the program was conducted by Richard G. Christner assisted by Calvin R. Belden, James W. Faber, L. Arne Logan, Robert C. McField, Howard L. Southworth, and Dean M. Kaestner; and by Timothy R. Hitchcock and Dinshaw R. Irani of Hitchcock Industries, Inc., the second-source foundry for contracted work.

Complete details of the Phase IV work were reported in reference 4.

B.   TASK 1—FABRICATION OF DEMONSTRATION COMPONENTS AT BOEING

1.   Mold Design

The vertical pouring position was selected for the full-scale bulkhead castings (Fig. 47). This position was chosen for the following reasons:

o   Directional solidification is promoted in parts cast in the vertical position, because metal is gated into the casting only when and where it is required.

o   Solidification can be controlled by the judicious placement of chills.

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o   Mold sag would have been a potential problem with the horizontal pouring position.

The part was poured in the upside-down position relative to its installation in the airplane.

A three-step, cascading sprue system, used to minimize the turbulence effects of the long vertical drop of the metal, is shown in Figure 48. To prevent aspiration of air into the gating system, and to ensure rapid filling of the sprue system during the initial stages of metal pouring, the total area at the base of the sprues decreased from upper to lower by approximately 50% per step. The area of the bottom sprues was 0.56 sq in., which yielded a combined metal flow rate of 20 lb/sec of metal in the runner system. Tapered rectangular sprues were used to reduce metal swirling and minimize the formation of a vortex at the top of the sprue. Pouring basins were used to provide a consistent pouring process.

The casting was gated from both sides using two independent gating systems. Each side of the casting had two runner systems. The bottom runners filled the casting to the top of the A1/B1 flasks, at which time the second runner systems were activated to fill the remainder of the casting. The runners were 2.5 x 2.5 inches, with a pop-off at the end to prevent the first metal that entered the runners from entering the mold cavity. On each side, there were 13 ingates that connected to the vertical risers. The risering systems used are shown in Figure 49 for the aft side and Figure 50 for the forward side. Thirteen vertical risers were located on each side of the casting. A series of step gates in each riser allowed the metal to flow into the mold cavity. These step gates, shown in Figure 51 for the aft side and Figure 52 for the forward side, not only provided a means of getting metal into the mold cavity, but also served as reservoirs of molten metal to feed the casting. In general, the riser size used was a 2.5-inch-diameter semicircle.

Very close-tolerance machined molding flasks were used as a key to ensure the dimensional accuracy of the bulkhead casting. Design of the flask sections with respect to parting planes and stripping sequence was based upon the mold fabrication sequence shown in Figure 53. Six pattern flasks

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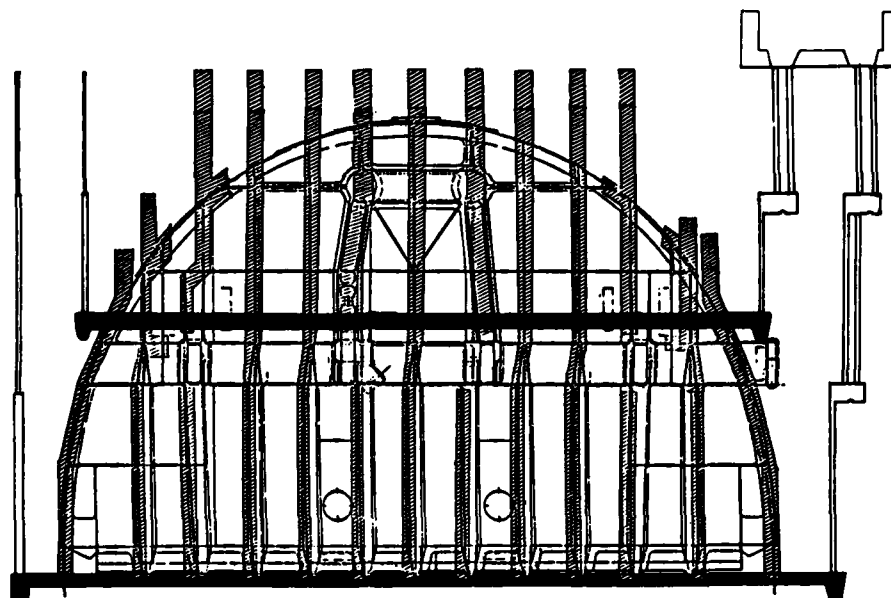
Figure 47.   Gating System Layout
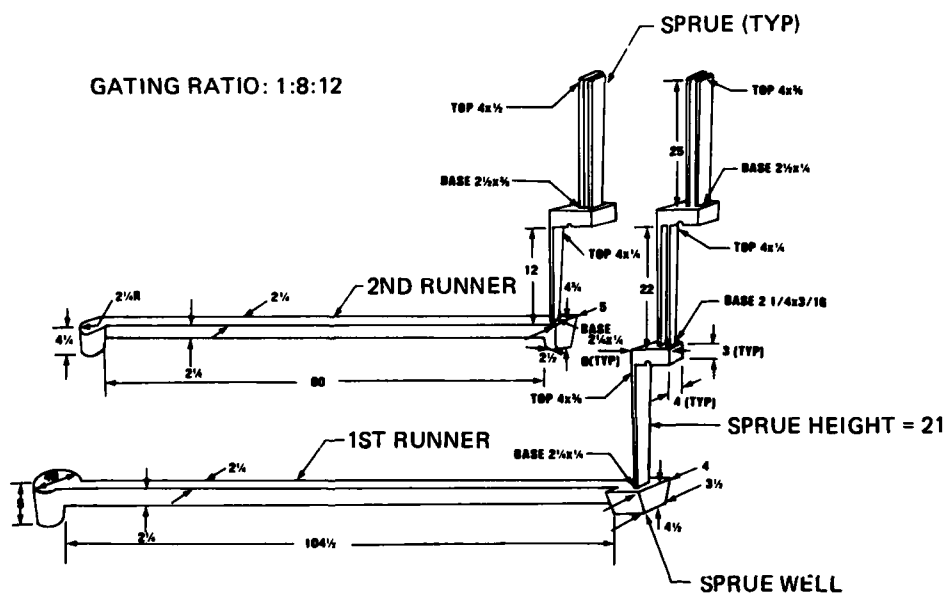
Figure 48.   Cascade Sprue System

93
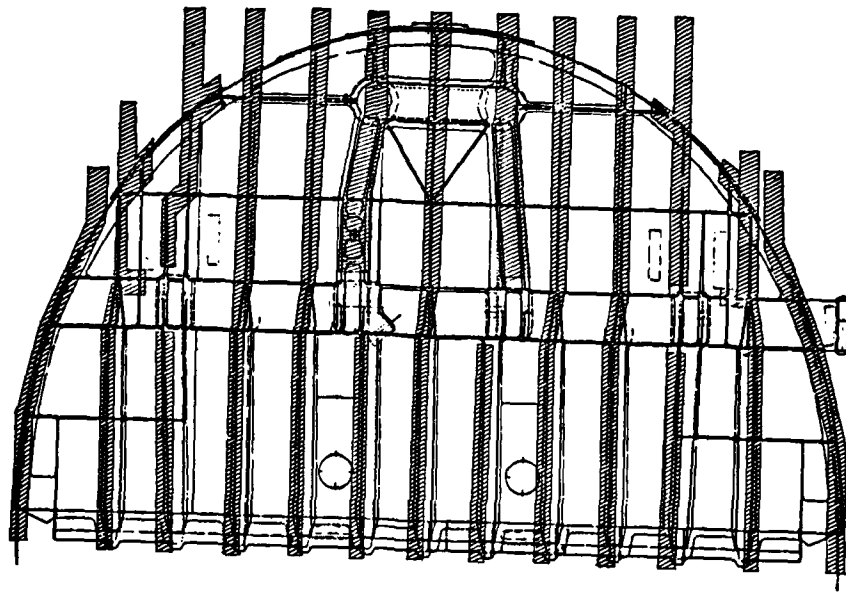
Figure 49.　　Mold Riser System—Aft Side
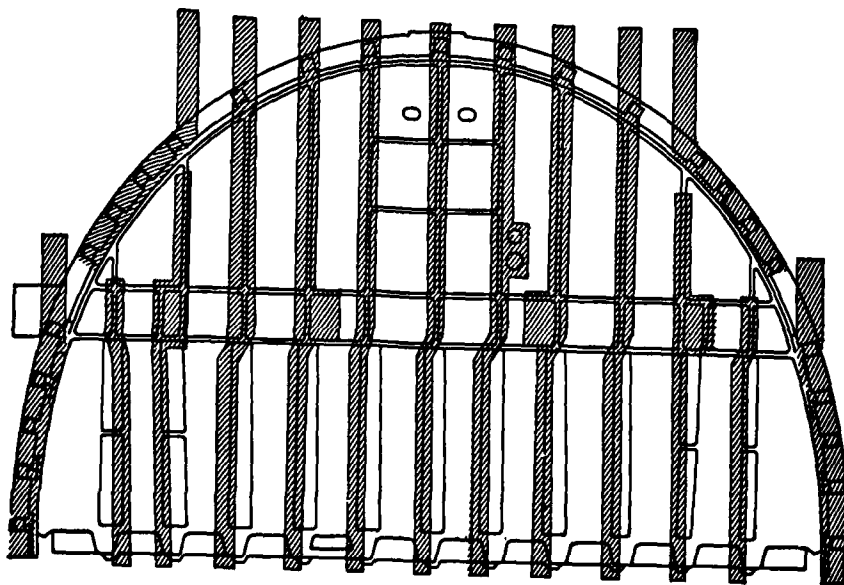
Figure 50.　　Mold Riser System—Forward Side
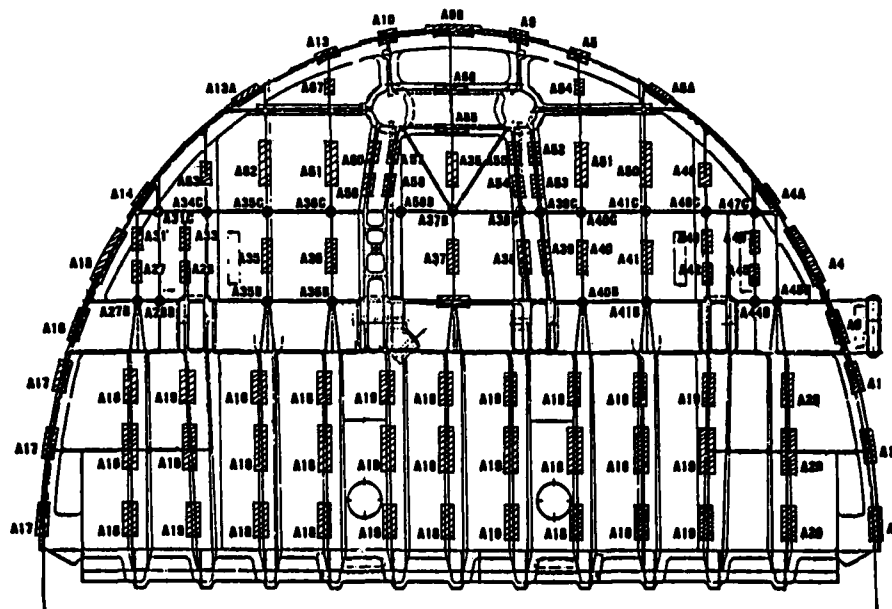
Figure 51. Step Gate Locations—Aft Side
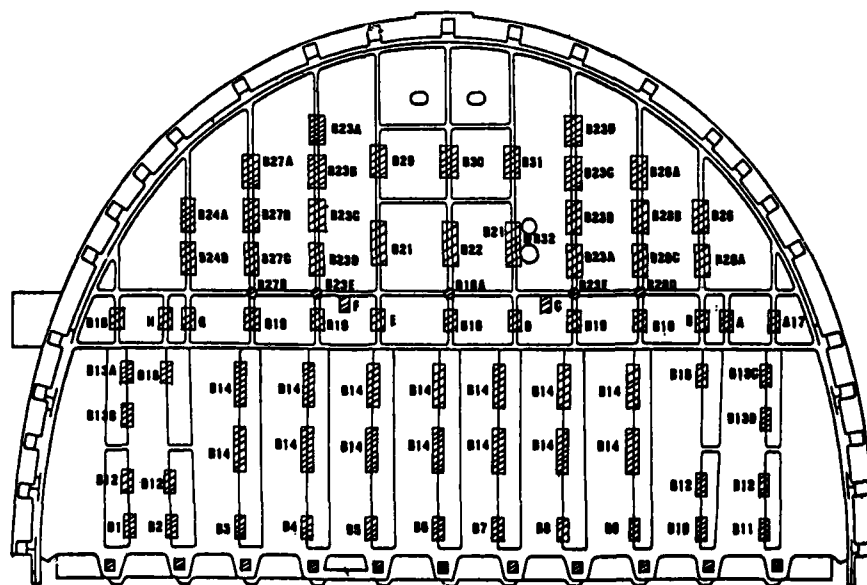
Figure 52. Step Gate Locations—Forward Side

95
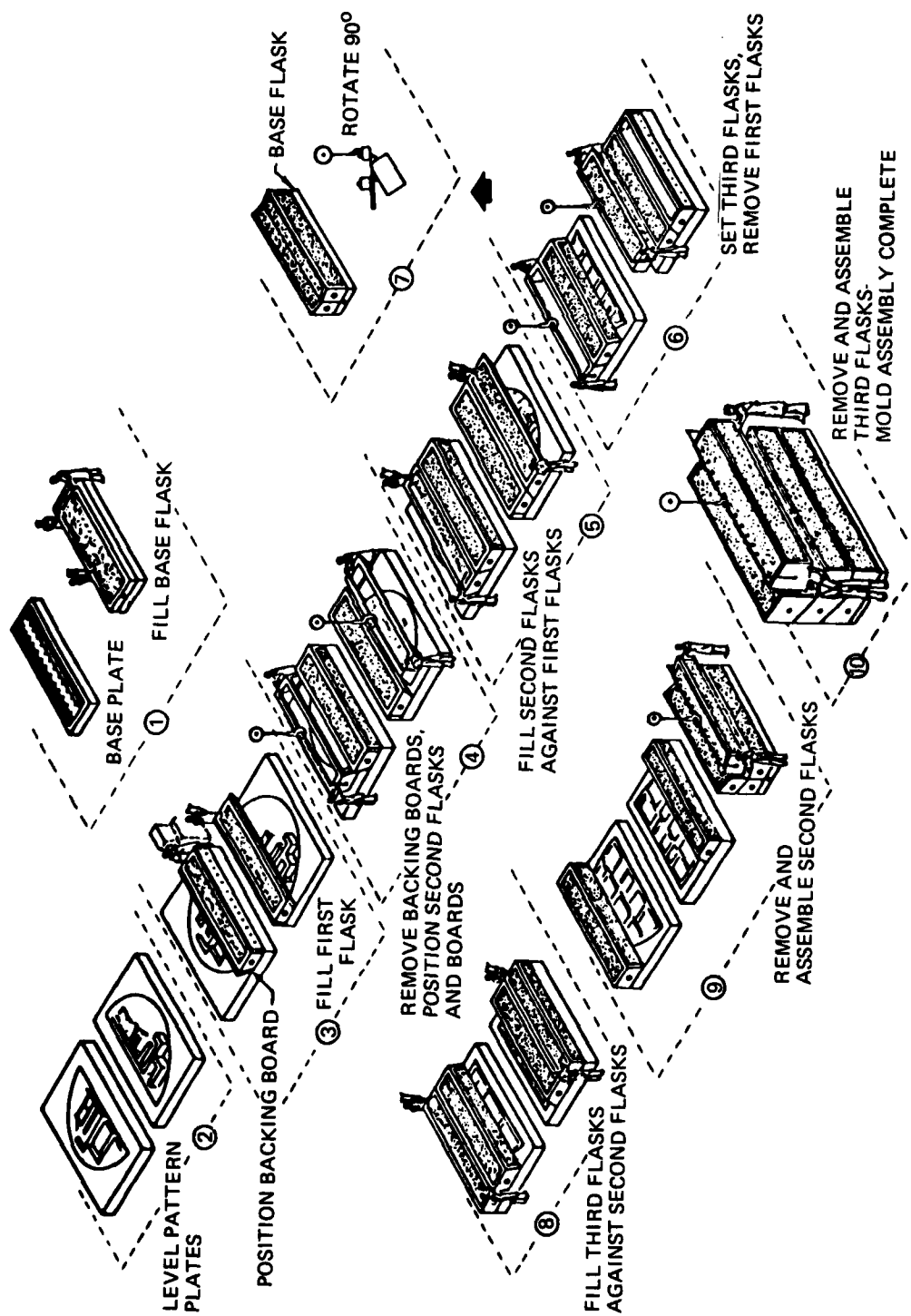
Figure 53.   Mold Setup and Assembly Sequence

BASE FLASK

ROTATE 90°

① BASE PLATE   FILL BASE FLASK

② LEVEL PATTERN PLATES

POSITION BACKING BOARD

③ FILL FIRST FLASK

④ REMOVE BACKING BOARDS, POSITION SECOND FLASKS AND BOARDS

⑤ FILL SECOND FLASKS AGAINST FIRST FLASKS

⑥ SET THIRD FLASKS, REMOVE FIRST FLASKS

⑦

⑧ FILL THIRD FLASKS AGAINST SECOND FLASKS

⑨ REMOVE AND ASSEMBLE SECOND FLASKS

⑩ REMOVE AND ASSEMBLE THIRD FLASKS. MOLD ASSEMBLY COMPLETE

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and one base flask were designed and fabricated from steel. A draft angle of 2 degrees was provided on the vertical sides of each flask to allow for stripping from the pattern. The flasks rested on machined steel plates, leveled to within 0.002 inch, and were held in place by standard foundry flask pins. A completed, stacked bulkhead mold is shown in Figure 54.

The mold consisted of 35 cores, located as shown in Figures 55 and 56 for the aft and forward sides, respectively. Core placement was done using core bolts rather than paste.

The mold, as designed, required 1750 pounds of metal. This included the bulkhead, attached coupons, risers, gates, runners, sprues, and pouring basins. Consideration was given to using as little metal as possible, but not at the expense of quality.

2. Pattern Fabrication

All pattern tooling was manufactured at Dependable Pattern Works, Inc. of Portland, Oregon. The tooling included the forward and aft match-plate pattern sections, base flask pattern, step gate patterns, backing boards, base plate, core boxes, and all flasks with necessary guide pins and bolts.

Design of the pattern sections incorporated a 0.125-inch-per-foot shrinkage allowance. The gating ratio used in the pattern design was 1:8:12, and a draft angle of 1.0 degree per side was incorporated for flask stripping from the pattern. Plastic materials and wood primarily were used in pattern fabrication in areas where strength was not a major consideration. All step gate patterns were made of cast aluminum. Pattern sections forming the webs or ribs on the bulkhead casting were made from sheet aluminum because of strength requirements of those sections. Twelve-inch-deep "I" beams were used to ensure maximum pattern stiffness allowing optimum across-the-parting-line (thickness) tolerances. Core boxes for the bulkhead mold also were made with plastic and wood materials.
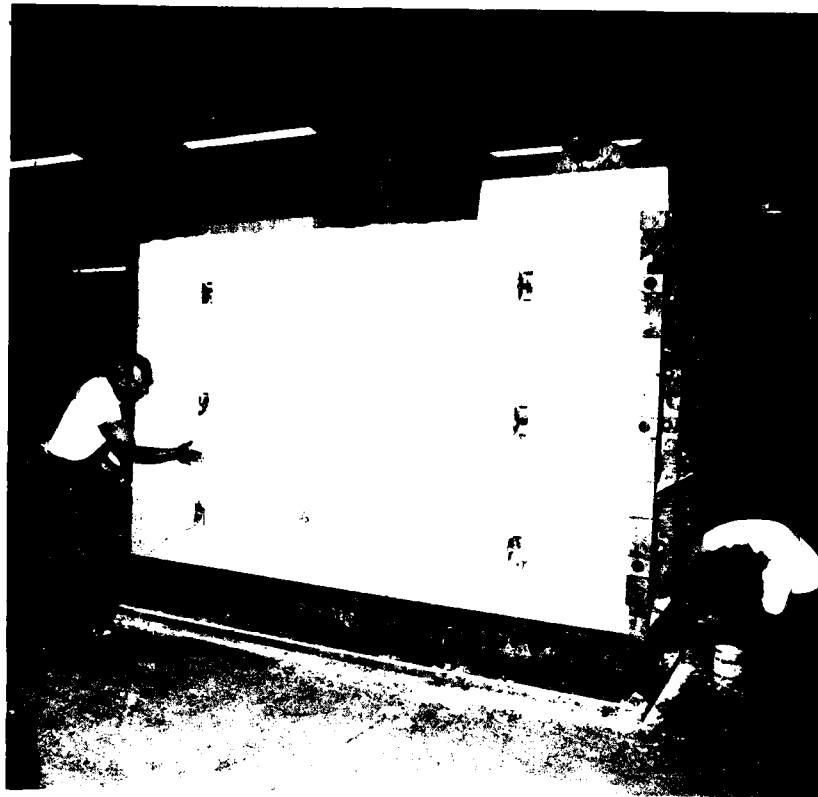
Figure 54.   Stacked Body Bulkhead Mold
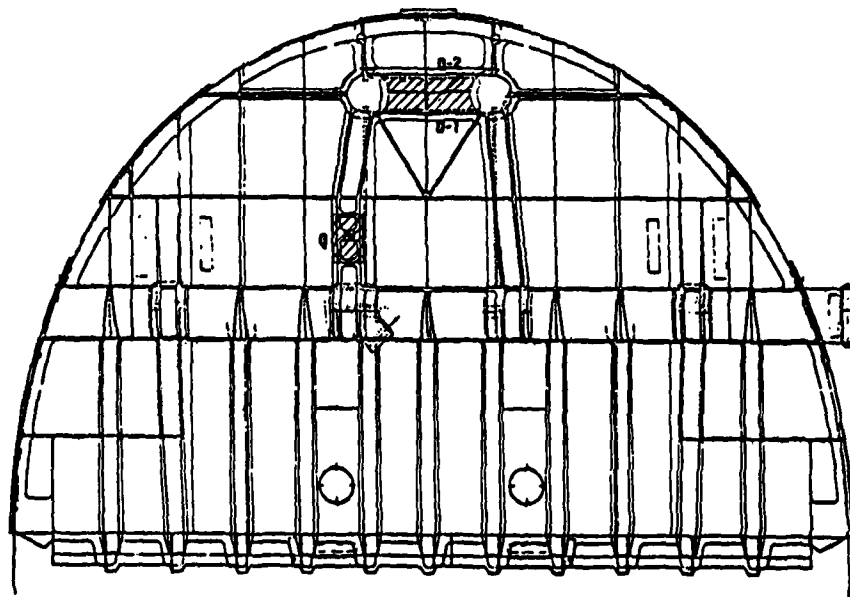
Figure 55.   Core Locations—Aft Side
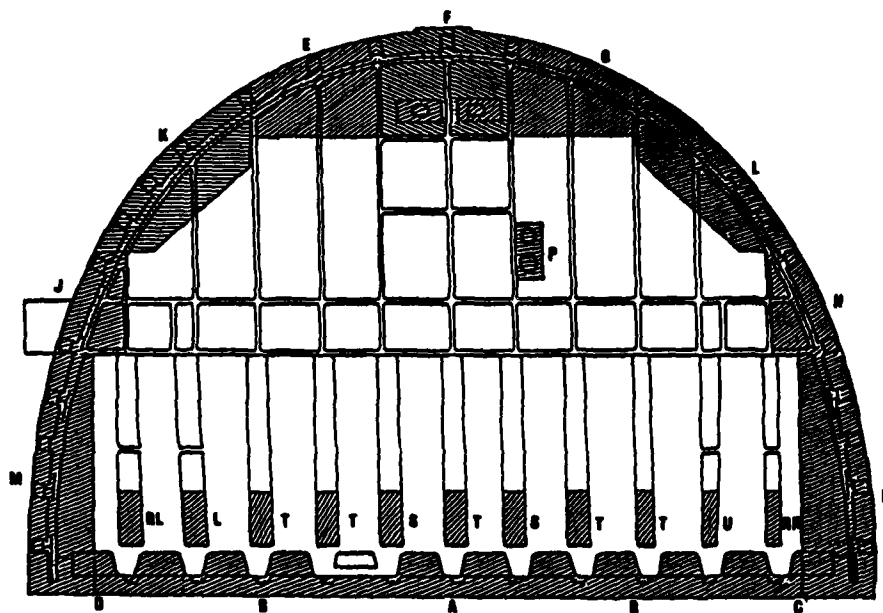
Figure 56.   Core Locations—Forward Side

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3. Mold Fabrication

Prior to mold fabrication, the pattern sections shown in Figure 57 and the base plate were leveled optically with leveling telescopes and bubble levels to within 0.005 inch. With the exception of the torque-box internal cores, all mold sections were made with a three-part air-set binder system consisting of Ashland "Linocure" AW, BW-3, and Part C. All air-set sand contained 1.1% total binder content and was prepared in a continuous mixer. The torque-box internal cores were bonded with 3.5% sodium silicate-CO_2 to provide ease in shakeout operations. The molding sequence for the bulkhead castings was shown in Figure 53. Before depositing molding sand in the pattern flasks or core boxes, a coating of Ashland LP-16 "Zip-Slip" parting agent was sprayed on all surfaces in contact with the sand. Chills located inside the core boxes and on the aft and forward sides of the bulkhead mold also were positioned before molding. Chill locations and materials for the aft side of the bulkhead mold are shown in Figure 58; those for the forward side are shown in Figure 59.

The mold base flask incorporated the two bottom runner systems. Each runner was lined with 3/4-inch-thick ceramic foam insulation and had tin-plated steel filter screens located in each pouring well. Immediately before mold assembly, the surface of the base flask section that would be in contact with the molten aluminum was coated with amorphous carbon with an acetylene torch. Steel wool also was positioned in the pouring wells to minimize turbulence and oxide formation in the molten aluminum as it filled the runner systems.

Each of the flasks forming the mold cavity was filled with molding sand according to the sequence described in Figure 53. Each flask was located on the pattern with flask guide pins and was clamped to the neighboring flask to inhibit side movement. Prior to filling the flasks with sand, and after parting agent was applied and chills were positioned, the cores forming the cascading sprue were positioned. The gating and risering system in the bulkhead mold was assembled during the molding of each flask section. Cast aluminum gaggers, for sand reinforcement, were
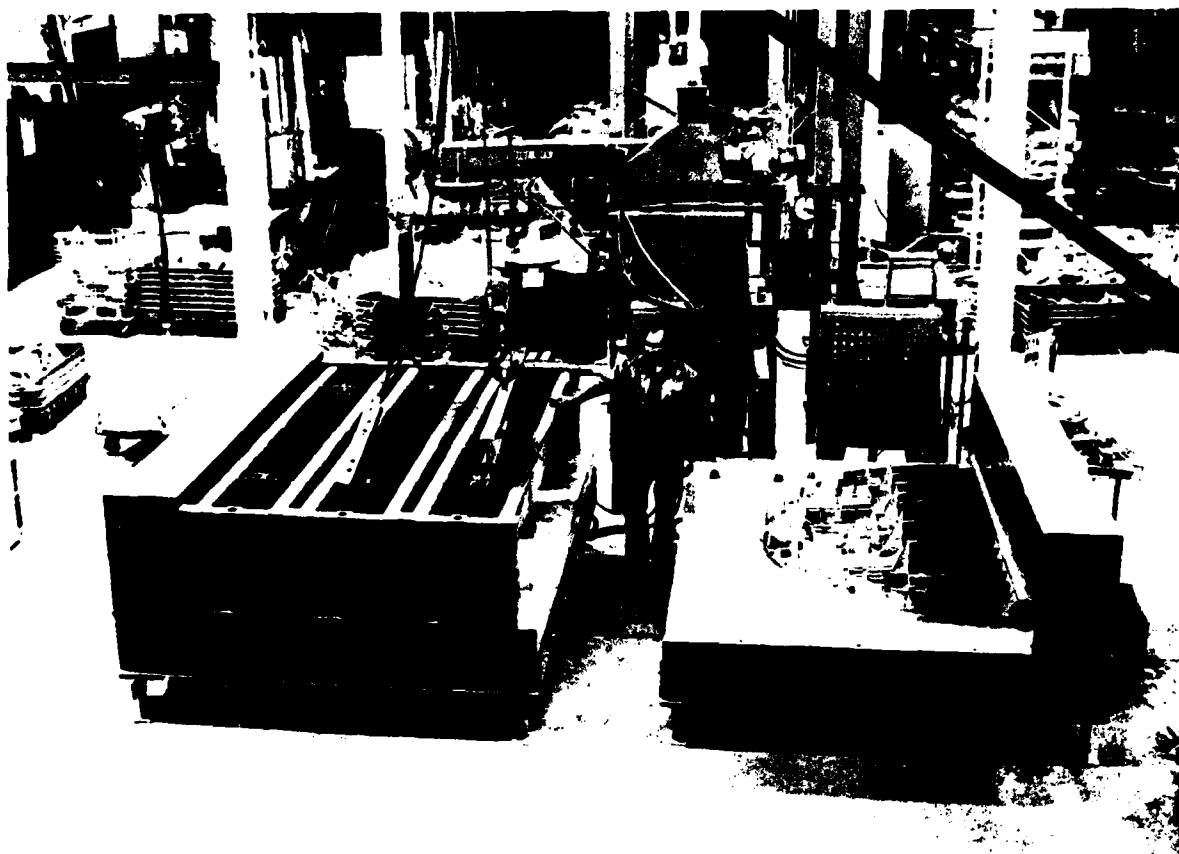
Figure 57.   Forward and Aft Sides of YC-14 Station 170 Body Bulkhead Pattern

MATERIAL:
■ ALUMINUM
▨ COPPER
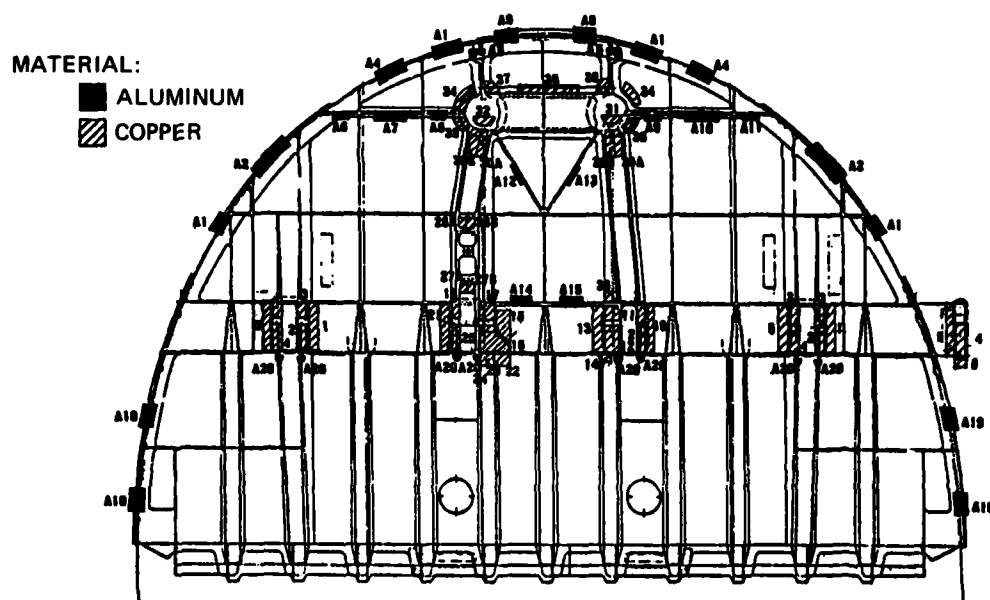
Figure 58.   Chill Locations—Aft Side

MATERIAL:
■ ALUMINUM
▨ COPPER
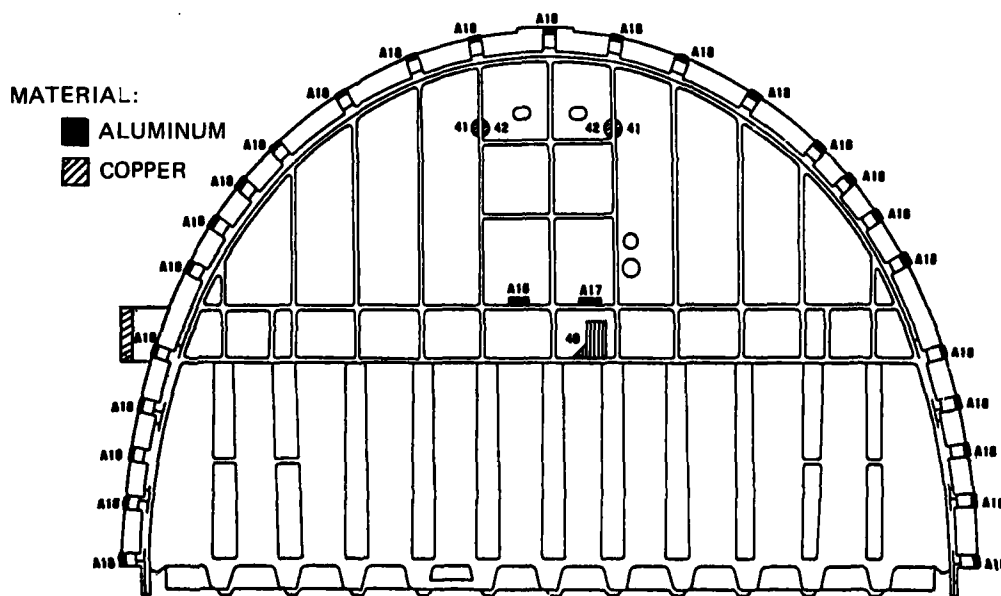
Figure 59.   Chill Locations—Forward Side

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placed in the sand at locations shown in Figure 60 for the aft side and in Figure 61 for the forward side.

Because of the thin pattern wall thickness (0.100 inch) and the complexity of the bulkhead pattern, special precautions were necessary in flask stripping operations. Flask/mold removal from the bulkhead patterns required the use of hydraulic jacks and alignment braces to ensure perpendicular movement of the flasks away from the pattern face. Each flask was sequentially stripped from the pattern and rotated 90 degrees, and excess sand was trimmed away. In this rotated position, the appropriate cores were positioned in the flask sections and secured by nut and bolt assemblies. The flask sections then were sequentially stacked on the base flask. To increase the fluidity of the molten aluminum as it filled the mold cavity, the surfaces of the mold that formed the mold/metal interface were coated with amorphous carbon. Because amorphous carbon has an insulating capability, it was removed from all chill surfaces before stacking the next flask section. As the flasks were stacked, each neighboring flask was bolted to the adjacent flask to form a single, monolithic flask/mold. Final assembly of the mold included placement of the pouring basins over the sprue openings and filling of all parting seams with sodium silicate bonded molding sand to inhibit run-out problems during pouring.

4.   Melting and Pouring

Melting operations for each of the bulkhead castings were performed in 1000-pound-capacity gas-fired melting furnaces. Two furnaces were used, each containing approximately 960 pounds of metal. Each of the two melts consisted of B356.2 aluminum alloy adjusted to A357 composition per preliminary specification M-XXXX, Castings, Aluminum Alloy A357, Primary Aircraft Structure (Appendix B). To ensure clean base material, the B356.2 ingots and all alloy constituents were stored in a controlled area, separate from other foundry alloy lots. Melting operations were performed according to instructions outlined in the Manufacturing Plan (Appendix A of reference 4).

