DEPARTMENT OF THE NAVY

DAVID TAYLOR MODEL BASIN

HYDROMECHANICS

○

AERODYNAMICS

○

STRUCTURAL MECHANICS

○

APPLIED MATHEMATICS

BUCKLING AND ULTIMATE STRENGTH OF PLATING LOADED IN EDGE COMPRESSION.

PROGRESS REPORT 2 – UNSTIFFENED PANELS

by

William F. Conley, Louis A. Becker,
and Ralph B. Allnutt

STRUCTURAL MECHANICS LABORATORY

RESEARCH AND DEVELOPMENT REPORT

May 1963

Report 1682

BUCKLING AND ULTIMATE STRENGTH OF PLATING
LOADED IN EDGE COMPRESSION
PROGRESS REPORT 2 – UNSTIFFENED PANELS

by

William F. Conley, Louis A. Becker,
and Ralph B. Allnutt

May 1963

Report 1682
S-F013 03 01

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

The buckling and ultimate compressive strengths were determined for various types of steel and aluminum plates. Each plate was simply supported and loaded in edge compression. Ultimate strengths were different from those expected, using present design procedures and, as a result, a design change is recommended.

INTRODUCTION

The procedure now used by the Bureau of Ships for designing stiffened panels is outlined in a design data sheet.[1] This procedure indicates that the plating should be designed as though it were a panel simply supported on all four edges. The length and width of the panel are the same as the stiffener spacings. The design sheet includes a curve for the allowable compressive load on any size plate, assuming the tensile yield stress and modulus of elasticity are known.

The design curve mentioned above had been determined from some early experimental work done at the David Taylor Model Basin and summarized in Reference 2. It does not include data from the newer types of steel or aluminum now being used in ship design. Thus, all designs using these materials are actually done by extending the design curve shown in Reference 1. The Bureau of Ships recognized this problem and requested[3] the Model Basin to conduct tests to extend the present design curves to handle the newer types of material.

---

1 References are listed on page 14.

The experimental work authorized by Reference 3 was carried out at the Model Basin in the late 1950's and early 1960's. Tests were conducted on 50 different plates made up from several kinds of steel and aluminum. The buckling and ultimate compressive strengths of each panel were determined. As a result of these experiments, a new design procedure is proposed. The new procedure is believed to be valid for all common shipbuilding materials having stress-strain curves similar to those tested and the geometries currently being used in shipbuilding.

Information was also requested[3] on the effects of welding on aluminum panels. Seventy-one panels each with one or more welded seams, were made up of various types of aluminum and were tested. The results of these tests are listed in the Appendix.

TEST SETUP AND PROCEDURE

THE PANELS

The panels were made up from standard plates as received from the mill. Two basic sizes were used, 18 by 36 in. and 12 by 36 in. The thickness of the plates varied from 1/8 to 3/8 in. Several types of material were used including high-tensile steel (HTS), specially treated steel (STS), high-yield steel (HY-80), 5456-aluminum (both H-24 and H-321), and 6061-aluminum (T6). Table 1 shows the dimensions of all plates used in this program. Each plate had all four edges machined round so that it would be free to rotate in the test jig; see Figure 1. Each plate was instrumented with strain gages prior to being put in the

