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**CAST ALUMINUM STRUCTURES TECHNOLOGY (CAST)
STRUCTURAL TEST AND EVALUATION (PHASE V)
PART III—STATIC PROPERTY ALLOWABLES**

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Seattle, Washington 98124

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Final Report for Period June 1976-August 1979

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This document contains static mechanical properties of A257-T6 aluminum alloy castings. Properties of castings are relatable to non-destructively measured soundness and aluminum dendrite size. A criterion is developed for design properties in terms of these physical parameters applicable to all castings of the same alloy and temper regardless of size, shape, method of production, mold materials or other process variables.		

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FOREWORD

This report was prepared by the Boeing Military Airplane Company, Advanced Airplane Branch, Seattle, Washington under USAF Contract No. F33615-76-C-3111. The contract work was performed under project 486U under the direction of the Air Force 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 Air Force Materials Laboratory. The Air Force Project Engineer was John R. Williamson of the AMS Program Office, Structural Mechanics Division, Air Force Flight Dynamics Laboratories (AFWAL/FIBAA).

The Boeing Military Airplane Company, Advanced Airplane Branch, was the contractor, with Donald E. Strand as Program Manager, Donald D. Goehler as Technical Leader, and Cecil E. Parsons as Allowables Manager. This phase of the program was conducted by Dale L. McLellan assisted by James W. Faber, Frederick J. Feiertag, and Howard L. Southworth.

This report is Part III of a three-part report on Phase V activities. The contractor's report number is D180-25724-3. The report covers work from June 1976 through August 1979. Other work performed on the CAST program is 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 June 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

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NOMENCLATURE

A, B, C, D	radiographic soundness grades per ASTM E155
DAS	dendrite arm spacing
DCS	dendrite cell size
N	sample size
R	reduced property ratio
$\bar{X}$	sample mean
X_A	statistical A-basis tolerance limit
k	tolerance limit factor for a normal distribution and a specified probability, confidence and degrees of freedom
n	shape factor
r, $\bar{r}$	property ratio and average value
s	sample standard deviation
e/D	edge margin
α	confidence coefficient
ν	degrees of freedom
χ^2	chi-squared; a statistic

Properties	Allowables	
TUS	F_{tu}	tensile ultimate strength
TYS	F_{ty}	tensile yield strength
ELONG	e	total elongation
CYS	F_{cy}	compression yield strength
SUS	F_{su}	shear ultimate strength
BYS	F_{byr}	bearing yield strength
BUS	F_{bru}	bearing ultimate strength

TABLE OF CONTENTS

	Page
SECTION I. INTRODUCTION	1
SECTION II. TENSION PROPERTIES	3
1. General	3
2. Casting Geometry Effects	3
3. Foundry Variables Effects	4
4. Heat-Treatment Effects	12
SECTION III. ALLOWABLES DEVELOPMENT	21
1. General	21
2. Phase II Test Plan	21
3. Tension Allowables	26
4. Derived Properties	33
SECTION IV. ALLOWABLES ASSESSMENT	39
1. Bulkhead Tension Properties	39
2. Allowables Assessment	41
3. Supplemental Assessment	46
SECTION V. CONCLUSIONS AND RECOMMENDATIONS	53
REFERENCES	55
APPENDIX A. TEST SPECIMENS AND PROCEDURES	57
APPENDIX B. FOUNDRY VARIABLES	61
APPENDIX C. ELONGATION MEASUREMENTS	79
APPENDIX D. INTEGRAL COUPON PROPERTIES	83
APPENDIX E. STATIC MECHANICAL PROPERTIES DATA	91
APPENDIX F. CORRELATIVE PROPERTIES	111
APPENDIX G. DERIVED PROPERTIES	131
APPENDIX H. BULKHEAD COUPON DATA	139

LIST OF ILLUSTRATIONS

Figure		Page
1	Variations in Elongation with Thickness	6
2	Variations in Elongation with DAS	7
3	Foundry Variables, Heavy Lug	9
4	Effects of Foundry Variables on TUS and TYS	10
5	Effects of Foundry Variables on Elongation	11
6	Variations in TUS and TYS with DAS	13
7	Elongation Variations with DAS	14
8	TUS-TYS-ELONG Relationships for A356 Castings	16
9	TUS-TYS-ELONG Relationships for A357-T6 Castings	18
10	Tensile Property Trends for Aluminum Alloy Castings	20
11	Station 170 YC-14 Bulkhead	22
12	Part A Test Section	23
13	Part B Test Section	24
14	Average Strength Trends with Dendrite Arm Spacing and Soundness	27
15	Average Elongation Trends with Dendrite Arm Spacing and Soundness	28
16	Standard Deviations of TUS and TYS for A357-T6 Castings	30
17	Standard Deviations of Elongation for A357-T6 Castings	31
18	Derived Property Ratios	37
19	TUS Data Comparisons, Soundness Grade A	42
20	TUS Data Comparisons, Soundness Grades B and C	43
21	TYS Data Comparisons, Soundness Grade A	44
22	TYS Data Comparisons, Soundness Grades B and C	45
23	Elongation Data Comparisons, Soundness Grade A	47
24	Elongation Data Comparisons, Soundness Grades B and C	48
25	TUS Data Comparisons, Supplemental Tests	49
26	TYS Data Comparisons, Supplemental Tests	50
27	Elongation Data Comparisons, Supplemental Tests	51
28	Static Specimen Configurations	58
29	Forward Face, Boeing Part A Castings	62
30	Aft Face, Boeing Part A Castings	63
31	Details of Drag, Hitchcock Castings Part A	68

Figure		Page
32	Details of Cope, Hitchcock Castings Part A	69
33	Details of Part B	74
34	Pouring System, Boeing Part A and B Castings	78
35	Elongation Analysis	80
36	Relations between Integral Coupons and Casting TUS Properties	84
37	Relations between Integral Coupons and Casting Elongation Properties	85
38	Relations between Integral Coupons and Casting TYS Properties	86
39	Integral Coupon-Casting TYS Correlations, Integral Coupon X7, Part B Castings	89
40	Bulkhead Specimen Locations	140

LIST OF TABLES

Table		Page
1	<i>Manufacturing Variables--Thickness</i>	5
2	Phase II Allowables Specimen Quantities	25
3	Phase II Tension Property Statistics	29
4	CAST Program Tension Allowables	34
5	Derived Property Ratios Summary	35
6	Tensile Properties of Sta. 170 YC-14 Bulkheads	40
7	Chill Details, Boeing Part A	64
8	Ingate Details, Boeing Part A	65
9	Summary of Foundry Variables, Part A Boeing Castings	66
10	Ingate and Riser Details, Hitchcock Part A	70
11	Chill Details, Hitchcock Part A	71
12	Summary of Foundry Variables, Part A Hitchcock Castings	72
13	Ingate Details, Boeing Part B	75
14	Insulator Details, Boeing Part B	75
15	Chill Details, Boeing Part B	76
16	Summary of Foundry Variables, Part B Boeing Castings	77
17	Elongation Analysis	81
18	Static Mechanical Properties Data	93
19	Correlative Properties	112
20	Derived Property Ratio Analysis--Compression	132
21	Derived Property Ratio Analysis--Shear	133
22	Derived Property Ratio Analysis--Bearing Yield Strength $e/D=1.5$	134
23	Derived Property Ratio Analysis--Bearing Ultimate Strength $e/D=1.5$	135
24	Derived Property Ratio Analysis--Bearing Yield Strength $e/D=2.0$	136
25	Derived Property Ratio Analysis--Bearing Ultimate Strength $e/D=2.0$	137
26	Bulkhead Tensile Properties	141

SECTION I

INTRODUCTION

The purpose of the CAST program was to demonstrate that the use of high-strength aluminum alloy castings could be extended to primary structural components of airframe construction. The program objectives included efforts to establish structural and manufacturing technologies and to demonstrate the integrity, producibility, and reliability of representative cast airframe structures. One specific objective was to establish realistic static design allowables and to eliminate the need for using casting design factors.

Castings were obtained during Phase II, Manufacturing Methods, for purposes of developing a static data base from which allowables were 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. Section II of this report contains the results of these evaluations, concluding with a physical parameter basis for allowables development. Section III presents tension allowables and derived properties for compression, shear, and bearing developed during Phase II.

An assessment of tension allowables was made in Phase V, Structural Test and Evaluation. Four of twenty YC-14 bulkheads produced in Phase IV, Fabrication of Demonstration Articles and Production Hardware, were sampled for tensile coupon properties and physical parameters. Results of this assessment are contained in Section IV of this report. These evaluations show that realistic static design allowables of high-strength aluminum alloy castings can 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.

SECTION II

TENSION PROPERTIES

1. GENERAL

This section reports results of examinations of tensile property variations in relation to the following parameters:

1. Casting geometry (thickness)
2. Foundry variables (distances from ingates, risers, chills, etc.)
3. Heat treatment

From these evaluations, TUS and ELONG dependencies are established with dendrite arm spacing (DAS) and X-ray soundness grade as defined by ASTM E155 standards. In addition, supplemental data for both A357 and A356 casting alloys indicates that TYS variations are related to the artificial aging conditions of the heat-treatment process.

2. CASTING GEOMETRY EFFECTS

Phase II provided an excellent opportunity to determine whether tensile properties are related to casting geometry. Geometry was represented by the thicknesses of casting zones. Section III contains a complete description of Phase II test castings, referred to as Parts A and B.

The effects of casting-zone thickness on tensile properties observed in Phase II were:

1. TUS increases with thickness (Part A castings)
2. TUS decreases with thickness (Part B castings)
3. TYS does not vary with thickness
4. ELONG increases with thickness (Part A castings)
5. ELONG decreases with thickness (Part B castings)

These results are shown in Table 1.

Elongation data for thickness extremes in Table 1 are shown in Figure 1. The trends of increasing ELONG with thickness for Part A castings and decreasing ELONG with thickness for Part B castings are clearly identified. Elongation of A357-T6 does not develop a consistent function with casting-zone thicknesses for these parts. Within each thickness band, a range of ELONG values suggests a relatively large scatter. Two physical characteristics of these materials are offered as an explanation for interpreting these results. Each ELONG result is identified by the DAS and soundness grade. In both thin and thick regions, it is apparent that the smallest DAS and highest soundness (grade A) result 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. It therefore seems reasonable, as an initial effort, to categorize ELONG (and TUS) according to levels of DAS and soundness. Figure 2 shows the soundness grade A results of the previous diagram related to DAS.

The amount of scatter in this trend band could be due to any of the following items:

1. Natural ELONG scatter
2. Errors in test and/or measurement of ELONG
3. Errors in DAS measurement
4. Unidentified gradations within ASTM soundness grade A
5. Other unidentified physical or metallurgical characteristics

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

3. FOUNDRY VARIABLES EFFECTS

At the onset of the program, it was considered that tensile properties might be relatable to manufacturing parameters. Earlier efforts by Battelle, per reference 1, had shown that tensile properties of A357-T6 castings could be separated into categories described by distances from chills and risers. They concluded that this approach was instructive, but not feasible or desirable.

TABLE 1 MANUFACTURING VARIABLES -- THICKNESS

Section Thickness (in.)	Part A								Part B			
	Boeing				Hitchcock				Boeing			
	Qty.	TUS (ksi)	TYS (ksi)	EL. (%)	Qty.	TUS (ksi)	TYS (ksi)	EL. (%)	Qty.	TUS (ksi)	TYS (ksi)	EL. (%)
.10	34	46.0	40.8	2.0	44	46.7	40.8	1.8	34	47.8	40.8	3.6
.20-.25	28	47.5	41.2	2.2	25	47.1	40.4	2.4	10	51.2	42.5	5.1
.30	8	48.3	41.2	3.0	10	49.1	41.0	3.6	35	47.9	41.5	2.8
.50	7	47.4	41.1	3.0	10	47.8	39.2	4.3	10	46.4	42.0	1.2
1.0	7	48.8	40.9	4.2	9	49.4	39.9	5.1	10	45.2	40.2	1.2
2.0	16	48.5	40.2	5.2	20	48.5	40.2	4.2	0	-	-	-
3.0	0	-	-	-	0	-	-	-	10	44.9	40.1	1.2
Casting Average	100	47.3	40.9	2.9	118	47.6	40.4	3.0	109	47.5	41.2	2.8

Note: Integral coupon data not included.

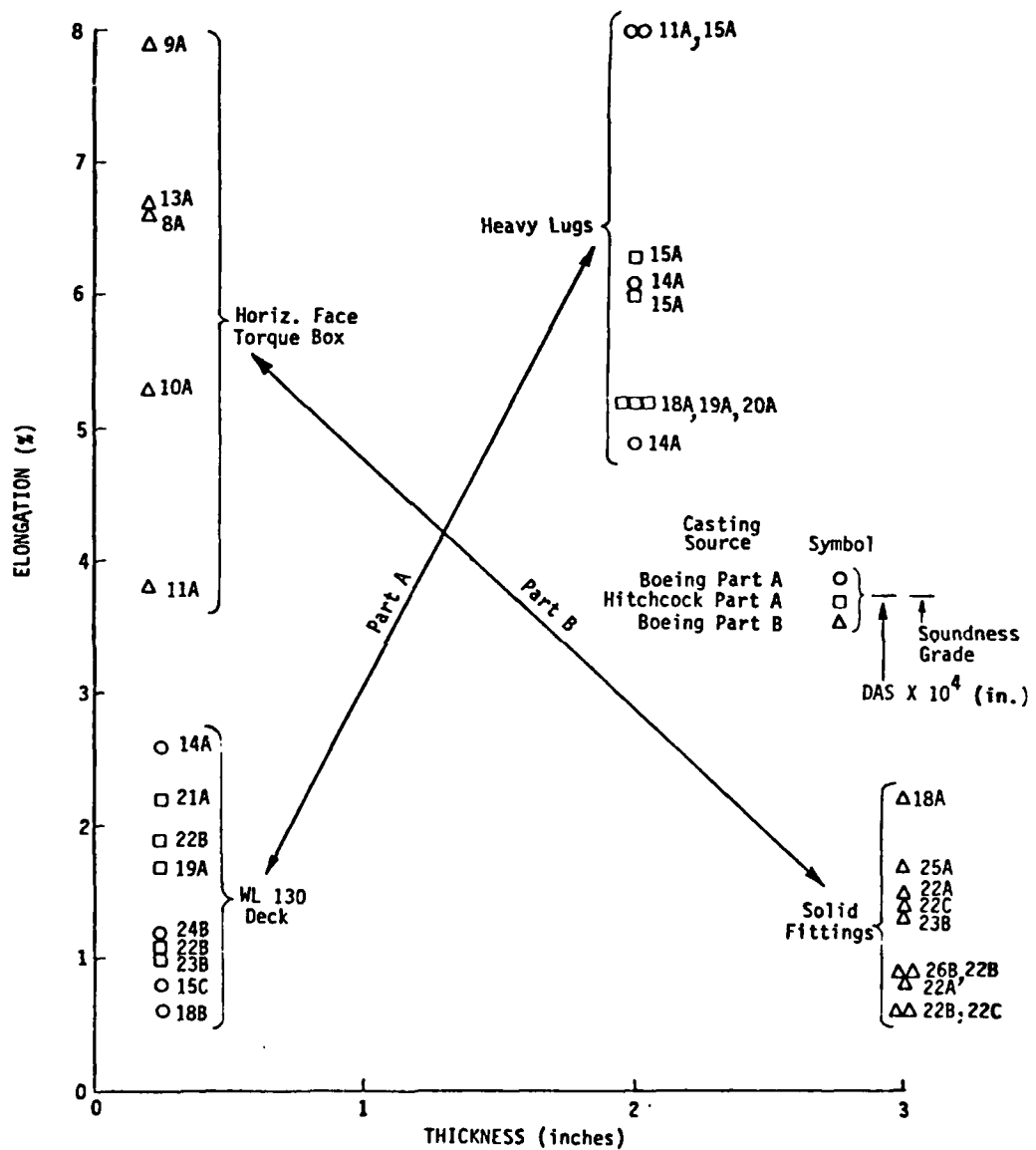


FIGURE 1 VARIATIONS IN ELONGATION WITH THICKNESS
A357-T6 CAST

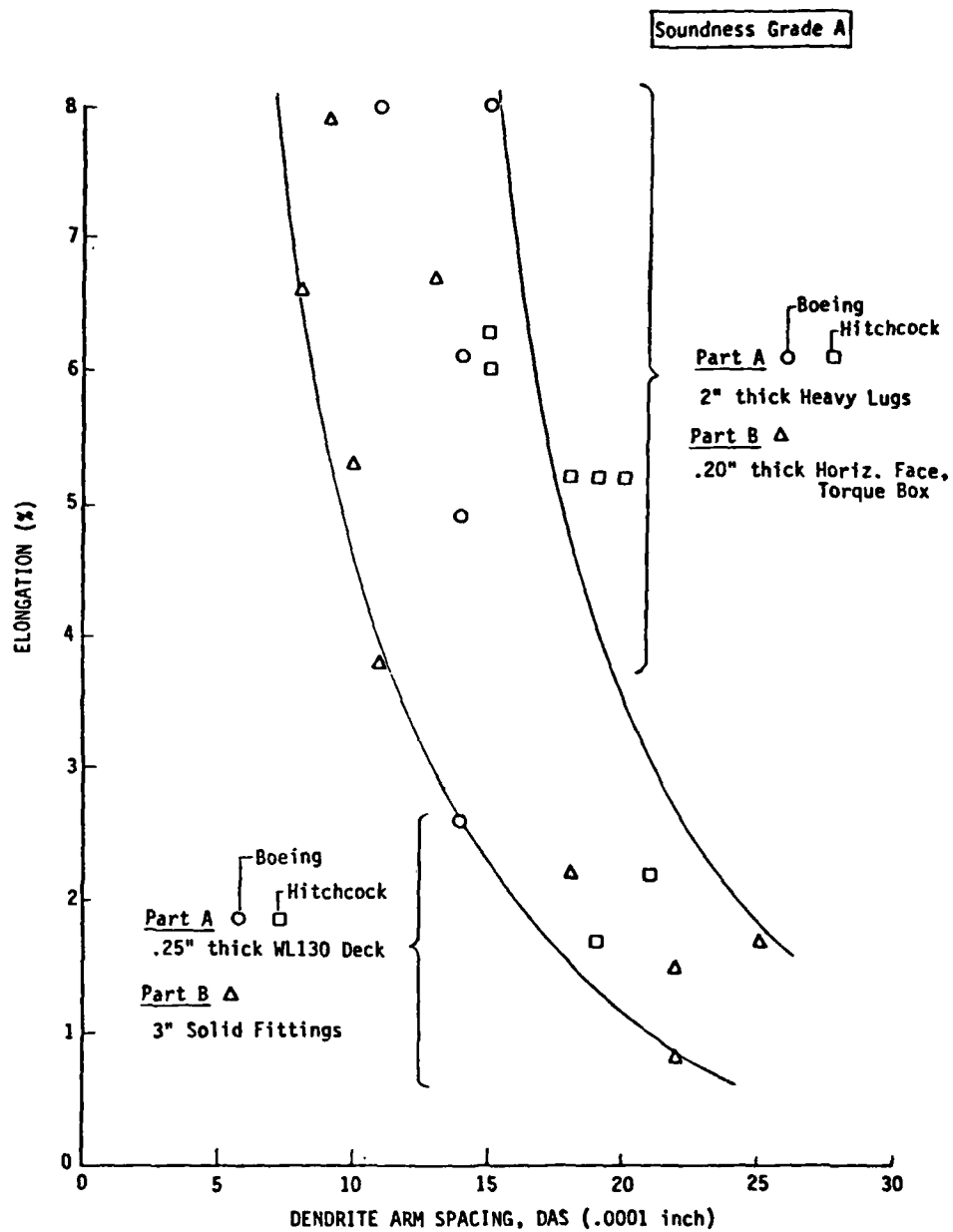


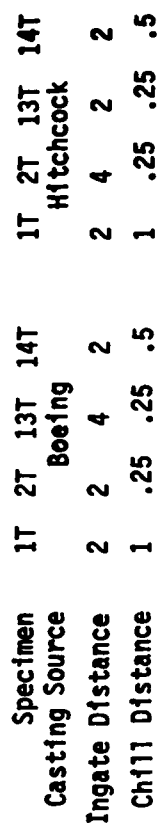
FIGURE 2 VARIATIONS IN ELONGATION WITH DAS
A357-T6 CAST

To confirm the Battelle conclusion, tensile properties from the heavy lugs of Phase II Part A castings were categorized according to distances from ingates and chills. Riser distance was not included because the Boeing castings, with the patterned mold cavity situated vertically, contained no risers. Figure 3 shows the heavy lug tensile coupons locations common to both Boeing and Hitchcock castings. Compression, shear, and bearing coupons have been omitted for clarity. Each lug surface that was directly chilled is identified with chill material type, size, and location.

The lug is shown positioned according to the pouring method used by Boeing with a horizontal ingate. Hitchcock castings were poured with the mold cavity in a horizontal plane. Their ingating and risering are also identified in the figure. Specimens from the two foundry products were the same distances from ingates and chills although chill sizes and materials differed. These differences in manufacturing methods were designed to enable selection of the best approach to produce complete bulkheads in Phase IV.

Lug tensile properties are shown in Figures 4 and 5 plotted against distances from chills and ingates. In Figure 4, both TUS and TYS are shown on the same ordinate scale. TUS data at each chill distance location form a 2- to 3-ksi band. TUS results at 2-inch distance from the ingate form a 4-ksi band and essentially envelop those results at the 4 inches from ingate location. The trends in TUS and TYS for distance from chills are inconclusive. Based upon the physical trends for DAS and soundness with tensile properties provided in the preceding discussion for thickness effects, it is expected that TUS would (1) decrease with distance from chills and (2) increase with distance from ingates. These trends cannot be fully confirmed with these data, probably because of chilling and ingate insulating opposing interactive effects.

Figure 5 shows lug ELONG results. The trends appear to be the same as shown for TUS with distances from chills and ingates. This is consistent with the trends for ELONG and TUS relative to thickness influences. Information presented in both of these figures supports the Battelle conclusion that such a method for categorizing tensile properties is not desirable.



Dimensions in inches

Foundry	Chill Types	Code Letter	Material
Boeing	Form & Rect.	Cxx	Copper
Hitchcock	Normal	Nxx	Cast Iron
"	Form	Fxx	70000 Manganese Bronze

FIGURE 3 FOUNDRY VARIABLES, HEAVY LUG
Part A Castings
A357-T6
CAST

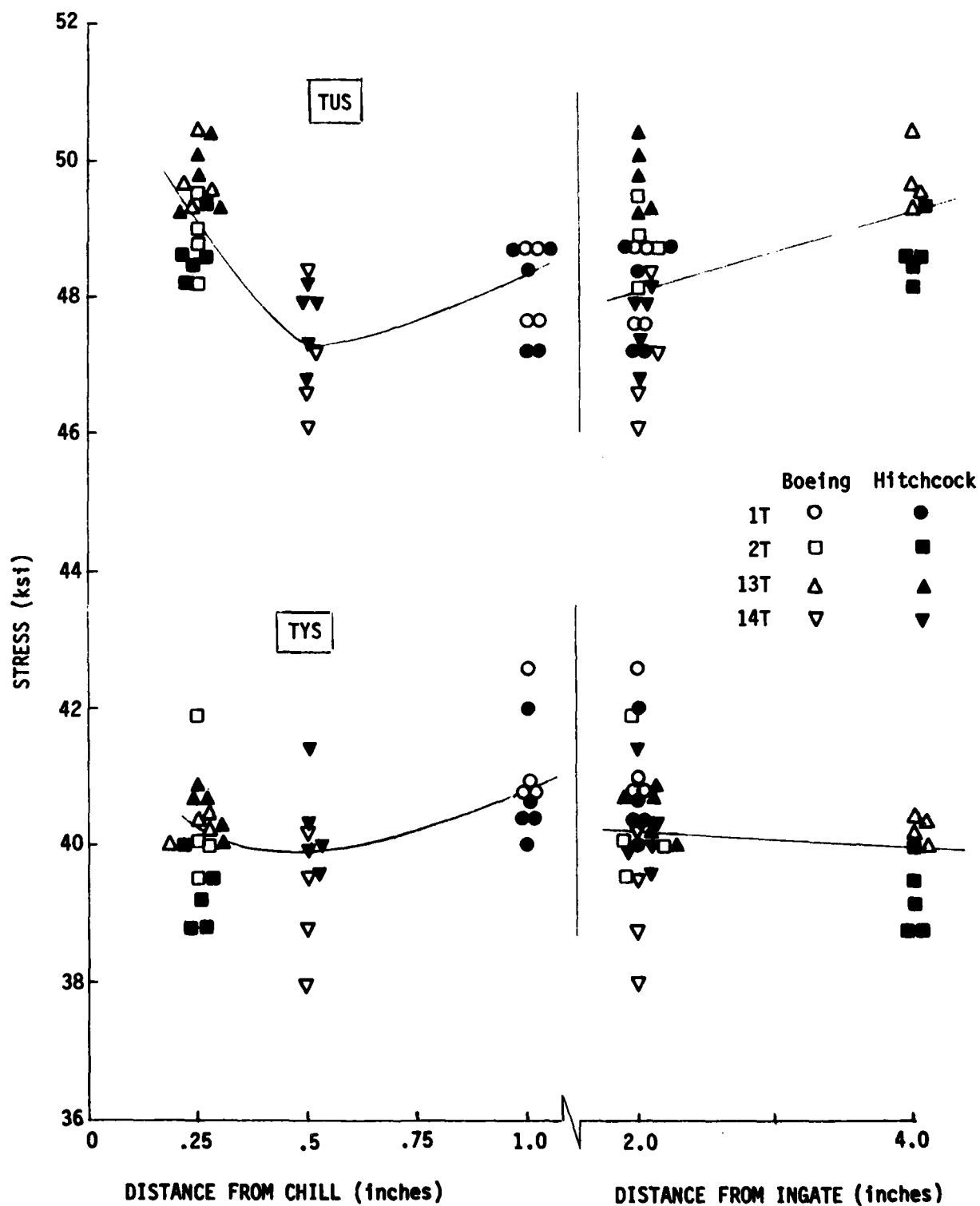


FIGURE 4 EFFECTS OF FOUNDRY VARIABLES ON TUS AND TYS
A357-T6
Heavy Lugs, Part A Castings

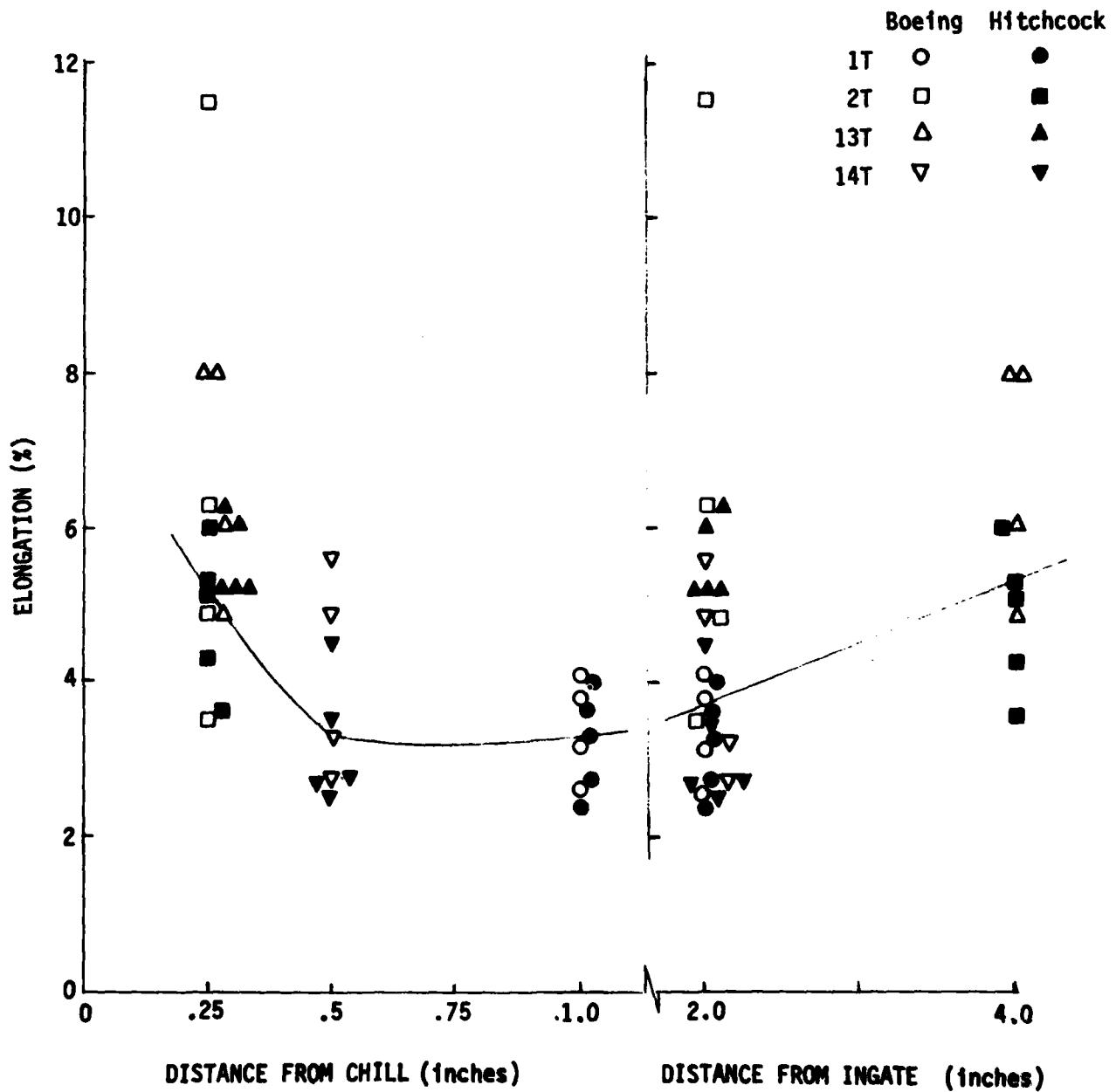


**FIGURE 5 EFFECTS OF FOUNDRY VARIABLES ON ELONGATION
A357-T6
Heavy Lugs, Part A Castings**

These same data have been replotted in Figures 6 and 7 as functions of DAS. The decreasing TUS and ELONG and invariant TYS relations established with DAS previously in the discussion of thickness effects are also demonstrated with these data. Essentially all results represent specimen soundness grade A material. Only three of the thirty-six results are for soundness grade B. The finite TUS and ELONG bands describe the possibilities of unidentified gradations within grade A soundness or other test or measurement uncertainties previously mentioned. TYS shows no relation with DAS as was also the case with data for various casting thicknesses. These results support a dual-basis DAS/soundness concept for categorizing TUS and ELONG properties.

4. HEAT-TREATMENT EFFECTS

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. Significant variations were measured for TYS from different zones of castings produced in both Phases II and IV. However, the average TYS value from Phase II castings seemed to be invariant for different levels of DAS and soundness grades. It would be beneficial to understand the cause of differences between individual measurements to establish realistic allowables. The amount of process control required to establish consistency should also be determined for both specification controls and to insure the applicability of allowables.

A356 is the predecessor alloy of A357 and contains approximately one-half the magnesium content of the newer alloy. A356 contains no beryllium, whereas A357 does. Two sources of A356 data were available from which individual tensile test results could be analyzed with reference to dendrite cell size (DCS) and some heat-treatment effects.

Prior to a discussion of these effects, a few comments are required to establish a graphical format suitable to demonstrate relative influences of heat treatment, dendrite measurement (DCS or DAS), and soundness on each of the three tensile properties. Without exception, all observed A356 and A357 data, including all test results from the CAST program, demonstrate a common characteristic.

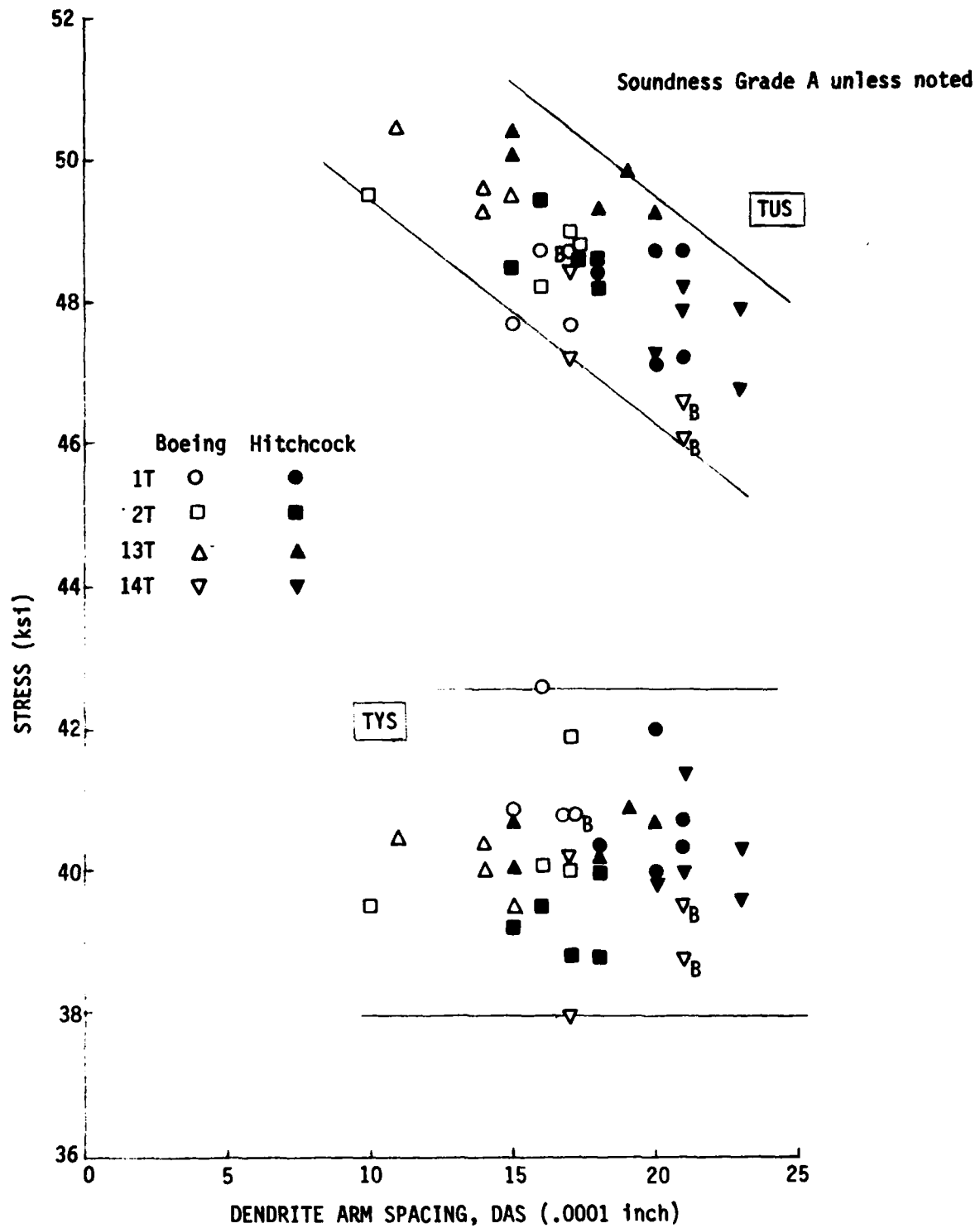


FIGURE 6 VARIATIONS IN TUS AND TYS WITH DAS
A357-T6 CAST
Heavy Lugs, Part A Castings

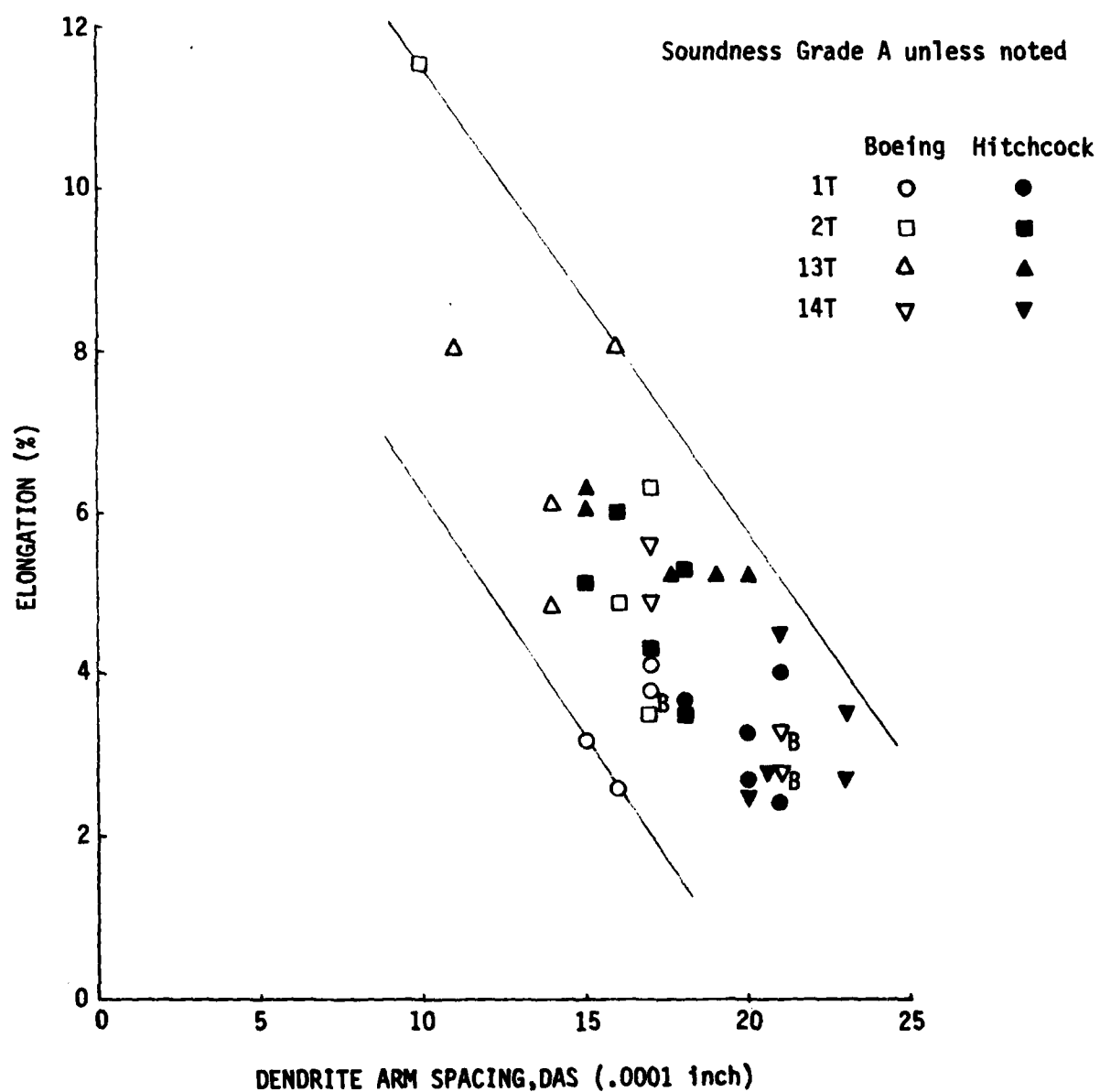


FIGURE 7 ELONGATION VARIATIONS WITH DAS
A357-T6 CAST
Heavy Lugs, Part A Castings

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 has been conveniently determined that the plastic portion of the curve can be described analytically by the following power function:

$$\text{ELONG} = 0.2(\text{TUS}/\text{TYS})^n$$

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.

