AD-A051 682 DAVID W TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT CE--ETC F/G 13/10
SMALL WATERPLANE AREA TWIN HULL (SWATH) SHIP STRUCTURAL WEIGHT --ETC(U)
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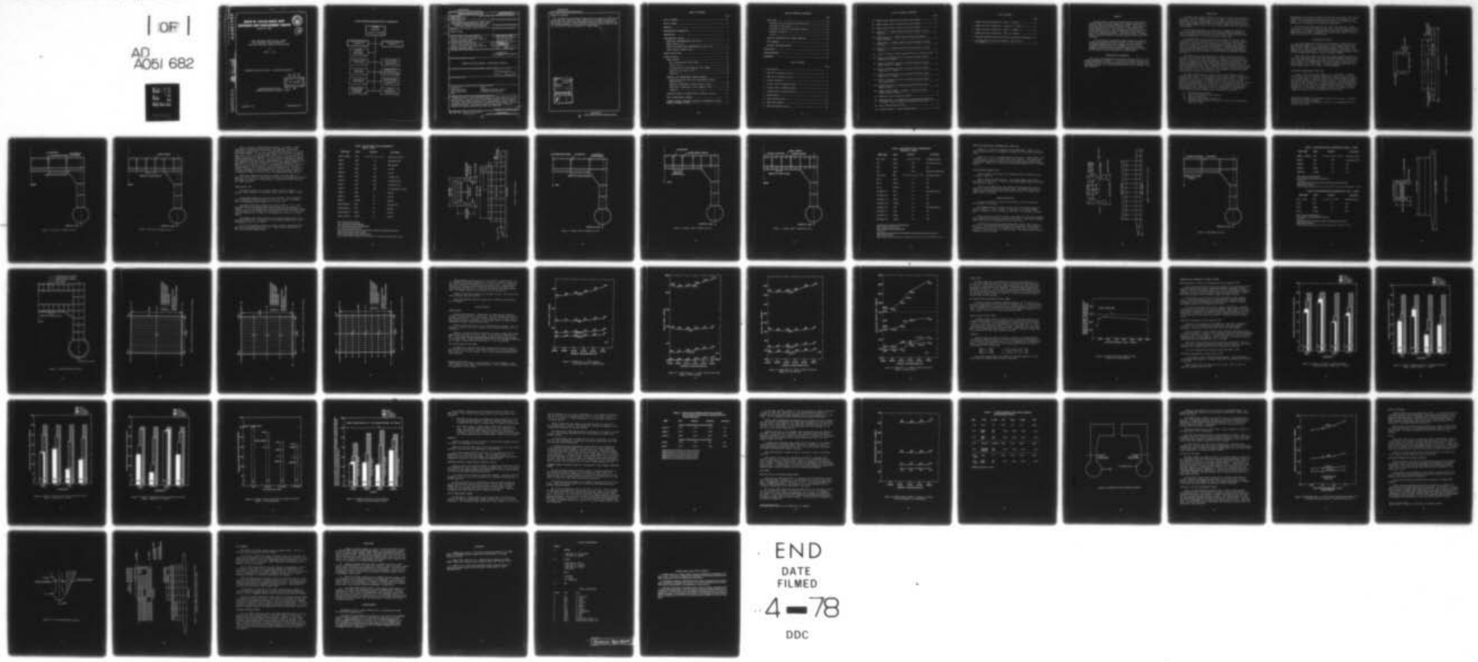

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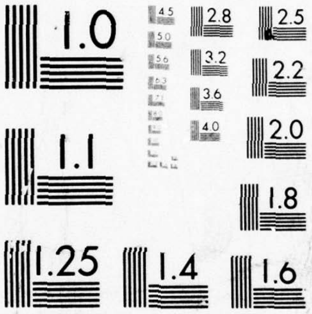

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SMALL WATERPLANE AREA TWIN HULL (SWATH) SHIP STRUCTURAL WEIGHT PARAMETRICS USING THE STRUCTURAL SYNTHESIS DESIGN PROGRAM

by

James H. King

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ADVANCED CONCEPTS OFFICE
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September, 1977

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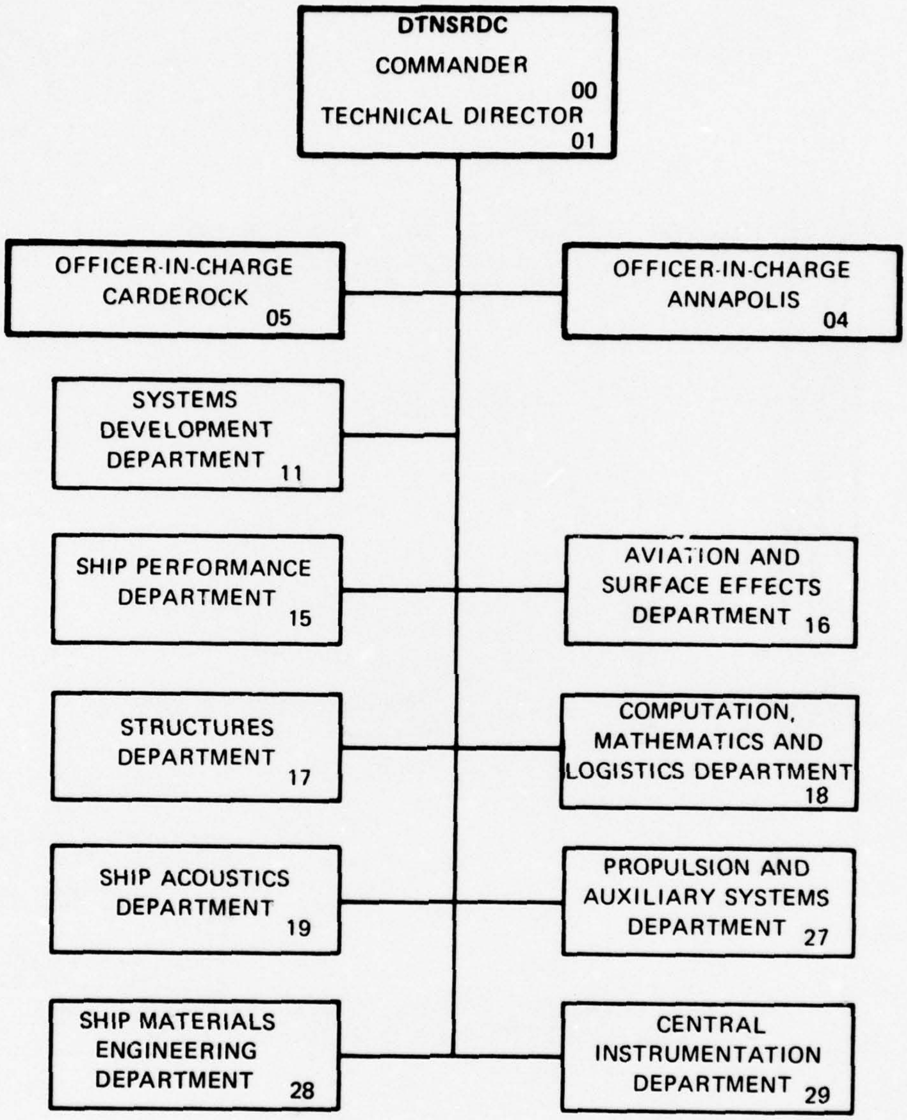

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
⑭ DTNSRDC/SDD-78/1

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
⑥ SMALL WATERPLANE AREA TWIN HULL (SWATH) SHIP STRUCTURAL WEIGHT PARAMETRICS USING THE STRUCTURAL SYNTHESIS DESIGN PROGRAM

5. TYPE OF REPORT & PERIOD COVERED

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
⑩ James H. King

8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS
David W. Taylor Naval Ship R&D Center
Systems Development Department, Code 1170
Bethesda, Maryland 20084

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
Program Element 62543N
Work Unit 1170-098
Task Area SF43 411-211

11. CONTROLLING OFFICE NAME AND ADDRESS
David W. Taylor Naval Ship R&D Center
Systems Development Department, Code 1170
Bethesda, Maryland 20084

12. REPORT DATE
⑪ Sep[redacted]77

13. NUMBER OF PAGES
61 ⑫ 59p.

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

15. SECURITY CLASS. (of this report)
UNCLASSIFIED

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)
⑯ F43411
⑰ SF43411211

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

SWATH Ships	HY100
Structural Weight	Intermediate Lateral Supports
High Tensile Steel	Transverse Frame Spacing
HY80	

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

Several means for reducing SWATH primary structural weight were studied parametrically. This was to aid in broadening the structural data base for the NAVSEC SWATH Design Synthesis Model. The parameters studied included: transverse frame spacing, materials, intermediate lateral support, and use of longitudinal girders. Associated studies of bending moment, effective breadth, and special plating effects were also conducted. → over

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It was found that accumulated weight savings can amount to 10-20% of the primary structure relative to that calculated by the SWATH Synthesis Model, that primary structural weight-estimating techniques should be dependent on the structural geometry, and that detailed structural studies should be made on a case basis as early as possible in a SWATH design.

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ABSTRACT

Several means for reducing Small Waterplane Area Twin Hull (SWATH) primary structural weight were studied parametrically using the Structural Synthesis Design Program. This was to aid in broadening the structural data base for the NAVSEC SWATH Design Synthesis Model. The parameters studied included: transverse frame spacing, materials, intermediate lateral support, and use of longitudinal girders. Associated studies of bending moment, effective breadth, and special plating effects were also conducted.

It was found that accumulated weight savings can amount to 10-20% of the primary structure relative to that calculated by the SWATH Synthesis Model, that primary structural weight-estimating techniqeus should be dependent on the structural geometry, and that detailed structural studies should be made on a case basis as early as possible in a SWATH design.

ADMINISTRATIVE INFORMATION

This project was conducted by the Advanced Concepts Office of the Systems Development Department. The work was performed under work unit 1170-098 supported by the Small Waterplane Area Twin Hull (SWATH) Ship Development project, Mr. Larry Benen (NAVSEA 0322) Project Manager, Task Area SF43411211.

INTRODUCTION

In recent years, several studies of structural weights for Small Waterplane Area Twin Hull (SWATH) ships have been made. These include Aronne, Lev, and Nappi[1], in which the development of the structures subroutines for the NAVSEC SWATH Synthesis Model (SSM), the DTNSRDC Structural Synthesis Design Program (SSDP, SWATH version), and various early SWATH structural parametrics are discussed.

It has been an objective, for some time, to broaden the parametric structural weight/design data base for the SSM such that the designs produced would better reflect current structural design capabilities and knowledge for SWATH ships. That is the purpose of this study.

The DTNSRDC Structural Synthesis Design Program[2,3] calculates actual scantlings of a ship's primary structure. The techniques used are directly analogous to those used in hand calculations of structure. The design criteria and processes are those used by NAVSEC for conventional stiffened plate construction, as described in Reference 3. Scantlings and weights derived using the SWATH version of this program have been checked against traditional drawing board designs for several ships and agreement has been excellent.[1]

The NAVSEC SSM uses many algorithms in order to perform feasibility studies (i.e., determine the significance of various ship characteristics and their effect on the total ship design). Therefore, the structural algorithm in the SSM has to be less complex than the more detailed SSDP. Nonetheless, agreement between these two programs has been excellent when the same design conditions were used. However, the SSM is based upon ship designs with a constant 24" (61 cm) transverse frame spacing, and High Tensile Steel (HTS) material (with a correction factor for aluminum). It also has fixed transverse and longitudinal bulkhead spacing.

The SSM (to date) does not account for the use of transverse frame spacings other than 24" (61 cm), non-HTS steels (HY80, HY100), variable longitudinal girder spacing, or intermediate lateral supports (ILS). It may be desirable, as will be seen, to change these factors, in which case SSM accuracy can deteriorate. On the other hand it was recognized that the current SSM structural algorithm is an interim one, to be used until further data could be presented. Therefore, in order to assist NAVSEC in broadening the applicability of the structures portion of the SSM and to reduce weight, the following structural parameters were investigated using SSDP:

- Transverse Frame Spacing,
- Use of Intermediate Lateral Supports,
- High Strength Steels,
- Spacing of Longitudinal Girders, and
- Aluminum Primary Structural Weight as a Fraction of Steel Primary Structural Weight.

Longitudinal and transverse bulkhead spacing were not studied, since weight modifications associated with them result directly from changes in their number. In the following studies, results referred to as "base" are those which would be generated by the interim SSM algorithms.

The next section deals with the four basic ships and their variants used in the study and the design criteria used. The third section contains discussions of the weight saving methods and some other considerations in SWATH structural design. A summary of the conclusions arrived at from this study is presented in the fourth section.

CONFIGURATIONS STUDIED

Four basic ships were used for the investigation. These were a Mine Countermeasures (MCM) ship, a Frigate (FF), an Air Capable Mine Countermeasures ship (AMCM) and a nuclear powered Aircraft Carrier (CVN). The MCM was one of several designs developed by NAVSEC for the PMS 300 investigation of MCM alternatives. The other three ships were designed by NAVSEC for the Advanced Naval Vehicles Concept Evaluation (ANVCE).

These ships were chosen for this study because purposeful design work was being conducted on them. They were far enough along in design so that their size and configuration were fairly settled. The choice of ships put great emphasis on the 2000T-6000T size range of immediate interest but included values in the 25000T range. It was reasonably certain that these were feasible ships. Each of them is described below.

SWATH MINE COUNTERMEASURES (MCM) SHIP

Figure 1 shows the overall geometry of the 2100T MCM*. A typical midship section for the original configuration (Mod 0) is shown in Figure 2. A second version of this ship (Mod 1) had a larger number of longitudinal girders (shorter transverse stiffener spans). Its typical midship section is shown in Figure 3. A version without a cross-structure doublebottom** in the upper box was investigated specifically for the PMS 300 application. It is similar to the Mod 0 version, and since it was not an integral part of this study its midship section is not shown. However, insight was gained from the non-doublebottom ship studies.

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*A metric ton (tonne) is approximately equal to the long ton. Therefore, only long ton weights are given.