TABLE 1

Physical and Strength Properties of Plates Tested

PLATE NUMBER	MATERIAL	HEAT	NOMINAL SIZE INCHES	MEASURED THICKNESS INCHES	COMPRESSIVE YIELD STRENGTH KSI (measured)	B* $\left[\frac{b}{t}\sqrt{\frac{\sigma_y}{E}}\right]$	F (observed) $\left[\sigma/\sigma_y\right]$	OBSERVED ULTIMATE LOAD KIPS	ULTIMATE STRESS KSI				BUCKLING LOAD KIPS	
									OBSERVED	CALCULATED			OBSERVED	CALCULATED (BRYAN'S EQ)
										EQUATION 4 $\left[\sigma=\sigma_y\left(\frac{1.82}{B}-\frac{0.82}{B^2}\right)\right]$	EQUATION 3 $\left[\sigma=\sigma_y\left(\frac{2.25}{B}-\frac{1.25}{B^2}\right)\right]$	VON KARMANS EQUATION $\sigma=\frac{\pi t}{b\sqrt{3(1-u^2)}}\sqrt{E\sigma_y}$		
A1	HY80	--	36x18x1/8	0.121	96.6	8.44	0.204	43.0	19.7	19.7	24.0	21.7	11.9	10.8
A2	HY80	--	36x12x1/8	.120	99.7	5.76	.277	39.8	27.6	29.0	35.2	32.9	14.4	15.6
B1	HY80	--	36x18x3/16	.182	115.4	6.13	.261	98.6	30.1	31.8	38.5	35.8	48.9	36.7
B2	HY80	--	36x12x3/16	.181	116.7	4.13	.372	94.3	43.4	45.8	55.1	53.7	28.0	53.6
C1	HY80	--	36x18x1/4	.239	115.5	4.67	.358	178.0	41.4	40.6	49.0	47.0	--	82.1
C2	HY80	--	36x12x1/4	.242	116.6	3.09	.437	148.0	51.0	58.6	69.6	71.6	111.7	127.9
D1	HY80	--	36x18x5/16	.318	102.0	3.30	.448	257.0	45.7	48.6	57.8	58.7	--	193.3
D2	HY80	--	36x12x5/16	.310	103.6	2.27	.636	245.0	65.9	66.5	77.5	86.7	--	269.3
A1	STS	--	36x18x1/4	0.238	131.8	5.01	0.368	208.0	48.6	43.5	52.6	50.0	110.0	81.3
A2	STS	--	36x18x1/4	.246	130.7	4.83	.358	207.0	46.8	44.7	53.8	51.4	113.0	89.5
A3	STS	--	36x12x1/4	.246	130.7	3.22	.490	189.0	64.0	63.5	75.7	77.1	115.9	134.5
A4	STS	--	36x12x1/4	.243	130.1	3.25	.490	186.0	63.8	63.0	74.7	76.1	109.2	129.9
B1	STS	--	36x18x3/8	.359	101.1	2.91	.505	330.0	51.1	53.4	63.2	66.0	295.2	278.4
B2	STS	--	36x18x3/8	.364	101.3	2.87	.538	357.0	54.5	54.1	64.0	67.1	319.6	279.0
B3	STS	--	36x12x3/8	.358	101.4	1.97	.830	370.0	86.1	72.3	83.1	97.8	--	415.0
B4	STS	--	36x12x3/8	.360	102.9	1.95	.821	365.0	84.5	73.8	84.9	100.3	--	421.6
A1	HTS	--	36x18x1/8	0.118	65.0	7.10	0.255	35.2	16.6	15.6	19.0	17.4	14.2	10.0
A2	HTS	--	36x18x1/8	.119	65.7	7.08	.260	36.6	17.1	15.8	19.3	17.6	14.3	10.1
B1	HTS	--	36x18x3/16	.190	48.1	3.79	.456	75.0	21.9	20.3	24.4	24.1	25.7	41.4
B2	HTS	--	36x18x3/16	.190	47.6	3.77	.399	65.0	19.0	20.2	24.2	24.0	39.7	41.4
C1	HTS	--	36x18x1/4	.243	52.0	3.08	.505	114.0	26.2	26.3	31.1	32.1	93.5	86.5
C2	HTS	--	36x18x1/4	.245	52.0	3.06	.480	110.0	25.0	26.4	31.3	32.3	97.0	88.6
D1	HTS	--	36x18x5/16	.298	50.3	2.47	.631	170.0	31.7	30.3	35.6	38.7	--	159.7
D2	HTS	--	36x18x5/16	.297	50.9	2.50	.643	175.0	32.7	30.4	35.6	38.7	--	159.4
D3	HTS	--	36x12x5/16	.298	51.2	1.66	.847	155.0	43.4	40.9	46.2	58.6	--	239.5
D4	HTS	--	36x12x5/16	.299	51.8	1.67	.861	160.0	44.6	41.2	46.6	58.9	--	241.6
78	6061 AL	T6	36x18x5/16	0.311	39.7	3.63	0.436	96.8	17.3	17.4	20.8	20.7	56.0	61.0
79	6061 AL	T6	36x18x5/16	.309	39.3	3.63	.461	100.0	18.1	17.2	20.6	20.6	66.2	60.0
80	6061 AL	T6	36x18x1/4	.246	40.2	4.61	.388	69.2	15.6	14.3	17.2	16.5	33.2	30.1
81	6061 AL	T6	36x18x1/4	.244	38.8	4.57	.407	69.5	15.8	13.9	16.8	16.1	36.0	29.9
82	6061 AL	T6	36x18x3/16	.188	39.8	5.94	.326	44.3	13.0	11.2	13.7	12.5	15.5	13.2
83	6061 AL	T6	36x18x3/16	.192	43.2	6.06	.286	41.5	12.1	12.0	14.6	13.0	14.5	14.2
84	6061 AL	T6	36x18x1/8	.123	37.5	8.91	.235	19.5	8.8	7.3	8.9	8.0	4.0	3.8
85	6061 AL	T6	36x18x1/8	.123	41.6	9.38	.214	19.8	8.9	7.7	9.4	8.4	4.2	3.8
A1	5456 AL	H24	36x18x1/8	0.128	37.4	8.57	0.204	17.6	7.6	7.5	9.2	8.3	4.8	4.1
A2	5456 AL	H24	36x18x1/8	.128	37.4	8.57	.203	17.5	7.6	7.5	9.2	8.3	3.7	4.1
B1	5456 AL	H24	36x18x3/16	.193	39.5	5.84	.291	40.0	11.5	11.4	13.7	_2.8	11.1	14.6
B2	5456 AL	H24	36x18x3/16	.195	39.5	5.79	.292	40.5	11.5	11.5	13.9	12.9	15.1	15.1
C3	5456 AL	H24	36x12x1/4	.254	35.0	2.79	.556	59.4	19.5	19.1	22.6	23.8	49.7	49.7
C4	5456 AL	H24	36x12x1/4	.255	38.2	2.90	.428	50.0	16.3	20.2	24.0	25.1	37.6	50.2
C1	5456 AL	H24	36x18x1/4	.257	38.2	4.32	.335	59.2	12.8	14.4	17.3	16.8	31.5	34.3
C2	5456 AL	H24	36x18x1/4	.255	38.2	4.35	.376	66.0	14.4	14.3	17.2	16.7	37.6	33.5
200	5456 AL	H321	36x18x1/8	0.129	34.1	8.12	0.207	16.4	7.1	7.2	8.8	8.0	4.4	4.1
201	5456 AL	H321	36x18x1/8	.129	34.1	8.12	.216	17.1	7.4	7.2	8.8	8.0	3.5	4.4
100	5456 AL	H321	36x18x3/16	.191	31.4	5.62	.359	38.7	11.3	9.4	11.3	10.6	14.1	14.1
302	5456 AL	H321	36x12x1/4	.264	34.7	2.67	.455	50.0	15.8	19.7	23.2	25.1	33.6	55.8
302A	5456 AL	H321	36x12x1/4	.264	34.7	2.63	.572	61.1	19.3	19.9	23.4	24.7	53.6	55.8
303	5456 AL	H321	36x12x1/4	.264	34.7	2.67	.464	51.0	16.1	19.7	23.2	25.1	35.2	55.8
300	5456 AL	H321	36x18x1/4	.264	34.7	4.00	.407	67.2	14.1	14.0	16.8	16.5	36.6	37.1
301	5456 AL	H321	36x18x1/4	.265	34.7	3.99	.410	67.9	14.2	14.0	16.8	16.5	31.5	37.7

