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STRUCTURAL DESIGN OF A 2000-TON HYDROFOIL SMALL WATERPLANE AREA SHIP (HYSWAS)

by

Natale S.' Nappi and Frank M. Lev

ADVANCED SHIP DIVISION
STRUCTURES DEPARTMENT
TECHNICAL NOTE

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‘ABSTRACT

This note describes the procedure used to perform structural designs and weight studies for a 2000-ton Hydrofoil Small Waterplane Area Ship (HYSWAS). Parametric studies were performed to determine the sensitivity of structural weight fractions to primary bending loads and materials of construction. These ships were designed to resist both hullborne and foilborne wave induced bending moments. The secondary loads consisted of slamming pressures, external hydrostatic head, live loads and structural dead loads. The need for further studies was reported and suggestions for decreasing the structural weight fraction, such as relaxation of the effective width requirement, were discussed.

ADMINISTRATIVE INFORMATION

The work described herein was performed for the Advanced Concepts Office of the Systems Development Department. Funding was provided under the NSRDC in-house independent exploratory development program ZF6 14 12, Ellemcnt 62756N.

I. INTRODUCTION

The Navy, specifically the System Development Department (NSRDC), is currently investigating a Hydrofoil Small Waterplane Area Ship (HYSWAS) concept in the 2000-ton displacement range. Since very little prior knowledge exists in the area of reliable prediction of applied loads. precise design procedures, and typical scantlings, the Structures Department (173) was requested to develop adequate structural design methods and subsequent weight estimates for this ship.

It was decided to perform this work in three phases. Phase I is to provide estimation of structural weights for a 2000-ton HYSWAS; Phase II is to provide the necessary program (i.e.. the HYSWAS version of the Structural Synthesis Design Program[1]) to perform parametric variations of HYSWAS type ships: and Phase III is to provide weight equations by developing an automatic data generating program which will produce the required data needed by the HYSWAS version of SSDP. This note is a report of the Phase I portion of the HYSWAS program. As such it was concerned with the design procedures used to optimize the structural weight of this ship: estimate the structural weight fractions; and to perform structural weight parametric studies relating to primary loads, and material of construction. Due to limitations in time and funding no parametric studies were conducted for variation of the slamming pressures.

The structural design studies were conducted in two phases, one rfor each loading condition (i.e.; transverse bending moment and longitudinal bending moment). The minimum scantlings (plate and beams) determined by the transverse bending loads were used as the initial scantlings for the longitudinal bending loads. The final set of minimum scantlings. provided by these design studies, were used to calculate the "basic" structural weights (tons) and densities (lb/cu ft) for the upper hull. strut and lower hull structures. The "basic" structural weight consists of plating. beams. stanchions, etc. from groups 100 to 110. 114 and 152 of the Bureau of Ships Consolidated Index (BSCI) system. A preliminary design and weight estimate was also made for the Main and Aft foils.

Throughout the process (i.e., design, analysis, and weight study) U.S. Navy specified properties of the following materials were used:

- Steel- MS
  - HTS
  - HY 80
  - HY 100
- Alum–5456-H111

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[1] Nappi, N.S. and F.M. Lev, "Midship Section Design for Naval Ships," NSRDC Report 3815 (1972).

These studies show that use of conventional plate and stiiffener construction techniques result in HYSWAS concepts which have reasonable structural weight fractions and hence potentially acceptable useful payload plus fuel characteristics,.

II. DESIGN PROCEDURE

A. PRINCIPAL DESIGN TOOL

The principal design tool used to design the structure of HYSWAS for both the transverse and longitudinal bending loads was the SWATH[2] version of the Structural Synthesis Dcsiyn Program (SSDP).[1] The scantlings resulting from this program are structurally adequate and comply with the cuncnt U.S. Navy design criteria for ship design. For a more thorough description of the design tool and its design options, see Reference 2.

B. STRUCTURAL ARRANGEMENTS

Sturctural design and weight parametric studies were accomplished for the HYSWAS configuration illustrated in Figure 1. The principal dimensions of this ship are presented in Figure 2.

For design purposes the HYSWAS was divided into eight cross sections; five longitudinal sections for the transverse bending loads and three transverse sections for the longitudinal bending loads. These sections are defined as follows:

- Longitudinal Sections
  - Hull Section, Wing Section } Upper Hull Structure
  - Platform Section, Knee Section, Pin Section } Strut Structure
- Transverse Sections
  - 1/6 L Section, 1/2 L Section, 3/4 L Section } See Figure 1

For the longitudinal sections, the transverse bulkhead plating and the deck and shell plating were assumed to act as webs and flanges, respectively, of a box girder.

For the transverse sections. the longitudinal bulkhead plating and the deck and shell plating were assumed to act as members of a box girder as they do for a monohull ship. These girders

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[2]Lev, F.M., et al., "Structural Weight Determination for SWATH Ships," NSRDC Report 4355 (1975).