**Within this report, "doublebottom" refers to the doublebottom in the cross-structure (box).

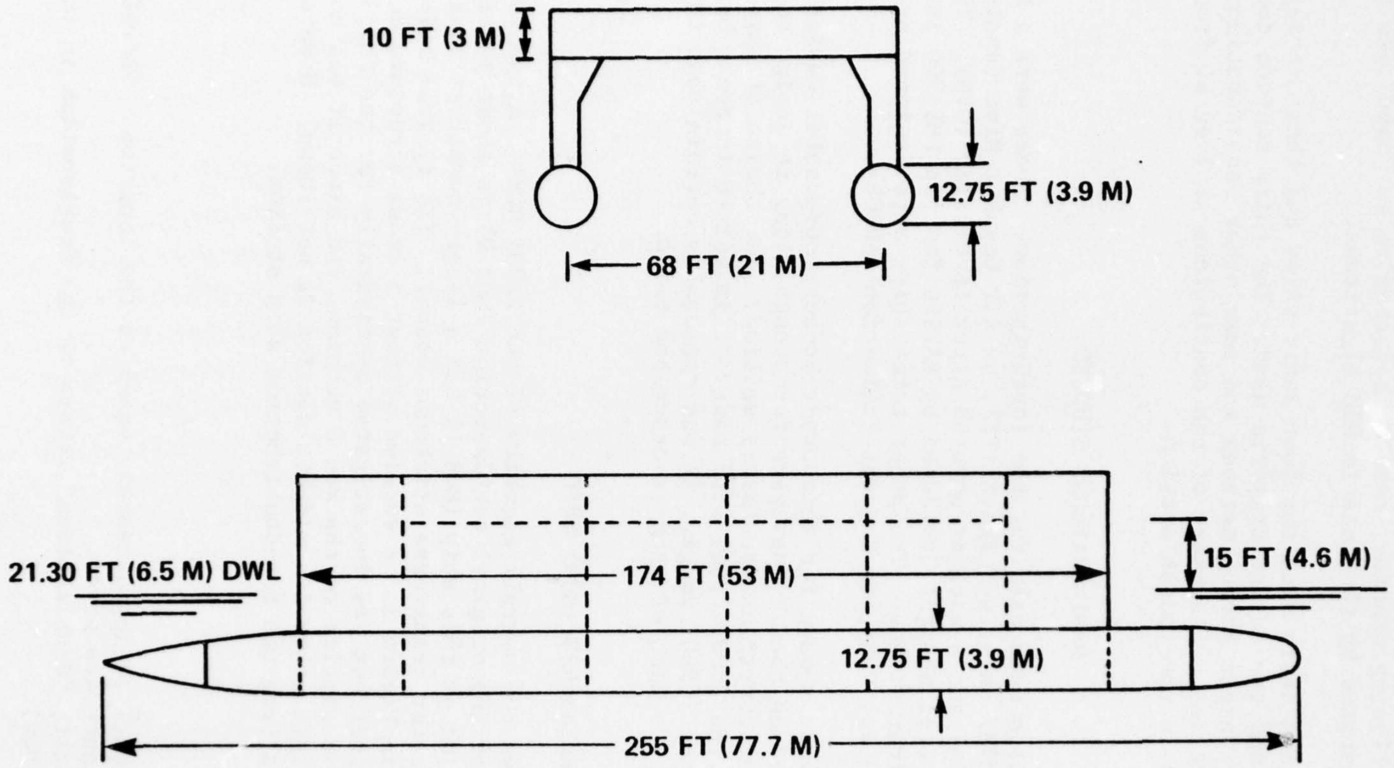

Figure 1 - MCM Geometry

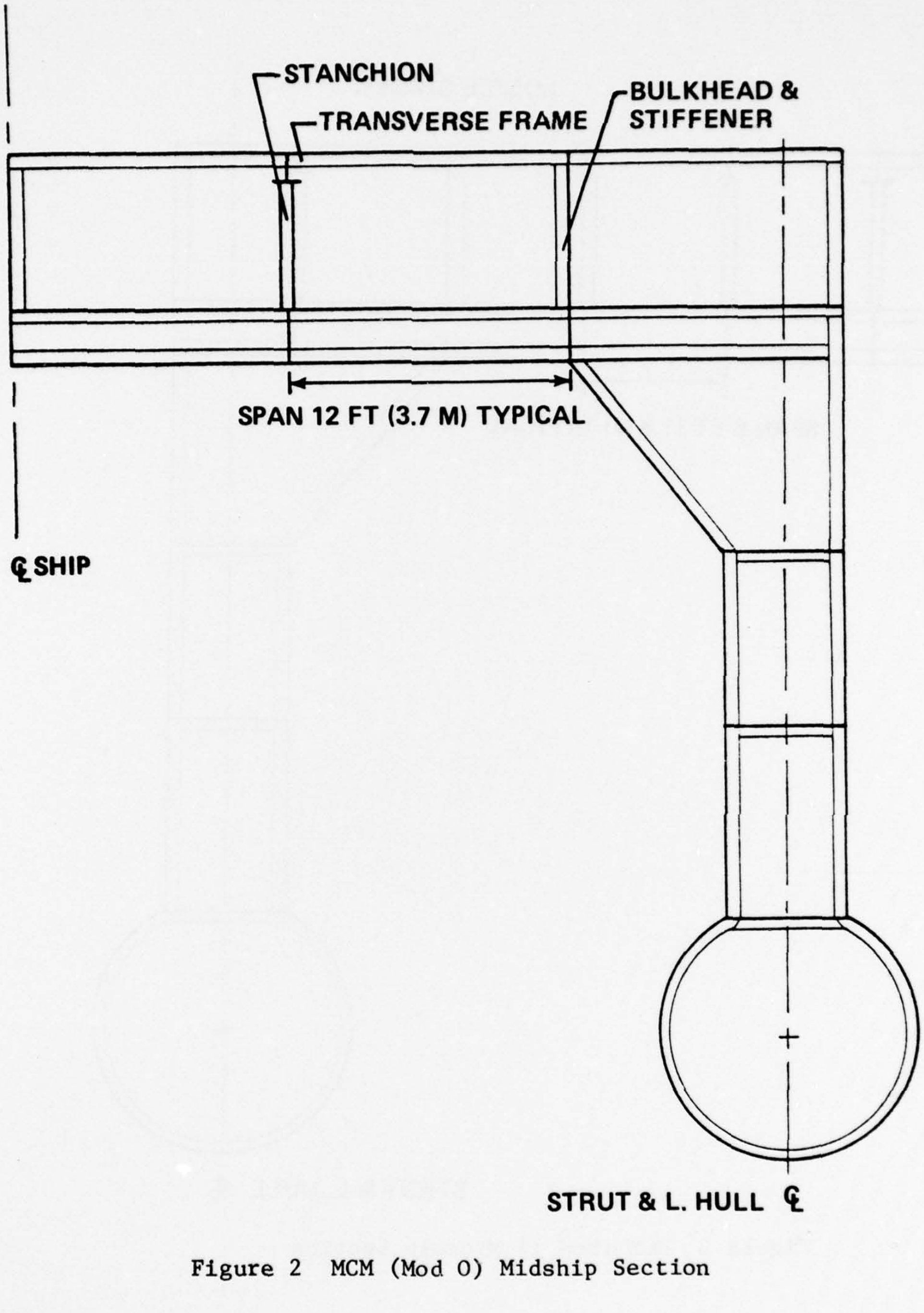

Figure 2 MCM (Mod 0) Midship Section

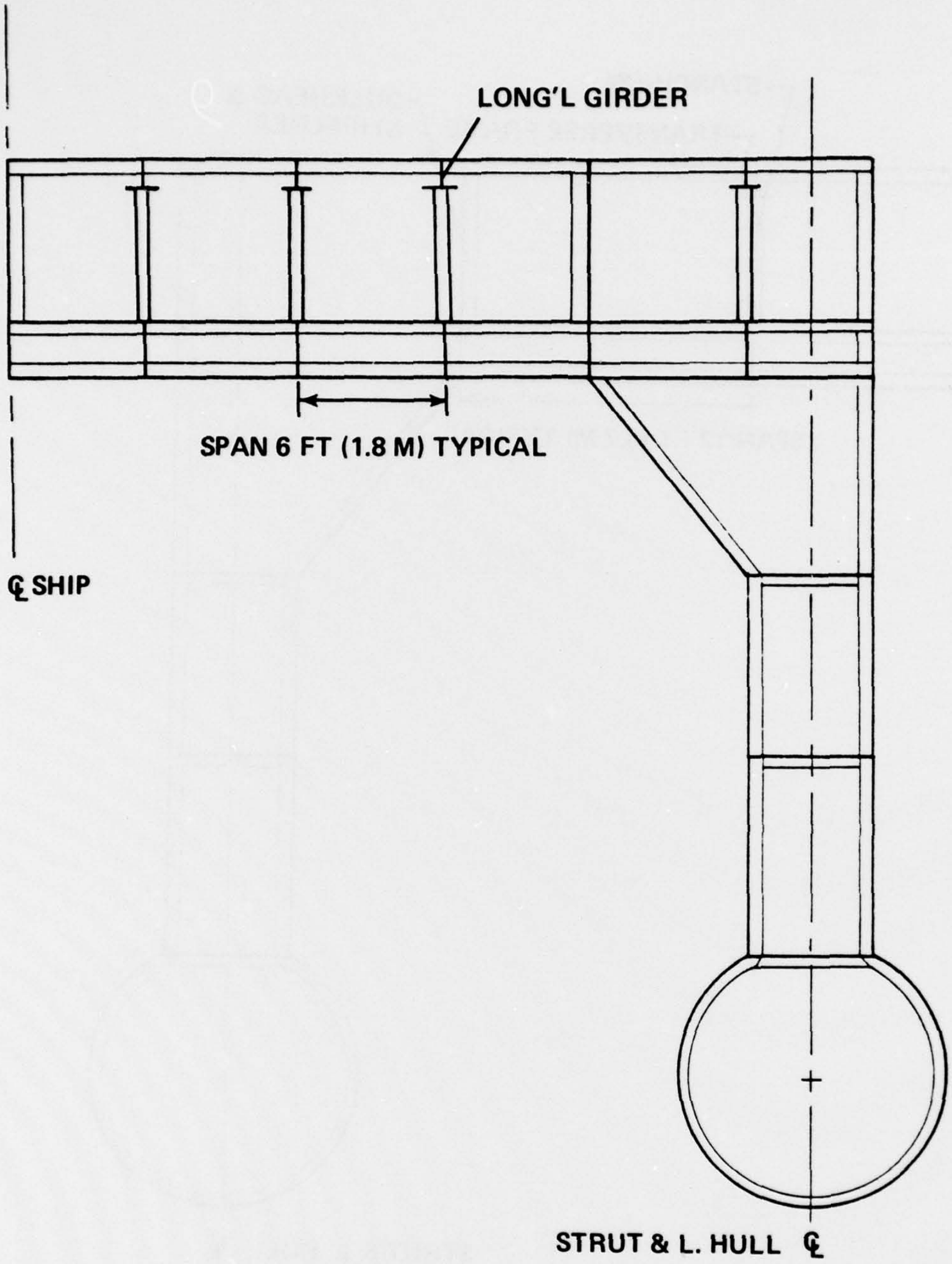

Figure 3 MCM (Mod 1) Midship Section

Table 1 outlines the MCM variations studied. Ships MCM 1 - MCM 6 were used to investigate minimum-weight frame spacing. The original doublebottom version had a 4 ft (1.2 m) deep doublebottom and 9 ft (2.7 m) deck height (MCM 8). It was found that weight could be saved if a shallow box, e.g., 7-1/2 ft (2.3 m) deck height and 2-1/2 ft (0.76 m) doublebottom (MCM 7), was used. The shallow 10 ft (3.0 m) deep box was used on all subsequent designs (MCM 9 - MCM 21). The ship without a doublebottom (MCM 9) was designed with optimum frame spacing (spacing not constant longitudinally) and compared to that with constant 24" (61 cm) frame spacing (MCM 10). MCM's 11, 12, and 13 show the effect of changing the side force (transverse bending moment). MCM 14 shows the effect of decreasing the effective breadth of material for resisting transverse bending to 75%. The benefits of using intermediate lateral supports (ILS) and high strength steels are illustrated in MCM's 15, 16 and 17 for the minimum weight frame spacing.

Additional longitudinal girders were placed in the box (Mod 1) in MCM's 18, 19, 20, and 21. These reduce the spans of the transverse stiffeners. The benefit of this type of construction is illustrated for HTS, HTS with ILS, HY80, and HY100.

SWATH FRIGATE (FF)

The overall geometry of the 3400T Frigate is shown in Figure 4. A typical midship section of the original version (Mod 0) is shown in Figure 5.

Two modified versions of this ship were evaluated. Mod 1 (Figure 6) had a longitudinal girder spacing of 8 ft (2.4 m). Figure 7 shows Mod 2 with its longitudinal girder spacing of 4 feet (1.2 m).

The Frigate variations examined are listed in Table 2. FF 1 - FF 4 were used to find the minimum weight frame spacing for the ship made of aluminum. FF 5 is the optimum (non-constant) frame spacing aluminum Frigate. Savings using ILS with aluminum were investigated for FF 6. FF 7 has a short strut and shallow box; it aided in investigating the influence of bending moment.

The minimum weight frame spacing for the Frigate constructed of steel was found (FF's 8-13). The benefits of ILS and high strength steels were investigated for FF's 14, 15, and 16.

The use of longitudinal girders to reduce transverse frame span (Mod 1, Mod 2) was investigated using FF's 17-24. These studies included use of HTS, ILS, and high strength steels.

TABLE 1 - SWATH STRUCTURAL PARAMETRICS-
MCM (Δ = 2100T)

SHIP NAME	MAT'L	FR SPAC*	FEATURES
MCM 1 - MCM 6	HTS	15", 18", 21", 24", 27", 30"	Doublebottom (DB)
MCM 7	HTS	24"	DB, Shallow Box
MCM 8	HTS	24"	DB, Deep Box
MCM 9	HTS	OPT	w/o DB
MCM 10	HTS	24"	w/o DB
MCM 11	HTS	OPT	w/o DB F=1.0Δ
MCM 12	HTS	OPT	w/o DB F=0.25xΔ
MCM 13	HTS	OPT	w/o DB F=0.75Δ
MCM 14	HTS	OPT	75% Eff Breadth, w/o DB
MCM 15	HTS	15"	ILS, DB
MCM 16	HY80	15"	ILS, DB
MCM 17	HY100	15"	ILS, DB
MCM 18 (Mod 1)	HTS	15"	Doublebottom
MCM 19 (Mod 1)	HTS	15"	ILS, DB
MCM 20 (Mod 1)	HY80	15"	ILS, DB
MCM 21 (Mod 1)	HY100	15"	ILS, DB

OPT = Optimum frame spacing
ILS = Intermediate Lateral Supports
DB = Ship has cross-structure doublebottom
F = 0.5xΔ unless otherwise noted
Ship characteristics are defined by mod number, material, frame spacing, and features.
Ships are Mod O unless otherwise noted.
100% Effective Breadth unless otherwise noted.
*15 in = 38 cm; 18 in = 46 cm; 21 in = 53 cm; 24 in = 61 cm; 27 in = 69 cm; 30 in = 76 cm.