* E Steel 30,000 KSI
E Aluminum 10,060 KSI

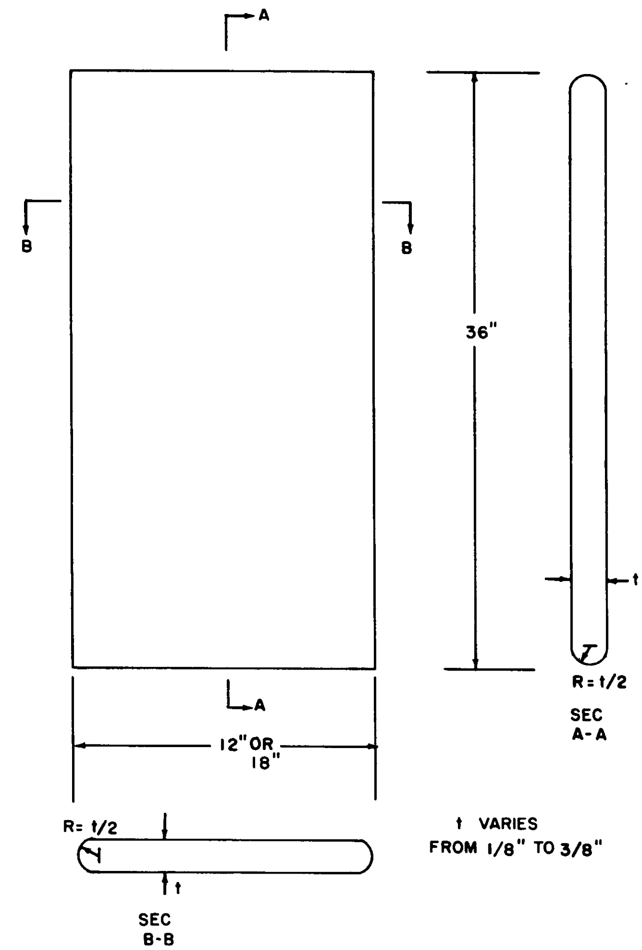


Figure 1 - Typical Plate

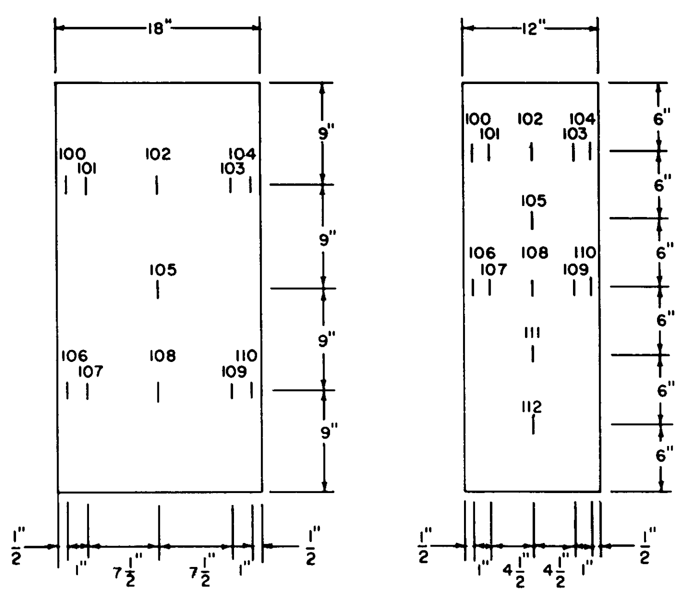


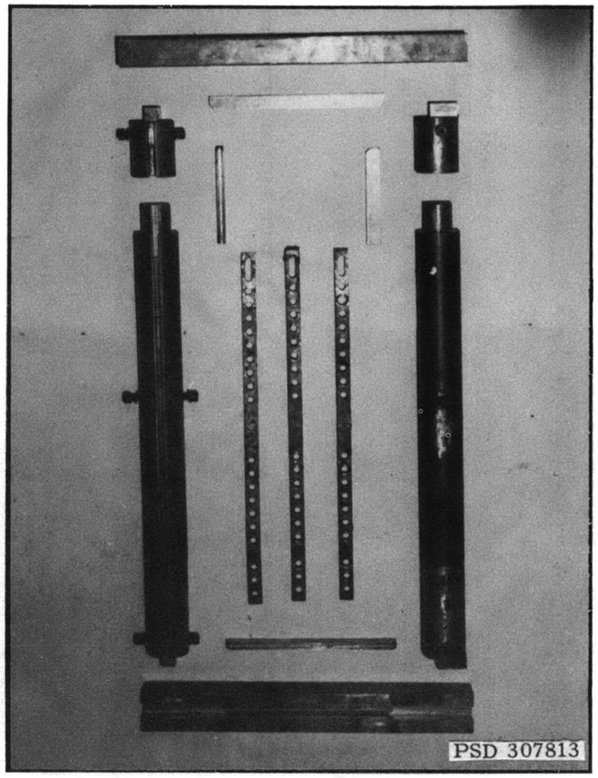
Figure 2 - Strain Gage Locations

Note: Gages are backed up on other side of plate. (200 Series) jig. These were located to indicate the buckling loads. The locations were as shown in Figure 2.

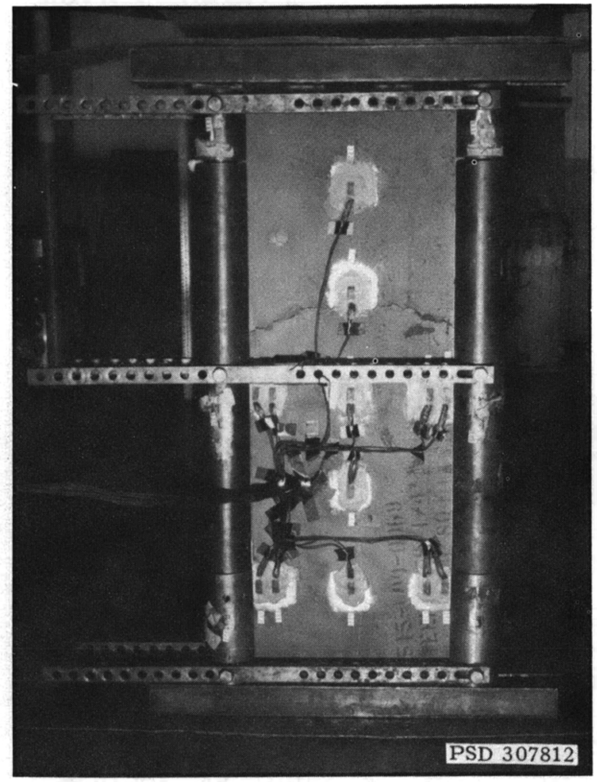
THE TEST FIXTURE

After a plate was instrumented, it was placed in the test jig. This jig is shown in Figure 3 and described in detail in Reference 4. Basically the jig consists of a top and bottom support held apart by two telescoping columns. All four pieces have slots to take radius insert supports. These inserts have the same radius as the panel under test so that the panel is free to rotate. (This requirement made it necessary to have a new set of inserts for each plate thickness.) The columns are prevented from moving laterally by bars bolted to the columns. As shown in Figure 3, the plate is about 1/4 in. longer than the jig. This means that the top support rests on the panel and, under load, is pressed against the panel. As load is applied, the initial 1/4-in, gap decreases due to the contraction of the panel. (The 1/4-in. gap is located away from the bearing load to minimize the possibility of local crippling.)