Two sources of A356 casting tensile data are illustrated in Figure 8 using the above nondimensionalized strength-elongation format. Frederick and Bailey (ref. 2) provided A356-T6 tensile properties for two artificial aging temperatures, 320°F and 350°F. All other conditions of manufacture and processing were the same. The aging temperature causes a shift from ($n = 13$) to ($n = 22$). Spear and Gardner (ref. 3) provided tensile properties for material identified as A356-T62. The -T62 temper signifies user heat treatment that may produce different mechanical properties. At first, it would appear that the mechanical properties of the A356-T62 and those of the 320°F aged A356-T6 are the same. DCS values have been added to these plots to show general agreement between the two sets of data described by ($n = 13$). Actually, there is a larger difference between the mechanical properties from the two data sources at ($n = 13$) than there is between the two aging temperature conditions distinguished by ($n = 13$) and ($n = 22$).

	<u>$n = 13$</u>		<u>$n = 22$</u>
Temper:	-T62	-T6	-T6
Age:	NA	320°F	350°F
TUS (ksi)	35 to 42	43 to 51	45 to 51
TYS (ksi)	29 to 32	34 to 37	41 to 43
ELONG (%)	2 to 14	3 to 15	1 to 11

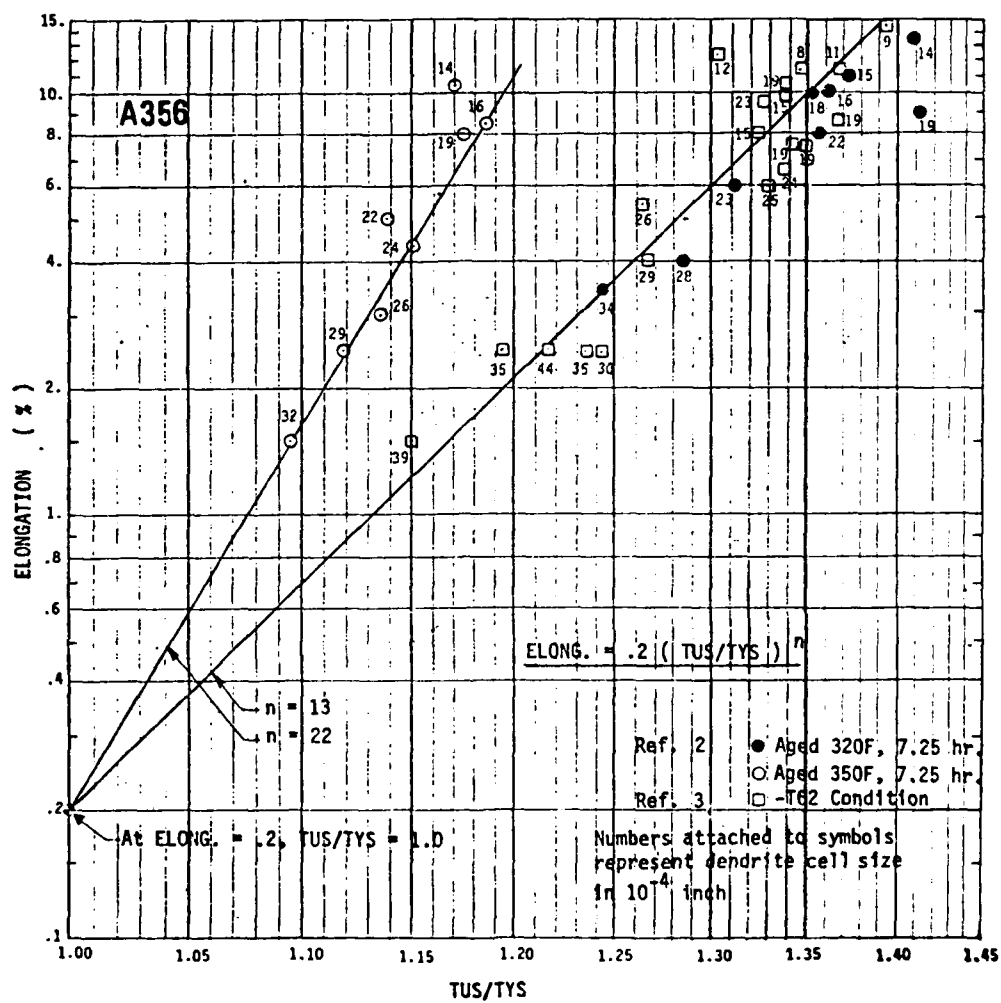


FIGURE 8 TUS-TYS-ELONG RELATIONSHIPS FOR A356 CASTINGS

Apart from the differences in properties at the ($n = 13$) condition, it would appear that TYS and shape factor are changed by heat treatment. This is shown by the increase in TYS from the 320°F to the 350°F aging temperature and the shift from ($n = 13$) to ($n = 22$). The general characteristics of this diagram are shifts along a constant shape-factor line for different DCS values (and soundnesses as found with A357-T6 CAST data) and differing shape factors for different aging conditions.

The characteristics identified with A356 can be applied to A357 tensile properties. Battelle Columbus Laboratories, under subcontract to Boeing on this program, supplied in excess of 5000 tension test results from A357-T6 castings. Data sources included 15 cooperating foundries and airframe companies supplying properties from 47 different parts. Data were categorized into 14 (TUS/TYS/ELONG) groups including the four described in procurement specification MIL-A-21180C. These data are summarized in reference 1. Other than tensile properties, most test results were identified by foundry source, mold type, and thickness of the tested zone.

Although statistics were supplied by Battelle for data of each category, a complete reanalysis was performed to evaluate normality, compute representative statistics, and determine the acceptability of data according to specification requirements of each (TUS/TYS/ELONG) set of data. Both TUS and TYS seem to follow linear normal trends, whereas ELONG fits normality best when logarithmically transformed. Recomputed statistics of reference 1 data have been combined with Phase II results in Figure 9. Phase II data were categorized into four DAS levels and four soundness grades. The result shows three trends, each identified by a different shape factor ($n = 14$, 16, and 18.5). All of the CAST data groups and a few of those from Battelle can be described by the shape factor of ($n = 16$). The majority of Battelle-reported data groups are split into two outer bands described by ($n = 14$) and ($n = 18.5$). Using the CAST data, both DAS and soundness produce different coordinates along a single shape-factor line and these parameters have interchangeable influences. Low soundness and small DAS can produce the same ELONG and TUS (assuming TYS remains constant) that is obtained with higher soundness and a larger DAS.

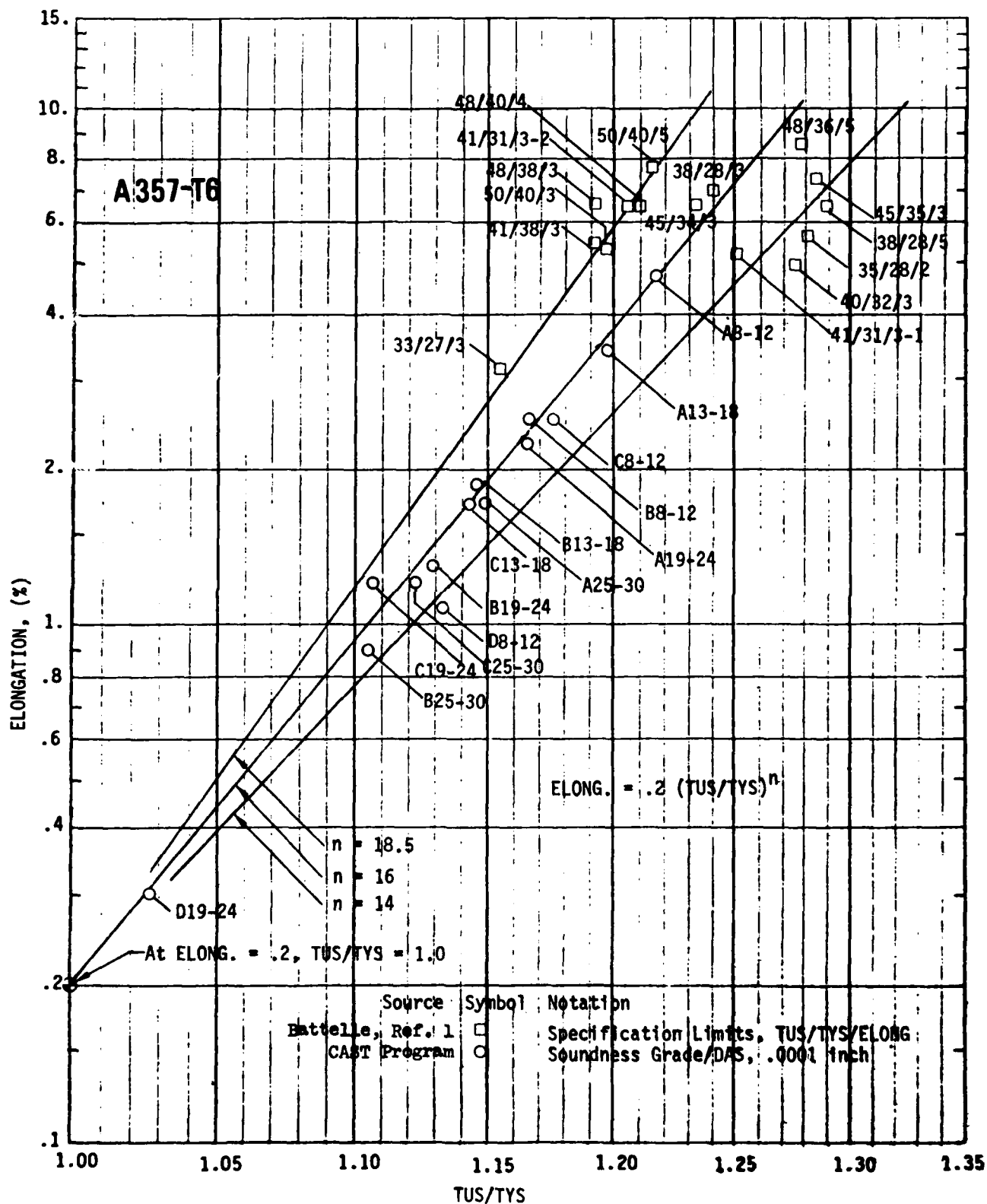


FIGURE 9 TUS-TYS-ELONG. RELATIONSHIPS FOR A357-T6 CASTINGS

Basic characteristics demonstrated in ELONG versus TUS/TYS diagrams for both A356 and A357 alloys can be combined. Figure 10 shows the composite plot for both materials and the trends they develop. As the artificial aging temperature is increased, both TYS and shape factor (n) increase. A357-T6 results from Hughes (ref. 4), supplemented by TYS results via personal communique that were not officially reported, were analyzed and have been added to this composite diagram.

Boundaries are 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.

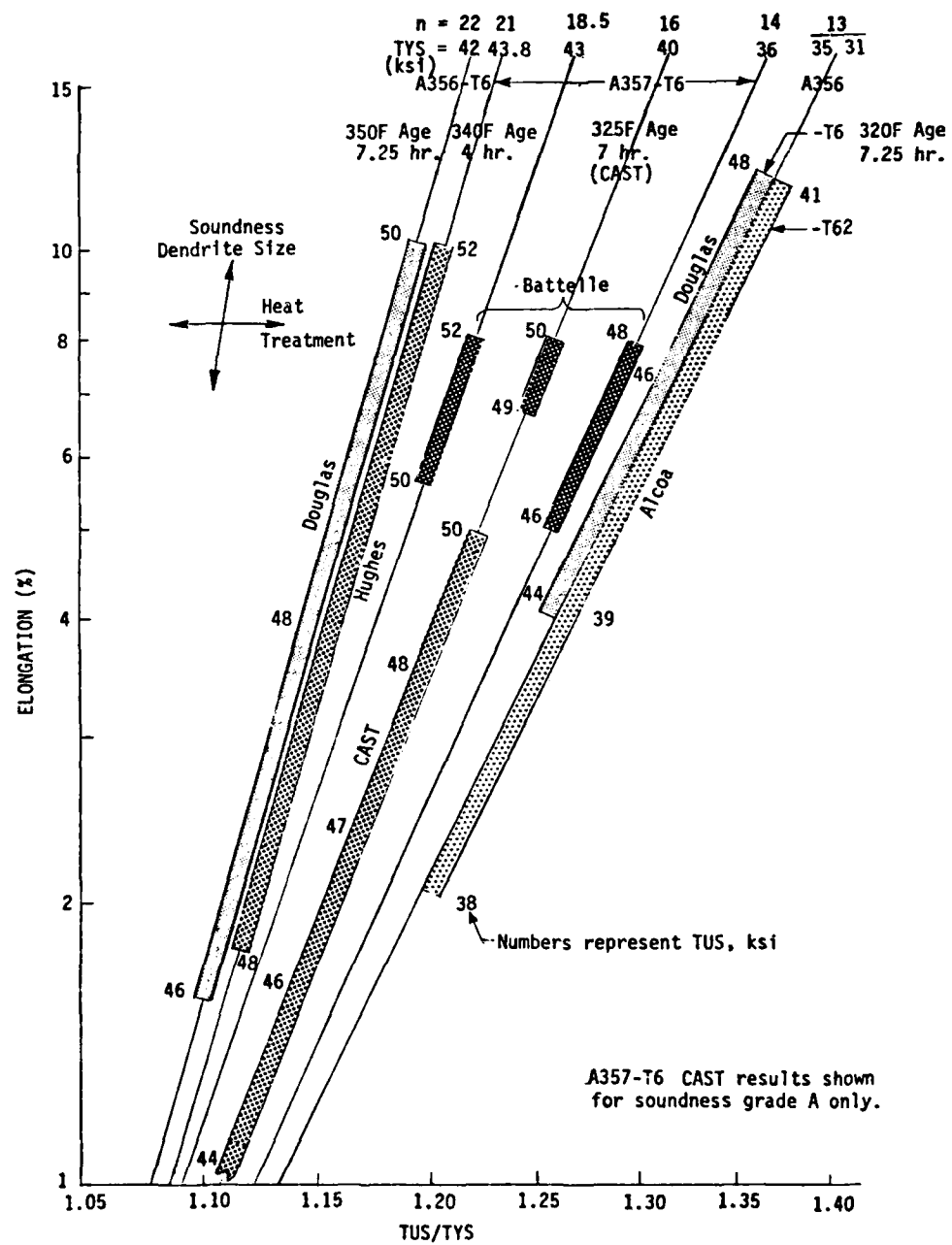


FIGURE 10 TENSILE PROPERTY TRENDS FOR ALUMINUM ALLOY CASTINGS

SECTION III

ALLOWABLES DEVELOPMENT

1. GENERAL

In this section, the Phase II data base, supplemented by Battelle-gathered data per reference 1, are used to establish allowables for the CAST bulkheads and a format for the general category of A357 castings.

2. PHASE II TEST PLAN

Fourteen bulkhead segment castings produced in Phase II were cut up for testing and analysis to develop a static design properties data base. These 14 segments consisted of two different portions of the bulkhead as shown in Figure 11. Boeing produced four of the Part A segments and five of the Part B segments. Hitchcock Industries produced five of the Part A segments. The segments shown in Figures 12 and 13 were representative of Phase I preliminary concepts of the full-size bulkhead design. Figures 12 and 13 also illustrate static specimen locations. The primary emphasis was given to tension coupons representing all zones of each part configuration. Compression, shear and bearing coupons were located in adjacent casting zones to develop derived properties. All coupons located in the Hitchcock Part A castings duplicated those of the Boeing Part A castings to evaluate potential differences between foundries.

Table 2 identifies target classes and soundnesses for all casting zones. These targets were designated for test purposes only and do not reflect actual design requirements for the bulkhead. The intent in setting these tests standards was to evaluate the capability of producing the highest strength/elongation and soundness grades in the most massive and difficult casting zones.

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.

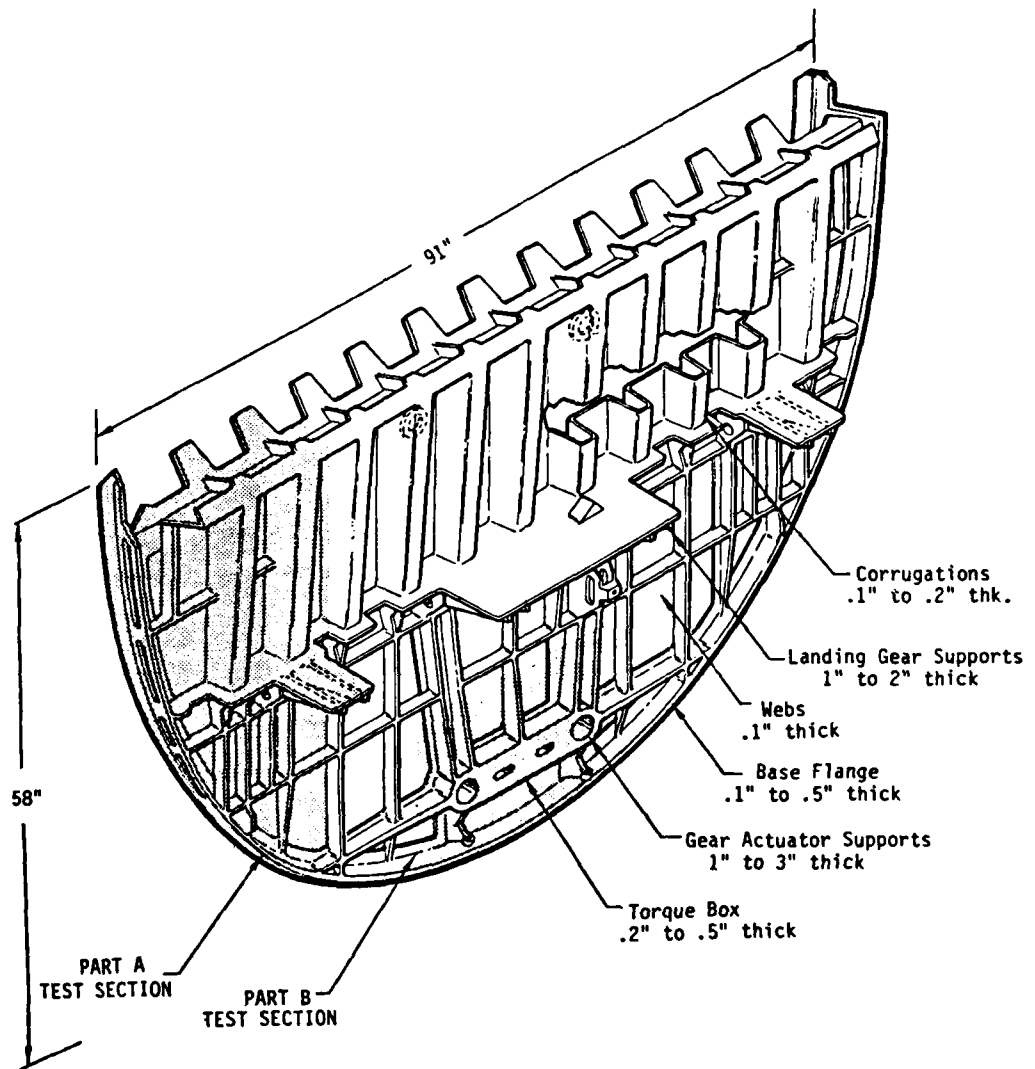


FIGURE 11 STATION 170 YC-14 BULKHEAD
Aft Side A357-T6 Casting

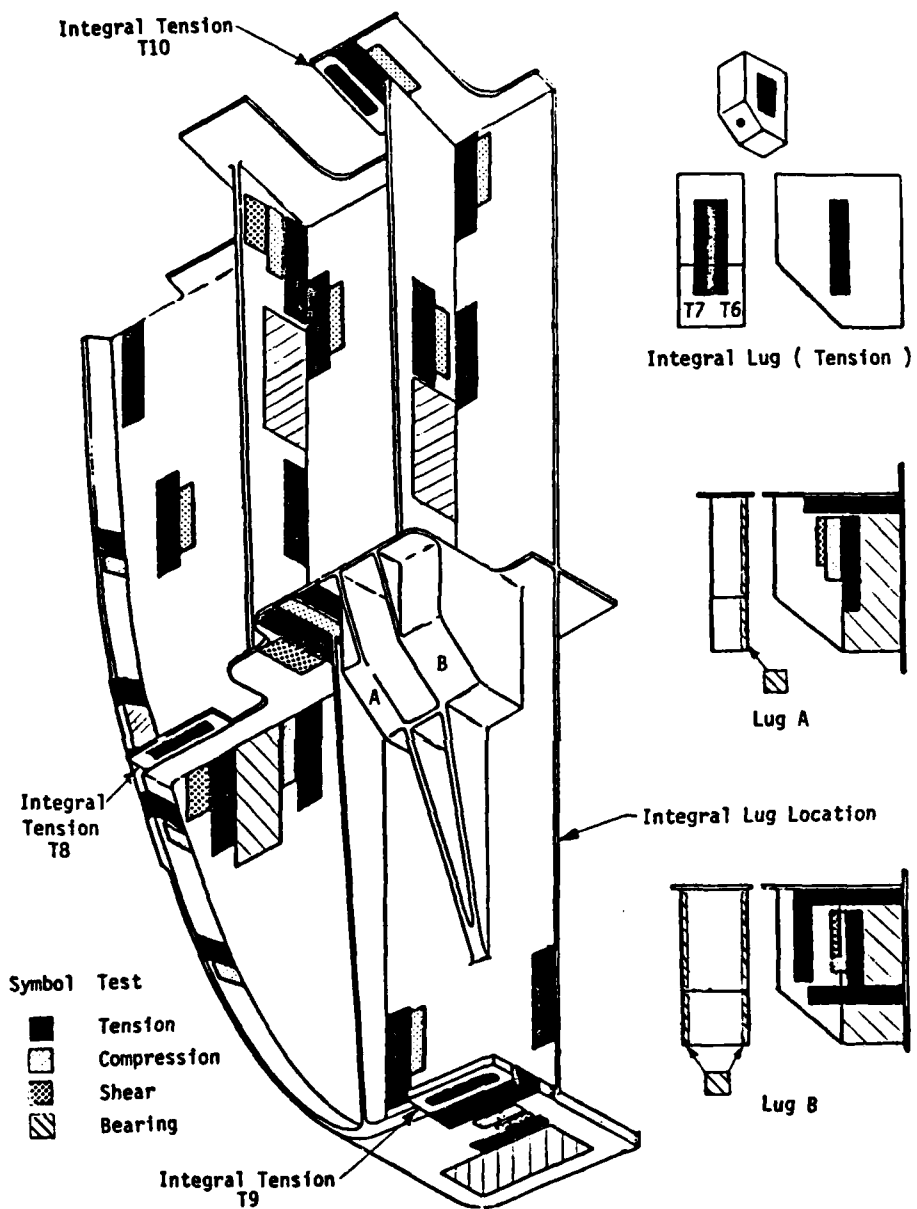


FIGURE 12 PART A TEST SECTION

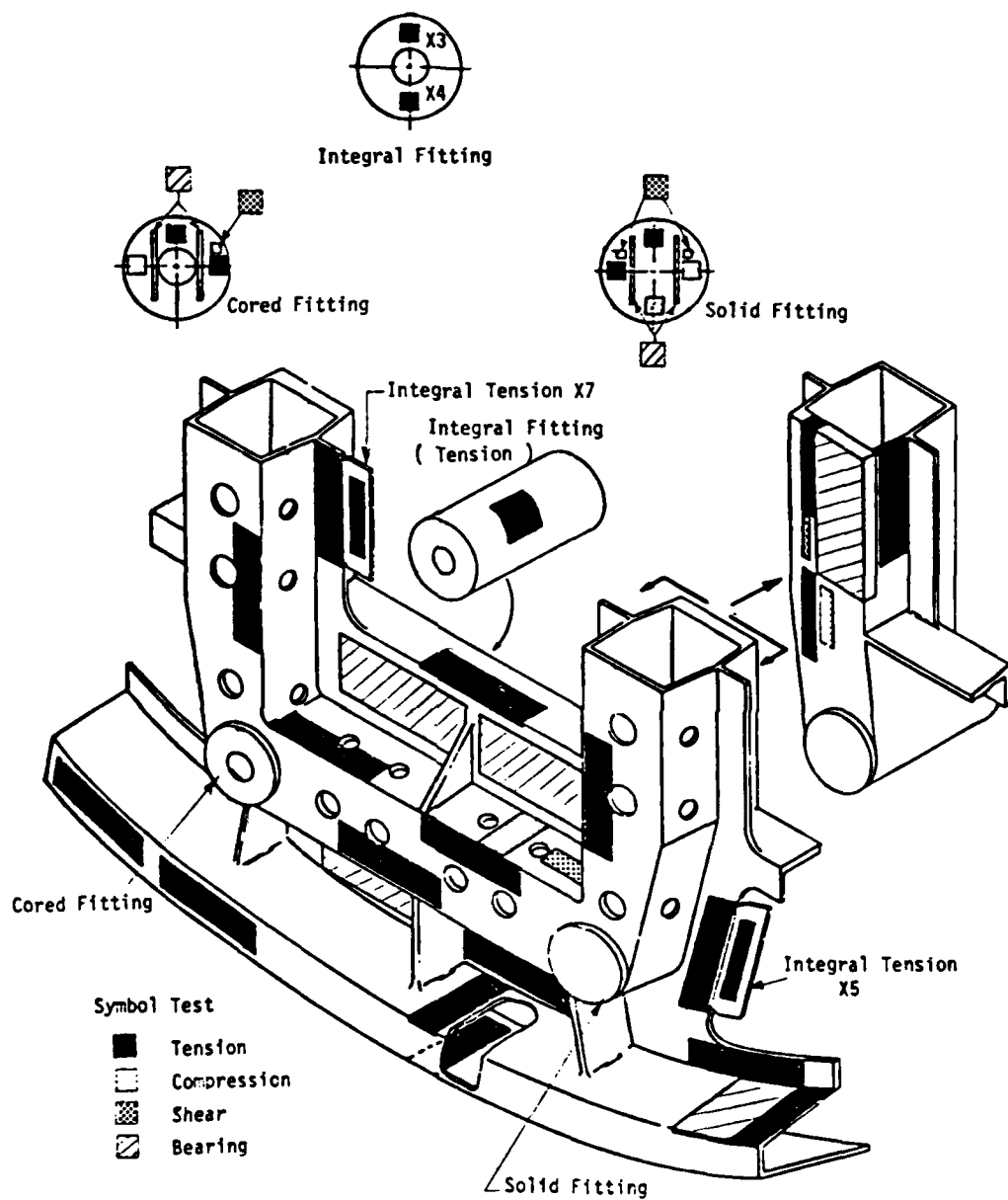


FIGURE 13 PART B TEST SECTION

TABLE 2 PHASE II ALLOWABLES SPECIMEN QUANTITIES

FOUNDRY	TYPE OF CASTING	QUANTITY	LOCATION	NOMINAL THICKNESS (IN.)	REQUIREMENTS CLASS	SOUNDNESS	TEST COUPON QUANTITIES				
							TENSION	COMPR.	SHEAR	BEARING e/D=1.5	BEARING e/D=2.0
Boeing	Part A	4	Landing Gear Spts.	1 & 2	Critical	B	6	2	2	2	1
			Base Flange Pad Up	.5	Other	C	2	1	1	0	1
			Side Flange Pad Up	.3	Critical	B	2	1	0	0	1
			Deck	.2-.25	Other	C	2	1	1	0	0
			Stiffeners	.2	Other	C	5	4	1	1	1
			Webs	.1	Other	C	9	6	1	0	1
			subtotals (4 castings)			104	60	24	12	20	20
Hitchcock	Part A	5	Landing Gear Spts.	1 & 2	Critical	B	6	2	2	2	1
			Base Flange Pad Up	.5	Other	C	2	0	0	0	1
			Side Flange Pad Up	.3	Critical	B	2	0	0	0	1
			Deck	.2-.25	Other	C	2	0	0	0	0
			Stiffeners	.2	Other	C	3	1	1	0	0
			Webs	.1	Other	C	9	0	0	0	1
			subtotals (5 castings)			120	15	15	10	20	20
Boeing	Part B	5	Gear Actuator Spts.	1 & 3	Critical	B	4	3	3	2	2
			Torque Box, Vertical	.5	Other	C	2	1	1	1	0
			Torque Box, Horiz.	.3	Critical	B	2	0	0	0	0
			Torque Box, Vertical	.3	Other	C	2	0	0	0	0
			Flanges	.25-.3	Other	C	4	0	0	1*	1
			Torque Box, Horiz.	.2	Critical	B	1	1	1	0	0
			Flanges, Webs	.1	Other	C	7	0	0	1	1
subtotals (5 castings)			110	25	25	24	20	20			
							* 4 castings only				
Totals:							334	100	64	46	60
							604				

Specific testing details and specimen configurations are contained in Appendix A. Details concerning foundry variables are contained in Appendix B. Appendix C contains a discussion of elongation measurement methods. Appendix D contains a discussion of integral cast-on specimens and their relation to tensile properties of various locations within castings. Individual test results from Phase II are contained in Appendix E.

3. TENSION ALLOWABLES

Tensile property trends are shown in Figure 14 for TUS and TYS and in Figure 15 for ELONG. Average values of each property were computed for each soundness grade over four selected DAS ranges identified in Table 3. Smaller DAS and better soundness produce higher TUS. TYS does not vary significantly with either of these parameters. ELONG being the strain coordinate of TUS has the same physical parameter dependencies. In Figures 14 and 15, symbols represent the average tensile property values plotted at the midpoint of each DAS range. An insufficient quantity of results for soundness grades B and C may have prevented a real separation in effects to be demonstrated.

Figures 16 and 17 show standard deviations for strength and elongation of A357-T6 tensile data from this program, the Battelle-gathered results, and those computed from Hughes-reported results per reference 4. DAS, soundness, and all other identifiers have been omitted purposely to illustrate that this material can be characterized by constant standard deviations for strength ($S_f = 1.77$ ksi) and elongation ($S_e = 0.41$, or 1.5 percent strain). No distinction is necessary between the dispersion characteristics of TYS and TUS. These computed standard deviations combine and project a constant value for an infinitely large sample. The only noticeable difference between CAST and Battelle data is that the latter source provided larger samples. Hughes TUS results are intermixed with CAST results. TYS was not officially reported by Hughes on the basis that it was invariant with DCS. It is therefore not shown in the figure, although a standard deviation was computed to be 1.53 ksi. Five of the Battelle-reported strength data groups form a separate standard-deviation trend that is not obvious in the elongation dispersion results. The reasons for these results are unknown and are not considered further in developing the general characteristics for this material.

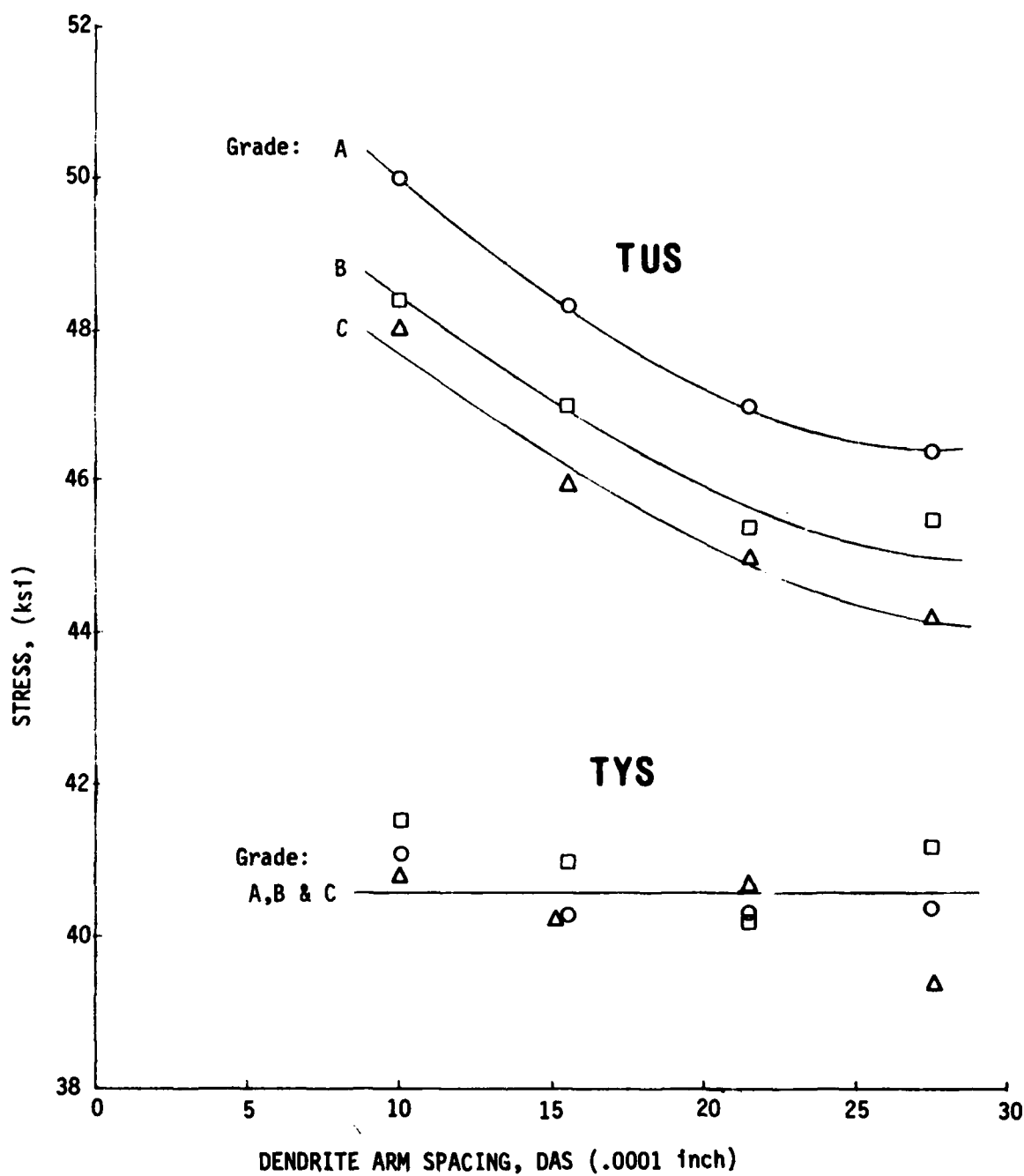


FIGURE 14 AVERAGE STRENGTH TRENDS WITH DENDRITE ARM SPACING AND SOUNDNESS
A357-T6
CAST

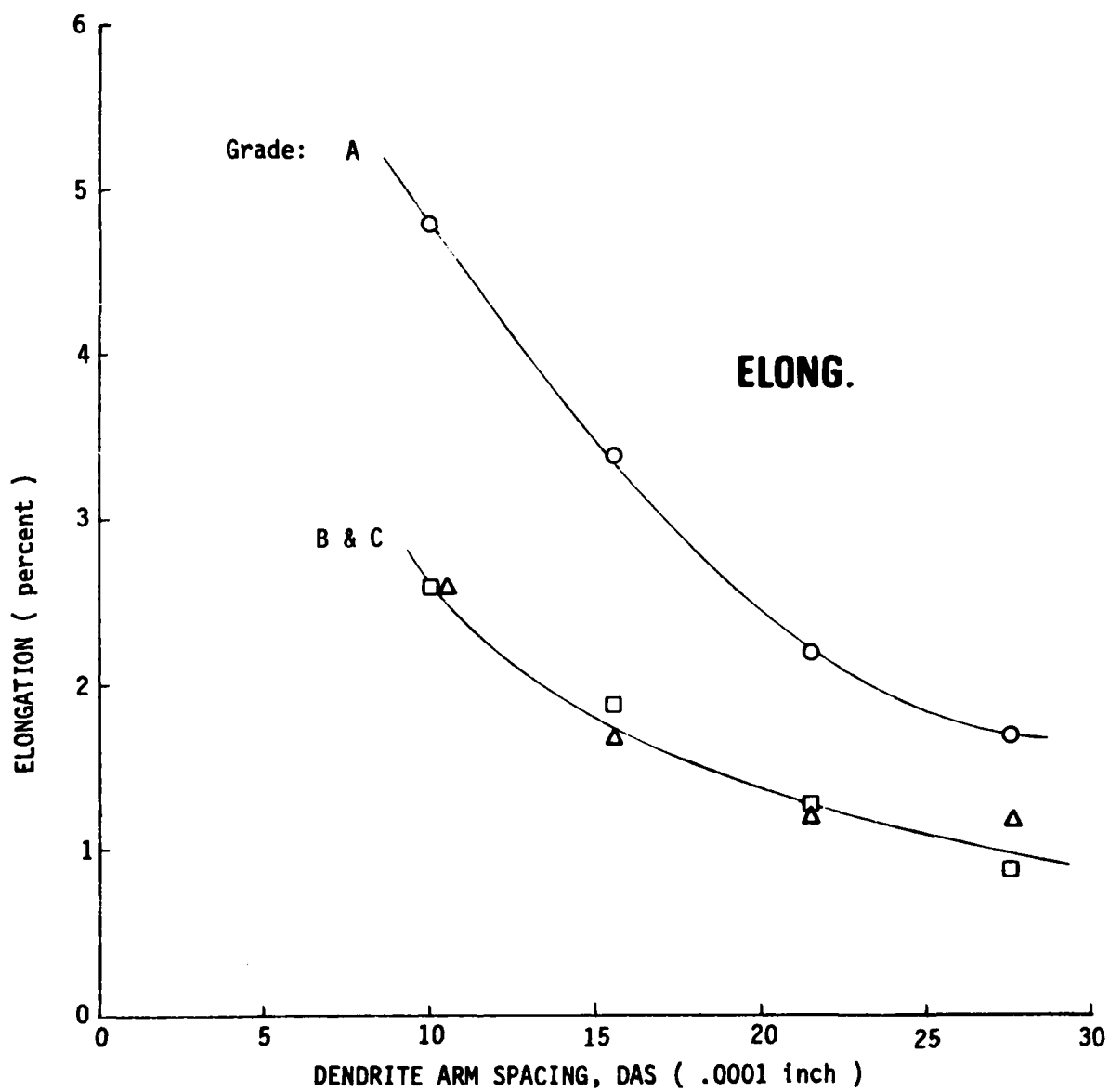


FIGURE 15 AVERAGE ELONGATION TRENDS WITH DENDRITE ARM SPACING AND SOUNDNESS
A357-T6 CAST

TABLE 3 PHASE II TENSION PROPERTY STATISTICS
A357-T6 CAST

Specimen DAS	PROPERTY	Specimen Soundness Grade												
		A				B				C				D
		MAX.	MIN.	AVG.	S.D.	MAX.	MIN.	AVG.	S.D.	MAX.	MIN.	AVG.	S.D.	AVG.
LEVEL 1 Up To .0012 inch	TUS	N = 14 51.9	44.5	50.0	1.5	N = 13 53.7	44.8	48.4	2.2	N = 3 51.5	42.8	48.0	4.6	N = 1 42.7
	TYS	44.7	37.5	41.1	1.7	44.4	37.3	41.5	1.7	42.7	37.8	40.8	2.6	37.7
	ELONG	11.5	2.5	4.8	1.46	6.7	1.4	2.6	1.92	4.4	1.3	2.6	1.33	1.1
LEVEL 2 .0013 to .0018 inch	TUS	N = 120 52.3	41.9	48.3	1.6	N = 69 53.9	39.6	47.0	2.5	N = 29 50.0	42.5	45.9	2.0	N = 0 ---
	TYS	46.9	37.5	40.3	1.5	46.8	33.5	41.0	2.4	44.0	35.4	40.2	1.1	---
	ELONG	12.4	0.6	3.4	1.73	7.2	0.4	1.9	1.89	5.5	0.6	1.7	1.65	---
LEVEL 3 .0019 to .0024 inch	TUS	N = 70 50.0	42.4	47.0	1.5	N = 35 48.4	41.5	45.4	1.6	N = 14 49.7	44.4	45.0	1.7	N = 1 41.5
	TYS	42.9	38.1	40.3	1.2	42.9	38.5	40.2	1.1	43.4	37.2	40.7	1.4	40.4
	ELONG	8.1	0.6	2.2	1.77	4.0	0.5	1.3	1.69	3.6	0.6	1.2	1.50	0.3
LEVEL 4 .0025 to .0030 inch	TUS	N = 4 46.9	46.0	46.4	0.4	N = 9 47.5	43.1	45.5	1.4	N = 4 44.6	43.3	44.2	0.6	N = 0 ---
	TYS	41.5	38.6	40.4	1.3	43.2	39.6	41.2	1.4	41.0	37.4	39.4	1.6	---
	ELONG	3.3	1.1	1.7	1.59	1.3	0.6	0.9	1.20	4.3	0.5	1.2	2.50	---