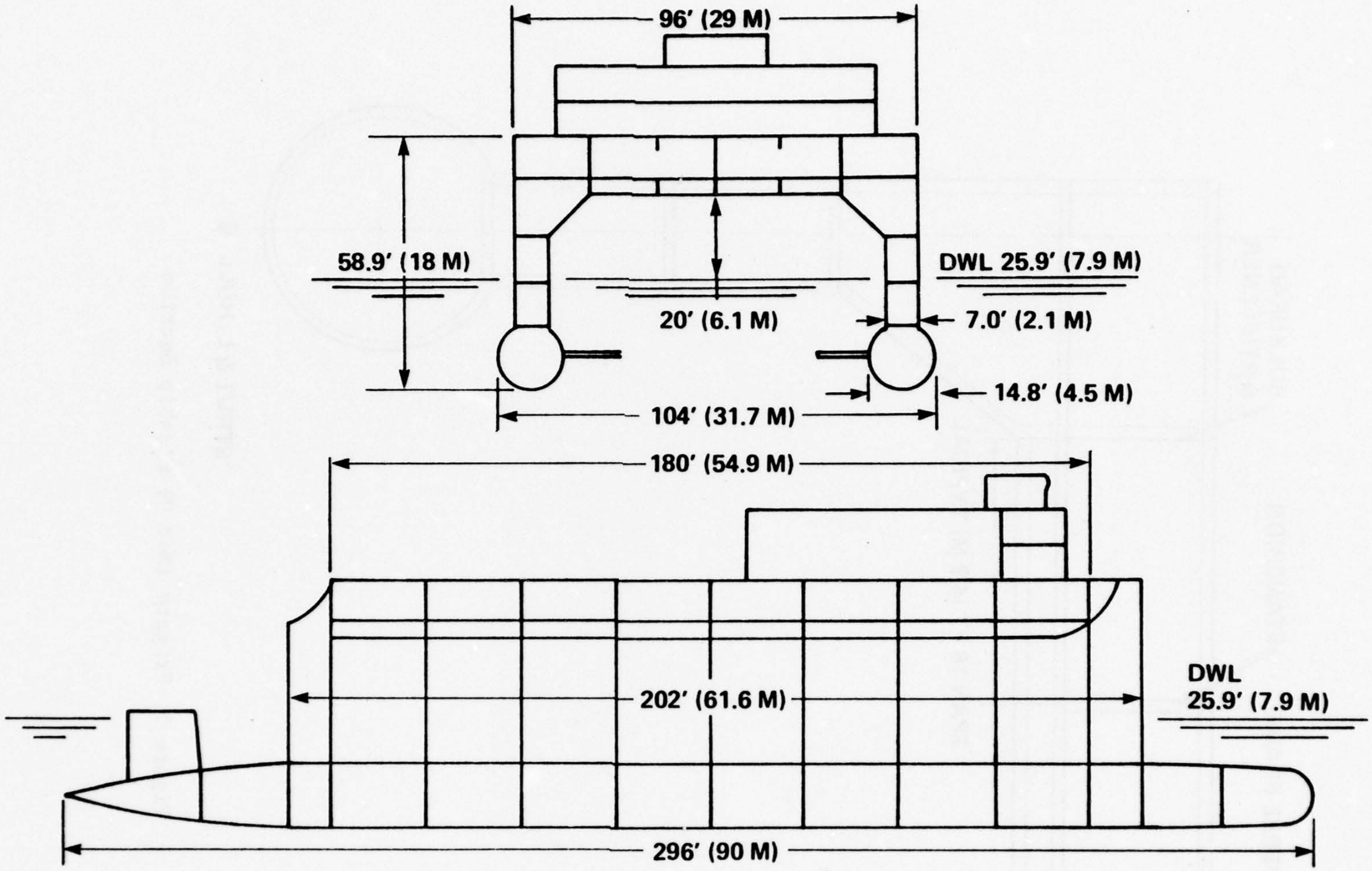

Figure 4 – Frigate Geometry

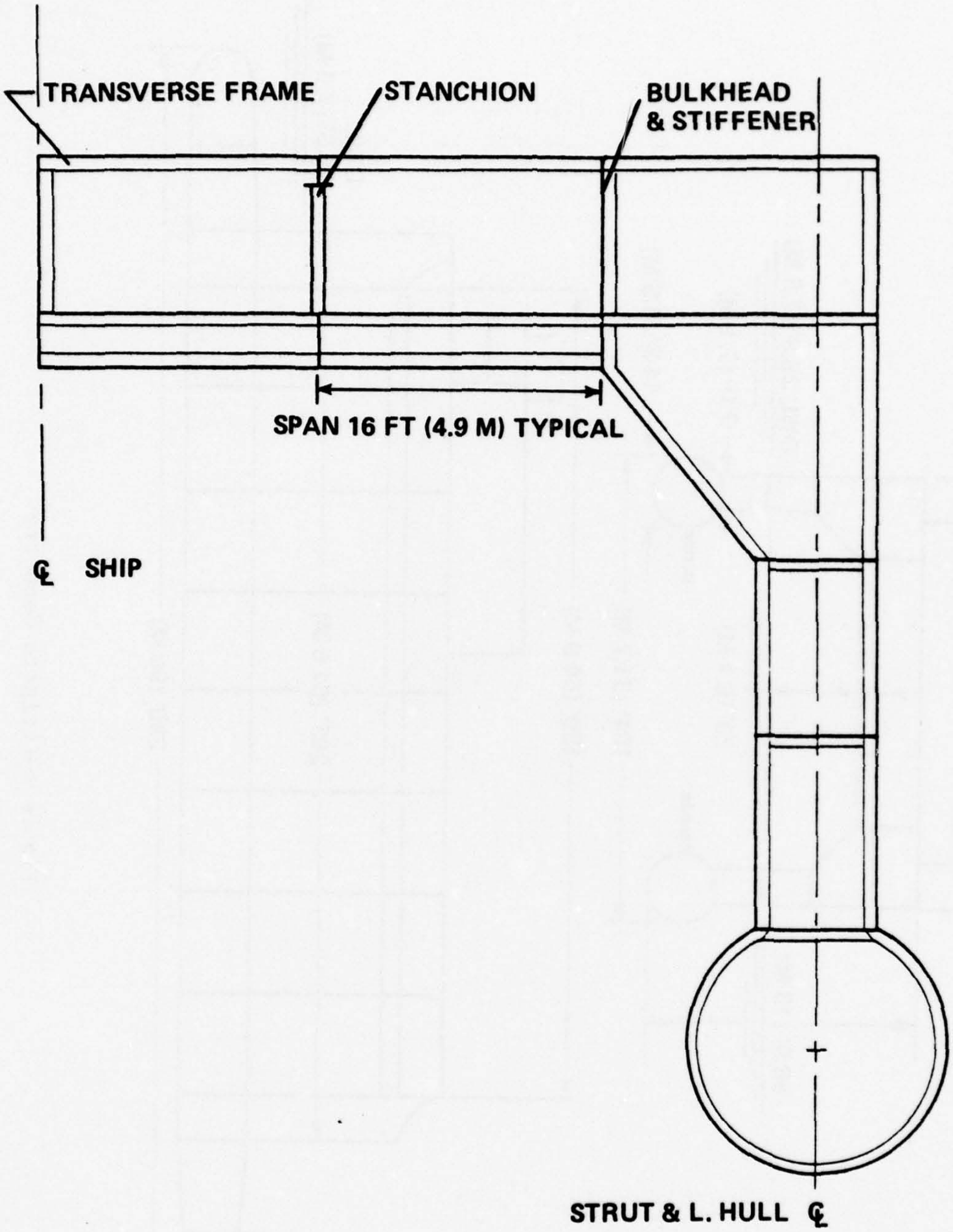

Figure 5 Frigate (Mod 0) Midship Section

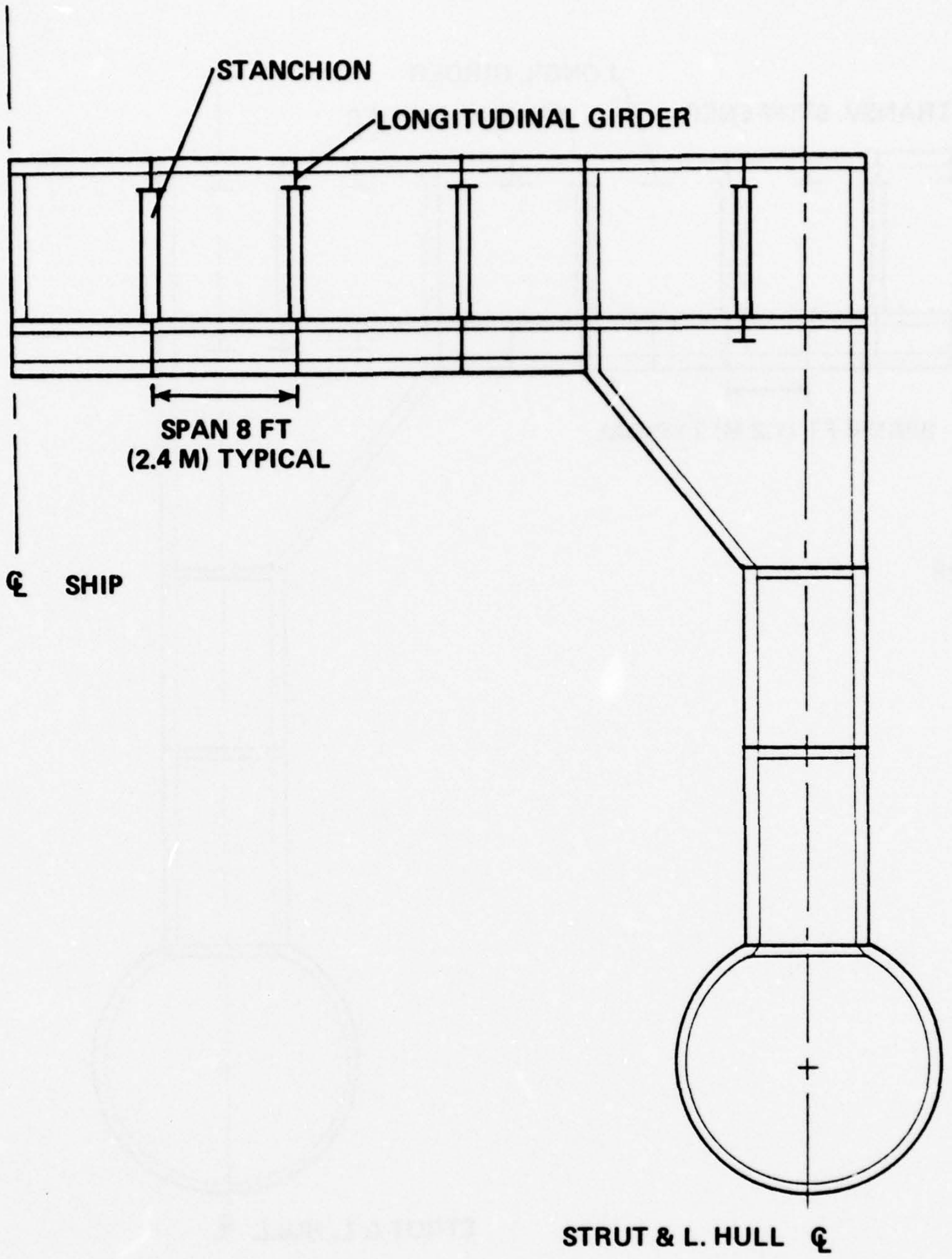

Figure 6 Frigate (Mod 1) Midship Section

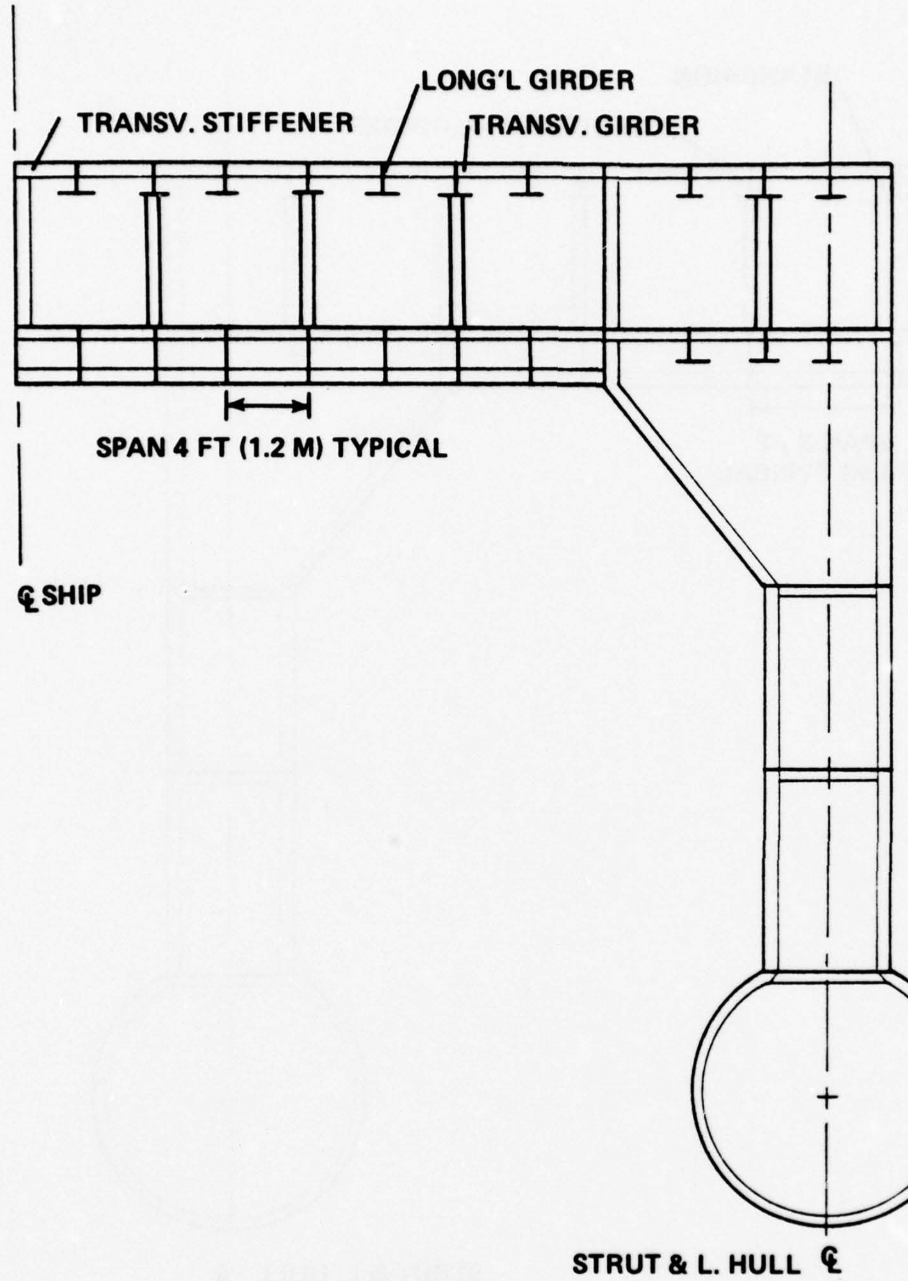

Figure 7 Frigate (Mod 2) Midship Section

TABLE 2 - SWATH STRUCTURAL PARAMETRICS-FRIGATE (Δ = 3400T)

SHIP NAME	MAT'L	FR SPAC*	FEATURES
FF 1 - FF 4	Alum	21", 24", 27", 30"	No Special Features
FF 5	Alum	OPT	No Special Features
FF 6	Alum	OPT	ILS
FF 7	Alum	OPT	Short Strut, Shallow Box
FF 8 - FF 13	HTS	15", 18", 21", 24", 27", 30"	No Special Features
FF 14	HTS	15"	ILS
FF 15	HY80	15"	ILS
FF 16	HY100	15"	ILS
FF (Mod 1) 17	HTS	15"	No Special Features
FF (Mod 1) 18	HTS	15"	ILS
FF (Mod 1) 19	HY80	15"	ILS
FF (Mod 1) 20	HY100	15"	ILS
FF (Mod 1) 21	HTS	15"	No Special Features
FF (Mod 1) 22	HTS	15"	ILS
FF (Mod 1) 23	HY80	15"	ILS
FF (Mod 1) 24	HY100	15"	ILS

All ships had a cross-structure doublebottom.
OPT = Optimum Frame Spacing
Ships are Mod O unless otherwise noted.
F = 0.5 x Δ
Ship characteristics are defined by mod number, material, frame spacing, and features.
100% Effective breadth
*15 in = 38 cm; 18 in = 46 cm; 21 in = 53 cm; 24 in = 61 cm; 27 in = 69 cm; 30 in = 76 cm.

SWATH AIR-CAPABLE MINE COUNTERMEASURES (AMCM) SHIP

Figure 8 illustrates the geometry of the 5800T AMCM. Figure 9 is a typical midship section. No modified configuration of this ship was investigated.

Table 3 is a list of the AMCM structural variations. AMCM 1-AMCM 6 were investigations to find the minimum weight frame spacing. The optimum (non-constant spacing) frame spacing for this ship constructed of HTS was found using AMCM 7. AMCM's 8, 9, and 10 were ILS and high strength steel investigations.

SWATH AIRCRAFT CARRIER (CVN)

Figure 10 shows the geometry of the SWATH CVN and its midship section is shown in Figure 11.

Table 4 lists the CVN variations. The minimum weight frame spacing was found using CVN 1-CVN 5. Use of ILS and high strength steels was studied with CVN's 6, 7, and 8.

As part of the ANVCE study, the flight deck and hangar deck were designed for aircraft landing and handling loads. The ANVCE flight deck and hangar deck scantlings were used without modification for the flight and hangar decks of all CVN's.

DESIGN RESTRICTIONS

In order to maintain consistency and realism, several restrictions were imposed on the designs.

The framing system of a section of main deck of the Mod 0 Frigate is shown in Figure 12. This is similar to those used on the MCM and AMCM. The Mod 1 Frigate is shown in Figure 13, and Mod 2 is illustrated in Figure 14.

Unlike some other advanced concepts, most SWATH ships have been designed with standard marine plate and stiffener construction. Marine grade aluminum (5456) and steel are the materials used for these ships.

In addition to meeting the above limitations, several other criteria were used. The transverse bending moment was estimated as that produced by a transverse side force of 0.5 Δ imposed on the lower hull. Further discussion of this can be found in a later section. The minimum plate thickness allowed was 3/16" (4.8 mm).

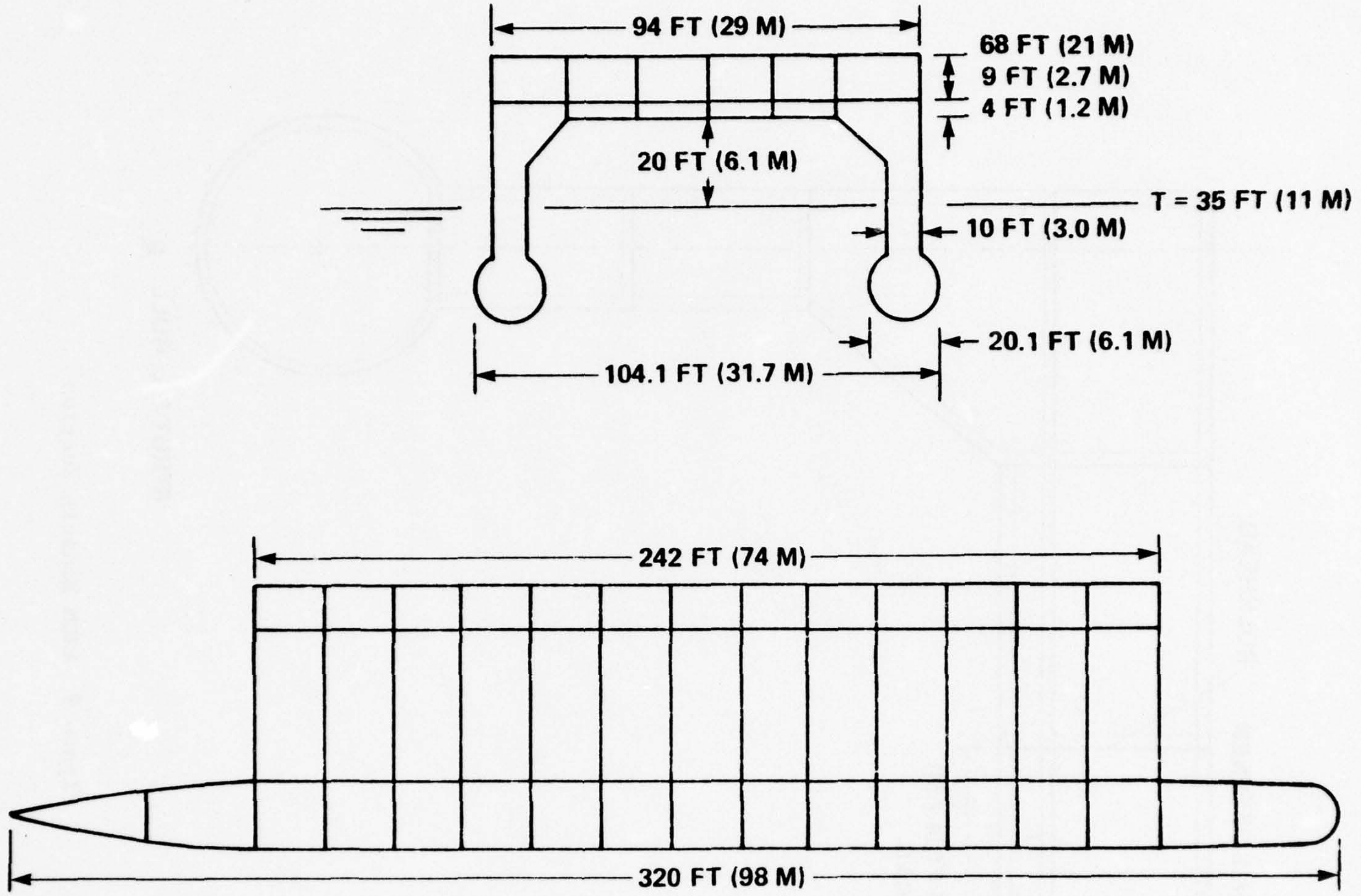

Figure 8 - AMCM Geometry (Not to Scale)