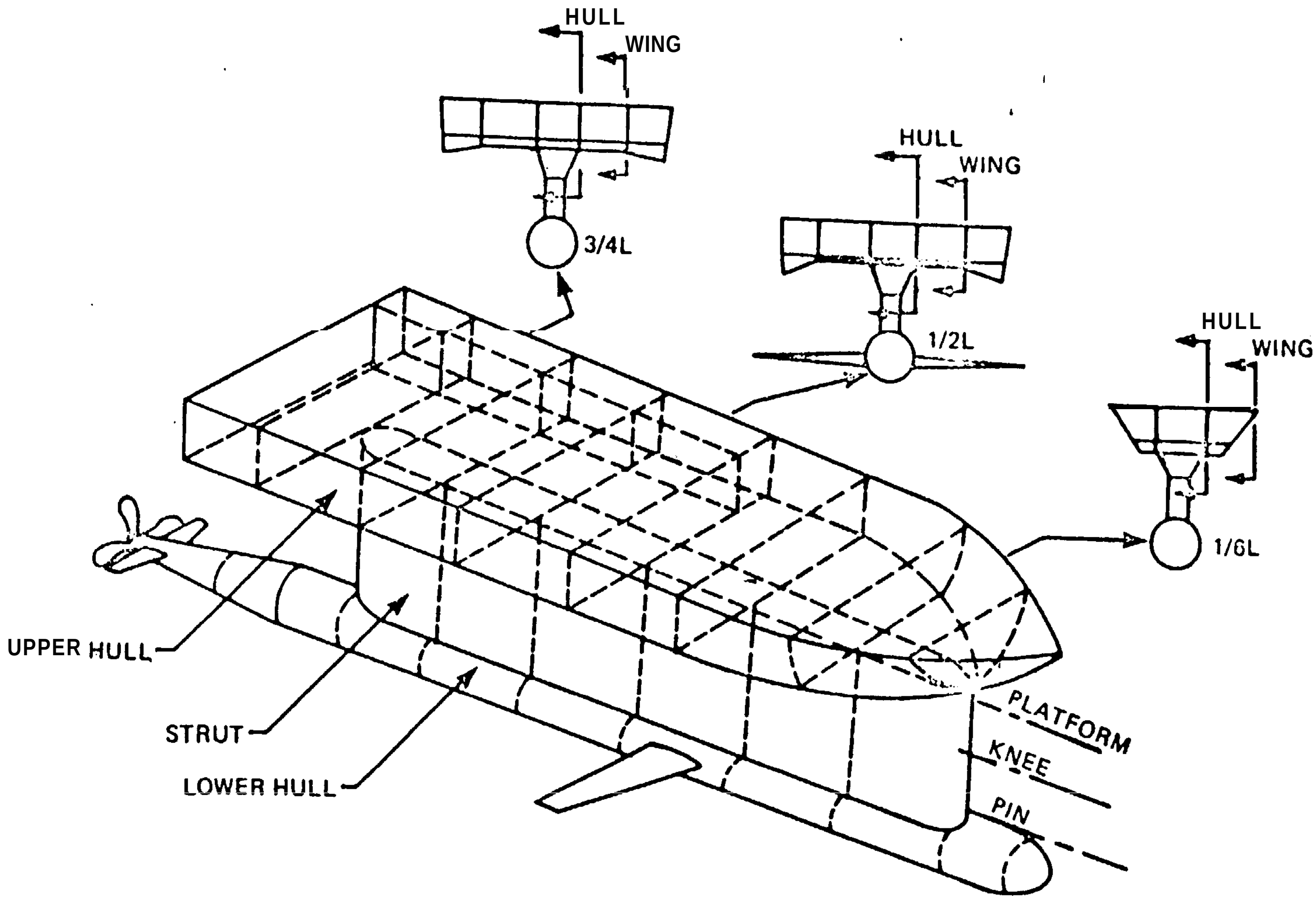
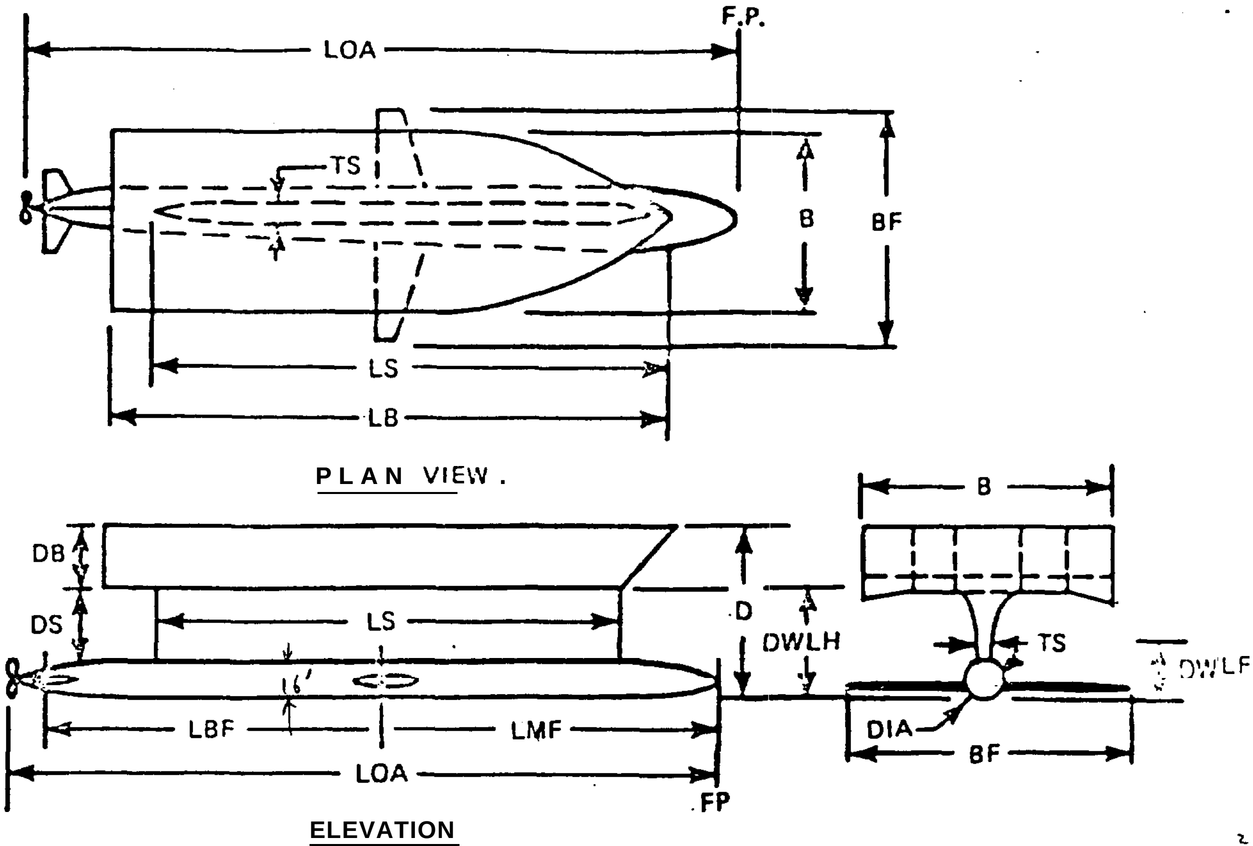


Figure 1 – Structural Arrangement of HYSWAS



Foil Area 22.05 × 87 = 1918.35 ft²

1170
312
1632
368

Parameters	HYSWAS
Nominal Displacement A (tons)	2000.0
Length Overall (LOA)	260.0
Length of Upper Hull (LB)	230.0
Length of Strut (LS)	190.0
Breadth of Upper Hull (B)	75.0
Breadth of Main Foil (BF)	87.0
Depth of Upper Hull (DB)	15.0
Depth of Strut (DS)	21.0
Thickness of Strut (TS)	7.2
Diameter of Lower Hull (DIA)	16.0
Depth of Ship (D)	52.0
Design Waterline Hullborne (DWLH)	37.3
Design Waterline Foilborne (DWLF)	24.0
Distance of Main Foil from FP (LMF)	105.0
Length between Foils (LBF)	135.0

Figure 2 – Principal Dimensions of HYSWAS
(Dimensions in feet)

were designed to resist primary bending moments, secondary slamming loads, hydrostatic loads. live loads and vertical shear loads.