TUS, ksi

TYS, ksi

ELONG, percent

N = quantity of results in each cell

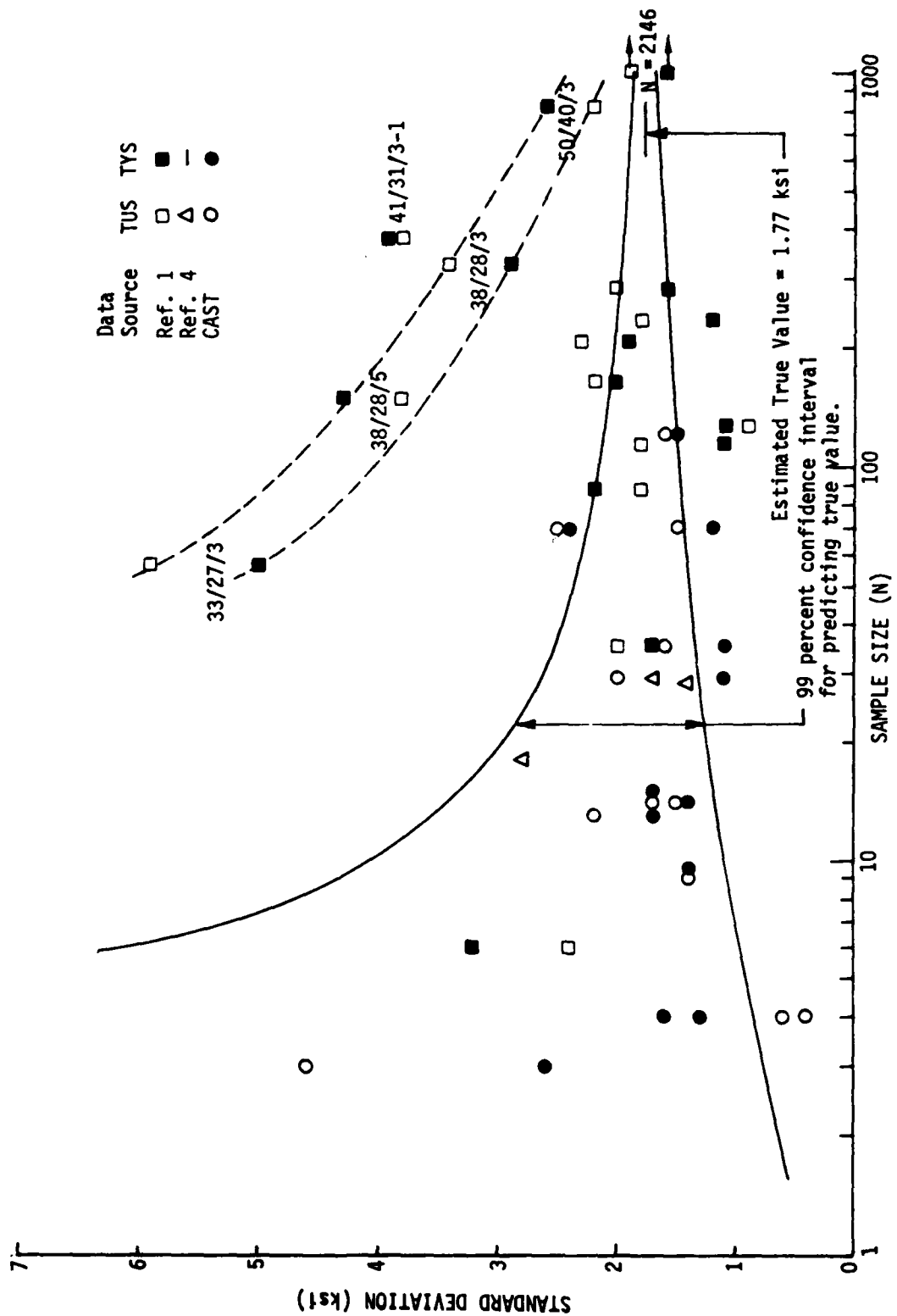


FIGURE 16 STANDARD DEVIATIONS OF TUS AND TYS FOR A357-T6 CASTINGS

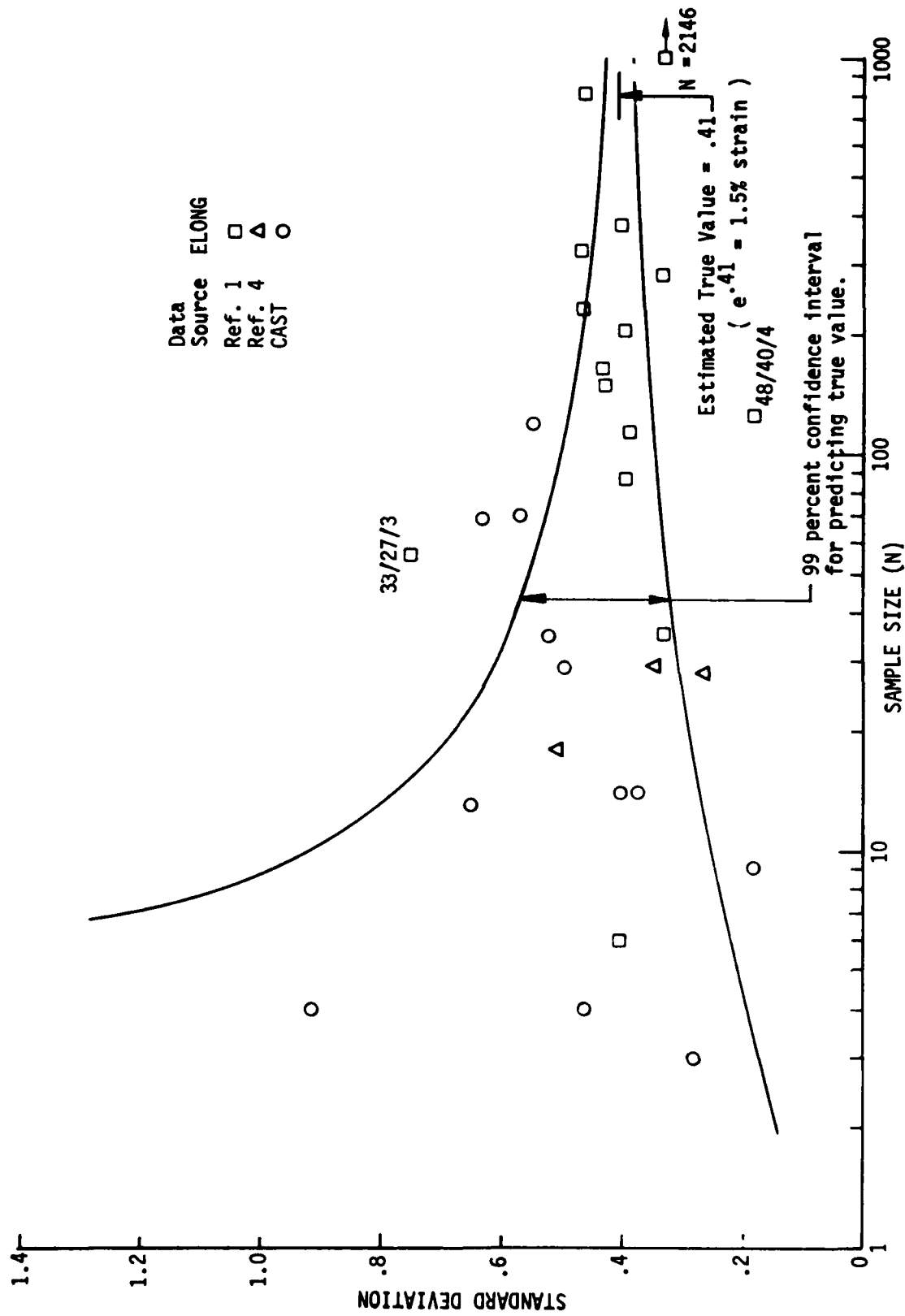


FIGURE 17 STANDARD DEVIATIONS OF ELONGATION
FOR A357-T6 CASTINGS

In Figures 16 and 17, the convergent solid curves represent theoretical 99 percent confidence level limits for estimating the population standard deviations assuming that sample standard deviations follow the chi-squared distribution with (N-1) degrees of freedom. The curves were constructed using the following expressions per reference 5:

$$\text{Lower Limit} = \frac{s}{\sqrt{\frac{\chi^2_{\alpha/2, \nu}}{\nu}}}$$

$$\text{Upper Limit} = \frac{s}{\sqrt{\frac{\chi^2_{1-\alpha/2, \nu}}{\nu}}}$$

where:

s = standard deviation estimate of the population

χ^2 = chi-squared values for ($\alpha/2$) and ($1 - \alpha/2$) probability levels

ν = degrees of freedom (N-1)

N = sample size

Results from the above analysis for mean values and standard deviations of A357-T6 tensile properties can be 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.

$$X_A = \bar{X} - ks$$

where:

X_A = statistical A-basis value with 95 percent confidence, 99 percent proportion

$\bar{X}$ = mean value

k = statistical confidence/proportion coefficient

s = standard deviation

Since both strength and elongation standard deviations have been established as population characteristics, the term k corresponds to an infinite sample size and becomes the Student's t -value, named after W. S. Gosset and contained in many statistical books and tables. For example, see page 87 of reference 6. The t -value for a 99 percent proportion is 2.326.

Using this value with the standard deviations of 1.77 ksi for strength and 0.41 for elongation allows the above expression to be rewritten for each property:

$$\begin{aligned}F_{tu} &= \overline{TUS} - 4.12 \text{ ksi} \\F_{ty} &= \overline{TY\bar{S}} - 4.12 \text{ ksi} \\e &= \overline{ELONG} - 0.954\end{aligned}$$

The elongation allowable must be transformed by (e^X) to obtain a design value in percent strain. Proposed tension property allowables from Phase II of the CAST program are presented in Table 4.

The above tension design properties format should be applicable to A357 castings regardless of method of manufacture or heat-treatment processing. For the particular chemistries, heat treatments, levels of DAS, and soundness grades produced in this program, specific tension allowables will be tested against CAST bulkhead properties in Section IV of this report. As shown in Section II, slight variations within the acceptable limits of heat treatment, and possibly chemistry, may produce casting zones with the same DAS and soundness, but significantly different tensile properties. This means that although DAS and soundness may represent suitable dual-basis design property qualifiers, there are other physical aspects that must be qualified prior to assuming the general state of applicability.

4. DERIVED PROPERTIES

A summary of derived property ratios analyses is presented in Table 5. Compression, shear and bearing data are contained in Appendix E. These data were ratioed by tension data for specimens of adjacent casting locations and are contained in Appendix F. These ratios were grouped into the tension DAS/soundness cells previously established and statistics were computed for each cell of ratios including average ratio $(\bar{r})$ and standard deviation (s) . The average ratios

TABLE 4 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

TABLE 3 DERIVED PROPERTY RATIOS SUMMARY
A357-T6 CAST

Property Ratio	DAS Level	Tension Specimen Soundness Grades											
		A			B			C			D		
		N	$\bar{r}$	s	N	$\bar{r}$	s	N	$\bar{r}$	s	N	$\bar{r}$	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	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	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	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	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 $\bar{r}$ = 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

are plotted against cell sample size in Figure 18 to illustrate that neither DAS nor soundness influences ratio values. This permits all data of each property ratio to be pooled to develop a reduced ratio design property. The reduced ratios are shown by lines in the figure and are naturally weighted towards the larger cell sample averages.

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.

$$\begin{array}{ll} F_{cy}/F_{ty} = 1.045 & F_{bry}/F_{ty} = 1.627 (e/D = 1.5); = 1.959 (e/D = 2.0) \\ F_{su}/F_{tu} = 0.720 & F_{bru}/F_{tu} = 1.538 (e/D = 1.5); = 2.02 (e/D = 2.0) \end{array}$$

Appendix G contains derived property ratio analysis details.

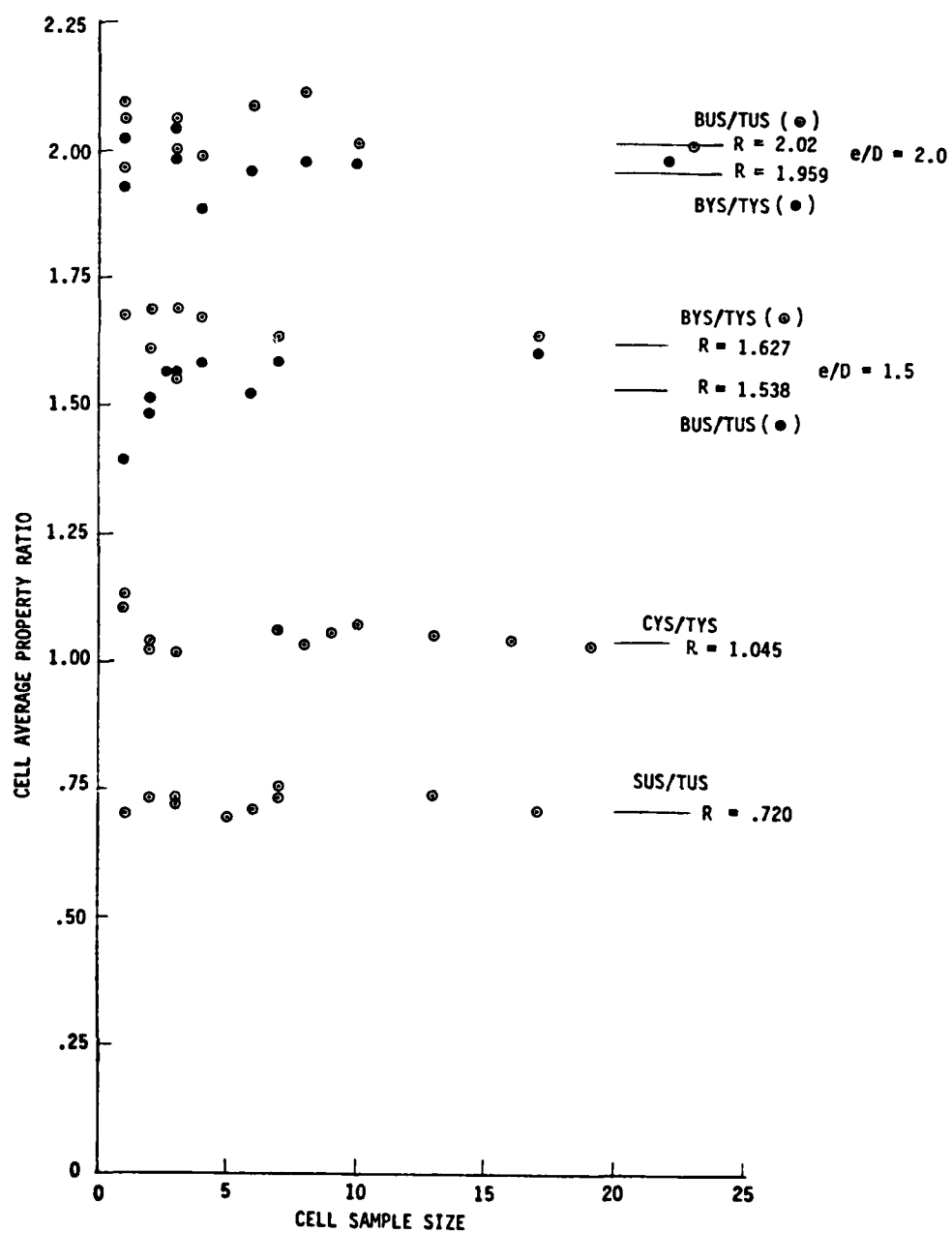


FIGURE 18 DERIVED PROPERTY RATIOS
A357-T6 CAST

SECTION IV ALLOWABLES ASSESSMENT

1. BULKHEAD TENSION PROPERTIES

Four bulkheads from the 20 parts 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. One of the two Hitchcock castings, identified herein as H2, was reported as having been produced from low-phosphorus ingot. This casting was selected for evaluation primarily to determine if any differences in properties resulted from that chemistry. Other fabrication and processing features were common among all castings.

Bulkhead tensile properties can be categorized into six zones: Lugs, Upper (Slant Beam) Flange, Corrugations, Webs and Stiffeners, Fittings, and the Periphery Flange. Average properties for each of these zones are listed in Table 6. Comparative results are shown for each of the four castings. The heavily chilled lug zones exhibit the highest strengths and elongations. The periphery flange exhibits the lowest properties. Specimens from the periphery flange showed the largest DAS and greatest amounts of shrinkage. Individual test results are contained in Appendix H.

Observations made from properties listed in Table 6 are as follows:

1. Boeing castings MO8 and MO9 exhibit similar properties.
2. Hitchcock casting H2 exhibits consistently higher TUS and ELONG than casting H9.
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 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

TABLE 6 TENSILE PROPERTIES OF
Sta. 170 YC-14 BULKHEADS
A357-T6 Phase V CAST

Casting Location:	Boeing Foundry		Hitchcock Foundry	
	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)

requirements, especially in the periphery flange. This is not abnormal for initial production development. Future efforts will be directed to improving ductility.

2. ALLOWABLES ASSESSMENT

Phase V tensile properties were used to assess allowables established in Phase II. The link between these two groups of information is specimen DAS and soundness measurements. These two parameters dictate the allowables applicable to Phase V bulkhead TUS and ELONG properties.

Results of this assessment are dependent upon the statistical basis used to establish allowables. A statistical A-basis was selected for tensile properties. Only the resulting allowables for TUS and ELONG vary with DAS levels and soundness grades. The tentative allowable for TYS is a constant ($F_{ty} = 36.5$ ksi).

The assessment of allowables for TUS is shown in Figure 19 (grade A) and Figure 20 (grades B and C). In each diagram, individual results are plotted against specimen measured DAS values. Only three of the TUS results fell below the Phase II developed allowables. Two of these results are soundness grade A. Specimen 20 from Boeing casting MO8 failed at 29.2 ksi prior to yield. The reason for this premature failure is unknown. The other grade A suballowable result is from a Hitchcock casting H9 lug. Prior to test, a gas pore was noted open to the specimen gage section surface. This defect was approximately 0.015 inch in diameter, and caused the specimen to fail at 10 ksi. Both of the above results show the importance of nondestructive inspection requirements. Defects in these two casting zones should have been nondestructively identified and weld corrected prior to actual production casting acceptances. One grade C TUS result per Figure 20 at a DAS of 0.0028 inch had a value of 40 ksi where the tentative allowable is 40.1 ksi. This difference is not significant. In general, Phase V TUS results show that the Phase II developed allowables are acceptable.

TYS data are shown in Figures 21 (grade A) and 22 (grades B and C). Eight results are below the tentative allowable of 36.5 ksi. Two of the grade A results were previously discussed. The other two grade A results are between 35 and 36 ksi, and not sufficient to cause an allowables adjustment. Figure 22 shows four grade B TYS results below 36.5 ksi. These and three of the four grade A results are

TUS

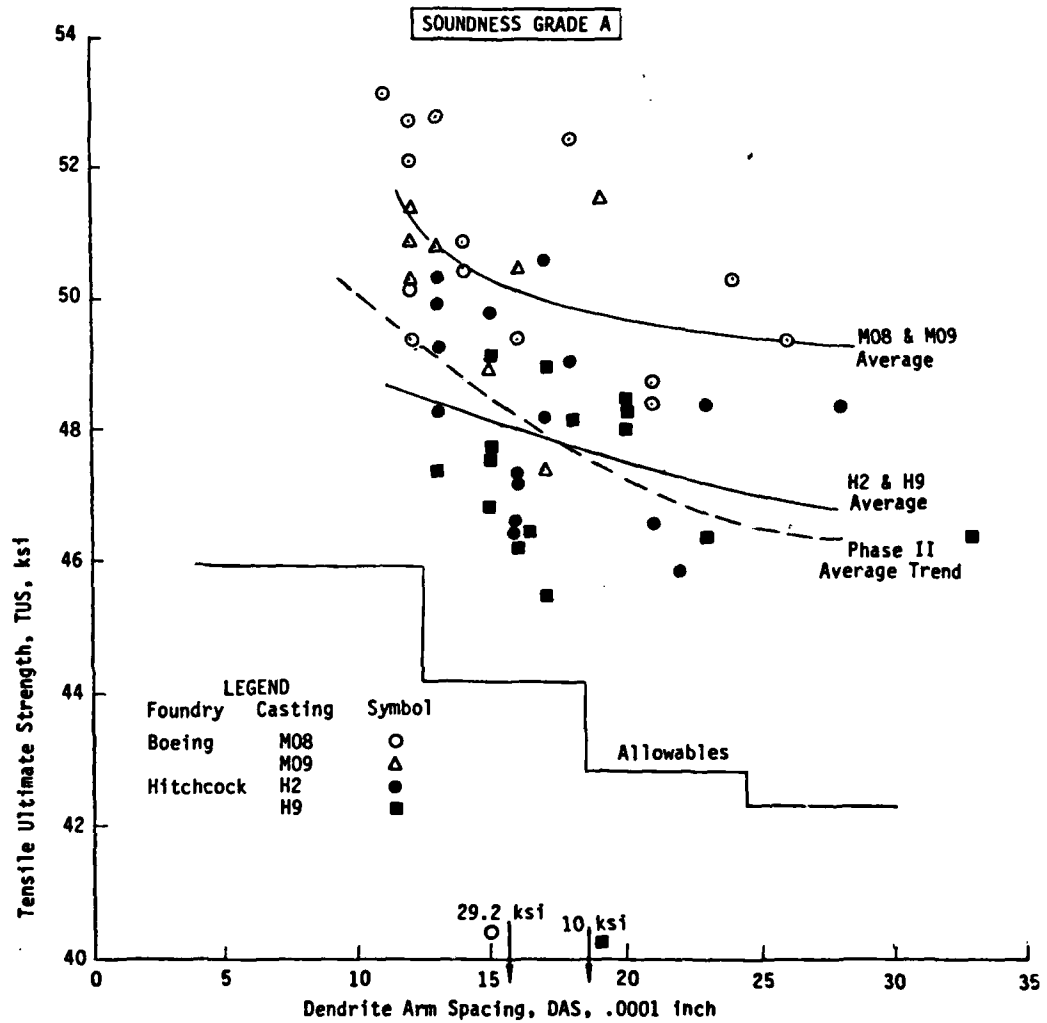


FIGURE 19 TUS DATA COMPARISONS
A357-T6 CAST

TUS

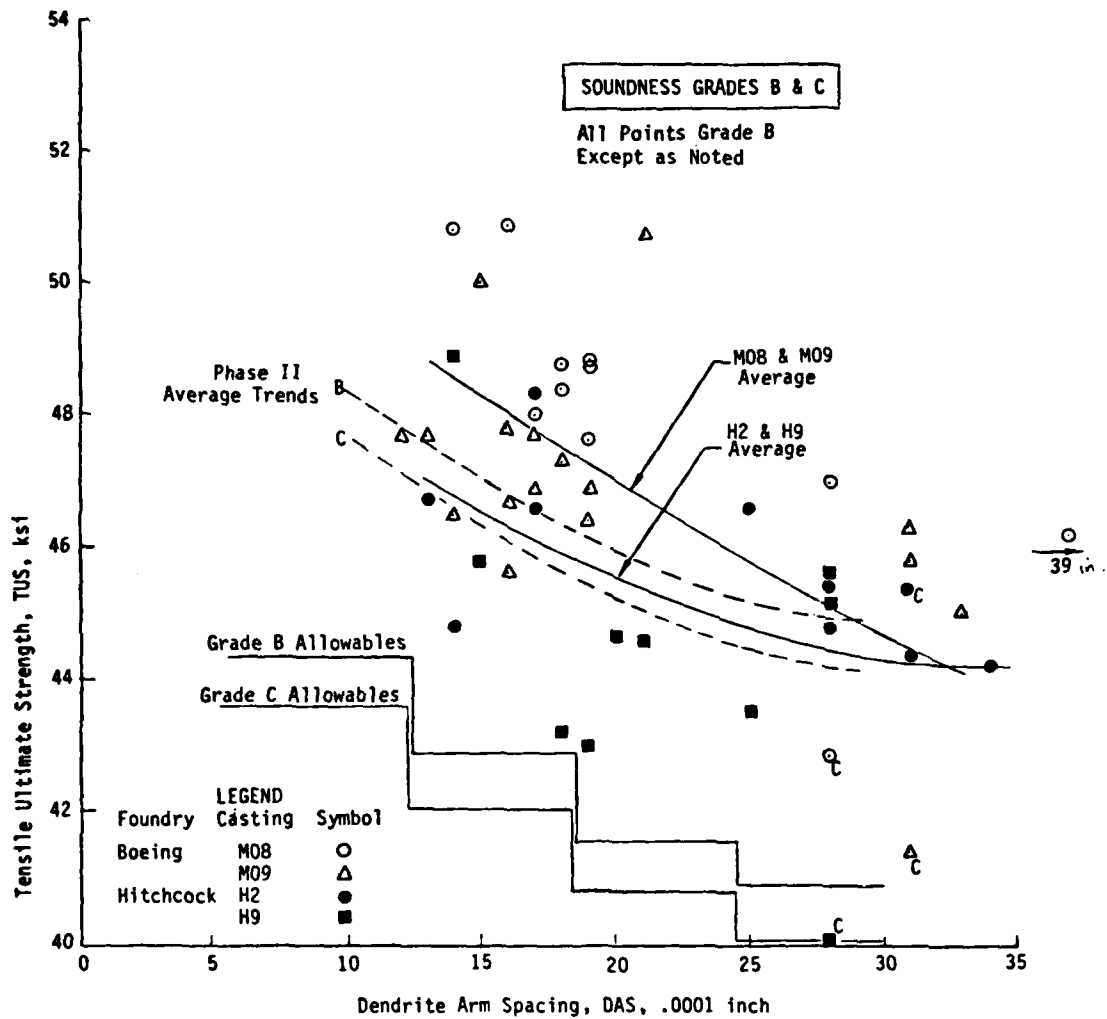


FIGURE 20 TUS DATA COMPARISONS
A357-T6 CAST

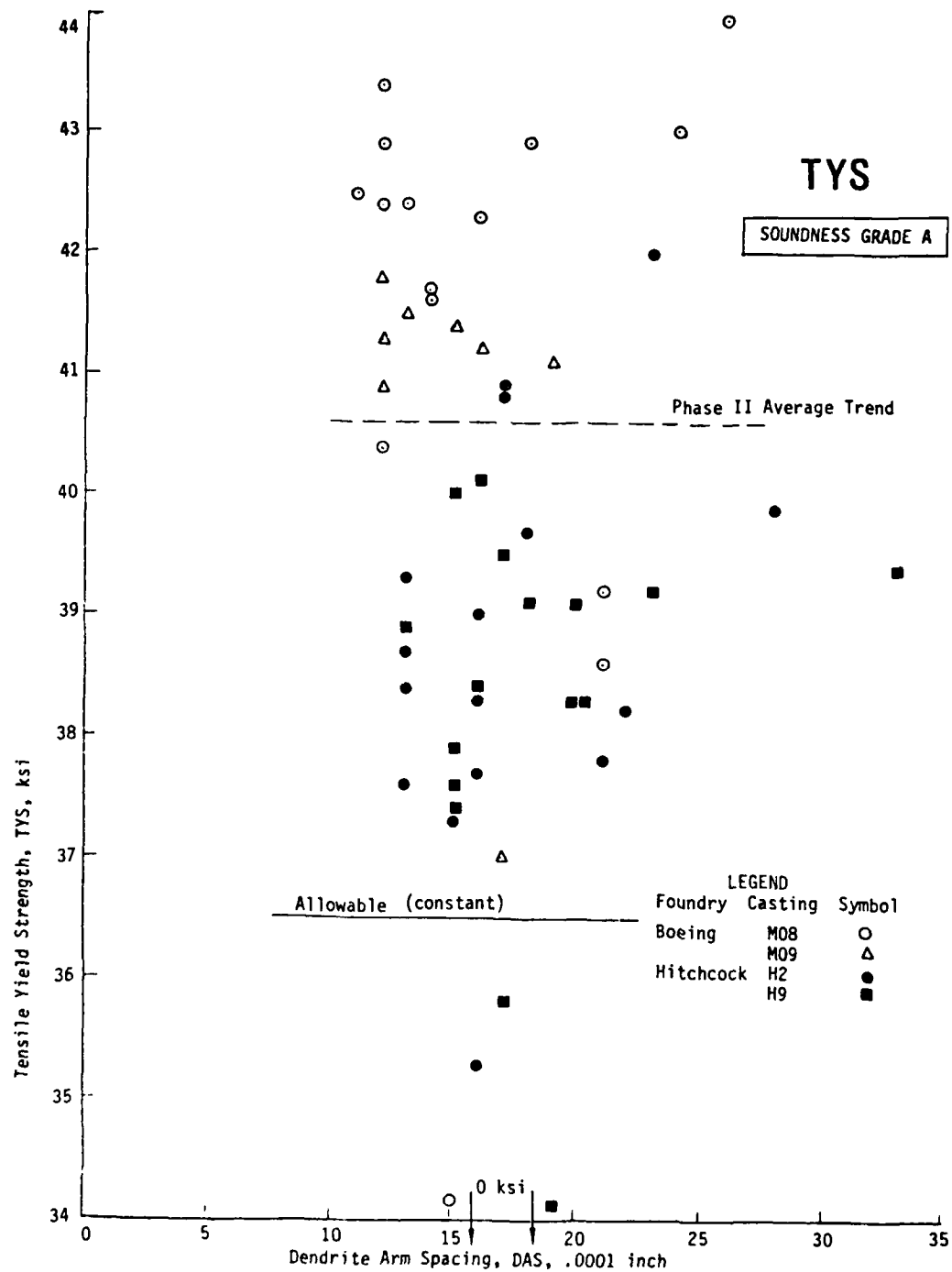


FIGURE 21 TYS DATA COMPARISONS
A357-T6 CAST

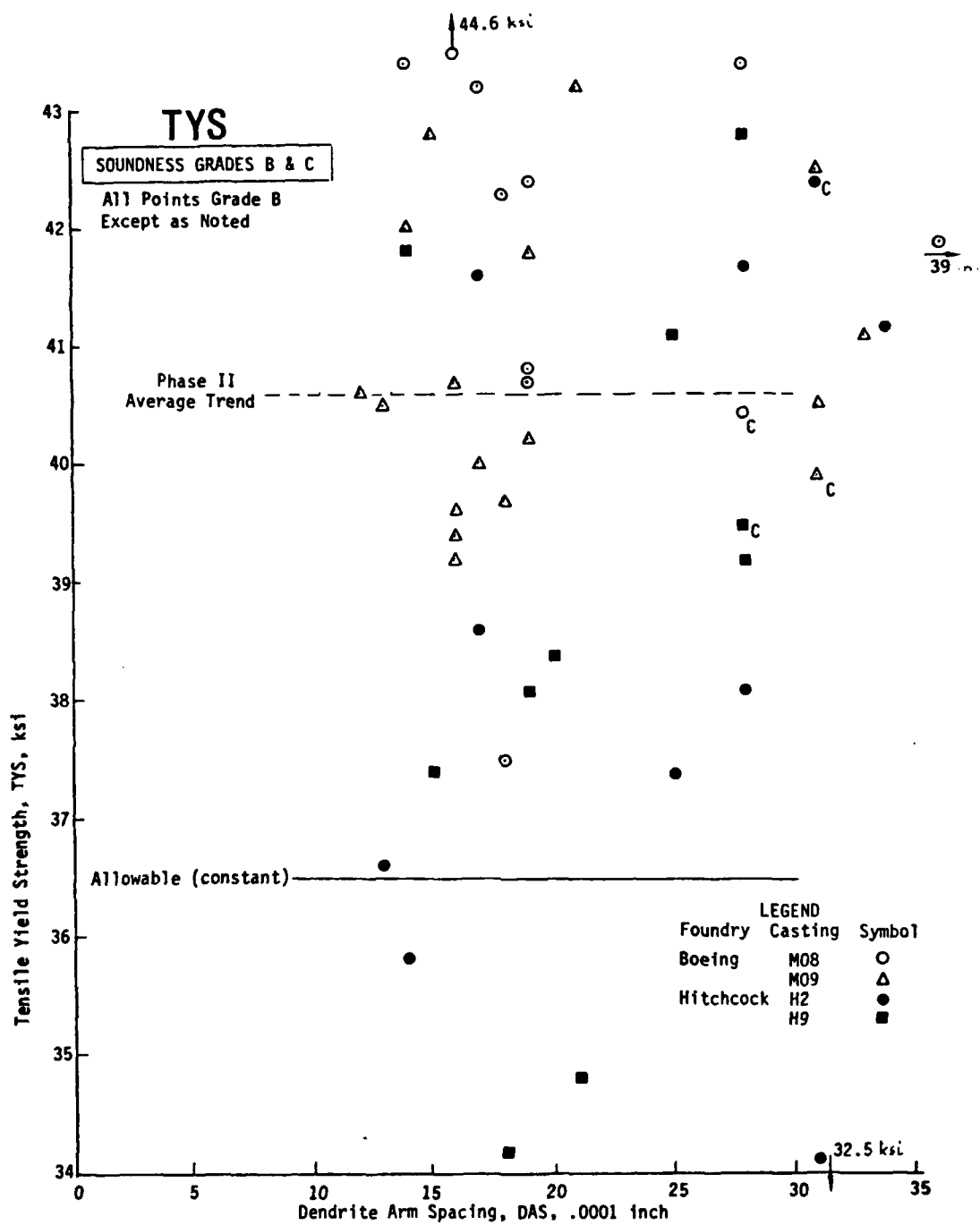


FIGURE 22 TYS DATA COMPARISONS
A357-T6 CAST

from Hitchcock castings. In both Figures 21 and 22, it is noted that Hitchcock castings TYS results are generally less than the Boeing castings TYS values. The dividing line seems to be the Phase II average trend value of 40.6 ksi. This may have been caused by a minimum artificial aging condition used by Hitchcock as noted for other data in Section II. Overall, the allowable for TYS appears to be adequate.

ELONG assessments are shown in Figures 23 (grade A) and 24 (grades B and C). Only two grade A results fall below the allowable. These were discussed for TUS and are not considered to represent acceptable material properties. The grade A ELONG allowables are believed to be adequate. In Figure 24, grades B and C have the same allowables in each of the four DAS level ranges. In the highest DAS level, two grade C results are less than the allowable of 0.4 percent, but the amounts they deviate below the allowable are minimal. It is therefore believed that the allowables established in Phase II for ELONG are adequate without any adjustment.

3. SUPPLEMENTAL ASSESSMENT

In addition to the 26 specimen locations in each bulkhead casting used to describe tension characteristics and to assess allowables, 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 were also excised from one-half of the periphery flange at alternate step gate and chill locations from casting MO9. Results are shown in Figures 25, 26, and 27 for TUS, TYS, and ELONG, respectively. Phase II allowables are superimposed. Results are segregated by soundness grade and plotted against DAS.

All TUS grade A results are above the allowables. See Figure 25. The majority of grade B results are sufficiently above the allowables. Only two grade B and three grade C results fall below the allowables. The marginal points below the grade C allowables suggest no adjustments are necessary.