After the plate was aligned in the jig, the entire assembly was placed under the 600,000-lb testing machine and loaded in compression. The load increments varied from 1000 to 20,000 lb, depending on the plate size and material. Strains were recorded at each load increment. Load was applied to each plate until its ultimate load was reached.



a. Disassembled



b. Assembled with Plate Inside

Figure 3 - The Test Fixture

TEST RESULTS AND DISCUSSION

The test results are shown in Table 1 which lists the plate size and material, and the buckling and ultimate loads. The buckling load is determined from the strains by the method outlined in Reference 5. As explained in detail in the reference, the buckling load is the load at which the strain difference curve reverses slope (the inflection point). This buckling load is compared to that calculated from Bryan's equation.[6] The agreement is good in some cases but not in others. There are several reasons for the poor agreement. First, it is difficult to define the inflection point precisely in many cases. Second, it is assumed in the equations that the plates are flat; this may not be true when standard mill plates are used. Third, the load may not be distributed evenly across the plate. (It has been noted in some cases that the membrane strain is as much as 10 percent higher near the top of the plate than near the bottom.) Fourth, the support at the edges may not always be a truly simple support. (If all the above happen on one plate, the disagreement between the theoretical values and experimental could be appreciable.)

To effectively compare the ultimate strength of various plates, a strength factor (F) and a width factor (B) were computed for each plate; see Table 1. These factors, which are similar to those used in Reference 2, are found from the following equations:

$$F = \frac{P}{b\,t\,\sigma_y} \qquad [1]$$

and

$$B = \frac{b}{t} \sqrt{\sigma_y / E} \qquad [2]$$

where P is the ultimate compressive load in pounds determined from the testing machine,

b is the width of the panel in inches,

t is the thickness of the panel in inches,

σ_y is the yield strength of the panel in pounds per square inch, and

E is the modulus of elasticity of the panel in pounds per square inch.

The values of B and F (Table 1) are plotted in Figure 4 along with the present design curve as proposed by Reference 2, namely

$$F = \frac{2.25}{B} - \frac{1.25}{B^2} \qquad [3]$$

As can be seen, there is as much as a 25-percent discrepancy between the curve and the experimental data points. Unfortunately, the data points are on the unsafe side of the curve.

Nothing appeared wrong with the basic experimental work and thus the original work[7,8] which was used to establish Equation [3] was examined. This showed that a discrepancy had resulted from using the tensile yield strength in Equation [3] instead of compressive yield strength as is used in this report. To verify this, some of the data of References 7 and 8 were recalculated, using the compressive yield

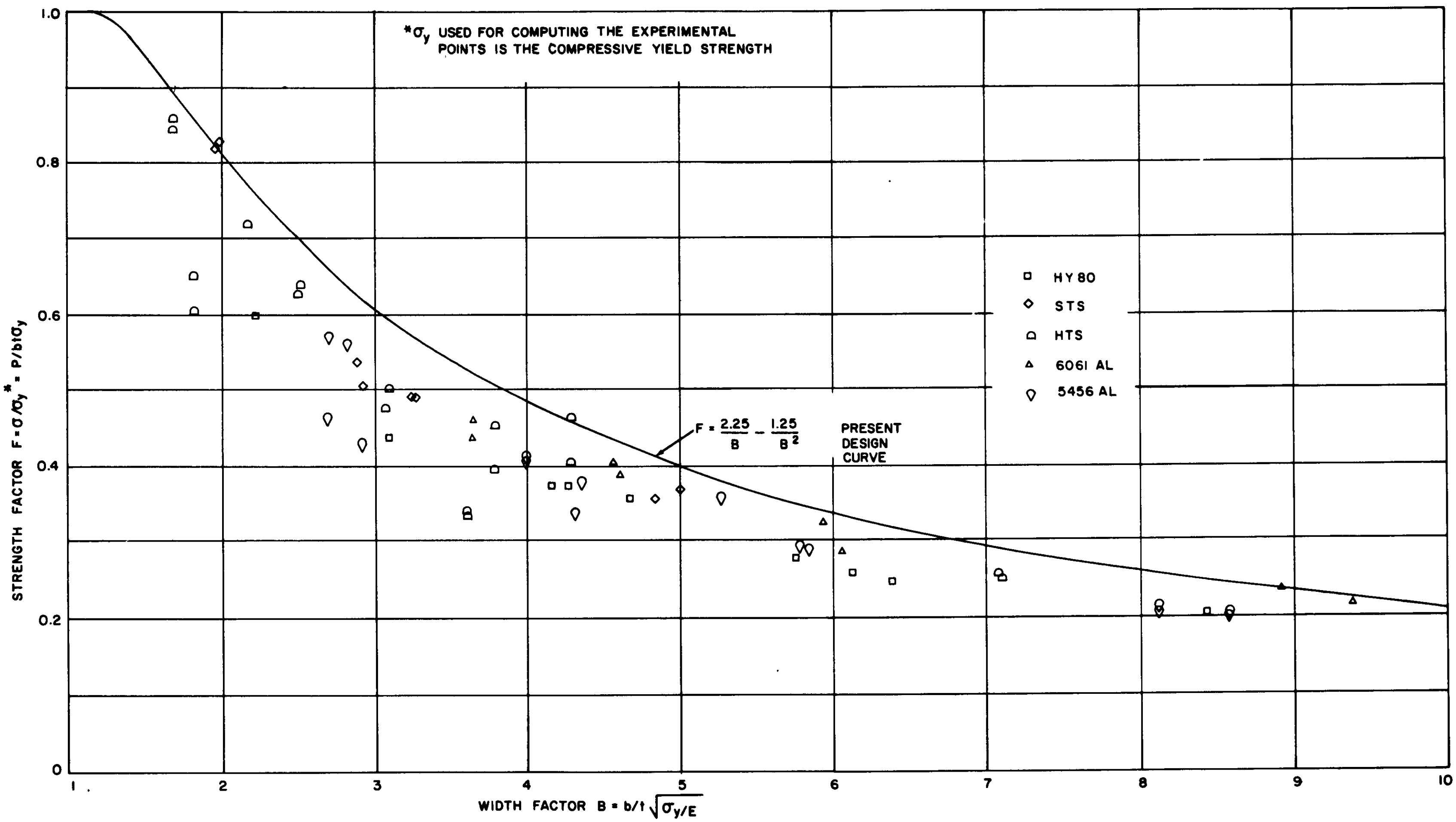


Figure 4 - Curve of Plate Strength Factor versus Width Factor

rather than the tensile yield strength. (The compressive yield strength was determined from current tests on furniture steel.) The recalculated points then fell among the data obtained from the present series of tests; see Figure 5.