O 12 IN. LONG
△ 24 IN. LONG
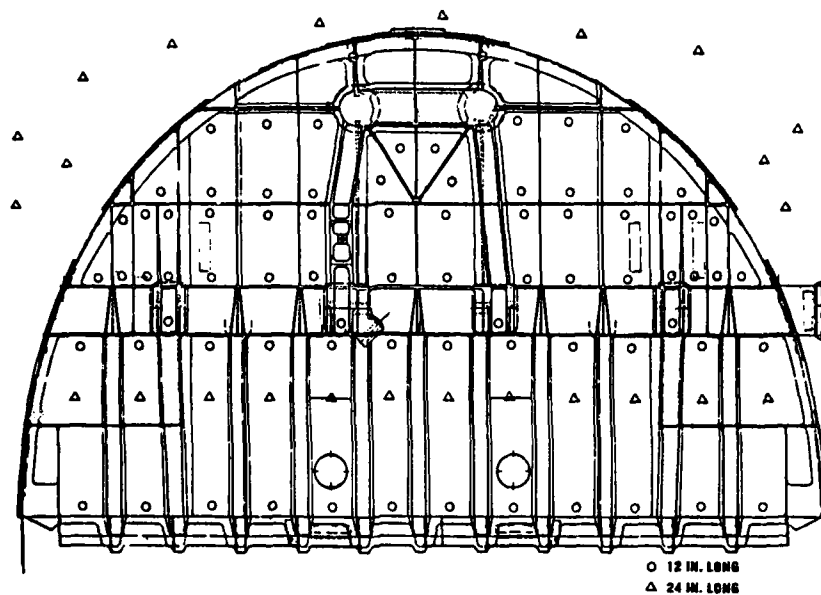
Figure 60. Approximate Gagger Locations—Aft Side

O 12 IN. LONG
△ 24 IN. LONG
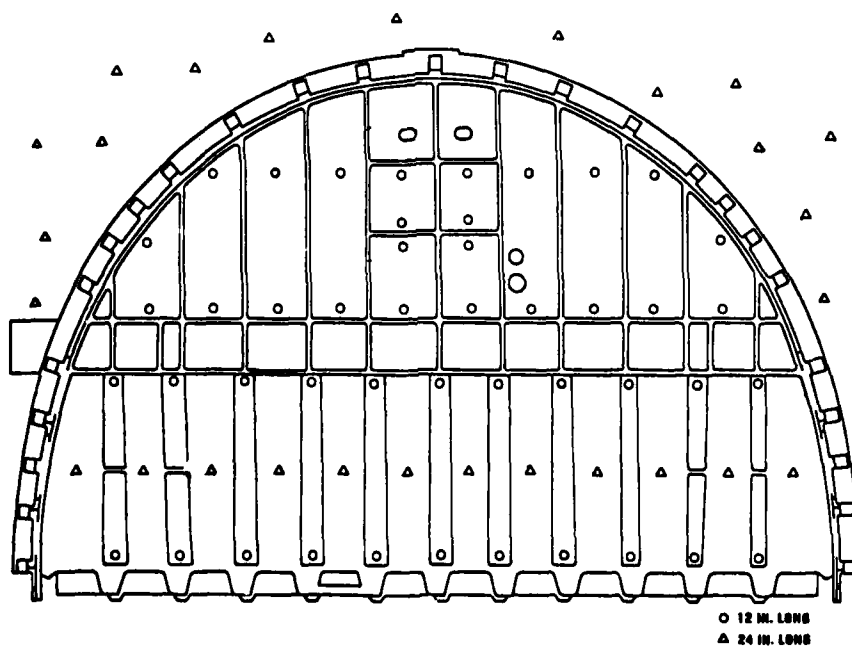
Figure 61. Approximate Gagger Locations—Forward Side

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After melting, each heat was held at 1250-1300°F until mold and pouring preparations were complete. During this holding period, a molten sample was taken, allowed to solidify, and checked for proper chemistry by spectrographic techniques. If required, alloy additions were made and chemistry was rechecked before proceeding to degassing operations.

After alloy composition was within the specific limits for A357, the melt temperature was raised to 1300-1325°F. At 1300-1325°F, each charge was purged with 90-95% nitrogen/5-10% chlorine gas mixture for 40 minutes. Upon completion of the degassing operation, each charge was allowed to set for about 15 minutes to allow all of the degassing media to come to the surface. Then the surface of each charge was skimmed to remove dross. Graphite-coated degassing and skimming utensils were used to avoid iron contamination of the charge. If trapped gas or oxides were still present in the charges after degassing operations, the operation was repeated for 20-30 minutes and rechecked. If the degassing operation was successful, the metal was poured within 2 hours of the final gas check. If more than 2 hours were expended between degassing and pouring operations, the degassing operation was repeated.

Prior to tapping the furnaces, each of the two 1000-pound-capacity ladles was cleaned, coated with graphite wash, and then preheated to 1600 ± 50°F with natural-gas-fired lances. Each of the ladles was covered with an insulating lid to ensure retention of heat and was not allowed to cool lower than 1300°F before filling with molten metal. During this preheating operation, mold preparations were completed and the temperature of the molten aluminum alloy in each furnace was raised to 1480 ± 10°F. When this temperature was attained, the oxides were carefully removed from the surface of each molten bath by skimming.

Furnace tapping was accomplished by positioning a preheated ladle below the pouring lip of the furnace and adjusting the angle of the ladle to equal that of the metal flow to minimize turbulence and the resulting formation of oxides and gas in the metal. Both of the filled ladles (approximately 960 pounds each) were moved by crane to the mold. Immediately prior to

pouring, the molten charges were skimmed, and a sample was taken for spectrographic analysis.

Temperature monitoring of each of the filled ladles was achieved with portable immersion-type pyrometers. The pouring temperature for the bulkhead casting was 1440°F; temperatures below 1430°F were not sufficient for complete filling of the mold cavity.

Each of the mold pouring basins contained two plugs that covered the sprue systems leading to the bottom and middle runner systems in the mold. After the pouring basins were filled, the basin plug cores for the bottom runner system were removed in unison. The height of the molten aluminum filling the mold cavity was monitored by a battery-operated indicator light system. Each of the runner systems contained electrical lead wires from the lighting system (Fig. 62). The ends of the lead wires were not connected, so that as the metal filled the runners, the molten aluminum surrounded the wires and completed the circuit. The indicator lights on the monitoring panel thereby showed the height of the molten aluminum as it filled the mold cavity. When the metal rose in the mold to a level slightly below the middle runner system, the plugs covering the middle sprue system were removed. Filling of the middle runners and successive mold filling were indicated by a third set of lights on the panel. Figure 63 shows actual pouring of the aluminum into a pouring basin.

5.   Mold Shakeout and Trimming Operations

Mold shakeout operations typically began approximately 1 to 1-1/2 hours after pouring. The sand contained in the flasks was mechanically removed with chipping hammers and chisels to a depth of about 1/2 inch from the casting. The remainder of the sand surrounding the casting was removed by grit blasting.

Removal of the risers and step gates was accomplished with reciprocating saws. The step gates were cut off the casting so that only a minimum amount of material (1/4 to 1/8 inch) remained to be trimmed off. Figure 64 shows rough trimming of a bulkhead casting with reciprocating saws.

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THERMOGARDS FOR RISERS NO. 3, 6, 8 & 11 FROM 2ND RUNNER UP
ARE 3½" ID THE OTHERS ARE 2½" ID.

2ND RUNNER

THERMOGARD

ELECTRICAL WIRE
LOCATION (6)

1ST RUNNER

GROUND WIRE
LOCATION (2)

NOTE: ELECTRICAL WIRE LOCATIONS FOR FWD SIDE CORRESPOND TO AFT SIDE
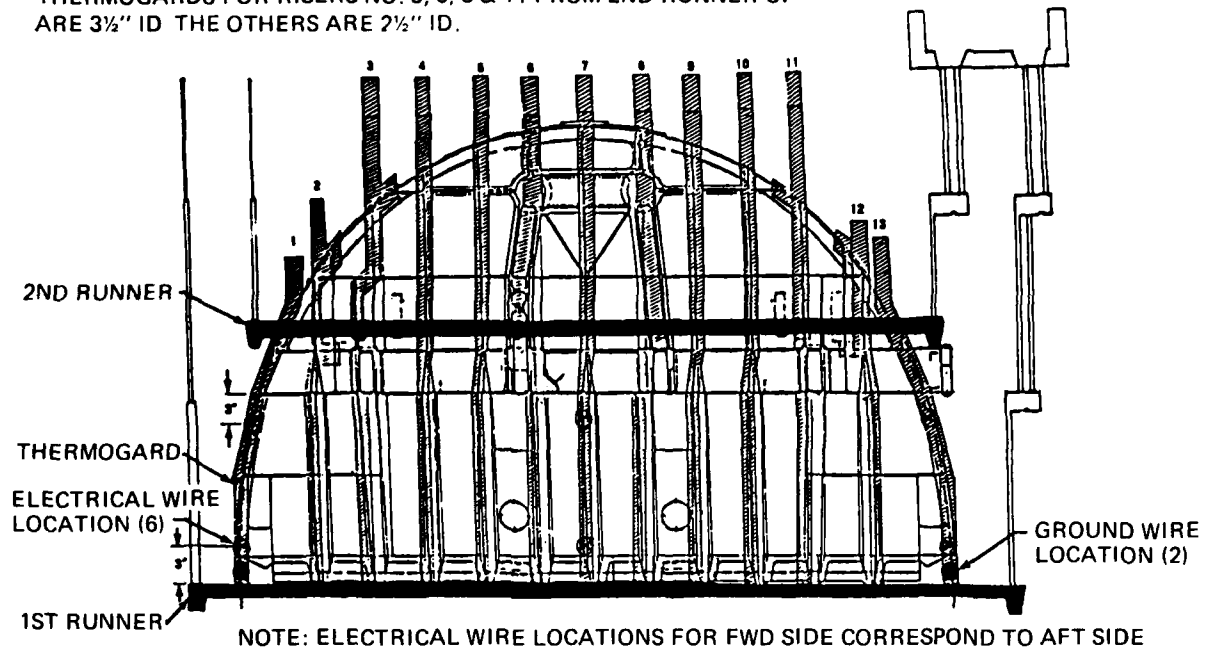
Figure 62.   Electrical Wire Locations—Aft Side

Figure 63.   Pouring the Bulkhead Casting

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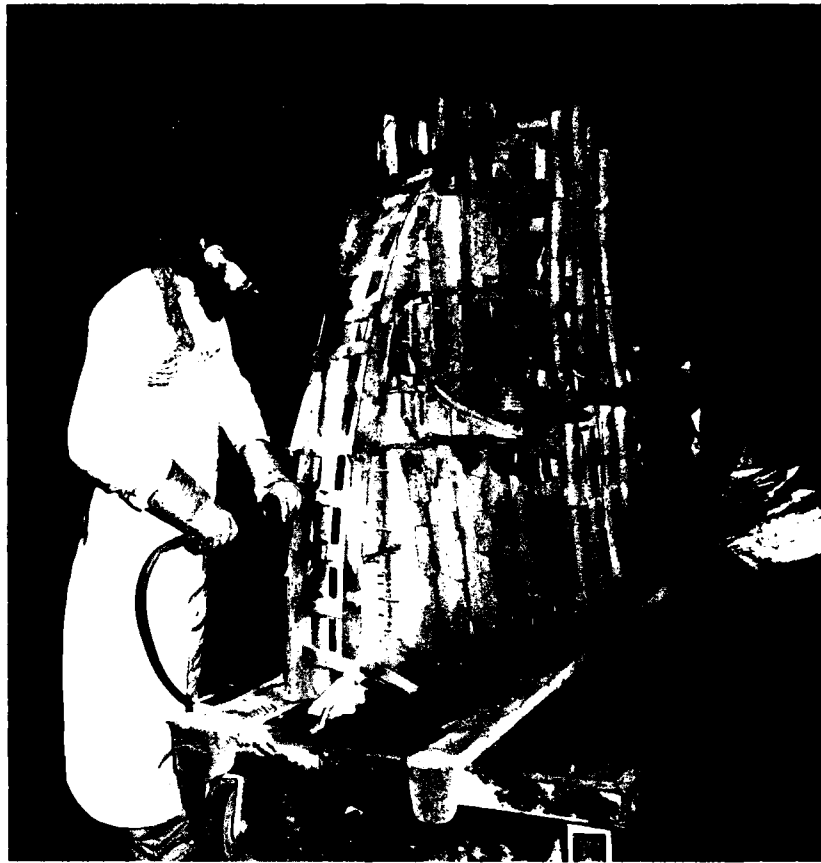
Figure 64.   Rough Trimming Gates and Risers from the Bulkhead Casting

Flashing, surface burrs, and the remaining step gate material were removed with portable grinders.

6. **Summary of Foundry Data**

A summary of pertinent foundry data for the 10 Boeing castings is shown in Table 15.

7. **Weld Correction**

Casting defects such as cracks, shrinkage, porosity, and misruns were corrected on bulkhead castings M04 and M07 according to procedures described in preliminary specification W-XXXX, Welding, Fusion, Correction of Primary Structural A357 Aluminum Alloy Castings (Appendix D). Defects were identified visually and by radiographic and penetrant inspection techniques. All weld correction was performed prior to heat-treatment operations. Areas of weld correction on bulkhead casting M04 are shown in Figure 65. The decision on whether or not to weld-correct specific defects on the casting was dependent upon the severity of the defect, its location relative to critically stressed areas of the casting, its nature (shrinkage, porosity, or crack), and its relative size. Judgments were based on data (DFR's) from the effects-of-defects testing. Weld-corrected areas on casting M07 are shown in Figure 66.

All weld correction was accomplished by gas tungsten arc welding (GTAW) in the alternating current (AC) or direct current (DC) mode or by the gas metal arc welding (GMAW) process. The process selection was dependent upon such factors as material thickness, available welding equipment, and availability of suitable weld filler material.

8. **Heat Treatment and Straightening Operations**

Bulkhead castings M04 and M07 were processed through solution heat treatment, quenching, and aging operations per Table IV of specification M-XXXX, Castings, Aluminum Alloy A357, Primary Aircraft Structure (Appendix B). During solution heat-treatment and quenching procedures,

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Table 15. Foundry Data Summary—Boeing-Produced Bulkhead Castings

Ladle Chemistry (%)

Cast-ing No.	Melt No.	Cu 0.20 max.	Si 6.5-7.5	Fe 0.10 max.	Mn 0.10 max.	Zn 0.10 max.	Mg 0.55-0.65	Ti 0.10-0.20	Be 0.04-0.07	Date	Pouring Temp. (°F)	Pouring Time (sec.)	Inspection Remarks
M01	-- --	0.009 0.001	6.6 6.7	0.07 0.07	0.001 0.001	0.005 0.005	0.65 0.66*	0.11 0.11	0.064 0.061	2-1-78	1445	75+	Numerous misruns in corrugations.
M02	A80174 A80175	0.001 0.001	6.6 6.5	0.07 0.06	0.001 0.001	0.005 0.005	0.66* 0.66*	0.11 0.11	0.054 0.062	2-10-78	1450	75+	Misruns in corrugations, lower webs, and periphery. Major shrinkage at WL 130 deck.
M03	A80238 A80239	0.005 0.005	6.7 6.7	0.07 0.07	0.001 0.001	0.005 0.005	0.72* 0.72*	0.11 0.11	0.065 0.076	2-21-78	1450	75+	Misruns in corrugations. Some shrinkage at WL 130 deck.
M04	A80293 A80294	0.001 0.001	6.5 6.6	0.09 0.09	0.001 0.001	0.005 0.005	0.64 0.67*	0.11 0.11	0.066 0.063	3-3-78	1440	75+	Minor misruns in corrugations, WL 150 tabs, and one web at lower right hand side. Some shrinkage at WL 130 deck.
M05	A80358 A80359	0.001 0.001	7.0 6.9	0.11 0.09	0.002 0.002	0.005 0.005	0.63 0.72*	0.12 0.12	0.061 0.069	3-20-78	1430	75+	Very minor misruns in webs and one corrugation. Minor shrinkage at WL 130 deck.
M06	A80408 A80409	0.002 0.001	6.9 7.3	0.08 0.09	0.001 0.001	0.005 0.005	0.64 0.60	0.11 0.12	0.056 0.057	3-31-78	1440	72+	Nonfill area at lower corner of casting.
M07	A80527 A80528	0.001 0.001	7.2 7.2	0.09 0.09	0.001 0.001	0.001 0.001	0.68* 0.68*	0.12 0.12	0.067 0.072*	4-25-78	1445	76+	2 misruns approx. 2 x 3 in. in corrugations at WL 135. 4 minor misruns in webs.
M08	A80666 A80667	0.001 0.003	7.0 7.0	0.09 0.10	0.001 0.002	0.001 0.001	0.67* 0.68*	0.12 0.11	0.061 0.056	5-23-78	1440	75+	Very minor misruns, 3 areas in corrugations.
M09	A80753 A80754	0.001 0.001	6.9 7.2	0.08 0.08	0.001 0.001	0.005 0.005	0.67* 0.69*	0.13 0.12	0.040 0.053	6-8-78	1440	75+	Minor misruns in corrugated sections and lower web.
M10	A80809 A80810	0.002 0.002	6.8 6.8	0.09 0.09	0.001 0.001	0.005 0.005	0.69* 0.68*	0.12 0.12	0.048 0.020	6-19-78	1445	72+	Minor misruns in web sections and one in the corrugated section.

*Outside specification limits. Acceptable to Engineering.
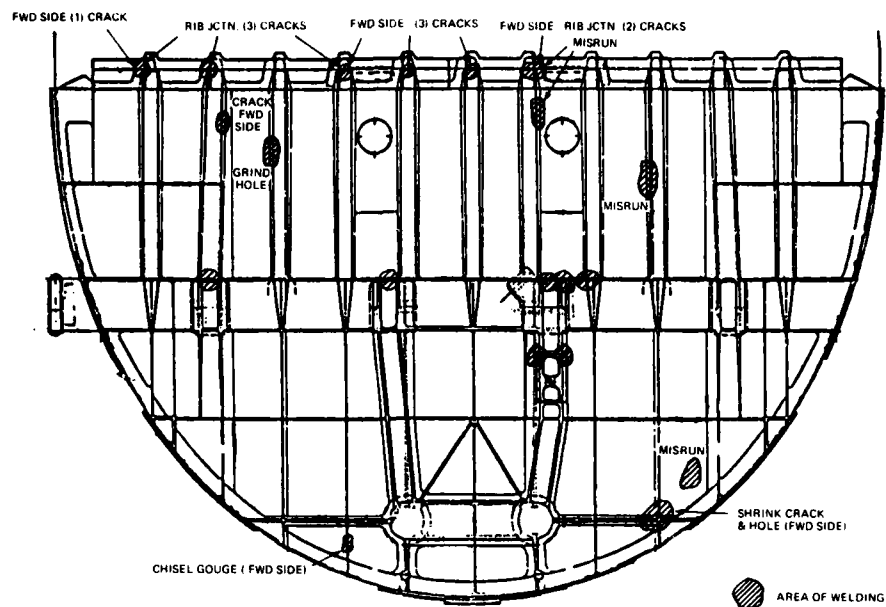
Figure 65.   Weld Correction Locations—Bulkhead Casting M04
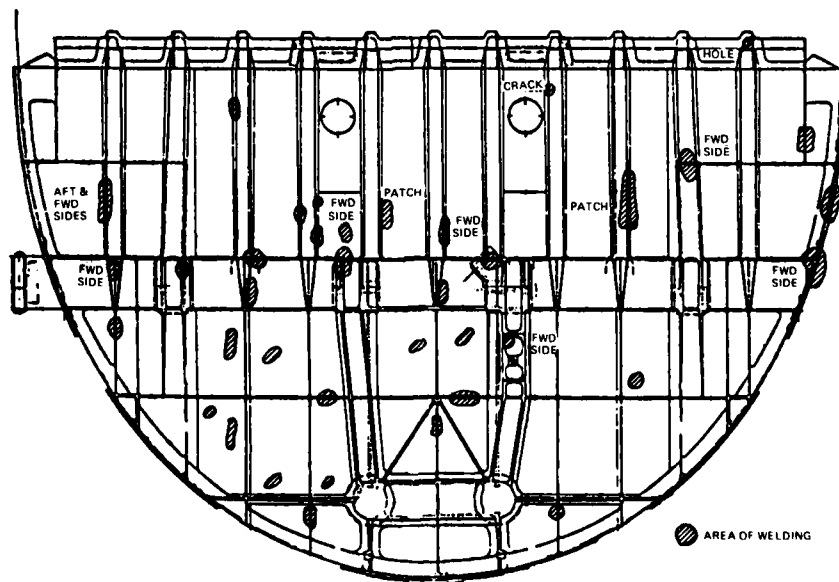
Figure 66.   Weld Correction Locations—Bulkhead Casting M07

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the castings were supported by a heat-treat fixture. The castings were solution heat treated at $1010^\circ F$ for 24 hours. Quench delay was 9 seconds. The castings were quenched in $160^\circ F$ water and were held in the quench tank for about 5-10 minutes to allow complete cooling to the temperature of the quenchant.

Because A357 is a precipitation-hardening alloy, the bulkhead castings were immediately covered with dry ice after quenching to inhibit natural aging. The dry ice was maintained on the parts for a minimum of 30 minutes to ensure temperature equilibrium between the dry ice and the casting. The dry ice then was removed and the parts were mechanically straightened as required. Straightening operations on A357 were limited to a total of 6 hours. The actual amount of straightening required was much less than anticipated. Straightening was needed on several ribs, the tabs at the base of the casting, and the shelves at WL 130. In addition, some oil-canning occurred in the web areas. The time necessary to straighten each casting was 2 manhours.

The castings were naturally aged at room temperature for 24 hours and artificially aged at $325^\circ F$ for 8 hours.

9.   Machining and Conversion Coating

Bulkhead castings M04 and M07 were machined as required per drawing 162-00018 (Appendix A). Each of the castings was machined on a numerically controlled (NC) milling machine with 5-axis milling capability for periphery and lug face machining operations. Boring operations for the lug sections of the bulkhead castings were performed with a pneumatic portable boring assembly.

Casting M04 was chromic acid anodized, and casting M07 was alodined as a production expedient. Upon completion of the conversion coating, bushings were placed in the lug section holes per drawing requirement.

10. **Casting Weights**

Castings M04 and M07 were weighed after final machining. The final weight of casting M07 was 198 pounds; that of M04 was 197 pounds. The theoretical weight of the bulkhead casting is 181 pounds in the finished machined condition. The excess weight of castings M04 and M07 resulted from additions to the pattern to correct mislocated lugs and to increase thickness of the periphery wall; also, the torque box was not finish machined. In a production situation, the pattern would have been reworked to correct all deficiencies without adding excess material to the casting.

11. **Fatigue Test Setup and Transition Structure**

Also included in Phase IV was the construction of a transition section structure for testing of bulkhead castings under dynamic and static load conditions. Bulkhead casting M07 was installed in the transition section for durability (fatigue) testing at the Air Force Flight Dynamics Laboratory (AFFDL), Wright-Patterson Air Force Base, Ohio. Details of the full-scale testing are presented in Section VI.

12. **Quality Control**

The primary NDE methods employed in Phase IV were fluorescent penetrant for surface discontinuities and X-radiography for internal soundness. State-of-the-art materials and methods were evaluated during Phase II, and optimum techniques were selected for application in Phase IV. While X-ray and penetrant inspections are commonly used in the casting industry for inspection of nonferromagnetic castings, conventional radiography was judged to be inadequate for ensuring Grade B quality for fine porosity in critical, heavy sections of the bulkhead castings. Ultrasonic techniques were evaluated to provide additional assurance in assessing the internal soundness of these heavy sections (from 0.75 to 4 inches thick). It also was necessary to develop suitable nondestructive methods for metallographic measurement of DAS (dendrite arm spacing) on designated surface areas of the full-size castings. This procedure provided measurements relating to effectiveness of chills and likely level of mechanical properties attained in

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local areas of a casting. Dimensional inspections and mechanical property determinations were accomplished by conventional procedures.

Radiographic quality grade B was attained in the thickest sections of the program castings by extensive use of properly designed and placed chills. This quality was confirmed by supplementing radiography with ultrasonic inspection. Results of radiographic inspections of full-scale test castings M04 and M07 are summarized in Figures 67 and 68, respectively. All discontinuities shown were accepted upon Engineering analysis.

Based upon laboratory tests, available facilities, and practical considerations, a fluorescent penetrant inspection system was selected using a self-developing, water-washable penetrant with no developer. This system was considered to provide a sensitivity equal to Group V materials per MIL-I-25135 when used without developer.

Penetrant inspections were performed at several stages of the manufacturing operations. To avoid the problem of tight defects being closed by sawing, grinding, and grit blasting, a requirement was imposed on the program castings that 0.0002 to 0.0004 inch of material be chemically removed from all surfaces after cleanup. Chemical etching also was required following local grinding of welds prior to penetrant inspection. The first inspection was performed after cleanup, X-ray inspection, and initial weld corrections. Any additional weld correction areas were locally reinspected. Full penetrant inspection was again accomplished following heat treatment and straightening. Final inspection then was performed on the finish machined castings prior to protective finishing. Uncorrected discontinuities revealed by penetrant inspection also are indicated in Figures 67 and 68.

DAS determinations were made on the full-size Boeing castings at 21 locations as shown in Figure 69. Each determination represents an average value of three or more measurements. Typical results are presented in Table 16. Details of the method of determining DAS are presented in Section III.

LEGEND

C = X-RAY GRADE
+ = WORSE THAN
- = BETTER THAN
d = DROSS
gp = GAS POROSITY
O = SMALL AREA ONLY

▷ PENETRANT INDICATION.
POSSIBLE SMALL COLD SHUT.
UNREPAIRED
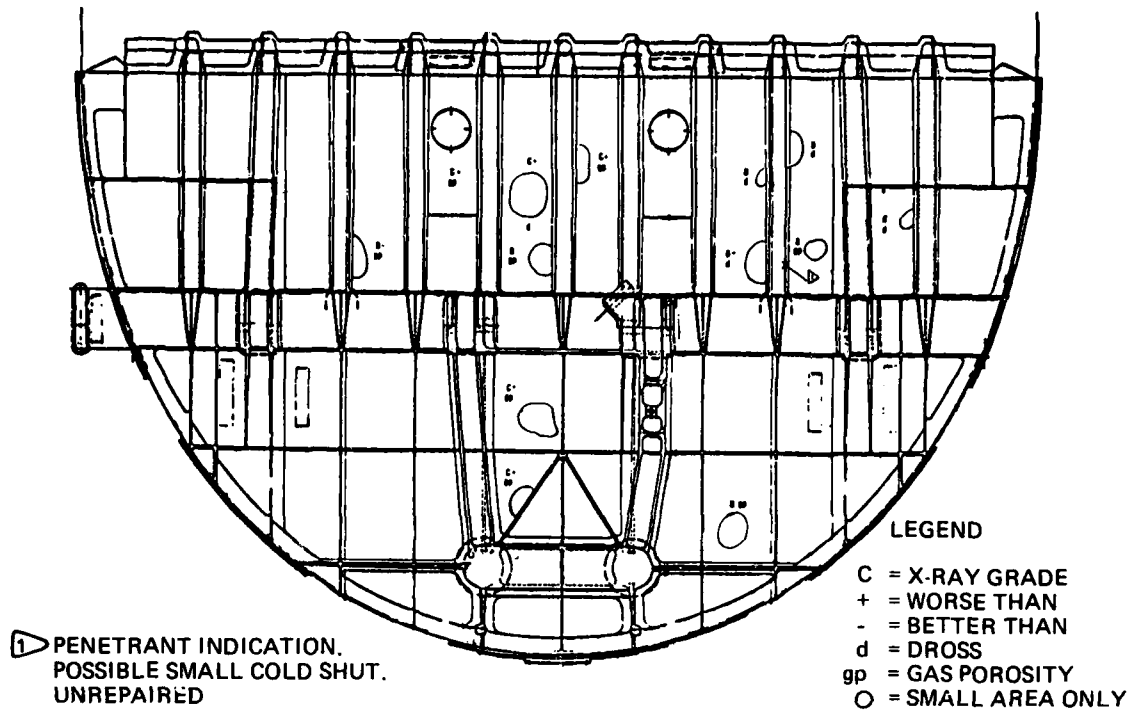
Figure 67.   Radiographic and Penetrant Inspection Results—Boeing Bulkhead Casting
M04

▷ CRACK; APPROX .25"

▷ LINE POROSITY - CORNER,
UNDER FLANGE

▷ POROSITY - RIB RADIUS UNDER FLANGE

▷ LINE POROSITY; APPROX .25"

▷ CRACK; APPROX .25"

LEGEND

D = X-RAY GRADE
+ = WORSE THAN
- = BETTER THAN
gp = GAS POROSITY
S = SHRINKAGE
O = SMALL AREA ONLY
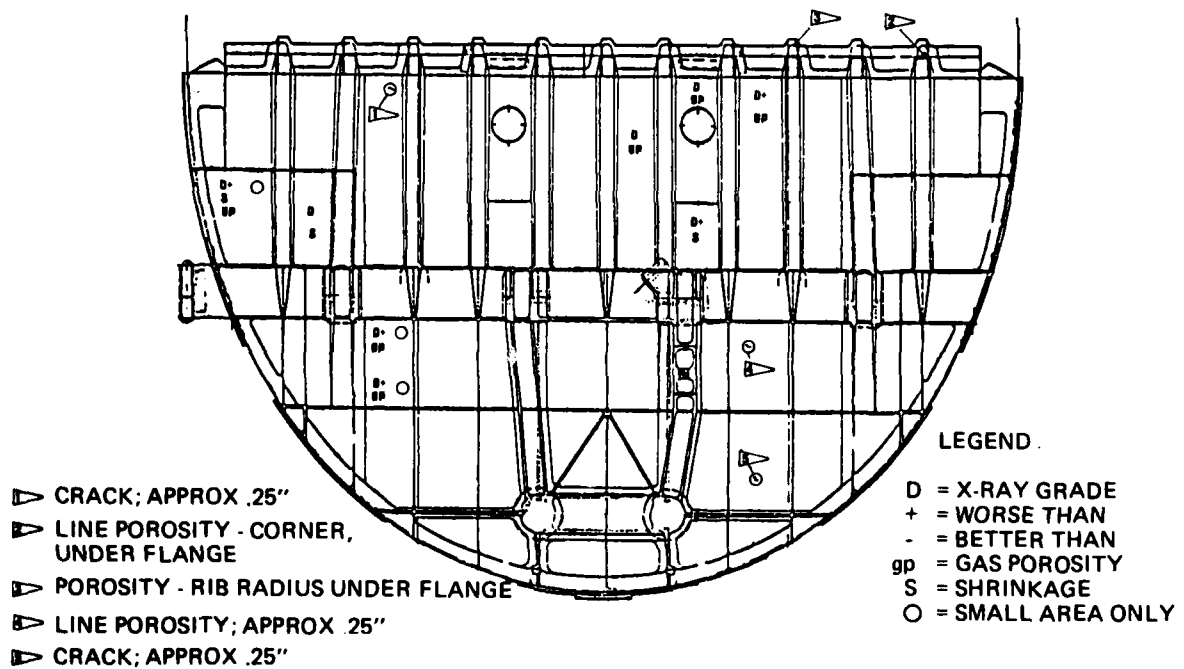
Figure 68.   Radiographic and Penetrant Inspection Results—Boeing Bulkhead Casting
M07
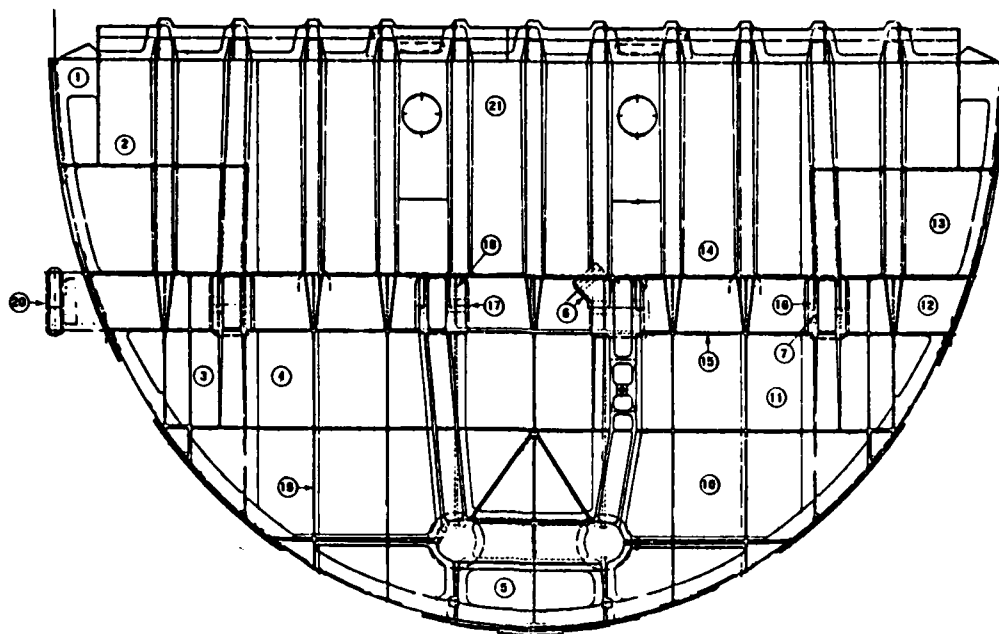
Figure 69.   Dendrite Arm Spacing (DAS) Measurement Locations—Boeing Castings

Table 16.   DAS Measurements on Typical Boeing Castings

Test Location	DAS Values (0.0001 inch) for Bulkhead Castings				
	M02	M03	M04	M05	M07
1	16	13	16	16	17
2	13	13	14	14	9
3	13	14	13	14	11
4	13	14	17	12	10
5	10	11	8	9	12
6	5	6	11	13	8
7	7	8	8	11	8
8	21	18	17	28	14
9	5	8	10	10	7
10	11	11	10	14	10
11	12	11	12	12	10
12	12	12	14	12	11
13	11	12	11	8	11
14	9	10	10	11	7
15	11	10	7	11	7
16	7	8	6	9	8
17	5	6	8	10	8
18	6	6	7	11	8
19	20	21	28	24	21
20	21	13	—	12	15
21	13	12	12	14	11

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Ultrasonic techniques were investigated to supplement required radiography by providing improved detection of dispersed small gas or shrinkage porosities in casting sections up to 4 inches thick. Of the several approaches evaluated, the pulse-echo, direct porosity detection method gave the best results. Comparative reference standards were created from cast material that had 0.75-inch-thick samples removed and radiographed to establish the radiographic quality grade. It was found that due to differences in pore sizes, shapes, and distribution that can exist within material of a particular quality grade, the oscillograph display of the ultrasonic signal response can vary considerably with small displacement of the transducer. The inspector, therefore, must make a subjective judgment of the "average" ultrasonic responses when comparing oscilloscope patterns obtained from the reference standard and the casting. This can be substantially improved by using a storage oscilloscope upon which can be displayed superimposed patterns obtained from a series of closely adjacent transducer positions. Typical displays of this type are shown in Figure 70, representing relatively sound material in the top pattern (equivalent to radiographic Grade B) and less sound material at the bottom (between B and C). This technique was used in inspecting all sections of the castings greater than 0.75 inch thick. All of these areas met the Grade B requirements.

The trimmed and cleaned castings were fit-checked against a dimensional check fixture. The first casting (tool-tryout casting) was inspected extensively with the fixture and an NC bridge mill having 3-axis digital readout to four decimals. As a result of this inspection, the casting pattern was modified in a few areas, primarily to increase the machining allowances. The second production casting (MO2) was inspected to check the pattern changes and compliance with drawing dimensions. Random thickness measurements were obtained ultrasonically with a Branson Digital Thickness Gage. Machined castings were additionally checked to the finished part drawing. These checks pertained to the location and dimensions of the slots and bolt holes at the attachment points for the nose landing gear assembly, as well as establishing the outer machined contour of the castings. Thickness measurements in certain web and channel areas

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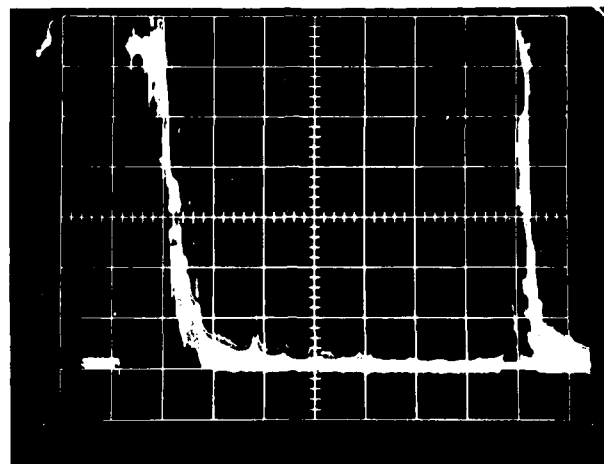
RELATIVELY SOUND MATERIAL
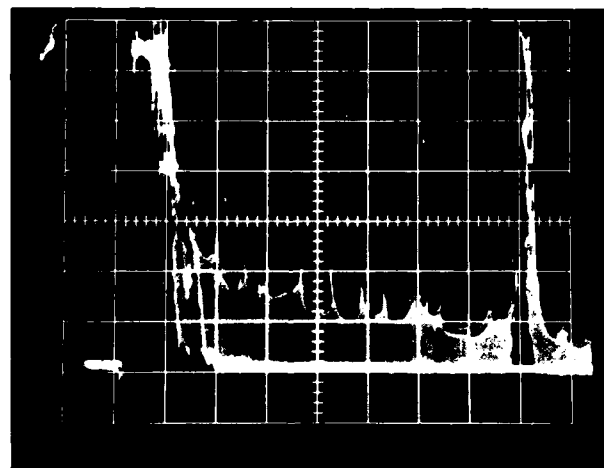
LESS SOUND MATERIAL

Figure 70.   Oscillograph Patterns of Ultrasonic Pulse-Echo Signals from Cast
Materials Containing Different Levels of Porosity

were above the nominal drawing values. The reason for these excessive thickness indications is not known.