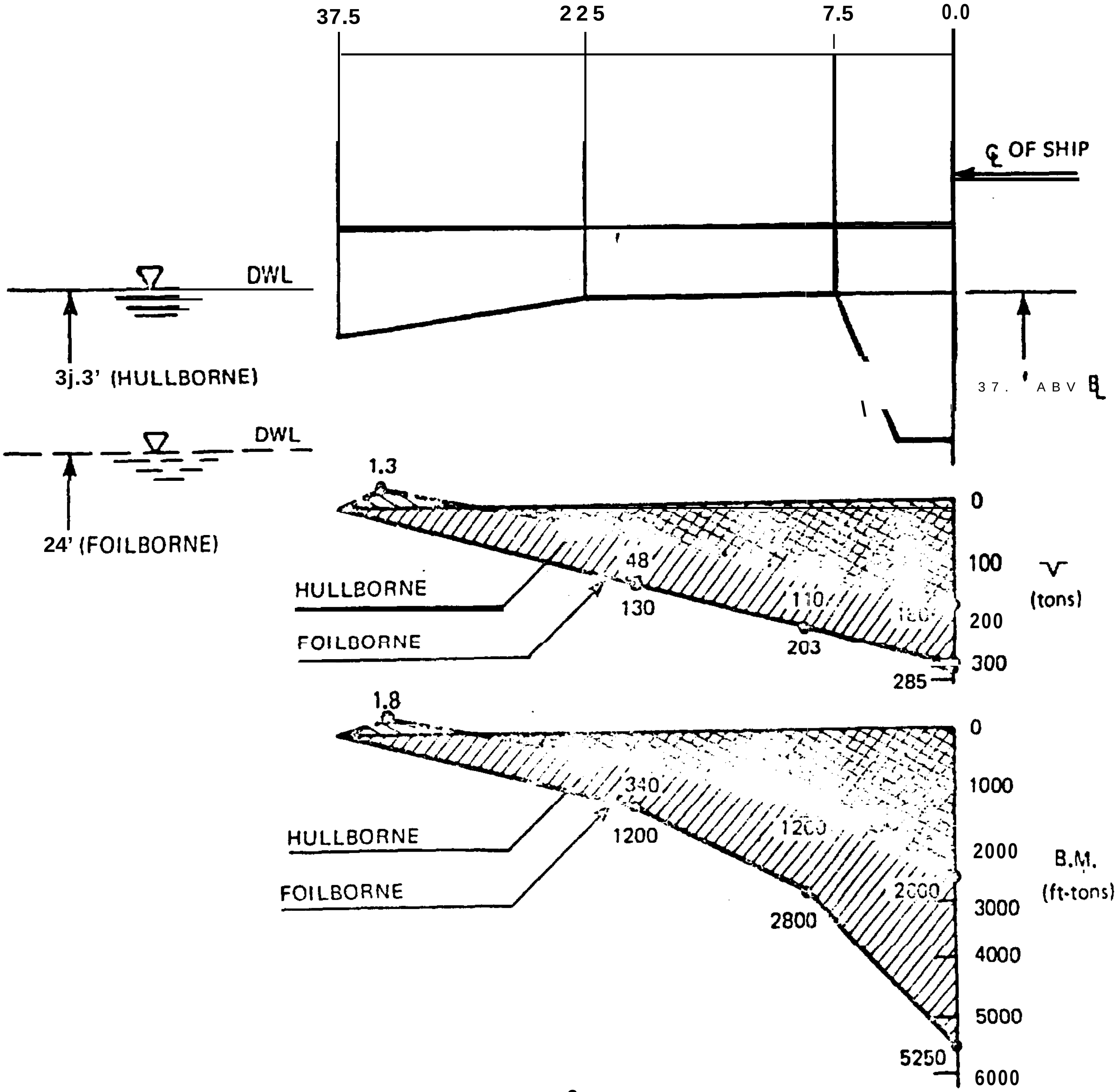
C. DESIGN LOADS

1. Primary Loads

The primary loads used in the design of the five longitudinal sections (i.e.. hull, wing, platform, knee and pin) are given below.

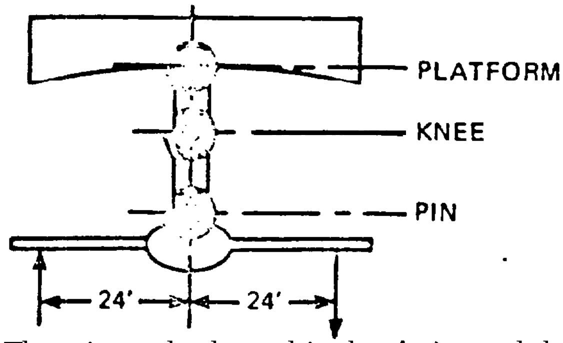
(a) Upper Hull Structure

For the upper hull structure there are two loading conditions. hullborne and foil-borne. For both conditions the shear and bending moments are shown below.



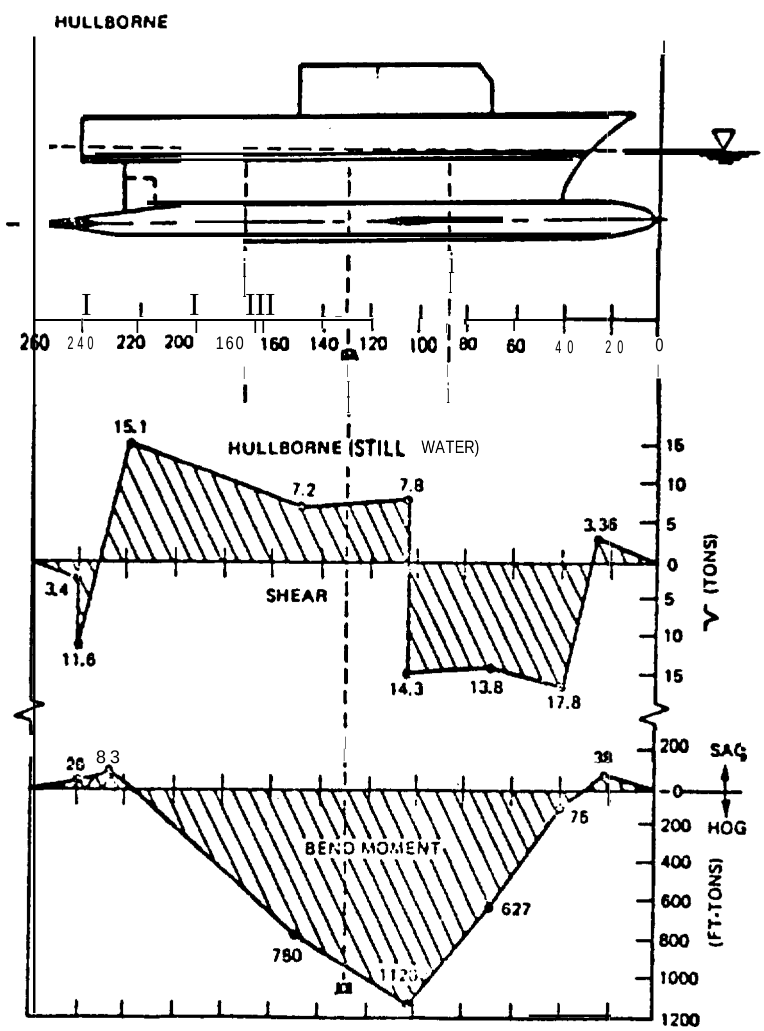
(b) Strut Structure

For the strut structure the maximum transverse bending moment occurs when the foils are differentially activated to compensate for the rolling of the ship. The maximum design bending moment applied at the platform, knee, and pin sections was 17.500 ft-tons.* A table of righting moments for various foil pressure is given below.