From the above discussion, it can be seen that the choice of proper yield strength is very important. Since compression is the predominant load, the compressive yield stress is the important material property and must be considered in any generalized strength curve. Equation [3] which uses the tensile yield strength is valid for furniture steel, the predominant material used in its empirical derivation, since σ_y compressive equals a constant K* times σ_y tensile for a specific material. However, an error will result if such a curve is extrapolated to include another material having a different K value, that is a different ratio of σ_y compressive to σ_y tensile.

In view of the above, a new design curve (Figure 6) is recommended. It is based on the equation

$$F = \frac{1.82}{B} - \frac{0.82}{B^2} \qquad [4]$$

where all terms are as before and σ_y is the compressive yield strength of

* K is determined from specimen tests on each type of material. The specimens (DTMB drawings S 915 for tensile and S 10981 for compression) are loaded at a rate of .001 in/in/min until yield occurs. Yield is based on 0.2 percent offset both in tension and compression. (This corresponds to lower or plateau yield for discontinuous materials.) In addition, the compression specimens are loaded in a Baldwin subpress and use a modified Montgomery-Templin jig to prevent bending. Also compressometers and extensometers are used.

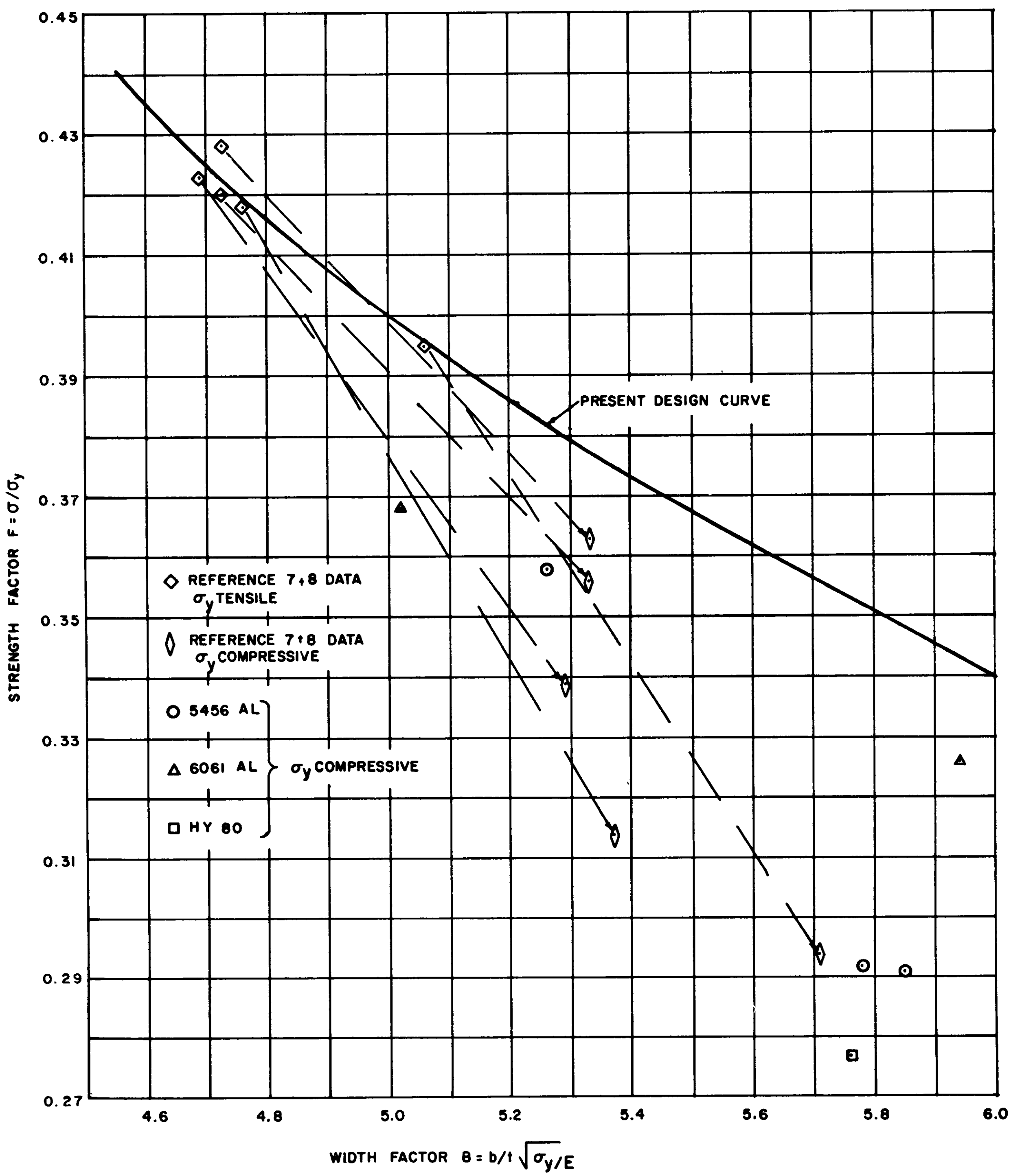


Figure 5 - Enlarged Portion of Curve of Plate Strength Factor versus Width Factor