Mechanical properties obtained from integrally cast material on the static and fatigue test castings (M04 and M07 respectively) are presented in Table 17.

13. Cost Comparison

Based upon estimates of costs for the fabrication of 300 shipsets, an approximate cost reduction of 35% would result from fabricating YC-14 station 170 body/nose landing gear support bulkheads by state-of-the-art casting methods. The cost reduction figure results from differences in sheet-metal buildup costs for the bulkhead configuration versus fabrication of a single monolithic cast structure.

In Phase III, cost estimates were made for the sheet-metal built-up bulkhead. Based upon current techniques, sheet-metal fabrication of 300 bulkheads would result in a total cost of $3,745,227. This figure represents a unit cost of $12,484 per sheet-metal bulkhead. In contrast, current estimates show that fabrication of the bulkheads by state-of-the-art casting methods would result in a total cost of $2,447,675 for 300 bulkheads. This figure represents a unit cost of $8,159 per cast bulkhead. Therefore, a savings of $4,325 is realized by fabricating the bulkhead by casting. The total cost savings percentage is as follows:

$$\text{cost savings} = \frac{\$12,484 - \$8,159}{\$12,484} \times 100 = 35\%$$

C. TASK 2—FABRICATION OF DEMONSTRATION COMPONENTS AT HITCHCOCK INDUSTRIES, INC.

The second-source foundry for the CAST program, Hitchcock Industries, Inc. of Minneapolis, Minnesota also produced 10 bulkhead castings (Fig. 71). This portion of the program was conducted to demonstrate that the casting process was transferable from the Boeing foundry to the Hitchcock foundry and would

Table 17. Mechanical Properties for Bulkhead Castings M04 and M07 (Specimens Machined from Integrally Cast Coupons)

Serial Number	Date Poured	Bar Size	UTS (psi)	YS (psi)	Elongation (Percent)
M04	3/3/78	0.357 RD	49,000*	42,100	4*
		0.357 RD	52,300	43,300	5
		0.357 RD	51,500	41,900	7
		Requirement:	50,000 min.	40,000 min.	5 min.
		0.48 x 0.150 FLT	48,900	42,700	3
		Requirement:	40,000 min.	30,000 min.	3 min.
M07	4/25/78	0.357 RD	51,700	43,900	5
		0.357 RD	53,100	43,500	8
		0.357 RD	52,600	42,800	9
		Requirement:	50,000 min.	40,000 min.	5 min.
		0.48 x 0.134 FLT	48,900	38,900	4
		0.48 x 0.145 FLT	51,300	42,100	5
		Requirement:	40,000 min.	30,000 min.	3 min.

* Properties deemed acceptable for purposes of this casting.

Figure 71. Hitchcock Bulkhead Casting No. 8

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yield reproducible results. Hitchcock used all of the tooling furnished by Boeing, including patterns, flasks, chills, and heat-treat fixture, in the production of their castings. The transfer of tooling and technology from Boeing to Hitchcock proceeded very smoothly.

Figure 72 shows an overall view of the area where molding, assembling, melting, and pouring were performed in the Hitchcock foundry. Figure 73 shows the layout of Hitchcock's work area.

1.   Variations in Procedures

The foundry practices and resulting Manufacturing Plan (Appendix A of ref. 4) established in Phase II were applied by Hitchcock Industries in the production of their 10 bulkhead castings, with only a few variations as noted. These variations involved the use of normal Hitchcock foundry procedures.

Mold segments were vented with 1/8-inch-diameter drilled holes and grooved vertically with a file to a depth of about 1/16 inch to aid the running of the thin walls of the casting. Mold segments were torched to skin dry the mold surface and then were sprayed with an insulating mold wash (Pyroseal). The Pyroseal was burned off by retorching the mold surface. The mold surface then was hand rubbed to remove excess Pyroseal and to smooth the surface. The surfaces of the mold that form the mold/metal interface then were coated with amorphous carbon.

Melting was accomplished in two gas-fired furnaces, each of which contained a removable crucible. Approximately 800 pounds of metal were melted in each furnace. Degassing of the melt was performed at the pouring temperature of $1450^\circ F$, rather than at $1300\text{-}1325^\circ F$ as was done at Boeing. Effectiveness of degassing was determined by allowing the metal sample to solidify in a vacuum freeze chamber at 30 inches of mercury.

The crucibles containing the molten metal were lifted out of the furnaces by cranes and poured directly into the mold, which was only approximately 14 feet away (Figs. 72 and 73).

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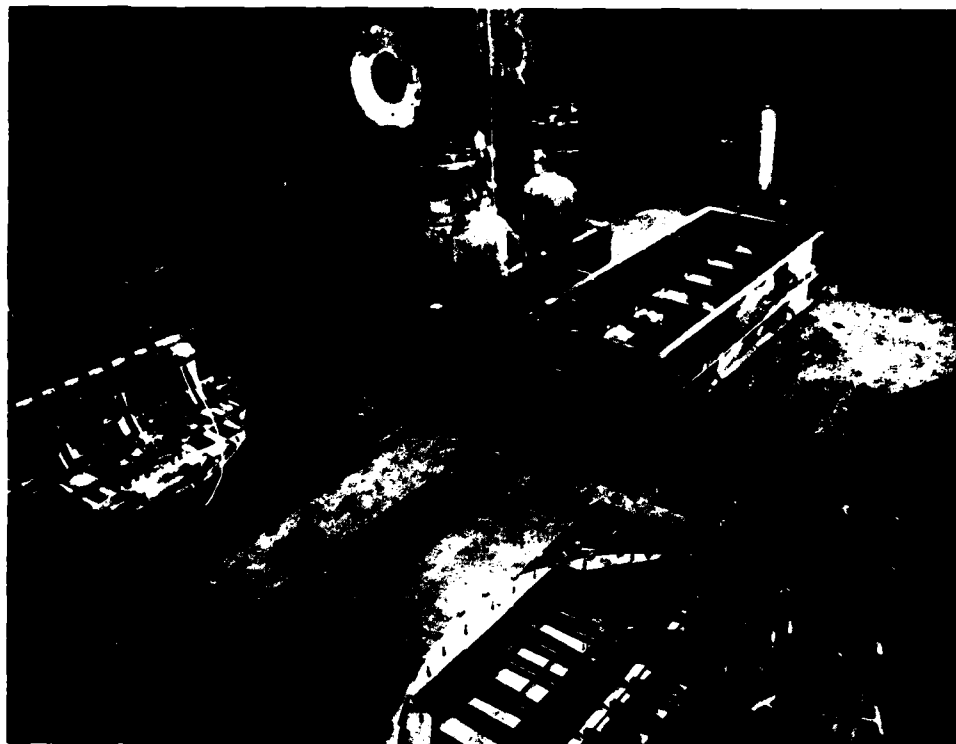
Figure 72.   Overall View of CAST Program Foundry Area at Hitchcock Industries, Inc.
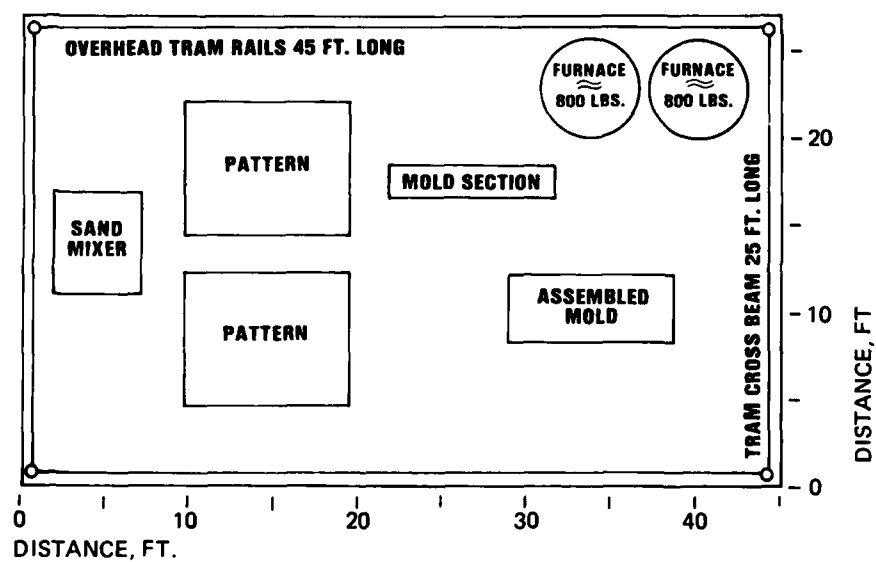
Figure 73.   Layout of Foundry Work Area at Hitchcock Industries, Inc.

Mold shakeout consisted of stripping the flasks, placing the mold in an oven, and baking at 700°F for 8 hours to burn off the binder in the sand. This operation resulted in all the sand falling off the casting.

2.   Summary of Foundry Data

Table 18 presents a summary of foundry data for the 10 Hitchcock castings. Included are the ladle chemistry and the pouring date, temperature, and time for each casting. Results of visual, penetrant, and radiographic inspections and major process differences are summarized also.

3.   Quality Control

Quality control procedures for the castings produced at Hitchcock Industries were similar to those used at Boeing. Approximately 99% of all radiographs that were taken of the castings showed Grade B or better. DAS measurements were made on the bulkhead castings at 26 locations as shown in Figure 74. Typical results are presented in Table 19.

Random thickness measurements were obtained ultrasonically for Hitchcock castings 2 and 9. These castings were in the as-cast, uncleaned condition. Thickness measurements in certain web and channel areas were above the nominal drawing values. The reason for these excessive thickness indications is not known.

No ultrasonic inspections for internal defects were performed by Hitchcock Industries.

4.   Disposition of Castings

Casting numbers 8 and 10 were weld corrected and completely cleaned up for display purposes. These castings were not heat treated. Number 8 was shipped to Boeing, and number 10 was shipped to the Air Force for display. Casting numbers 2 and 9 were heat treated and shipped to Boeing for cut-up for mechanical property test bars and nondestructive inspection cross-check during Phase V. Casting numbers 4 and 5 were weld corrected, heat

Table 18. Foundry Data Summary—Hitchcock-Produced Bulkhead Castings

Casting No.	Melt No.	Pot No.	Cu	Si	Fe	Mn	Zn	Mg	Ti	Be	Date	Temp. (°F)	Time (sec.)	Inspection Remarks
Specified:			0.20 max.	6.5-7.5	0.10 max.	0.10 max.	0.10 max.	0.55-0.65	0.10-0.20	0.04-0.07				
1	DA7-100	1	<0.01	6.50	0.10	0.01	0.02	0.60*	0.12	0.06	9-18-78	1450	77+	Many misruns in ribs and corrugation side walls. Some shrinkage porosity at rib junctions. Some light shrinkage and sponge porosity in webs outside corrugations. Some dross in two corrugations.
		2	<0.01	6.67	0.12*	0.01	0.02	0.60	0.11	0.05				
		3	<0.01	6.70	0.10	0.01	0.02	0.64	0.10	0.06				
2	DA7-102	1	0.01	6.71	0.09	0.01	0.02	0.63	0.15	0.06	9-28-78	1450	77+	Fewer misruns than No. 1. Some light microshrinkage in webs.
		2	0.01	6.70	0.10	0.01	0.02	0.61	0.14	0.07				
		3	0.01	6.70	0.10	0.01	0.02	0.63	0.15	0.07				
3	DA7-105	1	0.01	6.80	0.08	0.01	0.02	0.52*	0.19	0.05	10-6-78	1450	77+	Minor misruns mainly in ribs and corrugation side walls. Some shrinkage mainly at ingates on periphery.
		2	0.01	6.90	0.08	0.01	0.01	0.55	0.19	0.05				
4	DA7-106	1	0.02	6.78	0.09	0.01	0.02	0.61	0.16	0.06	10-17-78	1450	77+	Minor misruns mainly in ribs and corrugation side walls. Some microshrinkage mainly in webs between corrugations. Some shrinkage on periphery.
		2	0.02	6.75	0.08	0.01	0.02	0.63	0.16	0.07				
5	DA7-109	1	0.02	6.51	0.08	0.01	0.02	0.61	0.16	0.07	10-26-78	1450	77+	Minor misruns mainly in ribs and corrugation side walls. Some shrinkage on periphery. Some microshrinkage in webs.
		2	0.02	6.70	0.08	0.01	0.02	0.57	0.16	0.07				
6	DA7-112	1	0.02	6.68	0.08	0.01	0.02	0.59	0.16	0.05	11-3-78	1450+	67+	Sprues 14% larger than for Nos. 1-5. No grooving in well surfaces; only vent holes. Many misruns mainly in webs and corrugation side walls. Some shrinkage on periphery.
		2	0.02	6.88	0.08	0.01	0.02	0.62	0.16	0.07				
7	DA7-116	1	<0.01	6.50	0.09	<0.01	0.01	0.64	0.16	0.07	11-14-78	1450+	67+	Sprues 14% larger than for Nos. 1-5. Minor misruns mainly in corrugation side walls. One chill dropped at heaviest lug. Some microshrinkage in webs.
		2	<0.01	6.70	0.09	<0.01	0.01	0.59	0.16	0.05				
8	DA7-119	1	<0.01	6.69	0.06	<0.01	<0.01	0.65	0.16	0.07	11-21-78	1450+	67+	Sprues 14% larger than for Nos. 1-5. Minor misruns mainly in ribs and corrugation side walls. Some shrinkage on periphery. Some microshrinkage in webs.
		2	<0.01	6.60	0.06	<0.01	<0.01	0.56	0.16	0.04				
9	DA7-122	1	<0.01	6.50	0.06	<0.01	<0.01	0.64	0.16	0.06	12-1-78	1450+	67+	Sprues 14% larger than for Nos. 1-5. Minor misruns, 4 in ribs and 2 in web. Slightly more metal penetration than normal. Some shrinkage on periphery. Some light microshrinkage in webs.
		2	<0.01	6.60	0.06	<0.01	<0.01	0.59	0.16	0.06				
10	DA7-124	1	<0.01	6.60	0.08	0.03	0.02	0.69*	0.14	0.06	12-8-78	1450+	67+	Sprues 14% larger than for Nos. 1-5. Minor misruns, 3 in ribs and 1 in web. Only one small penetrant indication (dirt).
		2	<0.01	6.65	0.08	0.02	0.02	0.68*	0.14	0.05				

*Outside specification limits. Acceptable to Engineering.

Figure 74.   Locations for Measurement of DAS (Dendrite Arm Spacing) on Hitchcock Bulkhead Castings

Table 19.   DAS Measurements on Typical Hitchcock Castings

Test Location	DAS (0.0001 inch)		
	Casting No. 2	Casting No. 7	Casting No. 9
1	15	1/	17
2	15	13	16
3	17	20	23
4	13	17	15
5	13	16	20
6	14	14	17
7	13	15	16
8	14	14	17
9	14	13	17
10	13	14	13
11	11	13	15
12	11	15	15
13	11	20	27
14	12	15	15
15	12	12	12
16	11	14	11
17	22	21	19
18	16	19	16
19	13	17	15
20	14	21	18
21	14	10	14
22	15	15	14
23	14	15	18
24	14	14	17
25	20	20	19
26	22	19	23

1/   Not available - ear broke off.

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treated, and shipped to Boeing. The remaining four castings, numbers 1, 3, 6, and 7, were shipped to Boeing in the as-cast and rough-cleaned condition.

SECTION VI
PHASE V—STRUCTURAL TEST AND EVALUATION

A. INTRODUCTION

The objectives of Phase V were to demonstrate the structural integrity of the cast bulkhead by full-scale test and to evaluate the fatigue and fracture properties of cast A357 aluminum. Also accomplished was an assessment of tension allowables for A357.

The full-scale test and evaluation portion of the program was conducted by Christian K. Gunther; the Air Force test engineer was Don Brammer. The allowables portion of the program was conducted by Dale L. McLellan assisted by James W. Faber, Frederick J. Feiertag, and Howard L. Southworth. Cecil E. Parsons was Allowables Manager.

Complete details of the Phase V work were reported in reference 5.

B. PART I—FULL-SCALE TEST

1. Introduction

During Phase III, the bulkhead was analyzed for static strength, durability, and damage tolerance. A sufficient margin of safety was demonstrated for all critical conditions. The demonstration of static strength, durability, and damage tolerance by full-scale test provides a check of the analysis and identifies critical areas of the airframe not previously identified by analysis or component testing. A successful demonstration of structural integrity by a full-scale test provides a high degree of confidence that the component will function satisfactorily in its intended service environment.

2. Scope of Full-Scale Test Program

The test program consisted of full-scale testing of two cast A357-T6 aluminum bulkheads. The test articles were installed in the test fixture consecutively and testing was conducted in the following manner:

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o   Test Article I (Boeing Bulkhead M07)
        Durability Test Program
        Damage Tolerance Test Program I
o   Test Article II (Boeing Bulkhead M04)
        Damage Tolerance Test Program II,
        including Residual Static Strength Test

The following briefly summarizes each portion of the full-scale test program:

o   The Durability Test Program consisted of applying spectrum load blocks made up of repeated flight-by-flight loads resulting from the AMST design mission profile mix to Test Article I. Spectrum load blocks corresponding to the usage of four design service lives were applied.

o   Damage Tolerance Test Program I was conducted concurrently with the last two lives of durability testing on Test Article I and consisted of crack growth and residual strength testing. Initial flaws were implanted prior to the third lifetime of durability testing.

o   Damage Tolerance Test Program II was conducted on Test Article II and consisted of two lifetimes of cyclic loading with initial damage and of residual strength testing of the thus fatigue-damaged bulkhead.

3.   Full-Scale Test Setup

The test article, the station 170 bulkhead of the YC-14 fuselage, is described and shown in Figures 2 and 3 of Section I. The bulkhead serves a dual purpose: first, it is the backup structure for the nose landing gear; second, the upper portion serves as a pressure bulkhead. The nose gear trunnion is attached to the bulkhead at four clevises by means of two yoke fittings.

The test fixture and test setup were designed to provide as realistic and efficient a means as possible for all bulkhead testing. The test setup was installed in Building 65 at Wright-Patterson AFB. The test article was attached to 5 feet of transition structure that simulated the surrounding

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fuselage structure. The test article, including transition structure, was supported at station 230 and cantilevered from A-frames, as shown in Figure 75. The test loads were applied by hydraulic actuators through a simulated landing gear trunnion support structure. Instrumentation was provided to determine stress distributions for verification of the stress analysis, to demonstrate the adequacy of the test setup, and to provide data to preclude premature structural failure. The instrumentation included load cells, strain gages, deflection indicators, crack detectors, and pressure transducers.

The repeated loads, which are the result of the design usage of the AMST aircraft, were applied for durability and damage tolerance testing in accordance with MIL-A-008866B (USAF). The design usage is represented by a mission mix consisting of blocks of missions made up of five different types of flights. The usage of one design service life (25,000 hours) is represented by the application of the loads due to 1,516 blocks of missions. The repeated loads consist of nose-gear loads and pressurization. Air pressure is acting on the upper portion of the bulkhead during flight. The landing loads vary according to the aircraft sinkrate distribution of MIL-A-008866 for conventional landings.

The loads for static test (residual strength) were in accordance with MIL-A-008866A. The bulkhead was subjected to two load conditions: spring-back landing and Boeing side-load landing. The objective was to demonstrate that the bulkhead was capable of sustaining 150 percent of the limit loads (equal to 100 percent of ultimate).

During the test, data from six load cells, six deflection indicators, two pressure transducers, and 114 strain-gage channels were monitored and recorded.

4. **Full-Scale Test**

A photoelastic coating survey was conducted after completion of the test setup to study the general stress field, identify local stress concentrations, and determine optimum strain-gage locations. A strain survey of the test

TRANSITION STRUCTURE

TEST ARTICLE

LOAD APPLICATION POINT B

HYDRAULIC ACTUATOR

DUMMY TRUNNION

PRESSURE BULKHEAD

A-FRAMES

LOAD APPLICATION POINT A
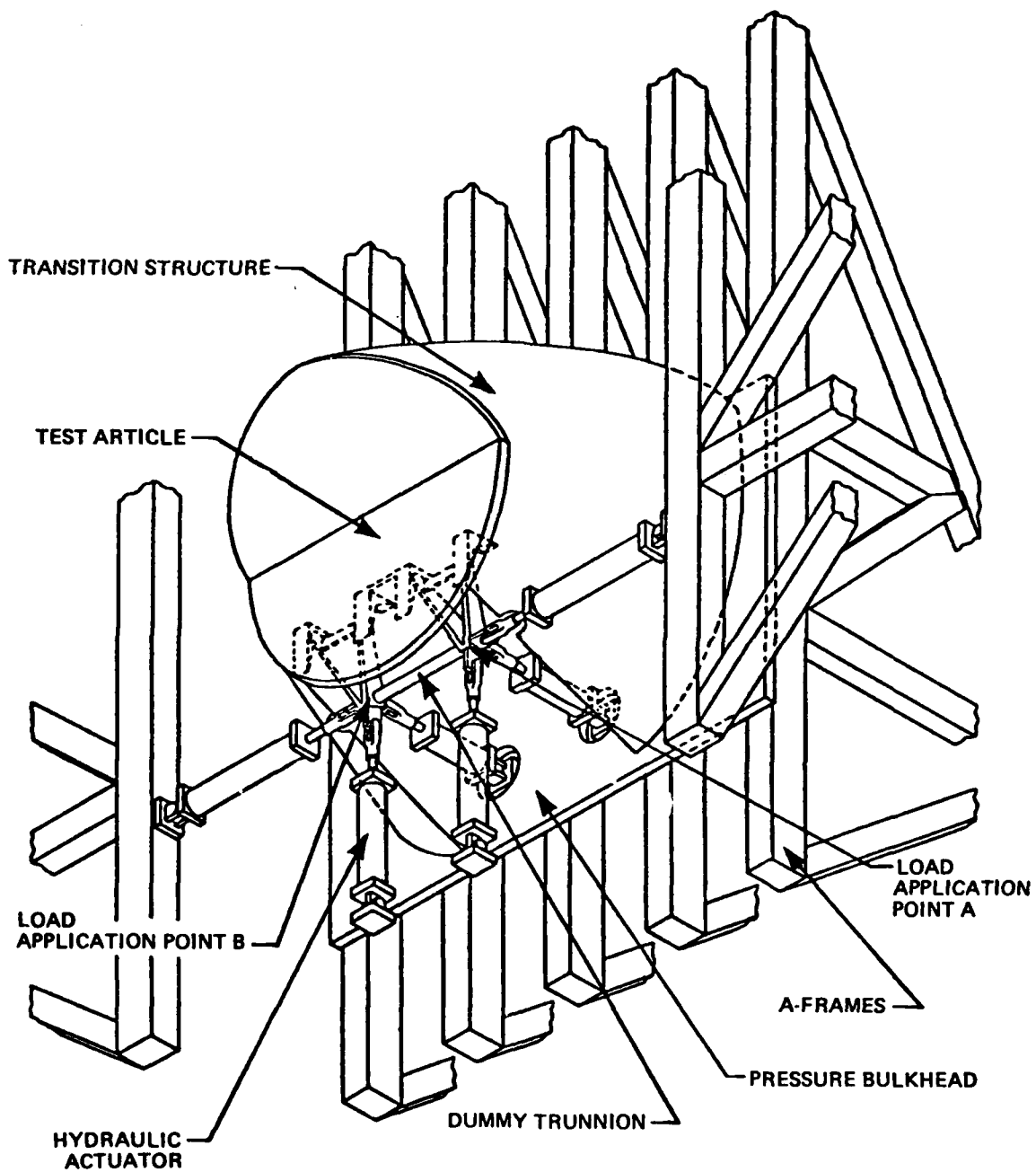
Figure 75.   Schematic of Full-Scale Test Setup

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setup, including the bulkhead, transition structure, and loading fixture, was conducted. Locations for strain gages on the bulkhead were determined based on results of the photoelastic coating survey.

An intensive inspection of the bulkhead was conducted prior to the start of cyclic loading for the durability test. This and prior inspections indicated that a number of processing defects existed in the casting (Fig. 76). The quench cracks were considered to be the most severe preexisting defects in the bulkhead. A crack growth analysis of an assumed idealized crack at this location indicated that the bulkhead should be able to withstand the service loads for the duration of the durability test without any significant crack growth initiating from these quench cracks. Therefore, no repairs were attempted.

Load cycling was begun in December 1978. The loads applied were as described in Section B.3 above and in Appendix A of reference 5. Two lifetimes of simulated service were completed in March 1979. Sawcuts then were introduced into the bulkhead at the most critical locations to simulate initial damage according to the damage tolerance requirements of MIL-A-83444. Through-the-thickness sawcuts were introduced (Fig. 77). Load cycling was resumed, and two more lifetimes of testing were completed in July 1979. Limit loads of the Boeing side-load landing condition were applied to demonstrate residual strength capability. A total of 6,294 blocks of flights were applied representing slightly more than four lifetimes of service simulation. Only small amounts of crack growth (maximum 0.008 inch) had occurred from the sawcuts. The inspections conducted during the test period did not reveal any other indications of fatigue damage to the bulkhead. This portion of the full-scale test program did not fully demonstrate that the durability and damage tolerance requirements were met for the attachment lugs. Due to an error in the repeated loads, only the requirements for the part function as a pressure bulkhead and for the redistribution of symmetric nose-gear loads were met. The demonstration of meeting all durability and damage tolerance requirements was completed by conducting a second damage tolerance test program, as described below.

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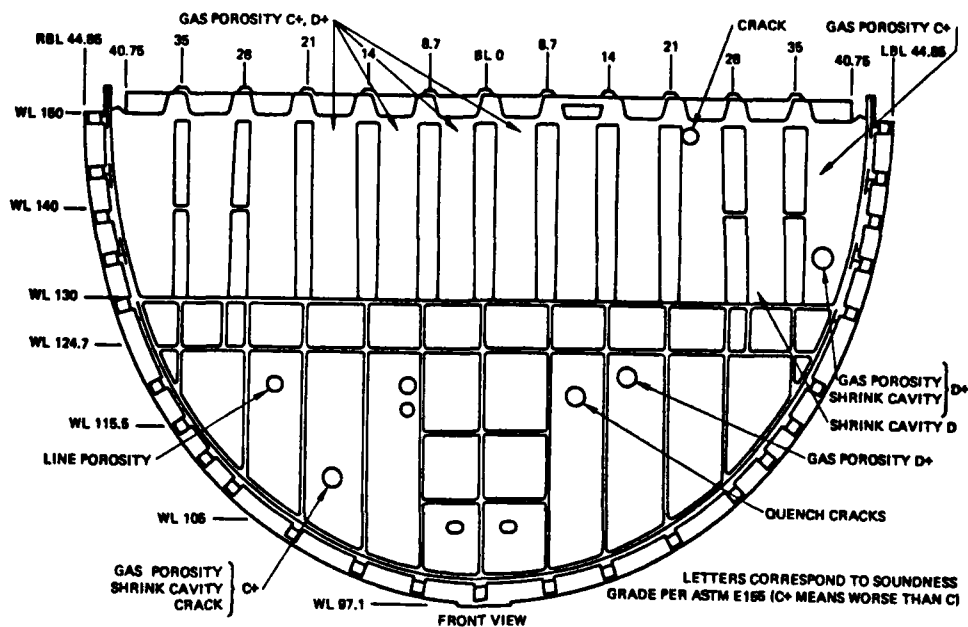
Figure 76.   Initial Condition of Test Article I
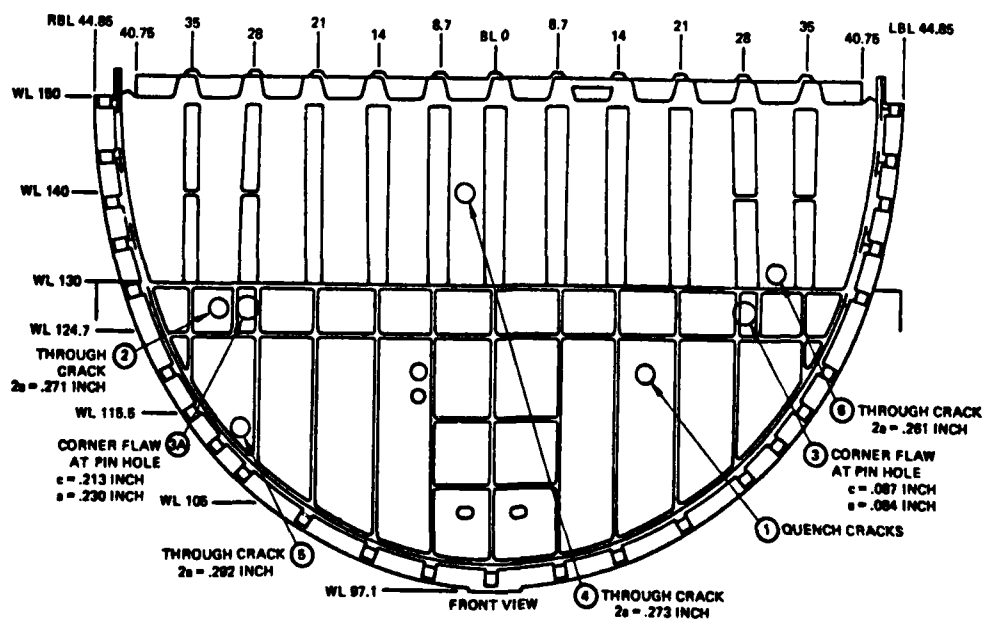
Figure 77.   Initial Flaw Locations on Test Article I

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This phase of the full-scale test program began in September 1979. A second test article had been installed in the transition structure after completion of the test program described above. Strain gages were installed and limit loads corresponding to springback landing and Boeing side-load landing were applied. These tests were successfully completed. Initial damage was introduced (Fig. 78) and cyclic loads (Appendix B of ref. 5) corresponding to two lives of design service usage were applied. The cyclic test program was completed in November 1979. No fatigue damage was discovered. Residual strength tests were carried out following the completion of the cyclic test. The purpose of these tests was to determine the load-carrying capacity of the preflawed bulkhead that had been subjected to two lifetimes of simulated service usage. The two ultimate conditions (springback landing and Boeing side-load landing) first were applied, each to 100 percent of ultimate. No visible damage or permanent deformations were observed. With the completion of these tests, it was demonstrated that the static strength requirements for the bulkhead were met and that the residual strength capacity of the bulkhead was at least equivalent to the ultimate load. To further study the residual strength capability, another sawcut was introduced, and loads corresponding to the Boeing side-load landing condition again were applied. The bulkhead and the transition structure withstood these loads sucessfully to 120 percent of ultimate. No failures occurred during the test and no permanent deformation was observed after the test. The successful completion of this portion of the full-scale test program fully demonstrated that the cast bulkhead met all durability and damage tolerance requirements of MIL-A-008866B (USAF) and MIL-A-83444 (USAF).

C. PART II—FATIGUE AND FRACTURE PROPERTIES OF CAST ALUMINUM BULKHEADS

1. Introduction

During the course of the CAST program, fatigue and fracture test data were developed to support the durability and damage tolerance analysis efforts. These data were obtained from specimens that were machined from separately cast plates and blocks (ref. 1). Although a relatively large

number of specimens were tested, the question of the properties of the cast bulkheads remained. Unlike data on wrought materials, independent specimen data do not necessarily correlate to properties of full-scale castings. A large number of foundry variables, such as location of chills and risers, greatly influence the material properties. Therefore, fatigue and fracture properties evaluation of the cast bulkheads was performed in addition to the full-scale test evaluation of structural integrity.

2.   Fatigue and Fracture Test Data

Of the 20 A357-T6 bulkheads produced during Phase IV, two Boeing bulkheads (M08 and M09) and two Hitchcock bulkheads (2 and 9) were selected for mechanical, fatigue, and fracture property testing. The Boeing castings were cut into five pieces prior to heat treatment; the Hitchcock castings were heat treated in one piece. Heat treatment was as follows:

o   Solution heat treatment: $1010 \pm 10^{\circ}F$ for 24 to 25 hours

o   Quench delay: 10 seconds maximum

o   Quenchant: $160 \pm 15^{\circ}F$ water

o   Natural aging: Room temperature for 16 to 24 hours

o   Precipitation heat treatment
       (aging): $325 \pm 10^{\circ}F$ for 7 to 8 hours

Constant-amplitude fatigue specimens were obtained from each of the four castings. They were removed from the sidewalls of the corrugations in Zone 1 (Fig. 79). Crack growth specimens were removed from the shear webs in Zones 3 and 5. Only the attachment lugs, among the critical areas, were thick enough to remove compact specimens for fracture toughness testing. Specimens were obtained from lugs number 1, 2, 7, and 8 from each casting.

Constant-amplitude fatigue tests were conducted on specimens as shown in Figure 80. The specimen surfaces were basically left as cast, except that some cleanup was performed when protrusions were present. Because of the nature of the castings, the specimens did not have completely uniform thicknesses and were not completely flat. All tests were performed in
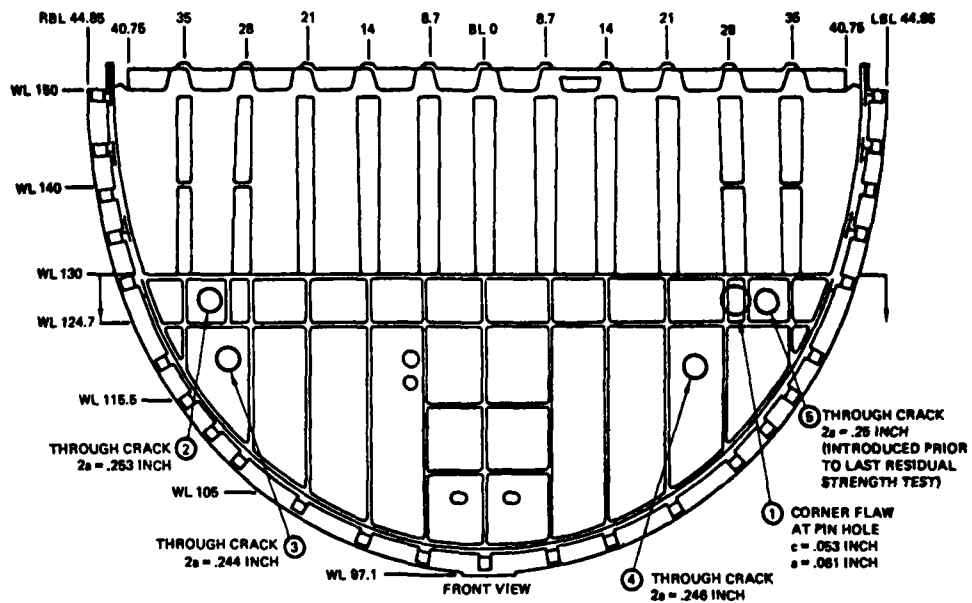
Figure 78. Initial Flaw Locations on Test Article II
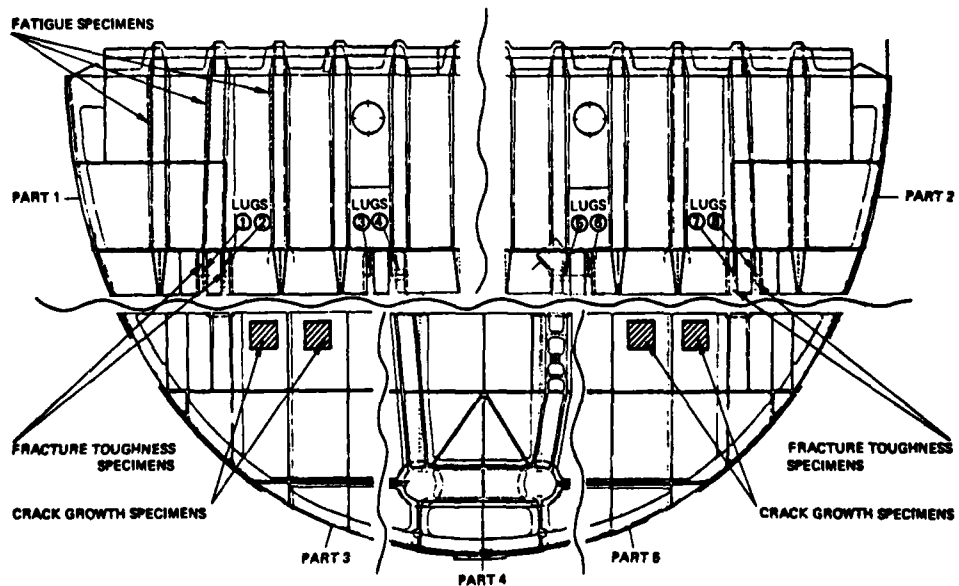
Figure 79. Specimen Locations on Cast Bulkhead

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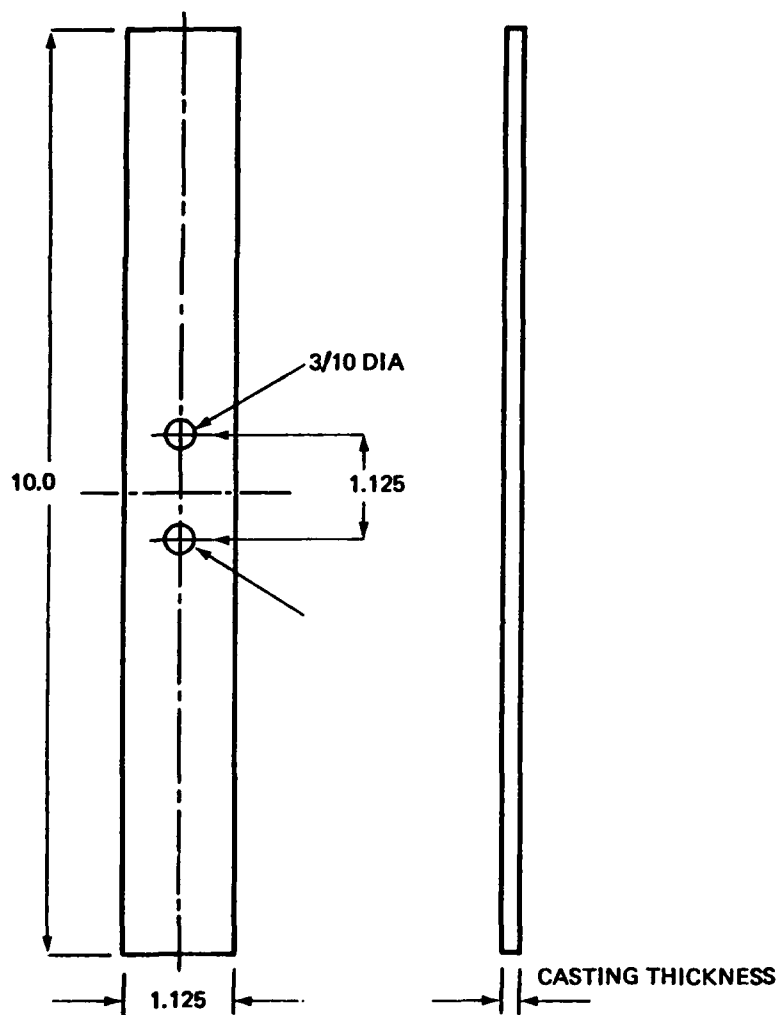
Figure 80.   Double Center-Notched Fatigue Specimen

laboratory air environment at a stress ratio of R = 0.06. The test results, compared to the data from the independent specimens, are shown in Figure 81. The bulkhead data scatter over a wider range of cycles to failure, but the number of data points also is larger at this maximum stress level. Assuming a two-parameter Weibull distribution for S-N data, it was found that the number of cycles for 37% probability of survival (61,000) for these data was approximately the same as for the independent specimen data (56,000).