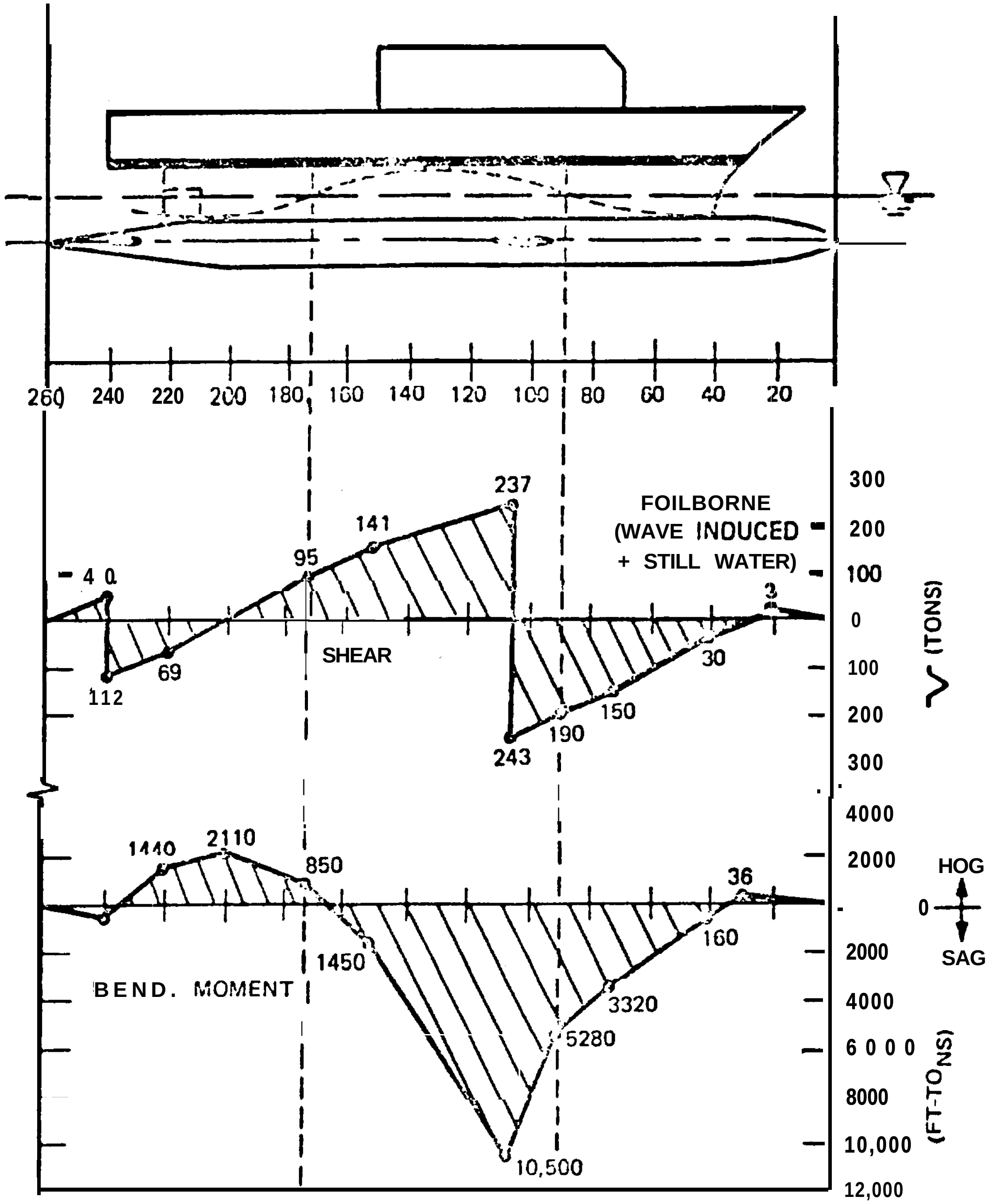
Foil Pressure (psf)	Righting Moment (ft-tons)
420	3,000
600	6,500
900	12,000
1,200	17,500

The primary loads used in the design and the three transverse sections (i.e., 1/6 L, 1/2 L and 3/4 L) for both the hullborne and foilbome conditions are shown below.



*This load was obtained from the System Development Department, Code 117.

(b) FOILBORNE


260
240
220
200
180
160
140
120
100
80
60
40
20
FOILBORNE
(WAVE INDUCED
+ STILL WATER)
40
237
141
95
112
69
SHEAR
243
190
150
30
3
300
200
100
0
100
200
300
V (TONS)
1440
2110
850
1450
BEND. MOMENT
10,500
5280
3320
160
36
4000
2000
2000
4000
6000
8000
10,000
12,000
HOG
0
SAG
(FT-TONS)

2. Secondary Loads

The secondary loads used in the design of the HYSWAS structural members are given in Table 1.

TABLE 1 – SUMMARY OF SECONDARY LOADS

Structure	Secondary Loads: Live Load (psf)	Secondary Loads: Hydrostatic Head (ft)	PSI
Main Deck	—	4	1.8
Second Deck	200	3	1.3
Third Deck	150	7	3.1
First Platform	150		
Second Platform	150	29	12.9
Transverse Bulkheads		44*	19.6
Strut and Lower Hull			
@ 1/6 L	1000	52	23.1
@ 1/2 L	1000	50	22.2
@ 3/4 L	1000	42	18.7
External Shell (Abv. W.L.) (Slamming) @ 1/6 L	30 psi		
@ 1/2 L	10 psi		
@ 3/4 L	10 psi		

*To the Damage Control Level (DCL)

3. Loading Combinations for Structural Segments

Each structural segment (i.e.. shell, deck, bulkhead) is designed to have adequate strength to withstand the combination of loadings shown in Table 2. For the shell. deck, platforms. bulkheads, and innerbottom segments see Reference 2 for a more detailed description of these combinations of loadings.