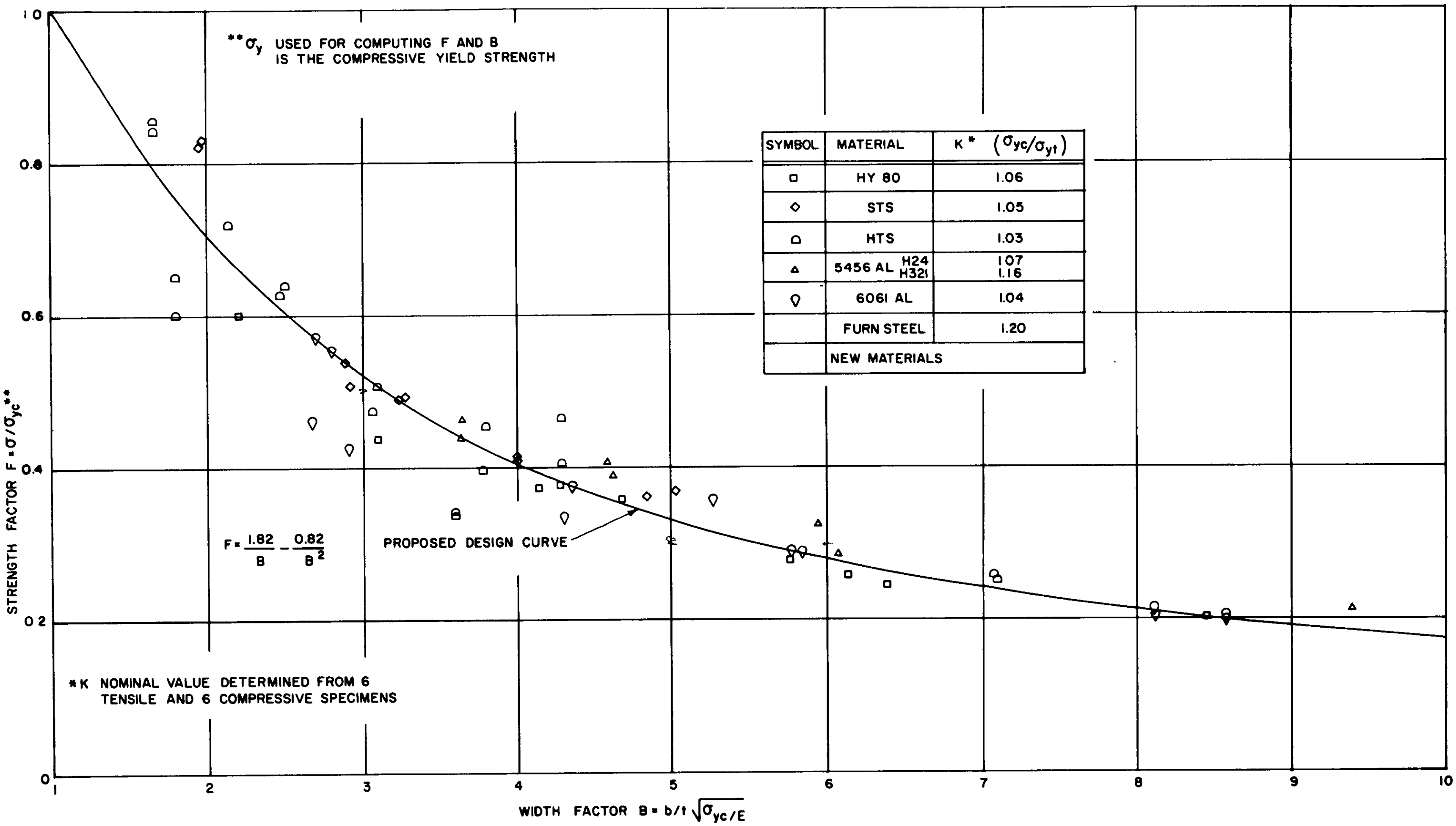


Figure 6 - Modified Curve of Plate Strength Factor versus Width Factor

the material. However, from a practical viewpoint, this is not the best form for the curve since a ship designer generally will have the tensile properties of his material. Therefore, Equation [4] is supplemented with a list of nominal K values for the materials tested; see Figure 6. Figure 6 may be used for additional materials if either σ_y compressive or $K\sigma_y$ tensile and E are known and the stress-strain curve of the material is similar to those of steel or aluminum. It is interesting to note how well all the published data fit Equation [4] when the compressive yield strength is used.

CONCLUSIONS AND RECOMMENDATIONS

1. It is concluded that simply supported panels will fail under loads that are as much as 15 percent less than those predicted by the present Bureau of Ships design curve.

2. It is recommended that Figure 6 of this report supersede Figure 3 of Reference 2 as the basis for plate design; that is, F becomes equal to $1.82/B - 0.82/B^2$. It must be remembered that the yield strength used here should be compressive σ_c or $K\sigma_t$, not the tensile σ_t.

3. It is recommended that K be determined in systematic studies for all materials of interest in ship design work.

REFERENCES

1. Bureau of Ships Design Data Sheet DDS 1100-3, "Strength of Structural Members" (7 Mar 1956).
2. Frankland, J. M., "The Strength of Ship Plating under Edge Compression," David Taylor Model Basin Report 469 (May 1940).
3. Bureau of Ships letter J1/2 (442) Ser 442-52 of 28 May 1959.
4. Duffy, D. J. and Allnutt, R. B., "Buckling and Ultimate Strengths of Plating Loaded in Edge Compression. Progress Report 1 - 6061-T6 Aluminum Plates," David Taylor Model Basin Report 1419 (Apr 1960).
5. Coan, J. M., "Large Deflection Theory for Plates with Small Initial Curvature Loaded in Edge Compression," Journal of Applied Mechanics, pp 143-151 (Jun 1951).
6. Timoshenko, S., "Theory of Plates and Shells," McGraw Hill, Inc. (1940) p.316.
7. Sweeney, R. J., "The Strength of Hull Plating under Compression. Progress Report 2," U. S. Experimental Model Basin (Oct 1933).
8. Sweeney, R. J., "The Strength of Hull Plating under Compression. Progress Report 1," U. S. Experimental Model Basin (Oct 1933).

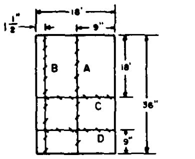
APPENDIX

THE EFFECTS OF WELDING ON ALUMINUM PANELS

Table 2 shows the effects of various weld locations on the strength of aluminum panels. The results are plotted against the new and the old design curves. Where current design practices are used, welding appears to weaken the plating by as much as 20 percent. However, if the recommended new design curve is used, F calculated and F observed for the nonwelded are much closer and thus the welding effects are better indicated. When this new curve is used, the welding effects are not adverse except in the case of the D weld for 6061-aluminum. The maximum strength reduction is only 5 percent. Grinding the welds weakens the C- and D-weld configurations slightly but does not generally affect the A and B welds. When two welds are used, the plate strength is similar to the strength of a plate with a single weld provided this one weld is the weaker of the two used in the combination.