Crack growth rate tests were conducted using compact-type specimens (Fig. 82). All testing was performed in laboratory air environment. The crack growth rate data were combined in Figure 83 and compared to the data obtained from the independent specimens. The two sets of data are in complete agreement for all intents and purposes. Also, there was no significant difference between the data from Boeing and Hitchcock specimens. Overall, it was gratifying to see the agreement between the independent specimen data and the bulkhead data. This demonstrated that useful crack growth rate data can be obtained from separately cast material.

Plane-strain fracture toughness tests were conducted using compact-type specimens (Fig. 84). The specimens were located in the attachment lugs as shown in Figure 85. These lugs had been heavily chilled to obtain optimum properties. All tests were conducted in laboratory air environment. The crack front of all specimens exhibited too much curvature and, for that reason, no valid plane-strain fracture toughness (K_{IC}) data were obtained. The data are henceforth referred to as K_Q data. An examination of the data showed that the results fall into one of three categories: (1) failure during fatigue cracking, (2) lower K_Q values compared to item 3, and (3) consistently good K_Q results for the remaining specimens. Boeing bulkhead M08 had slightly better fracture toughness in the lug areas than Hitchcock bulkhead number 2. Hitchcock bulkhead number 9 had the lowest fracture toughness. Records of the process variables for the individual bulkheads did not offer a clue to this relative ranking in fracture toughness.

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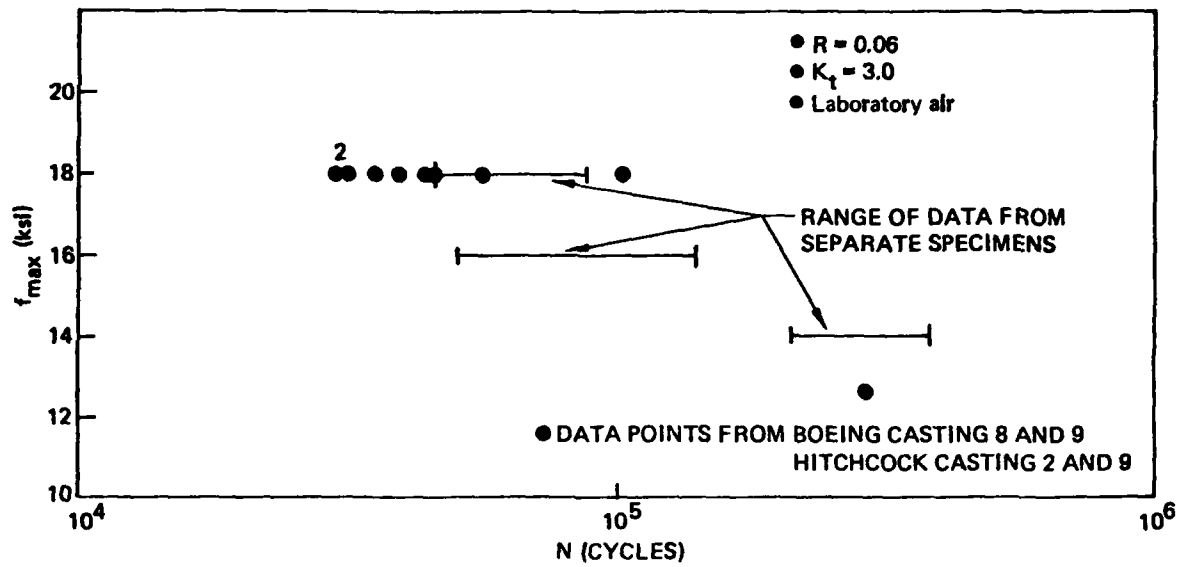
Figure 81. S-N Data Obtained from Cast Bulkheads and Separate Specimens
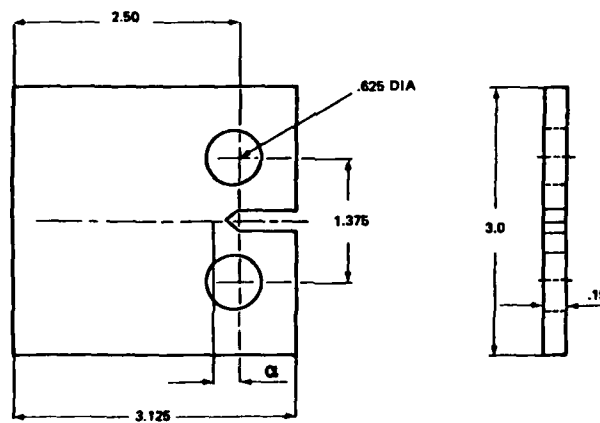
Figure 82. Crack Growth Rate Test Specimen

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+ Data from Boeing castings 8 and 9
○Data from Hitchcock castings 2 and 9
R = .06 Laboratory air
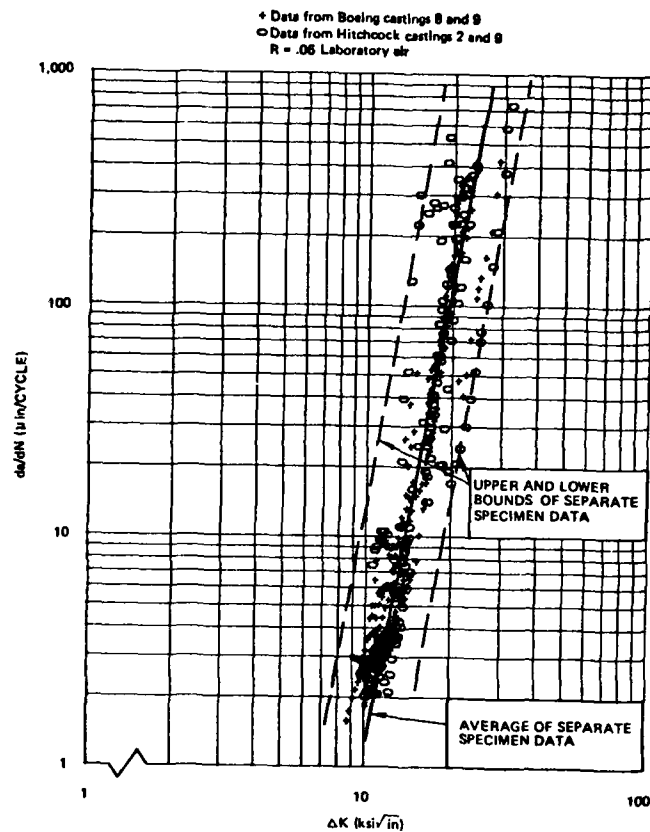
Figure 83.   Crack Growth Rates—All Specimens
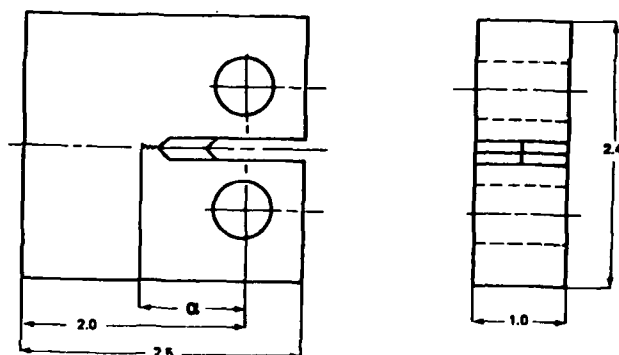
Figure 84.   Fracture Toughness Test Specimen

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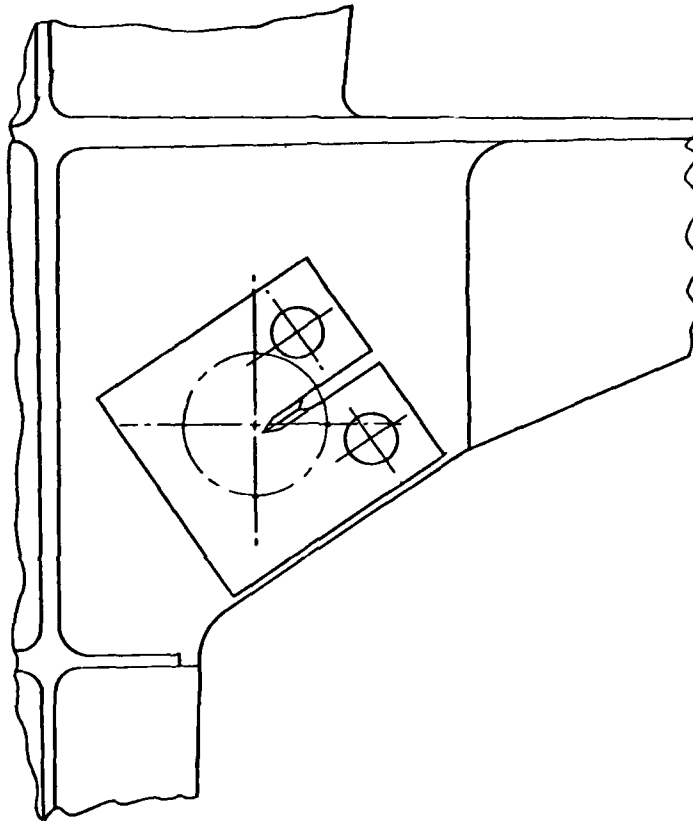
Figure 85.   Location of Fracture Toughness Specimen in Attachment Lug

D. PART III—STATIC PROPERTY ALLOWABLES

1. Introduction

One specific objective of the CAST program was to establish realistic static design allowables and to eliminate the need for using casting design factors. Castings were obtained during Phase II for purposes of developing a static data base from which allowables could be developed. The key issue of allowables development pertains to the basis upon which data are categorized. For this purpose, influences of casting-zone geometries, foundry variables, and nondestructively measurable physical parameters were evaluated. Tension allowables and derived properties for compression, shear, and bearing were developed. An assessment of tension allowables was made in Phase V. Four of twenty bulkhead castings produced in Phase IV were sampled for tensile coupon properties and physical parameters. These evaluations showed that realistic static design allowables for high-strength aluminum alloy castings could be developed if based upon the physical conditions of the material that control and dictate such behaviors. Furthermore, the subject of casting factors can be viewed in relation to casting production controls and inspections required of the relevant physical conditions.

2. Tension Properties

Tensile property variations were examined in relation to casting geometry (thickness), foundry variables (distance from ingates, risers, and chills), and heat treatment. Phase II provided an excellent opportunity to determine whether tensile properties are related to casting geometry. The Parts A and B castings are described in the following section. The observed effects of casting-zone thickness on tensile properties observed in Phase II were that TUS and ELONG increased with thickness for the Part A castings but decreased for the Part B castings, and TYS did not vary with thickness.

The two physical characteristics, DAS and soundness, are offered as an explanation for interpreting these results. In both thin and thick regions, the smallest DAS and highest soundness (grade A) resulted in the highest

ELONG. These two physical parameters may not be entirely responsible for ELONG variations, but they are the two characteristics measured for all coupons. As an initial effort, ELONG (and TUS) can be categorized according to DAS and soundness. Figure 86 shows ELONG versus DAS for the soundness grade A results. The amount of scatter in this trend band could be due to any of the following items:

o   Natural ELONG scatter

o   Errors in test and/or measurement of ELONG

o   Errors in DAS measurement

o   Unidentified gradations within ASTM soundness grade A

o   Other unidentified physical or metallurgical characteristics

In the above discussion, and for all future data analysis purposes, both DAS and soundness refer to measurements made on tested specimens adjacent to the fracture zones. ELONG was obtained from full-range stress-strain curves.

Evaluation of the effects of foundry variables (i.e., distance from chills and ingates) also showed that a dual-basis DAS/soundness concept was the proper path to take in categorizing tensile properties, particularly TUS and ELONG.

The general effect of heat treatment for high-strength aluminum alloy castings is an increase in TYS. Particular segments of the heat-treatment process such as quench delay, quench rate, and artificial aging may produce significantly different effects. Prior to a discussion of heat-treatment effects, a few comments are required to establish a graphical format suitable to demonstrate relative influences of heat treatment, dendrite measurement, and soundness on each of the three tensile properties. Without exception, all observed A356 and A357 data (ref. 6, 7, and 8), including all test results from the CAST program, demonstrated a common characteristic. There is no necking of tensile specimens. Total elongation is the same as uniform elongation and is the strain coordinate of TUS. Using TUS and ELONG as terminus coordinates of a stress-strain curve, it was conveniently determined that the plastic portion of the curve could be described analytically by the following power function:

142
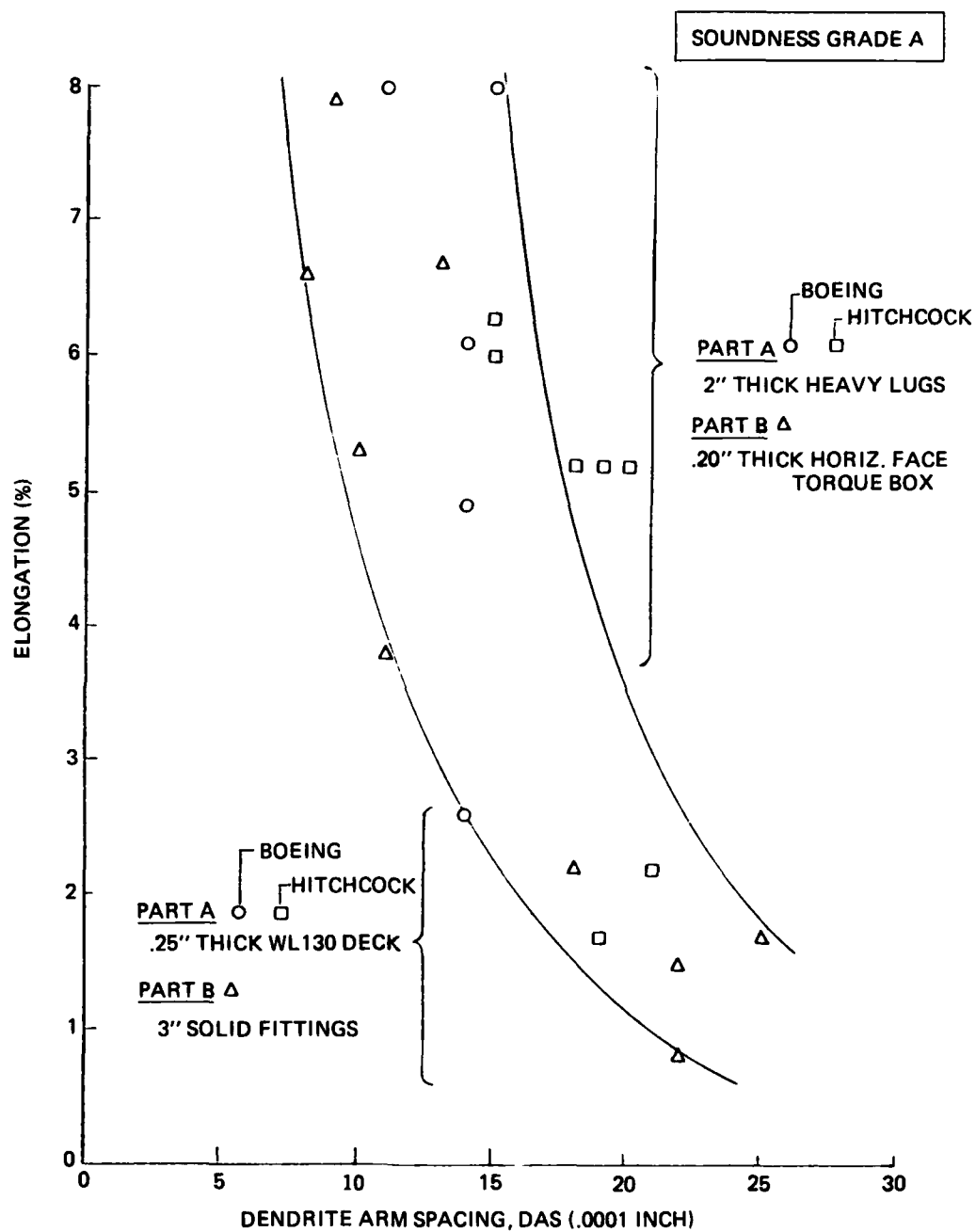
Figure 86. Variations in Elongation with DAS

$$ELONG = 0.2(TUS/TYS)^n$$

The power coefficient n is the shape factor. Values of TUS and corresponding ELONG vary with different DAS levels and soundness grades for the A357-T6 CAST data.

This study resulted in a composite diagram (Fig. 87) of ELONG versus the TUS/TYS ratio for both alloys. As the artificial aging temperature is increased, both TYS and shape factor (n) increase. Boundaries were established by A356 with four intermediate shape factors describing A357 results. Regardless of alloy type, there is a consistency developed. Numbers shown along the trend lines indicate average TUS values. At up to 4 percent ELONG, these TUS values are about the same for the A357 CAST results and the A356 with the 350°F age. The offset between these trends is due to a 2-ksi difference in TYS as an apparent result of the two aging conditions. It also appears that the three groupings of Battelle results may be due to differences in aging conditions. Positions along each shape-factor line identify dendrite size and soundness, whereas lateral position seems to be heat-treatment dependent. With this concept, the differences between CAST and Battelle A357 data must be attributed to dendrite size and/or soundness along the (n = 16) line. All of these data are represented by a single TYS of 40 ksi. The above discussion identifies soundness, dendrite size, and heat treatment as each having specific influences on tensile properties of A356 and A357 alloy castings. Information is not currently available to develop an understanding of how tensile properties might vary with chemistry or impurity levels, but it is obvious that development of reliable properties for these materials requires a much more in-depth knowledge of effects. The assurance that a production casting possesses certain static properties must be assessed from the controls and inspections required by the procurement specification and engineering drawings. With these devices, there is good reason to expect consistency in properties from part to part.
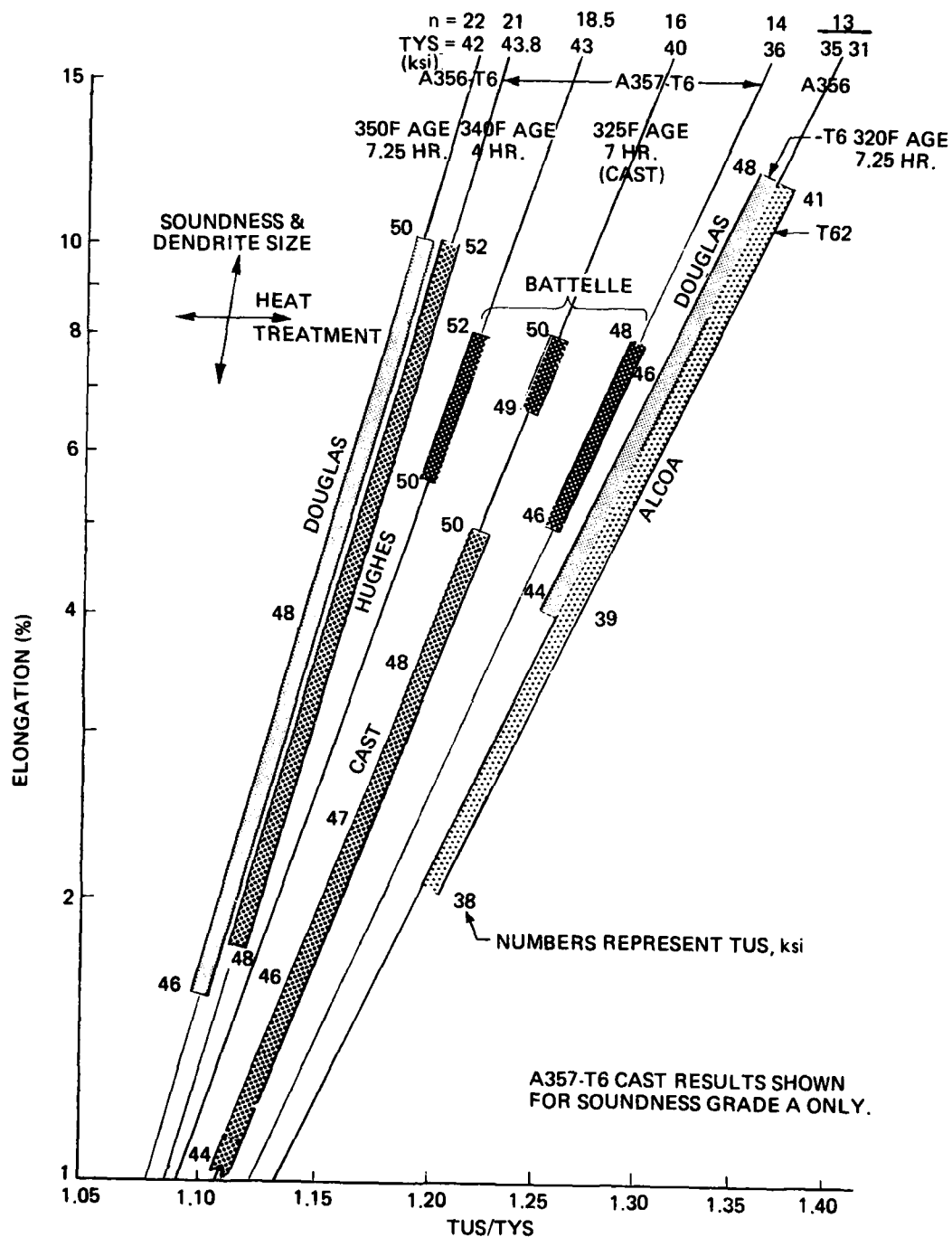
Figure 87.   Tensile Property Trends for Aluminum Alloy Castings

3. Allowables Development

The Phase II data base, supplemented by Battelle-gathered data (ref. 9), was used to establish allowables for the CAST bulkheads and a format for the general category of A357 castings.

Fourteen bulkhead segment castings, consisting of two different portions of the bulkhead (Figs. 88, 89, and 90) were produced in Phase II and cut up for testing and analysis to develop a static design properties data base. Boeing produced four Part A segments and five Part B segments, and Hitchcock Industries produced five Part A segments. The segments were representative of Phase I preliminary design concepts for the full-size bulkhead. Figures 89 and 90 also show static specimen locations. Compression, shear and bearing coupons were located in adjacent casting zones to develop derived properties. Six hundred and four static coupons were machined from castings for allowables development. An additional 65 integral cast-on tension coupons were made to evaluate heat-treatment response.

Trends for TUS and TYS and for ELONG are shown in Figures 91 and 92, respectively. Average values of each property were computed for each soundness grade over four selected DAS ranges. Smaller DAS and better soundness produced higher TUS and ELONG. TYS did not vary significantly with either of these parameters. Standard deviations for strength and elongation of A357-T6 tensile data were $S_f = 1.77$ ksi and $S_e = 0.41$ (or 1.5 percent strain), respectively. No distinction was necessary between the dispersion characteristics of TYS and TUS. Results from analysis of mean values and standard deviations of A357-T6 tensile properties were combined to establish CAST program allowables and a general format for all other A357 produced castings. This format is that proposed by MIL-HDBK-5 for establishing statistical design values based upon normal data distributions. Proposed tension property allowables from Phase II of the CAST program are presented in Table 20. This tension design properties format should be applicable to A357 castings regardless of method of manufacture or heat treatment.

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91"

58"

CORRUGATIONS
.1" TO .2" THICK

LANDING GEAR SUPPORTS
1" TO 2" THICK

WEBS
.1" THICK

BASE FLANGE
.1" TO .5" THICK

GEAR ACTUATOR SUPPORTS
1" TO 3" THICK

TORQUE BOX
.2" to .5" THICK

PART A
TEST SECTION
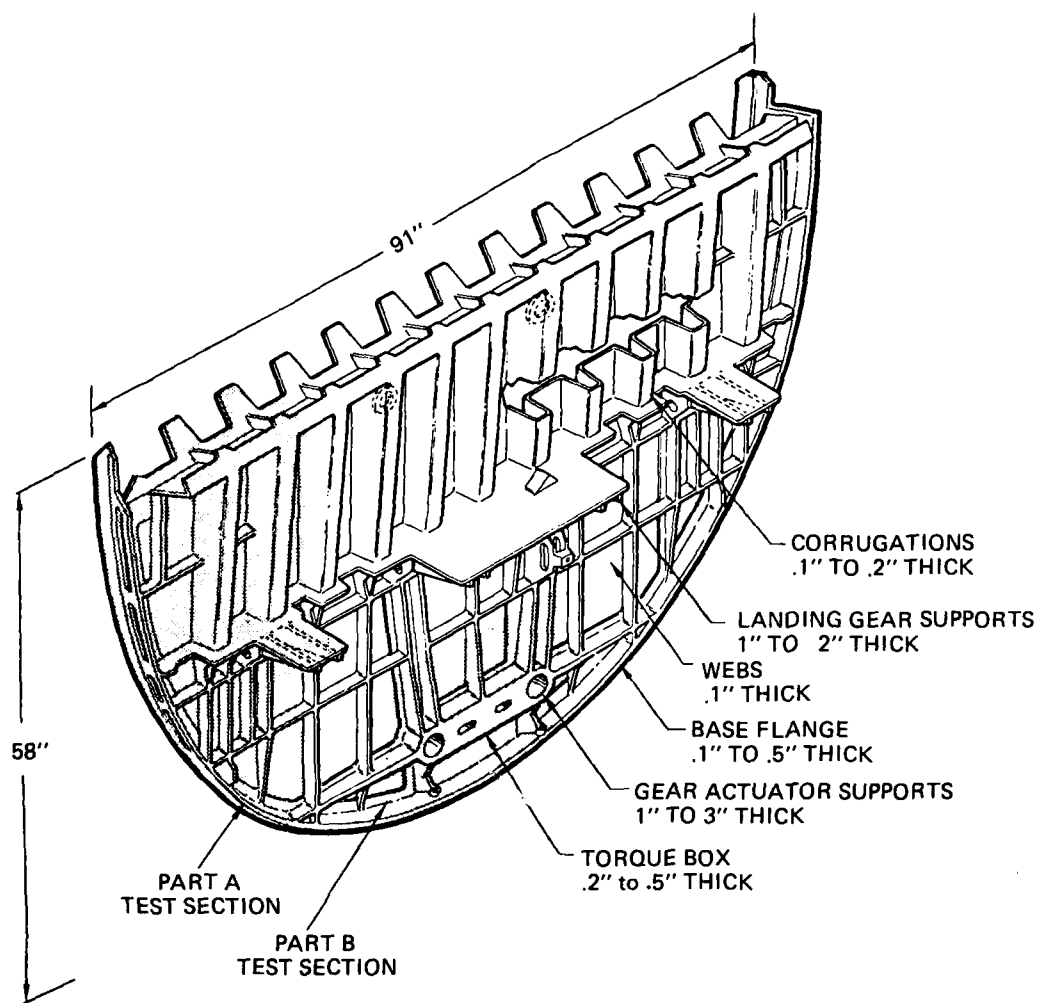
PART B
TEST SECTION

Figure 88.   Station 170 YC-14 Bulkhead, Aft Side, Showing
Allowables Test Sections "A" and "B"

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INTEGRAL TENSION
T10

INTEGRAL LUG (TENSION)

LUG A

INTEGRAL LUG LOCATION

INTEGRAL
TENSION
T8

LUG B

SYMBOL   TEST
   ■   TENSION
          COMPRESSION
   ▨   SHEAR
   ⌐   BEARING

INTEGRAL TENSION
T9
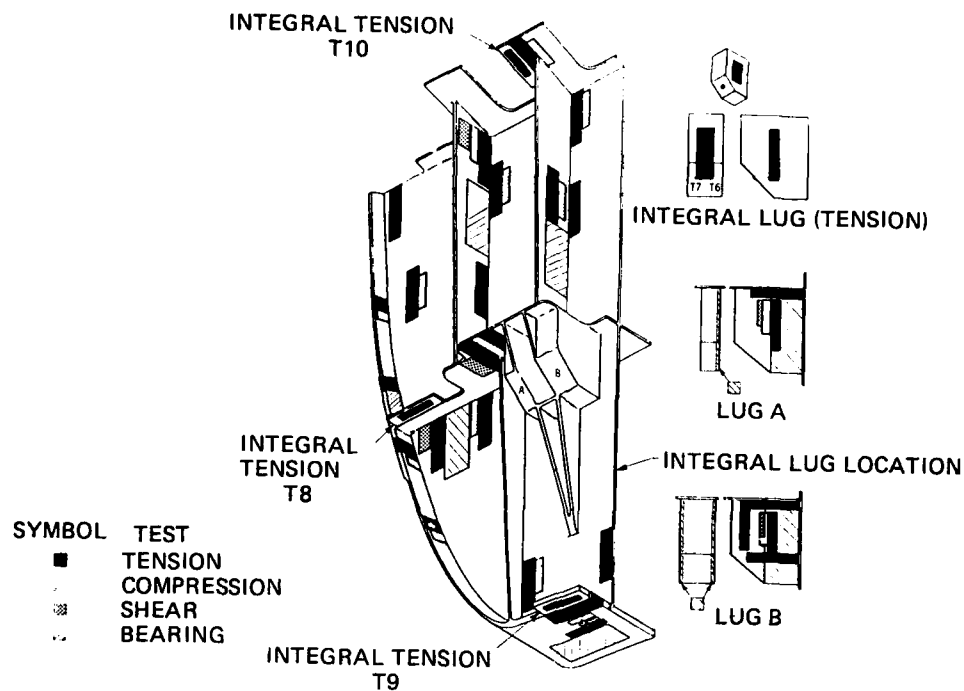
Figure 89.   Part "A" Test Section

INTEGRAL FITTING

CORED FITTING   INTEGRAL   SOLID FITTING
                       TENSION X7
                       INTEGRAL FITTING
                         (TENSION)

CORED FITTING

INTEGRAL TENSION
X5

SYMBOL   TEST
   ■   TENSION
   ⊓   COMPRESSION
   ▨   SHEAR
   ◺   BEARING

SOLID FITTING
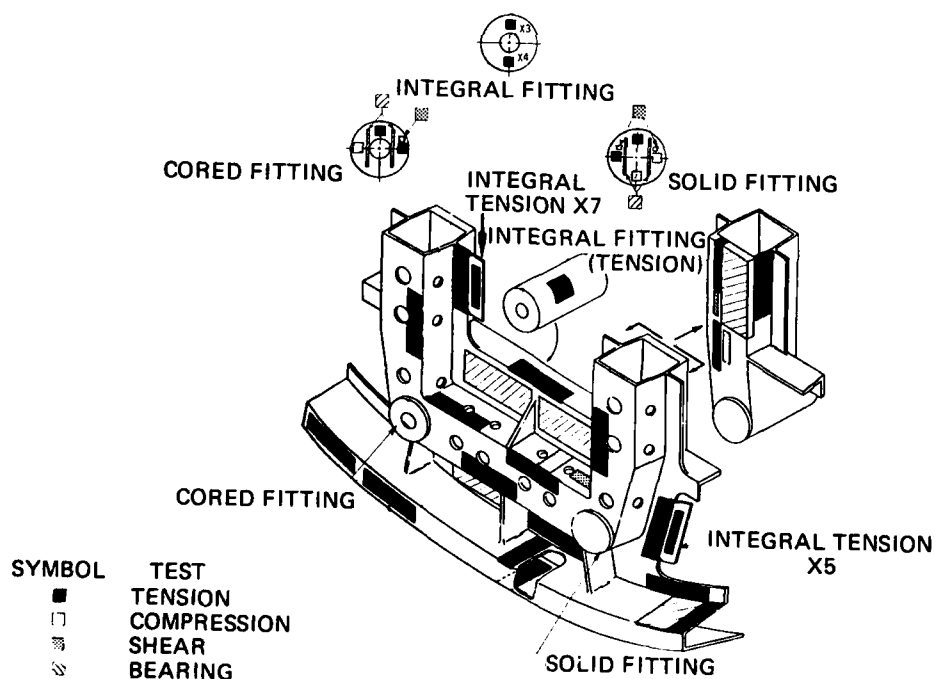
Figure 90.   Part "B" Test Section

148
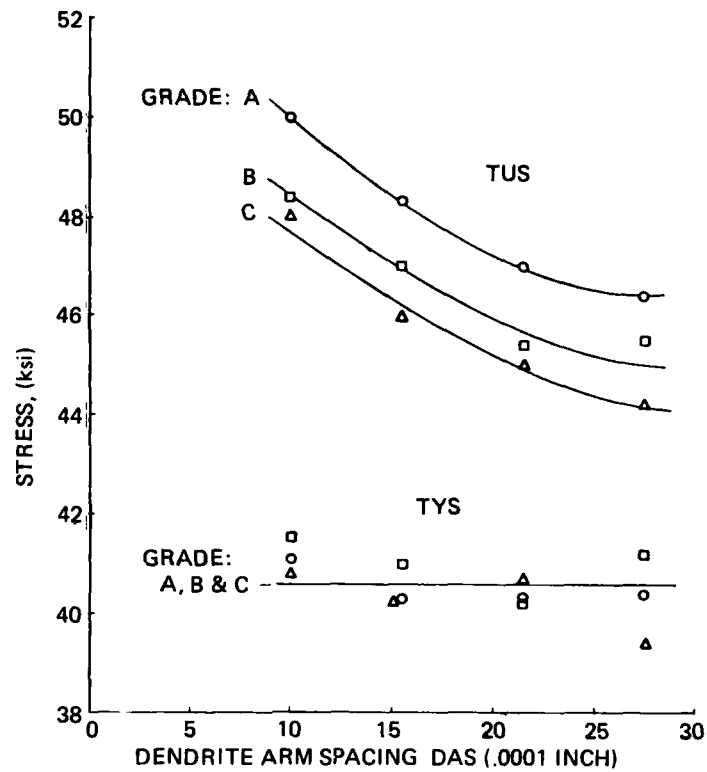
Figure 91.   Average Strength Trends with Dendrite Arm Spacing and Soundness
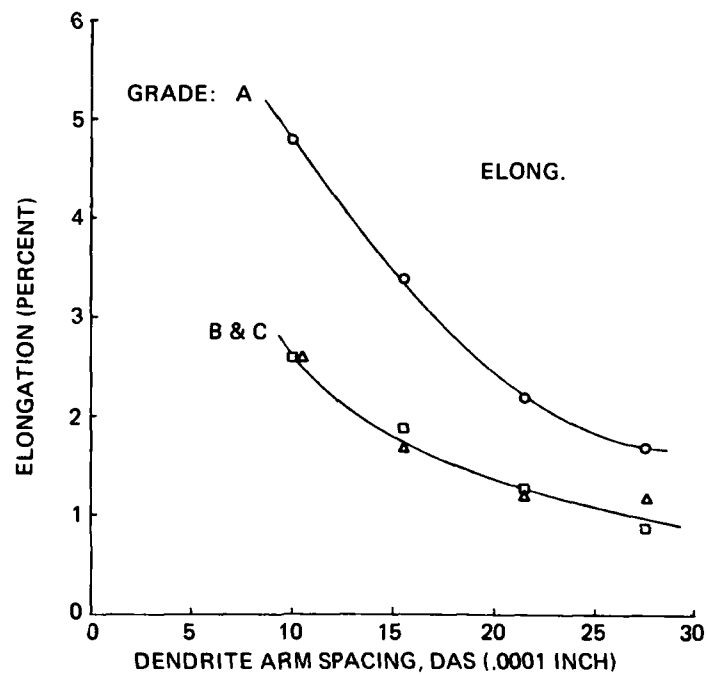
Figure 92.   Average Elongation Trends with Dendrite Arm Spacing and Soundness

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Table 20. CAST Program Tension Allowables

Specimen DAS Range	Property	Specimen Soundness Grade (ASTM E-155)			
		A	B	C	D
Up to .0012 inch	F_{tu}	45.9	44.3	43.6	—
	F_{ty}	36.5	36.5	36.5	—
	e	1.8	1.0	1.0	—
.0013 to .0018 inch	F_{tu}	44.2	42.9	42.1	—
	F_{ty}	36.5	36.5	36.5	—
	e	1.3	0.6	0.6	—
.0019 to .0024 inch	F_{tu}	42.9	41.5	40.8	—
	F_{ty}	36.5	36.5	36.5	—
	e	0.8	0.5	0.5	—
.0025 to .0030 inch	F_{tu}	42.3	40.9	40.1	—
	F_{ty}	36.5	36.5	36.5	—
	e	0.6	0.4	0.4	—
	F_{tu}, ksi F_{ty}, ksi e , percent				

A summary of derived property ratios analyses is presented in Table 21. These ratios were grouped into the tension DAS/ soundness cells previously established and statistics were computed for each cell of ratios including average ratio (r) and standard deviation (s). Neither DAS nor soundness influenced ratio values. The recommended use of derived property ratios for A357-T6 castings is to first obtain the tensile property allowable according to DAS and soundness, then multiply that allowable by the reduced ratios shown below to obtain the compression, shear, or bearing allowables:

o $\quad F_{cy}/F_{ty} \quad = 1.045$

o $\quad F_{su}/F_{tu} \quad = 0.720$

o $\quad F_{bry}/F_{ty} \quad = 1.627 (e/D = 1.5); \ = 1.959 (e/D = 2.0)$

o $\quad F_{bru}/F_{tu} \quad = 1.538 (e/D = 1.5); \ = 2.02 (e/D = 2.0)$

4. Allowables Assessment

Four of the 20 bulkheads produced during Phase IV were used to assess allowables developed in Phase II. Tension coupons were measured after tests for DAS and soundness in zones adjacent to fracture. The four castings included two each produced by the Boeing and Hitchcock foundries. Average properties for each of the six zones of the castings are listed in Table 22. The heavily chilled lug zones exhibited the highest strengths and elongations. The periphery flange exhibited the lowest properties. Specimens from the periphery flange showed the largest DAS and greatest amounts of shrinkage. Observations made from properties listed in Table 22 were as follows:

1. Boeing castings MO8 and MO9 exhibited similar properties.
2. Hitchcock casting H2 exhibited consistently higher TUS and ELONG than casting H9 (the former casting was produced from low-phosphorus ingot).
3. The Boeing castings have higher TUS and TYS but lower ELONG than Hitchcock castings.