In Figure 26, all supplemental TYS test results, with the exception of one grade B result at a DAS of 0.0017 inch, exceed the 36.5-ksi allowable. The one test result

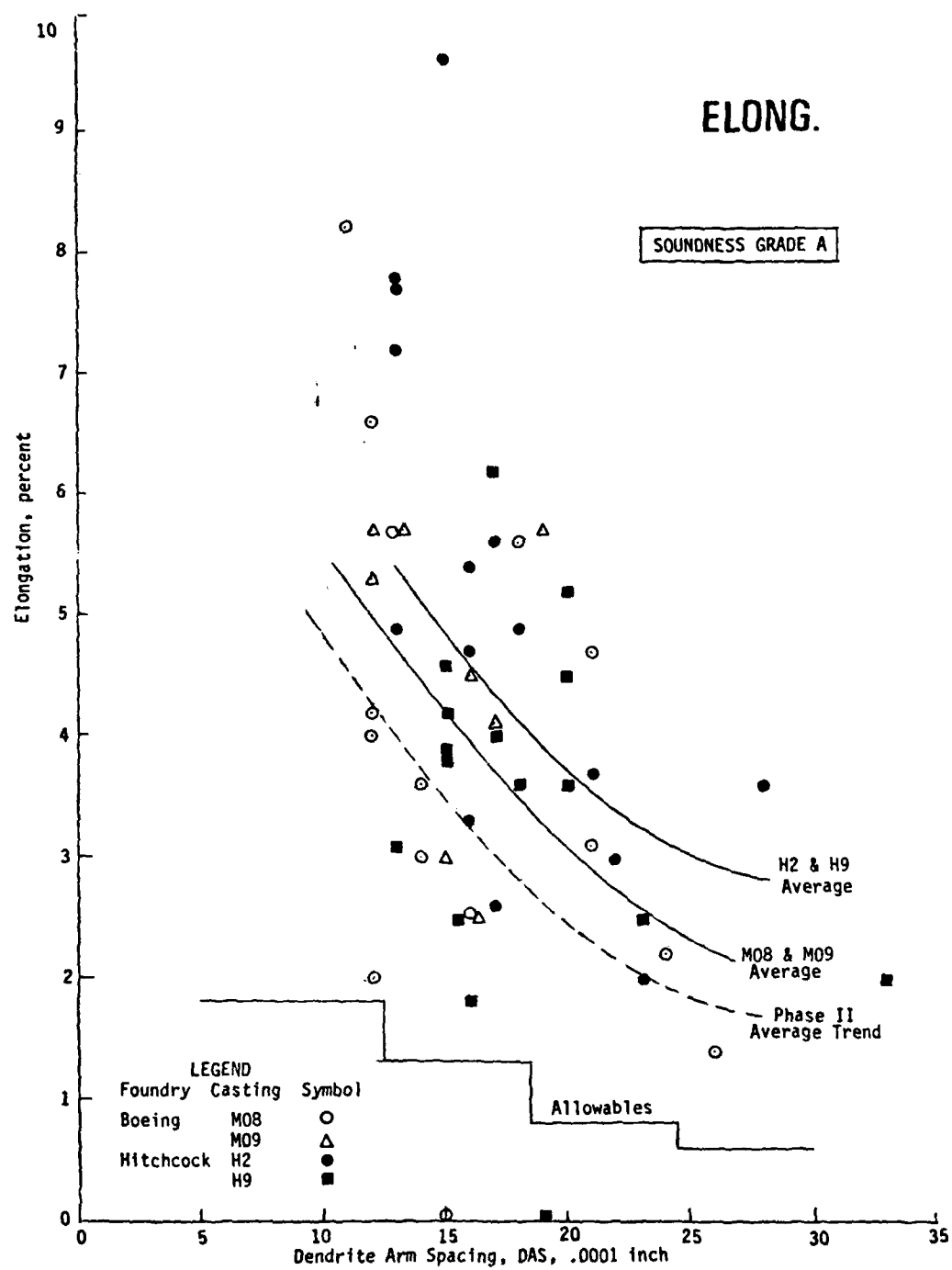


FIGURE 23 ELONGATION DATA COMPARISONS
A357-T6 CAST

ELONG.

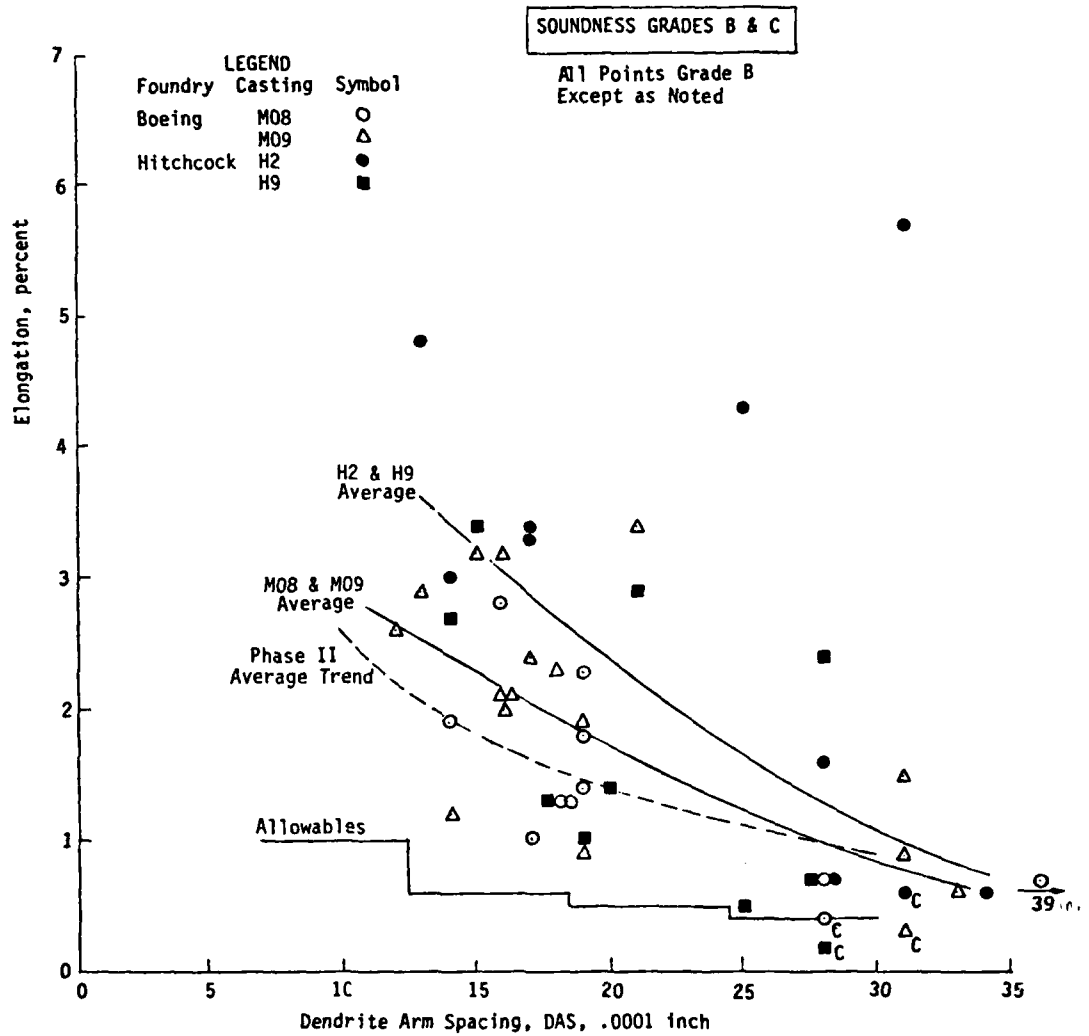


FIGURE 24 ELONGATION DATA COMPARISONS
A357-T6 CAST

TUS

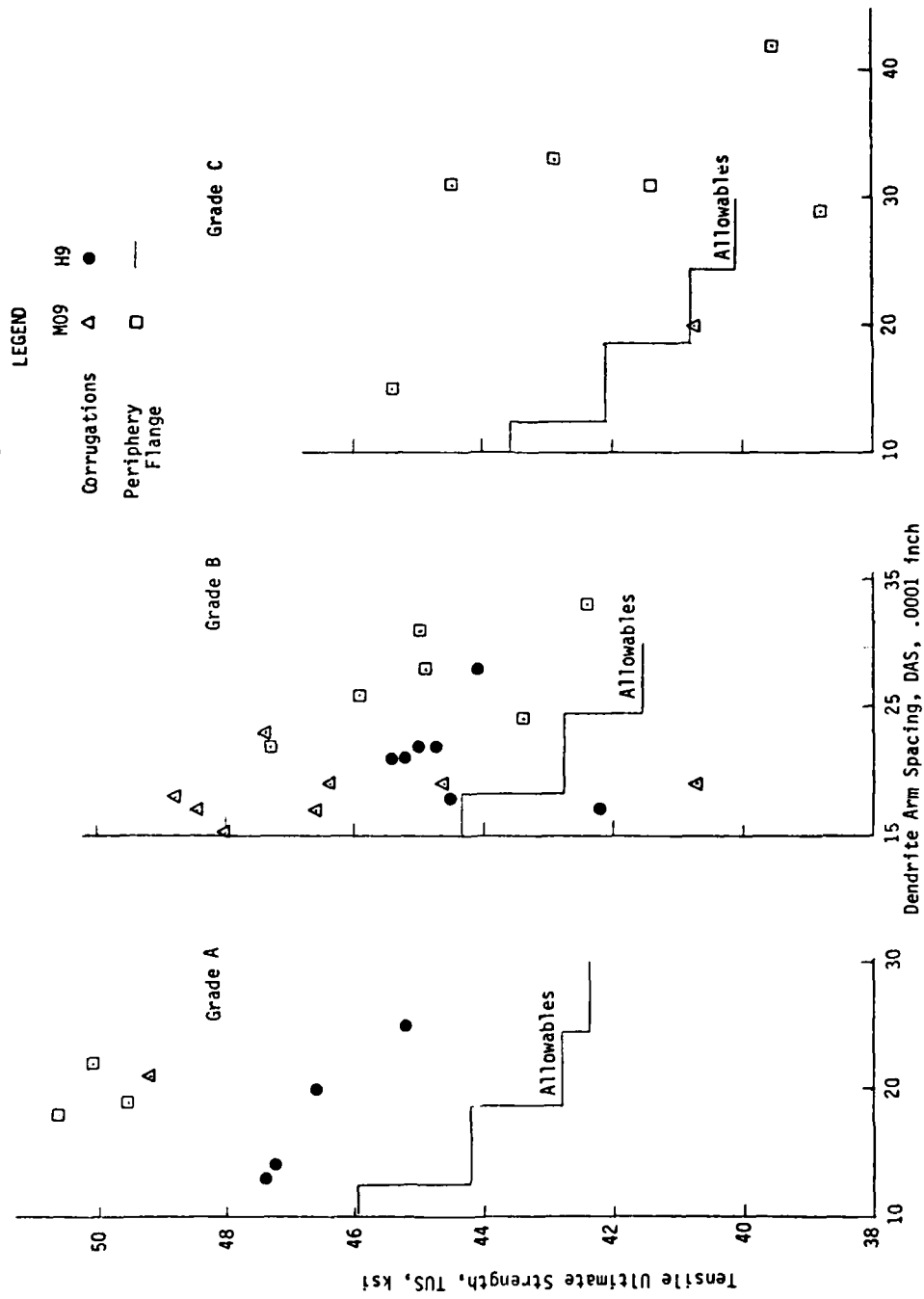


FIGURE 25 TUS DATA COMPARISONS
SUPPLEMENTAL TESTS
A357-T6 CAST

TYS

LEGEND
 M09 H9
 Corrugations Δ $\bullet$
 Periphery $\square$ —
 Flange

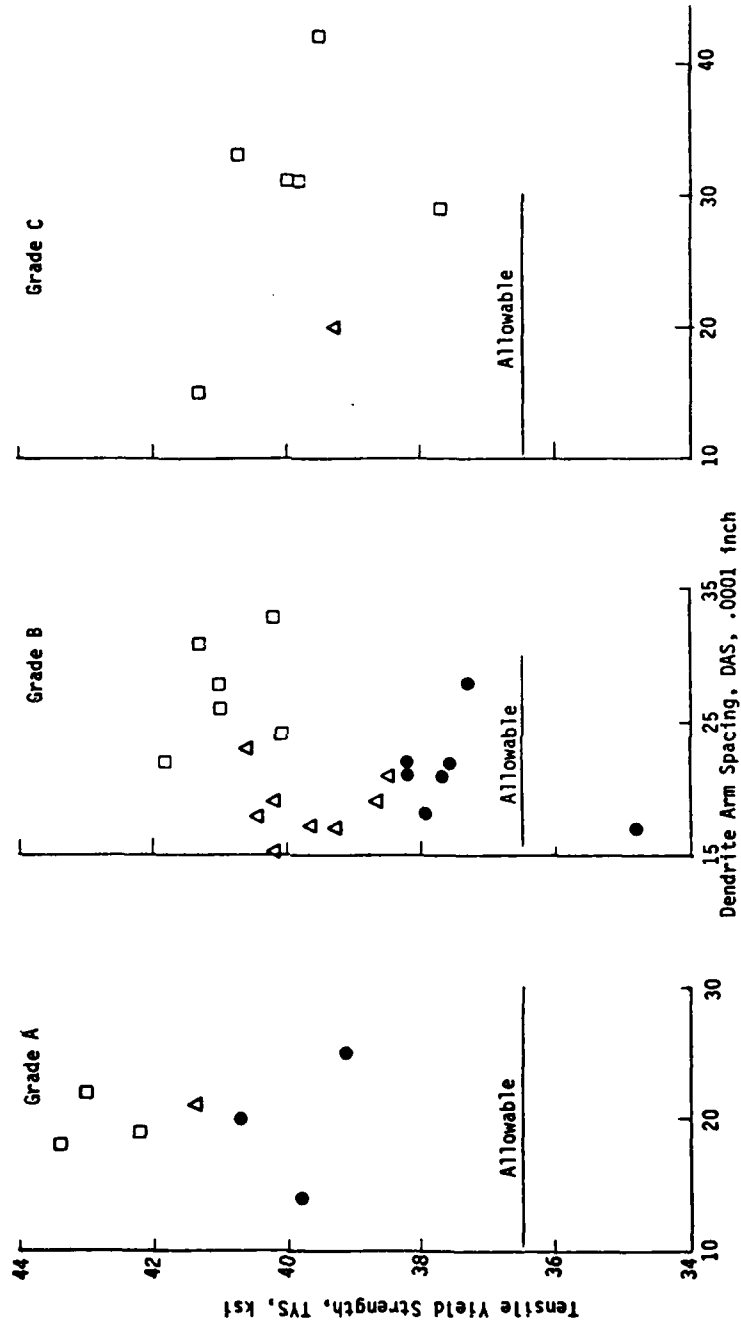


FIGURE 26 TYS DATA COMPARISONS
 SUPPLEMENTAL TESTS
 A357-T6 CAST

ELONG.
 LEGEND M09 H9
 Corrugations Δ $\bullet$
 Periphery $\square$ -
 Flange

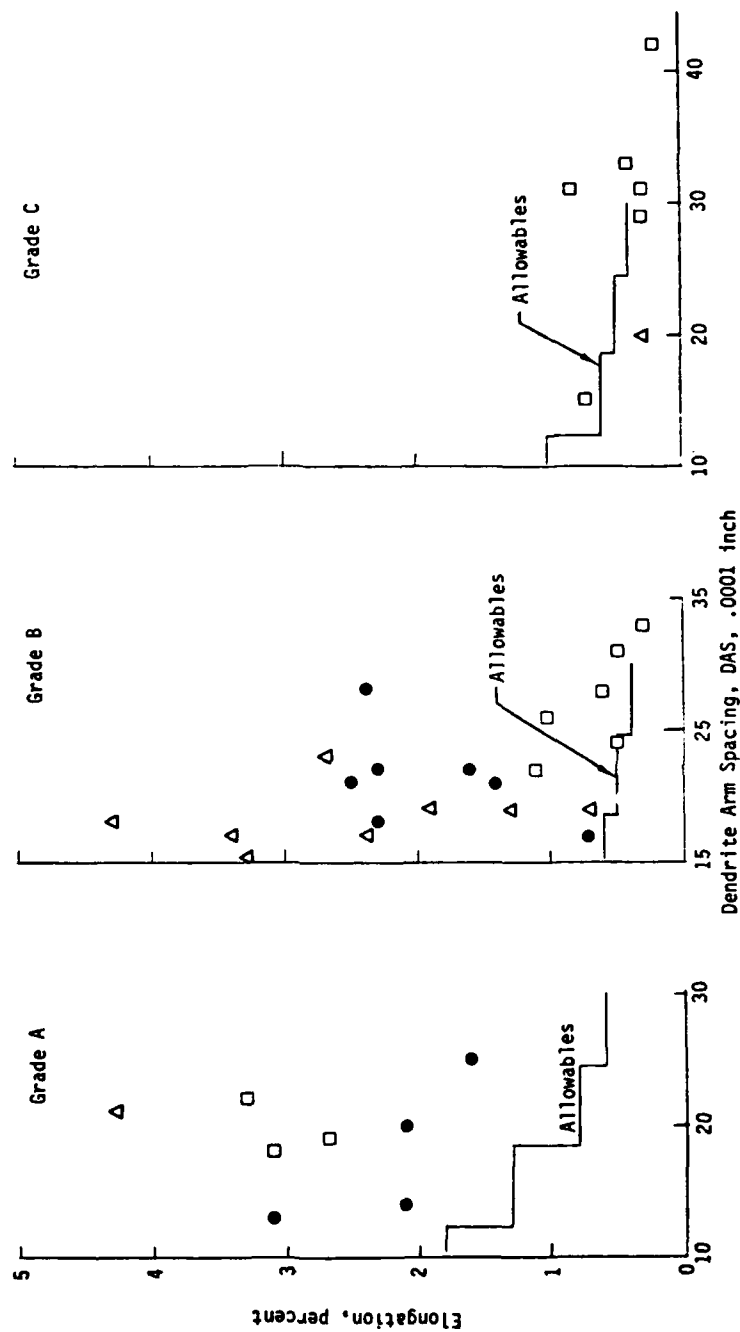


FIGURE 27 ELONGATION DATA COMPARISONS
 SUPPLEMENTAL TESTS
 A357-T6 CAST

with a TYS of 34.8 ksi has questionable validity. That specimen failed in the gage-to-grip transition zone apparently due to a much lower soundness quality than in the reduced gage section. This single result is not sufficient to cause an allowables adjustment.

In Figure 27, all grade A ELONG results are shown to support the allowables, as do the majority of grade B results. Only two grade B results are marginal. The grade C ELONG supplemental test results are all below 1 percent strain. One corrugation and six periphery flange zones had soundness grade C. Five of the six periphery flange results represent DAS values above 0.0029 inch. Material of this soundness and DAS range cannot be expected to demonstrate an appreciable ductility. In general, the supplemental ELONG test results support the allowables.

SECTION V

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. These tensile properties increase with smaller dendrite arm spacings and higher soundness.
2. Yield strength is primarily influenced 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 aluminum dendrite size as determined for A357. Soundness effects on A356 have not been evaluated.

With respect to design properties:

1. Static allowables have been 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 have been 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.

REFERENCES

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APPENDIX A

TEST SPECIMENS AND PROCEDURES

GENERAL

Test specimens and procedures were in accordance with ASTM. Two Baldwin Universal test machines were used, one a 20-kip Model CS and the other a 120-kip Model CS. These machines were calibrated in accordance with ASTM Method E4-72 to ensure loading accuracy within 1.0 percent. The machines are equipped with integral automatic load or strain pacers and autographic load-strain recorders. The extensometers conformed to ASTM E83-67 classification B1, having an accuracy of 0.0001 in./in.

Specific test specimens and procedures for the tension, compression, shear, and bearing tests are described in the following paragraphs. All static tests were conducted in a laboratory air environment.

TENSION

Two configurations were used. One was round for tests from casting zones 0.5 inch thick or greater. All lesser thickness zones were tested using flat specimens as shown in Figure 28. The specimens and testing procedures were in accordance with ASTM E8-69.

COMPRESSION

Flat and round specimens, per Figure 28, were used as applicable. Both were tested in accordance with ASTM E9-70 using a loading subpress. Side support to prevent buckling of flat specimens was provided by a Montgomery-Templin compression fixture using rollers.

SHEAR

Double-shear cylindrical specimens, 1/4 inch in diameter, Figure 28, were used for the thicker sections of the castings. Double-shear flat specimens were used for the thinner sections of the castings.

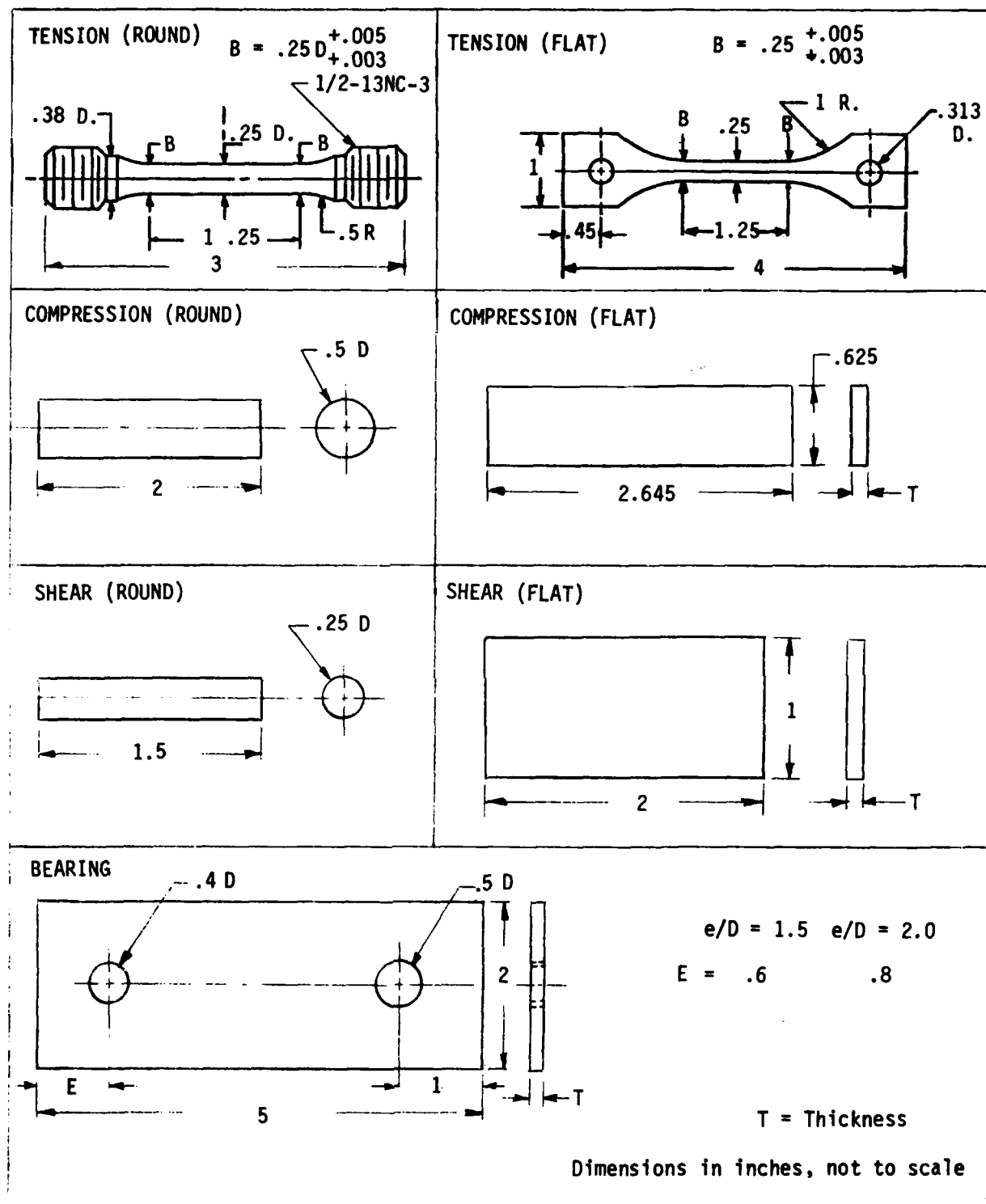


FIGURE 28 STATIC SPECIMEN CONFIGURATIONS

BEARING

Bearing tests were conducted in accordance with ASTM Method E238-68. Specimens, as shown in Figure 28, have a constant ratio of bearing pin diameter to thickness (D/t) of 4.0 and of specimen width to bearing pin diameter (W/D) of 5.0, and edge margin ratios (e/D) of 1.5 and 2.0. Bearing specimens were machined flat from all mid-depth locations of all thick sections. Specimens, pins and fixtures were cleaned prior to testing in accordance with ASTM E238-68.

Book

APPENDIX B

FOUNDRY VARIABLES

BOEING PART A CASTINGS

Details of specimens from Boeing Part A castings are described in relation to the following variables:

1. Location within each casting
2. Strength/elongation class and quality grade
3. Nominal section thickness
4. Distance from ingates
5. Distance from chills
6. Distance from risers and insulators, when applicable

Boeing Part A castings were poured in a vertical position, thereby eliminating risers. The allocation of coupons from these castings is shown in Table 2. In addition each casting contained five integral cast-on tensile coupons as shown in Figure 2.

The foundry variables are identified in Figures 29 and 30. These figures represent forward and aft faces of the Part A castings, respectively. In Figure 29, 12 ingates are designated by the symbols I1-I12. The forward face was chilled with 21 aluminum chills (A1-A21) and 25 copper chills (C1-C25). The aft face was chilled with 13 aluminum chills (A22-A34) and 17 copper chills (C26-C42). Details of chills are contained in Table 7. Table 8 shows ingate details.

Pertinent foundry variables for these castings consist of ingate and chill distances to specimens. These details are summarized in Table 9. Each specimen is identified by the coding explained in Appendix E, the nominal thickness of that section of the casting and the target values for strength/elongation and quality.

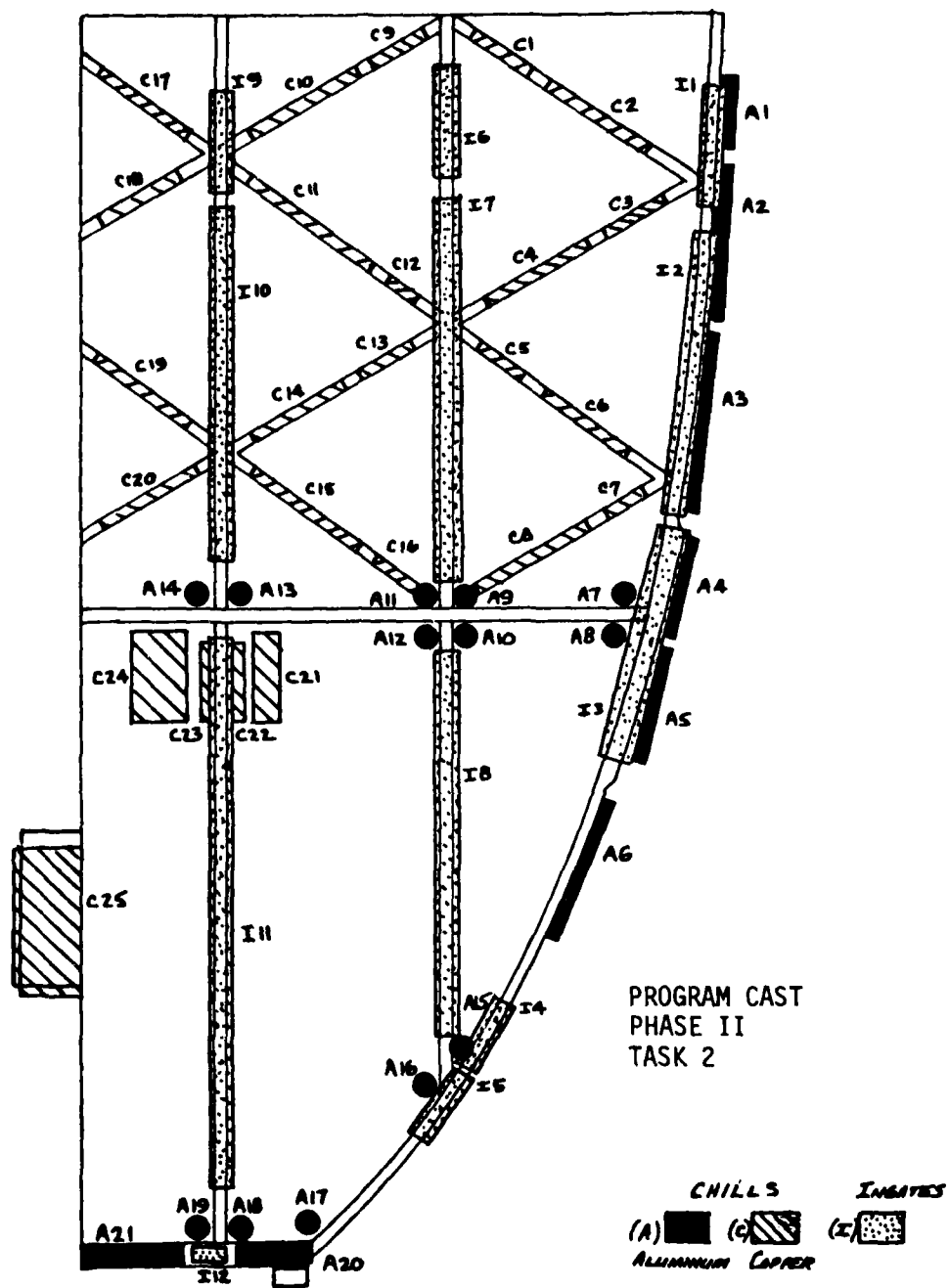


FIGURE 29 FORWARD FACE, BOEING PART A CASTINGS

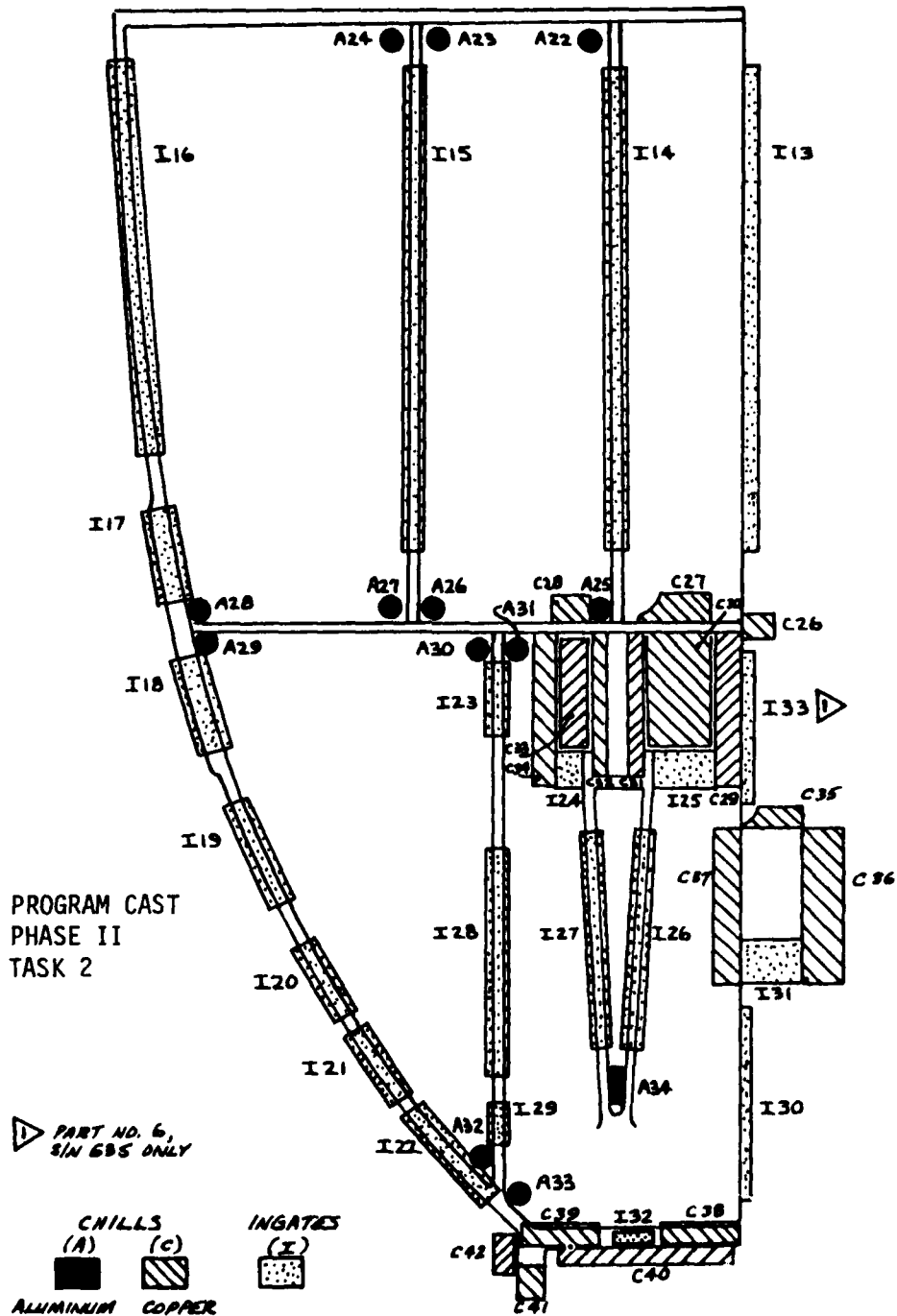


FIGURE 30 AFT FACE, BOEING PART A CASTINGS

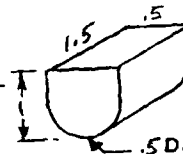
TABLE 7 CHILL DETAILS
Boeing Part A

Chill

Dimensions
(x) (y) (z)

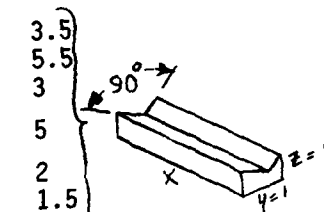
Aluminum

A1	1	3	1
A2, A3	1	6	1
A4, A5	1	4	1
A6	1	6	1
A7-A19	.75D	2	-
A20	2	1	.75
A21	3	1	1
A22-A33	.75D	2	-
A34	.5	1.5	1

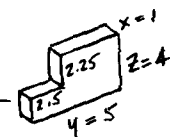


Copper

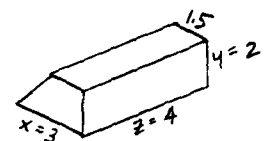
C1, C3	3.5		
C2, C4	5.5		
C5	3		
C6, C8, C10,	5		
C11, C14, C14	2		
C7	1.5		
C9, C12, C13, C16	3.5		
C17-C20	1.25	5	2
C21	.5	5	1.5
C22, C23	2.5	5	2
C24	3	5	3.5
C25	1.5	.5	2
C26			
C27			



C34



C35



C38, C39

3	1.25	1.25
---	------	------

C40

5	1	1
---	---	---

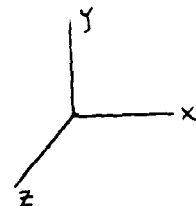
C41

1	1.25	5
---	------	---

C42

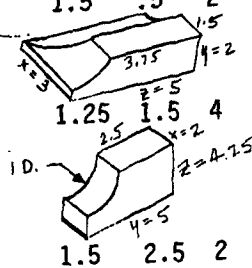
1	1.5	5
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1 Dimensions in inches per orientations:



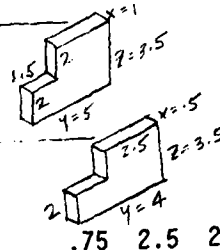
C28

C29, C36



C30

C31



C32

C33

TABLE 8 INGATE DETAILS
Boeing Part A

Ingate	At Casting		At Riser		1
	(x)	(y)	(x)	(y)	
I1	.375	8	.5	8	
I2	.375	7	.5	7	
I3	.75	7.5	.875	7.5	
I4	.375	3	.5	3	
I5	.375	2.5	.5	2.5	
I6	.375	4.5	.5	4.5	
I7	.375	11.75	.5	12.5	
I8	.375	14	.5	14	
I9	.375	3	.5	3	
I10	.375	11.5	.5	12	
I11	.375	17	.5	17	
I12	1.5	.5	1.5	.75	
I13	.5	15.75	.75	16.5	
I14, I15	.5	19.5	.625	21.5	
I16	.375	15.5	.625	15.5	
I17, I18	.625	3.375	.75	3.625	
I19	.375	4.125	.5	4.375	
I20-I22	.5	3	.625	3.125	
I23	.375	1.375	.375	1.75	
I24	.625	2.5	1.25	2.5	
I25	1.625	2.5	2.5	2.5	
I26, I27	.375	5.875	.5	6	
I28	.312	8.5	.5	8.75	
I29	.312	1.5	.312	1.25	
I30	.5	6.75	.75	7.12	
I31	1.625	2.5	2.5	2.5	
I32	.5	1.75	.75	2	
I33	.5	6.75	.75	7.12	2

1 Dimensions in inches per orientations:

2 Used for casting no. 6 (S/N 635) only.

TABLE 9
SUMMARY OF FOUNDRY VARIABLES
PART A BOEING CASTINGS
PHASE II TASK 2
BOEING PATTERN NO. 6R672039

NOMINAL SECTION THICKNESS (INCHES)	DISTANCE FROM (INCHES):										COPPER CHILL				
	TARGET CLASS: 50/40/5										ALUMINUM CHILL				
	0-.5	.5-1	1-2	2-5	>5	0-.5	.5-1	1-2	2-5	>5	0-.5	.5-1	1-2	2-5	>5
0.1															
0.2															
0.3				4B, 7C 5T, 6T					4B, 7C 5T, 6T					4B, 7C 5T, 6T	
0.5															
1.0			3T 2C, 2S	4T 5B					2C, 2S 3T, 4T 3B						
2.0			11, 2T 14, 1C 1S T6, T7	13T 18, 2B					1T, 2T 13T, 14T 1C, 1S 18, 2B T6, T7				1T, 14T 1C, 1S T6, T7		

NOMINAL SECTION THICKNESS (INCHES)	DISTANCE FROM (INCHES):										COPPER CHILL				
	TARGET CLASS: 40/30/3										ALUMINUM CHILL				
	0-.5	.5-1	1-2	2-5	>5	0-.5	.5-1	1-2	2-5	>5	0-.5	.5-1	1-2	2-5	>5
0.1			10T, 18T 11T, 1C 14T, 20T 15T, 1C 11T, 1C	13S, 7T, 1S 10C, 9T, 10C 11T, 1C 12C, 1C 13T, 20T 14T, 1C 15T, 1C	10B, 3C 8T, 11C 12C, 1C 13T, 20T 14T, 1C 15T, 1C										
0.2			22T 6S, 6C	19T, 20T 13C, 7B 25T, 9C 6B	15T, 16T 5C, 5S 20T	26T, 10C 28T, 9C	18T 6C, 6S	3S 9T, 8C	7T, 8T 3C, 15C 12C, 21T T5, T10 23T	10T, 10B 11T, 11C 24T 14C				15T 6C, 5S 16T	9T, 8C 21T, 12C 11T, 1C 13T, 24T 22T, 14C 17T, 8B 20T, 21T 6C, 6S 18, 13C
0.3				TB					TB						TB
0.5			11T, T9 4C, 4S	12T, 6B 4C, 4S					12T, 6B 4C, 4S T9, 11T					6B	
1.0															
2.0															

HITCHCOCK PART A CASTINGS

Details of allowable specimens from five Hitchcock Part A castings are described in relation to the following variables:

1. Location within each casting
2. Strength/elongation class and quality grade
3. Nominal section thickness
4. Distance from ingates
5. Distance from risers
6. Distance from chills

The five Hitchcock castings provided 180 allowables test specimens. In addition to allowables specimens, five integral cast-on tension specimens were located at selected zones of each casting similar to the Boeing Part A castings.