TABLE 2

Physical and Strength Properties of Welded Plates Tested

PLATE NUMBER	TYPE OF ALUMINUM AND HEAT	WELDS AND PLATE SIZE 	MEASURED THICKNESS INCHES	MEASURED COMPRESSIVE YIELD STRENGTH KSI	B $\left[\frac{b}{t}\sqrt{\frac{\sigma_y}{E}}\right]$ E = 10060 KSI	OBSERVED ULTIMATE LOAD KIPS	ULTIMATE STRESS σ_o OBSERVED	ULTIMATE STRESS σ_1 $\left[\sigma_y\left(\frac{1.82}{B}-\frac{0.82}{B^2}\right)\right]$	ULTIMATE STRESS σ_2 $\left[\sigma_y\left(\frac{2.25}{B}-\frac{1.25}{B^2}\right)\right]$	F_o $\left[\sigma_o/\sigma_y\right]$	F_1 $\left[\sigma_1/\sigma_y\right]$	F_2 $\left[\sigma_2/\sigma_y\right]$	α_1 $\left[F_o/F_1\right]$	α_2 $\left[F_o/F_2\right]$
B3	5456 - H24	A	0.196	39.2	5.73	42.0	11.9	11.5	13.9	0.304	0.293	0.355	1.04	.86
C5	5456 - H24	A	.255	35.9	4.22	65.4	14.2	13.8	16.6	.397	.385	.463	1.03	.86
C13	5456 - H24	A	.255	36.0	4.22	68.0	14.8	13.9	16.7	.411	.385	.463	1.07	.89
101	5456 - H321	A	.192	31.4	5.24	40.0	11.6	10.0	12.1	.369	.317	.384	1.16	.96
304	5456 - H321	A	.253	36.2	4.27	--	--	--	--	--	--	--	--	--
312	5456 - H321	A	.253	34.9	4.19	69.4	15.2	13.5	16.3	.437	.387	.466	1.13	.94
A1	6061 - T6	A	.185	39.4	6.09	45.2	13.6	10.9	13.2	.345	.277	.336	1.25	1.03
A2	6061 - T6	A	.186	40.2	6.05	45.1	13.5	11.2	13.6	.335	.279	.338	1.20	.99
B4	5456 - H24	B	.196	39.2	5.73	39.2	11.1	11.5	13.9	.283	.293	0.355	0.97	.80
C6	5456 - H24	B	.254	35.0	4.18	63.9	14.0	13.6	16.3	.399	.388	.466	1.03	.86
C14	5456 - H24	B	.256	36.2	4.22	66.0	14.3	13.9	16.8	.396	.385	.463	1.03	.86
D2	5456 - H321	B	.190	33.7	5.48	37.0	10.6	10.3	12.4	.321	.305	.369	1.05	.87
102	5456 - H321	B	.192	31.4	5.24	36.5	12.8	10.0	12.0	.337	.317	.383	1.06	.88
305	5456 - H321	B	.255	34.8	4.15	69.2	15.1	13.6	16.3	.434	.391	.469	1.11	.93
313	5456 - H321	B	.252	34.0	4.15	68.4	15.1	13.3	15.9	.443	.391	.469	1.13	.94
B1	6061 - T6	B	.189	39.8	5.98	41.1	12.1	11.2	13.5	.304	.281	.341	1.08	.89
B2	6061 - T6	B	.188	39.8	6.02	42.6	12.6	11.1	13.5	.317	.279	.340	1.14	.93
B5	5456 - H24	C	.197	39.2	5.71	42.4	12.0	11.5	14.0	.305	.294	0.356	1.04	.86
C7	5456 - H24	C	.255	36.2	4.24	65.6	14.3	13.9	16.7	.394	.383	.461	1.03	.85
C15	5456 - H24	C	.255	35.1	4.17	69.5	15.1	13.7	16.4	.431	.389	.467	1.11	.92
103	5456 - H321	C	.191	31.4	5.26	44.0	12.8	9.9	12.0	.408	.316	.383	1.29	1.07
306	5456 - H321	C	.253	35.6	4.23	67.2	14.8	13.7	16.4	.414	.384	.462	1.08	.90
314	5456 - H321	C	.252	35.0	4.21	68.8	15.2	13.5	16.2	.434	.386	.463	1.12	.94
C1	6061 - T6	C	.188	39.9	6.01	40.0	11.8	11.2	13.5	.296	.280	.339	1.06	.87
C2	6061 - T6	C	.189	39.7	5.97	37.5	11.1	11.2	13.6	.280	.282	.342	0.99	.82
B6	5456 - H24	D	.195	39.2	5.76	40.0	11.4	11.4	13.7	.291	.291	0.353	1.00	.82
C8	5456 - H24	D	.254	35.5	4.21	63.6	13.9	13.7	16.4	.392	.386	.462	1.02	.85
C16	5456 - H24	D	.255	35.3	4.18	67.5	14.7	13.7	16.4	.417	.388	.466	1.07	.89
104	5456 - H321	D	.190	31.4	5.29	39.2	11.5	9.9	11.9	.365	.315	.380	1.16	.96
307	5456 - H321	D	.254	34.1	4.13	67.4	14.7	13.4	16.1	.432	.393	.472	1.10	.92
D1	6061 - T6	D	.186	39.3	6.04	34.8	10.4	11.0	13.3	.265	.279	.339	0.95	.78
D2	6061 - T6	D	.185	40.0	6.13	35.1	10.5	11.0	13.4	.263	.276	.334	0.95	.79
B7	5456 - H24	AC	.196	38.7	5.69	42.9	12.2	11.4	13.8	.315	.295	0.356	1.07	.88
C9	5456 - H24	AC	.256	34.5	4.12	69.0	15.0	13.6	16.3	.434	.394	.472	1.10	.92
C17	5456 - H24	AC	.253	34.8	4.18	67.5	14.8	13.5	16.2	.427	.388	.466	1.10	.92
105	5456 - H321	AC	.190	31.4	5.29	38.4	11.2	9.9	11.9	.358	.315	.380	1.14	.94