The lowest of combined bulkhead average properties form two groups: Critical Area (lugs) 48/38/5 and Other Areas 44/34/2. Ultimate strength design requirements for both Critical (46/40/5) and Other (40/30/3) Areas

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<center>Table 21. Derived Property Ratios Summary</center>

Property Ratio	DAS Level	A			B			C			D		
		N	r̄	s	N	r̄	s	N	r̄	s	N	r̄	s
CYS/TYS	1	7	1.063	.032	2	1.039	.093	1	1.136	-	1	1.106	-
	2	19	1.032	.036	16	1.048	.033	10	1.074	.032	0	-	-
	3	13	1.058	.020	9	1.063	.032	8	1.038	.024	0	-	-
	4	2	1.026	.029	3	1.020	.075	0	-	-	0	-	-
SUS/TUS	1	5	.694	.0085	0	-	-	1	.701	-	0	-	-
	2	17	.713	.033	6	.715	.010	3	.731	.049	0	-	-
	3	13	.740	.021	7	.732	.049	7	.756	.018	0	-	-
	4	2	.737	.023	3	.737	.010	0	-	-	0	-	-
BYS/TYS e/D = 1.5	1	3	1.555	.059	0	-	-	0	-	-	0	-	-
	2	17	1.645	.083	7	1.641	.056	2	1.613	.037	0	-	-
	3	3	1.690	.025	4	1.676	.043	2	1.694	.026	0	-	-
	4	1	1.679	-	0	-	-	0	-	-	0	-	-
BUS/TUS e/D = 1.5	1	3	1.561	.155	0	-	-	0	-	-	0	-	-
	2	17	1.607	.092	7	1.583	.081	2	1.507	.128	0	-	-
	3	4	1.582	.226	6	1.522	.142	3	1.567	.200	0	-	-
	4	2	1.481	.032	1	1.396	-	0	-	-	0	-	-
BYS/TYS e/D = 2.0	1	1	1.929	-	3	2.05	.131	0	-	-	0	-	-
	2	22	1.984	.070	10	1.978	.105	4	1.882	.042	0	-	-
	3	8	1.980	.046	6	1.959	.042	3	1.983	.094	0	-	-
	4	0	-	-	1	2.03	-	0	-	-	0	-	-
BUS/TUS e/D = 2.0	1	1	1.970	-	3	2.00	.083	1	2.07	-	0	-	-
	2	23	2.02	.103	10	2.02	.090	4	1.991	.099	0	-	-
	3	8	2.12	.120	6	2.09	.127	3	2.06	.068	0	-	-
	4	0	-	-	1	2.10	-	0	-	-	0	-	-

Notes: CYS = Compression Yield Strength   N = sample size
        SUS = Shear Ultimate Strength   r̄ = average ratio value
        BYS = Bearing Yield Strength   s = standard deviation value
        BUS = Bearing Ultimate Strength   e/D = edge margin

DAS Levels: 1 = up to .0012 inch; 2 = .0013 to .0018 inch;
            3 = .0019 to .0024 inch; 4 = .0025 to .0030 inch

DAS measurements from specimen fracture zones

Reduced ratios (R) shown in section 3 were computed for
each property using the following expression:

$$R = \bar{r} - t_{.95}\frac{s}{\sqrt{N}}$$

where $t_{.95}$ is the 95% confidence factor for a sample size of N.

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Table 22. Tensile Properties of Station 170 YC-14 Bulkheads

	Boeing Foundry		Hitchcock Foundry	
Casting Location:	M08	M09	H2	H9
Lugs	52.6/42.6/6.1	51.0/41.4/5.4	49.4/38.1/7.7	48.1/38.1/5.1
Upper Flange	48.2/39.5/3.1	46.9/38.5/2.7	45.3/34.5/4.7	44.4/34.9/2.7
Corrugations	49.1/40.6/2.0	47.4/39.8/3.0	47.0/38.6/3.7	45.5/38.5/2.1
Webs & Stiffeners	49.7/42.7/2.1	46.7/40.8/1.7	46.8/39.1/2.8	45.9/39.1/2.3
Fitting	50.3/43.0/2.2	50.5/41.2/4.5	48.4/39.9/3.6	46.4/39.4/2.0
Periphery Flange	45.0/41.9/0.6	44.8/40.9/1.0	44.8/41.8/0.6	42.6/41.2/0.4
Averages	Boeing		Hitchcock	
Lugs	51.8/42.0/5.8		48.8/38.1/6.4	
Other Areas	47.2/40.6/2.0		45.3/38.5/2.4	

Note: Data are averages of TUS (ksi)/TYS (ksi)/Elong. (percent)

are exceeded in both cases. A slight deficiency for TYS in lugs can be eliminated by heat treatment. Elongation properties do not support the Other Areas design requirements, especially in the periphery flange. This is not abnormal for initial production development.

Phase V tensile properties were used to assess allowables established in Phase II. The link between these two groups of information was specimen DAS and soundness measurements. These two parameters dictate the allowables applicable to Phase V bulkhead TUS and ELONG properties. The assessment of allowables for TUS is shown in Figures 93 (grade A) and 94 (grades B and C). In each diagram, individual results are plotted against specimen measured DAS values. In general, Phase V TUS results showed that the Phase II developed allowables were acceptable. TYS data are shown in Figures 95 (grade A) and 96 (grades B and C). Overall, the allowable for TYS was adequate. ELONG assessments are shown in Figures 97 (grade A) and 98 (grades B and C). In general, the allowables established in Phase II for ELONG were adequate without any adjustment.

Supplemental tests were conducted to describe tension properties of two other zones in detail. Tension coupons were excised from all left-hand walls of corrugation stiffeners from castings MO9 and H9. Tension coupons also were excised from one-half of the periphery flange at alternate step gate and chill locations from casting MO9. Results for TUS, TYS, and ELONG supported the allowables.

5. Conclusions and Recommendations

Technology improvements developed during the CAST program pertaining to static properties of high-strength aluminum alloy castings are summarized into the categories of material behavior, design properties, and their general applicability:

With respect to material behavior:
1. Ultimate strength and elongation of A357-T6 castings depend upon dendrite arm spacing and soundness, increasing with smaller dendrite arm spacing and higher soundness.

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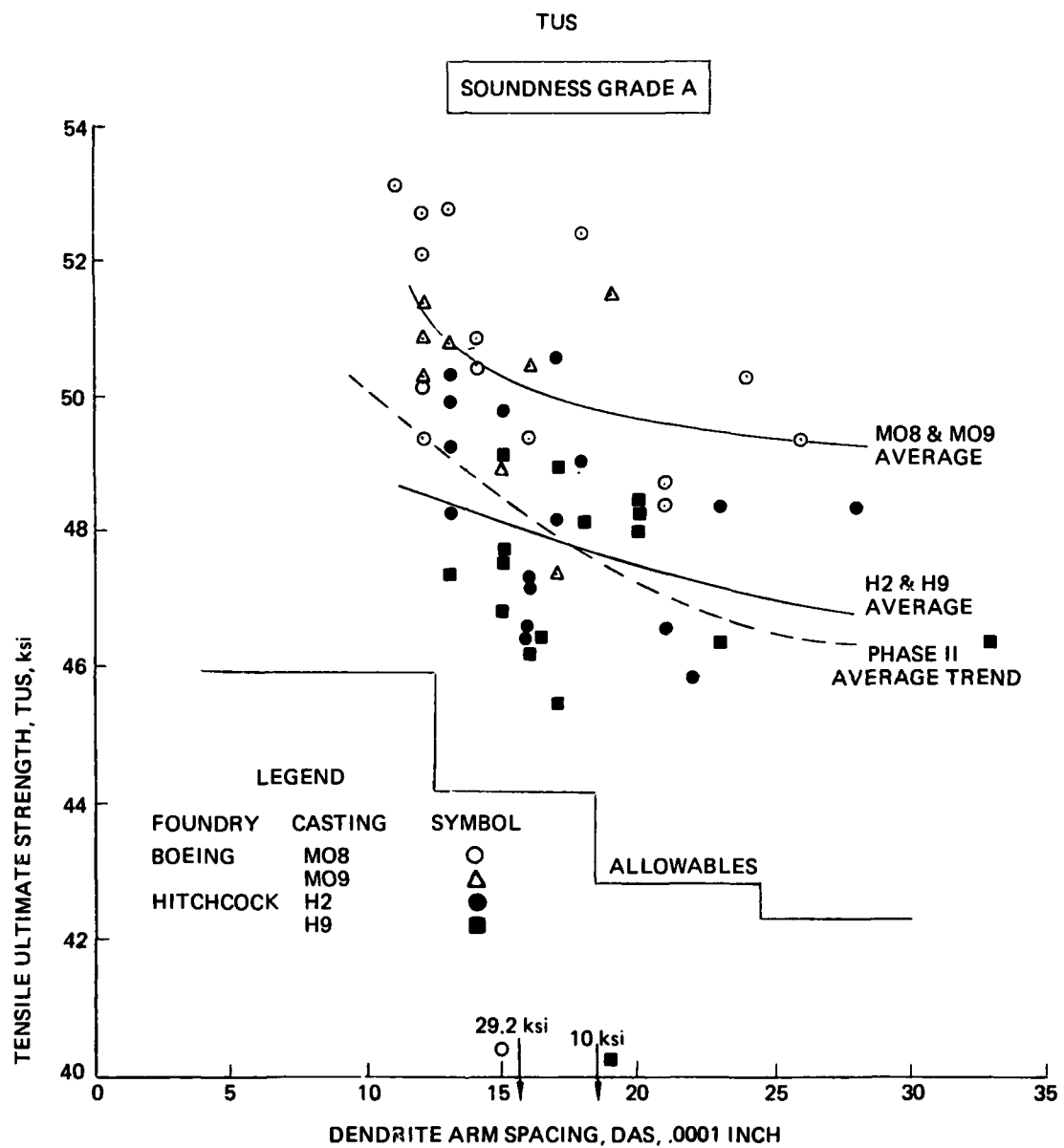
Figure 93.   TUS Data Comparisons, Soundness Grade A
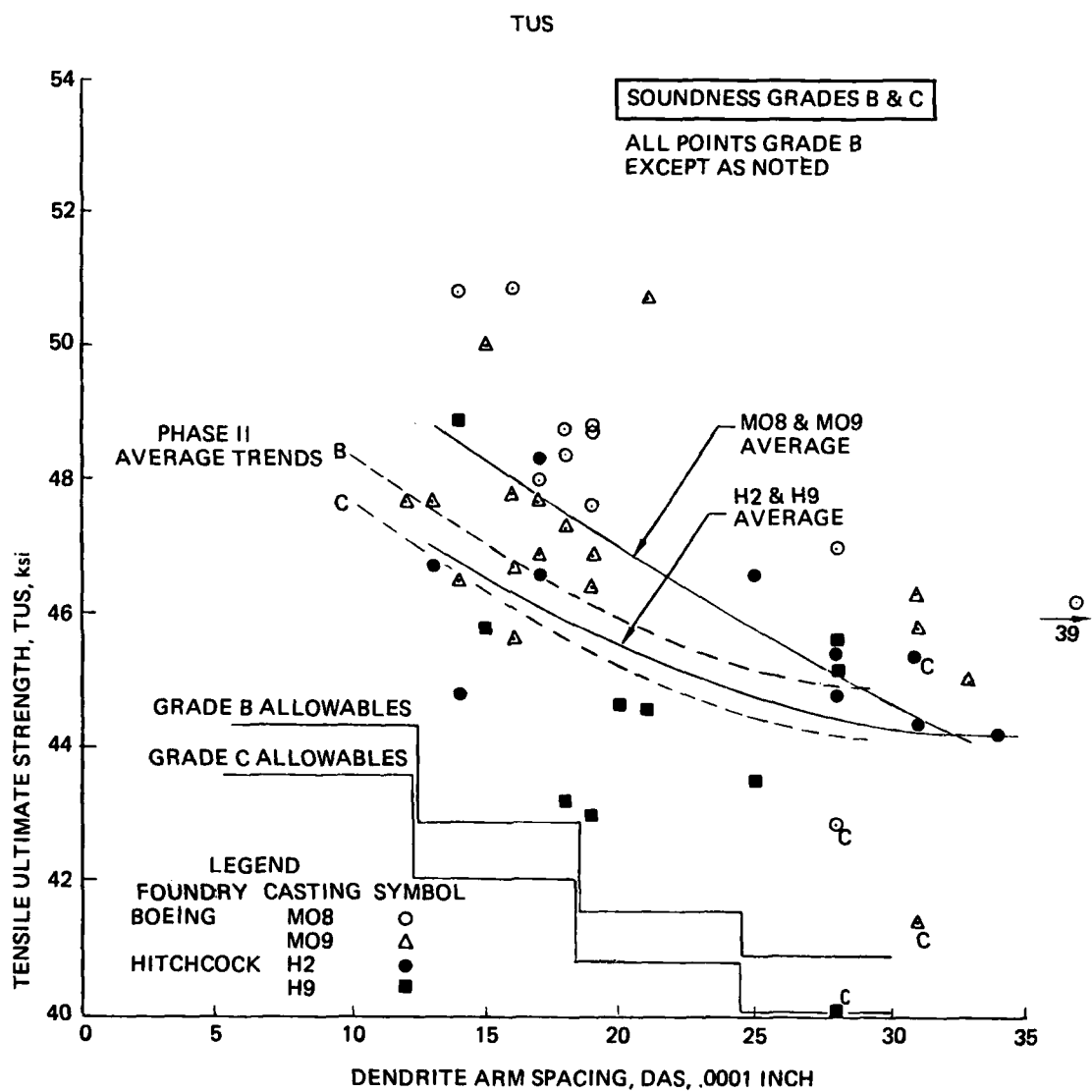
Figure 94.   TUS Data Comparisons, Soundness Grades B and C
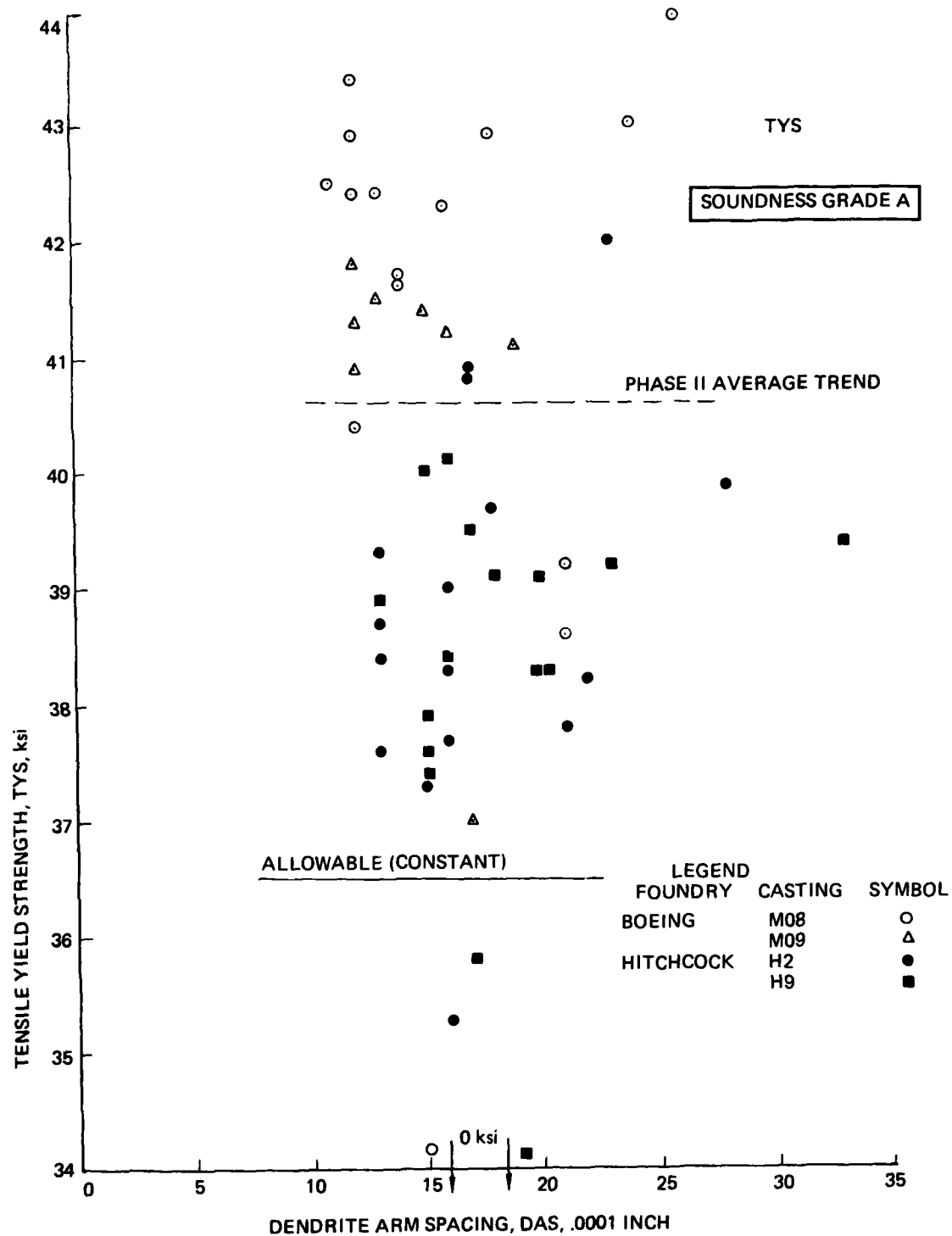
Figure 95.   TYS Data Comparisons, Soundness Grade A

157
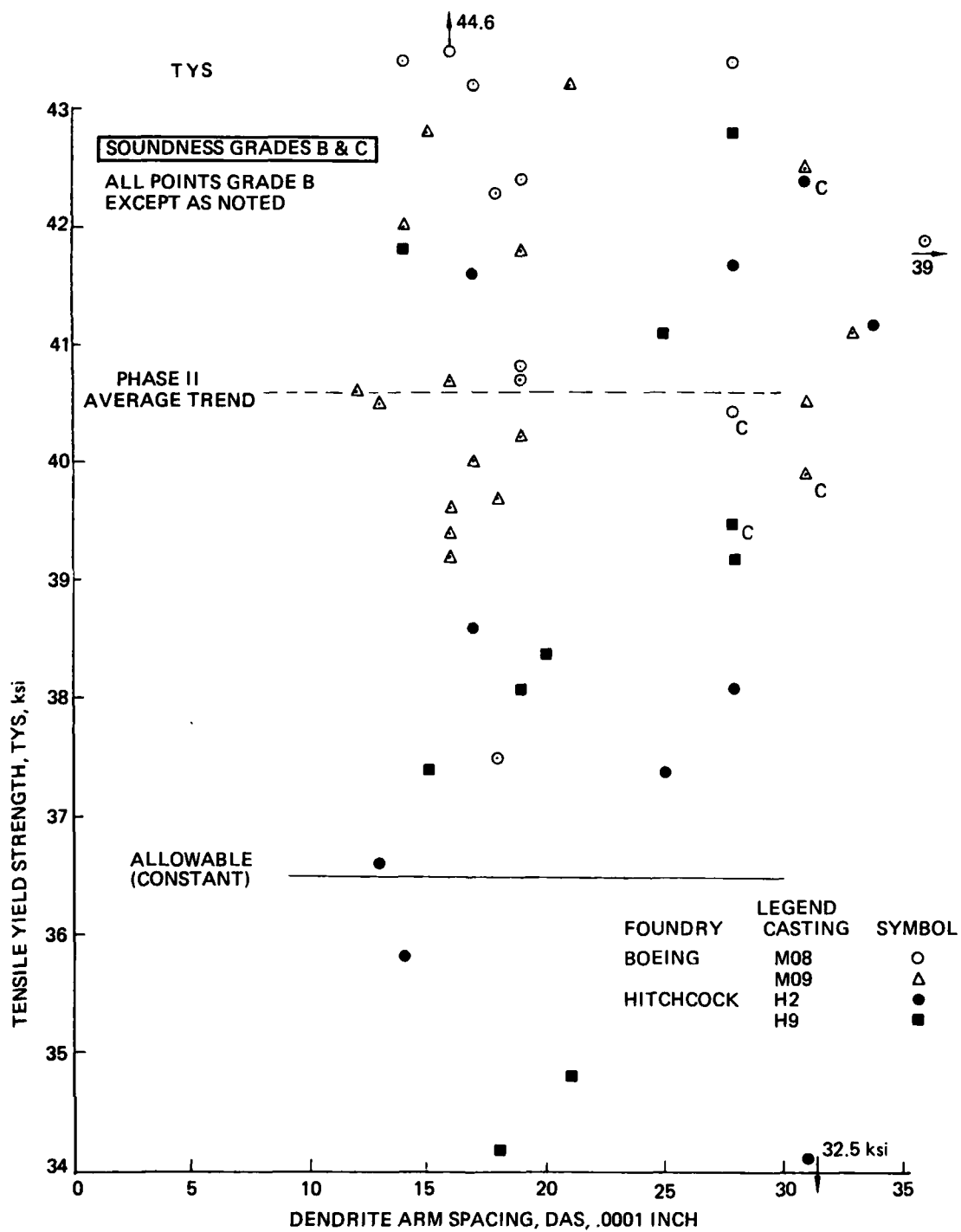
Figure 96.   TYS Data Comparisons, Soundness Grades B and C

158
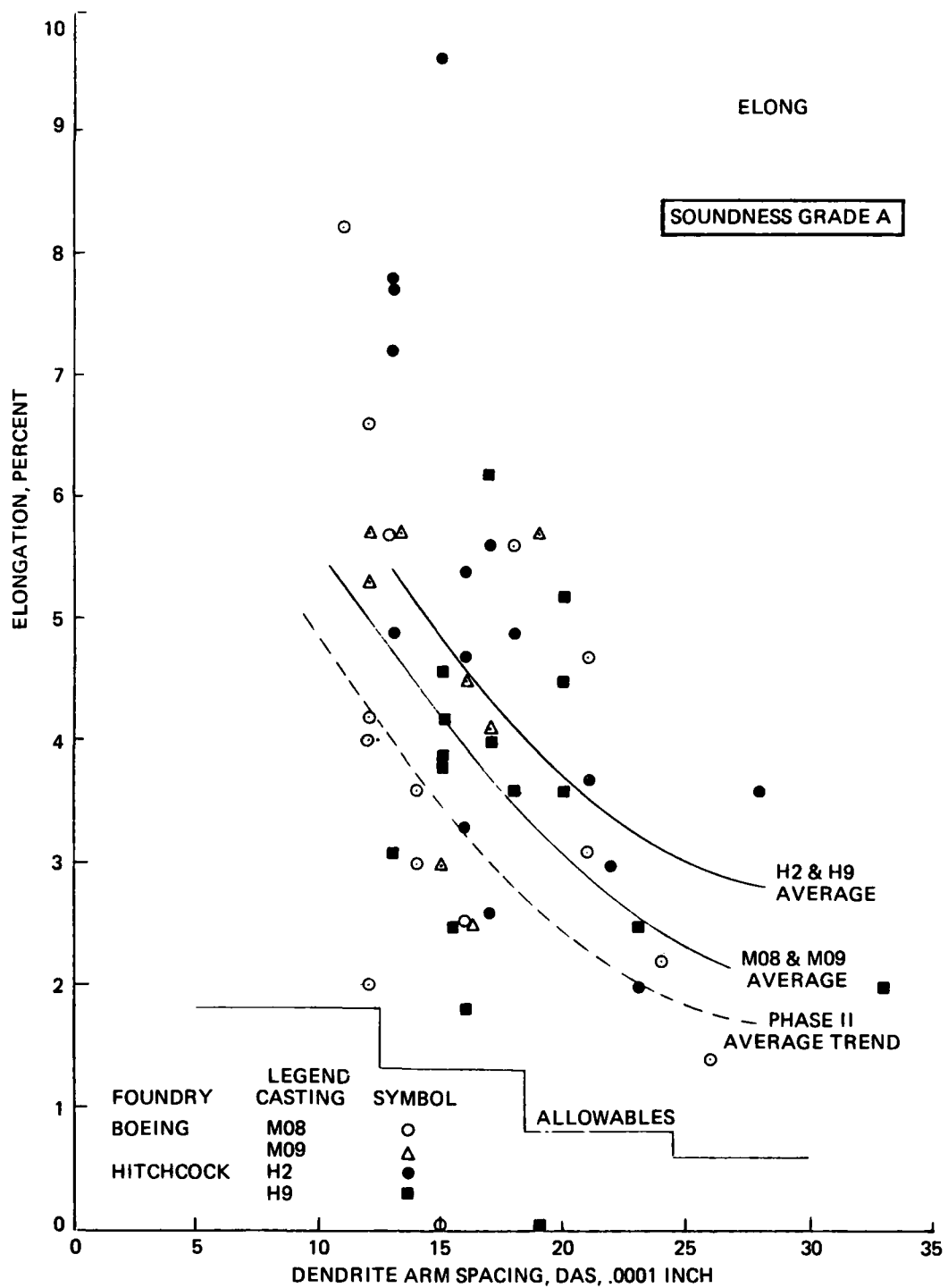
Figure 97. Elongation Data Comparisons, Soundness Grade A

159
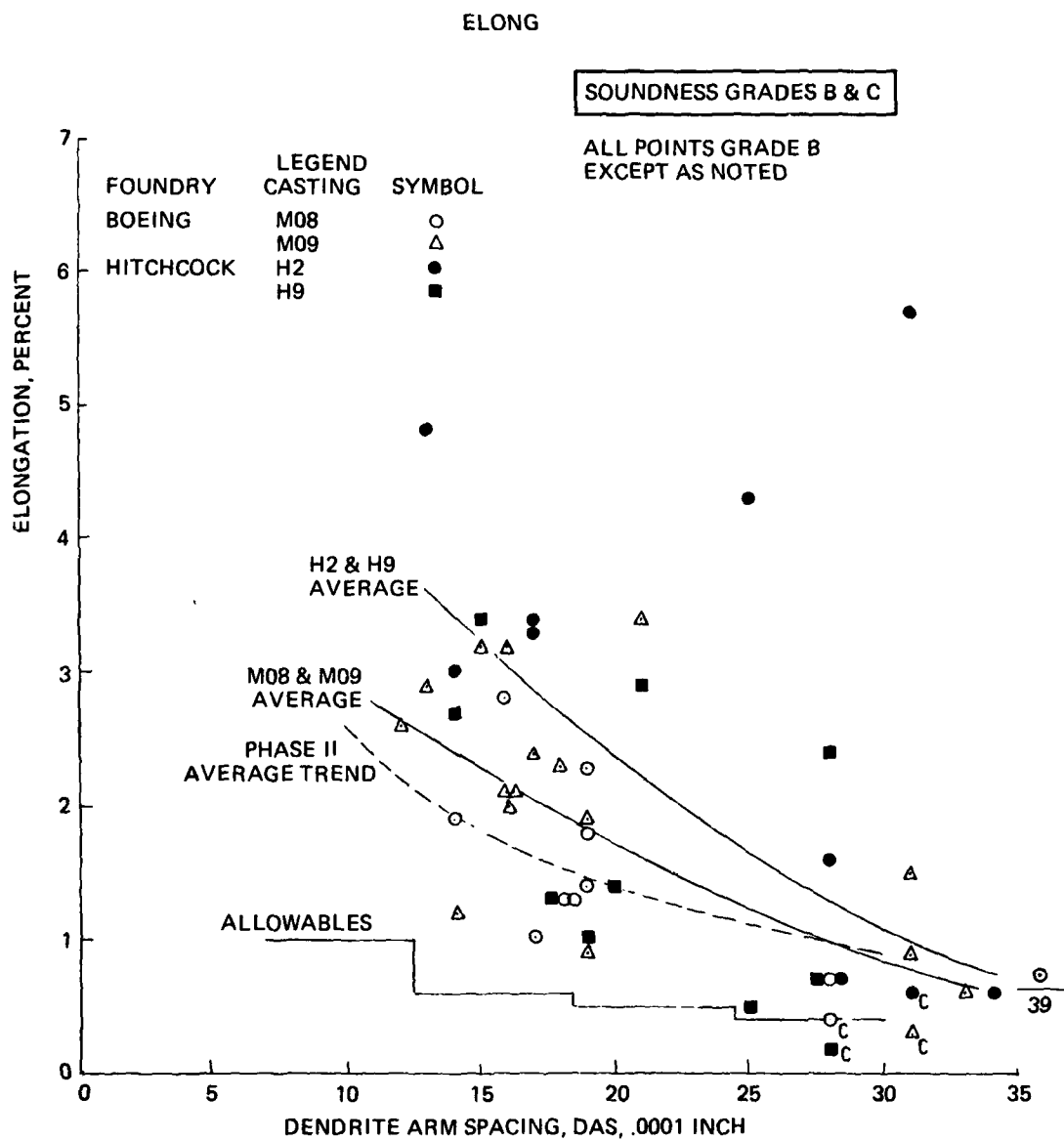
Figure 98.   Elongation Data Comparisons, Soundness Grades B and C

2.	Yield strength is influenced primarily by heat treatment.

3.	Tensile properties are not direct functions of foundry variables or casting geometry, although these variables influence the resulting physical conditions of all casting zones.

4.	A356 casting data demonstrate the same dependencies on dendrite size as determined for A357. Soundness effects on A356 have not been evaluated.

With respect to design properties:

1.	Static allowables were developed from CAST program tensile data. Ultimate strength and elongation values depend upon specific categories of dendrite arm spacing and soundness. Yield strength is a constant.

2.	These allowables were validated with data obtained from full-scale CAST bulkheads.

With respect to applicability:

1.	Static design properties developed in the CAST program must be qualified for applicability to all A357 castings produced by all foundries. The purpose of this qualification is to ensure that ultimate strength and elongation dependencies on dendrite arm spacing and soundness are not altered by differences in either chemistry or heat treatment. Specific applicability of the yield strength allowable depends upon the particular conditions employed in the heat-treatment process.

2.	The general applicability of design properties also depends upon the consistency of casting production. Consistently acceptable products require use of a procurement specification in which controls and inspections are based upon the physical parameters that influence static properties.

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SECTION VII
PHASE VI—TECHNOLOGY TRANSFER

A.   INTRODUCTION

The objective of Phase VI was to carry on an aggressive technology transfer effort throughout the CAST program.

One of the most important facets in accomplishing this objective was the maintenance of an "open door" policy, which ensured in-plant access, both at Boeing and at Hitchcock Industries, Inc., to representatives of the aerospace and foundry industries and government.

The specific means by which the program technology was made available to government and industry were: technical reports, technical bulletins, papers and presentations, oral presentations, visual aids, drawings, engineering specifications, and movies. Each of these categories of technology transfer is discussed below. A datafax transmission system, set up between Boeing and the Air Force, provided direct, rapid transmittal of text and sketches.

This phase of the program was conducted by James W. Faber assisted by all others assigned to the program.

B.   TECHNICAL REPORTS

The following final technical reports, covering the six phases of the program, were issued:
o   Report No. AFFDL-TR-77-36, "Phase I—Preliminary Design," May 1977
o   Report No. AFFDL-TR-78-62, "Phase II—Manufacturing Methods," May 1978
o   Report No. AFFDL-TR-78-7, "Phase III—Detailed Design," January 1978
o   Report No. AFFDL-TR-79-3029, "Phase IV—Fabrication of Demonstration Articles and Production Hardware," March 1979

o   Report No. AFWAL-TR-80-3021, "Phase V—Structural Test and Evalua-
tion," Part I—"Full-Scale Test," Part II—"Fatigue and Fracture Properties
of Cast Aluminum Bulkheads," and Part III—"Static Property Allowables,"
April 1980.

o   Report No. AFWAL-TR-80-3020, "Phase VI—Summary Technical Report,"
April 1980

All of these reports are available from the National Technical Information
Service (NTIS).