Foundry variables are identified in Figures 31 and 32. These are drag (forward face) and cope (aft face) sides of the Hitchcock castings, respectively. In Figure 31, 23 ingates are designated by the symbols I1-I23. The geometries of these ingates are summarized in Table 10. Chilling of the drag side is also shown in Figure 31 by 14 normal chills (N1-N14) and 16 form chills (F1-F16). All normal chills were cast iron. All form chills were 70,000 manganese bronze. Details of chills are summarized in Table 11.

Figure 32 shows the locations of 23 risers (R1-R23), 42 normal chills (N15-N56) and 5 form chills (F17-F21) on the cope-side of these castings. Chill geometries are summarized in Table 11. Details of the risers are summarized in Table 10.

Table 12 shows the relations between foundry variables and specimen locations. The information is separated into two groups based on the target strength/elongation classes and quality grades. Each specimen is identified by its nominal section thickness and the closest distance from ingates, risers, and chills. These distances are measured from the ingate, riser, and chill at the mold cavity surface to the center of the specimen.

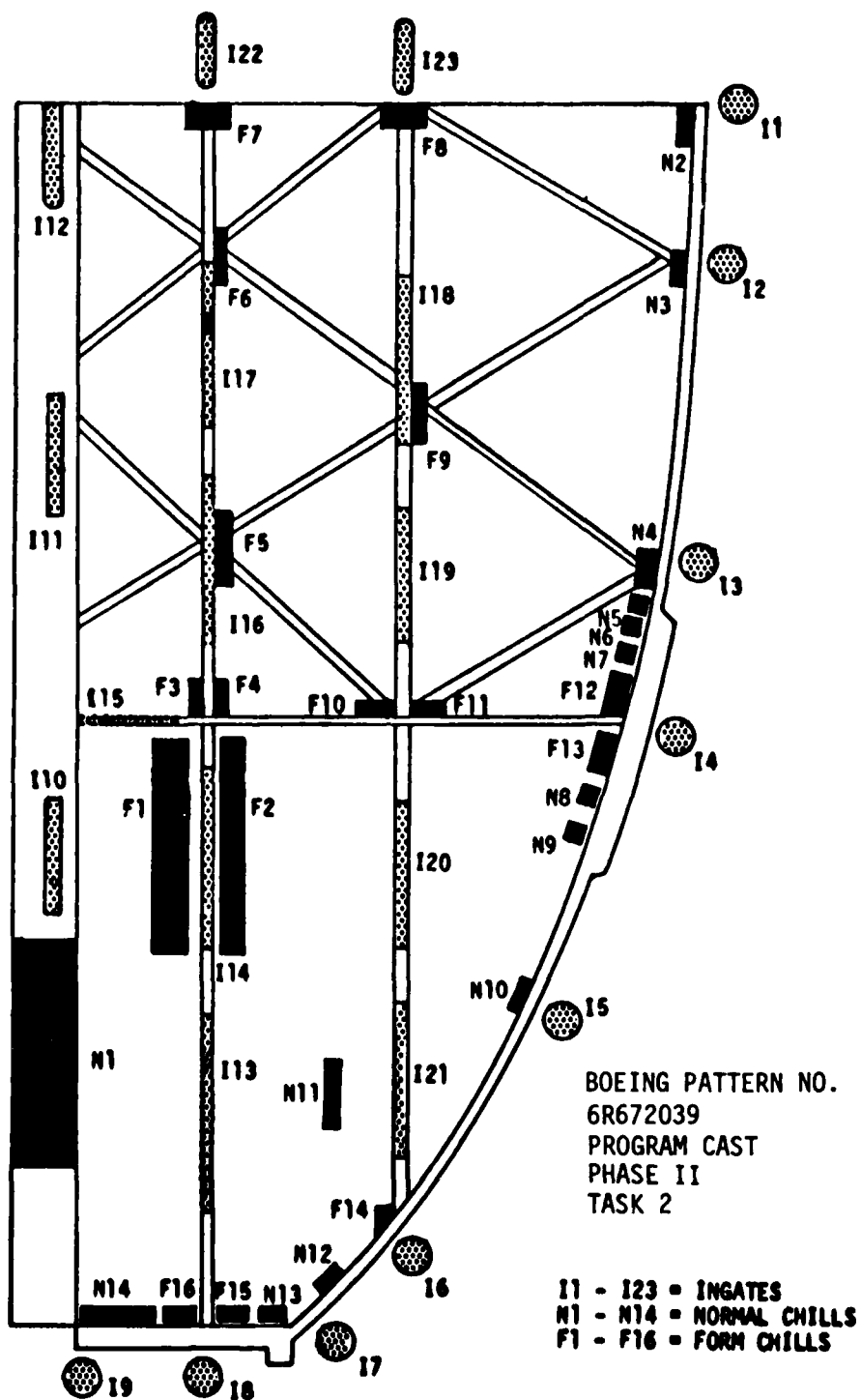


FIGURE 31 DETAILS OF DRAG HITCHCOCK CASTINGS PART A

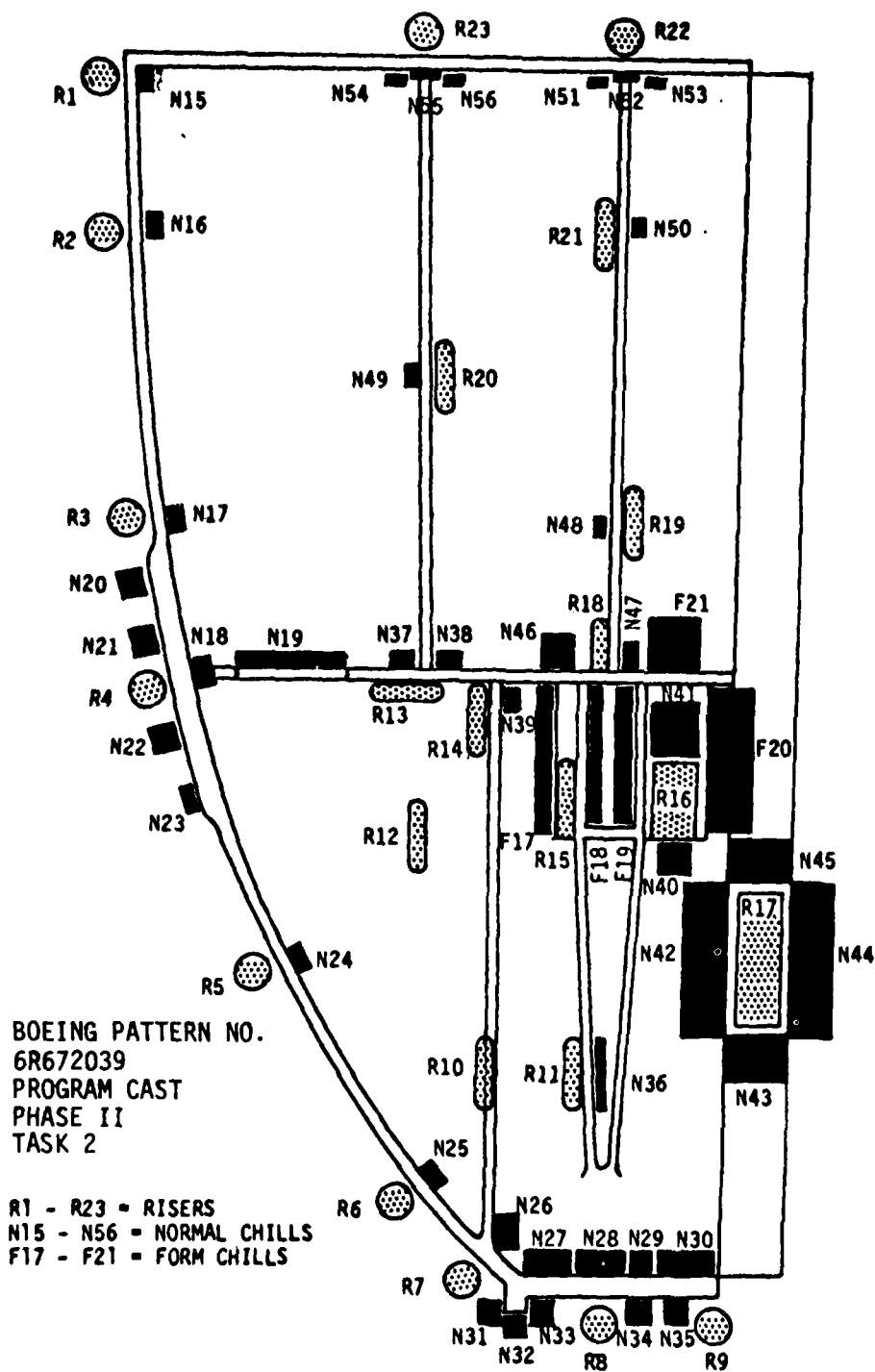


FIGURE 32 DETAILS OF COPE HITCHCOCK CASTINGS PART A

TABLE 10 INGATE AND RISER DETAILS HITCHCOCK PART A

ITEM	SHAPE	DIMENSIONS AT:	
		CASTING	RUNNER
Ingate			
I1-I9	Cylindrical	1 D.	1.25 D.
I10-I12	Rectangular	.25 x 4	.5 x 5
I13, I14	"	.1 x 5.5	.5 x 6
I15	"	.1 x 3.5	.5 x 4
I16-I19	"	.1 x 4.5	.5 x 5
I20, I21	"	.1 x 4	.5 x 4.5
I22	"	.75 x 4	.375 x 3.5
I23	"	1 x 4	.375 x 3.5
Riser			
R1-R9	Cylindrical	1.25 D.	
R10	Rectangular	.75 x 2.5	
R11	"	.75 x 2	
R12	"	.75 x 2.5	
R13, R14	"	.5 x 2	
R15	"	.75 x 2.5	
R16	"	1.75 x 2.5	
R17	"	1.75 x 3.5	
R18-R21	"	.5 x 2	
R22, R23	Cylindrical	1.5 D.	

TABLE 11 CHILL DETAILS
Hitchcock Part A

CHILL	DIMENSIONS			
	(x)	(y)	(z)	
Normal (Cast Iron)				
N1	1	6	2	
N2-N4	.5	1	2	
N5-N9	.5	.5	2	
N10	.5	1	2	
N11	.5	4	1	
N12, N13	1	.5	2	
N14	2	.5	2	
N15-N17	.5	1	2	
N18	.75	1	2	
N19	4	.5	1	
N20-N22	1	1	4	
N23	.5	1	4	
N24-N26	.5	1	2	
N27	1.5	1	1	
N28, N30	2	1	1	
N29	1	1	2	
N31-N35	1	1	4	
N36	.25	2	1	
N37, N38	1	.5	3	
N39	.5	1	2	
N40	1	1	1.5	
N41	1.5	2	2	
N42	1.5	5	2	
N43	2	1.5	2	
N44	1.5	5	2	
N45	2	1.5	2	
N46	1	1	4	
N47-N50	.5	1	3	
N51-N56	.5	.25	3	
Form (70,000 Manganese Bronze)				
F1	1.5	6	4	
F2	1	6	4	
F3, F4	.5	1	2	
F5	1	2	1	
F6	.5	2	1	
F7, F8	2	1	.5	
F9	.5	2	1	
F10, F11	1	.5	2	
F12, F13, F14	.5	1	2	
F15, F16	1	.5	2	
F17	1	5	4	
F18	.5	5	4	
F19	.75	5	4	
F20	2	5	4	
F21	2	2	4	

 Dimensions in inches per orientations:

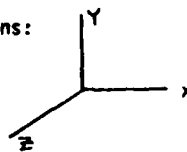


TABLE 12 SUMMARY OF FOUNDRY VARIABLES
PART A HITCHCOCK CASTINGS
PHASE II TASK 2
BOEING PATTERN NO. 6R672039

DISTANCE FROM (INCHES)		TARGET CLASS 50/40/5					TARGET GRADE B				
		INGATE					RISER				
NOMINAL SECTION THICKNESS (INCHES)		0-0.5	.5-1	1-2	2-5	> 5	0-0.5	.5-1	1-2	2-5	> 5
0.1											
0.2											
0.3				6T	5T 4B				5T 6T	4B	
0.5											
1.0		3T	4T	2C 2S				3T 4T 2C		3T 4T 2C 3B 2S	
2.0				1T 13T 14T 15 3B	1B 2B T6 T7			1T 14T 1C 1S 1B 2B 3B	13T	1T 14T 1C 1S 1B 2B T6 T7	

DISTANCE FROM (INCHES)		TARGET CLASS 40/30/3					TARGET GRADE C				
		INGATE					RISER				
NOMINAL SECTION THICKNESS (INCHES)		24T	21T	23T	7T 8T 9T 10T 11T 12T 13T 14T 15T 16T 17T 18T 19T 20T 21T 22T 23T 24T 25T 26T 27T 28T 29T 30T 31T 32T 33T 34T 35T 36T 37T 38T 39T 40T 41T 42T 43T 44T 45T 46T 47T 48T 49T 50T 51T 52T 53T 54T 55T 56T 57T 58T 59T 60T 61T 62T 63T 64T 65T 66T 67T 68T 69T 70T 71T 72T 73T 74T 75T 76T 77T 78T 79T 80T 81T 82T 83T 84T 85T 86T 87T 88T 89T 90T 91T 92T 93T 94T 95T 96T 97T 98T 99T 100T 101T 102T 103T 104T 105T 106T 107T 108T 109T 110T 111T 112T 113T 114T 115T 116T 117T 118T 119T 120T 121T 122T 123T 124T 125T 126T 127T 128T 129T 130T 131T 132T 133T 134T 135T 136T 137T 138T 139T 140T 141T 142T 143T 144T 145T 146T 147T 148T 149T 150T 151T 152T 153T 154T 155T 156T 157T 158T 159T 160T 161T 162T 163T 164T 165T 166T 167T 168T 169T 170T 171T 172T 173T 174T 175T 176T 177T 178T 179T 180T 181T 182T 183T 184T 185T 186T 187T 188T 189T 190T 191T 192T 193T 194T 195T 196T 197T 198T 199T 200T 201T 202T 203T 204T 205T 206T 207T 208T 209T 210T 211T 212T 213T 214T 215T 216T 217T 218T 219T 220T 221T 222T 223T 224T 225T 226T 227T 228T 229T 230T 231T 232T 233T 234T 235T 236T 237T 238T 239T 240T 241T 242T 243T 244T 245T 246T 247T 248T 249T 250T 251T 252T 253T 254T 255T 256T 257T 258T 259T 260T 261T 262T 263T 264T 265T 266T 267T 268T 269T 270T 271T 272T 273T 274T 275T 276T 277T 278T 279T 280T 281T 282T 283T 284T 285T 286T 287T 288T 289T 290T 291T 292T 293T 294T 295T 296T 297T 298T 299T 300T 301T 302T 303T 304T 305T 306T 307T 308T 309T 310T 311T 312T 313T 314T 315T 316T 317T 318T 319T 320T 321T 322T 323T 324T 325T 326T 327T 328T 329T 330T 331T 332T 333T 334T 335T 336T 337T 338T 339T 340T 341T 342T 343T 344T 345T 346T 347T 348T 349T 350T 351T 352T 353T 354T 355T 356T 357T 358T 359T 360T 361T 362T 363T 364T 365T 366T 367T 368T 369T 370T 371T 372T 373T 374T 375T 376T 377T 378T 379T 380T 381T 382T 383T 384T 385T 386T 387T 388T 389T 390T 391T 392T 393T 394T 395T 396T 397T 398T 399T 400T 401T 402T 403T 404T 405T 406T 407T 408T 409T 410T 411T 412T 413T 414T 415T 416T 417T 418T 419T 420T 421T 422T 423T 424T 425T 426T 427T 428T 429T 430T 431T 432T 433T 434T 435T 436T 437T 438T 439T 440T 441T 442T 443T 444T 445T 446T 447T 448T 449T 450T 451T 452T 453T 454T 455T 456T 457T 458T 459T 460T 461T 462T 463T 464T 465T 466T 467T 468T 469T 470T 471T 472T 473T 474T 475T 476T 477T 478T 479T 480T 481T 482T 483T 484T 485T 486T 487T 488T 489T 490T 491T 492T 493T 494T 495T 496T 497T 498T 499T 500T 501T 502T 503T 504T 505T 506T 507T 508T 509T 510T 511T 512T 513T 514T 515T 516T 517T 518T 519T 520T 521T 522T 523T 524T 525T 526T 527T 528T 529T 530T 531T 532T 533T 534T 535T 536T 537T 538T 539T 540T 541T 542T 543T 544T 545T 546T 547T 548T 549T 550T 551T 552T 553T 554T 555T 556T 557T 558T 559T 560T 561T 562T 563T 564T 565T 566T 567T 568T 569T 570T 571T 572T 573T 574T 575T 576T 577T 578T 579T 580T 581T 582T 583T 584T 585T 586T 587T 588T 589T 590T 591T 592T 593T 594T 595T 596T 597T 598T 599T 600T 601T 602T 603T 604T 605T 606T 607T 608T 609T 610T 611T 612T 613T 614T 615T 616T 617T 618T 619T 620T 621T 622T 623T 624T 625T 626T 627T 628T 629T 630T 631T 632T 633T 634T 635T 636T 637T 638T 639T 640T 641T 642T 643T 644T 645T 646T 647T 648T 649T 650T 651T 652T 653T 654T 655T 656T 657T 658T 659T 660T 661T 662T 663T 664T 665T 666T 667T 668T 669T 670T 671T 672T 673T 674T 675T 676T 677T 678T 679T 680T 681T 682T 683T 684T 685T 686T 687T 688T 689T 690T 691T 692T 693T 694T 695T 696T 697T 698T 699T 700T 701T 702T 703T 704T 705T 706T 707T 708T 709T 710T 711T 712T 713T 714T 715T 716T 717T 718T 719T 720T 721T 722T 723T 724T 725T 726T 727T 728T 729T 730T 731T 732T 733T 734T 735T 736T 737T 738T 739T 740T 741T 742T 743T 744T 745T 746T 747T 748T 749T 750T 751T 752T 753T 754T 755T 756T 757T 758T 759T 760T 761T 762T 763T 764T 765T 766T 767T 768T 769T 770T 771T 772T 773T 774T 775T 776T 777T 778T 779T 780T 781T 782T 783T 784T 785T 786T 787T 788T 789T 790T 791T 792T 793T 794T 795T 796T 797T 798T 799T 800T 801T 802T 803T 804T 805T 806T 807T 808T 809T 810T 811T 812T 813T 814T 815T 816T 817T 818T 819T 820T 821T 822T 823T 824T 825T 826T 827T 828T 829T 830T 831T 832T 833T 834T 835T 836T 837T 838T 839T 840T 841T 842T 843T 844T 845T 846T 847T 848T 849T 850T 851T 852T 853T 854T 855T 856T 857T 858T 859T 860T 861T 862T 863T 864T 865T 866T 867T 868T 869T 870T 871T 872T 873T 874T 875T 876T 877T 878T 879T 880T 881T 882T 883T 884T 885T 886T 887T 888T 889T 890T 891T 892T 893T 894T 895T 896T 897T 898T 899T 900T 901T 902T 903T 904T 905T 906T 907T 908T 909T 910T 911T 912T 913T 914T 915T 916T 917T 918T 919T 920T 921T 922T 923T 924T 925T 926T 927T 928T 929T 930T 931T 932T 933T 934T 935T 936T 937T 938T 939T 940T 941T 942T 943T 944T 945T 946T 947T 948T 949T 950T 951T 952T 953T 954T 955T 956T 957T 958T 959T 960T 961T 962T 963T 964T 965T 966T 967T 968T 969T 970T 971T 972T 973T 974T 975T 976T 977T 978T 979T 980T 981T 982T 983T 984T 985T 986T 987T 988T 989T 990T 991T 992T 993T 994T 995T 996T 997T 998T 999T 1000T						

BOEING PART B CASTINGS

Details of allowable specimens from five Boeing Part B castings are described in relation to the following variables:

1. Location within each casting
2. Strength/elongation class and quality grade
3. Nominal section thickness
4. Distance from ingates
5. Distance from insulators
6. Distance from chills

These five castings provided 204 allowables test specimens as described in Table 2. In addition to allowables specimens, four integral cast-on tension specimens were located at selected zones of each casting. Refer to Figure 13.

The foundry variables are identified in Figure 33. The forward and aft faces of the castings show 27 ingates, designated by the symbols I1-I27. The geometries of these ingates are summarized in Table 13. Six plaster insulators were used on the vertical box segments and are designated as INS. 1 through INS. 6. Table 14 contains insulation geometry details. Chilling is also shown in Figure 33 by 56 aluminum (A1-A56) and 35 copper (C1-C35) chills. Details of chills are summarized in Table 15.

Table 16 shows the relations between foundry variables and specimen locations. The information is separated in two groups based upon the target strength/elongation classes and quality grades. Each specimen is identified by its nominal section thickness and the closest distance from ingates, insulators, and chills. These distances are measured from the mold cavity surface to the center of the specimen.

The tabulated foundry variables information for Boeing Parts A and B castings do not include riser details. This is due to the vertical flow method of casting. Refer to Figure 34. An end view shows the directions of metal flow into the mold. Sprues at both ends are connected to horizontal feeders located at the base of the mold. On both FWD and AFT sides, vertical risers allow metal to flow upwards into the horizontal ingates. Therefore, the pertinent foundry variables information are ingate sizes and locations plus chills and insulators.

BOEING PATTERN NO. 7R672039
PROGRAM CAST PHASE II TASK 2

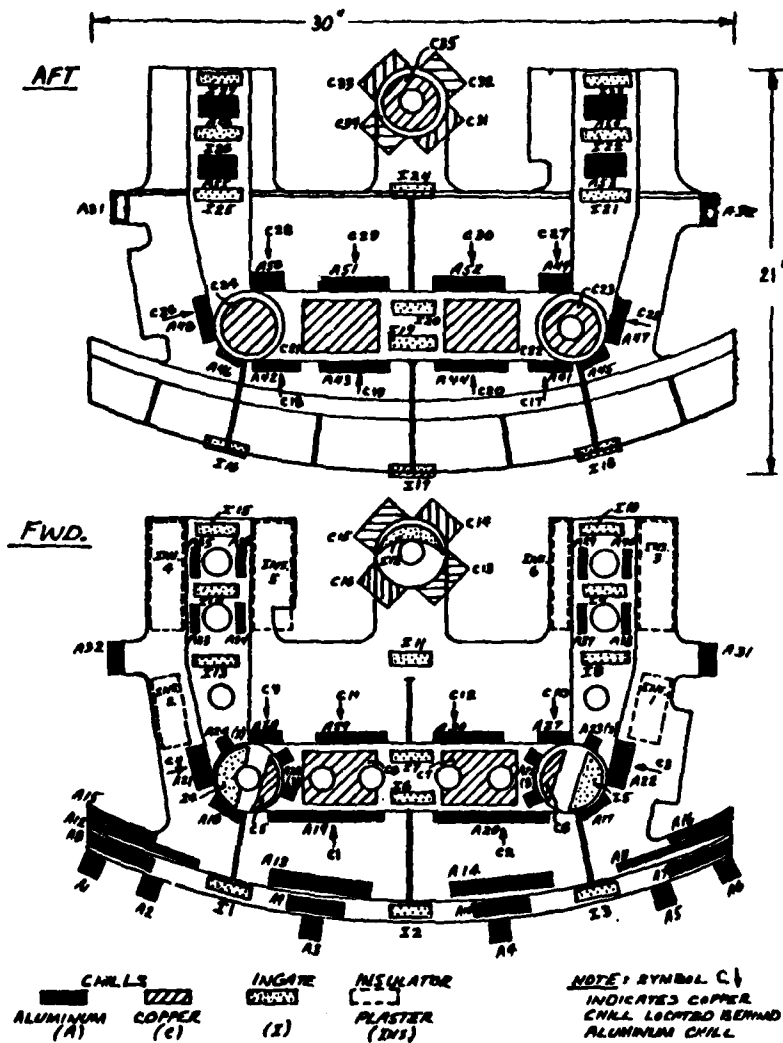


FIGURE 33 DETAILS OF PART B

TABLE 13 INGATE DETAILS
Boeing Part B

INGATE	SHAPE	DIMENSIONS AT:		CASTING	
		RISER (x) (y)		(x) (y)	
I1-I3	Rectangular	1.75 .5		1.375 .625	
I4, I5	Semicircular	1.25 R.		1.25 R.	
I6-I11	Rectangular	1.75 .5		1.875 .625	
I12	Semicircular	1.25 R.		1.25 R.	
I13-I27	Rectangular	1.75 .5		1.875 .625	

1 Dimensions in inches per orientations:

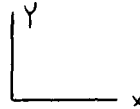


TABLE 14 INSULATOR DETAILS
Boeing Part B

INSULATOR	DIMENSIONS		
	(x) (y) (z)		
INS 1, INS 2	1.5 4 .25		
INS 3, INS 4	1.5 5 .25		
INS 5	2 5 .25		
INS 6	1 5 .25		

1 Dimensions in inches per orientations:

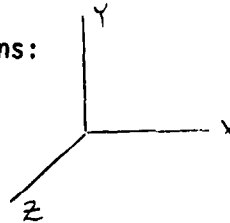


TABLE 15 CHILL DETAILS
Boeing Part B

CHILL

DIMENSIONS
(x) (y) (z)

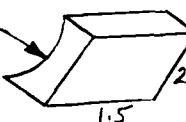
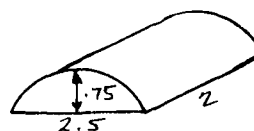


Aluminum:

A1-A6	1	1	5
A7, A8	3	1	1
A9, A10	2.5	1	1
A11, A12	5.25	.75	.5
A13, A14	4.5	1	.5
A15, A16	3	.5	.5
A17, A18	1.5	.5	2
A19, A20	5	.5	1
A21, A22	1	2	.5
A23, A24	.5D.	.5 (3 ea.)	
A25, A26	.5D.	.5 (8 ea.)	
A27, A28	1.5	.5	1
A29, A30	3	.5	1
A31, A32	.75	1.5	.5
A33-A40	.5	1.5	.5
A41, A42	2	.5	1
A43, A44	3	.5	1
A45, A46	1.5	.5	.5
A47, A48	1	2	1
A49, A50	1.5	1	.75
A51, A52	3	.5	.75
A53-A56	1.75	1	.5

Copper:

C1, C2	5	.5	1
C3, C4	1	2	1.5
C5, C6	.75	2.5	2
C7, C8	3.5	2.5	.125
C9, C10	1.25	.5	1.5
C11, C12	3	.5	1.5
C13-C16	1.75 R.		
C17, C18	2	.5	1.25
C19, C20	3	.5	1.25
C21, C22	3.5	1.5	.125
C23	2.5D	2 with 1"D. hole at center	
C24	2.5D	2	
C25, C26	1	2	1.5
C27, C28	1.25	1	1.5
C29, C30	3	.5	1.25
C31-C34	Same as C13-C16		
C35	Same as C23		



1 Dimensions in inches per orientations:

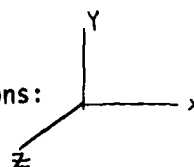


TABLE 16
SUMMARY OF FOUNDRY VARIABLES
PART B BOEING CASTINGS
PHASE II TASK 2 - ALLOWABLES

	NOMINAL SECTION THICKNESS (INCHES)										TARGET CLASS 50/40/5					TARGET GRADE B									
	DISTANCE FROM: (INCHES) INGATE										ALUMINUM CHILL					COPPER CHILL					INSULATOR				
	0-0.5	.5-1	1-2	2-5	>5	0-.5	.5-1	1-2	2-5	>5	0-.5	.5-1	1-2	2-5	>5	0-.5	.5-1	1-2	2-5	>5					
0.1																									
0.3			5x 6x	7x 4w	4Y	7x, 4Y, 4W	5x, 6x			5x, 6x, 7x, 4Y, 4W									4Y	5x, 6x, 7x, 4W					
0.5																									
1.0										x1, x3, x4 1w, 1z, 2z									x1, 1x, 2x, 1y, 1w, 1z, 2z	x3, x4					
3.0										x2, 3x, 4x, 2w, 3w									x2, 3x, 4x, 2y, 3y, 2w, 3w, 5z, 4z						

TARGET CLASS 40/30/3												TARGET GRADE C																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																														

X1, X2, X6, X8 PREPRODUCTION CASTINGS ONLY; X3, X4, X5, X7 INTEGRAL TENSILE COUPONS

X	Tension
Y	Compression
Z	Shear Bearing

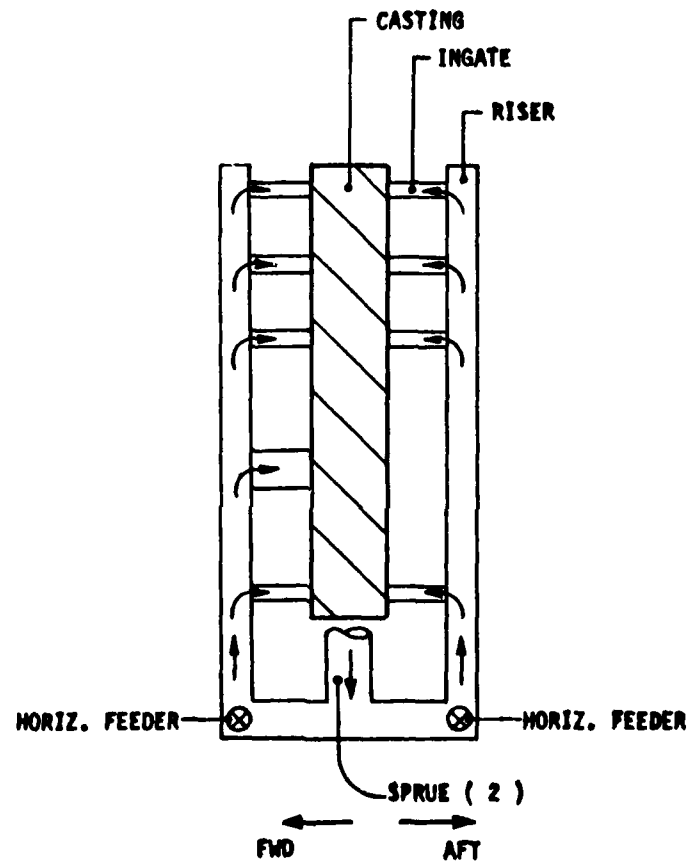


FIGURE 34 POURING SYSTEM BOEING PART A AND B CASTINGS

APPENDIX C

ELONGATION MEASUREMENTS

Two methods were used to measure elongation in all tensile tests. First, full-range stress-strain curves were recorded to failure. Secondly, fractured coupons were carefully fitted together to physically measure the extension between gage marks in accordance with ASTM E8-69. Stress-strain curve recorded elongations are generally less than physically measured values and they are also believed to be the more accurate of the two methods, recognizing the difficulties in fitting irregular fractured surfaces to obtain physical measurements. The physical measurement method is quicker, less costly, and currently used for many materials including high-strength aluminum alloy castings.

Phase II comparative elongation measurement results are plotted in Figure 35 and summarized in Table 17. In Figure 35, the abscissa represents elongations measured from the fractured coupons. Statistics of stress-strain curve elongations are plotted on the ordinate. Averages for round and flat coupons are shown by symbols. The ranges and quantities of results are designated for each level of measured elongation. A comparison of results between round and flat configurations shows:

1. Flat coupons give slightly lower average elongations, the difference being 1 percent or less.
2. There is more scatter associated with flat coupon results. At 7 percent measured elongation, 15 flat coupon results ranged from 2.6 percent to 12.4 percent with an arithmetic average of 5.6 percent strain. The single condition involving the largest quantity of data is for flat specimens at 3 percent measured elongation. Recorded values range from 0.5 to 4.7 percent strain with an arithmetic average of about 1.9 percent strain.

With the exception of the two flat coupon results at 9 percent measured elongation, stress-strain curve average elongations are less than the measured values. The differences increase with the larger measured elongations. In many cases, minimum recorded elongations are far less than measured values. It should be noted that all reference to elongation in this report concerning CAST program tests signifies stress-strain recorded values.

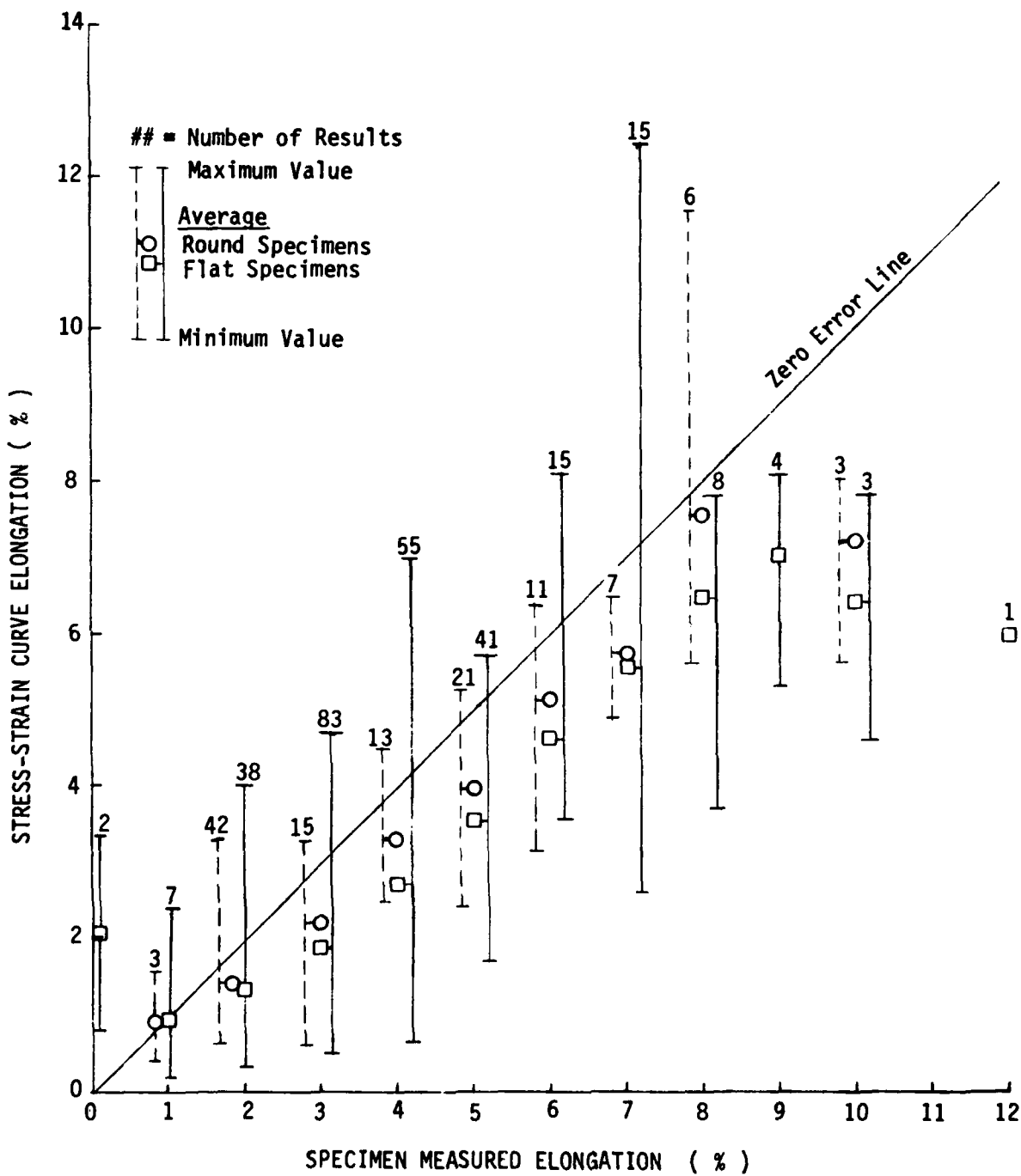


FIGURE 35 ELONGATION ANALYSIS
 A357-T6 CAST

TABLE 17 ELONGATION ANALYSIS
A357-T6 CASTINGS

SPECIMEN MEASURED ELONGATION (%)	STRESS-STRAIN CURVE ELONGATION (%)							
	Round Specimens				Flat Specimens			
	Qty.	Max.	Min.	Avg.	Qty.	Max.	Min.	Avg.
0	0	-	-	-	2	3.4	0.8	2.1
1	3	1.5	0.4	0.83	7	2.4	0.2	0.89
2	42	3.3	0.6	1.40	38	4.0	0.3	1.31
3	15	3.3	0.6	2.19	83	4.7	0.5	1.87
4	13	4.5	2.5	3.29	55	7.0	0.6	2.72
5	21	5.3	2.4	3.94	41	5.7	1.7	3.53
6	11	6.3	3.1	5.13	15	8.1	3.5	4.66
7	7	6.5	4.9	5.69	15	12.4	2.6	5.55
8	6	11.5	5.6	7.53	8	7.8	3.7	6.29
9	0	-	-	-	4	8.1	5.3	7.00
10	3	8.0	5.6	7.20	3	7.8	4.6	6.40
11	0	-	-	-	0	-	-	-
12	0	-	-	-	1	-	-	5.90
	121				272			

Blank

APPENDIX D

INTEGRAL COUPON PROPERTIES

Integral cast-on tensile coupons were detached from all castings after final processing. Tensile properties of integral coupons are contained in the data summary in Appendix E.

Tensile properties of integral coupons are required primarily to ensure that a casting has been properly heat treated. Both TUS and ELONG properties can be assessed from parts in the as-cast condition via nondestructive measurements for DAS and soundness. Chemistry, from selectively located attached chips or ladle samples, can be ensured without damaging the castings. However, TYS is not influenced by the variations in DAS or soundness that cause significant TUS and ELONG changes. In Section II, Tension Properties, it is shown that TYS is a responsive parameter to heat treatment. Therein, data illustrate that different sources for the -T6 condition material can produce essentially the same TUS and ELONG properties, but markedly different TYS values. This applies to both A357 and A356 alloys.