308	5456 - H321	AC	.260	35.5	4.11	71.2	15.2	14.0	16.8	.429	.395	.473	1.09	.91
316	5456 - H321	AC	.259	34.3	4.06	69.8	14.8	13.7	16.4	.431	.398	.478	1.08	.90
AC1	6061 - T6	AC	.187	40.7	6.12	39.0	11.5	11.2	13.6	.284	.275	.335	1.03	0.86
AC2	6061 - T6	AC	.186	40.6	6.15	39.9	11.9	11.1	13.5	.293	.274	.333	1.07	0.89
B8	5456 - H24	AD	.196	38.7	5.69	46.2	13.1	11.4	13.8	.339	.295	0.356	1.15	.95
C10	5456 - H24	AD	.255	34.8	4.15	67.8	14.8	13.6	16.3	.425	.391	.469	1.09	.91
C18	5456 - H24	AD	.254	35.8	4.24	73.0	16.0	13.7	16.5	.446	.383	.461	1.16	.97
106	5456 - H321	AD	.191	31.4	5.26	38.0	11.1	9.9	12.0	.352	.316	.383	1.11	.92
317	5456 - H321	AD	.259	35.7	4.14	74.3	15.9	14.0	16.8	.447	.392	.470	1.19	.95
AD1	6061 - T6	AD	.185	40.9	6.17	37.4	11.2	11.2	13.6	.274	.274	.332	1.00	0.81
AD2	6061 - T6	AD	.186	41.9	6.25	41.1	12.3	11.3	13.7	.293	.270	.328	1.08	0.87
B9	5456 - H24	BC	.195	38.7	5.69	40.0	11.3	11.4	13.8	.293	.295	.356	0.99	.82
C11	5456 - H24	BC	.256	33.8	4.08	67.5	14.6	13.4	16.1	.433	.387	.476	1.09	.91
107	5456 - H321	BC	.190	31.4	5.29	38.0	11.1	9.9	11.9	.354	.315	.380	1.12	.93
D7	5456 - H321	BC	.189	33.4	5.51	38.8	11.4	10.1	12.3	.339	.303	.367	1.12	.92
310	5456 - H321	BC	.259	34.8	4.09	73.2	15.7	13.8	16.5	.451	.396	.475	1.14	.95
318	5456 - H321	BC	.258	36.3	4.19	67.7	14.6	14.0	16.9	.401	.387	.466	1.04	.86
BC1	6061 - T6	BC	.187	40.6	6.07	35.3	10.4	11.3	13.7	.256	.278	.337	0.92	.76
BC2	6061 - T6	BC	.188	40.6	6.08	38.4	11.4	11.2	13.6	.280	.277	.336	1.01	.83
B10	5456 - H24	BD	.195	38.7	5.72	40.2	11.5	11.3	13.8	.296	.293	.356	1.01	.83
C12	5456 - H24	BD	.255	36.1	4.22	61.6	13.4	13.9	16.7	.372	.385	.463	0.97	.80
C20	5456 - H24	BD	.254	36.1	4.24	69.5	15.2	13.8	16.6	.422	.383	.461	1.10	.92
108	5456 - H321	BD	.191	32.3	5.34	36.0	10.5	10.1	12.2	.325	.312	.377	1.04	.86
311	5456 - H321	BD	.265	33.8	3.94	69.2	14.5	13.8	16.6	.429	.409	.490	1.05	.88
319	5456 - H321	BD	.259	37.7	4.25	67.6	14.5	14.4	17.3	.385	.383	.459	1.01	.84
BD1	6061 - T6	BD	.187	41.0	6.13	32.8	9.8	11.3	13.7	.239	.276	.334	0.87	.72
BD2	6061 - T6	BD	.187	41.0	6.13	34.6	10.3	11.3	13.7	.251	.276	.334	0.91	.75
AG1*	6061 - T6	A	.193	41.3	5.95	49.5	14.2	11.7	14.2	.343	.283	0.343	1.25	1.00
AG2	6061 - T6	A	.185	40.4	6.15	46.5	13.9	11.1	13.5	.344	.275	.333	1.25	1.03
BG1	6061 - T6	B	.185	41.8	6.27	43.0	12.9	11.2	13.7	.308	.269	.327	1.14	.94
BG2	6061 - T6	B	.185	41.9	6.27	41.4	12.4	11.3	13.7	.295	.269	.327	1.10	.90
CG1	6061 - T6	C	.187	41.6	6.16	39.9	11.8	11.4	13.8	.272	.273	.332	1.00	.82
CG2	6061 - T6	C	.187	43.8	6.32	37.1	11.0	11.7	14.2	.251	.267	.325	0.94	.77
DG1	6061 - T6	D	.188	42.1	6.19	36.7	10.9	11.5	13.9	.258	.273	.331	0.95	.78
DG2	6061 - T6	D	.187	43.0	6.27	33.6	9.9	11.6	14.1	.230	.269	.327	0.86	.70

* G Indicates welds ground smooth and flush with metal.

INITIAL DISTRIBUTION

Copies

9 CHBUSHIPS
- 1 Lab Mgt (Code 320)
- 3 Tech Lib (Code 210L)
- 1 Structural Mech Hull Matls & Fab (Code 341A)
- 1 Prelim Des Br (Code 420)
- 1 Hull Des (Code 440)
- 2 Scien & Res Sec (Code 442)

2 CHBUWEPS (RRRE)

2 CHONR, Struc Mech Br (Code 439)

2 CDR, USNOL

2 DIR, USNRL

2 NAVSHIPYD PTSMH

2 NAVSHIPYD MARE

2 NAVSHIPYD NYK, MATLAB

1 CDR, USNOTS, China Lake

1 DIR, USNEES

1 DIR, USNAES

1 SUPT, USNPGSCOL

1 CO, USNROTC & NAVADMINU, MIT

1 SUPSHIP, Groton

1 EB Div, Gen Dyn Corp

1 SUPSHIP, Pascagoula

1 Ingalls Shipbldg Corp

1 SUPSHIP, Newport News

1 NNSB & DD Co.

1 Army Ballistic Missile Agcy, Struc Mech Lab, Redstone Arsenal, Huntsville