C.   TECHNICAL BULLETINS

Technical bulletins were issued periodically throughout the program to provide
to industry and government timely information on technical developments
generated by CAST.   An extensive list of industry and government personnel
received these technical bulletins.   The following 18 technical bulletins were
issued during the course of the program:

o   No. 1, "Introduction to CAST Program," August 1976
o   No. 2, "CAST—A Breakthrough for Primary Structure Cost Reduction,"
November 1976
o   No. 3, "Casting Design for Weight, Cost, and Structural Objectives,"
February 1977
o   No. 4, "Foundry Technology for Advanced Casting Design Concepts," April
1977
o   No. 5, "Foundry Technology for Advanced Casting Design Concepts,"
August 1977
o   No. 6, "Dependable Tools Are Key to Accurate Molds," October 1977
o   No. 7, "Dendrite Arm Spacing (DAS) Technology for Advanced Casting
Design Concepts," June 1978
o   No. 8, "Portable Metallographic Technique for Determination of Dendrite
Arm Spacing (DAS) on Castings," June 1978
o   No. 9, "Tensile Properties of A357-T6 Castings," June 1978
o   No. 10, "Ultrasonic Inspection Techniques for Improved Detection of
Internal Porosity in Aluminum Castings," June 1978
o   No. 11, "Full-Scale Component Fabrication," October 1978
o   No. 12, "CAST Bulkhead Full-Scale Test Program," January 1979

o   No. 13, "Fatigue and Fracture Characterization of A357 Cast Aluminum Alloy," January 1979

o   No. 14, "Effects of Defects in Cast Aluminum Primary Aircraft Structure," May 1979

o   No. 15, "Bulkhead Tensile Properties," November 1979

o   No. 16, "Technology Transfer for CAST Bulkhead Fabrication," August 1979

o   No. 17, "Manufacturing Lessons Learned during CAST Bulkhead Fabrication," January 1980

o   No. 18, "Full-Scale Structural Test of Bulkhead Casting," February 1980

D.   PAPERS AND PRESENTATIONS

The following technical papers and presentations were given by Boeing or Air Force personnel as noted:

o   Presentation by D. D. Goehler, "Cast Aluminum Structures Technology," Near Net Shape Conference, West Palm Beach, Florida, December 3, 1976

o   Presentation and Paper by D. D. Goehler, "Cast Aluminum Structures Technology," AIAA Aircraft Systems and Technology Meeting, Seattle, Washington, August 22-24, 1977

o   Presentation by C. K. Gunther, "Application of Fracture Mechanics Principles to Cast Aluminum Primary Aircraft Structures," Technical Session of Committee E-24 on Fracture Testing of American Society for Testing and Materials, San Diego, California, October 13, 1977

o   Presentation by D. D. Goehler, "Cast Aluminum Structures Technology," 1977 Triple Shows, Chicago, Illinois, October 25-27, 1977

o   Article by D. D. Goehler, "Structural Castings for Aircraft: A Progress Report from Boeing," Metal Progress, March 1978

o   Presentation by D. D. Goehler, "Cast Aluminum Structures Technology," DoD MTAG Casting Workshop, Arlington, Texas, March 28, 1978

o   Presentation by J. R. Williamson, "Cast Aluminum Structures Technology," 82nd AFS Casting Congress and Exposition, Detroit, Michigan, April 28, 1978

o   Presentation by J. W. Faber, "Cast Aluminum Structures Technology," Poster Session at Pacific Northwest Metals and Minerals Conference, Portland, Oregon, May 16, 1978

o   Presentation and Paper by D. D. Goehler, "Cast Aluminum Structures Technology," SAMPE Meeting, Lake Kiamesha, New York, October 17-19, 1978

o   Presentation and Paper by D. D. Goehler and John R. Williamson, "Cast Aluminum Structures Technology (CAST)," Society of Manufacturing Engineers, Daytona Beach, Florida, September 25-27, 1979

o   Presentation and Paper by C. K. Gunther, "Cast Aluminum Primary Aircraft Structure," Symposium on Cast Metals for Structural and Pressure Containment Applications, Winter Annual Meeting of American Society of Mechanical Engineers, New York, New York, December 2-7, 1979

E.   ORAL PRESENTATIONS

Three oral presentations, in the form of program technical reviews for industry and government, were conducted:

o   May 24-25, 1977 at The Boeing Company, Seattle, Washington, at the end of Phase I—Preliminary Design

o   May 2-4, 1978 at The Boeing Company, Seattle, Washington, at the end of Phase II—Manufacturing Methods

o   June 13, 1979 at Wright-Patterson Air Force Base, Dayton, Ohio, after the end of Phase IV—Fabrication of Demonstration Articles and Production Hardware

F.   VISUAL AIDS

Visual aids, such as viewfoils and photographs, were provided to the Air Force throughout the program. Two models, one a quarter-size model of the baseline fabricated sheet-metal bulkhead and the other a full-size model of the CAST bulkhead configuration made of foam-board material, were constructed early in the program.

G.   DRAWINGS

Two production drawings were prepared:

o   Boeing Drawing No. 162-00017, Bulkhead Casting, Station 170

o   Boeing Drawing No. 162-00018, Bulkhead Assembly, Station 170

These drawings are presented in Appendix A.

H. ENGINEERING SPECIFICATIONS

Four engineering specifications were prepared: (1) a material and process specification, (2) a casting vendor qualification specification, (3) a weld-correction process specification, and (4) a process specification for determination of dendrite arm spacing. The specifications are as follows:

o   M-XXXX, Castings, Aluminum Alloy A357, Primary Aircraft Structure

o   Q-XXXX, Selection and Qualification of Foundry Contractors (Suppliers) for Primary Aircraft Structural Castings, A357 Aluminum Alloy

o   W-XXXX, Welding, Fusion, Correction of Primary Structural A357 Aluminum Alloy Castings, Process for

o   D-XXXX, Aluminum Alloy A357 Castings, Dendrite Arm Spacing, Process for Determination of

These specifications are presented in Appendixes B, C, D, and E, respectively.

I. MOVIE

A 16-mm sound, color motion picture highlighting the program work was prepared. This 16-minute film is entitled "Cast Aluminum Structures Technology (CAST)," and is available from the Air Force.

SECTION VIII
CONCLUSIONS AND RECOMMENDATIONS

1.   The CAST program demonstrated that the use of premium-quality aluminum castings in airframe construction could be extended to large primary structural components like the YC-14 body/nose landing gear support bulkhead.

2.   The program goal of demonstrating a minimum of 30% acquisition cost savings over a built-up sheet-metal structure with no weight penalty and no increase in maintenance cost was met and exceeded. A 35% cost savings was demonstrated.

3.   The overall reproducibility of the bulkhead casting process from one foundry to another was well demonstrated, as revealed by a comparison of castings from the two foundries involved in the program. The technology transfer achieved from process development through actual fabrication of castings in a second production foundry was excellent.

4.   The casting specifications and fabrication processes developed for manufacture of the program bulkheads met the program goals and objectives. Casting properties and quality met Engineering requirements.

   A follow-on to the CAST program is planned to identify the physical and process variables that influence elongation, with the objective of improving minimum elongation of aluminum castings.

5.   It is recommended that the integrity of a large primary structure aluminum casting be demonstrated in actual service.

6.   It is recommended that, simultaneous with the service demonstration, additional development work be done relative to determination of effects of defects, fatigue and fracture properties, and improvement of nondestructive evaluation procedures for large primary structure aluminum castings.

APPENDIX A

PRODUCTION DRAWINGS

162-00017—BULKHEAD CASTING, STATION 170

162-00018—BULKHEAD ASSEMBLY, STATION 170
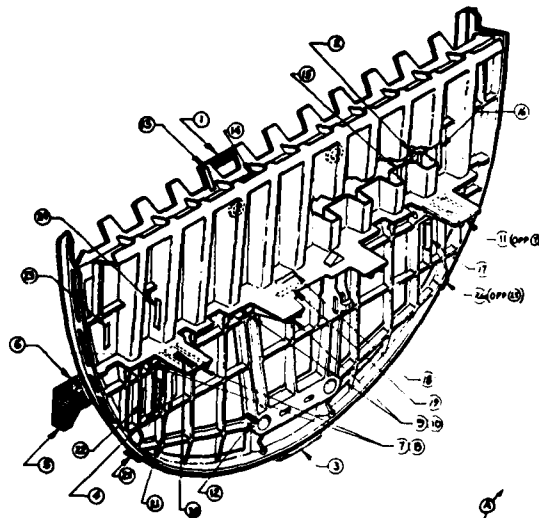
TABLE 1

SPECIMEN	DAS (MAX) (.001 in)	ASTM-E8 COUPON CONFIG	X-RAY GRADE
1	17	FLAT	B
2	17	FLAT	B
3	17	ROUND	B
4	17	FLAT	B
5	17	ROUND	A
6	17	FLAT	B
7	17	ROUND	A
8	17		A
9	17		A
10	17		A
11	17		A
12	13	ROUND	A
13	17	FLAT	B
14	17		B
15	17		B
16	17		B
17	17		B
18	17		B
19	17		B
20	17		B
21	17		B
22	17		B
23	17	FLAT	B
24	17	ROUND	B
25	17	ROUND	B

MECHANICAL PROPERTY TEST COUPON INFORMATION

1 THRU 6 - INTEGRAL CAST-ON COUPONS
7 THRU 11 & 11 (OPP 11) LUG SPECIMENS; 12 FTG SPECIMEN PREPRODUCTION TEST
13 & 14 SLANTED BEAM SPECIMENS EXCISED COUPONS
15 THRU 19 & 11 (OPP 11) WEB, FLANGE OR CHORD SPECIMENS

MEASURE DENDRITE ARM SPACING (DAS) ON CASTING SURFACE PER D-XXXX (CAST).
ACCEPTABLE D.A.S. VALUES & X-RAY GRADES ARE LISTED IN TABLE 1.
TEST ALL TENSILE SPECIMENS PER M-XXXX (CAST)
ALL TENSILE COUPONS SHALL BE PERMANENTLY IDENTIFIED BY CASTING
 & LOCATION.
ALL EXCESS PORTIONS OF A CASTING WHICH ARE REMOVED DURING THE EXCISION
OF TENSILE COUPONS MUST BE PERMANENTLY MARKED FOR IDENTIFICATION.
SEE DRAWING (SHT 2,3 & 4) FOR DETAILED LOCATION OF SPECIMENS

| -1 | 162-0001B | CAST PROGRAM | TEST ONLY | 1234 |

NOTES

REV STATUS	
SH	LTR
2	A
3	A
4	A

1. SPECIFICATIONS AND STANDARDS FOR THE CONTROL OF MANUFACTURING OPERATIONS (AS APPLICABLE)

FUEL, SEALANTS & WET METAL PARTS FOR DAC USED　　　BOLT & NUT INSTALLATION PER DAC USED

RIVET INSTALLATION & SYMBOLS FOR DAC USED　　　PART MARKING PER DAC USED

FINISH CODES FOR DELIVERY AS USED

[2] DATUM TARGET POINT DIMENSION. GEN'L DWG. TOL. DOES NOT APPLY

[3] HORIZONTAL DIMENSION TO DATUM PLANE C (R BL .291 REF)

[4] STEP RESULTING FROM CASTING DRAFT

[5] LEVEL 3, GRADE 'A' IN CRITICALLY STRESSED AREAS, LEVEL 3 GRADE 'B' ELSEWHERE
PER M-XXXX. INSPECT PER M-XXXX. CRITICALLY
STRESSED AREAS DEFINED ON DRAWING AS SHOWN: [----].

[6] RAISED .25 LETTERS & NUMBERS (RUBBER STAMP OPTIONAL)

7 DIMENSIONS & TOLERANCES
EDGE RADII　　.03 ±.03
FILLET RADII　.25 ±.06　EXCEPT AS NOTED
CORNER RADII　.06 ±.06
DRAFT ANGLE　1/2° MAX
SEE DIM. & TOL BLOCK, ZN A-2
BREAK ALL SHARP EDGES .02 MIN

[8] HEAT TREAT TG PER M-XXXX.

[9] WELD CORRECTION OF DEFECTS DETECTED PRIOR TO MACHINING IS ALLOWED
PER　　W-XXXX (CAST)
HEAT TREAT CORRECTED CASTING PER [8]
INSPECT CORRECTED CASTING PER [5]

REVISIONS

ZONE	LTR	DESCRIPTION	DATE	APPROVED
C & A	A	REVISE SHELF, WL 130 BETWEEN LBL 70 & RBL 70 TO MATCH DWG ON SHTS 2, 3 & 4.	3-19-79	
D4		COMPLETED TABLE I MECH PROP TEST COUPON INFO.	7/24/77	
A1 C2 D2 CG		REVISED SPECIFICATION NO'S TO MATCH RELEASED SPECS.		

PARTS LIST

					PART OR IDENTIFYING NUMBER	NOMENCLATURE OR DESCRIPTION	ZONE	MATERIAL AND SPECIFICATION	CODE IDENT NO			REV LTR
					W-XXXX (CAST)	PROCESS SPEC					A	
					D-XXXX (CAST)	PROCESS SPEC					A	
					-1	BULKHEAD CASTING	A4-2	A357 ALUMINUM PER M-XXXX (CAST)	[8]	F210	[5]	1/4

REVISED APPROVAL	CONTRACT NUMBER F33615-76-C-3111	THE **BOEING** COMPANY	
DWG QUAL	DR P.C. JONES	CORPORATE OFFICES　SEATTLE WASHINGTON USA	
STRESS	CHK	BULKHEAD CASTING	
MARK & PROCESS	APPD	STATION 170	
	DES	CAST	Figure 1
	PROJECT APPROVAL	J 81205 162-00017	

CONTRACTOR NUMBER

DIMENSIONING & TOLERANCING PER ANSI 14.5
CALLED DIMENSIONS SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCES ANGLES ± 1/2°
DECIMALS .XX± .03
DECIMALS .XXX± .010

162-00017　REV A1

169

B.S 170
SEE ZN A8-A9

WL 124.60

2.25   .100

C9 c5-3

108 B5-3   200

.140

45° (TYP)

45° (TYP)

1.0R (TYP) .30

.150 (TRUE) (TYP)

1.5 (TRUE) (TYP)

1.00

.024 (REF) WL 150

12 R

45°

5.100

.120

1.10

22½°

.120   1.00   .120
WL 115.5

1.00
.56

CASTING DATUM PLANE A

24.987 TO CASTING DATUM PLANE B

3.09
.30

1.00
.60

WL 107.00

2C7

B STA 166 (REF)

B STA 170 (REF)

4.00

CASTING DATUM PLANE A

CONSTANT

1.0 DIA
1.54

.30

2.70
2.00

WL 105.02 WL 135 (REF)

2.00
.13R
2.70

CASTING DATUM PLANE A

TP 3/A @ L.E. .500

2°
.5R

.100

.100

25.51 RH
23.99 LH TO
CASTING DATUM
PLANE C

A12

30° (TYP)

(INBD OF BL 13.5) 2.0
(OUTBD OF BL 13.5) .15

5.51 (TYP)

1.50 (TYP)

.5R (TYP)

.20 (REF)

(INBD OF BL 13.5) .40
(OUTBD OF BL 13.5) .35

2.0 R (REF)

OPT

BODY STA 166.00

BODY 1 M.L. PER
M.D.D. 10B (YC-14)
AT B.L.O

.115 (TYP)

.200 INBD OF BL 13.5
.15 OUTBD OF BL 13.5

.10 MIN

.12R (TYP)

2.75 (TYP)

BODY STA 170.00

1A4

1.50 (REF)

.10 MIN (TYP EXC AS SHOWN)

.130

.28 (REF)

.50-LBL 50 TO R.BL 50
FOR TEST COUPON

CASTING DATUM PLANE B
(WL 130.007 REF)

.12R
.50

.120 (TYP)

.200 (TYP)

4.007 2

.75 2

TP 6/C

WL 126.00 (REF)

24 (REF)

3.00 (TYP)

3.00 (TYP)

.81 R (TYP)

1.35 (TYP)

C5

.310

SEE ZN D10

WL 124.60

.310

2.60

This is an engineering drawing showing various casting details and cross-sections.

$1C8_{B5-3}$

.200

$2C8_{C2-3}$

3.100

.120   1.0

12 R   31 R

22½°

WL 150

19.993
TO CASTING DATUM
PLANE B

3.50

.200

CASTING DATUM
PLANE A

9.94

.140
(REF)

WL 140

WL 139   T.P.
A
(2A-OPP)

8.993
TO CASTING
DATUM PLANE B

.120

1.25

1C7

B.S.
170

B.S.
170

$3C7_{A12}$ $2C7_{B11}$ $1C7_{B7}$

H_{2N-B1}

G_{2N-B1}

WL 135.00

LBL 37.00
(2A-OPP)

T.P.
A

LBL 28.00

T.P.
A
(WL 130.007)
(3B-OPP)

$B7_{A5-3}$

B.L. 44.50

F_{2N-B1}

INTEGRALLY CAST
TEST SPECIMENS

$B5_{B12-3}$

2.25   1.35

WL 115.5

CASTING DATUM
PLANE A

30°

B.S. 166

B.S. 170

YC-14 BODY I.M.L.

3A6

$6A6_{A9-3}$

$2A6_{B13}$

$1A6_{B12}$

$3A6_{A7}$

$5A6_{C12-3}$

INTERSECTION BODY
STA 170 & BODY I.M.L.
PER MDD 108 (YC-14)

$4A6_{A3}$ $4A5_{A10}$

.24 (REF)

3.00
(TYP)   3.00 (TYP)

.81 R (TYP)

1.35 (TYP)

C5

WL 124.60

.310

2.60

LBL
150.00

LBL
28.00

LBL
21.00

LBL
44.00

BC5-3

162-0

3

STA 170 BULKHEAD CASTING   ½ SIZE   REAR VIEW

PART NO. 162-00017-1
CLASS I
GRADE 3
SEE SHEET I FOR NOTES

PREMIUM QUALITY CASTING

162-00017   A

CASTING DATUM PLANE C

.241 (REF)
.160 (TYP)
2.25 (REF)

BL 0
BL 0

.100 (REF)
.135

CASTING DATUM PLANE A

140 (REF)
300 (REF)
.22

3.09 (REF)

INSEC BL 70 ¢
WL 105.02 (REF)

B4

CASTING DATUM PLANE A
t_2
.10 MIN
YC-14 BODY IML PER M.D.D. 10B
h
t_1
BS 170
.10 MIN

CHORD DIMENSIONS
STRAIGHT TAPER BETWEEN REF PLANES

REF PLANE (¢ TO CONTOUR)	REF PLANE COORDS AT INSEC BS 170 ¢ BODY IML	DIMENSION t_1	t_2	h
D	B.L 0 W.L 97.12	.28	.250	1.50
E	B.L 13.50 W.L 99.34	.28 / .23	.250 / .200	1.50
F	B.L 41.61 W.L 130.0	.23	.200	1.00
G	B.L 43.54 W.L 140.06	.23	.200	1.00
H	B.L 44.65 W.L 146.35	.23	.200	1.00
SEE DETAIL ZN C7	ABOVE WL 146.35	.23	.200	SEE ZN C7

* STEP AT VERTICAL BEAM, B.L 13.5 (REF)

2.25
1.35

CASTING DATUM PLANE A
1.00
.50
WL 105.02

30°
WL 105.02

BS 166
YC-14 BODY IML
BS 170

1A5

BULKHEAD CASTING
STATION 170
CAST

Figure 2

CONTRACT F33615-76-C-3111
R.C. JONES
THE BOEING COMPANY

J 81205 162-00017

162-00017 A2

PCM

This is an engineering/casting blueprint drawing. The following text labels are visible:

185-00017

C

B

A

5A6-2

YC-14 BODY IML

B.L 20.50

CASTING DATUM PLANE A

B.L 13.90

B.L 7.00

BS 170

WL 124.60

1.35

3.09 (REF)

.50 R (REF)

1.88 (REF)

CASTING DATUM PLANE B

CASTING DATUM PLANE A

.143

.135

.158

2.25

.100

.140

C11

B.L (REF)

.120 (TYP)

STRAIGHT TAPER SEE C11 C10

LBL 7.00

.250

.10

.135

.120

.120

1.00

B5-2

FWD FLANGE
(OUTBD OF B L 13.5) .160
(B.L 7.0 TO 13.5) .250
(BL 7.0 TO R BL 7.0) .310
EXCEPT AS NOTED

22
19.12 R

AFT FLANGE
(OUTBD OF B L 13.5) .120
(B.L 7.0 TO 13.5) .250
(LBL 7.0 TO R BL 7.0) .310
EXC. AS NOTED

.120 (TYP-AFT FLANGES EXCEPT AS NOTED)

.160 (TYP-FWD VERTICAL FLANGES-EXCEPT AS NOTED (SEE C13-2 B12.2)

INTERSECTION VERTICAL/HORIZONTAL BEAM WITH YC14 BODY I.M.L. (REF)

CASTING DATUM PLANE A

BS 170

(BL 345 LH ONLY) OPP

1.20
1.00

TYP FLANGE INBD TO PROVIDE OPEN ANGLE - ALL LH BEAMS
B.L .55 ALL R H BEAMS - OPP AS SHOWN

BS 166

4A5-2
BL 13.90 VERTICAL BEAM AS SHOWN
TYP. FOR VERTICAL BEAMS AT BL's (33R) (70L&R)
(205L&R),(270L&R) (345L&R)
TYP FOR HORIZONTAL BEAMS AT WL 124.6 & WL 130
PLUS SEE 2C7-2 B11-2

CASTING DATUM PLANE A

CASTING DATUM PLANE B

5.4

BS 170

.140

1.6

4.2

3.25

OPTIONAL CORNERS

A8

WL 130.007

TO CASTING DATUM PLANE B
23.01

WL 107.00

.250

.350

WL 105.02

2.80

1.40

3.00

.250

A11

.100

.160

100

2.80

.50

3.25

3.09

A11 A12

2A5-2

This is an engineering drawing containing multiple cross-sectional views and detail callouts.

DIM'S THIS AREA - SAME AS 6AG-2/A9-3
EXCEPT AS NOTED.

INTEGRALLY CAST
TEST SPECIMEN
(R H ONLY)

CASTING DATUM
PLANE A
(B S 170 REF)

CASTING DATUM
PLANE B
(WL 130.007 REF)

$C11_{C10}$

$C11$

TRIM LINE
(REF)

2A10

1A10

$2A10_{B10}$

CASTING DATUM
PLANE A

TO CASTING
DATUM PLANE B
24.99

50R

2A5-2

3A5-2

6A6-2

L H ONLY
INTEGRALLY CAST
TEST SPECIMEN

TRIM LINE

TO CASTING
DATUM PLANE B

$A9_{A9}$

A9

$A8_{A12}$

CLEVIS

SEE $C13-2_{B12-2}$

$1A10_{A10}$

162-00017   A 3

LBL 35.00
35.24 LH
34.76 R.H.
1.00

LBL 28.00
28.24 LH
27.76 R.H.
.80

LBL 21.00
21.24 LH
20.76 R.H.
.95

LBL
.95

44.57 LH
44.09 R.H.
3.49
2.73
.25R (TYP)
BL 44.35
41.04 LH
40.56 R.H.
BL 40.80
.12R
2.13
.20

INSEC WL 150 & B.S 170
WITH YC-14 BODY IML

C9-2

.50
1.00 (TYP)
.60 (TYP)
.25R (TYP)
.50
.50

€ TAB (TYP)

1C8-2
SLANTED BEAM TAB

B.S.166

YC-14 BODY IML

35R

45.04 2.10 TO
CASTING DATUM PLANE C
BL 44.80
.140
.170

INTEGRALLY CAST TEST
SPECIMEN LH ONLY
.06R (OPT)
1.00

3.00 (TYP)
1.40 (TYP)
.70
(TYP)
.25R (TYP)
.140
34.74 LH
34.26 RH
BL 34.50
€ CORRUGATION

(TYP) 5°
.50
.120
BL 32.08
.70
.140
38R
.300
90
1.80
.74 (2 PLACES)
€ CORR WL 130
BL 28.22

29.28 LH
28.80 RH
1.64
BL 29.04
LBL 28.00
(SB-OPP)
.50
45°
TP 4B
.85
16.95 (REF)
BL 25.75
25.99 LH
25.51 RH
.140
.100
.100 (TYP INBD THIS LOC)
1.05 (2 PLACES)
.140 (TYP OUTBD THIS LOC)
28.46 LH
27.98 RH
20.74 LH
20.26 RH
BL 20.50
€ CORRUGATION
.80
BL 13.50
€ CORRUGAT

11.10 (TYP)

B7-2

.12 (REF)

SCALE STABLE RE
FOR EDGE DIMENS

162-00017 | A | 3

3

L.B.L. 7.00

B.L.

R.B.L. 7.00

7.24 L.H.
6.76 R.H.

.241

14.24 L.H.
13.76 R.H.

1.25 1.00

INTEGRALLY CAST
TEST SPECIMEN
(L.H. ONLY) TRIM LINE

1.15 .241

.50(TYP) 1.50(TYP)

.5 R.
(TYP)

4.50(TYP)

.10 .18

.5 R.
(TYP)
1.06(TYP) .120(TYP)

B.L.
170

B.L. (REF) & ℄ CORRUGATION LOCATIONS A
IDENTICAL TO B.L. & ℄ TAB LOCATIONS, VIEW

t_w

t_w .140

B L (REF

℄ CORR
AT INSEC

9-2 ROTATED 45° CLOCKWISE

CASTING DATUM
PLANE C

INSEC BWL 150 WITH
B. STA 170

.70

t_c

.50 .40

RESULTANT EDGE
FROM ½° CASTING DRAFT
(TYP)

℄
SYM
EXCEPT AS NOTED .33

CASTING DATUM
PLANE A

2C8-2

CORRUGATION - UPPER END
STRAIGHT TAPER TO LWR END AS SHOWN IN B7-2

2.50(TYP)

1.50(TYP)

8-2 ROTATED 45° CLOCKWISE
M TABBED FLANGE

INSEC LWR SURFACE SLANTED BEAM
WITH AFT FACE OF TAB FLANGE

B.L. (REF)	t_w	t_c
0	.100	.100
7.00	.100	.100
14.00	.100	.100
21.00	.100	.100
28.00	.140	.140
35.00	.140	.140

L.B.L.
7.00

CASTING DATUM PLANE C

R.B.L.
7.00

L.B.L.
7.56

7.24

6.76

R.B.L.
7.56

8.20

6.76 7.72

L.B.L.
6.60

6.84

6.36

.241 (REF)

R.B.L.
6.60

CASTING DATUM PLANE A

.87 1.60/1.67 1.87

2.12 1.64/1.61 .87

B.S. 170
(REF)

B (W.L 124.6)

C (W.L 131)

.250 .38 R

.100 (TYP AT
B.L. 19.5 & 20 S)

.38 R .250

CORRUGATION

.09

B.L.
13.50
℄
CORRUGATION

.56 1.56

R.B.L.
0.33
℄
CORRUGATION

1.81 .56

14.24
13.76

B.L.
℄
SYM
EXCEPT AS NOTED

BLE REPRODUCTION
DIMENSIONS

.12 (REF) .12 (REF)

1

4

2C8-2

Figure 3

5.64
TO CASTING DATUM
PLANE C

R.B.L. 5.88 (REF)

8.44
TO CASTING DATUM
PLANE C

3.52

1.16

.50

1.36

1.00

R.B.L. 8.68 (REF)   Q-CLEVIS (RBL 8.78)

CASTING DATUM
PLANE A

.35 (BOTH SIDES)

.50

A4

1.50 (TYP)

B.S.
170

CASTING DATUM
PLANE B
WL 130.007

DIM'S THIS AREA SAME AS 6A6-2₄₉₋₃
EXCEPT AS NOTED

CASTING DATUM
PLANE A

CASTING DATUM
PLANE A

R.B.L.
5.88

R.B.L.
8.68
(REF)

STRAIGHT TAPER
TO .250 AT
WL 124.6

14.51
TO CASTING DATUM
PLANE B

.350

.350

2.52 (REF)

.50

WL 124.60

.25 (REF)

.31 (REF)

1.35

1.58

.50 R

.140

.100

WL 115.50

.120

1.75 DIA.

.25 R (TYP)

1.70

WL 119.35 (REF)

.130

SEE 2A5-2₄₁₁₋₃
FOR DIM'S
THIS AREA

R.B.L.
2.00

.50

.220
BOTH SIDES

Q
CLEVIS
R.B.L.
8.78

A5

A4 C5

1.50 DIA.

1.96

WL 115.5

A5 A6

4A4-2

WL 110.08 (REF)

DIM'S THIS AREA - SAME AS 6A6-2A9-3
EXCEPT AS NOTED

5.25

2.60

10.66

4.60 2.79

3.06

.50

1.00

2.00 2.27

1.96

1.11

1.58

1.35

2A5-2AH-3
DIM'S
AREA

STRAIGHT TAPER
SEE 2A5-2AH-3

3A4-2

BULKHEAD CASTING
STATION 170
CAST Figure 4

F33615-76-C-3111

P.C. Jones

J 81205 162-00017

162-00017 A14

175

PCM

| | 6 | 5 | 4 | 3 |

D

C

B

A

-1	162-00001	CAST FTG/CAM	TEST ONLY	1234	
PART NUMBER	NEXT ASSY	USED ON	EFFECTIVITY	DWG SH NUMBER	REV LTR
			APPLICATION		

| | 6 | 5 | 4 | 3 |

NOTES

1. SPECIFICATIONS AND STANDARDS FOR THE CONTROL OF MANUFACTURING OPERATIONS (AS APPLICABLE)
   - FORM, STRAIGHTEN & FIT METAL PARTS PER BAC 5300
   - BOLT & NUT INSTALLATION PER BAC 5300
   - RIVET INSTALLATION & SYMBOLS PER BAC 5300
   - PART MARKING PER BAC 5300
   - FINISH CODES PER DOCUMENT 80-020

2. DATUM TARGET PT. DIM. GEN'L DWG TOL. DOES NOT APPLY.
3. NAS 77A00-00P BUSHINGS ARE OPTIONAL TO BAC B28X00M000 IN EQUIV. DIA & LENGTH.
4. STEP RESULTING FROM CASTING DRAFT.
5. ✓ ALL MACHINED SURFACES EXCEPT AS NOTED
6. BREAK ALL SHARP EDGES .03.02.
7. INSTALL BUSHINGS WITH WET PRIMER (F 20.06) PER BAC 5435
8. CASTING REFERENCE ONLY
9. ALL HOLES ON THIS & THRU THE LANDING GEAR FITTING LUGS TO BE CONCENTRIC WITHIN .002.
10. SPOTFACE 1.75 DIA. FLAT, .05-.07 FILLET RADIUS, ONLY AS REQD TO PROVIDE FLAT SURFACE FOR BUSHING FLANGE, .02 MAX DEPTH.
11. PENETRANT INSPECT MACHINED SURFACES PER BAC 5423.

REV STATUS

SH	LTR
2	
3	
4	

REVISIONS

ZONE	LTR	DESCRIPTION	DATE	APPROVED

PARTS LIST

QTY	PART NUMBER	NOMENCLATURE OR DESCRIPTION	ZONE	MATERIAL AND SPECIFICATION	FIN	REV LTR
4	BAC B28X20M090	BUSHING ③	C9-3			
2	BAC B28X20M075	BUSHING ③				
2	BAC B28X16M055	BUSHING ③	B3-4			
2	BAC B28X16M085	BUSHING ③	C10-3			
1	-2	BULKHEAD	A4-2	MAKE FROM 162-00017-1 ⑪	F1704 R	
-	-1	BULKHEAD ASSY			R	

CONTRACT NUMBER: F33615-76-C-3111

THE BOEING COMPANY
SEATTLE, WASHINGTON

BULKHEAD ASSEMBLY
STATION 170
CAST

Figure 5

J | 81205 | 162-00018

162-00018

CASTING DATUM
PLANE B
(WL 130.007 REF)

CASTING DATUM
PLANE A

CASTING DATUM
PLANE B
(WL 130.007 REF)

WL 124.60

CASTING DATUM
PLANE A

CASTING DATUM
PLANE A

45°

TAB ℄

13.06 (REF)

TAB ℄

CASTING
PLANE B

B STA
66
(REF)

2C7 Ⓑ

B STA
170
(REF)

5.15 (REF)

1.75 (REF)

4.00
(REF)
CASTING DATUM
PLANE A

CONSTANT

WL 115.5

.13

B.S.
166
(REF)

-2

INSEC YC-14 BODY I.M.L.

2A6

B.S.
170
(REF)

B.S.
166
(REF)

-2

CF
CASTING

INSEC YC-14 BODY I.M.L.

B.S.
170
(REF)

1A6

B.S. 166 (REF)

INSEC YC-14
BODY I M L

-2

B.S. 170 (REF)

CASTING DATUM
PLANE A

BL
37.00
TYP
11A

LBL
35.0

37.241 LH TO CASTING
36.759 RH DATUM PLANE C

BL
40.80
(REF)

LBL
28.0

.140
(REF)

.100 (REF)

25.51 RH
25.99 LH TO
CASTING DATUM
PLANE C (REF)

BL
25.75
(REF)

A12 A11

3C7

SEE A12 A11

A12 Ⓑ

SEE ZN A8-A9

WL 124.60

C9 C5-3

108 BS-3

45°(REF)

.024 (REF)

WL 150

-2

CASTING DATUM
PLANE A

WL 115.5

24.987
TO CASTING
DATUM PLANE B

.30

WL 107.00

13.06 (REF)

2C7 8

B STA
166
(REF)

B STA
170
(REF)

.30

5.15 (REF)

1.75 (REF)

4.00
(REF)
CASTING DATUM
PLANE A

CONSTANT

TYP
3 A
@ L.B. .500

WL 105.02 — WL 135 (REF)

2.00

2.00

5R

CASTING DATUM
PLANE A

-2

.12R

CASTING DATUM
PLANE B
(WL 130.007 REF)

.40
(REF)

.100 (REF)

-2

1.50
(TYP)
(REF)

25.51 RH
25.99 LH TO
CASTING DATUM
PLANE C (REF)

B.L.
25.75
(REF)

.20
(TYP)

1.60

.20R

.5.51
(TYP)

.20 (INBD OF
BL 135)
.15 (OUTBD OF
BL 135)

1.50 (REF)

4.00 2

.75
2

OPT.