TABLE 2 – STRUCTURAL SEGMENT LOADINGS

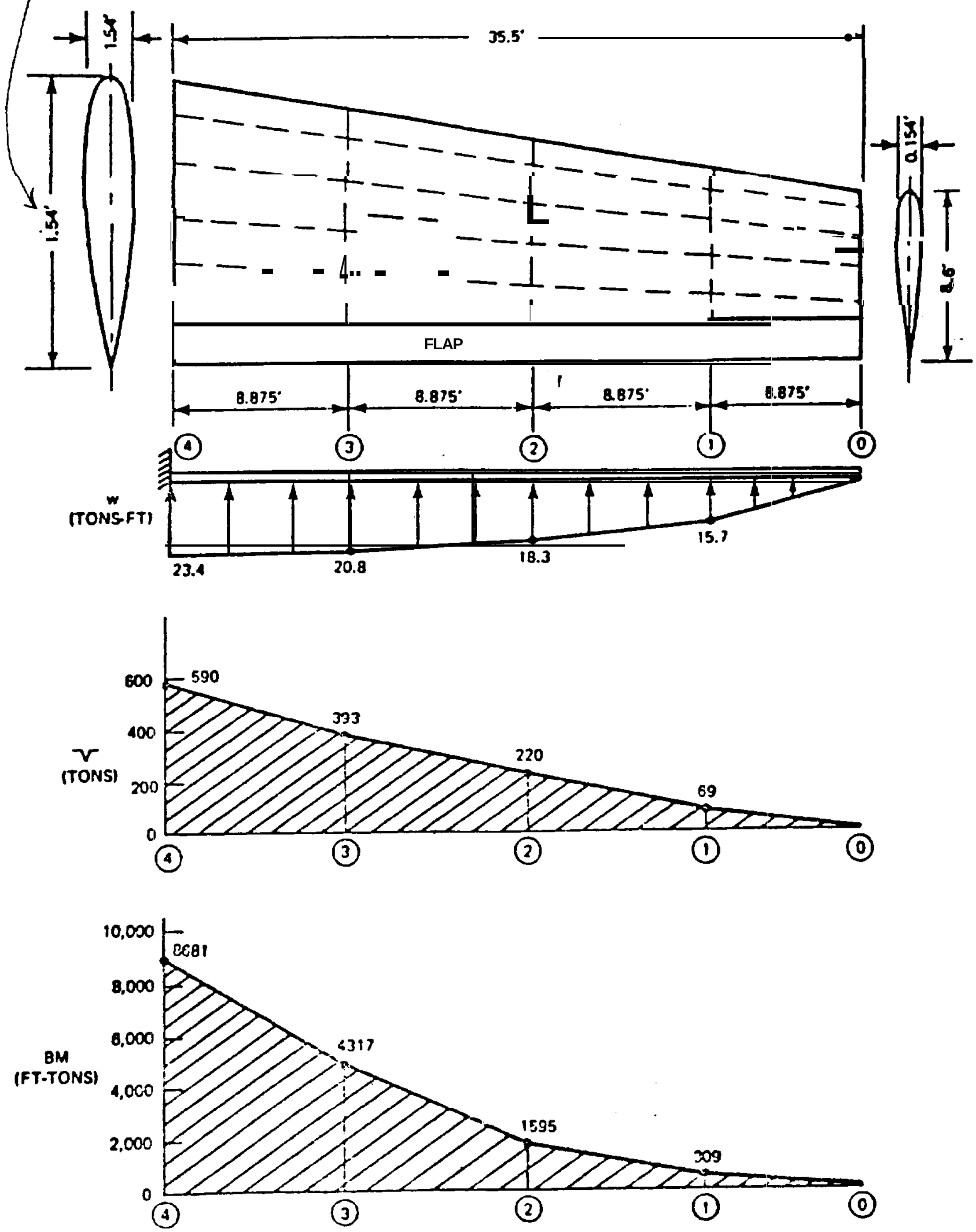
Structural Segments of	Loadings Combined: Primary Stresses	Live Load	Dead Load	Tank Top Head	Tank Overflow	Vital or Normal Damage Head	External Hydrostatic Head	Slamming Load
Shell	X						X	
	X		X	X				
			X		X			
	X							X
Decks	X	X	X					
	X		X	X				
			X		X			
			X			X		
Bulkheads	X		X					
	X		X	X				
			X		X			
			X			X		

4. Foil Loads

Two foil systems are required to provide the necessary lift for the foilborne conditions; a main foil located at Frame 105, and an aft foil located at Frame 240.

For design purposes. the main foil was assumed to have a NACA 0010 configuration, with a semi-span of 35.5 feet, a root chord of 15.4 feet, a tip chord of 8.6 feet and an extreme lift load of 590 tons resulting from the righting moment loading condition.

The load pressure distribution, and the resulting primary shear and bending loads are given below.



III. PARAMETRIC STUDIES

In order to determine the effects on structural weight, parametric weight studies were conducted for the following variations:

- Primary Bending Loads
- Materials of Construction

A. VARIATION OF PRIMARY BENDING LOADS

For this study. the "control" ship had the following characteristics: hybrid combination of material with an all steel (HTS) strut and lower hull structure and an aluminum (5456) upper hull structure; principal dimensions as shown in Figure 2; transverse frame spacing of 9.5 feet and longitudinal spacing of 16 inches; secondary loads as given in Table 1; and primary bending loads as given in section II.C. 1 of this report.

The "control" ship had a maximum longitudinal bending moment of approximately 12.000 ft-tons. This moment and all other bending moments (i.e., longitudinal and transverse) were first increased by 50 percent, then increased by 100 percent due to whipping from wave-induced loads, and finally decreased to zero.

The results of this study are presented in Table 3 and in Figure 3.

Using the control ship as the basis for comparison for the four designs; then we have a total weight increase of 4.32 percent (i.e., from 417 tons to 435 tons) for the ship with a 50 percent increase in maximum bending moments; a total weight increase of 7.43 percent (i.e.. from 417 tons to 448 tons) for the ship with a 100 percent increase in maximum bending moments; and a total weight decrease of 7.91 percent (i.e., from 417 tons to 384 tons) for the ship without longitudinal bending moments.

The structural weight fractions for the previous designs were computed and the results plotted in Figure 4. For this study and in this displacement range. the structural weight fraction was only moderately sensitive to the large changes in maximum bending moments. See section IV.2 for recommendations of addition studies.

TABLE 3 – SUMMARY OF "BASIC" WEIGHTS AND DENSITIES VERSUS MAXIMUM LONGITUDINAL AND TRANSVERSE BENDING MOMENT

Description of Study	Upper Hull		Strut		Lower Hull		Total	
	Weight (tons)	lb/ft^3	Weight (tons)	lb/ft^3	Weight (tons)	lb/ft^3	Weight (tons)	lb/ft^3
Control Ship (1.0xB.M.)	183	1.37	94	6.88	140	7.51	417	3.20
(1.5 x B.M.)	186	1.90	100	7.33	149	7.99	435	3.34
(2.0 x B.M.)	187	1.90	105	7.33	156	8.78	448	3.44
(0.0 x B.M.)	179	1.83	80	5.88	125	6.70	384	2.95