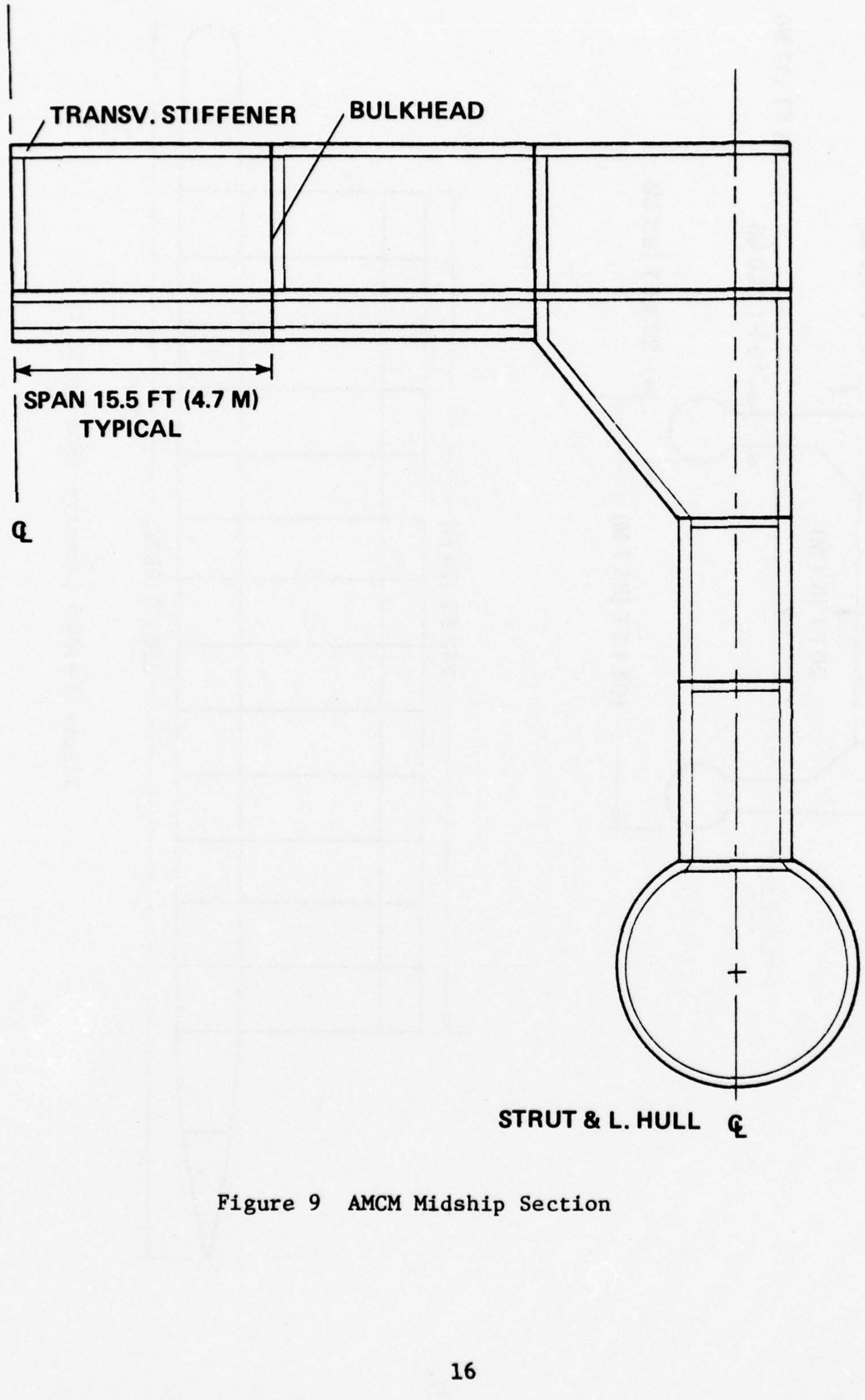

Figure 9 AMCM Midship Section

TABLE 3 - SWATH STRUCTURAL PARAMETRICS - AMCM (Δ = 5800T)

SHIP NAME	MAT'L	FR SPAC*	FEATURES
AMCM 1 - AMCM 6	HTS	15", 18", 21", 24", 27", 30"	No Special Features
AMCM 7	HTS	OPT	No Special Features
AMCM 8	HTS	18"	ILS
AMCM 9	HY80	18"	ILS
AMCM 10	HY100	18"	ILS

OPT = Optimum Frame Spacing
All ships have a cross-structure doublebottom.
F = 0.5 x Δ
Ship characteristics are defined by material, frame spacing, and features.
100% Effective breadth
*15 in = 38 cm; 18 in = 46 cm; 21 in = 53 cm; 24 in = 61 cm; 27 in = 69 cm; 30 in = 76 cm.

TABLE 4 - SWATH STRUCTURAL PARAMETRICS - CVN (Δ = 27000T)

SHIP NAME	MAT'L	FR SPAC*	FEATURES
CVN 1 - CVN 5	HTS	15", 18", 21", 24", 30"	No Special Features
CVN 6	HTS	15"	ILS
CVN 7	HY80	15"	ILS
CVN 8	HY100	15"	ILS

OPT = Optimum Frame Spacing
All ships have a cross-structure doublebottom.
F = 0.5 x Δ
Ship characteristics are defined by material, frame spacing, and features.
100% Effective breadth
*15 in = 38 cm; 18 in = 46 cm; 21 in = 53 cm; 24 in = 61 cm; 30 in = 76 cm.