The task is to selectively locate integral coupons on a casting that will signify TYS for the most critical zones. Integral coupon locations are identified for the Phase II Parts A and B castings in Figures 12 and 13, respectively. Results obtained from these parts are illustrated in Figures 36, 37, and 38 for TUS, ELONG, and TYS, respectively.

In each figure, integral coupon and corresponding casting location tensile properties from all 14 castings are shown collectively. In each figure, a 1:1 line has been established for visual clarity. If integral and adjacent casting properties were the same, all data would be expected to fall on these lines. These experimental data show that the results for each of the three properties are situated around the unity line. The deviations can be categorized into two areas. These are (1) absolute deviations from the unity line and (2) slope deviations from the unity line. These categories are discussed below for each property.

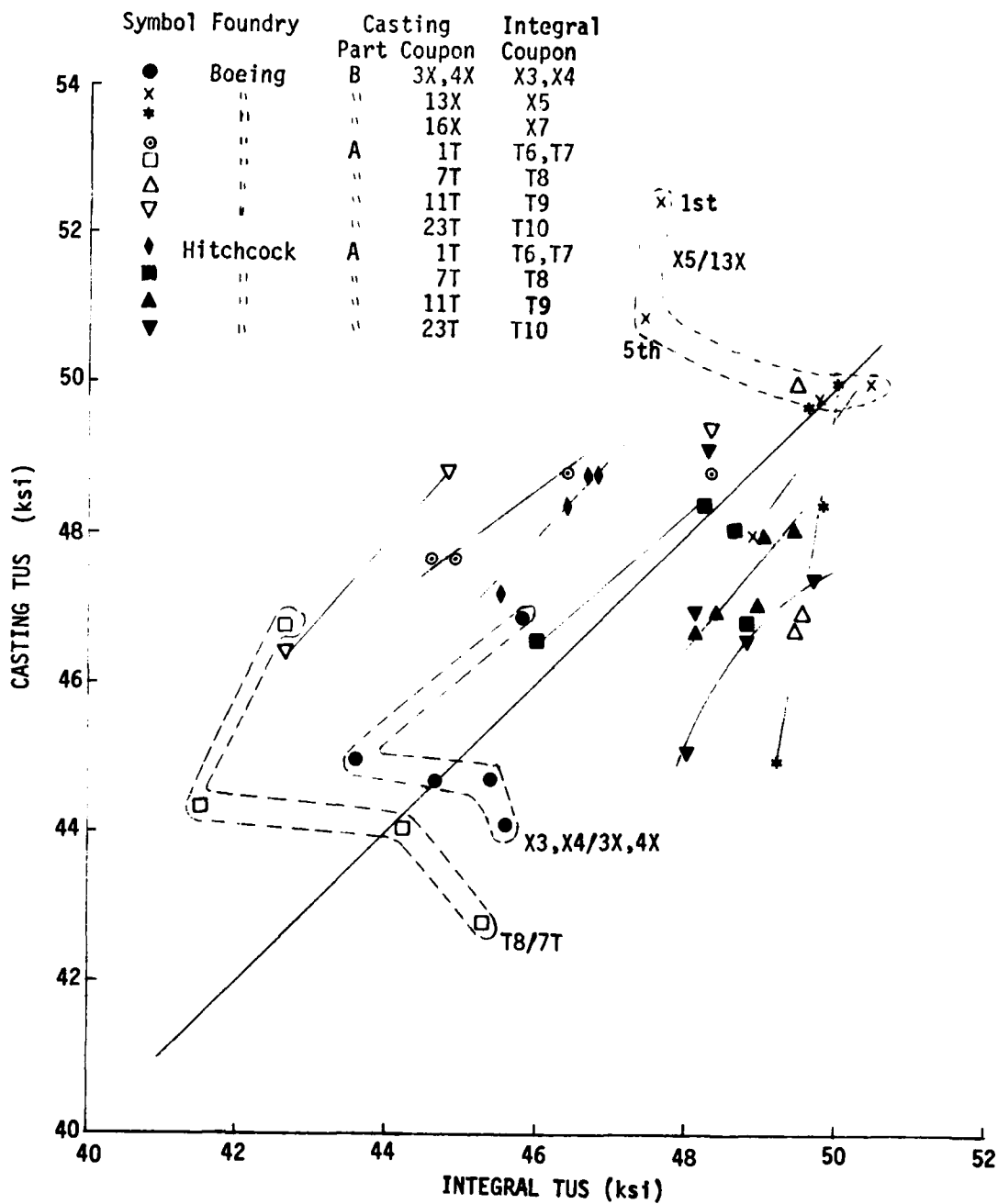


FIGURE 36 RELATIONS BETWEEN INTEGRAL COUPONS AND CASTING TUS PROPERTIES
A357-T6

CAST

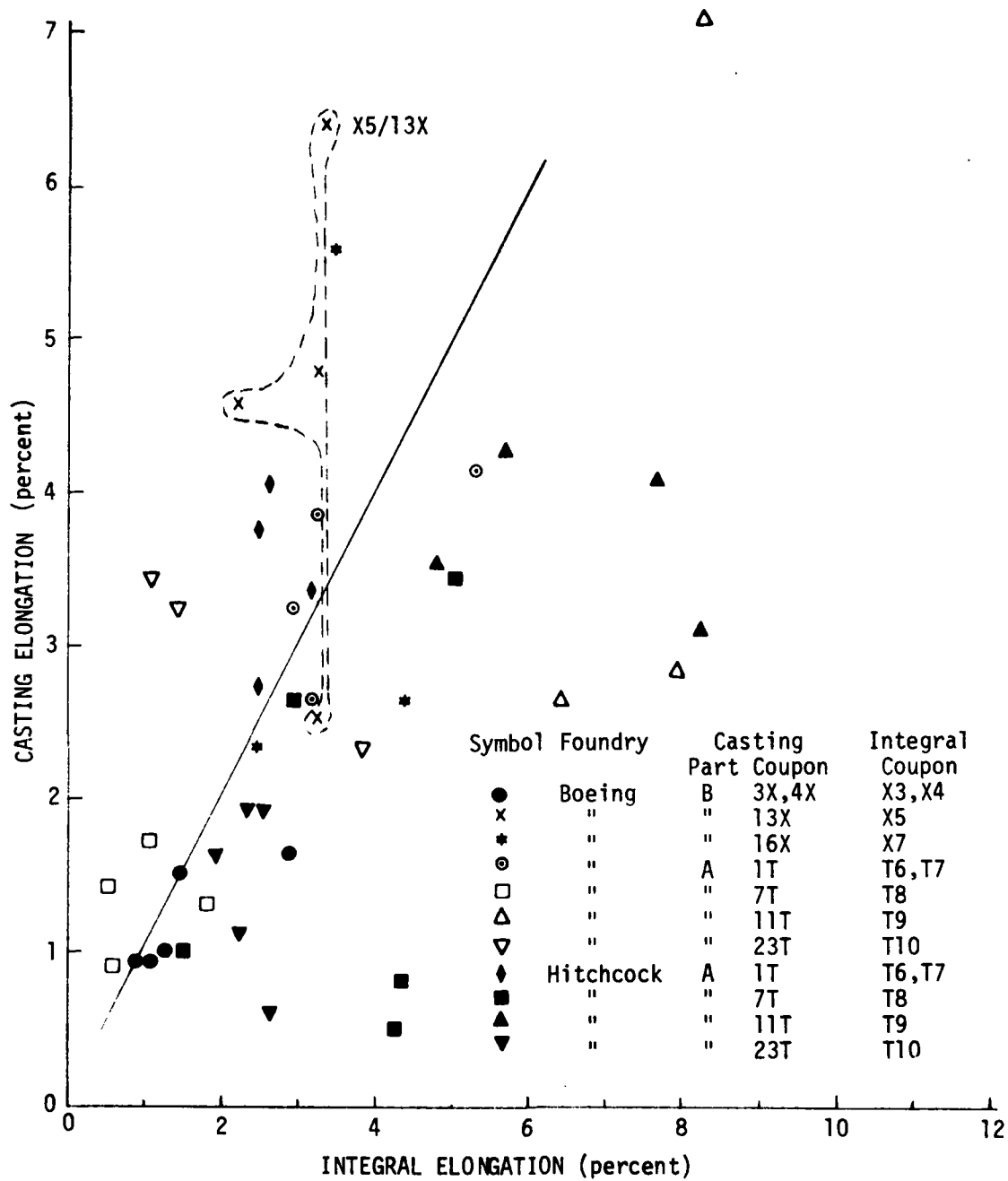


FIGURE 37 RELATIONS BETWEEN INTEGRAL COUPONS AND CASTING ELONGATION PROPERTIES
A357-T6 CAST

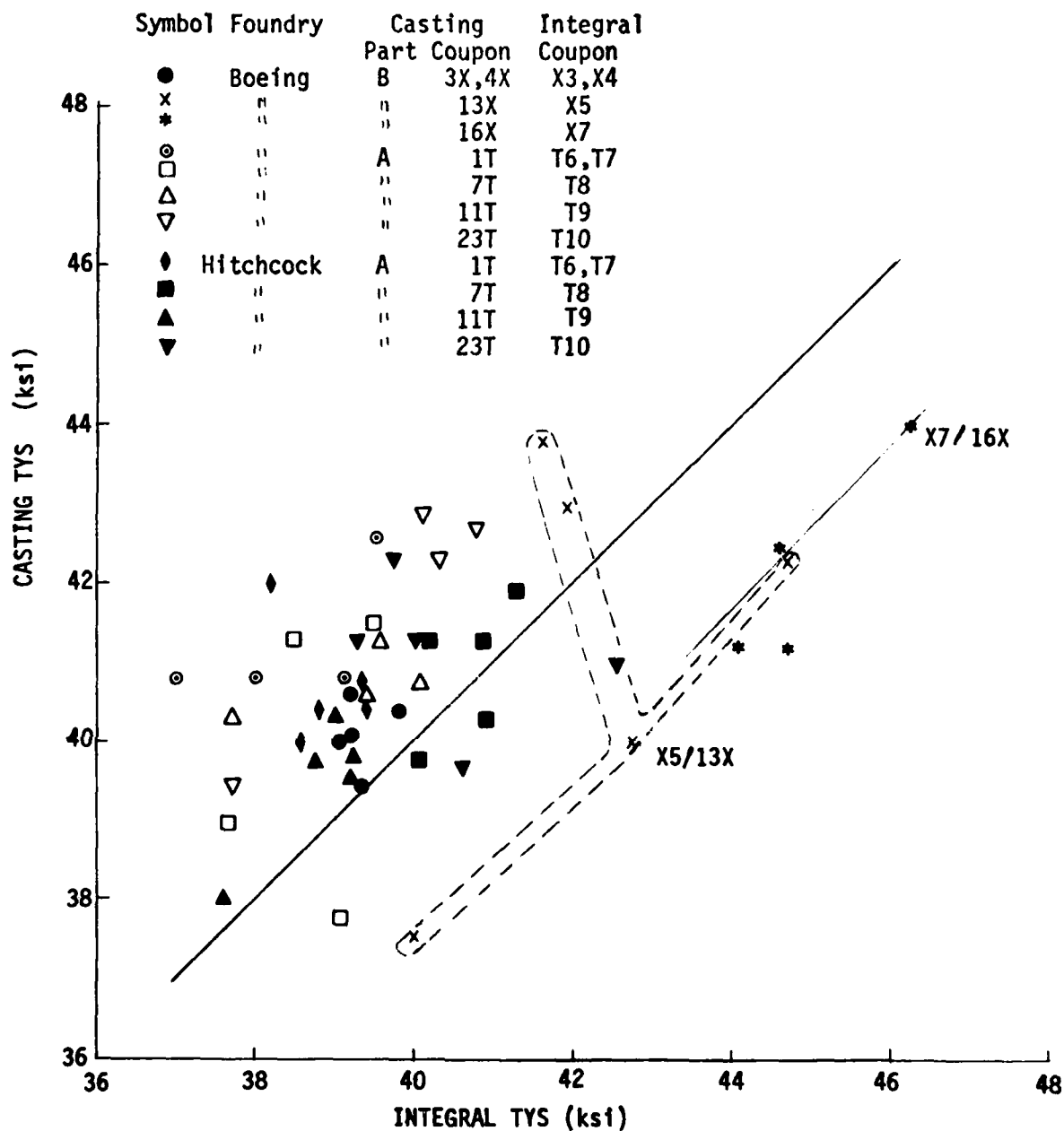


FIGURE 38 RELATIONS BETWEEN INTEGRAL COUPONS AND
CASTING TYS PROPERTIES
A357-T6 CAST

TUS (Fig. 36):

The general trends developed from the same locations in replicate castings are lines offset but parallel to the unity line. This means that integral coupons have either higher or lower TUS values than the corresponding casting zones and the variations between castings are identifiable by integral coupon properties. Integral coupon T8 from Boeing Part A castings is obviously not a good indicator for the casting 7T location, the adjacent lower web. The trend is converse to the unity trend line. The same situation applies to the Part B casting integral lug (X3 and X4) in relation to the solid 3-inch-diameter fitting (3X, 4X). The only other nonrelatable comparison is between the Part B right outside flange (13X) and the adjacent integral coupon (X5). Three of the five results fall near the unity line while the other two show much higher casting TUS values (13X) than what would be expected from integral coupon TUS values (X5). The two results causing the trend inconsistency represent the first and fifth castings. No intentional differences in manufacture regarding placement of chills or insulators were made. This type of inconsistency illustrates the importance for precise repetition of manufacture between all production castings.

ELONG (Fig. 37):

Results tend to band around the unity line showing a general relation between ELONG for integral coupons and castings. The Part B casting (X5/13X) group does not follow this trend, as was the case using TUS values.

TYS (Fig. 38):

The overall range of TYS is relatively small from all integral coupon and casting locations in comparison to TUS. It is somewhat more difficult to observe the general trends of results situated about the unity line. The (X5/13X) comparison shows poor correlation for TYS, as was the case for both TUS and ELONG. One group of results illustrates a very good relationship. These are Part B specimens (X7/16X) from the vertical torque box inner flange location. These results parallel the unity line showing integral coupons to be 2 to 3 ksi higher in TYS than the adjacent flange.

As a matter of interest, the X7 integral coupon TYS results were compared with properties representing a variety of Part B casting zones. These results are shown in Figure 39. This series of seven graphs shows TYS of the X7 integral coupons on the abscissa and casting zone TYS values as ordinates. Each graph contains two casting-zone results to evaluate similarities of response. Each graph also contains a unity line to designate a 1:1 response between casting and integral coupon values. The cored fitting (1X) is less responsive than the solid 3-inch-diameter fitting (4X) to X7 changes. The solid fitting TYS remains about 5 ksi less than X7. However, TYS of both fittings can be estimated using the X7 integral coupon TYS. The horizontal torque box TYS properties (6X, 7X) are between 3 and 4 ksi less than X7. The right vertical torque box coupons (8X, 9X) are estimated well by X7. They exhibit about one-half as much TYS variations as do the integral coupons. The left side of the base attachment flange is not relatable to X7 TYS variations. Vertical torque box zones (16X, 18X) are relatable to X7 TYS variations. As cited previously, 16X lags X7 by about 3 ksi. Location 18X is from the opposite vertical torque box, immediately adjacent to the inner flange. TYS from this location seems to respond about four times greater than the X7 integral coupons. Base attachment flange, right side coupons (19X, 20X) show different results. The higher TYS from 19X is the result of that zone being directly chilled, whereas 20X is adjacent to the same chill. The heavy chilling effect at 19X may have prevented TYS variations similar to those noted in other casting zones and at X7. In the center of the base attachment flange, coupons (21X, 22X) show a fairly consistent 3 ksi less TYS than X7.

As shown in detail for Part B castings, some zones respond very well with integral coupons while others do not respond at all to integral coupon property variations. It has also been shown that numerous casting zones are relatable to a single integral coupon. The entire analysis presented above has been made independent of DAS and soundness properties. Since TYS does not seem to be a function of these two physical parameters, it is suggested that only the comparisons using TYS data be considered relevant. Both TUS and ELONG are influenced by DAS and soundness, and these variables were not accounted for in those comparisons. If this type of analysis is considered applicable to infer TYS properties of casting zones, as it is believed to be, it must also be recognized that both casting zones and integral coupon TYS values are, to some degree, variable. This is on an individual basis and is most likely reflective of the difference in responses of various casting zones to the same nominal heat treatment. The above points must be considered during preproduction casting development.

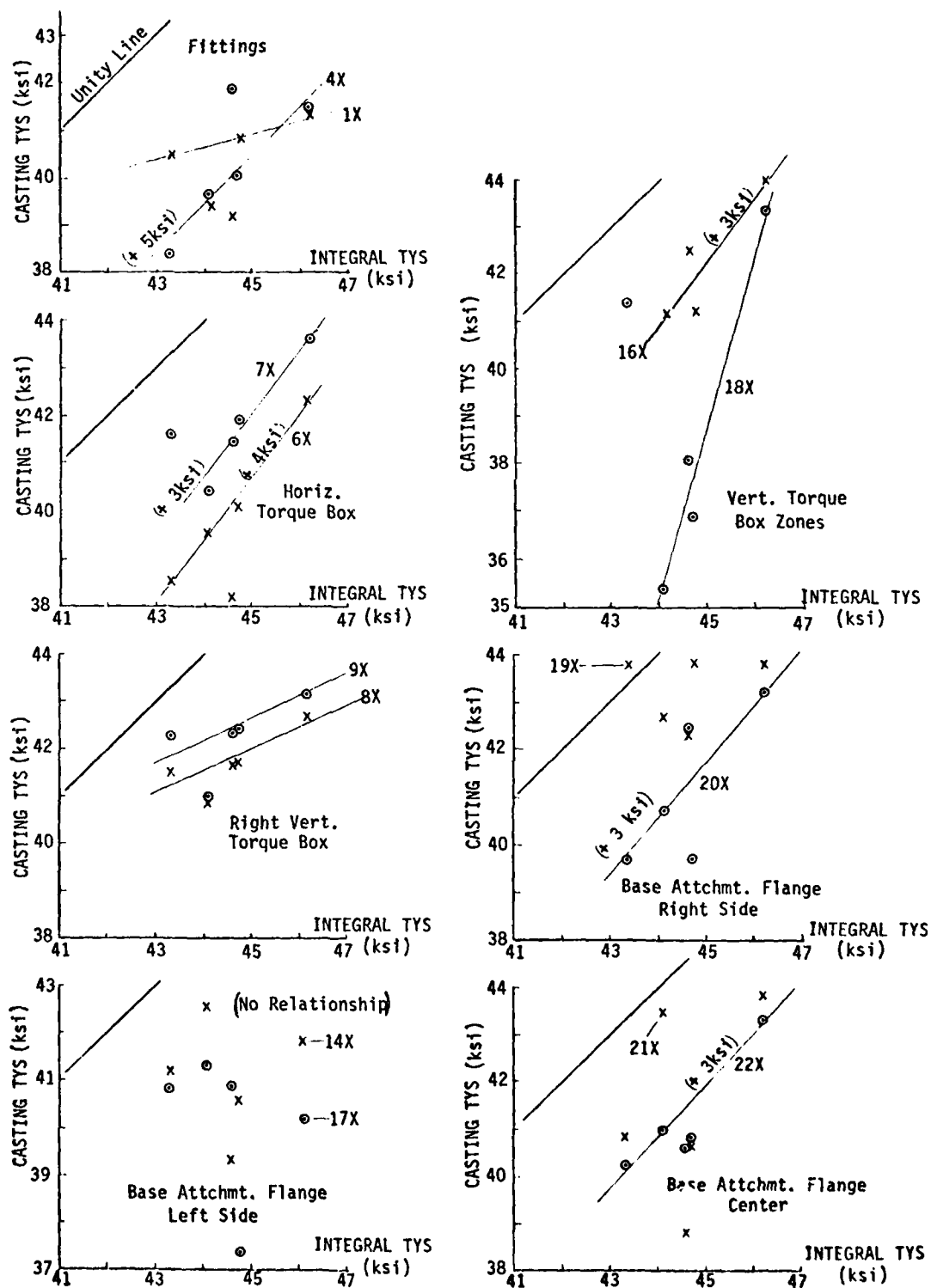


FIGURE 39 INTEGRAL COUPON-CASTING TYS CORRELATIONS
 Integral Coupon X7, Part B Castings
 Left Vertical Torque Box
 Inner Flange
 A357-T6

APPENDIX E

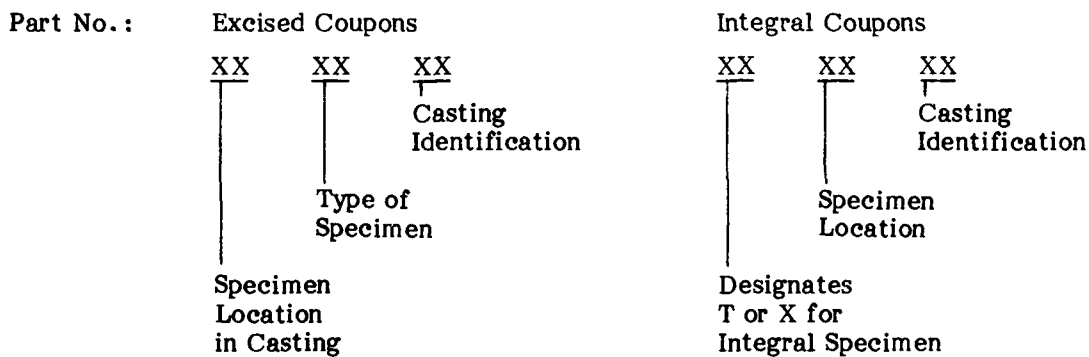
STATIC MECHANICAL PROPERTIES DATA

EXPLANATION

Table 18 contains static mechanical property test data developed during Phase II Task 2, Manufacturing Methods. All test coupons were excised from castings following final heat treatment (A357-T6) and inspections. Specimen configurations and test details are summarized in Appendix A. The segments of the Station 170 bulkhead cast for this phase are referred to as Parts A and B, shown in Figures 12 and 13, respectively.

Nomenclature used in Table 18 is explained below.

Specimen



<u>Casting Group</u>	<u>Boeing Part A</u>	<u>Hitchcock Part A</u>	<u>Boeing Part B</u>
Type of Specimen:			
Tension	T	T	X
Compression	C	C	Y
Shear	S	S	Z
Bearing e/D = 1.5 <u>1/</u>	B	B	W
e/D = 2.0	B	B	W

1/ Specimen location odd numbers designate e/D = 1.5; even numbers designate e/D = 2.0.

<u>Casting Group</u>	<u>Boeing Part A</u>	<u>Hitchcock Part A</u>	<u>Boeing Part B</u>
Casting Identification:	Serial #	Serial #	Serial #
	3 632	5H 005	7 397
	4 633	6H 006	8 400
	5 634	7H 007	9 403
	6 635	8H 008	10 406
		9H 009	11 409

Static Properties:

TUS	Tensile Ultimate Strength
TYS	Tensile Yield Strength
ELONG	Total Elongation (Uniform Elongation)
CYS	Compression Yield Strength
SUS	Shear Ultimate Strength
BUS	Bearing Ultimate Strength
BYS	Bearing Yield Strength

TABLE 18 STATIC MECHANICAL PROPERTIES DATA

Contract F 33615-76-C-3111 CAST

CASTING GROUP: BOEING PART A

LOCATION	ZONE THICKNESS NOMINAL (in.)	TENSION				CONPR.			SHEAR		BEARING					
		PART NO.	TUS (ksi)	TYS (ksi)	ELONG (%)		PART NO.	CYS (ksi)	PART NO.	SUS (ksi)	e/D = 1.5		PART NO.	BUS (ksi)	BYS (ksi)	e/D = 2.0
					A	B										
LUG B CENTER	2.0	1T3	47.7	40.9	5	3.2	1C3	42.9	1S3	34.0						
		1T4	48.7	40.8	5	4.1	1C4	43.9	1S4	34.1						
		1T5	47.7	40.8	6	3.8	1C5	41.2	1S5	33.9						
		1T6	48.7	42.6	5	2.6	1C6	44.5	1S6	34.0						
LUG B EDGE	2.0	2T3	49.5	39.5	8	11.5										
		2T4	48.8	40.0	7	6.3										
		2T5	48.2	40.1	7	4.9										
		2T6	49.0	41.9	5	3.5										
LUG A CENTER	1.0	3T3	49.1	40.6	5	4.1	2C3	42.0	2S3	34.0						
		3T4	43.1	40.8	3	0.6	2C4	42.9	2S4	34.8						
		3T5	48.2	40.8	4	3.4	2C5	42.6	2S5	35.5						
		3T6	48.2	42.3	5	2.7	2C6	43.7	2S6	34.6						
LUG A TOP	1.0	4T3	50.0	40.5	10	5.6										
		4T4	50.2	40.1	8	7.0										
		4T5	48.1	41.2	3	3.1										
		4T6	47.9	40.8	5	3.8										
PAD UP ATTACHMT. FLANGE	.30	5T3	50.0	41.2	7	7.2										
		5T4	52.3	41.7	8	3.7										
		5T5	47.7	40.5	6	3.5										
		5T6	47.7	43.2	4	1.2										
PAD UP ATTACHMT. FLANGE	.30	6T3	49.4	41.2	6	4.3	7C3	43.4								
		6T4	49.0	42.5	3	2.3	7C4	44.9								
		6T5	44.8	39.3	3	1.1	7C5	43.5								
		6T6	45.2	40.2	4	1.1	7C6	44.2								

A From fitted fractured specimens, 1 inch gage
 B From full-range stress-strain curves

① Failed outside gage zone

TABLE 18 STATIC MECHANICAL PROPERTIES DATA (CONTINUED)

CASTING GROUP: BOEING PART A

Contract F 33615-76-C-3111

CAST

LOCATION	ZONE THICKNESS NOMINAL (in.)	TENSION				COMPR.		SHEAR		BEARING			
		PART NO.	TUS (ksi)	TVS (ksi)	ELONG (%)		PART NO.	CYS (ksi)	PART NO.	SUS (ksi)	e/D = 1.5		BYS (ksi)
					A	B					PART NO.	BUS (ksi)	
WEB LWR. LEFT	.10	7T3	44.1	39.0	3	1.7			3S3	34.0			10B3
		7T4	46.8	41.5	3	1.4			3S4	33.8			10B4
		7T5	42.8	37.8	3	1.3			3S5	30.0			10B5
		7T6	44.4	41.3	4	0.9			3S6	30.0			10B6
WEB LWR. LEFT	.10	8T3	46.9	40.3	4	2.5	3C3	42.6					
		8T4	45.8	40.8	4	1.6	3C4	45.1					
		8T5	47.9	39.8	7	4.4	3C5	44.1					
		8T6	45.6	40.1	4	1.9	3C6	42.1					
WEB BOTTOM	.10	9T3	47.0	40.5	5	2.4	8C3	43.8					
		9T4	46.4	41.9	5	1.1	8C4	43.4					
		9T5	45.2	39.3	4	1.6	8C5	43.8					
		9T6	45.8	40.7	4	1.4	8C6	43.9					
WEB BOTTOM	.10	10T3	45.1	38.8	5	2.7							
		10T4	39.0	①	3	0.1							
		10T5	45.5	40.2	3	1.5							
		10T6	47.9	43.1	3	0.8							
PAD UP BASE FLANGE	.50	11T3	47.0	40.6	5	2.8	4C3	43.6	4S3	32.9			
		11T4	41.4	41.3	1	0.2	4C4	42.5	4S4	32.4			
		11T5	50.0	40.7	4	7.0	4C5	40.6	4S5	32.8			
		11T6	46.7	40.4	5	2.8	4C6	41.8	4S6	33.4			
PAD UP BASE FLANGE	.50	12T3	48.4	42.2	4	3.0							6B3
		12T4	46.2	41.5	3	1.1							6B4
		12T5	44.7	40.7	3	0.9							6B5
		12T6	48.7	41.7	5	3.7							6B6

A From fitted fractured specimens, 1 inch gage
 B From full-range stress-strain curves
 ① Failed prior to yield
 ② Failed in grip

TABLE 18 STATIC MECHANICAL PROPERTIES DATA (CONTINUED)

CASTING GROUP: BOEING PART A Contract F 33615-76-C-3111 CAST

LOCATION	ZONE THICKNESS NOMINAL (in.)	TENSION				ELONG (%)		COMPR.			SHEAR		BEARING					
		PART NO.	TUS (ksf)	TYS (ksf)	A	B	PART NO.	CYS (ksf)	PART NO.	SUS (ksf)	PART NO.	BYS (ksf)	e/D = 1.5			e/D = 2.0		
													PART NO.	BUS (ksf)	BYS (ksf)	PART NO.	BUS (ksf)	BYS (ksf)
LUG B TOP	2.0	13T3	49.6	40.0	8	6.1												
		13T4	50.5	40.5	10	8.0												
		13T5	49.5	39.5	10	8.0												
		13T6	49.3	40.4	7	4.9												
LUG B BOTTOM	2.0	14T3	46.1	38.8	4	3.3												
		14T4	48.4	40.2	5	4.9												
		14T5	47.2	38.0	8	5.6												
		14T6	46.6	39.5	5	2.8												
WL 130 DECK	.25	15T3	47.2	40.7	3	1.2												
		15T4	45.6	42.4	4	0.6												
		15T5	44.3	40.3	4	0.8	5C3	43.9	5S3	32.2								
		15T6	51.3	42.8	7	2.6	5C4	45.0	5S4	33.8								
WL 130 DECK	.25	16T3	51.0	①	12	4.9	5C5	41.9	5S5	35.2								
		16T4	51.3	38.0	10	4.6	5C6	39.6	5S6	33.4								
		16T5	50.1	41.3	7	4.7												
		16T6	49.8	43.3	5	2.5												
WEB UP-R. LEFT	.10	17T3	47.4	41.6	0	3.4	11C3	42.2										
		17T4	47.4	43.1	4	2.0	11C4	42.3										
		17T5	45.2	40.8	4	1.1	11C5	40.1										
		17T6	46.4	43.3	2	0.6	11C6	43.9										
WEB UP-R. LEFT	.10	18T3	39.6	33.5	3	1.8												
		18T4	35.1	②	1	0.0												
		18T5	45.5	40.3	4	1.4												
		18T6	41.9	35.2	7	4.3												

A From fitted fractured specimens, 1 inch gage

B From full-range stress-strain curves

① Inaccurate TYS recording

② Failed in grip

TABLE 18 STATIC MECHANICAL PROPERTIES DATA (CONTINUED)

Contract F 33615-76-C-3111 CAST

CASTING GROUP: BOEING PART A

LOCATION	ZONE THICKNESS NOMINAL (in.)	TENSION				COMPR.		SHEAR		BEARING			
		PART NO.	TUS (ksi)	TYS (ksi)	ELONG (%)		PART NO.	CYS (ksi)	PART NO.	SUS (ksi)	PART NO.	e/D = 1.5	
					A	B						BYS (ksi)	BUS (ksi)
FLANGE UPR. LEFT	.20	19T3	45.2	40.2	3	1.2							
		19T4	44.3	41.0	3	0.7							
		19T5	44.8	40.6	3	0.9							
		19T6	47.7	43.2	3	0.7							
FLANGE UPR. LEFT	.20	20T3	44.8	39.9	3	1.2	6C3	①	6S3	35.0			883
		20T4	47.5	42.6	3	1.3	6C4	43.0	6S4	34.5			884
		20T5	47.6	41.4	3	1.7	6C5	44.6	6S5	35.1			885
		20T6	46.3	42.9	3	0.9	6C6	44.0	6S6	34.7			886
WEB UPR. CENTER	.10	21T3	47.6	42.1	3	2.7	12C3	43.0					
		21T4	43.3	41.0	3	0.5	12C4	44.6					
		21T5	48.7	41.2	7	4.5	12C5	42.6					
		21T6	45.6	41.5	3	1.5	12C6	44.0					
FLANGE UPR. RT.	.20	22T3	46.0	40.1	3	1.0	13C3	42.6			783		
		22T4	45.9	41.8	3	0.8	13C4	46.5			784	76.2	70.1
		22T5	46.2	41.2	4	1.3	13C5	43.3			785	65.4	65.4
		22T6	48.7	42.9	5	1.7	13C6	45.7			786	76.8	73.0
WEB UPR. RT.	.10	23T3	47.8	42.9	5	2.1	14C3	43.3					
		23T4	48.9	42.3	5	3.2	14C4	44.0					
		23T5	46.4	39.4	5	3.4	14C5	42.5					
		23T6	49.4	42.8	5	2.3	14C6	48.1					
WEB UPR. RT.	.10	24T3	45.6	40.8	4	1.7							
		24T4	47.0	41.8	3	1.4							
		24T5	46.0	39.7	3	2.0							
		24T6	47.5	43.0	3	1.0							

A From fitted fractured specimens, 1 inch gage

B From full-range stress-strain curves

① Specimen buckled

② Failed prematurely

TABLE 18 STATIC MECHANICAL PROPERTIES DATA (CONTINUED)

Contract F 33615-76-C-3111 CAST

CASTING GROUP: BOEING PART A

LOCATION	ZONE THICKNESS NOMINAL (in.)	TENSION				COMPR.		SHEAR		BEARING					
		PART NO.	TUS (ksf)	TYS (ksf)	ELONG (%)		PART NO.	CYS (ksf)	PART NO.	SUS (ksf)	e/D = 1.5		e/D = 2.0		
					A	B					PART NO.	BUS (ksf)	BYS (ksf)	PART NO.	BUS (ksf)
FLANGE SIDE LOWER	.20	25T3	48.3	40.3	5	3.0	9C3	42.8							
		25T4	50.3	43.1	7	3.4	9C4	43.5							
		25T5	46.1	39.6	5	2.1	9C5	43.0							
		25T6	49.7	43.4	5	2.1	9C6	44.3							
FLANGE SIDE UPPER	.20	26T3	53.7	44.4	6	4.5	10C3	43.2							
		26T4	44.5	37.5	4	4.8	10C4	①							
		26T5	47.7	39.8	4	3.9	10C5	41.2							
		26T6	43.4	38.0	4	1.6	10C6	41.5							

A From fitted fractured specimens, 1 inch gage

B From full-range stress-strain curves

① Specimen buckled

TABLE 18 STATIC MECHANICAL PROPERTIES DATA (CONTINUED)

CASTING GROUP: BOEING PART A Contract F 33615-76-C-3111 CAST

LOCATION	ZONE THICKNESS NOMINAL (in.)	TENSION					COMPR.		SHEAR		BEARING			
		PART NO.	TUS (ksi)	TVS (ksi)	ELONG (%)		PART NO.	CYS (ksi)	PART NO.	SUS (ksi)	e/D = 1.5		e/D = 2.0	
					A	B					PART NO.	BYS (ksi)	PART NO.	BUS (ksi)
INTEGRAL LUG CENTER	2.0	T6/3	44.4	38.0	5	2.4								
		T6/4	48.4	39.0	7	5.0								
		T6/5	44.3	36.8	4	2.8								
		T6/6	46.5	39.5	4	2.7								
INTEGRAL LUG CENTER	2.0	T7/3	45.4	38.0	3	3.3								
		T7/4	48.2	39.2	6	5.5								
		T7/5	45.0	37.2	5	3.6								
		T7/6	46.3	39.5	4	3.5								
INTEGRAL WL 130 DECK	.25	T8/3	44.2	37.6	4	1.1								
		T8/4	42.7	39.5	2	0.5								
		T8/5	45.2	39.1	5	1.8								
		T8/6	41.5	38.5	3	0.6								
INTEGRAL PAD UP BASE FLANGE	.50	T9/3	49.5	39.4	10	7.8								
		T9/4	49.4	39.6	8	7.1								
		T9/5	49.5	40.1	9	8.1								
		T9/6	49.4	39.7	8	6.3								
INTEGRAL WL 150	.15	T10/3	① 40.1	40.1	5	②	15C3	40.9						
		T10/4	44.8	40.3	4	1.4	15C4	③						
		T10/5	42.7	37.7	3	1.1	15C5	41.7						
		T10/6	48.3	40.8	6	3.8	15C6	40.3						

A From fitted fractured specimens, 1 inch gage

B From full-range stress-strain curves

① TUS not recorded

② Elongation not recorded

③ Specimen damaged prior to test

TABLE 18 STATIC MECHANICAL PROPERTIES DATA (CONTINUED)

CASTING GROUP: HITCHCOCK PART A Contract F 33615-76-C-3111 CAST

LOCATION	ZONE THICKNESS NOMINAL (in.)	TENSION				COMPR.		SHEAR		BEARING					
		PART NO.	TUS (ksf)	TYS (ksf)	ELONG (%)		PART NO.	CVS (ksf)	PART NO.	SUS (ksf)	e/D = 1.5			e/D = 2.0	
					A	B					PART NO.	BUS (ksf)	BYS (ksf)	PART NO.	BUS (ksf)
LUG B CENTER	2.0	1T5H	48.4	40.4	5	3.7	1C5H	42.2	1S5H	34.6					
		1T6H	48.7	40.0	5	3.3	1C6H	42.2	1S6H	34.8					
		1T7H	47.2	42.0	3	2.7	1C7H	42.0	1S7H	34.6					
		1T8H	47.2	40.4	3	2.4	1C8H	41.7	1S8H	33.9					
		1T9H	48.7	40.7	4	4.0	1C9H	42.9	1S9H	34.6					
LUG B EDGE	2.0	2T5H	49.4	39.5	6	6.0					185H	81.0	63.0	285H	103.6
		2T6H	48.6	38.8	5	4.3					186H	77.8	67.0	286H	102.7
		2T7H	48.5	39.2	5	5.1					187H	84.3	65.0	287H	100.1
		2T8H	48.2	38.8	5	5.3					188H	78.8	65.8	288H	103.0
		2T9H	48.6	40.0	4	3.6					189H	80.9	65.8	289H	105.7
LUG A CENTER	1.0	3T5H	48.3	40.6	4	3.3	2C5H	42.1	2S5H	34.8					
		3T6H	49.0	40.1	4	2.5	2C6H	42.3	2S6H	35.0					
		3T7H	48.7	40.4	5	4.8	2C7H	41.8	2S7H	35.4					
		3T8H	49.8	41.0	5	4.4	2C8H	41.9	2S8H	35.2					
		3T9H	42.3	38.8	2	0.6	2C9H	42.8	2S9H	35.6					
LUG A TOP	1.0	4T5H	50.0	39.0	8	8.1									
		4T6H	49.7	39.3	7	5.3									
		4T7H	49.7	39.7	7	5.9									
		4T8H	49.3	39.4	6	5.7									
		4T9H	50.0	40.3	7	6.3									
PAD UP ATTACHMT FLANGE	.30	5T5H	49.8	39.7	6	5.0								485H	101.9
		5T6H	47.4	40.0	3	2.6								486H	92.4
		5T7H	50.0	41.0	5	4.3								487H	100.6
		5T8H	49.4	41.6	4	3.4								488H	94.8
		5T9H	49.5	40.4	6	4.7								489H	92.9