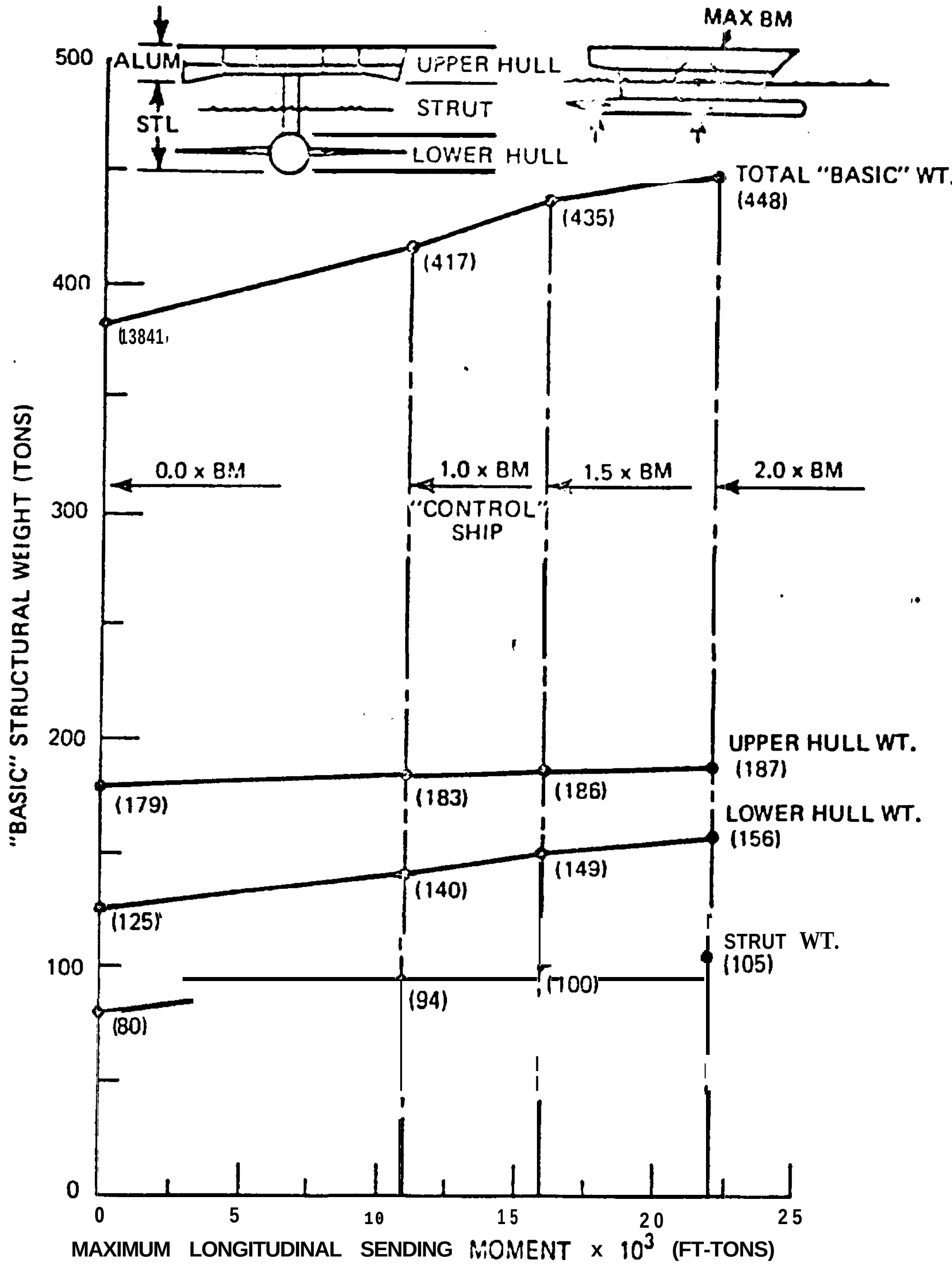


Figure 3 – "Basic" Structural Weight versus Maximum Longitudinal Bending Moments

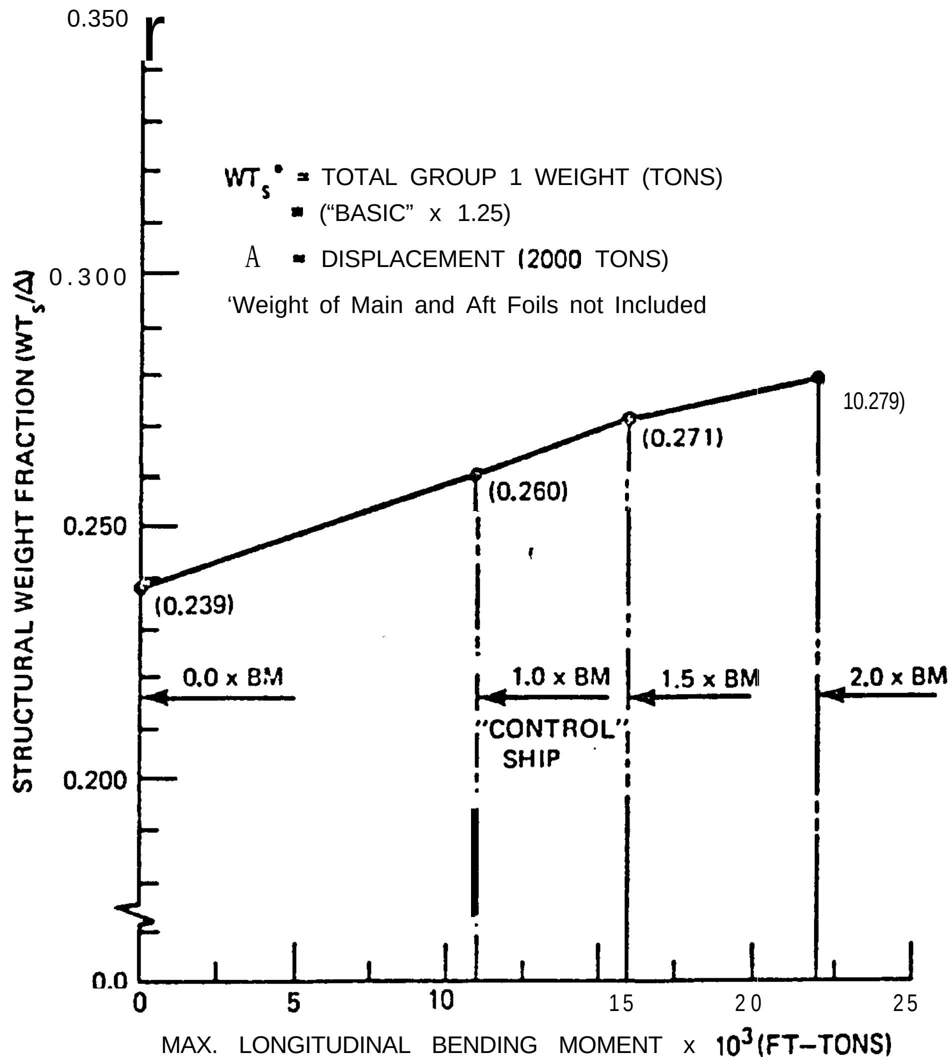


Figure 4 – Structural Weight Fraction versus Maximum Longitudinal Bending Moments

B. VARIATION OF MATERIAL OF CONSTRUCTION

Considerable reduction of structural weights is possible through the use of aluminum alloy for the primary construction material of the HYSWAS. Therefore, it was decided to perform a parametric study in order to assess the effects of material of construction on structural weights. The materials of construction used in this study were as follows:

1. All aluminum (5456)
2. HYBRID (Alum/STL-HTS) ("Control" Ship)
3. All steel (HTS)
4. All steel (HY-80)
5. All steel (HY-100)
6. All steel (MS)

The structural arrangements, frame spacing, loads and dimensions are the same as those used for the design of the "control" ship in the previous study.

The results of this study are presented in Table 4 and Figure 5. Using the "control" ship (i.e., Hybrid combination of construction material) as the basis of comparison, then we have a total weight reduction of 26.6 percent (i.e., from 417 tons to 306 tons) for the all aluminum ship; a total weight increase of 37.9 percent (i.e., from 417 tons to 575 tons) for the all steel (HTS) ship; a total weight increase of 39. I percent (i.e., from 417 tons to 580 tons) for the all steel (HY-80) ship: a total weight increase of 42.9 percent (i.e., from 417 tons to 596 tons) for the all steel (HY-100) ship; and a total weight increase of 43.4 percent (i.e., from 417 tons to 598 tons) for the all steel (MS) ship.