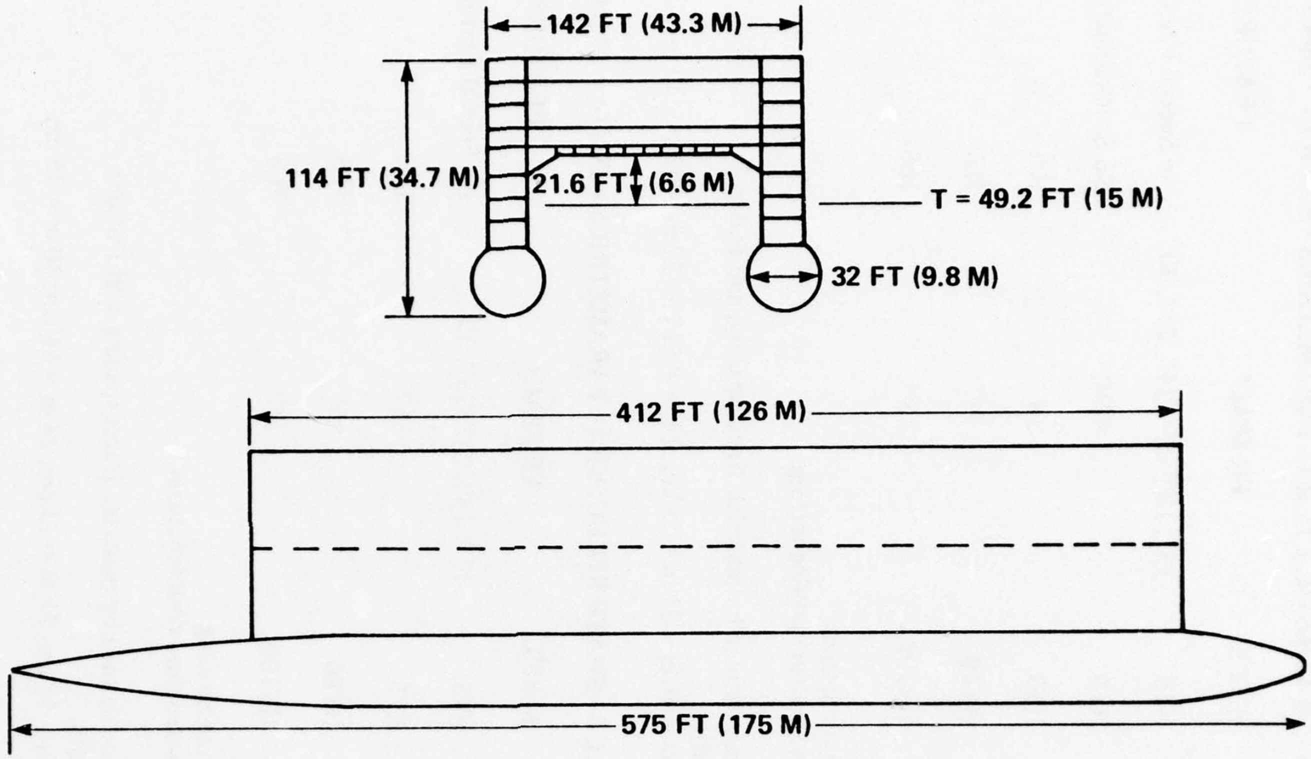

Figure 10 – SWATH CVN Geometry

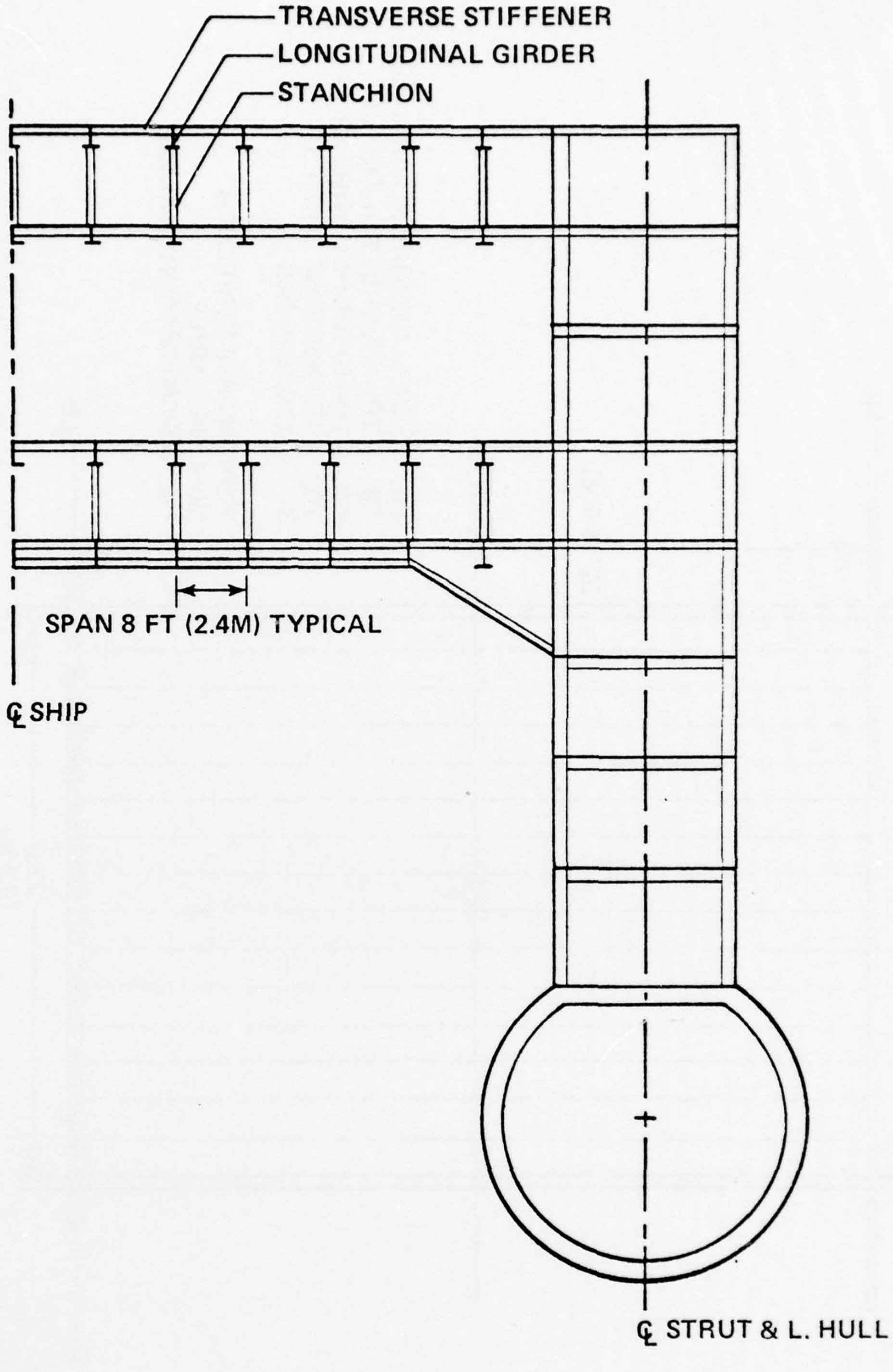

Figure 11 SWATH CVN Midship Section

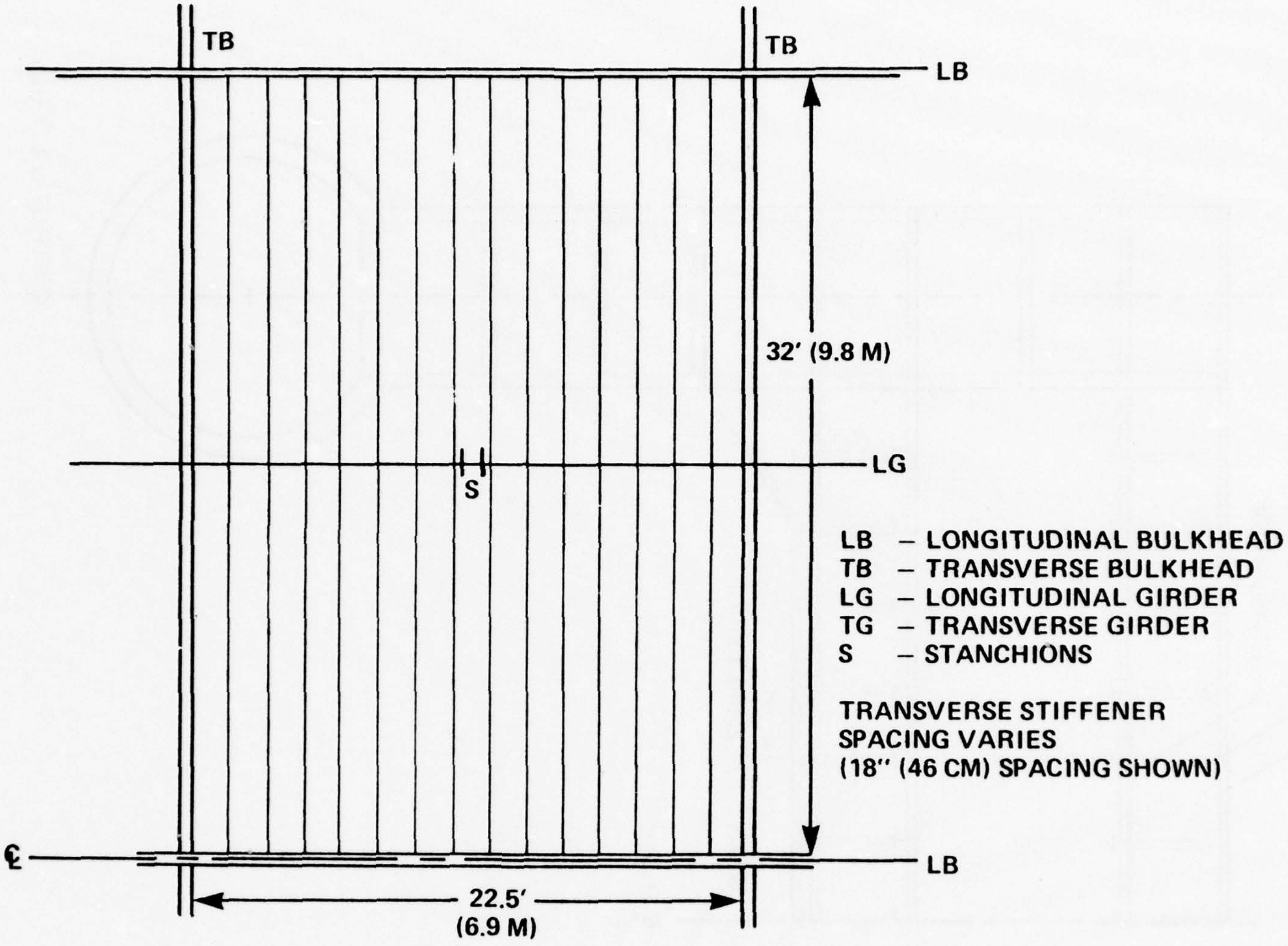

Figure 12- SWATH Frigate (Mod 0) Typical Main Deck Framing

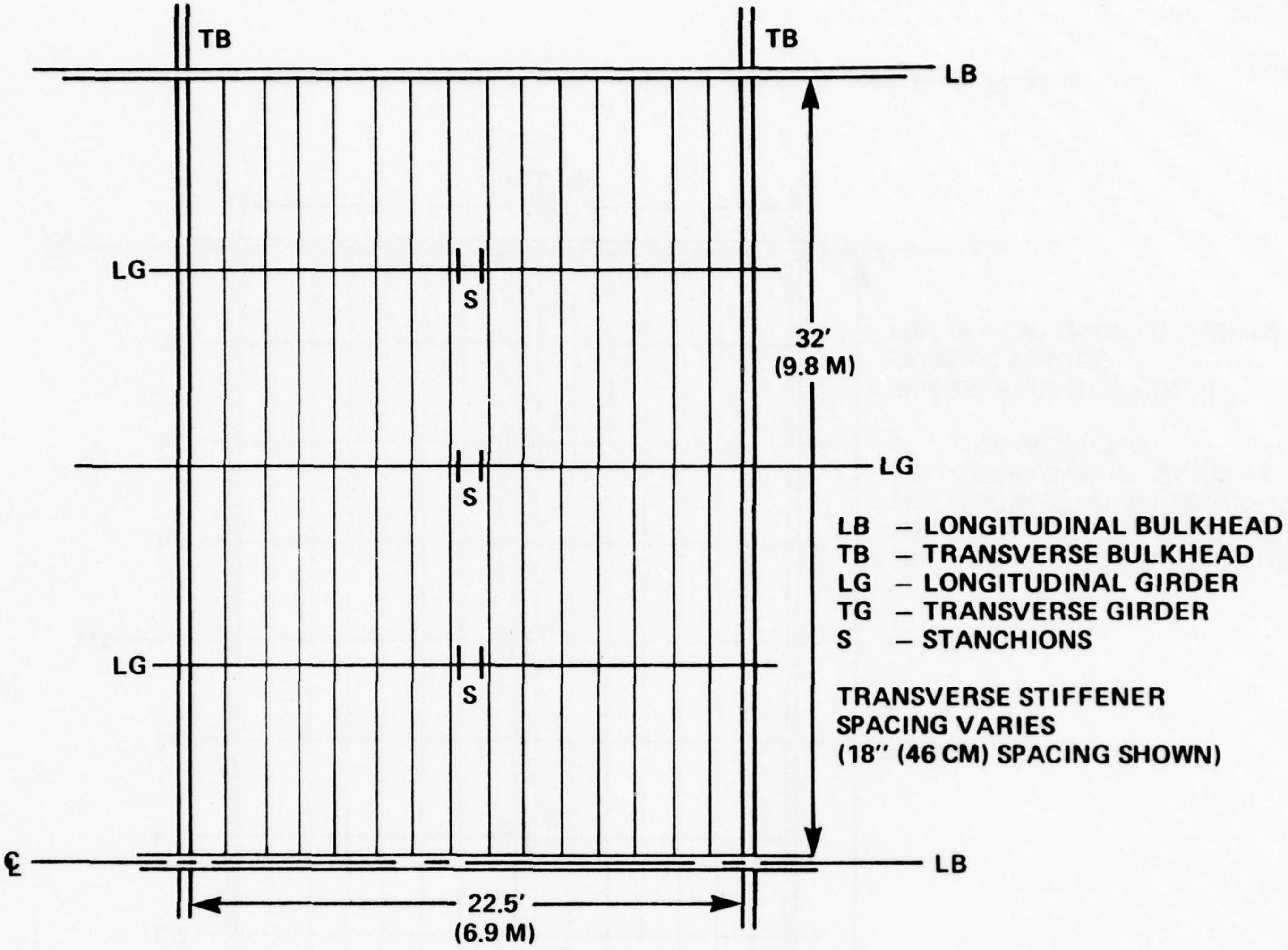

Figure 13 - SWATH Frigate (Mod 1) Typical Main Deck Framing

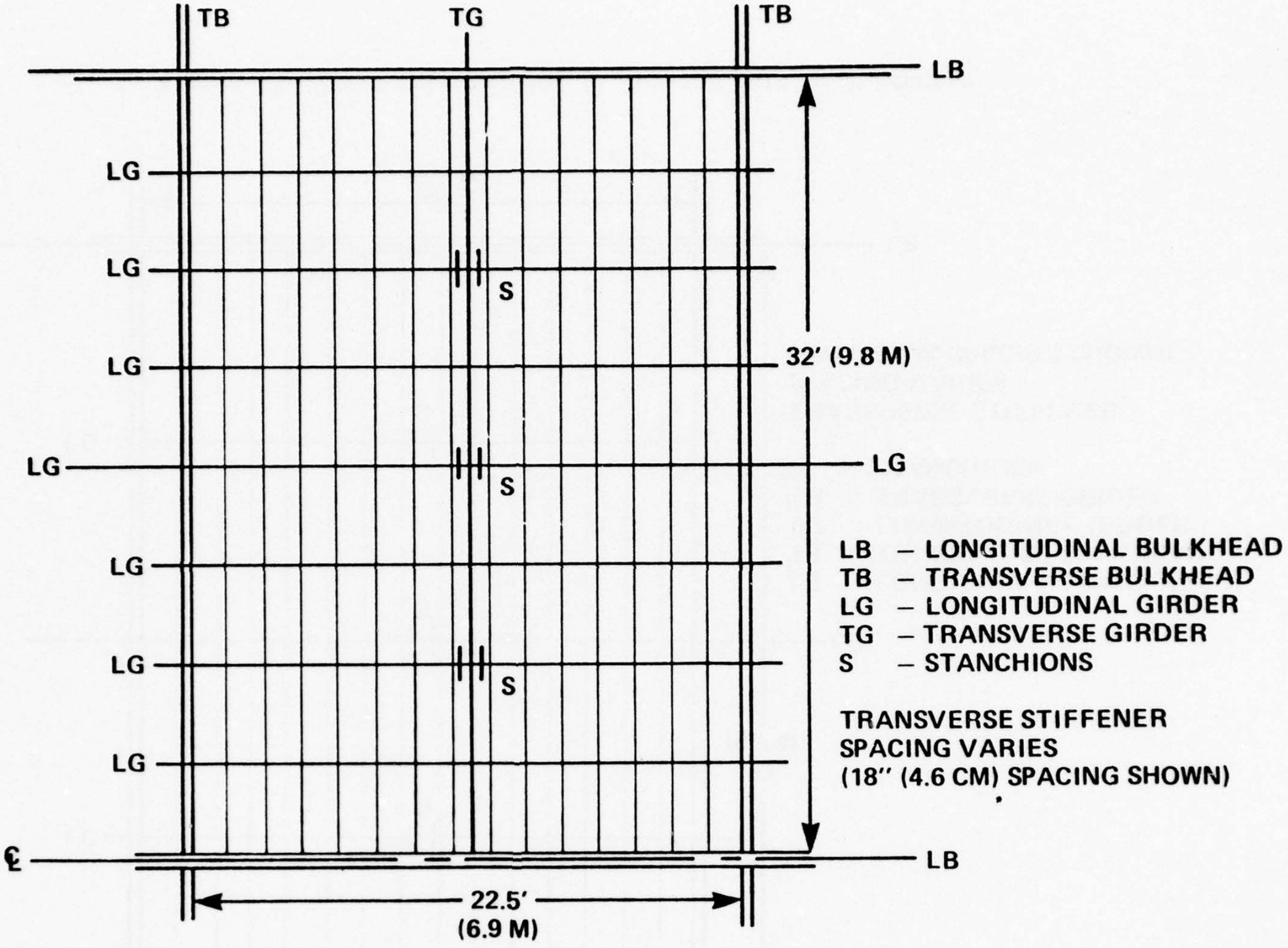

Figure 14 - SWATH Frigate (Mod 2) Typical Main Deck Framing

Slam pressures vary from 37.5 psi (2.64 kg/cm^2) on plates and 10 psi (0.7 kg/cm^2) on stiffeners amidships to 75 psi (5.3 kg/cm^2) on plates and 20 psi (1.4 kg/cm^2) on stiffeners at the bow and stern. These pressures were used on the upper box bottom and end plating and on inboard strut plating above the waterline. A 1500 psf (7300 kg/m^2) wave slap load was used. The damage control level was placed at the second deck.

Except for the special case of the aircraft carrier, no aircraft parking or landing loads were applied.

Steel and aluminum plates and shapes used in SSDP are given by Walz, Lev, and Nappi.[3]

FACTORS STUDIED

FRAME SPACING

Calculations were made to demonstrate how frame spacing influences primary structural weight for steel ships. Constant nominal frame spacing was used fore and aft. The actual spacings used were not exactly equal to those shown because of the need to fit an integer number of frames between bulkheads with equal spacing between frames.

Fifteen inches (38 cm) was set as the minimum frame spacing. This is because it was felt that closer spacings would become uneconomical for construction.

Figures 15 through 18 show the variation of primary weight with nominal frame spacing for each of the four ships. These ships are constructed of HTS. **In all cases the best frame spacing is closer than 24" (61 cm) used** in the current SSM. Weight improvement below 24" (61 cm) spacing is generally not as large as weight deterioration above a 24" (61 cm) spacing.

Mine Countermeasures Ship (MCM)

The MCM has the same minimum weight frame spacing for each component* and the total of 15" (38 cm). The overall weight at 15" (38 cm) spacing is 92% of that at 24" (61 cm) spacing. Each of the components shows an appreciable savings.

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*SWATH ships can be thought of as being made up of three segments: upper cross structure (box), struts, and lower hulls. These are often referred to as "components" in this report.