A From fitted fractured specimens, 1 inch gage

B From full-range stress-strain curves

① Premature failure

TABLE 18 STATIC MECHANICAL PROPERTIES DATA (CONTINUED)

Contract F 33615-76-C-3111 CAST

CASTING GROUP: HITCHCOCK PART A

LOCATION	ZONE THICKNESS NOMINAL (in.)	TENSION				COMPR.			SHEAR		BEARING					
		PART NO.	TUS (ksf)	TYS (ksf)	ELONG (%)	PART NO.	CYS (ksf)	PART NO.	PART NO.	SUS (ksf)	PART NO.	BUS (ksf)	BYS (ksf)	PART NO.	BUS (ksf)	BYS (ksf)
PAD UP ATTACHMT-FLANGE	.30	6T5H	50.0	41.3	6	5.1										
		6T6H	47.6	41.1	4	2.2										
		6T7H	48.8	41.5	4	3.0										
		6T8H	48.7	41.5	4	2.7										
		6T9H	49.5	41.9	4	3.4										
LWR.WEB LEFT	.10	7T5H	48.4	40.3	2	2.6								1085H	99.2	83.4
		7T6H	48.1	39.8	3	3.4								1086H	97.1	82.0
		7T7H	45.0	41.3	1	0.5								1087H	92.6	80.0
		7T8H	46.6	41.9	3	1.0								1088H	94.2	82.3
		7T9H	46.8	41.3	2	0.8								1089H	90.0	76.1
LWR.WEB LEFT	.10	8T5H	47.3	39.3	4	2.4										
		8T6H	47.6	41.6	5	2.7										
		8T7H	44.1	39.3	0	0.8										
		8T8H	46.2	40.3	3	1.0										
		8T9H	45.0	40.0	1	0.9										
WEB BOTTOM	.10	9T5H	49.0	41.3	5	3.2										
		9T6H	48.7	40.2	4	4.0										
		9T7H	45.4	40.1	4	1.9										
		9T8H	46.9	40.3	4	1.7										
		9T9H	49.3	40.5	5	4.5										
WEB BOTTOM	.10	10T5H	48.7	42.9	3	0.9										
		10T6H	47.9	39.7	4	3.4										
		10T7H	46.7	39.1	5	2.7										
		10T8H	47.2	40.2	4	2.7										
		10T9H	45.4	39.3	3	1.2										

A From fitted fractured specimens, 1 inch gage

B From full-range stress-strain curves

① Failed through weld correctable single pore

TABLE 18 STATIC MECHANICAL PROPERTIES DATA (CONTINUED)

Contract F 33615-76-C-3111 CAST

CASTING GROUP: HITCHCOCK PART A

LOCATION	ZONE THICKNESS NOMINAL (in.)	TENSION					COMPR.		SHEAR		BEARING			
		PART NO.	TUS (ksi)	TYS (ksi)	ELONG (%)		PART NO.	CYS (ksi)	PART NO.	SUS (ksi)	e/D = 1.5		e/D = 2.0	
					A	B					PART NO.	BYS (ksi)	PART NO.	BYS (ksi)
PAD UP BASE FLANGE	.50	11T5H	48.1	39.8	5	4.2								
		11T6H	46.7	38.1	5	4.0								
		11T7H	47.0	39.5	4	3.5								
		11T8H	47.1	40.3	4	3.1								
		11T9H	48.0	39.8	5	4.1								
PAD UP BASE FLANGE	.50	12T5H	48.7	39.5	6	4.3					685H	96.5	685H	75.2
		12T6H	47.9	37.9	8	6.7					686H	97.4	686H	73.8
		12T7H	47.3	38.7	6	4.8					687H	93.0	687H	76.9
		12T8H	47.8	38.9	6	3.1					688H	92.5	688H	75.0
		12T9H	48.9	39.5	6	5.1					689H	96.3	689H	75.1
LUG B TOP	2.0	13T5H	50.4	40.7	6	6.0								
		13T6H	50.1	40.1	6	6.3								
		13T7H	49.3	40.3	6	5.2								
		13T8H	49.2	40.7	5	5.2								
		13T9H	49.8	40.9	5	5.2								
LUG B BOTTOM	2.0	14T5H	47.9	40.3	4	3.5								
		14T6H	48.2	40.0	4	4.5								
		14T7H	46.8	39.6	4	2.7								
		14T8H	47.3	39.9	3	2.5								
		14T9H	47.9	41.4	3	2.8								
WL 130 DECK	.25	15T5H	44.8	39.7	2	1.7								
		15T6H	44.0	39.3	2	1.1								
		15T7H	44.9	38.9	2	1.9								
		15T8H	45.5	39.1	2	2.2								
		15T9H	44.1	39.4	2	1.0								

A From fitted fractured specimens, 1 inch gage
 B From full-range stress-strain curves

TABLE 18 STATIC MECHANICAL PROPERTIES DATA (CONTINUED)

Contract F 33615-76-C-3111 CAST

CASTING GROUP: HITCHCOCK PART A

LOCATION	ZONE THICKNESS (in.)	TENSION				COMPR.		SHEAR		BEARING					
		PART NO.	TUS (ksf)	TYS (ksf)	ELONG (%)		PART NO.	CYS (ksf)	PART NO.	SUS (ksf)	e/D = 1.5		PART NO.	BYS (ksf)	BUS (ksf)
					A	B									
WL 130 DECK	.25	16T5H	49.2	39.4	8	7.2									
		16T6H	46.6	39.3	1	2.4	①								
		16T7H	48.2	39.4	6	4.3									
		16T8H	47.1	38.8	5	3.2									
		16T9H	48.5	39.3	5	4.7									
WEB UPR. LEFT	.10	17T5H	41.5	40.4	2	0.3	②								
		17T6H	45.6	40.7	2	1.1									
		17T7H	44.8	40.0	2	1.2									
		17T8H	44.5	40.6	2	0.6									
		17T9H	45.6	40.3	2	1.5									
WEB UPR. LEFT	.10	18T5H	48.8	42.4	3	2.2									
		18T6H	47.7	41.2	3	1.4									
		18T7H	46.5	41.9	2	1.2	③								
		18T8H	47.5	42.9	2	1.2									
		18T9H	46.8	41.8	2	1.3									
FLANGE UPR. LEFT	.20	19T5H	48.6	41.6	2	2.3	6C5H	44.6	6S5H	36.5					
		19T6H	48.9	42.1	3	2.5	6C6H	④	6S6H	35.7					
		19T7H	47.8	42.0	3	1.6	6C7H	45.4	6S7H	36.8					
		19T8H	47.8	40.1	3	0.9	6C8H	44.9	6S8H	36.3					
		19T9H	47.8	41.4	3	2.1	6C9H	43.5	6S9H	37.0					
FLANGE UPR. LEFT	.20	20T5H	47.8	42.0	3	1.7									
		20T6H	47.0	41.8	3	1.5									
		20T7H	47.1	41.6	3	1.3									
		20T8H	47.2	42.7	3	1.2									
		20T9H	48.3	41.0	4	3.0									
						① Failed through weld correctable sand inclusion ② Failure attributed to two weld correctable pores ③ Failure through surface defect ④ Specimen buckled									

A From fitted fractured specimens, 1 inch gage

B From full-range stress-strain curves

TABLE 18 STATIC MECHANICAL PROPERTIES DATA (CONTINUED)

CASTING GROUP: HITCHCOCK PART A Contract F 33615-76-C-3111 CAST

LOCATION	ZONE THICKNESS NOMINAL (in.)	TENSION				COMPR.		SHEAR		BEARING			
		PART NO.	TUS (ksi)	TYS (ksi)	ELONG (%)		PART NO.	CYS (ksi)	PART NO.	SUS (ksi)	e/D = 1.5		e/D = 2.0
					A	B					PART NO.	BYS (ksi)	PART NO.
WEB UPR. CENTER	.10	21T5H	41.6	40.5	2	0.4	①						
		21T6H	45.7	39.7	2	1.8							
		21T7H	41.8	39.4	2	0.4	②						
		21T8H	46.6	40.2	2	1.0							
		21T9H	51.0	46.9	2	1.1	③						
FLANGE UPR. RIGHT	.20	22T5H	47.9	40.0	4	3.1							
		22T6H	47.3	39.8	4	2.3							
		22T7H	46.8	39.8	4	2.5							
		22T8H	47.6	40.2	4	2.5							
		22T9H	47.6	40.3	4	2.9							
WEB UPR. RIGHT	.10	23T5H	49.2	42.3	3	1.9							
		23T6H	47.4	41.0	3	1.6							
		23T7H	46.6	39.7	3	1.9							
		23T8H	45.1	41.2	2	0.6							
		23T9H	46.9	41.3	2	1.1							
WEB UPR. RIGHT	.10	24T5H	47.9	40.6	3	2.6							
		24T6H	46.4	39.6	3	2.2							
		24T7H	46.4	40.2	2	0.9							
		24T8H	46.7	40.3	3	1.7							
		24T9H	46.5	40.4	2	1.6							

A From fitted fractured specimens, 1 inch gage

B From full-range stress-strain curves

① Multiple longitudinal cracks ② Premature failure

③ Failed through weld correctable single pore

TABLE 18 STATIC MECHANICAL PROPERTIES DATA (CONTINUED)

Contract F 33615-76-C-3111 CAST

CASTING GROUP: HITCHCOCK PART A

LOCATION	ZONE THICKNESS NOMINAL (in.)	TENSION				COMPR.		SHEAR		BEARING			
		PART NO.	TUS (ksi)	TYS (ksi)	ELONG (%)		PART NO.	CYS (ksi)	PART NO.	SUS (ksi)	e/D = 1.5		e/D = 2.0
					A	B					PART NO.	BYS (ksi)	PART NO.
INTEGRAL LUG CENTER	2.0	T6/5H	46.7	39.4	2	2.8							
		T6/6H	46.7	38.6	2	3.3							
		T6/7H	45.1	38.2	2	2.4							
		T6/8H	45.5	39.2	1	1.5							
		T6/9H	46.8	38.7	3	2.8							
INTEGRAL LUG CENTER	2.0	T7/5H	46.0	38.2	2	2.2							
		T7/6H	46.5	38.5	2	3.0							
		T7/7H	45.1	38.1	2	2.5							
		T7/8H	41.9	39.7	1	0.4	①						
		T7/9H	46.9	39.9	2	2.3							
INTEGRAL ML 130	.25	T8/5H	48.2	40.9	4	3.0							
		T8/6H	48.6	40.1	7	5.0							
		T8/7H	49.3	40.9	5	4.2	②						
		T8/8H	45.9	41.3	3	1.5							
		T8/9H	48.7	40.2	5	4.3							
INTEGRAL PAD UP BASE FLANGE	.50	T9/5H	49.4	39.2	7	5.6							
		T9/6H	48.1	37.6	8	7.5							
		T9/7H	48.4	39.2	5	4.7							
		T9/8H	48.9	39.0	6	8.1							
		T9/9H	49.0	38.7	7	12.4							
INTEGRAL ML 150	.15	T10/5H	48.3	39.7	3	2.3							
		T10/6H	49.7	42.6	4	1.9							
		T10/7H	48.7	40.6	3	2.4							
		T10/8H	48.0	39.3	3	2.6							
		T10/9H	48.1	40.2	3	2.2							

A From fitted fractured specimens, 1 inch gage

B From full-range stress-strain curves

① Premature failure

② Failed through extensometer attachment point

TABLE 18 STATIC MECHANICAL PROPERTIES DATA (CONTINUED)

CASTING GROUP: BOEING PART B

Contract F 33615-76-C-3111

CAST

LOCATION	ZONE THICKNESS NOMINAL (in.)	TENSION					COMPR.		SHEAR		BEARING					
		PART NO.	TUS (ksf)	TYS (ksf)	ELONG (%)		PART NO.	CYS (ksf)	PART NO.	SUS (ksf)	e/D = 1.5			e/D = 2.0		
					A	B					PART NO.	BUS (ksf)	BYS (ksf)	PART NO.	BUS (ksf)	BYS (ksf)
FITTING 1	1.0	1X7	45.2	39.4	2	1.4	1Y7	42.1	1W7	33.8	1Z7	80.2	66.3	2Z7	98.6	77.4
		1X8	45.5	39.2	2	1.7	1Y8	40.8	1W8	32.9	1Z8	61.2	①	2Z8	98.2	78.1
		1X9	46.3	40.5	2	1.6	1Y9	42.4	1W9	33.8	1Z9	79.9	69.4	2Z9	98.6	81.1
		1X10	45.7	40.8	2	1.2	1Y10	42.2	1W10	33.6	1Z10	58.8	①	2Z10	94.9	79.5
		1X11	44.8	41.3	2	0.7	1Y11	42.8	1W11	33.0	1Z11	60.9	①	2Z11	97.0	81.0
FITTING 1	1.0	2X7	45.0	40.0	2	1.2										
		2X8	44.6	39.7	2	1.1										
		2X9	45.6	40.3	2	1.1										
		2X10	45.6	40.5	2	1.2										
		2X11	44.1	40.8	1	0.6										
FITTING 2	3.0	3X7	44.4	39.2	2	1.4	2Y7	40.1	2W7	34.0	3Z7	79.2	67.1	4Z7	88.1	78.8
		3X8	44.7	39.4	2	1.3	2Y8	②	2W8	33.6	3Z8	77.7	66.1	4Z8	91.0	78.7
		3X9	47.7	41.5	3	2.2	2Y9	42.0	2W9	34.6	3Z9	65.8	65.8	4Z9	95.6	78.8
		3X10	46.0	40.2	3	1.7	2Y10	42.0	2W10	33.0	3Z10	70.8	67.5	4Z10	103.5	80.6
		3X11	45.3	39.2	2	0.9	2Y11	43.5	2W11	34.3	3Z11	70.7	68.0	4Z11	96.3	84.2
FITTING 2	3.0	4X7	42.7	39.7	2	0.6	3Y7	43.4	3W7	35.3						
		4X8	44.7	41.9	2	0.6	3Y8	42.9	3W8	33.7						
		4X9	42.4	38.4	2	0.8	3Y9	43.6	3W9	33.5						
		4X10	45.6	40.1	2	1.5	3Y10	43.4	3W10	33.6						
		4X11	45.8	41.5	2	0.9	3Y11	44.4	3W11	33.7						
HORIZONT. TORQUE BOX	.30	5X7	45.2	37.0	4	3.0										
		5X8	46.6	37.9	4	3.1										
		5X9	45.8	38.8	4	2.5										
		5X10	47.5	41.2	5	2.0										
		5X11	50.6	41.7	3	3.8										

A From fitted fractured specimens, 1 inch gage

① Failed prior to yield

B From full-range stress-strain curves

② Specimen buckled

TABLE 18 STATIC MECHANICAL PROPERTIES DATA (CONTINUED)

CASTING GROUP: BOEING PART B Contract F 33615-76-C-3111 CAST

LOCATION	ZONE THICKNESS NOMINAL (in.)	TENSION				COMPR.		SHEAR		BEARING				
		PART NO.	TUS (ksi)	TYS (ksi)	ELONG (%)		PART NO.	CYS (ksi)	PART NO.	SUS (ksi)	e/D = 1.5		e/D = 2.0	
					A	B					PART NO.	BUS (ksi)	BYS (ksi)	PART NO.
HORIZ. TORQUE BOX	.30	6X7	47.7	39.5	6	4.0								
		6X8	46.1	38.2	3	3.0								
		6X9	44.8	38.5	3	1.7								
		6X10	47.4	40.1	4	2.9								
		6X11	46.9	42.3	3	1.3								
HORIZ. TORQUE BOX	.20	7X7	51.1	40.4	9	5.3	4Y7	45.5	4W7	36.0				
		7X8	51.3	41.4	9	6.7	4Y8	44.6	4W8	35.5				
		7X9	51.9	41.6	9	7.9	4Y9	45.1	4W9	36.2				
		7X10	51.7	41.9	8	6.6	4Y10	44.3	4W10	35.2				
		7X11	51.9	43.7	6	3.8	4Y11	46.0	4W11	36.1				
VERTICAL BOX RT. REAR	.50	8X7	44.9	40.8	2	1.1	5Y7	43.1	5W7	33.7	7Z7	69.6	68.5	
		8X8	45.6	41.7	2	1.6	5Y8	42.3	5W8	35.1	7Z8	64.7	64.7	
		8X9	46.1	41.5	2	1.5	5Y9	42.1	5W9	35.1	7Z9	66.3	66.3	
		8X10	46.1	41.7	2	1.2	5Y10	43.4	5W10	34.5	7Z10	71.5	70.7	
		8X11	45.3	42.7	2	0.6	5Y11	40.9	5W11	34.6	7Z11	64.7	64.7	
VERTICAL BOX RT. REAR	.50	9X7	46.3	41.0	2	1.1								
		9X8	47.5	42.3	2	1.8								
		9X9	47.1	42.3	3	1.0								
		9X10	47.7	42.4	2	1.4								
		9X11	47.4	43.2	2	0.9								
VERTICAL BOX LEFT FRONT	.30	10X7	45.4	43.4	2	0.6								
		10X8	47.8	45.0	1	0.6	②							
		10X9	49.0	44.1	3	1.9								
		10X10	46.7	42.2	3	1.5								
		10X11	49.0	44.9	2	1.4								

A From fitted fractured specimens, 1 inch gage

①

Failed prior to yield

B From full-range stress-strain curves

②

Failed through machine marks

TABLE 18 STATIC MECHANICAL PROPERTIES DATA (CONTINUED)

CASTING GROUP: BOEING PART B Contract F 33615-76-C-3111 CAST

LOCATION	ZONE THICKNESS (in.)	TENSION					COMPR.		SHEAR		BEARING					
		PART NO.	TUS (ksi)	TYS (ksi)	ELONG (%)		PART NO.	CYS (ksi)	PART NO.	SUS (ksi)	e/D = 1.5			e/D = 2.0		
					A	B					PART NO.	BUS (ksi)	BYS (ksi)	PART NO.	BUS (ksi)	BYS (ksi)
VERTICAL BOX RIGHT FRONT	.30	11X7	51.4	43.7	6	5.5										
		11X8	50.2	43.0	4	4.3										
		11X9	50.1	44.4	3	2.6										
		11X10	49.3	43.7	3	2.5										
		11X11	53.9	46.8	8	6.3										
WEB LMR. LEFT	.10	12X7	49.3	40.5	7	6.7										
		12X8	47.0	38.6	6	4.3										
		12X9	45.2	37.3	5	2.5										
		12X10	45.4	39.7	4	1.8										
		12X11	48.6	42.2	3	2.8										
FLANGE RIGHT OUTSIDE	.10	13X7	52.5	43.8	3	4.7										
		13X8	50.0	40.0	4	6.3										
		13X9	49.8	43.0	5	2.5										
		13X10	48.1	37.5	6	4.5										
		13X11	51.0	42.3	5	5.7										
ATTACHMT. FLANGE LEFT VERTICAL	.30	14X7	48.1	42.6	3	1.4										
		14X8	49.9	39.3	12	5.9										
		14X9	48.9	41.2	7	5.1										
		14X10	50.8	40.6	10	6.8										
		14X11	49.6	41.8	3	3.9										
HORIZ. FLANGE	.30	15X7	48.1	41.3	4	1.5										
		15X8	46.9	42.1	2	1.1										
		15X9	48.0	41.4	3	1.7										
		15X10	47.2	42.3	2	1.2										
		15X11	48.0	43.4	1	0.9										

A From fitted fractured specimens, 1 inch gage

B From full-range stress-strain curves

① Failed through machine marks

TABLE 18 STATIC MECHANICAL PROPERTIES DATA (CONTINUED)

CASTING GROUP: BOEING PART B Contract F 33615-76-C-3111 CAST

LOCATION	ZONE THICKNESS NOMINAL (in.)	TENSION					COMPR.			SHEAR			BEARING					
		PART NO.	TUS (ksf)	TYS (ksf)	ELONG (%)		PART NO.	CYS (ksf)	PART NO.	SUS (ksf)	PART NO.	BYS (ksf)	e/D = 1.5		e/D = 2.0		BYS (ksf)	BYS (ksf)
					A	B							PART NO.	BUS (ksf)	PART NO.	BUS (ksf)		
FLANGE LEFT INSIDE	.10	16X7	48.4	41.2	2	2.6												
		16X8	49.8	42.5	4	5.5												
		16X9	40.2	①	1	0.2												
		16X10	45.0	41.2	1	0.6	②											
		16X11	50.0	44.0	3	2.3												
ATTACHMT. FLANGE LEFT VERTICAL	.30	17X7	46.9	41.3	4	1.9												
		17X8	46.2	40.9	3	1.3												
		17X9	47.2	40.8	2	4.0												
		17X10	44.2	37.4	3	4.3												
		17X11	44.6	40.2	2	0.8												
VERTICAL BOX RIGHT INSIDE	.10	18X7	42.6	35.4	4	1.8												
		18X8	42.5	38.1	3	1.2												
		18X9	46.1	41.4	3	2.7												
		18X10	45.0	36.9	5	4.7												
		18X11	48.5	43.3	3	2.0												
FLANGE LWR. RT.	.25	19X7	51.5	42.7	7	4.4												
		19X8	49.8	42.3	5	3.0												
		19X9	49.8	43.8	3	1.4	③											
		19X10	51.0	43.8	5	5.4	③											
		19X11	52.0	43.8	3	2.5												
ATTACHMT. FLANGE LWR. RT.	.10	20X7	48.6	40.7	5	4.4							927	77.6		66.7		
		20X8	51.0	42.4	7	7.1							928	70.5		63.1		
		20X9	48.1	39.7	5	5.1							929	70.3		66.5		
		20X10	48.1	39.7	8	5.0							9210	82.2		75.5		
		20X11	50.0	43.2	4	3.9							NO 9211 PART					

A From fitted fractured specimens, 1 inch gage

① Failed prior to yield outside gage zone in defect

B From full-range stress-strain curves

② Failed through a correctable shrink pore

③ Failed through vibratool mark

TABLE 18 STATIC MECHANICAL PROPERTIES DATA (CONTINUED)

CASTING GROUP: BOEING PART B Contract F 33615-76-C-3111 CAST

LOCATION	ZONE THICKNESS NOMINAL (in.)	TENSION					COMPR.		SHEAR		BEARING				
		PART NO.	TUS (ksf)	TYS (ksf)	ELONG (%)		PART NO.	CYS (ksf)	PART NO.	SUS (ksf)	e/D = 1.5		e/D = 2.0		
					A	B					PART NO.	BYS (ksf)	PART NO.	BYS (ksf)	
ATTACHMT. FLANGE LMR. CENTER	.10	21X7	46.7	43.5	2	0.7	①								
		21X8	47.0	38.8	7	5.1									
		21X9	46.8	40.8	3	1.8									
		21X10	48.7	40.7	5	4.7									
		21X11	50.0	43.8	3	3.0									
ATTACHMT. FLANGE LMR. CENTER	.10	22X7	48.1	41.0	5	3.8									
		22X8	47.9	40.6	3	2.4									
		22X9	46.3	40.2	3	2.0									
		22X10	45.8	40.8	2	1.5									
		22X11	47.4	43.3	3	0.9									

A From fitted fractured specimens, 1 inch gage

B From full-range stress-strain curves

① Failed through a weld correctable surface pore

TABLE 18 STATIC MECHANICAL PROPERTIES DATA (CONTINUED)

Contract F 33615-76-C-3111 CAST

CASTING GROUP: BOEING PART B

LOCATION	ZONE THICKNESS (in.)	TENSION					COMPR.		SHEAR		BEARING			
		PART NO.	TUS (ksi)	TYS (ksi)	ELONG (%)		PART NO.	CYS (ksi)	PART NO.	SUS (ksi)	e/D = 1.5		e/D = 2.0	
					A	B					PART NO.	BYS (ksi)	PART NO.	BYS (ksi)
INTEGRAL FITTING	3.0	X3/7	44.8	39.2	2	1.2								
		X3/8	44.5	38.9	2	1.2								
		X3/9	44.6	39.0	2	1.6								
		X3/10	46.6	39.0	3	2.7								
		X3/11	45.1	39.9	2	1.1								
INTEGRAL FITTING	3.0	X4/7	45.2	39.4	2	1.3								
		X4/8	44.9	39.5	2	1.1								
		X4/9	44.8	39.2	2	1.3								
		X4/10	47.2	39.5	3	3.0								
		X4/11	43.1	39.6	2	0.7								
INTEGRAL FLANGE LMR. RT.	.10	X5/7	47.6	41.6	3	3.2								
		X5/8	50.5	42.7	5	3.3								
		X5/9	49.8	41.9	5	3.2								
		X5/10	48.9	40.0	4	2.2								
		X5/11	47.4	44.7	2	0.7	①							
INTEGRAL FLANGE UPR. LEFT	.10	X7/7	49.8	44.1	6	4.3								
		X7/8	49.8	44.6	3	3.2								
		X7/9	48.4	43.3	3	3.4								
		X7/10	49.2	44.7	2	2.5								
		X7/11	50.0	46.2	2	2.4	②							

A From fitted fractured specimens, 1 inch gage

B From full-range stress-strain curves

① Poorly recorded stress-strain curve

② Failed through a weld correctable surface flaw

APPENDIX F

CORRELATIVE PROPERTIES

EXPLANATION

Table 19 contains information regarding tension specimens and property ratios of corresponding compression, shear, and bearing to tension data. Gage section thicknesses are recorded for the prior-to-test condition. Dendrite Arm Spacing (DAS) measurements are recorded for both the casting surface of thick sections from which tension specimens were excised and all tension specimen gage zones. Specimen soundness grades A through D refer to the radiographically measured soundnesses of material adjacent to fracture zones of tested tension specimens. Grades B, C, and D are primarily the result of gas and shrink porosity. Distances from tension specimen gage sections were recorded to the nearest chills, risers, ingates, and insulators when used. Property ratios for compression, shear, and bearing are recorded adjacent to the respective tension specimens. Figures 12 and 13 show the locations of all derived property specimens in relation to tension specimens. Derived property ratios are analyzed to develop reduced ratios in Tables 20 through 25 of Appendix G.

TABLE 19 CORRELATIVE PROPERTIES

CONTRACT F 33615-76-C-3111 CAST

CASTING GROUP: BOEING PART A

Tension Specimen No.	Actual Thkns. (in.)	DAS (10 ⁻⁴ in.)		Specimen Quality Grade	Distance from specimen to:			Property Ratios				
		①	②		Ingate	Riser	Chill	Insulator	CYS TYS	SUS TUS	BYS TYS $\frac{e/h}{1.5}$	BUS TUS $\frac{e/h}{2.0}$
1T3	.25 D	21	15	A	C		D AI		1.049	.713		
1T4	"	25	17	A			B Cu		1.076	.700		
1T5	"	17	17	B					1.010	.711		
1T6	"	19	16	A					1.045	.698		
2T3	.25 D	See	10	A	C		D AI				1.597	1.655
2T4	"	Above	17	A			A Cu				1.638	1.684
2T5	"	"	16	A							1.581	1.606
2T6	"	"	17	A							1.601	1.637
3T3	.25 D	17	10	A	C		D AI		1.034	.692	1.581	1.646
3T4	"	21	14	B			A Cu		1.051	.718	1.672	1.695
3T5	"	14	14	A					1.044	.736	1.564	1.556
3T6	"	19	15	A					1.033	.718	1.532	1.660
4T3	.25 D	See	13	A	D		D AI					
4T4	"	Above	14	A			A Cu					
4T5	"	"	15	A								
4T6	"	"	17	A								
5T3	.1787	Not	14	B	D		D AI				2.10	2.08
5T4	.1719	Meas.	14	A			E Cu				1.902	1.736
5T5	.1802	"	15	B							1.867	1.826
5T6	.1783	"	17	C							1.836	1.845
6T3	.1980	Not	10	A	D		D AI		1.053			
6T4	.2000	Meas.	10	B			E Cu		1.105			
6T5	.1994	"	22	B					1.108			
6T6	.2010	"	18	C					1.050			

Distances:
 A 0 to 0.5 in.
 B 0.5 to 1.0 in.
 C 1.0 to 2.0 in.
 D 2.0 to 5.0 in.
 E 5.0 in. plus

① Measurement on Casting surface

② Measurement on Specimen surface

TABLE 19 CORRELATIVE PROPERTIES (CONTINUED)

CONTRACT F 33615-76-C-3111 CAST

CASTING GROUP: BOEING PART A

Tension Specimen No.	Actual Thkns. (in.)	DAS (10 ⁻⁴ in.)		Specimen Quality Grade	Distance from specimen to:				Property Ratios				
		①	②		Ingate	Riser	Chill	Insulator	CYS TYS	SUS TUS	BYS TYS	BUS TUS	BUS TYS
7T3	.1088	Not Meas.	15	C	D		D A1		1.074	.771		1.871	2.02
7T4	.1075		15	B			E Cu		1.096	.722		1.934	1.976
7T5	.1260		12	C					1.136	.701		NoBYS	2.07
7T6	.1095		13	C					1.034	.676		1.882	2.04
8T3	.1100	Not Meas.	13	A	E		D A1						
8T4	.1097		15	B			E Cu						
8T5	.1058		17	B									
8T6	.1101		17	C									
9T3	.1080	Not Meas.	13	C	D		C A1		1.081				
9T4	.1053		14	B			D Cu		1.036				
9T5	.1078		13	C					1.115				
9T6	.1088		14	B					1.079				
10T3	.1090	Not Meas.	13	C	D		E A1						
10T4	.1082		12	A			E Cu						
10T5	.1074		14	B									
10T6	.1071		13	C									
11T3	.2242	Not Meas.	20	B	C		D A1		1.053	.700		1.903	2.08
11T4	.2249		13	A			B Cu		1.027	.676		1.918	1.955
11T5	.2242		14	A					.998	.656		NoBYS	2.20
11T6	.2202		16	B					1.018	.715		1.855	2.06
12T3	.249 D	Not Meas.	21	B	D		C A1						
12T4	.249 D		17	A			B Cu						
12T5	.248 D		16	B									
12T6	.249 D		21	A									

Distances:

A 0 to 0.5 in.
 B 0.5 to 1.0 in.
 C 1.0 to 2.0 in.
 D 2.0 to 5.0 in.
 E 5.0 in. plus

- ① Measurement on Casting surface
 ② Measurement on Specimen surface

TABLE 19 CORRELATIVE PROPERTIES (CONTINUED)

CONTRACT F 33615-76-C-3111 CAST

CASTING GROUP: BOEING PART A

Tension Specimen No.	Actual Thkns. (in.)	DAS (10 ⁻⁴ in.)		Specimen Quality Grade	Distance from specimen to:				Property Ratios				
		①	②		Ingate	Riser	Chill	Insulator	CYS TYS	SUS. TYS	BYS TYS $\frac{BYS}{TYS} = 1.5$	BYS TYS $\frac{BYS}{TYS} = 2.0$	BUS TYS
13T3	.249 D	21	14	A	D		D A1						
13T4	.248 D	25	11	A			A Cu						
13T5	.249 D	17	15	A									
13T6	.249 D	19	14	A									
14T3	.250 D	See	21	B	C		D A1						
14T4	.249 D	Above	17	A			B Cu						
14T5	.250 D		17	A									
14T6	.249 D		21	B									
15T3	.1510	Not	24	B	E		C A1		1.079	.656			
15T4	.1478	Meas.	18	B			B Cu		1.050	.698			
15T5	.1550		15	C					1.027	.746			
15T6	.1480		14	A					.920	.661			
16T3	.1548	Not	15	A	E		C A1						
16T4	.1488	Meas.	15	A			A Cu						
16T5	.1600		15	B									
16T6	.1582		16	C									
17T3	.1084	Not	13	Not Meas.	D		E A1		1.014				
17T4	.1100	Meas.	13	Not Meas.			D Cu		.981				
17T5	.1968		11	Not Meas.					.983				
17T6	.1102		15	B					1.014				
18T3	.1107	Not	14	B	C		B A1						
18T4	.1085	Meas.	13	B			D Cu						
18T5	.1072		14	C									
18T6	.1154		16	B									

Distances:
 A 0 to 0.5 in.
 B 0.5 to 1.0 in.
 C 1.0 to 2.0 in.
 D 2.0 to 5.0 in.
 E 5.0 in. plus

Ratios from
 15T and 16T averages.

① Measurement on Casting surface
 ② Measurement on Specimen surface

TABLE 19 CORRELATIVE PROPERTIES (CONTINUED)

CONTRACT F 33615-76-C-3111 CAST

CASTING GROUP: BOEING PART A

Tension Specimen No.	Actual Thkns. (in.)	DAS(10 ⁻⁴ in.)		Specimen Quality Grade	Distance from specimen to:				Property Ratios				
		①	②		Ingate	Riser	Ch111	Insulator	CYS TYS	SUS TUS	BYS TYS e/h = 1.5	BUS TYS e/h = 1.5	BUS TYS e/h = 2.0
1913	.1595	Not Meas.	19	C	D		E A1					2.01	2.14
1914	.1722		21	B			D Cu					1.916	1.889
1915	.1772		19	C								2.06	2.01
1916	.1658		15	B								1.912	2.05
2013	.1698	Not Meas.	21	C	D		C A1		NoCYS .781				
2014	.1660		28	B			D Cu		1.009 .726				
2015	.1657		23	C					1.077 .737				
2016	.1670		19	C					1.026 .749				
2113	.1103	Not Meas.	16	B	D		D A1		1.021				
2114	.1100		25	C			D Cu		1.088				
2115	.1108		15	B					1.034				
2116	.1109		15	C					1.060				
2213	.1289	Not Meas.	20	B	C		E A1		1.062	NoBYS	NoBUS		
2214	.1206		18	B			D Cu		1.112	1.677	1.660		
2215	.1289		17	C					1.051	1.587	1.416		
2216	.1299		18	B					1.065	1.702	1.577		
2313	.1094	Not Meas.	19	B	D		D A1		1.009				
2314	.1100		17	A			D Cu		1.040				
2315	.1063		14	C					1.079				
2316	.1072		17	C					1.124				
2413	.1118	Not Meas.	15	B	D		E A1						
2414	.1128		14	B			D Cu						
2415	.1102		14	C									
2416	.1144		14	C									

Distances:
 A 0 to 0.5 in.
 B 0.5 to 1.0 in.
 C 1.0 to 2.0 in.
 D 2.0 to 5.0 in.
 E 5.0 in. plus

- ① Measurement on Casting surface
 ② Measurement on Specimen surface

TABLE 19 CORRELATIVE PROPERTIES (CONTINUED)

CASTING GROUP: BOEING PART A CONTRACT F 33615-76-C-3111 CAST

Tension Specimen No.	Actual Thkns. (In.)	DAS (10 ⁻⁴ in.)		Specimen Quality Grade	Distance from specimen to:				Property Ratios				
		①	②		Ingate Riser	Chiller	Insulator	CYS TYS	SUS TYS	BYS TYS	BUS TYS	BYS TYS	BUS TYS
25T3	.1582	Not	13	B	D	A	A1	1.062					
25T4	.1612	Meas.	17	A		E	Cu	1.009					
25T5	.1911		17	B				1.086					
25T6	.1581		20	C				1.021					
26T3	.0850	Not	11	B	D	A	A1	.973					
26T4	.0652	Meas.	12	A		E	Cu	NoCYS					
26T5	.0894		11	A				1.035					
26T6	.1111		17	C				1.092					

Distances:

A 0 to 0.5 in.
 B 0.5 to 1.0 in.
 C 1.0 to 2.0 in.
 D 2.0 to 5.0 in.
 E 5.0 in. plus

① Measurement on Casting surface
 ② Measurement on Specimen surface

TABLE 19 CORRELATIVE PROPERTIES (CONTINUED)

CONTRACT F 33615-76-C-3111 CAST

CASTING GROUP: BOEING PART A: INTEGRALS

Tension Specimen No.	Actual Thkns. (in.)	DAS (10 ⁻⁴ in.)		Specimen Quality Grade	Distance from specimen to:				Property Ratios				
		①	②		Ingate Riser	Ch111	Insul-ator	CYS TYS	SUS TUS	BYS TYS	BUS TYS	BYS TYS	BUS TYS
T6/3	.249 D	17	17	B	C	E A1							
T6/4	.248 D	30	21	A		B Cu							
T6/5	.248 D	26	16	C									
T6/6	.249 D	22	18	B									
T7/3	.249 D	See	18	B	C	E A1							
T7/4	.249 D	Above	21	A		B Cu							
T7/5	.249 D		21	C									
T7/6	.249 D		21	B									
T8/3	.2252	Not	18	B	D	D A1							
T8/4	.2212	Meas.	21	B		E Cu							
T8/5	.2183		17	B									
T8/6	.2241		24	B									
T9/3	.248 D	7	15	A	C	D A1							
T9/4	.245 D	9	15	A		A Cu							
T9/5	.248 D	9	19	A									
T9/6	.249 D	9	13	A									
T10/3	.1072	Not	13	B	E	D A1		1.020					
T10/4	.1005	Meas.	11	B		E Cu		NoCYS					
T10/5	.0974		12	D				1.106					
T10/6	.1084		14	A				.988					

Distances:
 A 0 to 0.5 in.
 B 0.5 to 1.0 in.
 C 1.0 to 2.0 in.
 D 2.0 to 5.0 in.
 E 5.0 in. plus

- ① Measurement on Casting surface
 ② Measurement on Specimen surface

TABLE 19 CORRELATIVE PROPERTIES (CONTINUED)