The structural weight fractions for these designs were computed and the results plotted in Figure 6. As can be seen. the structural weight fraction is very sensitive to changes in material of construction, especially from an all aluminum to an all steel ship and! from a hybrid combination to an all steel ship. However, the structural weight fraction is least sensitive to changes between steels (i.e., HTS, HY-80, HY-100 and MS). See section IV.3 for a further explanation of this phenomena.

TABLE 4 – "BASIC" WEIGHTS AND DENSITIES VERSUS MATERIAL OF CONSTRUCTION

Material of Construction	Upper Hull		Strut		Lower Hull		Total	
	Weight (tons)	lb/ft^3	Weight (tons)	lb/ft^3	Weight (tons)	lb/ft^3	Weight (tons)	lb/ft^3
Aluminum (5456)	184	1.88	47	3.49	75	4.02	308	235
Hybrid ("Control" Ship)	183	1.87	94	6.88	140	7.5 1	417	3.20
Steel (HTS)	340	3.47	94	6.91	141	7.54	575	4.41
Steel (HY 80)	345	3.53	95	7.01	140	7.5 1	580	4.46
Steel (HY 100)	356	3.64	96	7.05	144	7.69	596	4.58
Steel (MS)	352	3.59	97	7.14	149	7.99	598	4.59

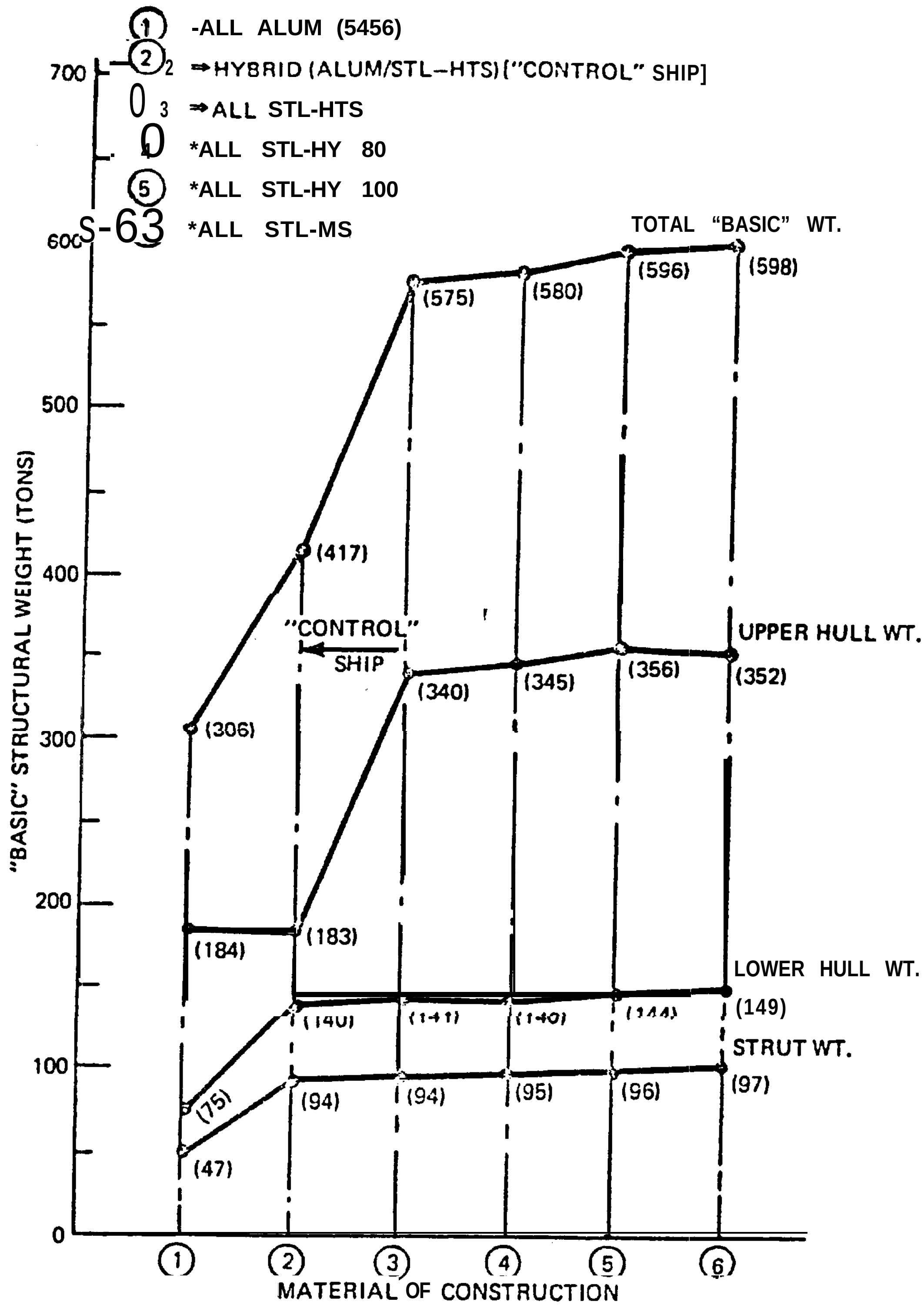


Figure 5 – "Basic" Structural Weight versus Material of Construction

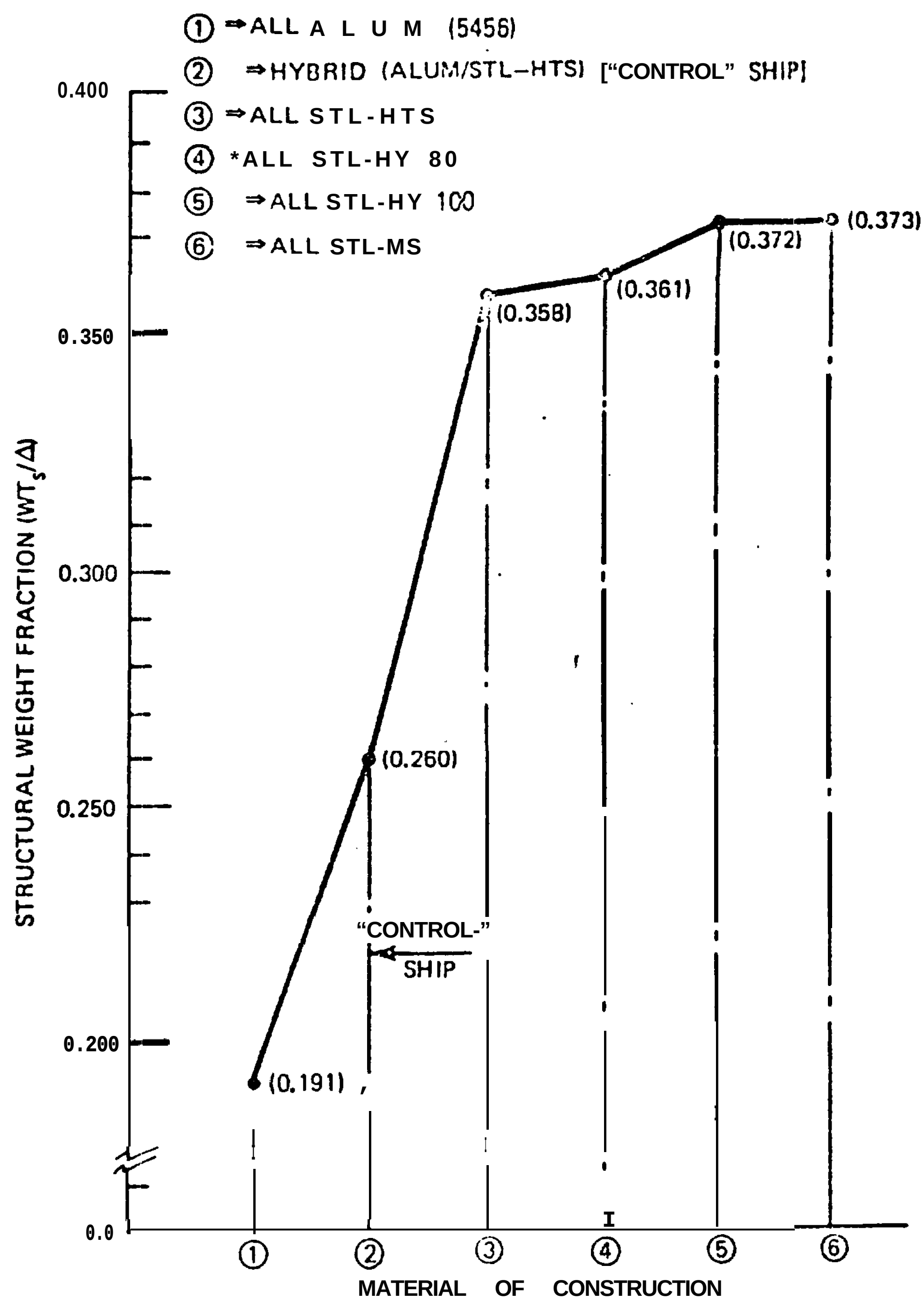
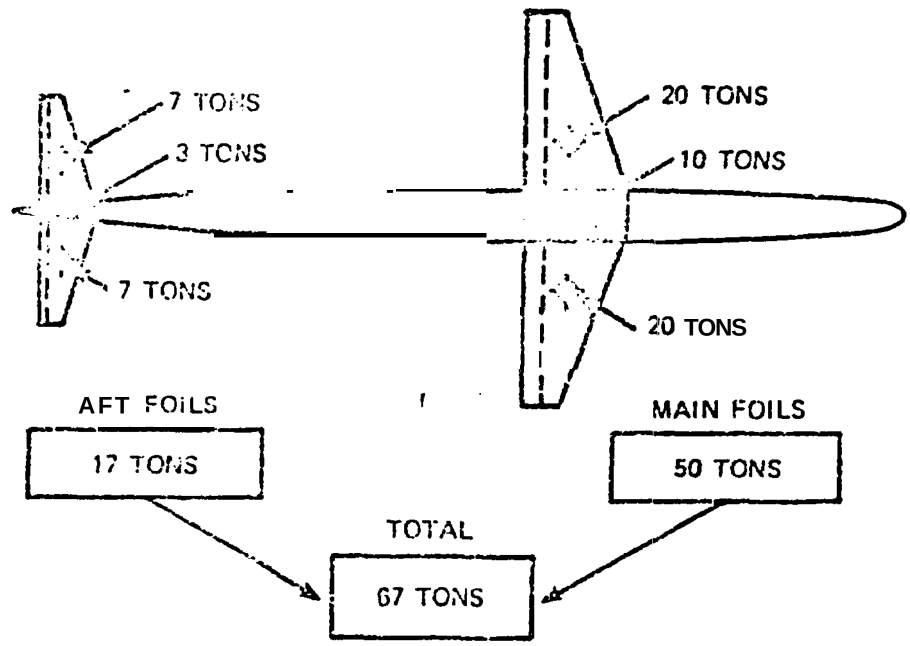


Figure 6 – Structural Weight Fraction versus Material of Construction

C. FOIL DESIGN AND WEIGHT ESTIMATES

The foil was assumed to act as a closed-box beam whose material is HY-100 throughout. For design purposes the main foil was divided into four sections and subjected to the loads as given in section II.C.4 of this note. The SWATH[1] version of SSDP was used as the main design tool for the determination of scantlings. Since this design was only an approximate attempt at estimating the weight of the foils no torsional analysis was performed. The resulting weights of these foils and back up structure are given below:



IV. DISCUSSION AND RECOMMENDATIONS

1. The Structural Synthesis Design Program (SSDP) has been successfully used to predict the weights of a HYSWAS. However, the weight estimating procedure was performed manually, thereby requiring considerable time. Hence, only two parametric variations were permitted (i.e., Bending Moments and Materials of Construction). Therefore, it is strongly recommended that Phase 11 (automatic weight calculation) be initiated in FY 76 and that Phase III (weight equations) be given consideration for implementation in FY 7'7 or late FY 76.