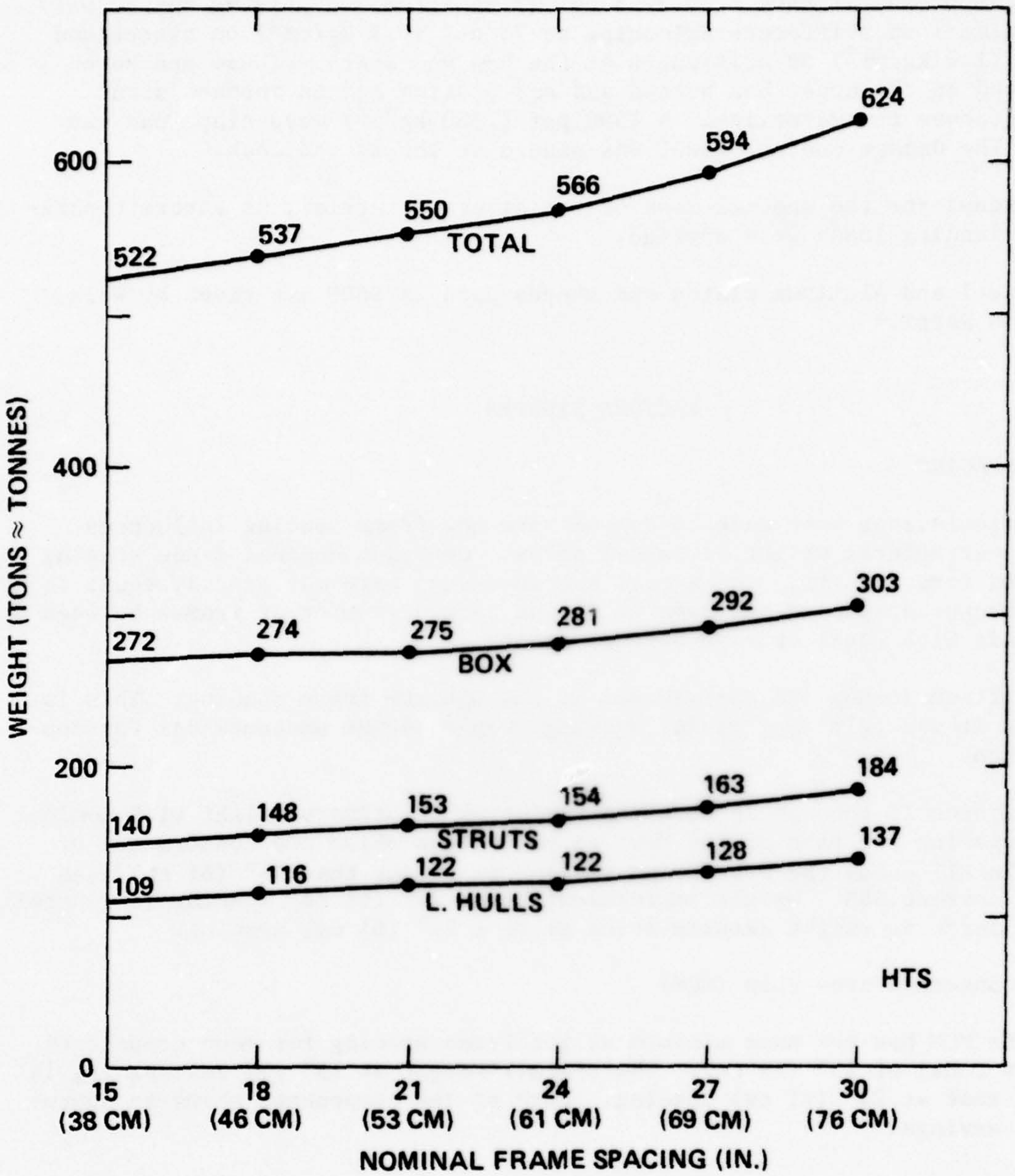

Figure 15 — SWATH MCM (Δ = 2100T) Primary Structural Weight vs Frame Spacing

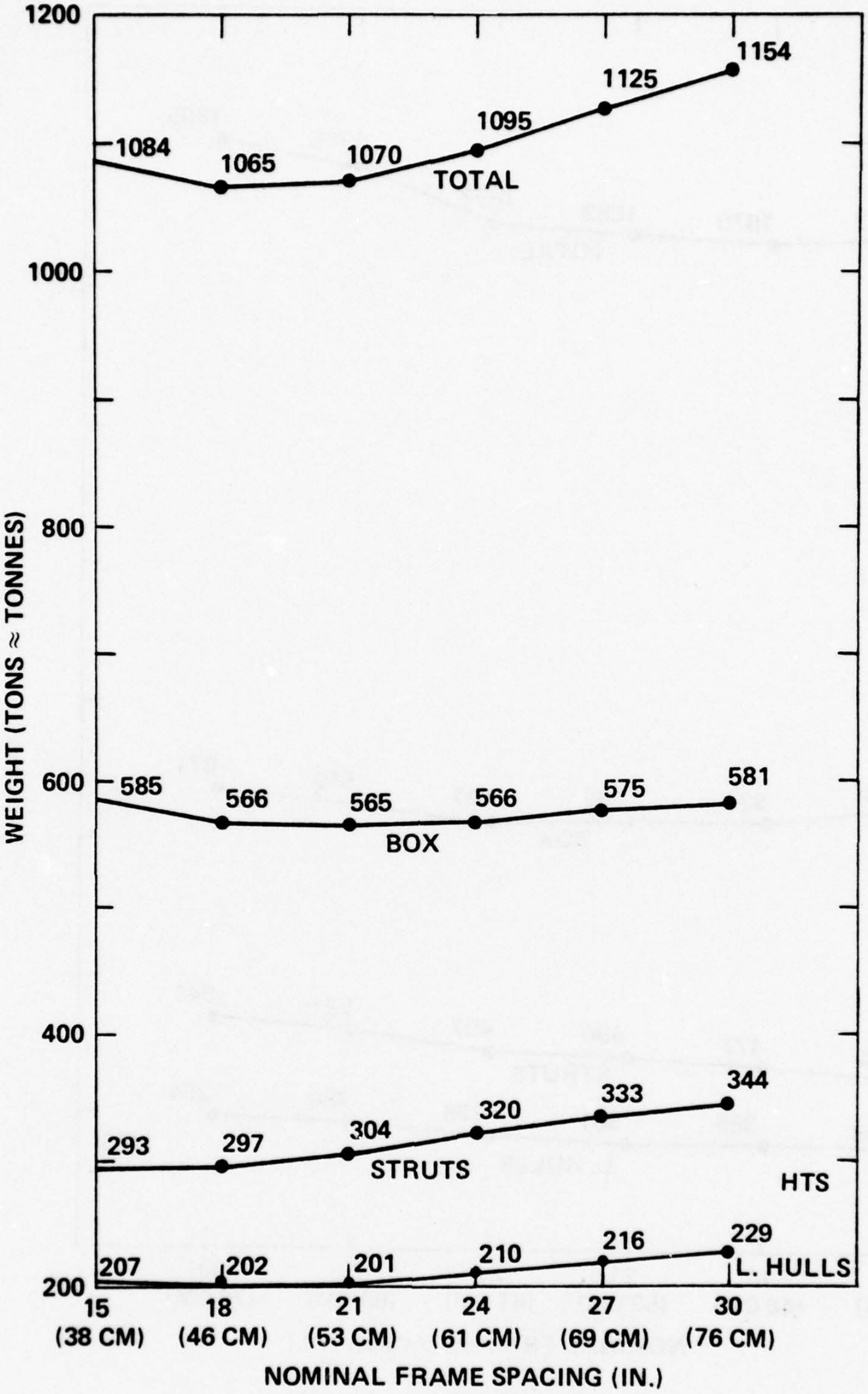

Figure 16 - SWATH Frigate (Δ = 3400T) Primary Structural Weight vs Frame Spacing

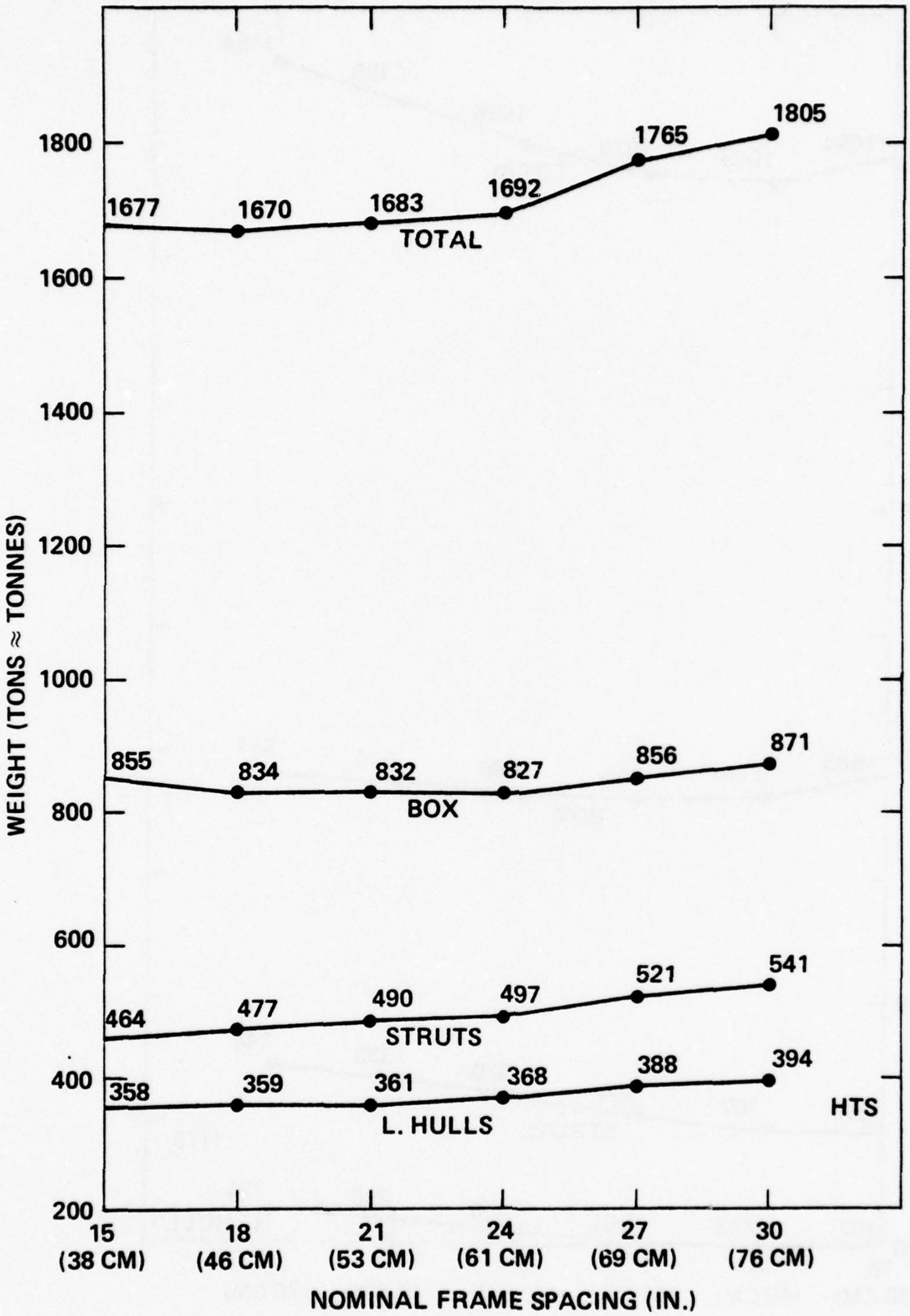

Figure 17— SWATH AMCM (Δ = 5800T) Primary Structural Weight vs Frame Spacing

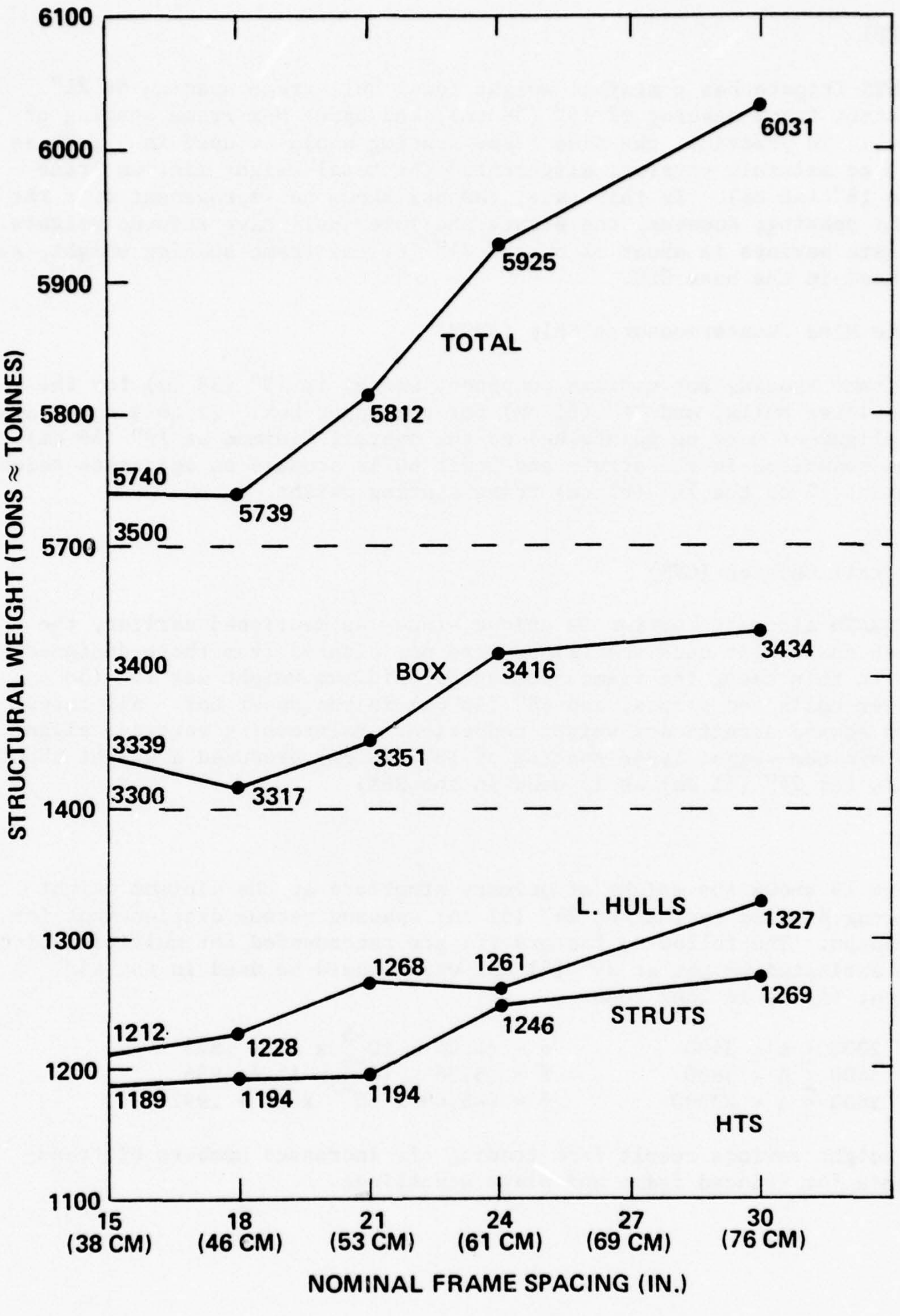

Figure 18 – SWATH CVN (Δ = 27000T) Primary Structural Weight vs Frame Spacing

Frigate (FF)

The HTS frigate has a minimum weight lower hull frame spacing of 21" (53 cm), strut frame spacing of 15" (38 cm), and upper box frame spacing of 21" (53 cm). In practice, the same frame spacing would be used in all three components to maintain vertical alignment. The total-weight minimum frame spacing is 18" (46 cm). In this case, the box shows no improvement over the 24" (61 cm) spacing; however, the struts and lower hull have reduced weights. The aggregate savings is about 3% of the 24" (61 cm) frame spacing weight, as would be used in the base SSM.

Air-Capable Mine Countermeasures Ship (AMCM)

The frame spacing for minimum component weight is 15" (38 cm) for the struts and lower hulls, and 24" (61 cm) for the upper box. In this case, also, vertical alignment must be maintained so the overall minimum at 18" (46 cm) is used. The reduction in the struts and lower hulls produce an aggregate reduction of about 1% of the 24" (61 cm) frame spacing weight.

SWATH Aircraft Carrier (CVN)

The SWATH aircraft carrier is unique since, as mentioned earlier, the flight deck and hangar deck scantlings were not altered from those designed by hand. In this case, the frame spacing for minimum weight was 15" (38 cm) in the lower hulls and struts, and 18" (46 cm) in the upper box. All three components showed significant weight reduction. Maintaining vertical alignment, the minimum weight frame spacing of 18" (46 cm) produced a weight about 97% of that for 24" (61 cm) as is used in the SSM.

Summation

Figure 19 shows the weight of primary structure at the minimum weight frame spacing divided by that at 24" (61 cm) spacing versus displacement for the four ships. The following factors (f) are recommended for multiplication times the estimated weight at 24" (61 cm) which would be used in the SSM. Displacement (Δ) is in long tons.

$$
\begin{array}{ll}
2000 \leq \Delta < 3400 & f = (4.64 \times 10^{-5} \times \Delta) + .825 \\
3400 \leq \Delta < 5800 & f = (5.38 \times 10^{-6} \times \Delta) + .956 \\
5800 \leq \Delta < 27000 & f = (-8.49 \times 10^{-7} \times \Delta) + .992
\end{array}
$$

The weight savings result from trading off increased numbers of transverse frames for reduced frame and plate scantlings.

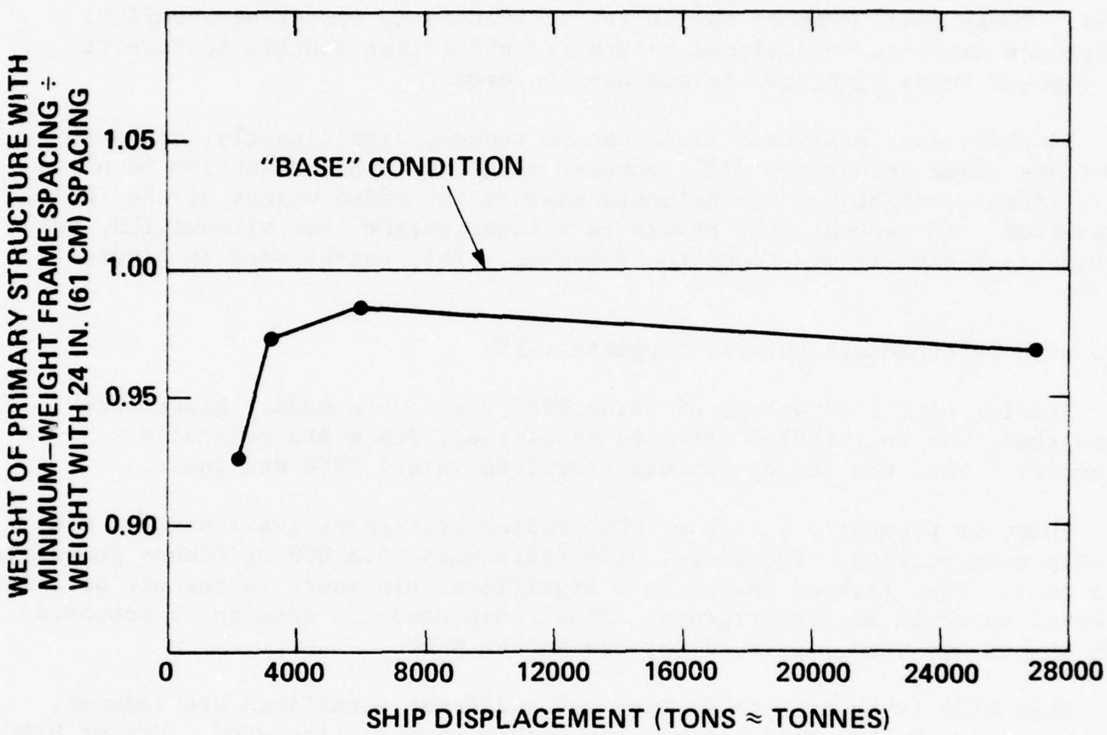

Figure 19—Primary Structural Weight Savings Permitted by Frame Spacing

MATERIALS AND INTERMEDIATE LATERAL SUPPORTS

High Tensile Steel (HTS) with Intermediate Lateral Supports (ILS)

Data presented previously showing the advantage of using minimum weight frame spacing used high tensile steel (HTS) without intermediate lateral supports. Since the stiffener lengths are long (in combination with material properties), in many cases stiffeners larger than those required to support the live load must be used in order to resist stiffener buckling.

This problem can be resolved by using intermediate lateral supports (ILS). These small members assist the stiffeners in resisting buckling. Stiffeners can then be designed to provide sufficient inertia to support the imposed loads with the minimum section area.

In this case, stiffener sizes can be reduced significantly, although sometimes plate scantlings will increase slightly. This reduction in plate and stiffener weight must be balanced against the added weight of the ILS's themselves. In general, the result is a lower weight than without ILS, but in rare instances it was found to be higher. This can be seen in Figures 20-25.

HY80 with Intermediate Lateral Supports (ILS)

Studies of the advantage of using HY80 steel were made. Experience shows that, due to the HY80 material properties, ILS's are generally necessary. Thus the ILS option was exercised in all HY80 designs.

There is presently a lack of HY80 rolled stiffeners available for use in ship construction. Therefore, HY80 stiffeners with HTS stiffener geometries were used. This lack of shapes is a significant hindrance to the use of this material where it is advantageous. Since this study, a catalog of proposed HY80 shapes has been developed for use in the SSDP.

When HY80 is used, both plating and stiffener scantlings are reduced. This must also be balanced against the weight of ILS's included. Use of HY80 requires that a larger number of ILS's be included than with HTS.

All of the components show reduced weight when HY80 is used.

HY100 with Intermediate Lateral Supports (ILS)

As with HY80, a lack of HY100 stiffeners applies. The development of these would be advantageous. Proposed shapes are now available for inclusion in the SSDP.

HY100 requires that ILS's be used in all cases. More of these are generally required than with HY80.