UNBD OF BL 135 .20
OUTBD OF BL 135 .15

-2

.10
MIN

.75
(TYP)

BODY
STA
166.00

.28 (REF)

.30 (REF)

WL 126.00 (REF)

TYP
6 C

A12 8

BODY 1 ML PER
M.D.D. 108 (YC-14)
AT B.L.0

BODY
STA
166.00

BODY
STA
170.00

1A4

C5 8

SEE ZN D10

162 00018

STA 170 BULKHEAD ASSY
REAR VIEW

162-00018-1
½ SIZE

C5AB

2A4
FWD OF B.S.170 ONLY SHOWN

CASTING DATUM PLANE C

CASTING DATUM PLANE A

CASTING DATUM PLANE B
WL 130.007

B4B2

SEE 2A4B3

3A4A3-4

4A4A5-4

2A4B3

2A5A11-3

1A5A3

E 2A8 BI

3A5A10-9

1A4A9

REF PLANE D
(SEE ZN B1)

CASTING DATUM
PLANE A

30°

CASTING DATUM
PLANE A

INSEC BL 7.0 &
W.L. 105.02 (REF)

WL 105.02

BS
166

BS
170

YC-14 BODY IML

4A6

BS
166

BS
170

YC-14 BODY IML

1A5

CASTING DATUM
PLANE A

-2

.22

3.09 (REF)

CASTING DATUM
PLANE A

t_2 (REF)

h (REF)

t_1

YC-14 BODY IML
PER M.D.D 108

B.S.
170

.10 MIN

INSEC B.L.7.0 ¢
W.L 105.02 (REF)

B4

CHORD DIMENSIONS
STRAIGHT TAPER BETWEEN REF PLANES

REF PLANE (⊥ TO CONTOUR)	REF PLANE COORD'S AT INSEC B.S 170 & BODY IML	DIMENSION		
		t_1	t_2 (REF)	h (REF)
D	B.L 0 W.L. 97.12	.28	.250	1.50
E	B.L. 13.50 W.L 99.34	.28 / .23	.250 / .200	1.50
F	B.L. 41.61 W.L. 130.0	.23	.200	1.00
G	B.L 43.94 W.L 140.06	.23	.200	1.00
H	B.L 44.65 W.L 146.35	.23	.200	1.00
SEE DETAIL ZN C7	ABOVE W.L 146.35	.23	.200	SEE ZN C7

* STEP AT VERTICAL BEAM, B.L 13.5 (REF)

-2

W.L 105.02

B.S.
170

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Figure 6

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162-00018

13   12   11

CASTING DATUM
PLANE B

CASTING DATUM
PLANE A

YC-14 BODY
IML
-2

BL
20.50

BL
13.50

CASTING DATUM
PLANE A

BL
700

BS170

WL 124.60

3.09
(REF)

5A6-2

.50R
(REF)

1.88
(REF)

C11 C10

BL
(REF)

LBL
7.00

135

-20

-5R

C INTERSECTION VERTICAL HORIZONTAL
BEAM WITH YC14
BODY I.M.L. (REF)

CASTING DATUM
PLANE A

B5-2 B

BS 170

1.10 (REF)

TYP FLANGE INBD TO PROVIDE
OPEN ANGLE - ALL L H BEAMS
B L .33 ¢ ALL R H BEAMS - OPP
AS SHOWN

BS 166

-2

TO CASTING
DATUM PLANE B
23.01

WL 10700

4A5-2 B

BL 13.50 VERTICAL BEAM AS SHOWN
TYP FOR VERTICAL BEAMS AT BL'S (33R)(70L4R)
(205 L4R)(270 L¢R) ¢ (345 L ¢ R)
TYP FOR HORIZONTAL BEAMS AT WL 124 6 ¢ W L 130
PLUS SEE 2C7-2 B11-2

WL 105.02

OPTIONA

.06R

A-1 B

A11 A12

3.09 (REF)

A11 A12

2A5-2

13   12   11

.1873 +.1883 DIA HOLE THRU INBD LUG ⌖ [5]
BAC B28X16M085 (2 PLACES) [7]
[10]

IS THIS AREA SAME AS 6A6-2,1+3
EXCEPT AS NOTED

.4372 +.4382 DIA HOLE THRU OUTBD LUG ⌖ [5]
BAC B28X20MO75 [10]

LBL 7.00

CASTING DATUM
PLANE A
(B S 170 REF)

CASTING DATUM
PLANE B
(WL 130 007 REF)

.4372 +.4382 DIA HOLE ⌖ [5]
BAC B28X20MO50 (2 PLACES) [7]
[10]

WL 140

.500

C11 ⌀
TO
INSEC
BL 700
& NL 105 02

INSEC WL 150 & BS 170
WITH YC 14 BODY IML

BL 40.80

BL 7.00

3.01 (TYP)
2.99
3.00
2.13 2.14
2.12

5.10
(TYP)
EXC AS SHOWN
IN 3A4-2,19-6

APPROX LINE OF TOOL RUNOUT AT 1 80 DIM (REF)

MAX LINE OF TOOL RUNOUT FOR 80 DIM
BETWEEN LUGS (TYP) .12 MIN CUTTER R (TYP)

NOTE: 1.80 DIM MACHINED FLAT SURFACE OUTLINE
IS OPTIONAL WITHIN LIMITS SHOWN (TYP)

EDGE OF MIN FLAT AREA REQUIRED AT
1.80 DIM BETWEEN LUGS (TYP)

1.55 R (TYP)

1.80 (REF)

B.S 166

YC-14 BODY
IML

CASTING DATUM PLANE C

B S 170

.2

2A10 [8]

2.05 (TYP)
(OR MR AS SHOWN)

1.50 (TYP EXCEPT
AS SHOWN IN 3A4-2,13-4)

CLEVIS ⌀

14 51
TO CASTING
DATUM PLANE B

CASTING
PLANE B

SPOTFACE 1.75 R , .06-.07 FILLET R
ONLY AS REQD TO PROVIDE FLAT MACHINED
SURFACE .02 MAX DEPTH

1A10 [8]

CASTING DATUM
PLANE A

2A10 B10

BS
170

A9 A9

A9

WL 115.50

BL 28.22

TO CASTING
DATUM PLANE B
30 51

6A6-2

1.00

1A10 A10

-.60

3A5-2

162-00018 [3]

C9-2 ⊡ ROTATED 45° CLOCKWISE

IC8-2 ⊡ ROTATED 45° CLOCKWISE
SLANTED BEAM TABBED FLANGE

¢ TAB
(TYP)

¢ CORRUGATION

¢ CORR
@WL 130

¢ CORRUGATION

¢ CORRUGATION

B7-2

162-00018

LBL 7.00

BL

.241

1.15

.50 (TYP) (REF)

1.90 (TYP)(REF)

RBL 7.00

4.50 (TYP)(REF)

.5R (TYP)

1.06 (TYP) (REF)

.120 (TYP)

.10

.8

CASTING DATUM PLANE C

INSEC BWL 150 WITH B STA 170

45° CLOCKWISE

RESULTANT EDGE FROM ½° CASTING DRAFT (TYP)

SYM EXCEPT AS NOTED

2.50 (TYP)

1.50 (TYP)

45° CLOCKWISE

INSEC LWR SURFACE SLANTED BEAM WITH AFT FACE OF TAB FLANGE

BS 120

T_w

BL (REF) & & CORRUGATION LOCATIONS ARE IDENTICAL TO BL & & TAB LOCATIONS, VIEW ICB2_{BS-3}

INSEC LWR SURFACE WITH AFT FACE OF

.140 (REF)

T_w

BL (REF)

& CORRUGATION AT INSEC & SLANTED

.70 (REF)

T_c

CASTING DATUM PLANE A

.2

2C8-2

CORRUGATION - UPPER END
STRAIGHT TAPER TO LWR END AS SHOWN IN B7-2_{AS-3}

B.L. (REF)	T_w (REF)	T_c (REF)
O	.100	.100
7.00	.100	.100
14.00	.100	.100
21.00	.100	.100
28.00	.140	.140
35.00	.140	.140

LBL 7.075

LBL 7.00

LBL 7.56

CASTING DATUM PLANE C

RBL 7.05

RBL 7.00

LBL 6.50

15.750 / 15.755 / 15.745

CASTING DATUM PLANE A

.241 (REF)

BAC B28K16M095 (2 PLACES)

(1 PLACE)

RBL 6.60

RBL 7.96

7.634 / 7.639 / 7.628

1.80/1.81 (TYP)/1.79

BS 170 (REF)

BAC B28R20M075

CORRUGATION

BAC B28K16M095 (2 PLACES)
(1 PLACE)

RBL 0.33

& CORRUGATION

.38

.70

.81

.56

BL

SYM EXCEPT AS NOTED

.2

12 (REF)

12 (REF)

BL (REF) & ℄ CORRUGATION LOCATIONS ARE
IDENTICAL TO BL & ℄ TAB LOCATIONS, VIEW IC8·2$_{B5-3}$

INSEC LWR SURFACE SLANTED BEAM
WITH AFT FACE OF TAB FLANGE

.140
(REF)

B·L (REF)

℄ CORRUGATION
AT INSEC @ SLANTED BEAM

.70
(REF)

I_W

I_C

I_W

-2

2C8-2

CORRUGATION - UPPER END
STRAIGHT TAPER TO LWR END AS SHOWN IN B7-2$_{A5-3}$

L (℄)	$I_W^{(REF)}$	$I_C^{(REF)}$
0	.100	.100
200	.100	.100
4.00	.100	.100
6.00	.100	.100
8.00	.140	.140
9.00	.140	.140

LINE A

B2C8·20MOTS

CONTRACT NUMBER
F 33615-76·C· 3111

R C JONES

THE BOEING COMPANY
CORPORATE OFFICES   SEATTLE WASHINGTON

BULKHEAD ASSEMBLY
STATION 170
CAST   Figure 7

J 81205 162·00018

SCALE FULL

162-00018

181

PCM

S 44
TO CASTING DATUM
PLANE C (REF)

A.B. 5.88 (REF)

B.44
TO CASTING DATUM
PLANE C

A.B. (48.20)   CLEVIS (RBL 878)

CASTING DATUM
PLANE A

A4

BS
170

CASTING DATUM
PLANE B
WL 130.007

CASTING DATUM
PLANE A

.30 (REF)

CASTING DATUM
PLANE A

CASTING .43"2 DIA HOLE THRU OUTBD LUG

WL 124.60

3 (REF)

-2

RBL
5.00

RBL
868
(REF)

14.51
TO CASTING DATUM
PLANE B

58

40

30

-2

STR TAPER

2 SQ (REF)

WL 115.50

WL .935 REF

-2

A4 c5

SEE 2A5-2
FOR DIM'S
THIS AREA

.595 .594 DIA HOLE THRU

RBL

WL 1155

CLEVIS
RBL
878

A5

A5 A6

4A4 2

CASTING DATUM
PLANE B
WL 130.007

CASTING DATUM
PLANE A

.30 (REF)

.70 (REF)

1.1873 1.1883 DIA. HOLE THRU INBD. LUG
BAC B28X16M055 (2 PLACES)

10.66

.50 (REF)

3.56

.50 (REF)

1.17

WL 119.35 (REF)

SEE 2A5-2 A11-3
FOR DIM'S
THIS AREA

.4375 .4375 DIA HOLE IN LINE
2.00

.60

4.00 (REF)

4.6 (X)(REF)

.38
.35

STRAIGHT TAPER
SEE 2A5-2 A11-3

3A4-2

F 33615-76 C-3111

BULKHEAD ASSEMBLY
STATION 170
C A S T   Figure 8

J 81205 1162-00018

PCM

162-00018   4

18

APPENDIX B

SPECIFICATION

M-XXXX

CASTINGS,
ALUMINUM ALLOY A357,
PRIMARY AIRCRAFT STRUCTURE

SPECIFICATION

CASTINGS,
ALUMINUM ALLOY A357,
PRIMARY AIRCRAFT STRUCTURE

1. SCOPE

1.1   This specification establishes the requirements for production of A357 aluminum alloy castings suitable for use as aircraft primary load structure.

1.2   Requirements to develop and utilize consistent manufacturing processes and inspection techniques are based upon production of castings having a high degree of reliability for mechanical properties.

1.3   The Engineering drawing established by the procuring activity shall define the casting geometry and the technical and quality requirements applicable to designated zones of the casting.

1.4   Production of castings shall be controlled by consistent manufacturing and inspection practices and by minimum mechanical property requirements for all casting zones stated on the Engineering drawing.
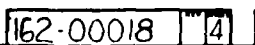
1.5   A qualified source foundry is required for this specification. The foundry shall be established by the procuring activity in accordance with the requirements stated in specification Q-XXXX.

1.6   The intent of this specification recognizes that both manufacturing and processing variables have an influence on mechanical properties. It is mandatory that no changes be introduced once the manufacturing and processing procedures have been developed and approved. Any proposed changes shall be evaluated by the procuring activity as a matter of reconfirmation of Preproduction Development.

1.7   Three sequential stages are required to establish production parts:

a.   Foundry Qualification per Specification Q-XXXX
(Demonstration of basic A357 casting capabilities)

b.   Preproduction Development
(Demonstration of capablities to produce specific sizes, shapes, and dimensions)

c.   First Production Lot
(Demonstration of typical Production castings)

Both the foundry and the procuring activity have specific requirements for each stage. These requirements are defined in section 3.

2. APPLICABLE DOCUMENTS

2.1 The following documents of the issue in effect on the date of invitation for bid or request for proposal form a part of this specification to the extent specified herein.

SPECIFICATIONS

Military

MIL-H-6088   -   Heat Treatment of Aluminum Alloys

MIL-I-6866   -   Inspection, Penetrant Method of

MIL-A-20695 -   Aluminum Products, Preparation for Storage and Shipment of

Cast Aluminum Structures Technology

W-XXXX   -   Welding, Fusion; Correction of Primary Structural A357 Aluminum Alloy Castings, Process for

D-XXXX   -   Aluminum Alloy A357 Castings, Dendrite Arm Spacing, Process for Determination of

Q-XXXX   -   Selection and Qualification of Foundry Contractors (Suppliers) for Primary Aircraft Structural Castings, A357 Aluminum Alloy

STANDARDS

Federal

Federal Test Method Standard No. 151 - Metals; Test Methods

Military

MIL-STD-105 -   Sampling Procedures and Tables for Inspection by Attributes

MIL-STD-129 -   Marking and Shipment for Storage

MIL-STD-453 -   Inspection, Radiographic

2.2 Other publications. The following documents form a part of this specification to the extent specified herein. Unless otherwise indicated, the issue in effect on the date of invitation for bids or request for proposal shall apply.

AMERICAN SOCIETY FOR TESTING AND MATERIALS

E8   -   Standard Method of Tension Testing of Metallic Materials

E94   -   Recommended Practice for Radiographic Testing

| E114 | – | Ultrasonic Pulse-Echo Straight-Beam Testing by the Contact Method |
| E155 | – | Reference Radiographs for Inspection of Aluminum and Magnesium Castings |

NATIONAL AEROSPACE STANDARDS COMMITTEE

| NAS 823 | – | Cast Surface Comparison Standards |

3. REQUIREMENTS

3.1 **Production of castings.** Preproduction Development, First Production Lot, and Production of Castings requirements shall govern the manufacture of all parts for compliance to this specification. The intent herein is to produce castings with consistent and acceptable mechanical properties that can be assured with a minimum amount of destructive testing. This specification is not intended to be restrictive to any specific manufacturing or processing technique. It should be recognized that the requirements stated for foundry qualification do not guarantee producibility of more complex geometry or sizable castings with the same mechanical properties.

3.2 Foundry Qualification.

3.2.1 **Procuring activity responsibilities.** It shall be the responsibility of the procuring activity to consider only foundries having proven capabilities in accordance with the requirements of specification Q-XXXX as potential sources for the manufacture and processing of A357 castings with this specification for use in primary aircraft structure applications. The procuring activity may either (a) select from currently qualified foundries, or (b) establish the qualification of candidate foundries in accordance with all requirements of specification Q-XXXX.

3.2.2 **Foundry responsibilities.** A foundry shall comply with all requirements of specification Q-XXXX to become a qualified source. All requirements of that specification are mandatory and cannot be waived. Furthermore, it shall be the responsibility of all qualified foundries to comply in a timely manner with any revision to specification Q-XXXX.

3.3 Preproduction Development.

3.3.1 General Requirements.

3.3.1.1 Preproduction development shall be performed by the foundry for each casting configuration. The purpose is to develop specific manufacturing and heat treatment process techniques that will provide acceptable mechanical properties for all casting zones in subsequent Production castings.

3.3.1.2 In addition to the basic chemistry and heat treatment parameter ranges required by this specification, DAS and soundness evaluation shall be conducted in a sufficient number of casting zones to ensure acceptable properties throughout a casting. Surface DAS and soundness measurement zones shall be specified by the procuring activity on the Engineering drawing in accordance with the criteria of tables I and III.

3.3.1.3 The maximum permissible DAS and the corresponding minimum acceptable soundness for all designated casting zones shall be established in relation to the tensile properties obtained from static test coupons from each zone.

3.3.1.4 For castings with sections exceeding 0.75 inch in thickness, cast ultrasonic reference standards shall be developed and correlated with radiographic soundness grades for fine, dispersed discontinuities such as interdendritic shrinkage porosity. These standards, with records of radiographic correlation, shall be approved by the procuring activity.

3.3.2 Procuring Activity Responsibilities.

3.3.2.1 The procuring activity shall be responsible for evaluating the results of all nondestructive and dimensional inspections and casting property tests.

3.3.2.2 A suitable segment of the complete casting configuration may be selected for Preproduction development.

3.3.2.3 Soundess grades shall be specified for all casting zones.

3.3.2.4 A suitable number of surface DAS measurement zones shall be designated to permit the strength and elongation characteristics of the entire casting to be identified by DAS/soundness data.

3.3.2.5 For all casting zone thicknesses exceeding 0.5 inch, DAS and soundness shall be designated from both the surface and mid-thickness locations. Tensile property requirements shall be designated for the mid-thickness locations of all such zones.

3.3.2.6 The procuring activity shall be responsible for establishing, on the Engineering drawing, specific limitations for each foundry on chemistry, heat treatment, DAS, soundness, and integral cast-on coupon tensile properties as a result of Preproduction castings data analysis. These limitations shall be based upon the relations between tensile properties shown in table I in light of the properties required per the Engineering drawing.

3.3.3 Foundry Responsibilities.

3.3.3.1 The foundry shall be responsible for establishing and reporting to the procuring activity the following preproduction information: mold materials, melting furnace details, melt transfer details, and mold and pouring information including types, sizes, and locations of all sprues, runners, ingates, risers, chills, insulation materials, and ladle chemistry. This information also shall include all heat treatment parameters including time and temperature of each phase and stacking and quench arrangements. This information shall be sufficient to reproduce the same part in Production.

3.3.3.2 The foundry shall utilize integral cast-on coupon blanks, as agreed upon by the procuring activity, to provide information regarding the effectiveness of heat treatment.

3.3.3.3 Completely heat-treated Preproduction castings shall be evaluated thoroughly by the foundry to provide the procuring activity the following information:

a. Soundness measurements of all portions of the casting including soundness measurements of coupon blanks subsequently excised from mid-thickness locations of zones exceeding 0.5 inch thickness. X-ray radiographic records shall be obtained and the criteria of table III shall apply. Ultrasonic inspection records shall be made for all zones exceeding 0.75-inch thickness.

    b.   DAS measurements per specification D-XXXX from an agreed upon number of casting surface locations sufficient to characterize the entire casting, plus DAS measurements from all coupon blanks excised from zones exceeding 0.5 inch thickness

    c.   Penetrant inspection records

    d.   Tensile properties, including full range stress-strain records to failure, of all integral and excised coupons

    e.   Dimensional conformity measurement records

    f.   Chemistry of molten metal in ladle

3.3.3.4   Heat treatment procedures shall be in accordance with MIL-H-6088 except that times and temperatures shall be within the ranges recommended in table IV.

3.4 First Production Lot.

3.4.1 General Requirements.

3.4.1.1   The First Production Lot of castings is defined as those castings produced under completed Preproduction Development controls from which the procuring activity will destructively test one or more parts to approve the process for continued production.

3.4.1.2   Depending upon Preproduction Development findings, various restrictions on both chemistry and heat treatment processing parameters may be required for Production castings. Such information shall be shown on the Engineering drawing, when required.

3.4.1.3 The Engineering drawing shall designate minimum soundness, maximum surface DAS, and minimum mechanical properties for all casting zones, from which the acceptability of castings will be judged. These criteria and those for dimensional conformity, chemistry, and heat treatment will constitute the technical basis for acceptability.

3.4.2 Procuring Activity Responsibilities.

3.4.2.1 The procuring activity shall be responsible for the evaluation of all First Production Lot data to judge acceptability.

3.4.2.2 The procuring activity shall be responsible for all details concerning specimen selection and testing from these castings.

3.4.3 Foundry Responsibilities.

3.4.3.1 The foundry shall be responsible for furnishing the First Production Lot of castings, fully heat treated, with the following information:

    a.   Radiographic soundness measurements and penetrant inspection records

    b.   DAS measurements of all zones identified on the Engineering drawing

c. Tested integral cast-on specimens, tensile properties, and full range stress-strain curves to failure for each specimen

d. Chemistry of molten metal in ladle for each casting

3.4.3.2 The foundry shall produce and process all parts in a manner consistent with the procedures in Preproduction Development. Intentional variations shall be reported to the procuring activity prior to implementation. Such changes may be sufficient to require further Preproduction Development.

3.5 Production of Castings.

3.5.1 General Requirements.

3.5.1.1 To provide maximum assurance that acceptable castings are supplied, a continuous inspection plan shall be implemented for Production castings.

3.5.1.2 All Production castings shall be evaluated for mechanical properties, soundness, and DAS per requirements of the Engineering drawing in accordance with the criteria of tables I and III.

3.5.1.3 Castings having any integral cast-on coupon tensile properties less than those shown on the Engineering drawing shall not be considered as production parts.

3.5.2 Procuring Activity Responsibilities.

3.5.2.1 The procuring activity shall be responsible for destructive testing of Production castings.

3.5.2.2 Test castings will be selected as follows from designated groups of Production castings from each production order of each casting part number, unless otherwise specified by the procuring activity:

Production Casting Group	Number of Test Castings
First 10	1
Next 15	1
Each subsequent 25	1

3.5.2.3 The basis for selection of the above sample test castings shall be a combination of chemistry, integral cast-on coupon tensile properties, DAS, and soundness values expected to produce the lowest casting tensile properties within specification/drawing requirements.

3.5.2.4 When all excised coupon tensile properties meet or exceed the zone requirements stated on the Engineering drawing, all other Production castings of the group represented by the sample casting can be accepted.

3.5.2.5 When any excised coupon tensile property fails to meet the zone requirement stated on the Engineering drawing, the Production casting group represented by the sample casting shall be rejected. Sampling shall return to the first Production casting group (First 10) of section 3.5.2.2.

3.5.3 Foundry Responsibilities.

3.5.3.1 The primary foundry responsibility for Production castings shall be to ensure a consistent method of manufacture and processing.

3.5.3.2 The foundry shall obtain and report results for all DAS and soundness measurements, penetrant inspections, and integral cast-on specimen tensile tests on Production castings.

3.5.3.3 All tested and identified integral cast-on specimens shall be shipped to the procuring activity with Production castings of that lot.

3.5.3.4 Spectrographic chemical analysis of one sample from each melt is required, and the chemistry of the melt shall meet the limits specified in table II after degassing and before pouring. Additionally, integral cast spectrochemical discs may be required by the Engineering drawing for use in foundry control.

3.5.3.5 Heat treatment shall be conducted to the requirements of this specification, unless modified by the Engineering drawing.

3.5.3.6 All castings shall be penetrant inspected. Surface finish shall be in accordance with the Engineering drawing and NAS 823.

3.5.3.7 Identification of product. Each casting shall be identified with the part number, heat number, and serial number by the use of raised numerals in a location designated on the Engineering drawing. The serial number shall be traceable to the casting melt and heat-treat lot records, mechanical properties reports, and NDE reports, including DAS inspection.

3.5.3.8 Castings on which it is impractical to provide raised numerals shall be marked in accordance with the requirements of the procuring activity.

3.5.3.9 Dimensions. The dimensions of the castings shall be within the tolerances specified on the applicable drawings.

3.5.3.10 Workmanship. Castings shall be uniform in quality and condition, sound, clean, and free from foreign materials.

3.5.3.11 Castings shall not be impregnated, chemically treated, or coated to prevent leaking, unless specified or allowed by the procuring activity. Impregnated castings shall be marked IMP.

4. QUALITY ASSURANCE PROVISIONS

4.1 Unless otherwise specified, the foundry is responsible for the performance of all nondestructive inspection requirements as specified herein. The foundry may utilize its own facilities or any commercial laboratory acceptable to the procuring activity. The procuring activity has the right to perform any of the inspections set forth in the specifications where such inspections are deemed necessary to assure that supplies and services conform to prescribed requirements.

4.2 Quality conformance. Quality conformance tests shall consist of all tests as described under section 4.3.

4.2.1 Visual and dimensional examination. Dimensions of castings cited on the Engineering drawing as acceptance criteria checks shall be inspected and reported for all Production casting lots. Samples from each lot shall be selected in accordance with MIL-STD-105, Inspection Level II, Acceptable Quality Level 2.5 percent defective.

4.2.2 Chemical composition. A sample shall be tested from each melt after all processing has been completed and the temperature of the melt is satisfactory to pour the casting. Additionally, integral cast spectrochemical discs may be required by the drawing.

4.2.2.1 Preparation of sample specimens for chemical analysis shall be in accordance with Methods 111.1 or 112.1 of Federal Test Method Standard No. 151.

4.2.2.2 The sample for spectrographic analysis may be taken from a broken tensile specimen. If a separate sample is used, it shall conform to the requirements of Federal Test Method Standard No. 151. It shall weigh approximately 20 grams.

4.2.3 Radiographic, ultrasonic, and penetrant inspection. All castings shall be radiographically and penetrant inspected. Section 3.3.3.3 defines thickness criteria for ultrasonic inspection.

4.2.4 Mechanical properties. Attached cast-on coupons shall be removed and tested from each fully heat-treated casting.

4.2.5 DAS measurements shall be made on all castings at each location specified on the Engineering drawing.

4.3 Test Methods.

4.3.1 Chemical composition. Analysis shall be by spectrographic or wet chemical methods in accordance with Methods 111.1 or 112.1 of Federal Test Method Standard No. 151. In case of dispute, chemical analysis by wet chemical methods shall be the basis for acceptance.

4.3.2 Radiographic inspection. Inspection shall be conducted in accordance with MIL-STD-453. Additional radiographic inspection may be specified by the procuring activity.

4.3.3 Ultrasonic inspection. Inspection shall be conducted in accordance with ASTM E114 for the detection of fine, dispersed discontinuities not considered detectable by radiographic means in cast sections exceeding 0.75 inch in thickness.

4.3.4 Penetrant inspection. Inspection shall be in accordance with MIL-I-6866 following the removal of all ingates, sprues, and risers and prepenetrant chemical etch.

4.3.5 Mechanical properties. Tension test specimens shall conform to ASTM E8. When the size or shape of the casting restricts the use of the above test specimens, the full-size casting may be tested. When testing of a complete casting is required, the strength requirement and the direction and method of loading of the full-size casting shall be specified on the Engineering drawing for the part concerned.

4.3.6 Visual and dimensional examination. Castings shall be examined for surface imperfections, identification, dimensions, and workmanship requirements of section 3.5.

4.3.7 Preservation, packing, and marking. Preservation, packing, and marking shall be examined for conformance with section 5 of this specification.

4.3.8 Rejection and retest. Failure of any specimens to conform to any requirement of this specification shall be cause for rejection of the represented casting. Retest will be permitted in accordance with Federal Test Method Standard No. 151.

5. PREPARATION FOR DELIVERY

5.1 Preservation and packing. All castings shall be preserved and packed in accordance with the requirements of MIL-A-20695. The procuring acitivity will specify the levels required (see section 6.2).

5.2 Marking of shipments. Each shipping container shall be marked in accordance with MIL-STD-129.

6. NOTES

6.1 Intended use. The high-strength aluminum alloy castings covered by this specification are intended for use in airframe, missile, and other applications where high strength and reliability are required.

6.2 Ordering data. Procurement documents should specify the following:

a. Title, number, and date of this specification

b. Alloy number, and minimum mechanical property requirements

c. Applicable drawing(s) numbers

d. Level of packing desired (see section 5.1)

e. Any other options desired

f. Where the results of preproduction tests should be sent, the activity responsible for testing, and instructions concerning submittal of the test reports

7. DEFINITIONS

7.1 A <u>Production Lot</u> is defined as those castings produced from a single furnace melt and heat-treated in the same furnace charge.

7.1.1 Depending upon size, geometric complexity, or foundry capabilities, a Production Lot may consist of a single casting or multiple castings.

7.2 A <u>Furnace Melt</u> is defined as metal withdrawn from a batch melting furnace charge of 2000 lb or less as melted for pouring castings or, when permitted by the procuring activity, a melt may be 4000 lb or less of metal withdrawn from a continuous melting furnace in not more than 8 consecutive hours.

7.3 Integral cast-on coupon tensile properties include the 0.2 percent offset yield strength, tensile ultimate strength, and total elongation.

Table 1. Minimum Mechanical Property Requirements—
A357-T6 Aluminum Alloy Castings

DAS (0.0001 inch)	ASTM Quality Grade (ASTM E155)								
	A			B			C		
	TUS	TYS	e	TUS	TYS	e	TUS	TYS	e
Level 1-- Up to 12	46/36/3			44/36/1			44/36/1		
Level 2-- 13 to 18	44/36/1			43/36/1			42/36/1		
Level 3-- 19 to 24	43/36/1			42/36/1			41/36/1		
Level 4-- 25 to 30	42/36/1			41/36/1			40/36/1		

NOTES

1. Properties shown in this table are minimum values for the corresponding DAS ranges and quality grades and are further identified by midrange chemistry and heat treatment processing parameters.

2. A357-T6 castings having extreme chemical constituent limits and/or heat treatment processing parameters may exhibit significantly different tensile properties.

3. All areas of a casting shall be defined by X/Y to correspond with minimum mechanical properties:

   X = maximum DAS (Level No.)

   Y = minimum quality grade

Table 2. Chemical Composition Limits, A357 Aluminum Alloy

Element	Percent, Minimum	Percent, Maximum
Copper	--	0.20
Silicon	6.5	7.5
Iron	--	0.10
Manganese	--	0.10
Zinc	--	0.10
Magnesium	0.55	0.65
Titanium	0.10	0.20
Beryllium	0.04	0.07
Others, each	--	0.05
Others, total	--	0.15
Aluminum	Remainder	

Table 3. Maximum Severity of Radiographic Imperfections

Radiographic Imperfections	Radiographic Reference Film	Grade A		Grade B		Grade C	
		Thickness (inch)					
		Up to 1/2	Over 1/2	Up to 1/2	Over 1/2	Up to 1/2	Over 1/2
Gas Holes	1.1	None		1	1	2	2
Gas Porosity (Round)	1.21	None		1	1	3	3
Gas Porosity (Elongated)	1.22	None		1	2	3	4
Shrinkage Cavity	2.1	None		1	N/A*	2	N/A*
Shrinkage Porosity or Sponge	2.2	None		1	1	2	2
Foreign Material (Less Dense)	3.11	None		1	1	2	1
Foreign Material (More Dense)	3.12	None		1	1	2	1
Segregation	--	None		None		None	
Cracks	--	None		None		None	
Cold Shuts	--	None		None		None	
Misruns	--	None		None		None	
Laps	--	None		None		None	
Surface Irregularities	--	Drawing Tolerance		Drawing Tolerance		Drawing Tolerance	
Core Shift	--						

*N/A = Not available

NOTES

1. When two or more types of defects are present to an extent equal to or not significantly better than the acceptance standards for respective defects, the parts shall be rejected.
2. When two or more types of defects are present and the predominating defect is not significantly better than acceptance standard, the part shall be considered borderline.
3. Borderline castings shall be reviewed for acceptance or rejection by the "designated" foundry engineer and procuring activity quality control.
4. Gas holes or sand spots and inclusions allowed by this table shall be cause for rejection when closer than twice their maximum dimension to an edge or extremity of a casting.
5. If shrinkage cavity discontinuities appear on radiographs, castings shall be dispositioned by the procuring activity.

- FOR INFORMATION ONLY -
NOT TO BE USED FOR PROCUREMENT

Table 4. Heat Treatment Recommendations,
A357-T6 Aluminum Alloy Castings

Solution Heat Treatment	Quench Delay	Quenchant	Natural Aging	Precipitation Heat Treatment (Aging)
1010 ± 10^OF for 16 hrs. min. 1/	10 sec. max.	175 ± 35^OF water	Room temp. for 20 ± 4 hrs.	325 ± 25^OF for 8 ± 4 hrs.

1/   For castings with 1-inch maximum thickness. Add 2 hours soak for each
     additional 1/2 inch thickness.

APPENDIX C

SPECIFICATION

Q-XXXX

SELECTION AND QUALIFICATION
OF FOUNDRY COUNTRACTORS (SUPPLIERS)
FOR PRIMARY AIRCRAFT STRUCTURAL CASTINGS,
A357 ALUMINUM ALLOY

SPECIFICATION

SELECTION AND QUALIFICATION
OF FOUNDRY CONTRACTORS (SUPPLIERS)
FOR PRIMARY AIRCRAFT STRUCTURAL CASTINGS,
A357 ALUMINUM ALLOY

1. SCOPE

1.1 This specification covers the selection and qualification of foundry contractors to manufacture A357 aluminum alloy castings to M-XXXX specification requirements for primary aircraft structural components. The foundry must be qualified prior to placement of purchase orders for castings requiring compliance to M-XXXX.

1.2 Qualification of foundries to this specification shall be approved by the casting procurement activity.

2. APPLICABLE DOCUMENTS

2.1 The following documents of the issue in effect on the date of invitation for bid or request for proposal form a part of this specification to the extent specified herein.

SPECIFICATIONS

Military

MIL-H-6088	– Heat Treatment of Aluminum Alloys
MIL-I-6866	– Inspection, Penetrant Method of
MIL-Q-9858	– Quality Control System Requirements
MIL-A-20695	– Aluminum Products, Preparation for Storage and Shipment of
MIL-I-45208	– Inspection System Requirements

Cast Aluminum Structures Technology

M-XXXX	– Castings, Aluminum Alloy A357, Primary Aircraft Structure
W-XXXX	– Welding, Fusion; Correction of Primary Structural A357 Aluminum Alloy Castings, Process for
D-XXXX	– Aluminum Alloy A357 Castings, Dendrite Arm Spacing, Process for Determination of

STANDARDS

Federal

Federal Test Method Standard No. 151 – Metals; Test Methods

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Military

> MIL-STD-105 – Sampling Procedures and Tables for Inspection by Attributes
>
> MIL-STD-129 – Marking and Shipping for Storage
>
> MIL-STD-453 – Inspection, Radiographic

2.2 Other Publications. The following documents form a part of this specification to the extent specified herein. Unless otherwise indicated, the issue in effect on the date of invitation for bids or request for proposal shall apply.

American Society for Testing and Materials

> E8 – Standard Method of Tension Testing of Metallic Materials
>
> E114 – Ultrasonic Pulse-Echo Straight-Beam Testing by the Contact Method
>
> E155 – Reference Radiographs for Inspection of Aluminum and Magnesium Castings

National Aerospace Standards Committee

> NAS 823 – Cast Surface Comparison Standards

3. REQUIREMENTS

3.1 General. The production of A357 aluminum alloy primary structural castings per specification M-XXXX requires qualified source foundries. Qualification requirements are separated into the following five categories:

a. Manufacturing
b. Processing
c. Inspection
d. Personnel
e. Demonstration of Capabilities

3.2 Manufacturing.

3.2.1 Positive control of mold configuration. The foundry shall have a mold configuration system that provides positive control of gate sizes, shapes, and locations; sprue sizes, shapes, and locations; runner sizes, shapes, and locations; chill sizes, materials, locations, and shapes; riser sizes, shapes, and locations; exothermic and insulating material sizes, shapes, and locations; and screen/filtering device sizes, materials, configurations, and locations.

> NOTE: Positive control means such systems as pins or core prints for chills, or painted locations plus inspection checkoff sheets with Quality Control signatures or stamps.

3.2.2 Positive control of melt chemistry. The foundry shall have a system that provides positive control of melt chemistry including a feedback loop from the spectrometer results to the melter on modifications to chemistry and results of these modifications.

3.2.3 Control of furnace operation and mold pouring. The foundry shall have a system that provides control of melt operations, such as temperature cycle, degassing technique and testing, charge materials, grain-refining material and technique, ladle preheat, and degassing materials. Additionally, pouring temperature and time shall be systematically controlled.

3.2.4 Mass spectrograph. The foundry shall possess and have in operation a mass spectrograph capable of determining the chemistry of A357 as defined in M-XXXX.

3.2.5 Welding facility. The foundry shall have a welding facility and qualified welders capable of correcting casting defects as defined in W-XXXX.

3.3 Processing.

3.3.1 Traceability. The foundry shall have a traceability system for heat or melt numbers, heat treat lot numbers, mechanical test results, dendrite arm spacing (DAS) inspection results, and nondestructive evaluation (NDE) reports for each casting. The system shall be capable of tracing any selected parameter to its particular casting and location.

3.3.2 Positive control of split lots. The foundry shall have a system that provides positive control of split lots including traceabilty per 3.3.1.

3.3.3 Heat treatment facility. The foundry shall have a heat treatment facility capable of meeting the requirements of MIL-H-6088 and M-XXXX.

3.3.4 Positive control of finishing operations. The foundry shall have a system that provides positive control of dimensional characteristics during straightening and finishing operations, including layout facilities, equipment, and personnel.

3.4 Inspection.

3.4.1 Quality program requirements. The foundry shall have a quality program that includes meeting the intent of paragraphs 3.2, 3.3, 3.4, and 3.5 of MIL-Q-9858.

3.4.2 Inspection system requirements. The foundry shall have an inspection system that meets or exceeds the requirements of MIL-I-45208.

3.4.3 Metallographic laboratory. The foundry shall have a metallographic laboratory capable of determining the dendrite arm spacing (DAS) as defined in D-XXXX.

3.4.4 Radiographic facility. The foundry shall have a radiographic facility capable of meeting the requirements of MIL-STD-453.

3.4.5 Penetrant facility. The foundry shall have a penetrant facility capable of meeting the Group IV requirements of MIL-I-6866.

3.4.6 Ultrasonic inspection facility. The foundry shall have an ultrasonic inspection facility capable of meeting the requirements of ASTM E114 and M-XXXX.

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3.4.7 Prepenetrant etch facility. The foundry shall have a prepenetrant etch facility capable of removing 0.0002-0.0004 inch per surface of a cast part and meeting the requirements of M-XXXX.

3.4.8 Mechanical property test facility. The foundry shall have a tensile specimen testing facility capable of conducting tests in accordance with ASTM E8 including full-range stress-strain curves to failures.

3.5 Personnel.

3.5.1 The foundry shall employ the technical and manufacturing personnel required to produce A357 castings with the reliability required by specification M-XXXX.

3.5.2 The foundry shall notify the qualifying activity of any change in technical personnel assigned to the team implementing M-XXXX. Requalification, in this case, shall consist of a procuring activity review of replacement personnel and new product development capability.

NOTE: Reorganization of other foundry personnel is an acceptable alternative providing that sufficient technical depth is maintained.

3.6 Demonstration of Capabilities.

3.6.1 The foundry shall have had previous experience, within the past 2 years, in the manufacture of A357 aluminum alloy structural castings.

3.6.2 The foundry shall provide evidence of manufacturing capability conforming to the general requirements of M-XXXX. This information shall be developed from an A357-T6 casting satisfying the following conditions:

a. At least one envelope dimension equal to or exceeding 12 inches

b. Thick sections 0.75 inch minimum and thin sections 0.30 inch maximum

c. ASTM quality grade B or better

d. Dendrite arm spacing (DAS) measurements no greater than 0.0020 inch

e. Integral cast-on specimen tensile property results demonstrating acceptable heat treatment processing

4. OPTIONAL PROCEDURES

4.1 Upon specific approval from the procuring activity, the foundry may utilize qualified commercial facilities and/or personnel readily available from other sources to perform heat treatment, inspection, weld correction, and specimen tensile testing.