CONTRACT F 33615-76-C-3111 CAST

CASTING GROUP: HITCHCOCK PART A

Tension Specimen No.	Actual Thkns. (in.)	DAS(10 ⁻⁴ in.)		Specimen Quality Grade	Distance from specimen to:				Property Ratios				
		①	②		Ingate	Riser	Chill	Insulator	CYS TYS	SUS TUS	BYS TYS e/h = 1.5	BUS TYS e/h = 1.5	BYS TYS e/h = 2.0
1T5H	.249 D	26	18	A	C	D	B		1.044	.715			
1T6H	.250 D	28	20	A					1.055	.714			
1T7H	.250 D	29	20	A					1.053	.733			
1T8H	.249 D	26	21	A					1.032	.718			
1T9H	.249 D	30	21	A					1.054	.710			
2T5H	.248 C	See above	16	A	B	B	A				1.595	1.640	2.020
2T6H	.248 C	See above	17	A					1.727		1.601	2.075	2.113
2T7H	.249 C	See above	15	A					1.658		1.738	2.066	2.064
2T8H	.250 D		18	A					1.696		1.635	2.085	2.137
2T9H	.249 D		18	A					1.645		1.665	2.065	2.175
3T5H	.249 C	See above	14	A	B	D	A		1.037	.720	1.635	1.662	
3T6H	.250 D	22	16	A					1.055	.714	1.608	1.535	
3T7H	.250 D	23	17	A					1.035	.727	1.656	1.643	
3T8H	.249 D	22	16	A					1.022	.707	1.673	1.514	
3T9H	.249 D	26	16	B					1.012	.726	1.610	1.612	
4T5H	.249 D	See above	16	A	B	D	A						
4T6H	.249 D	See above	16	A									
4T7H	.248 D	See above	18	A									
4T8H	.250 D		15	A									
4T9H	.250 D		20	A									
5T5H	.231		16	A	D	D	A						2.055
5T6H	.239		15	A									2.046
5T7H	.230	Not Meas.	18	A									1.952
5T8H	.234		19	A									1.995
5T9H	.236		15	A									1.972

Distances:
 A 0 to 0.5 in.
 B 0.5 to 1.0 in.
 C 1.0 to 2.0 in.
 D 2.0 to 5.0 in.
 E 5.0 in. plus

① Measurement on Casting surface
 ② Measurement on Specimen surface

TABLE 19 CORRELATIVE PROPERTIES (CONTINUED)

CONTRACT F 33615-76-C-3111 CAST

CASTING GROUP: HITCHCOCK PART A

Tension Specimen No.	Actual Thkns. (in.)	DAS (10 ⁻⁴ in.)		Specimen Quality Grade	Distance from specimen to:				Property Ratios				
		①	②		Ingate	Riser	Chfll	Insul-ator	CYS TYS	SUS TUS	BYS TYS $e/h = 1.5$	BUS TYS $e/h = 1.5$	BUS TYS $e/h = 2.0$
6T5H	.236	Not Meas.	16	A	C	D	A						
6T6H	.235		18	A									
6T7H	.238		20	A									
6T8H	.242		19	A									
6T9H	.232		18	A									
7T5H	.1144		18	A	D	E	D					2.069 2.050	
7T6H	.1321		17	A								2.060 2.019	
7T7H	.1010		17	C								1.937 2.058	
7T8H	.1190		21	A								1.964 2.021	
7T9H	.1203		13	A								1.843 1.923	
8T5H	.1194		17	A	D	D	D						
8T6H	.1392		16	A									
8T7H	.1067		22	A									
8T8H	.1315		19	A									
8T9H	.1252		13	A									
9T5H	.1220		15	A	D	D	C						
9T6H	.1253		15	A									
9T7H	.1087		21	A									
9T8H	.1171		21	A									
9T9H	.1197		13	A									
10T5H	.1093		14	A	D	D	B						
10T6H	.1185		19	A									
10T7H	.1097		19	A									
10T8H	.1164		19	A									
10T9H	.1183		16	B									

Distances:
 A 0 to 0.5 in.
 B 0.5 to 1.0 in.
 C 1.0 to 2.0 in.
 D 2.0 to 5.0 in.
 E 5.0 in. plus

- ① Measurement on Casting surface
 ② Measurement on Specimen surface

TABLE 19 CORRELATIVE PROPERTIES (CONTINUED)

CONTRACT F 33615-76-C-3111 CAST

CASTING GROUP: HITCHCOCK PART A

Tension Specimen No.	Actual Thkns. (in.)	DAS (10 ⁻⁴ in.)		Specimen Quality Grade	Distance from specimen to:				Property Ratios				
		①	②		Ingate	Riser	Chill	Insulator	CYS TYS	SUS TUS	BYS TYS	BUS TUS	BUS TYS
11T5H	.238	16	17	A	D	D	A						
11T6H	.237	16	19	A									
11T7H	.239	20	19	A									
11T8H	.238	18	20	A									
11T9H	.238	12	18	A									
12T5H	.249 D	See	17	A	D	D	A						
12T6H	.250 D	Above	17	A									
12T7H	.250 D		18	A									
12T8H	.249 D		17	A									
12T9H	.249 D		13	A									
13T5H	.250 D	26	15	A	C	E	A						
13T6H	.248 D	28	15	A									
13T7H	.249 D	29	18	A									
13T8H	.250 D	26	20	A									
13T9H	.250 D	30	19	A									
14T5H	.250 D	See	23	A	C	D	B						
14T6H	.249 D	Above	21	A									
14T7H	.250 D		23	A									
14T8H	.249 D		20	A									
14T9H	.250 D		21	A									
15T5H	.1791	Not	19	A	D	D	A						
15T6H	.1212	Meas.	22	B									
15T7H	.1489		22	B									
15T8H	.1769		21	A									
15T9H	.1737		23	B									

Distances:

A 0 to 0.5 in.
 B 0.5 to 1.0 in.
 C 1.0 to 2.0 in.
 D 2.0 to 5.0 in.
 E 5.0 in. plus

1.904 1.982
 1.947 2.033
 1.987 1.966
 1.928 1.935
 1.901 1.969

- ① Measurement on Casting surface
 ② Measurement on Specimen surface

TABLE 19 CORRELATIVE PROPERTIES (CONTINUED)

CONTRACT F 33615-76-C-3111 CAST

CASTING GROUP: HITCHCOCK PART A

Tension Specimen No.	Actual Thkns. (in.)	DAS (10 ⁻⁴ in.)		Specimen Quality Grade	Distance from specimen to:				Property Ratios				
		①	②		Ingate	Riser	Chill	Insulator	CYS TYS	SUS TUS	BYS TYS $\frac{BYS}{TYS} = 1.5$	BUS TUS $\frac{BUS}{TYS} = 2.0$	BUS TUS $\frac{BUS}{TYS} = 2.0$
16T5H	.1770	Not	14	A	D	E	A						
16T6H	.1800	Meas.	15	A									
16T7H	.1811		18	A									
16T8H	.1722		13	A									
16T9H	.1800		17	A									
17T5H	.1109	Not	20	D	D	D	D						
17T6H	.1091	Meas.	20	A									
17T7H	.1078		20	B									
17T8H	.1086		21	A									
17T9H	.1115		22	A									
18T5H	.1012	Not	22	A	D	D	C						
18T6H	.1165	Meas.	21	A									
18T7H	.1097		21	B									
18T8H	.1128		23	A									
18T9H	.1080		20	A									
19T5H	.1893	Not	18	A	A	E	D						
19T6H	.1840	Meas.	21	A									
19T7H	.1880		21	A									
19T8H	.1881		18	A									
19T9H	.1858		18	A									
20T5H	.215	Not	22	A	A	E	D		1.062	.764			
20T6H	.217	Meas.	16	A				Buckled		.760			
20T7H	.203		20	A					1.091	.781			
20T8H	.208		22	A					1.052	.769			
20T9H	.231		18	A					1.061	.766			

Distances:

- A 0 to 0.5 in.
 B 0.5 to 1.0 in.
 C 1.0 to 2.0 in.
 D 2.0 to 5.0 in.
 E 5.0 in. plus

- ① Measurement on Casting surface
 ② Measurement on Specimen surface

TABLE 19 CORRELATIVE PROPERTIES (CONTINUED)

CONTRACT F 33615-76-C-3111 CAST

CASTING GROUP: HITCHCOCK PART A

Tension Specimen No.	Actual Thkns. (in.)	DAS (10 ⁻⁴ in.)		Specimen Quality Grade	Distance from specimen to:				Property Ratios				
		①	②		Ingate	Riser	Chill	Insulator	CYS TYS	SUS. TUS	BYS TYS	BUS TYS	BUS TYS
21T5H	.1095	Not Meas.	15	A	B	E	D						
21T6H	.1442		17	A									
21T7H	.1250		17	B									
21T8H	.1301		18	A									
21T9H	.1258		16	A									
22T5H	.1668	Not Meas.	14	A	A	D	C						
22T6H	.1735		18	A									
22T7H	.1620		19	A									
22T8H	.1625		14	A									
22T9H	.1735		16	A									
23T5H	.1064	Not Meas.	17	A	C	E	C						
23T6H	.1500		19	A									
23T7H	.1122		24	A									
23T8H	.1076		23	B									
23T9H	.1185		25	A									
24T5H	.1088	Not Meas.	21	A	A	E	C						
24T6H	.1529		16	A									
24T7H	.1222		17	B									
24T8H	.1344		22	A									
24T9H	.1334		16	B									

Distances:

A 0 to 0.5 in.
 B 0.5 to 1.0 in.
 C 1.0 to 2.0 in.
 D 2.0 to 5.0 in.
 E 5.0 in. plus

- ① Measurement on Casting surface
 ② Measurement on Specimen surface

TABLE 19 CORRELATIVE PROPERTIES (CONTINUED)

CASTING GROUP: HITCHCOCK PART A INTEGRALS CONTRACT F 33615-76-C-3111 CAST

Tension Specimen No.	Actual Thkns. (in.)	DAS (10 ⁻⁴ in.)		Specimen Quality Grade	Distance from specimen to:			Property Ratios				
		①	②		Ingate	Riser	Ch111	Insul-ator	CYS TYS	SUS. TYS	BYS TYS	BUS TYS
T6/5H	.250 D	17	21	A	D	D	B					
T6/6H	.249 D	15	26	A								
T6/7H	.250 D	18	20	A								
T6/8H	.250 D	18	18	A								
T6/9H	.249 D	14	20	A								
T7/5H	.250 D	See Above	22	A	D	D	B					
T7/6H	.249 D		22	A								
T7/7H	.250 D		20	A								
T7/8H	.249 D		18	A								
T7/9H	.247 D		18	A								
T8/5H	.206	17	No DAS	A	D	D	A					
T8/6H	.234	21	18	A								
T8/7H	.235	16	No DAS	A								
T8/8H	.206	18	23	A								
T8/9H	.235	16	14	A								
T9/5H	.238	16	21	A	D	D	A					
T9/6H	.238	16	13	A								
T9/7H	.237	20	19	A								
T9/8H	.237	18	20	A								
T9/9H	.239	12	13	A								
T10/5H	.1458	Not Meas.	15	A	D	B	B					
T10/6H	.1381		20	A								
T10/7H	.1384		16	A								
T10/8H	.1323		16	A								
T10/9H	.1409		14	A								

Distances:
 A 0 to 0.5 in.
 B 0.5 to 1.0 in.
 C 1.0 to 2.0 in.
 D 2.0 to 5.0 in.
 E 5.0 in. plus

- ① Measurement on Casting surface
 ② Measurement on Specimen surface

TABLE 19 CORRELATIVE PROPERTIES (CONTINUED)

CONTRACT F 33615-76-C-3111 CAST

CASTING GROUP: BOEING PART B

Tension Specimen No.	Actual Thkns. (in.)	DAS (10 ⁻⁴ in.)		Specimen Quality Grade	Distance from specimen to:				Property Ratios						
		①	②		Ingate	Riser	Chill	Insulator	CVS TYS	SUS TUS	BYS TYS $\frac{e}{D} = 1.5$	BUS TUS $\frac{e}{D} = 1.5$	BYS TYS $\frac{e}{D} = 2.0$	BUS TUS $\frac{e}{D} = 2.0$	
1X7	.25 D	24	22	A	D		A A1	D	1.060	.749	1.670	1.778	1.950	2.186	
1X8	"	27	23	B			D Cu		1.034	.714	NoBYS	1.358	1.980	2.180	
1X9	"	23	19	A					1.050	.736	1.718	1.739	2.007	2.146	
1X10	"	24	22	A					1.038	.736	NoBYS	1.288	1.956	2.079	
1X11	"	19	23	B					1.043	.742	NoBYS	1.370	2.022	2.182	
2X7	.25 D	See	23	B	D		A A1	D	Ratios above developed using 1X and 2X averages.						
2X8	"	Above	30	B			D Cu								
2X9	"		21	A											
2X10	"		22	A											
2X11	"		28	B											
3X7	.25 D	20	22	C	D		A A1	D	1.016	.781	1.712	1.784	Ratios from 3X and 4X averages		
3X8	"	23	23	B			D Cu		NoCVS	.752	1.678	1.738			
3X9	"	24	18	A					1.051	.768	1.586	1.379			
3X10	"	20	25	A					1.046	.720	1.679	1.539			
3X11	"	25	22	B					1.078	.753	1.735	1.561			
4X7	.25 D	See	22	B	D		A A1	D	1.100	.810	Ratios from 3X and 4X averages				1.985 2.063
4X8	"	Above	22	C			D Cu		1.055	.754					1.878 2.036
4X9	"		22	A					1.091	.744					2.052 2.255
4X10	"		22	A					1.081	.734					2.010 2.270
4X11	"		26	B					1.100	.740					2.029 2.103
5X7	.216	Not Meas.	16	C	C		B A1	E							
5X8	.210		17	B			A Cu								
5X9	.220		13	B											
5X10	.221		20	B											
5X11	.206		18	B											

Distances:

A 0 to 0.5 in.

B 0.5 to 1.0 in.

C 1.0 to 2.0 in.

D 2.0 to 5.0 in.

E 5.0 in. plus

Distances:
 A 0 to 0.5 in.
 B 0.5 to 1.0 in.
 C 1.0 to 2.0 in.
 D 2.0 to 5.0 in.
 E 5.0 in. plus

- ① Measurement on Casting surface
 ② Measurement on Specimen surface

TABLE 19 CORRELATIVE PROPERTIES (CONTINUED)

CONTRACT F 33615-76-C-3111 CAST

CASTING GROUP: BOEING PART B

Tension Specimen No.	Actual Thkns. (in.)	DAS (10 ⁻⁴ in.)		Specimen Quality Grade	Distance from specimen to:				Property Ratios				
		①	②		Ingate	Riser	Chill	Insulator	CYS TYS	SUS TYS	BYS TYS $e/h = 1.5$	BUS TYS $e/h = 1.5$	BUS TYS $e/h = 2.0$
6X7	.230	Not	17	B	C		B Al	E					
6X8	.232	Meas.	17	B			A Cu						
6X9	.234		18	B									
6X10	.233		17	A									
6X11	.225		17	B									
7X7	.1696	Not	10	A	D		A Al	E	1.126	.704			
7X8	.1680	Meas.	13	A			A Cu		1.077	.692			
7X9	.1686		9	A					1.084	.697			
7X10	.1700		8	A					1.057	.681			
7X11	.1680		11	A					1.053	.696			
8X7	.250 D	Not	24	C	C		C Al	D	1.054	.739	1.675	1.526	
8X8	"	Meas.	23	C			D Cu		1.007	.754	NoBYS	1.390	
8X9	"		26	A					1.005	.753	NoBYS	1.423	
8X10	"		23	A					1.032	.735	1.681	1.524	
8X11	"		25	B					.952	.746	NoBYS	1.396	
9X7	.250 D	Not	23	C	B		A Al	D					
9X8	"	Meas.	23	B			E Cu						
9X9	"		22	A									
9X10	"		22	A									
9X11	"		25	B									
10X7	.1980	Not	14	A	C		A Al	D					
10X8	.1453	Meas.	15	B			E Cu						
10X9	.204		12	B									
10X10	.209		12	B									
10X11	.1898		16	B									

Distances:

A 0 to 0.5 in.
 B 0.5 to 1.0 in.
 C 1.0 to 2.0 in.
 D 2.0 to 5.0 in.
 E 5.0 in. plus

Ratios from 8X and 9X averages.

① Measurement on Casting surface
 ② Measurement on Specimen surface

TABLE 19 CORRELATIVE PROPERTIES (CONTINUED)

CONTRACT F 33615-76-C-3111 CAST

CASTING GROUP: BOEING PART B

Tension Specimen No.	Actual Thkns. (in.)	DAS (10 ⁻⁴ in.)		Specimen Quality Grade	Distance from specimen to:				Property Ratios				
		①	②		Ingate	Riser	Chill	Insul-ator	CYS TYS	SUS TYS	BYS TYS e/h = 1.5	BYS TYS e/h = 2.0	BUS TYS
11X7	.202	Not	10	B	C		A A1	D					
11X8	.202	Meas.	15	B			E Cu						
11X9	.202		15	B									
11X10	.202		13	B									
11X11	.200		14	B									
12X7	.1235	Not	12	B	E		D A1	E			1.928	1.931	
12X8	.1359	Meas.	14	B			D Cu				2.106	1.991	
12X9	.1295		12	B							2.188	2.091	
12X10	.1368		13	B							2.106	2.152	
12X11	.1466		11	B							2.038	1.969	
13X7	.1169	Not	15	B	E		C A1	A					
13X8	.1366	Meas.	14	A			C Cu						
13X9	.1180		11	A									
13X10	.1381		13	A									
13X11	.1340		12	A									
14X7	.221	Not	17	B	D		A A1	E					
14X8	.212	Meas.	13	A			E Cu						
14X9	.218		12	B									
14X10	.220		13	A									
14X11	.217		16	B									
15X7	.1871	Not	21	B	C		E A1	D	1.656	1.528	1.927	2.010	
15X8	.201	Meas.	17	B			D Cu		1.558	1.556	1.898	1.951	
15X9	.202		16	B					1.684	1.519	2.063	2.094	
15X10	.202		20	B					1.634	1.578	1.924	2.222	
15X11	.201		18	B					1.583	1.460	1.931	2.017	

Distances:
 A 0 to 0.5 in.
 B 0.5 to 1.0 in.
 C 1.0 to 2.0 in.
 D 2.0 to 5.0 in.
 E 5.0 in. plus

- ① Measurement on Casting surface
 ② Measurement on Specimen surface

TABLE 19 CORRELATIVE PROPERTIES (CONTINUED)

CASTING GROUP: BOEING PART B CONTRACT F 33615-76-C-3111 CAST

Tension Specimen No.	Actual Thkns. (in.)	DAS (10 ⁻⁴ in.)		Specimen Quality Grade	Distance from specimen to:			Property Ratios				
		①	②		Ingate Riser	Chill	Insulator	CYS TYS	SUS TYS	BYS TYS $\frac{e}{D} = 1.5$	BYS TYS $\frac{e}{D} = 2.0$	BYS TYS $\frac{e}{D} = 2.0$
16X7	.1030	Not Meas.	17	C	D	D Al	A					
16X8	.1080		15	C		E Cu						
16X9	.1150		15	D								
16X10	.1085		16	C								
16X11	.1107		16	C								
17X7	.1600	Not Meas.	19	C	A	D Al	E					
17X8	.1629		26	B		E Cu						
17X9	.1609		19	B								
17X10	.1607		26	C								
17X11	.1515		26	C								
18X7	.1566	Not Meas.	15	C	C	C Al	B					
18X8	.1514		15	C		E Cu						
18X9	.1492		17	B								
18X10	.1424		14	B								
18X11	.1187		15	B								
19X7	.1300	Not Meas.	12	C	D	A Al	C					
19X8	.1310		16	B		D Cu						
19X9	.1284		10	B								
19X10	.1295		12	B								
19X11	.1300		14	B								
20X7	.1015	Not Meas.	16	C	E	C Al	D			1.639	1.597	
20X8	.0911		12	A		E Cu				1.488	1.382	
20X9	.0988		14	A						1.675	1.462	
20X10	.1084		13	A						1.902	1.709	
20X11	.1183		14	B						No Bearing Specimen		

Distances:

A 0 to 0.5 in.
 B 0.5 to 1.0 in.
 C 1.0 to 2.0 in.
 D 2.0 to 5.0 in.
 E 5.0 in. plus

- ① Measurement on Casting surface
 ② Measurement on Specimen surface

TABLE 19 CORRELATIVE PROPERTIES (CONTINUED)

CONTRACT F 33615-76-C-3111 CAST

CASTING GROUP: BOEING PART B

Tension Specimen No.	Actual Thkns. (in.)	DAS (10 ⁻⁴ in.)		Specimen Quality Grade	Distance from specimen to:				Property Ratios				
		①	②		Ingate	Riser	Ch111	Insul-ator	CYS TYS	SUS TYS	BYS TYS e/h = 1.5	BYS TYS e/h = 2.0	BUS TYS
21X7	.0585	Not Meas.	13	Not Meas.	D		C A1	E					
21X8	.0893		14	A			E Cu						
21X9	.0942		13	B									
21X10	.1107		14	A									
21X11	.1132		15	A									
22X7	.1163	Not Meas.	17	B	D		D A1	E					
22X8	.1165		20	B			E Cu						
22X9	.1164		18	B									
22X10	.1158		22	B									
22X11	.1175		16	B									

Distances:

A 0 to 0.5 in.
 B 0.5 to 1.0 in.
 C 1.0 to 2.0 in.
 D 2.0 to 5.0 in.
 E 5.0 in. plus

① Measurement on Casting surface

② Measurement on Specimen surface

TABLE 19 CORRELATIVE PROPERTIES (CONTINUED)

CASTING GROUP: BOEING PART B INTEGRALS CONTRACT F 33615-76-C-3111 CAST

Tension Specimen No.	Actual Thkns. (in.)	DAS (10 ⁻⁴ in.)		Specimen Quality Grade	Distance from specimen to:			Property Ratios				
		①	②		Ingate	Riser	Ch111	Insul-ator	CYS TYS	SUS TYS	BYS TYS e/D = 1.5	BUS TYS e/D = 2.0
X3/7	.25 D	24	19	B	D		E A1	E				
X3/8	"	25	25	C			A Cu					
X3/9	"	20	19	B								
X3/10	"	23	18	A								
X3/11	"	26	25	B								
X4/7	.25 D	See	19	B	D		E A1	E				
X4/8	"	Above	21	C			A Cu					
X4/9	"		21	B								
X4/10	"		16	A								
X4/11	"		26	B								
X5/7	.1246	Not	15	A	E		D A1	B				
X5/8	.1410	Meas.	17	A			D Cu					
X5/9	.1228		12	C								
X5/10	.1281		12	B								
X5/11	.1280		17	B								
X7/7	.1195	Not	16	B	D		D A1	A				
X7/8	.1260	Meas.	16	B			E Cu					
X7/9	.1674		15	A								
X7/10	.1262		12	A								
X7/11	.1396		15	B								

Distances:

A 0 to 0.5 in.
 B 0.5 to 1.0 in.
 C 1.0 to 2.0 in.
 D 2.0 to 5.0 in.
 E 5.0 in. plus

① Measurement on Casting surface
 ② Measurement on Specimen surface

APPENDIX G

DERIVED PROPERTIES

Compression, shear, and bearing design values are derived as 95 percent lower confidence limits of ratios formed with tensile properties. Tables 20 through 25 present the ratios of CYS/TYS, SUS/TUS, BYS/TYS, and BUS/TUS grouped into the DAS and soundness cells used in Section III.3 to categorize tensile properties. In Tables 20 and 21, evaluations were made between round and flat specimen data for compression and shear to determine whether specimen configurations influenced the results. In both cases, configuration caused less than 2 percent difference in mean ratios of either CYS/TYS or SUS/TUS. Therefore, Phase II round and flat specimen data within each cell were combined to compute statistical means and standard deviations. Each table of property ratios shows the calculations made to obtain reduced ratio (R) values. The cell average ratios and reduced ratio values are shown in Figure 18. The reduced ratio line for each of the six property ratios is naturally weighted towards the larger sample cell averages.

The recommended use of derived property ratios for A357-T6 castings is as follows:

1. Obtain the appropriate tensile allowable as explained in Section III.
2. Multiply the tension allowable by the reduced ratio value shown below:

$$F_{cy} = 1.045 F_{ty}$$

$$\begin{aligned} F_{bry} &= 1.627 F_{ty}(e/D = 1.5) \\ &= 1.959 F_{ty}(e/D = 2.0) \end{aligned}$$

$$F_{su} = 0.720 F_{tu}$$

$$\begin{aligned} F_{bru} &= 1.538 F_{tu}(e/D = 1.5) \\ &= 2.02 F_{tu}(e/D = 2.0) \end{aligned}$$

TABLE 20 DERIVED PROPERTY RATIO ANALYSIS -- COMPRESSION

CAST Contract F 336 5-76-C-3111

Tension Specimen Quality Grade				
	A	B	C	D
Tension Specimen DAS range .0001 in.	1.034* 1.053 1.035 1.126 1.084 1.057 1.053 N = 7 r̄ = 1.063 s = .032	1.105 .973 N = 2 r̄ = 1.039 s = .093	1.136	1.106
Up To 12				
13 to 18	1.049* 1.009 1.077 1.076* .988 1.045* 1.044* 1.044* 1.037* 1.033* 1.055* 1.027 1.035* .998 1.022* N19 .920 1.061 r̄1.032 1.040 1.051* s .036	1.010* 1.034 1.051* 1.112 1.096 1.065 1.036 1.062 1.079 1.086 1.018 1.020 1.050 1.012* 1.014 N = 16 r̄ = 1.048 s = .033	1.074 1.092 1.034 1.081 1.115 1.027 1.060 1.051 1.079 1.124 N = 10 r̄ = 1.074 s = .032	Pooled Data: N = 92 r̄ = 1.051 s = .0369 t.95 = 1.662 R = r̄ - t.95s/√N R = 1.045
19 to 24	1.055* 1.050* 1.053* 1.038* 1.032* 1.091* 1.054* 1.081* 1.062 1.032* 1.091 N = 13 r̄ = 1.058 s = .020	1.108 1.100* 1.053 1.079 1.062 1.009 1.034* 1.043* 1.078* N = 9 r̄ = 1.063 s = .032	1.050 1.077 1.026 1.021 1.016* 1.055* 1.054* 1.007* N = 8 r̄ = 1.038 s = .024	
25 +	1.046* 1.005* N = 2 r̄ = 1.026 s = .029	1.009 1.100* .952* N = 3 r̄ = 1.020 s = .075	1.088 Specimen Configurations: Round 37 r̄ 1.044 s .028 cv 2.7% Flat 55 r̄flat = 1.011 r̄ .056 s .041 cv 3.9%	

Data are ratios (r) of CYS/TYS
 * = Round Specimens
 N = number of CYS/TYS ratios
 $\bar{r}$ = mean group ratio
 s = standard deviation
 cv = coefficient of variation, 100 $s/\bar{r}$

TABLE 21 DERIVED PROPERTY RATIO ANALYSIS-----SHEAR

Contract F 33615-76-C-3111

CAST

Tension Specimen Quality Grade				D
A	B	C		
Tension Specimen DAS range .0001 in. Up To 12	N = 5 $\bar{r}$ = .694 s = .0085	.701		
13 to 18	.692* .704* .697* .681* .696* .713* .720* .700* .714* .698* .727* .736* .707* .718* .760* .676* .766* .656* .768* .661* .692* .715*	N = 6 $\bar{r}$ = .715 s = .010	N = 3 $\bar{r}$ = .731 s = .049	Pooled Data: N = 64 $\bar{r}$ = .727 s = .0319 t _{.95} = 1.669 R = $\bar{r} - t_{.95}s/\sqrt{N}$ R = .720
19 to 24	.714* .736* .733* .736* .718* .744* .710* .734* .764* .735* .781* .769* .749*	N = 7 $\bar{r}$ = .732 s = .049	N = 7 $\bar{r}$ = .756 s = .018	Specimen Configurations Round N = 38 $\bar{r}$ = .732 s = .0237 cv = 3.24%
25 +	.720* .753*	N = 2 $\bar{r}$ = .737 s = .023	N = 3 $\bar{r}$ = .737 s = .010	Flat N = 26 $\bar{r}_{\text{flat}}$ = .981 $\bar{r}_{\text{round}}$ = .0402 5.60%

Data are ratios (r) of SUS/TUS

N = number of SUS/TUS ratios

* = mean group ratio

s = standard deviation

cv = coefficient of variation, 100s/ $\bar{r}$

* = Round Specimens

TABLE 22 DERIVED PROPERTY RATIO ANALYSIS --- BEARING YIELD STRENGTH $e/D = 1.5$

CAST Contract F 33615-76-C-3111

Tension Specimen Quality Grade			
A	B	C	D
Tension Specimen DAS range .0001 in. Up To 12	1.597 1.581 1.488 $N = 3$ $\bar{r} = 1.555$ $s = .059$		
13 to 18	1.638 1.645 1.581 1.635 1.601 1.608 1.564 1.656 1.532 1.673 1.595 1.586 1.727 1.675 1.658 1.902 1.696 $N = 17$ $\bar{r} = 1.645$ $s = .083$	1.672 1.677 1.702 1.610 1.558 1.684 1.583 $N = 7$ $\bar{r} = 1.641$ $s = .056$	1.587 1.639 $N = 2$ $\bar{r} = 1.613$ $s = .037$
19 to 24	1.670 1.718 1.681 $N = 3$ $\bar{r} = 1.690$ $s = .025$	1.678 1.735 1.656 1.634 $N = 4$ $\bar{r} = 1.676$ $s = .043$	Pooled Data: $N = 39$ $\bar{r} = 1.646$ $s = .070$ $t_{.95} = 1.685$ $R = \bar{r} - t_{.95}s/\sqrt{N}$ $R = 1.627$
25 +	1.679		

N = number of BVS/TYS ratios
 $\bar{r}$ = mean group ratio
 s = standard deviation

Data are ratios (r) of BVS/TYS for $e/D = 1.5$

TABLE 23 DERIVED PROPERTY RATIO ANALYSIS --- BEARING ULTIMATE STRENGTH $e/D = 1.5$

CAST

Contract F 33615-76-C-3111

Tension Specimen Quality Grade				D	
A		B	C		
Tension Specimen DAS range .0001 in.	1.655 1.646 1.382 N = 3 $\bar{r} = 1.561$ s = .155				
Up To 12					
13 to 18	1.684 1.665 1.606 1.662 1.637 1.535 1.656 1.643 N = 17 1.660 1.514 $\bar{r} = 1.607$ 1.640 1.379 $\bar{r} = 1.583$ 1.601 1.462 s = .092 1.738 1.709 1.635	1.695 1.660 1.577 1.612 1.556 1.519 1.460 N = 7 $\bar{r} = 1.583$ s = .081	1.416 1.597	N = 2 $\bar{r} = 1.507$ s = .128	Pooled Data: N = 45 $\bar{r} = 1.569$ s = .124 $t_{.95} = 1.681$ $R = \bar{r} - t_{.95} s / \sqrt{N}$ $R = 1.538$
19 to 24	1.778 1.739 1.288 1.524 N = 4 $\bar{r} = 1.582$ s = .226	1.358 1.370 1.738 1.561 1.528 1.578 N = 6 $\bar{r} = 1.522$ s = .142	1.784 1.526 1.390	N = 3 $\bar{r} = 1.567$ s = .200	
25 +	1.539 1.423 N = 2 $\bar{r} = 1.481$ s = .082	1.396			

Data are ratios (r) of BUS/TUS for $e/D = 1.5$

N = number of BUS/TUS ratios
 $\bar{r}$ = mean group ratio
s = standard deviation

TABLE 24 DERIVED PROPERTY RATIO ANALYSIS --- BEARING YIELD STRENGTH e/D = 2.0

CAST Contract F 33615-76-C-3111

Tension Specimen Quality Grade				D
A	B	C		
Tension Specimen DAS range .0001 in.	1.929	1.928 2.19 2.04	N = 3 $\bar{r} = 2.05$ s = .131	
Up To 12				
13 to 18	1.950 2.06 1.947 1.993 2.06 1.987 1.964 1.952 1.928 1.902 1.995 1.901 1.918 1.972 N = 22 2.02 2.07 $\bar{r} = 1.984$ 2.08 2.06 $\bar{r} = 1.984$ 2.07 1.843 s = .070 2.08 1.904	2.10 1.931 1.867 1.934 1.855 1.912 2.11 2.11 1.898 2.06	N = 10 $\bar{r} = 1.978$ s = .105	1.836 1.871 1.882 1.937 N = 4 $\bar{r} = 1.882$ s = .042 Pooled Data: N = 58 $\bar{r} = 1.976$ s = .078
19 to 24	1.903 1.995 1.964 1.950 2.01 1.956 2.05 2.01	1.916 1.980 2.02 1.985 1.927 1.924	N = 8 $\bar{r} = 1.980$ s = .046	t _{.95} = 1.672 R = $\bar{r} - t_{.95}s/\sqrt{N}$ R = <u>1.959</u>
25 +		2.03	N = 6 $\bar{r} = 1.959$ s = .042	

Data are ratios (r) of BYS/TYS for e/D = 2.0
 N = number of BYS/TYS ratios
 $\bar{r}$ = mean group ratio
 s = standard deviation

TABLE 25 DERIVED PROPERTY RATIO ANALYSIS --- BEARING ULTIMATE STRENGTH $e/D = 2.0$

CAST Contract F 33615-76-C-3111

Tension Specimen Quality Grade				D	
A		B	C	D	
Tension Specimen DAS range .0001 in.	1.970	1.931 2.09 1.969	2.07		
Up To 12		N = 3 $\bar{r} = 2.00$ s = .083			
13 to 18	2.11 2.14 1.982 2.04 2.18 2.03 2.04 2.05 1.966 1.736 1.949 1.935 1.955 2.01 1.969 2.20 1.877 N = 23 2.10 2.05 $\bar{r} = 2.02$ 2.11 2.02 2.06 1.923 s = .103	2.08 2.02 1.826 1.976 2.06 2.05 1.991 2.15 1.951 2.09	1.845 2.02 2.04 2.06	Pooled Data: N = 60 $\bar{r} = 2.04$ s = .105	
19 to 24	2.08 1.919 2.02 2.19 2.15 2.08 2.26 2.27	1.889 2.18 2.18 2.06 2.01 2.22	2.14 2.01 2.04	t _{.95} = 1.671 R = $\bar{r} - t_{.95}s/\sqrt{N}$ R = <u>2.02</u>	
25 +		N = 6 $\bar{r} = 2.09$ s = .127		N = 3 $\bar{r} = 2.06$ s = .068	
		2.10			

Data are ratios ($\bar{r}$) of BUS/TUS for $e/D = 2.0$
N = number of BUS/TUS ratios
 $\bar{r}$ = mean group ratio
s = standard deviation

APPENDIX H

BULKHEAD COUPON DATA

Tensile coupon properties of four bulkheads are contained in this section. This includes TUS, TYS, ELONG, specimen DAS and specimen soundness grades. Figure 40 shows the locations of all specimens. Numbers 1 through 26 were required per the Engineering drawing. These specimens were tested from the following castings.

Boeing foundry:	M08, M09
Hitchcock foundry:	H2, H9

Supplemental tests were performed to evaluate property trends in the corrugation stiffeners of castings M09 and H9, and in the periphery flange of M09. Tests were also performed on the three remaining lugs of M09 and H9, integral coupons of M10, and one additional H2 casting lug. Table 26 contains these results. Refer to Section IV for a summary analysis of these results.

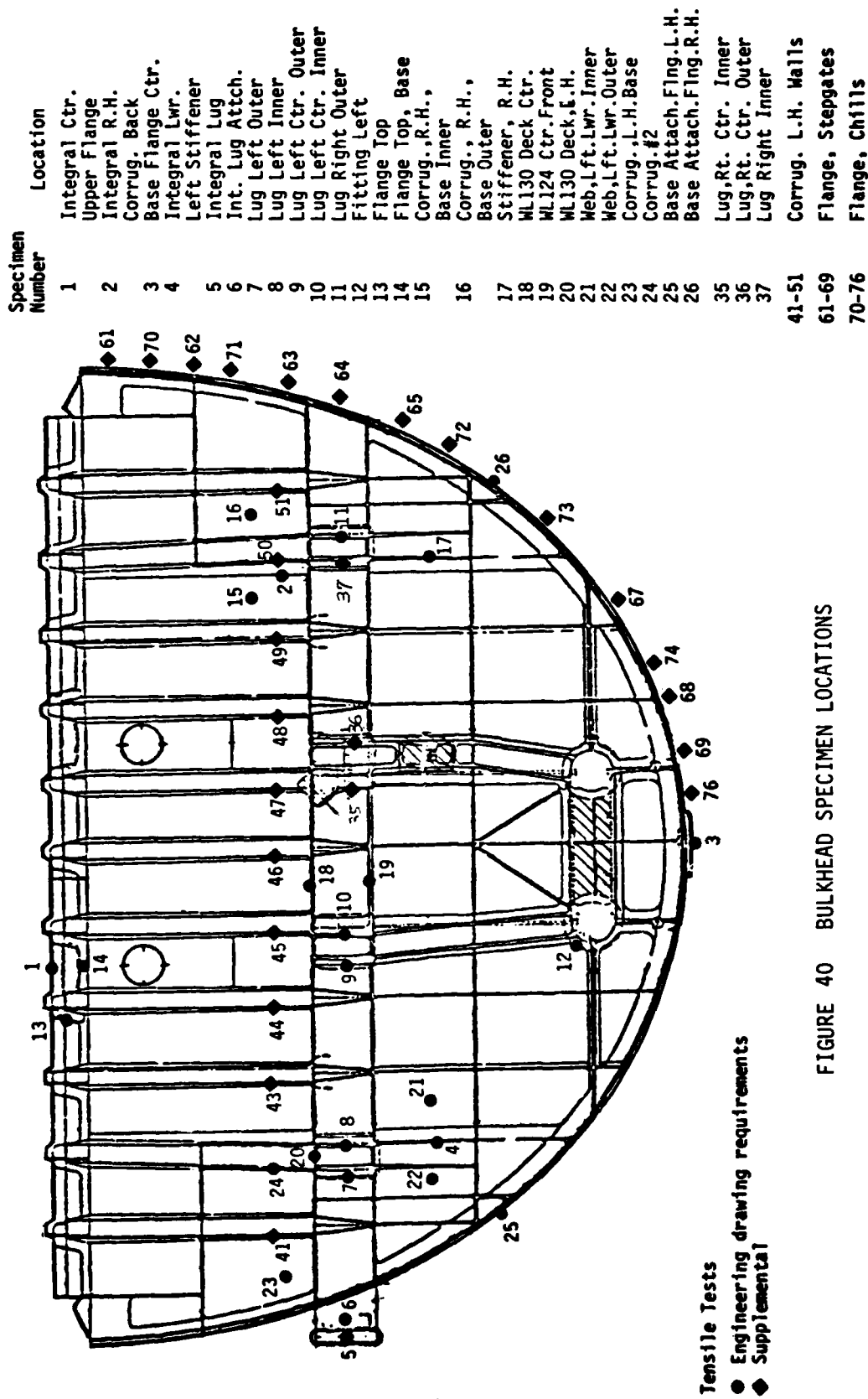


FIGURE 40 BULKHEAD SPECIMEN LOCATIONS

(NEW) GUNTER (NEW) GUNTER

★U.S. Government Printing Office: 1980 — 657-084/752