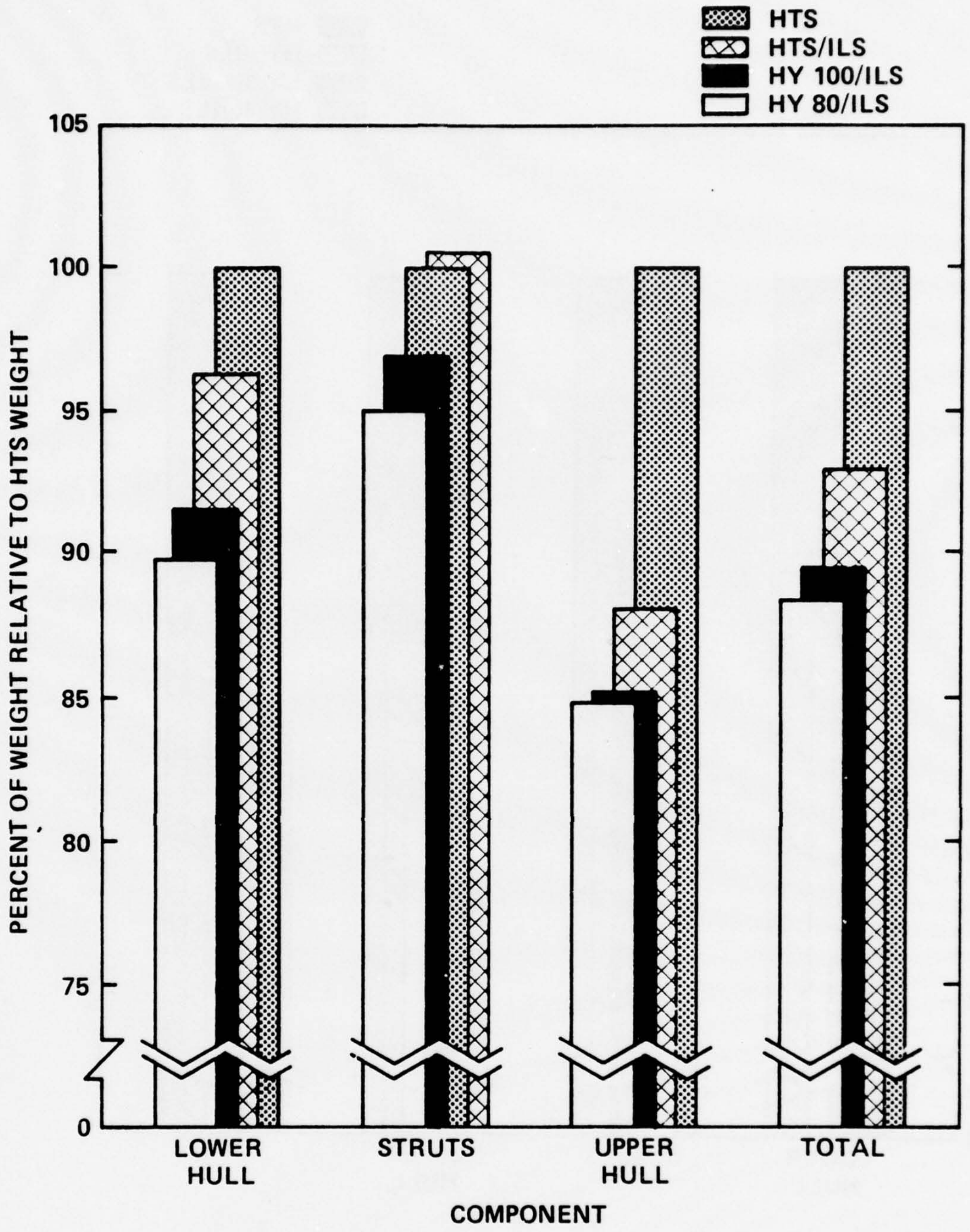

Figure 20 – Effect of Material and ILS on Primary Structural Weight - SWATH MCM (Δ = 2100T)

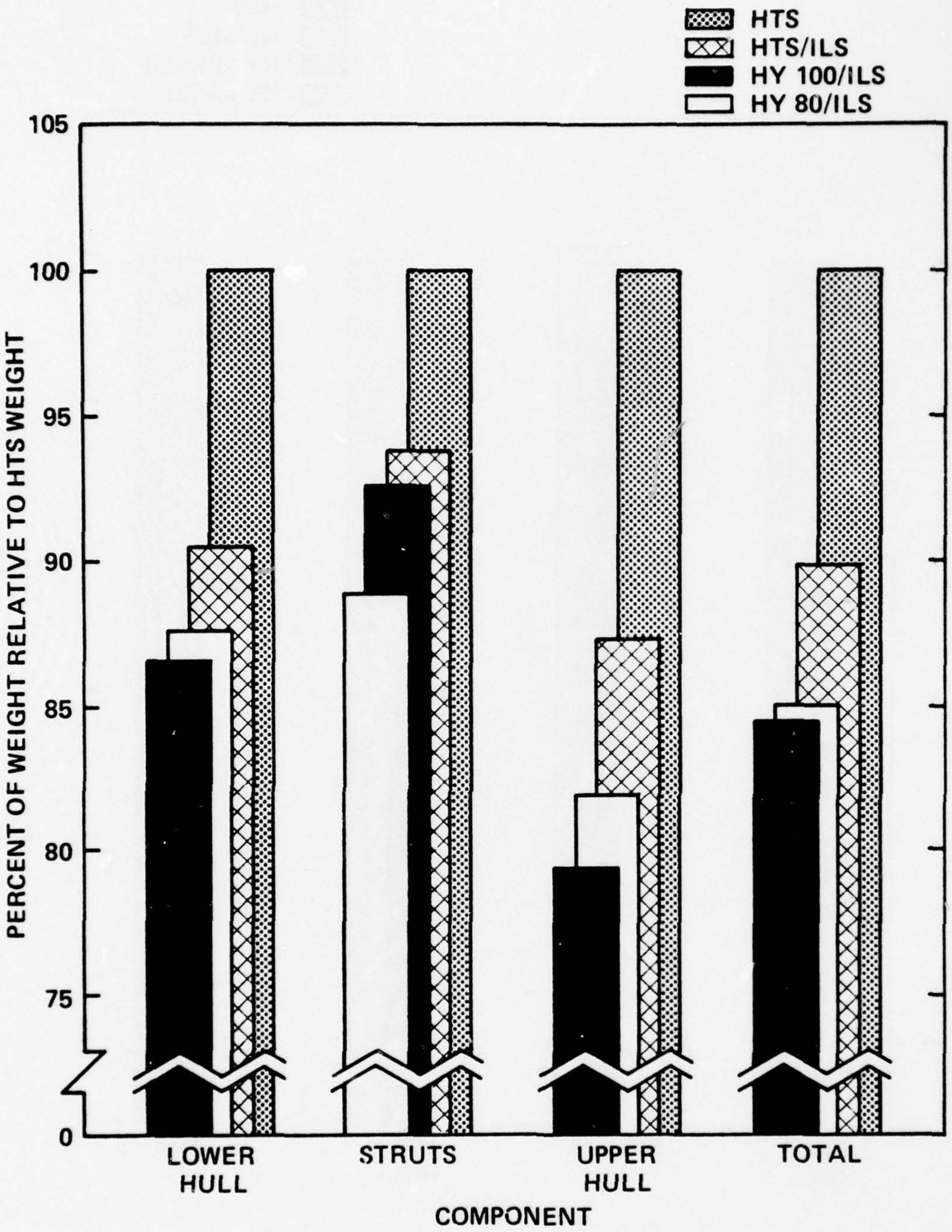

Figure 21 – Effect of Material and ILS on Primary Structural Weight - SWATH Frigate (Δ = 3200T)

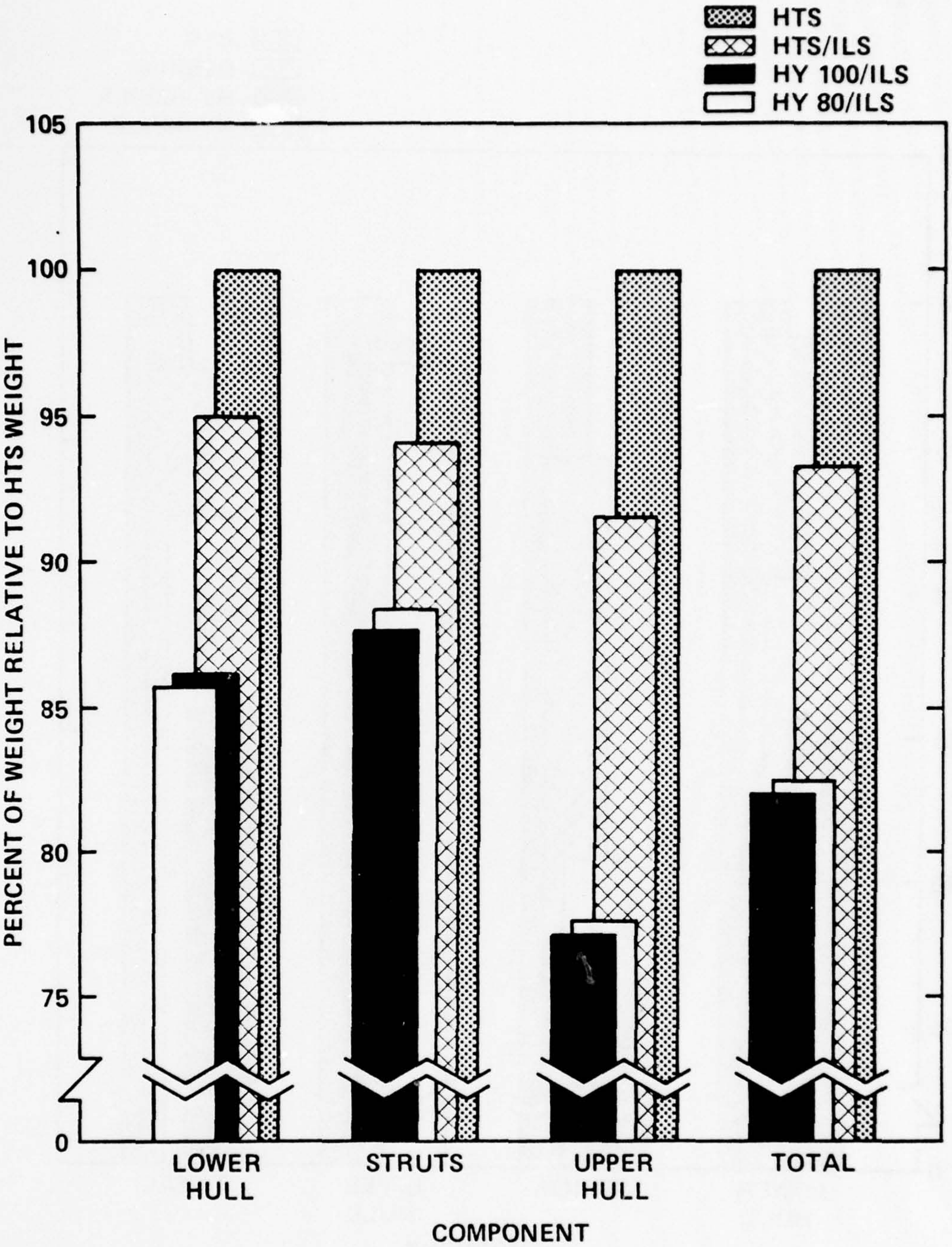

Figure 22—Effect of Material and ILS on Primary Structural Weight - SWATH AMCM (Δ = 5800T)

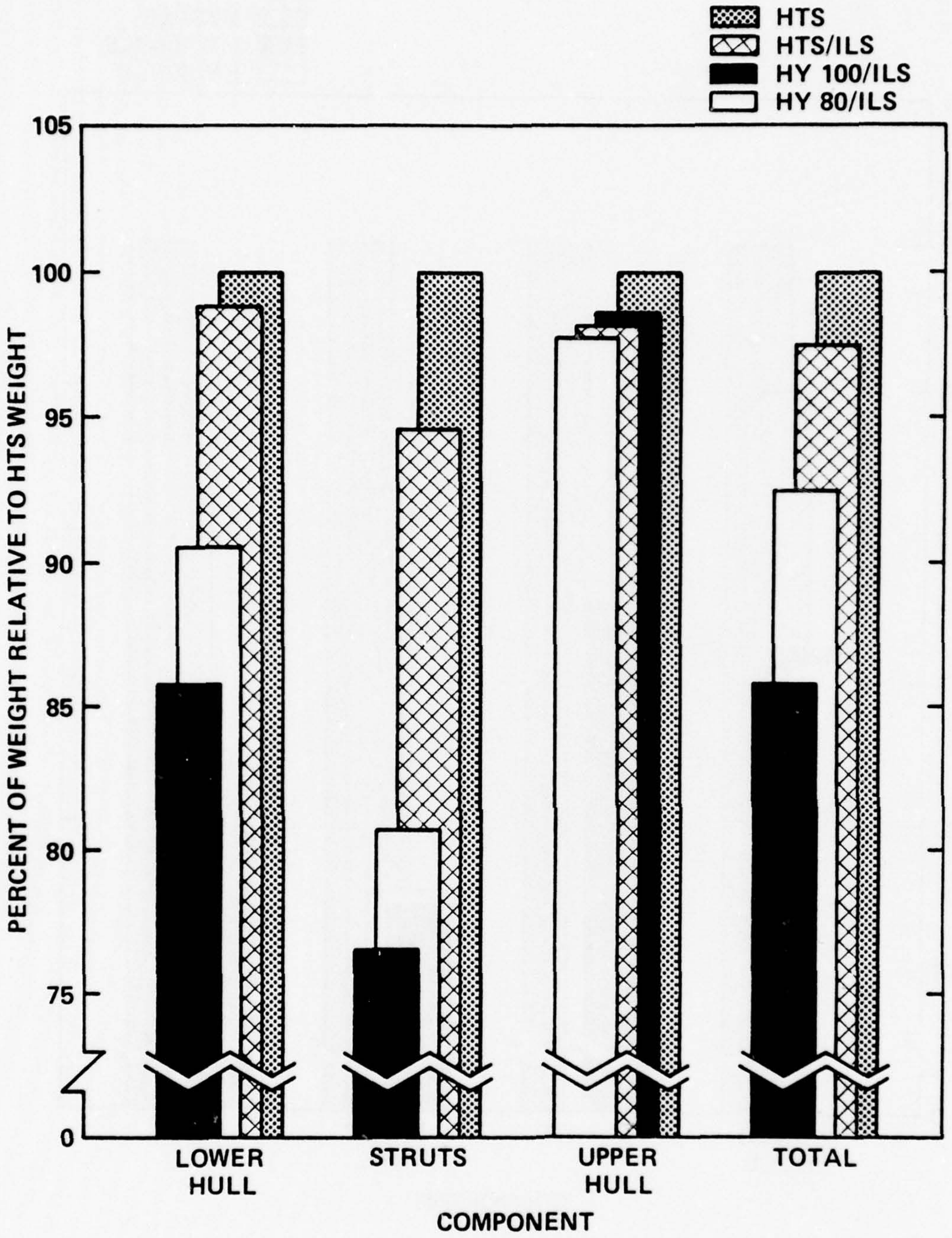

Figure 23 – Effect of Material and ILS on Primary Structural Weight - SWATH CVN ($\Delta = 27000T$)

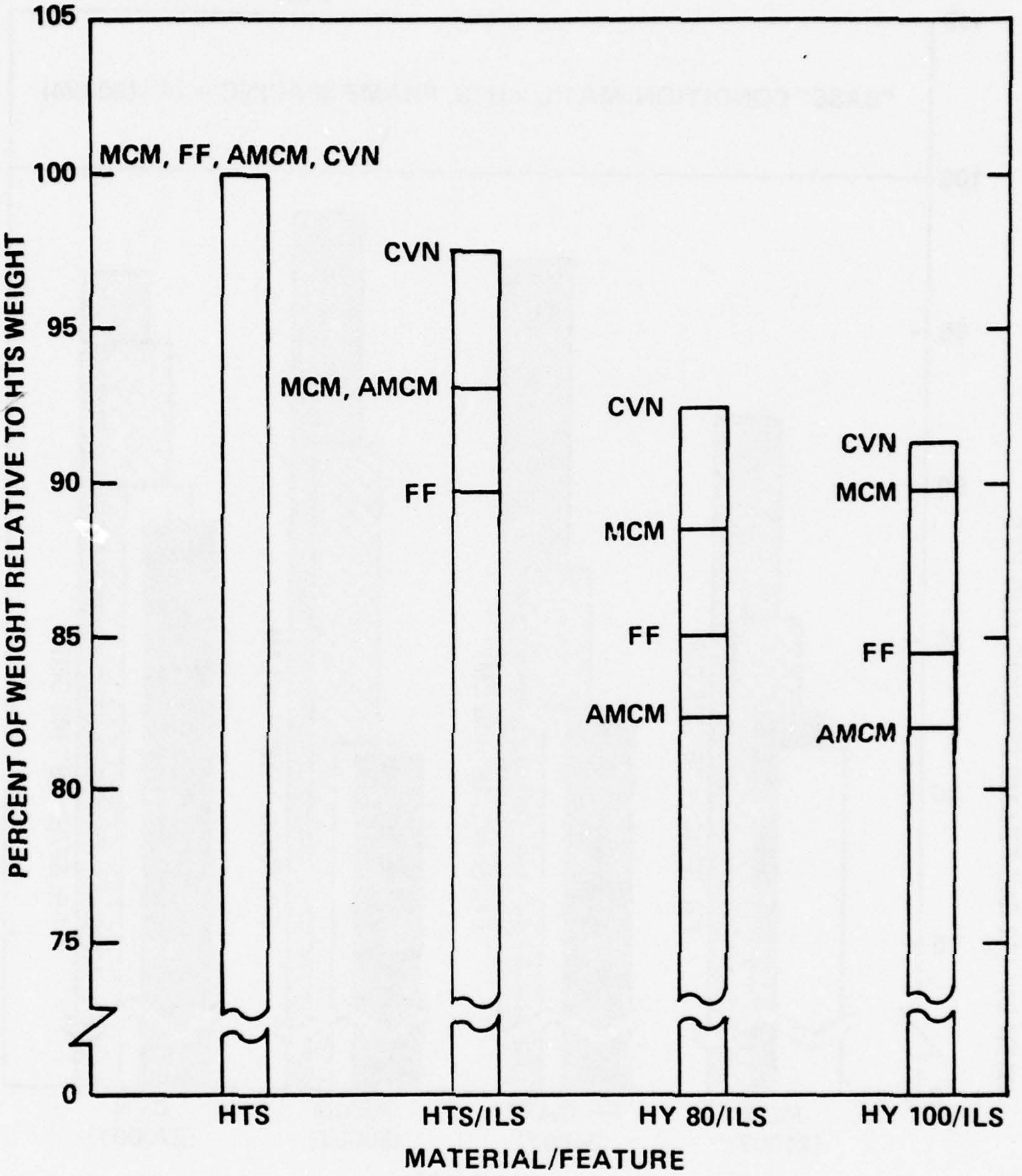

Figure 24 – Effect of Material and ILS on Primary Structural Weight - Total SWATH Ships