2. The governing factor in the structural design of the 2000-ton HYSWAS was the normal plating pressure. This is evident from Figure 4 where large variations in the primary bending moments produced very little change in the structural weight fractions. However, for larger ships the bending moments and shears may become the dominant factors whereby the structural weight fractions will be more sensitive to these loads. Further studies are required in the larger displacement range.

3. Figure 6 indicates that the structural weight fractions. for the 2000-ton HYSWAS, are very sensitive to the type of construction material. For example, the weight fraction for an all aluminum (5456) ship was 0.191 as compared to 0.358 for an all steel (HTS) ship. However.. the structural weight fractions, for the different steels (i.e., HTS, HY-80. HY-100, MS) changed very little. This could be attributed to that fact that for the higher strength steels the maximum effective width of plating, based on the Navy standard formulation of (2 $\sqrt{E/\sigma_y}$) t, is narrower, resulting in smaller flange area. Therefore, a larger tee beam is required for the plate-beam combination to resist the design secondary loads. Also the shape properties of the tee beams, as rolled, are based on the requirements of mild steel, making these tee beams incompatible with HY-80 and HY-100 plating. It is recommended that weight studies be conducted with the constraint of effective width released so that the use of higher strength steels would produce a somewhat lighter structure. It is further suggested that tee beams, for use in the higher strength steels. be developed or built-up to take advantage of the higher yield strength properties.

V. CONCLUSIONS

1. It has been demonstrated that the Structural Synthesis Design Program can be used to design a HYSWAS ship and manually compute the structural weight.

2. Rapid structural weight investigation and trends are not possible unless Phase II (automatic weight calculation) of the HYSWAS program is initiated.

3. Further studies are required, in the larger displacement range, to assess what loading factors are driving the structural weights.

4. Additional studies. using the higher strength steels, should be conducted so as to . evaluate the relaxation of effective width requirement on the weight of the ship.

5. In designing the HYSWAS ship, it may be worthwhile to examine the use of built-up tee beams for the higher strength steels.

ACKNOWLEDGMENT

The authors wish to acknowledge Messrs. Walz and Furio for their assistance in using the computer program that supplied the results used in this note.