5. QUALITY ASSURANCE PROVISIONS

5.1 The procuring source's quality assurance activity shall assure that all foundries producing castings to M-XXXX have been qualified per this specification.

5.2 Qualification of suppliers to this specification shall be accomplished annually.

APPENDIX D

SPECIFICATION

W-XXXX

WELDING, FUSION,
CORRECTION OF PRIMARY STRUCTURAL
A357 ALUMINUM ALLOY CASTINGS,
PROCESS FOR

W-XXXX
31 January 1980

SPECIFICATION

WELDING, FUSION,
CORRECTION OF PRIMARY STRUCTURAL
A357 ALUMINUM ALLOY CASTINGS,
PROCESS FOR

1. SCOPE

This specification covers the use of fusion welding for the correction of manufacturing imperfections in primary structural A357 aluminum alloy castings. The following fusion welding processes are involved:

  a.   Gas Tungsten Arc Welding; Direct Current-Straight Polarity (GTAW-DCSP)

  b.   Gas Tungsten Arc Welding; Alternating Current (GTAW-AC)

  c.   Gas Metal Arc Welding; Direct Current-Reverse Polarity (GMAW-DCRP)

2. APPLICABLE DOCUMENTS

2.1 The following documents of the issue in effect at the date of invitation for bid shall form part of this specification to the extent specified herein.

SPECIFICATIONS

Federal

O-A-51	– Acetone, Technical
TT-N-95	– Naphtha, Aliphatic
TT-M-261	– Methyl Ethyl Ketone, Technical
QQ-R-566	– Rods and Electrodes, Welding Aluminum Alloys
TT-I-735	– Isopropyl Alcohol
BB-O-925	– Oxygen, Technical, Gas and Liquid
BB-H-1168	– Helium, Technical

Cast Aluminum Structures Technology

M-XXXX	– Castings, Aluminum Alloy A357, Primary Aircraft Structure

Military

MIL-T-5021	– Tests, Aircraft Welders and Welding Operators Certification
MIL-H-6088	– Heat Treatment of Aluminum Alloys

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MIL-I-6866   - Inspection, Penetrant, Method of

MIL-A-18455 - Argon - Technical, Gas and Liquid

STANDARDS

MIL-STD-453 - Inspection, Radiographic

OTHER PUBLICATIONS

American Welding Society

AWS 5.12   - Tungsten, Arc Welding Electrodes

3. REQUIREMENTS

3.1 Equipment.

3.1.1 General. The welding equipment, such as welding machines, welding torches, regulators, flow meters, and filler metal feed mechanisms, shall be capable of making satisfactory welds when operated by a certified welder using the filler metal specified in 3.2.

3.1.1.1 Verification of equipment function. If, for any reason, the procuring activity representative doubts the capability of any welding equipment to function properly, he may require that verification tests be conducted using the questionable equipment.

a. The verification tests shall be selected by the representative from applicable tests specified in MIL-T-5021 or as he may otherwise specify.

b. The tests shall be performed by welder(s) certified for A357 cast aluminum alloy on the specific type of equipment in question and shall be selected by the representative.

c. If the results of these tests do not meet the requirements of MIL-T-5021, the questionable welding equipment shall not be used for welding on production castings until the necessary adjustments, repairs, or replacements have been made, and a second set of verification tests indicates satisfactory results.

3.1.2 Heating and cooling facilities.

3.1.2.1 Furnaces. Furnaces used for preheating castings prior to welding shall have suitable pyrometric controls as required by MIL-H-6088.

3.1.2.2 Cooling ovens. Cooling ovens shall be provided with suitable means for controlling the cooling rates to prevent damage to castings that have been preheated prior to corrective welding. Preheating furnaces may be used as cooling ovens providing they are capable of cooling rate control.

3.1.3 Prewelding preparation tools. Chipping, drilling, machining, gouging, and scraping tools used in the preparation of areas of castings for welding shall be kept sharp, clean, and otherwise maintained in good condition.

3.1.4 Protective equipment. Suitable protective equipment such as face shields, goggles, gloves, aprons, and ventilation facilities shall be used to protect personnel as may be required by the specific locality for the operation performed.

3.1.4.1 Ventilation equipment. Ventilation shall be provided in the welding area to protect all personnel from welding fumes and gases. Special precautions must be taken in the location and operation of such equipment to assure that the inert gas shielding envelope required to protect welds from atmospheric contamination is not disrupted.

3.2 Materials.

3.2.1 Filler metals.

a.   The as-deposited chemistry of filler metal used in the welding of castings shall conform to the nominal chemical composition of M-XXXX A357 aluminum alloy castings.

b.   Weld filler metal may be procured as wire in 36-inch lengths or continuous lengths procured level wound on spools.

3.2.2   Bare tungsten electrodes.   Bare tungsten electrodes for GTAW shall conform to the requirements of table I.

Table 1. Bare Tungsten Electrodes 1/

Classification		Procurement Specification	Usage 2/	AWS Color Code 3/
AWS Class	Type			
EWTh-2	2% thiorated	AWS 5.12 class EWTh-2	Preferred for DCSP GTAW	Red
EWZr	Zirconium	AWS 5.12 class EWZr	Preferred for AC GTAW	Brown

1/   Bare tungsten electrodes are classified on the basis of chemical composition.

2/   Unless otherwise specified in the certified procedure, the selection of the proper tungsten electrode is the user's option.

3/   Color coding is required and may be applied in the form of bands or dots, etc. at any place on the electrode, but the color material shall not cause adverse effects (such as porosity) on welds.

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3.2.3 Shielding gases. Shielding gases used in the corrective welding of A357 castings shall be as specified in table II.

Table 2. Shielding Gases

Gases	Specifications
Argon	MIL-A-18455
Helium	Federal Specification BB-H-1168 Grade A
Oxygen	Federal Specification BB-O-925 Type I or Type II
Gas mixtures	Purity of gases in mixtures shall be as specified for the individual gas.

3.2.4 Solvents. The cleaning and degreasing solvents listed in table III may be used for final cleaning prior to welding.

Table 3. Solvents

Solvent	Federal Specification
Acetone, technical	O-A-51
Aliphatic naphtha	TT-N-95
Methyl ethyl ketone	TT-M-261
Isopropyl alcohol	TT-I-735

3.2.5 Wire brushes. All wire brushes used in the precleaning or descaling operations prior to welding and after welding shall be of the AISI 300-series stainless steels and be maintained free from contaminants at all times by degreasing with one of the solvents listed in table III.

3.3 Required procedures and operations.

3.3.1 Casting preweld heat treat conditions. See 3.4.3 for recommended procedures.

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3.3.2 Preweld preparation. In the area to be welded, all defective material shall be completely removed by an appropriate method such as drilling, chipping, scraping, machining, gouging, etc.

a. The prepared area shall be made larger at the surface of the casting by sloping the sides at not less than 15 degrees with the vertical to the cast surface. This is necessary to achieve proper sidewall fusion for the depth of the hole.

b. The resulting surfaces on the prepared area shall be as free from sharp grooves, burrs, and feathery edges as practical.

c. The "as-cast" surface for a distance of at least 1 inch from the prepared area shall be removed by light scraping or wire brushing to remove scale oxides, imbedded sand, etc. to avoid contamination of the weld bead as it fairs into the casting.

d. All areas prepared for welding shall be carefully inspected by visual and penetrant methods to assure that defects such as cracks have been completely removed.

e. Immediately prior to welding, all prepared area surfaces and the surrounding area for at least 2 inches away shall be thoroughly degreased using one of the solvents listed in table III. After degreasing, the area shall be dried by using a clean lint-free cloth or by blowing with dry, oil-free air.

3.3.3 Preheating. When preheating is necessary to control porosity, cracking, etc., a temperature range of 150-300°F shall be used. The preheat temperature shall be maintained between passes during welding.

3.3.3.1 Method of heating.

a. The use of a furnace or oven as specified in 3.1.2 for preheating is preferred.

b. When it is not practical to place a large casting in a furnace or oven, preheating and interpass temperatures may be accomplished by the use of a gentle, soot-free flame. When a flame is used, the temperature gradient should be wide-spread and suitable pyrometric controls such as a pyrometer, temperature indicating sticks or liquid, etc. shall be employed. Care shall be exercised to avoid contaminating the intended weld area.

3.3.4 Weld fixtures. Weld fixtures that may be required for distortion control shall be kept clean and free from contaminants.

3.3.5 Welding. Welding shall be accomplished only by a certified welder using certified procedures in accordance with 3.5.

3.3.5.1 Welding processes. Only those processes allowed in 1. shall be used.

3.3.5.2 Weld shielding gases. The weld shielding gases used for repair welding shall conform to 3.2.3, table II. The exact gas or mixture and its flow rate shall be as developed and recorded on the approved welding procedure in accordance with the following requirements:

a. For GTA DCSP welding, the shielding gas shall be helium or helium-argon mixtures.

b. For GTA AC welding, the shielding gas shall be argon or argon-helium mixtures.

c. For GMA DCRP welding, the shielding gas may be argon, helium, argon-helium mixtures, argon with small percentages of oxygen, or argon-helium with small percentages of oxygen.

3.3.6 Postweld cooling. Cooling of castings after welding shall be accomplished slowly at a controlled rate to avoid distortion and possible cracking.

3.3.6.1 Oven or still air cooling. The use of a suitable furnace or oven as specified in 3.3.3 is preferred. However, in cases where preheating was done locally or it is impractical to place the casting in a furnace or oven, the casting shall be cooled in still air at room temperature or covered with a thermal insulating blanket.

3.3.7 Heat treatment. Except as allowed in 3.3.7.1, all castings shall be heat treated after welding to drawing and M-XXXX requirements in accordance with the general procedures outlined in MIL-H-6088.

3.3.7.1 As-welded condition. When they are identified on the drawing, certain areas of heat treated castings may be welded without postwelding re-heat-treatment.

3.3.8 Smoothness and weld contour. All welds shall fair into the adjacent metal in gradual, smooth transitions. Beads shall be smooth and free of slag, undercut, and excessive spatter. Sufficient weld metal shall be added to form a suitable fillet or backup. Excess metal shall be removed by shaving, machining, etc. in such a manner as not to create obscure defects that will show up during penetrant inspection.

3.3.9 Weld quality. All welds shall meet the nondestructive test requirements specified in 4.2.2.

3.3.10 Marking of welded castings. Each individual welded area of a casting shall be marked with the welder's identification number in a manner such that it will remain on the casting until it has passed final inspecton or permanently, depending upon the customer requirements.

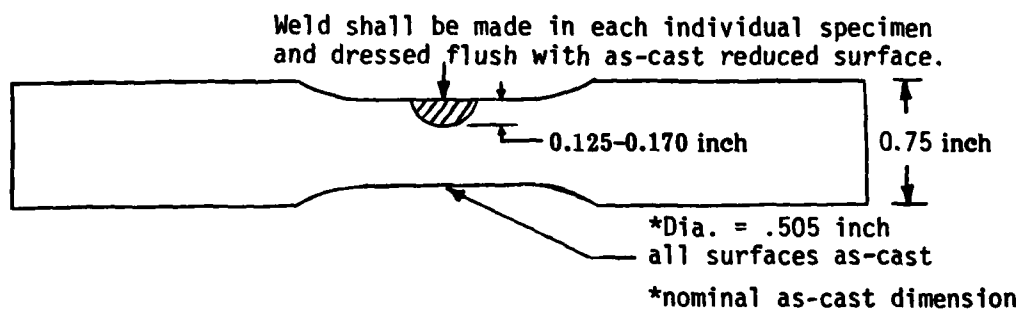3.4 Recommended procedures and operations.

3.4.1 Feasibility of correction by welding. The overall number and size of welds required on any one casting should be considered to determine if welding is economically feasible.

3.4.2 Additional NDT methods. Prior to welding, the prepared area may be inspected with additional nondestructive methods such as radiography, ultrasonics, or eddy current as necessary to assure that cracks have been completely removed and not just "smeared over" during defect removal.

3.4.3 Casting preweld heat-treat conditions. Whenever possible, welding should be accomplished only on castings in the "as-cast" or solution treated conditions. However, if it can reasonably be determined that satisfactory welds can be obtained in specific instances, welding may be performed on solution heat treated and aged castings. Consideration for re-heat-treating after welding shall be given in accordance with 3.3.7.

3.5 Certification of welds and welding procedures.

3.5.1 Welders certification. All welders shall be certified for aluminum alloys in accordance with MIL-T-5021, class A for each process to be used in production. Recertification shall be required every 6 months using a joint seven weld except a cast A357 test bar shall be used in lieu of the normal test piece. See figure 1.

Weld shall be made in each individual specimen and dressed flush with as-cast reduced surface.

0.125-0.170 inch

0.75 inch

*Dia. = .505 inch
all surfaces as-cast

*nominal as-cast dimension

Requalification Test Bar

Figure 1

Weld samples will be checked in accordance with MIL-T-5021. All X-rays and certification shall be retained on file and letter of certification shall be sent to the customer upon request.

3.5.2 Welding procedure certification. The welding procedures used for the correction of M-XXXX primary structural aluminum alloy casting produced by each contractor shall be certified. Certification will be accomplished on the first production lot of welded M-XXXX castings by the contractor demonstrating to the procuring activity by means of the tests required in 4. that the quality of the welded casting meets the requirements of 4.2.2(b).

3.5.2.1 No castings containing welds may be delivered until certification procedures have been granted in writing by the procuring activity or their representative.

4. QUALITY ASSURANCE PROVISIONS

4.1 Sampling, inspection, and tests.

4.1.1 General. All welded M-XXXX A357 aluminum alloy structural castings shall be subject to inspection by the authorized procuring activity representative or his designee who shall be given reasonable facilities to determine conformance with the requirements of this specification.

4.2 Sampling.

4.2.1 Welding procedure certification sampling. For consideration of procedures approval, the procuring activity representative shall select sufficient welded castings from the first lot of production parts to establish that the quality of the welded castings meets the requirements of 4.2.2(b). Insofar as practical, he shall select castings welded by different welders.

4.2.1.1 Procedure information and data. The following information, as applicable, shall be furnished with all welded castings submitted for consideration of approval of procedures.

a. Foundry or company doing the welding

b. Date welding was accomplished

c. Welding process (GTAW DCSP, GTAW AC, GMAW DCRP)

d. Manufacturer, type and serial number of welding machine, and torch

e. Type and purity of shielding gas (mixture percentages), flow rates, etc.

f. Filler wire composition and specification

g. Methods of preweld preparation (chipping, scraping, machining, drilling, etc.)

h. Preheat and interpass temperatures and method of application of heat for each

i. Postwelding method of cooling (oven or blanket), and rate.

j. Postweld heat-treat condition

k. Welder's name and identification number

l. Sketch of remanufactured casting showing welded areas (schematic)

m. Method of nondestructive inspection used after welding

n. Data from destructive tests (if required by procuring activity representative)

o. Company inspector name and stamp

4.2.2 Production inspection.

a. All welded castings shall be subjected to 100% inspection after heat treat using the inspection method(s) required for the casting by drawing and M-XXXX. If re-heat-treating is not required, only the weld and area within 1 inch of the weld need be inspected.

b. All welded castings shall meet the quality requirements specified on the drawing and in M-XXXX for the casting.

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4.3 Test methods.

4.3.1 Radiographic inspection. Radiographic inspection shall be performed in accordance with the procedures specified in MIL-STD-453 and as specified on the applicable drawing and in M-XXXX.

4.3.2 Penetrant inspection. Penetrant inspection shall be performed in accordance with MIL-I-6866 and as specified by the drawing and M-XXXX.

4.3.3 Destructive testing. The preparation of such microscopic and macroscopic specimens as may be required by the procuring activity representative to aid in evaluating preliminary welding techniques for production procedure and welder certification shall be in accordance with standard metallurgical practice. Microscopic examination shall be at 100 diameters magnification or higher.

4.3.4 Inspection responsibilities. Unless otherwise specified in the contract or purchase order, contractors are responsible for the performance of all inspection requirements as specified herein. Contractors shall have laboratory facilities for conducting the metallurgical, radiographic, penetrant, and other such test methods that are to be used to evaluate remanufactured casting quality. The contractor may, if he does not have the required facilities, engage those commercial laboratories necessary providing they are approved by the procuring agency.

4.3.5 Optional methods of inspection. The contractor may employ additional methods of inspection, such as ultrasonic and eddy current, that may not be specified on the drawing, to aid in determining the true nature of discontinuities.

5. This section is not applicable to this specification.

6. NOTES

6.1 Intended use. The process described by this specification is intended for use only in the correction of manufacturing imperfections in M-XXXX aluminum alloy A357 structural aircraft castings by fusion welding.

APPENDIX E

SPECIFICATION

D-XXXX

ALUMINUM ALLOY A357 CASTINGS,
DENDRITE ARM SPACING,
PROCESS FOR DETERMINATION OF

SPECIFICATION

ALUMINUM ALLOY A357 CASTINGS,
DENDRITE ARM SPACING,
PROCESS FOR DETERMINATION OF

1. SCOPE

1.1 This specification covers the procedures for determining the dendrite arm spacing (DAS) in M-XXXX A357 aluminum alloy castings in either the as-cast or heat-treated condition.

1.2 This specification describes a nondestructive test method for examining surface metallographic features of a casting to aid in the determination of its acceptability.

2. APPLICABLE DOCUMENTS

2.1 The following document of the issue in effect at the date of invitation for bid shall form a part of this specification to the extent specified herein.

SPECIFICATIONS

Cast Aluminum Structures Technology

M-XXXX –Castings, Aluminum Alloy A357, Primary Aircraft Structure

3. REQUIREMENTS

3.1 Equipment.

3.1.1 General. The testing equipment, such as polishing, replicating, and microscopic equipment, shall be capable of satisfactorily performing the required functions when operated by qualified personnel using the proper techniques.

3.1.2 Polishing equipment.

3.1.2.1 Portable mechanical polishing unit or electropolishing unit.

3.1.3 Microstructure replicating equipment. Transcopy (Max Erb Instrument Co.) or equivalent.

3.1.4 Photomicrographic equipment. Light microscope with camera attachment.

3.1.5 Portable microscope with 40X minimum magnification.

3.2 Materials.

3.2.1 Grinding and polishing materials.

3.2.1.1 Abrasive materials suitable for rough metallographic specimen preparation.

3.2.1.2 Polishing compounds of particle sizes suitable for preparing specimen for microstructural evaluation.

3.2.1.3   Electropolishing solution.   The recommended polishing solution is as follows:

Distilled water	120 ml
Tartaric acid	50 g
Ethyl alcohol	100 ml
Butyl cellosolve	100 ml
Perchloric acid (60%)	78 ml

3.2.2 Etching materials.

3.2.2.1 Chemical etching solutions.

3.2.2.1.1 Hydrofluoric acid, 0.5%, or Keller's etch.

3.2.2.2   Electroetching solution. The recommended etching solution is the same as the polishing solution in 3.2.1.3.

3.2.3 Replicating materials.

3.2.3.1 Plastic replica.

3.2.3.2 Replicating tape.

3.3 Required procedures and operations.

3.3.1 DAS test locations.

3.3.1.1 Castings. The location of DAS measurements shall be on one surface of the casting as close as possible to the center of the tensile coupon location as shown on the Engineering drawing. See example in figure 1.

3.3.1.2   Integral cast-on coupons.   A DAS measurement shall be taken on one surface at the center of each integral cast-on coupon. See example in figure 1.

3.3.1.3   DAS measurements also shall be made on the surface of the tensile specimen near the fracture after tensile testing during preproduction evaluation per M-XXXX.

3.3.2 DAS test procedure.

3.3.2.1   Test location preparation.   Surface preparation for all DAS measurements shall consist of prepolishing, final polishing, and etching to reveal the microstructure.

a   Microstructure shall clearly distinguish the dendrite arm spacing of the casting. Dendrite arm spacing is illustrated schematically in figure 2.

b.   If the test location is improperly polished, underetched, or overetched, it shall be repolished very lightly using the required abrasive specified in 3.2.1.1 and re-etched.

3.3.2.1.1 Prepolishing. Test locations shall be prepolished by grinding or sanding using the equipment specified in 3.1.2.1. Prepolishing should not remove more than 0.005 inch from the surface of the test location, but shall be sufficient to allow final polishing and etching to produce a detailed outline of the dendrite arm spacing.
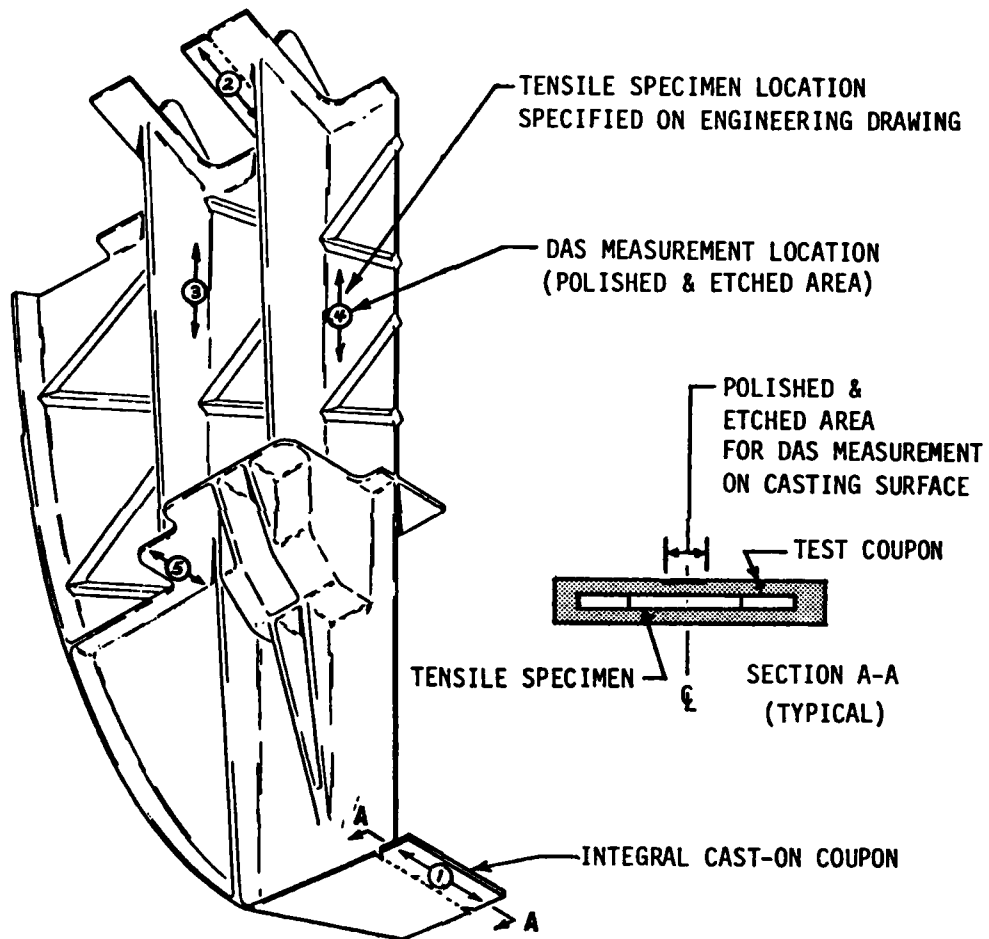
TENSILE SPECIMEN LOCATION
SPECIFIED ON ENGINEERING DRAWING

DAS MEASUREMENT LOCATION
(POLISHED & ETCHED AREA)

POLISHED &
ETCHED AREA
FOR DAS MEASUREMENT
ON CASTING SURFACE

TEST COUPON

TENSILE SPECIMEN

SECTION A-A
(TYPICAL)

INTEGRAL CAST-ON COUPON

FIGURE 1. TEST LOCATIONS
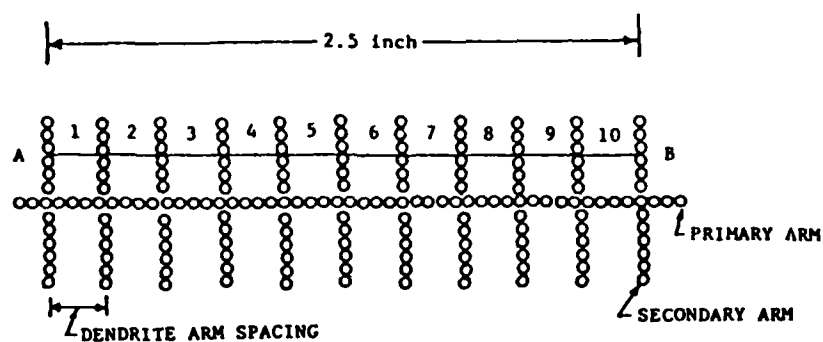
FIGURE 2. SCHEMATIC DIAGRAM OF DENDRITE ARM SPACINGS

3.3.2.1.2 Final polishing. Prepolished test locations shall be given a final polishing using either a mechanical polishing or an electropolishing method.

    a.   Mechanical polishing shall be performed using the equipment specified in 3.1.2.1 and the materials specified in 3.2.1.2.

    b.   Electropolishing shall be performed using the electropolisher specified in 3.1.2.1. The recommended polishing solution is listed in 3.2.1.3.

3.3.2.1.3 Etching. Etching shall be accomplished either by the chemical method or by electroetching.

    a.   Chemical etching shall be performed by swabbing the polished area with either 0.5% hydrofluoric acid or Keller's etch. Care must be exercised to prevent the etchant from coming into contact with other areas of the casting. Upon completion of etching, the area must be rinsed thoroughly with distilled water or acetone until all etchant is removed. The test area shall then be thoroughly dried. Use of Keller's etch must be limited to a maximum of 45 seconds to prevent overetching.

    b.   Electroetching shall be performed using units approved by the procuring activity. The recommended etching solution is the same as that used for electropolishing as specified in 3.2.1.3. Current density and etching time shall be sufficient to reveal the microstructure.

3.3.2.2 Microstructure replication. For the purpose of DAS measurements, the microstructure of the etched location on the casting and test coupons shall be transferred to a plastic replica using the equipment specified in 3.1.3 and standard replicating techniques.

    a.   "Shadowing" of the replica by vapor deposition to enhance the microstructure contrast is optional.

    b.   A 100X photomicrograph of the replica showing clearly defined dendrites shall be made using standard techniques and the equipment specified in 3.1.4.

    c.   The plastic replica and its photomicrographs shall be identified by test location and placed within an envelope that identifies the test casting represented.

    d.   After completion of the replicating operation, the test area of the casting shall be thoroughly cleaned with acetone and wiped dry with a clean, lint-free cloth to assure that residue and contaminants are removed.

3.3.2.3 DAS measurements. The DAS measurement shall be made by the intercept method which consists of drawing a straight line through the microstructure on the photomicrograph and counting the number of secondary dendrite arm spacings intercepting the line. DAS is calculated according to:

$$\text{DAS, in.} = \frac{\text{Length of intercept line (inches)}}{\text{No. of intercepting secondary arm spacings}} \times \frac{1}{\text{Mag.}}$$

3.3.2.3.1 Schematic presentation. A schematic presentation of dendrite pattern magnified 100 times is shown in figure 2. There are 10 dendrite arm spacings intercepting the line AB (2.5 inches long). DAS is calculated as follows:

$$\text{DAS, inches} = \frac{2.5}{10} \times \frac{1}{100} = 0.0025 \text{ inch}$$

3.3.2.3.2 Direction of measurements. At least two DAS measurements shall be made at each test location, including tensile specimens. The test area should be carefully scanned, and when possible, the measurements should be taken at angles approaching 90° to each other, but they may be parallel if necessary. Figure 3 shows typical DAS layouts, measurements, and calculations.

3.3.2.3.3 Calculated averages. The average DAS values shall be reported for each test location and for each area designated on the drawing (i.e., "critical" or "other") when there is more than one test location per area.

3.3.2.3.4 DAS acceptance criteria. The DAS for each designated area of a production casting for which the drawing requires a specific combination of ultimate strength, yield strength, and elongation (e.g., 50-40-5) shall be equal to or less than the maximum permissible DAS established for the same area during preproduction evaluation conducted in accordance with M-XXXX.

3.4 Recommended procedures and operations.

3.4.1 Test procedures.

3.4.1.1 Test location preparation.

3.4.1.1.1 Prereplication surface check. Prior to making a replica of the test location microstructure, it is recommended that preliminary checks of the prepolished, polished, and etched surfaces be made with the hand-held microscope specified in 3.1.5 to determine if the surface has been properly prepared before the next operation is conducted.

3.5 Certification of procedures and personnel. The casting supplier must receive certification of his DAS measurement procedures and personnel prior to the delivery of any casting made in accordance with M-XXXX. Any change in the certified procedures or personnel list will require recertification. To obtain certification or recertification, the supplier must submit the following information to the procuring activity:

3.5.1 Procedure certification. Submit documented procedures defining specific operations and equipment to be used, and copies of all reports or operation sheets used for recording results of DAS tests as specified in 4.3.

3.5.2 Personnel certification. Submit the names of candidate personnel and a brief resume of their qualifications and capabilities to accurately determine DAS measurements.
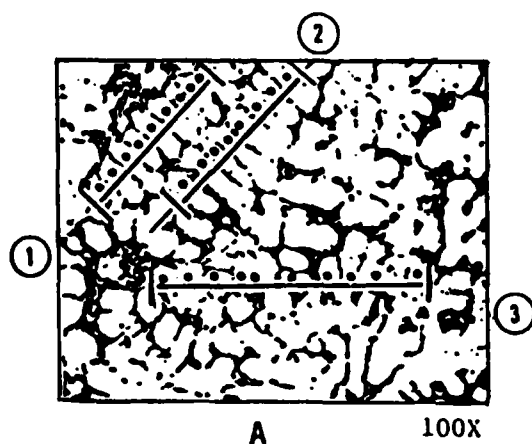
DAS, inch | DAS, inch

Location 1

$$DAS = \frac{1 \text{ inch Distance}}{9 \text{ Spacings}} \times \frac{1}{100}$$

DAS = 0.0011 inch

Location 2

$$DAS = \frac{1 \text{ inch Distance}}{8 \text{ Spacings}} \times \frac{1}{100}$$
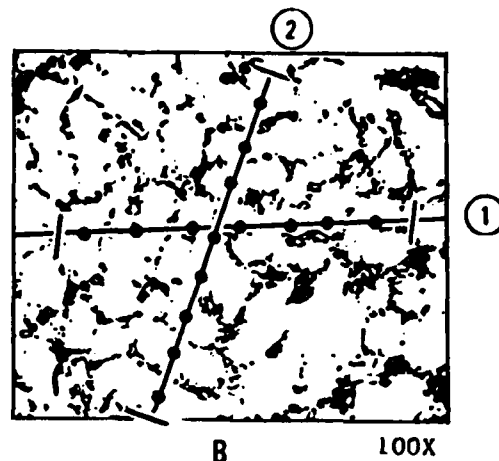
DAS = 0.0012 inch

Location 3

$$DAS = \frac{1.5 \text{ inch Distance}}{10 \text{ Spacings}} \times \frac{1}{100}$$

DAS = 0.0015 inch

Average of Area

$$DAS = \frac{0.0011 + 0.0012 + 0.0015}{3}$$

DAS = 0.0013 inch

Location 1

$$DAS = \frac{2 \text{ inch Distance}}{7 \text{ Spacings}} \times \frac{1}{100}$$

DAS = 0.0029 inch

Location 2

$$DAS = \frac{2 \text{ inch Distance}}{8 \text{ Spacings}} \times \frac{1}{100}$$

DAS = 0.0025 inch

Average of Area

$$DAS = \frac{0.0029 + 0.0025}{2}$$

DAS = 0.0027 inch

FIGURE 3. INTERCEPT METHOD OF DETERMINING DENDRITE ARM SPACINGS

4. QUALITY ASSURANCE PROVISIONS

4.1 Inspection responsibilities. Unless otherwise specified in the contract or purchase order, the casting supplier is responsible for the performance of all inspection requirements specified herein. Except as otherwise specified, the supplier may utilize his own facilities or those of a commercial laboratory acceptable to the procuring activity. The procuring activity has the right to perform any of the inspections set forth in this specification, including the destructive testing of selected production castings, when such inspection is deemed necessary to assure that supplies and services conform to prescribed requirements.

4.2 Maintenance of materials. The quality of all materials listed in 3.2 shall be periodically monitored to assure that they are of proper quality and consistency such that satisfactory results can be obtained with their use.

4.3 Certification of DAS procedures and personnel. For consideration of procedures and personnel approval, the casting supplier shall document the materials, operations, and steps required to conduct satisfactory DAS measurements for each casting of a different part number made in accordance with M-XXXX. The document shall include, but not be limited to, the following information derived from the preproduction evaluation:

a. Part number of casting

b. Laboratory conducting DAS tests

c. Date testing was conducted

d. Surface preparation equipment including prepolishing, polishing, etching, and replicating equipment

e. Materials including abrasives (type, e.g., paper or rubberized; size of grit), polishing compounds, etchants, type of replicating materials, etc.

f. Type and magnifying power of portable microscope

g. Metallographic equipment—type, name, and magnification used

h. Test report, including test locations, replicas, copies of photomicrographs showing DAS intercept lines, data sheets containing DAS calculations and results, with tensile data when required, and names of all personnel conducting procedures qualification DAS measurements

i. Resumes defining the qualifications of personnel conducting DAS measurements

j. Signatures of the casting supplier's representative

4.4 DAS testing instructions. DAS measurements shall be made on all preproduction and production castings as required by M-XXXX in accordance with the procedures and requirements of this specification.

4.5 Test reports. DAS measurements shall be reported on the same form as used to report the results of the tensile tests required by M-XXXX. When tensile tests are required, the results shall be reported with the corresponding DAS results.

4.6 Records. The plastic replicas and at least one legible copy of the corresponding photomicrograph showing the DAS measurements shall be kept on file at the testing facility for a period of 6 months except as specified in 4.6.1 or as specified in the purchase order.

4.6.1 DAS qualification casting records. A copy of the DAS test results, including the photomicrographs, from each preproduction qualification casting shall be forwarded to the procuring activity.

4.6.2 Production casting records. One copy of each DAS and tensile test report shall be forwarded directly to the procuring activity. In cases where a laboratory other than that of the casting supplier conducts the tests, a minimum of two copies of the test reports shall be forwarded to the casting supplier, one of which shall be forwarded to the procuring activity with the production castings.

5. PREPARATION FOR DELIVERY. This section is not applicable to this specification.

6. NOTES

6.1 Intended use. Dendrite arm spacing (DAS) measurements are intended for use as a nondestructive testing method to aid in determining that the strength and ductility of structural A357 castings made in accordance with M-XXXX meet the requirements of that specification and the Engineering drawing.

6.2 Definitions. The following terms and their definitions as applied to this specification are:

a. Dendrite arm spacing (DAS). The distance from the center of one secondary arm to the center of the adjacent secondary arm of a dendrite.

b. Tensile coupon. A cast-on appendage or a selected area of a casting that is designated to be destructively tested in tension.

c. Tensile specimen. The final configuration that is excised or otherwise prepared from the tensile coupon for testing.

REFERENCES

1.   Final Report, "Phase I (CAST)—Preliminary Design," Technical Report No. AFFDL-TR-77-36, May 1977.

2.   Final Report, "Phase II (CAST)—Manufacturing Methods," Technical Report No. AFFDL-TR-78-62, May 1978.

3.   Final Report, "Phase III (CAST)—Detailed Design," Technical Report No. AFFDL-TR-78-7, January 1978.

4.   Final Report, "Phase IV (CAST)—Fabrication of Demonstration Articles and Production Hardware," Technical Report No. AFFDL-TR-79-3029, March 1979.

5.   Final Report, "Phase V (CAST)—Structural Test and Evaluation," Technical Report No. AFWAL-TR-80-3021, April 1980.

6.   Frederick, S. F. and W. A. Bailey, "The Relation of Ductility to Dendrite Cell Size in a Cast Al-Si-Mg Alloy," Trans. of the Metallurgical Soc. of AIME, vol. 242, p. 2063, October 1968.

7.   Spear, R. E. and G. R. Gardner, "Dendrite Cell Size," AFS Trans. p. 209, 1963.

8.   Binder, H. F. et al., "Program for Evaluation of Effect of Dendrite Cell Size on Mechanical Properties of Aluminum Alloy Castings," Hughes Helicopters Report HH75-173, Report to U.S. Army Aviation Systems Command, Contract DAAJ01 74-C-0282, July 1975.

9.   Rice, R. C. and W. S. Hyler, "An Analysis of the Mechanical Properties of the A357 Aluminum Casting Alloy," AFS Trans., 78-117, p. 401, 1978.