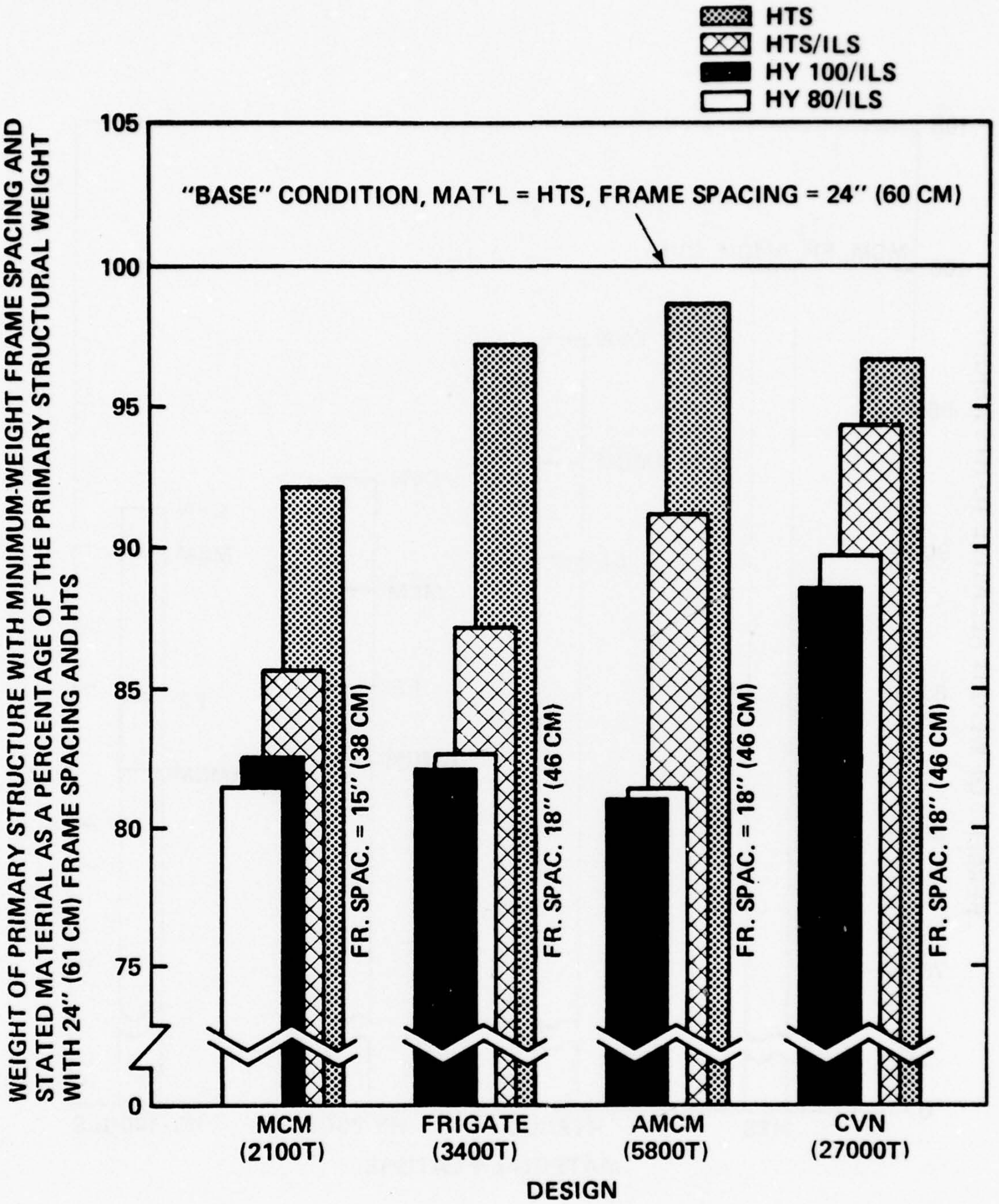

Figure 25 – Combined Material and Frame Spacing Primary Structural Weight Savings

Use of HY100 is generally not as profitable relative to HY80 as is HY80 to HTS. This is due to two reasons, which do not always apply simultaneously:

1. When HY80 is used, plate scantlings are often reduced to the 3/16" (4.8 mm) minimum thickness. Since the minimum is maintained, use of HY100 will not result in thinner plate or lighter plating weight.

2. When HY100 is used, a larger number of ILS's must generally be used. The cumulative weight of these ILS's can often offset the weight savings that might normally be expected in plating and stiffeners. The ILS's are required, due to reduced effective width, for high strength materials as discussed by Aronne, Lev, and Nappi.[1]

Summation

Figures 20 through 23 show the benefit of ILS and high strength material for each of the components of each ship.

Figure 24 shows the total effect of ILS and material for the four designs relative to that for HTS of minimum-weight frame spacing.

Use of high strength materials and ILS is not as beneficial for the SWATH CVN as it is for the other ships. This is probably due to the restriction that flight deck and hangar deck scantlings remain as originally designed for support of aircraft landing and parking loads.

CUMULATIVE EFFECT OF FRAME SPACING, MATERIAL, AND ILS

Figure 25 shows the cumulative benefit of combining altered frame spacing with intermediate lateral supports and high strength steels. This is shown as a fraction of what would be expected using HTS with 24" (61 cm) frame spacing as is done in the NAVSEC SWATH Synthesis Model.

It is clear that the potential savings are sizeable. Depending upon the designer's desires, this can be converted into increased fuel and payload, or reduced ship size.

As discussed earlier, past SWATH designs using the SSDP and SSM have agreed when consistant ground rules are used. In this study, the MCM and Frigate with 24" (61 cm) frame spacing and HTS designed using the SSDP showed very good agreement with those found by using the SSM. Therefore, it appears that these results could be applied to the SSM.

USE OF LONGITUDINAL GIRDERS

The MCM (Mod 1), Frigate (Mod 1), and Frigate (Mod 2) illustrate the benefit of using more longitudinal girders to reduce the span of transverse stiffeners. The transverse frames in MCM (Mod 0) had a span of 12 ft (3.7 m).

This was reduced to 6 ft (1.8 m) on MCM (Mod 1). The FF (Mod 0) transverse span of 16 ft (4.9 m) was reduced to 8 ft (2.4 m) on FF (Mod 1) and 4 ft (1.2 m) on FF (Mod 2). Further explanation of the structural layout is in an earlier section.

Table 5 shows the total weight of the Mod versions as a fraction of the equivalent Mod 0 version. The weights shown include the weight of extra girders and stanchions for the Mod versions.

For these ships, frame spacing was not reoptimized. It might be possible to use a frame spacing optimized for this type geometry and achieve even greater savings.

In these designs, only the upper box structure is affected. The lower hull and strut arrangements, scantlings, and weights remain exactly as they were for their Mod 0 counterparts.

A framing system with longitudinal girders might not be advantageous if the transverse bending moment is so large that it increases upper box scantlings above those required to satisfy local loads. Transverse bending is resisted primarily by the upper and lower flanges (deck and bottom shell) of the upper box. If plating and/or stiffener scantlings must be increased to provide enough area to reduce stresses to acceptable levels, then it is probably more worthwhile to use the larger stiffeners and omit some longitudinal girders. Thus, this framing system could be beneficial for the ship with one type of material and not beneficial if a lower strength material is used.

ALUMINUM PRIMARY STRUCTURAL WEIGHT AS A PERCENTAGE OF STEEL PRIMARY STRUCTURAL WEIGHT

The SSM estimates primary structural weight of aluminum SWATH ships by multiplying the estimated weight of the structure in steel times 0.55. This has been found to be appropriate in the past for ships with 24" (61 cm) frame spacing, but a further check was desired, and the applicability of this factor to ships with other frame spacings was questioned.

The primary structural weight of the Frigate in aluminum (5456) was estimated. Frame spacing was varied so as to find the frame spacing with the minimum structural weight.

The closest spacing that could be used was 21" (53 cm). This is because the SSDP has a requirement that the distance from the flange of one stiffener to the centerline of the next stiffener be greater than the stiffener depth (See p. 223 of Ref. 2.). This limit is based on providing sufficient clearance between stiffeners to permit ease of fitting up and welding during construction. When frame spacings closer than 21" (53 cm) were tried for this aluminum ship, the depth of stiffener required for support of the loads imposed failed to meet this requirement.

TABLE 5 - REDUCTION IN PRIMARY STRUCTURAL WEIGHT DUE TO USE OF LONGITUDINAL GIRDERS (REDUCED TRANSVERSE SPAN)

SHIP	HTS	HTS/ILS	HY80/ILS	HY100/ILS
	Fraction of Frigate/0 Primary Structural Weight			
Frigate/0	1.00	1.00	1.00	1.00
Frigate/1	0.915	0.97	0.978	1.01
Frigate/2	0.865	0.925	0.925	0.938
	Fraction of MCM/0 Primary Structural Weight			
MCM/0	1.00	1.00	1.00	1.00
MCM/1	0.914	0.955	0.950	0.944

Frigate/0 has 16 ft (4.9m) span for transverse frames.
Frigate/1 has 8 ft (2.4m) span for transverse frames.
Frigate/2 has 4 ft (1.2m) span for transverse frames.
MCM/0 has 12 ft (3.7m) span for transverse frames.
MCM/1 has 6 ft (1.8m) span for transverse frames.

Of the frame spacings studied, 24" (61 cm) produced the lightest structure, as shown in Figure 26. There is not a very great difference between the weights for any alternative frame spacings, in any of the components or in the total. This is explained further in the section on Material Influences.

Table 6 shows aluminum design primary structure weights and their comparison with similar steel designs. The comparison of designs with the same frame spacing (line 2) shows that, for this case, the aluminum/steel ratio of 0.55 is correct for the total weight, but not necessarily for each component of the ship (e.g., box, struts, lower hulls).

Comparing the best of the aluminum frame spacings with the best HTS spacing (line 3) shows the ratio increasing. The percentage weight improvement possible in aluminum is not as great as that in steel. Note that if the optimum frame spacings (non-constant spacing longitudinally) were used, this ratio would be closer to 0.55.

A design using optimized frame spacing and ILS was made for the aluminum frigate developed for the ANVCE study. When this is compared to the best frame spacing steel frigate with ILS (line 5), the ratio is much higher than 0.55 (Note: See Material Influences section).

When comparing Mod 1 frigates (line 7), the ratio is seen to be greater than 0.55.

These studies indicate that improvement potential in aluminum, while present, might not be as great as that in steel. This was only done for one ship. Before conclusive figures can be found, more aluminum-steel comparisons will be needed. It appears that the 0.55 ratio is satisfactory for the earliest design stages. At later stages, a detailed structural estimate and weight minimization effort should be carried out for the ship being designed.

SIDE FORCE

MCM Side Force And Effective Breadth Study

Early work, as described in Ref. 1, indicated that the transverse wave-induced bending moment is caused by a force applied at the center of each lower hull. Its magnitude could vary from $0.6 \times \Delta$ to $0.4 \times \Delta$ for displacements from 2000T to 20000T respectively. An average of $0.5 \times \Delta$ was generally used for conceptual designs and is the value used in this study.

More recent work* shows that the side force acts at the half-draft rather than at the lower hull center. Its value is $0.5 \times \Delta$ to $1.0 \times \Delta$, depending on a number of factors including displacement, strut length, hull separation, and draft. The net effect is that the transverse wave-induced bending moment is generally larger than was earlier thought. The two side force estimates are illustrated in Figure 27.

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*An unpublished report by J.P. Sikora and J.N. Andrews

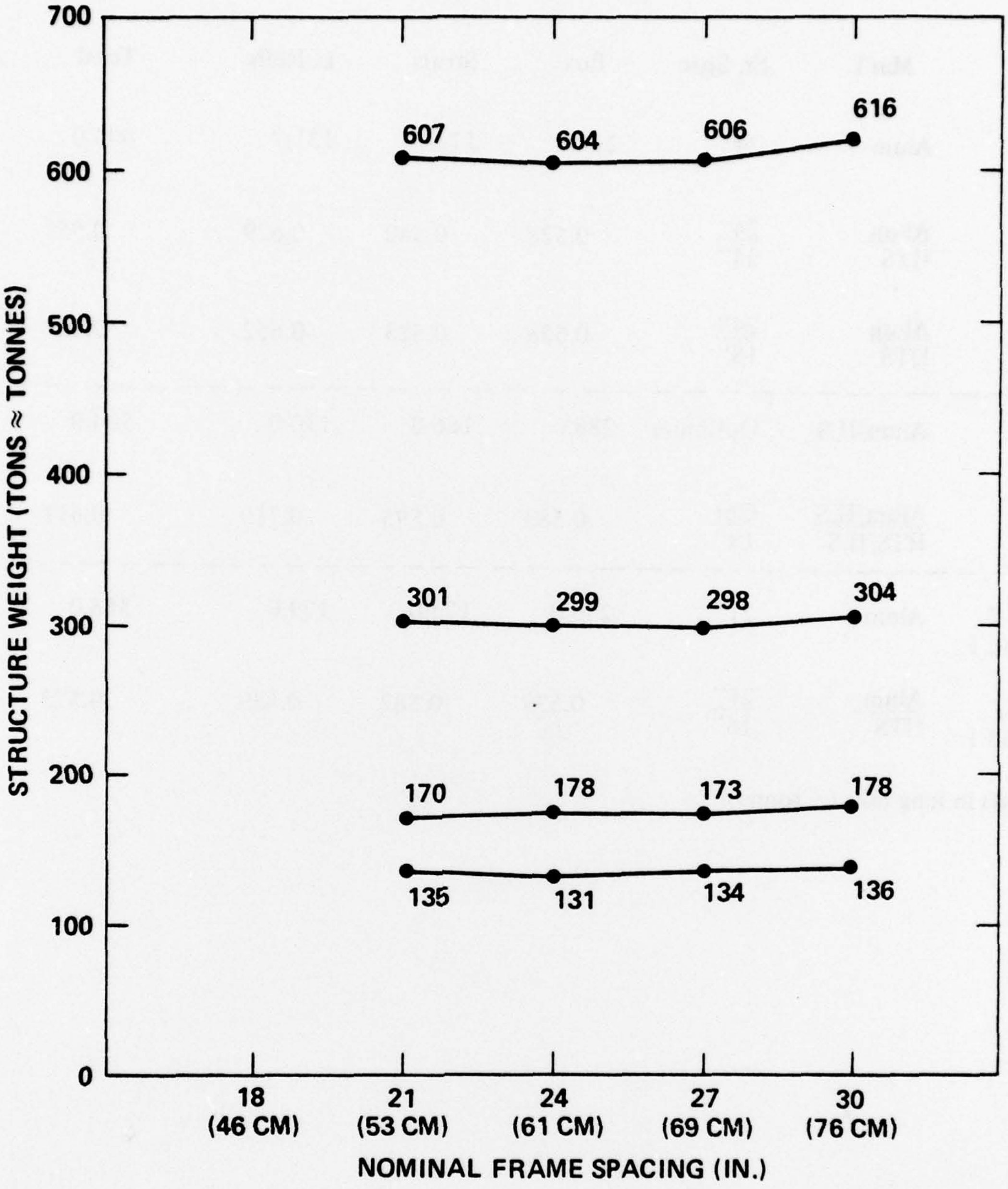

Figure 26 — SWATH Frigate (3400T) - Aluminum - Primary Structural Weight vs Frame Spacing

TABLE 6 - ALUMINUM PRIMARY STRUCTURAL WEIGHTS - SWATH FRIGATE (3400T)

Ship	Mat'l	Fr. Spac	Box	Struts	L. Hulls	Total
1. FF.	Alum	24"	299.1	173.1	131.7	603.0
2. FF.	Alum HTS	24" 24"	0.528	0.542	0.629	0.551
3. FF.	Alum HTS	24" 18"	0.528	0.583	0.652	0.567
4. FF.	Alum/ILS	Optimum	288.0	166.0	130.0	584.0
5. FF.	Alum/ILS HTS/ILS	Opt 18"	0.583	0.595	0.710	0.611
6. FF./ Mod 1	Alum	21"	256.0	173.0	129.0	558.0
7. FF/ Mod 1	Alum HTS	21" 18"	0.539	0.582	0.639	0.573

Weights in long tons (~ tonne).

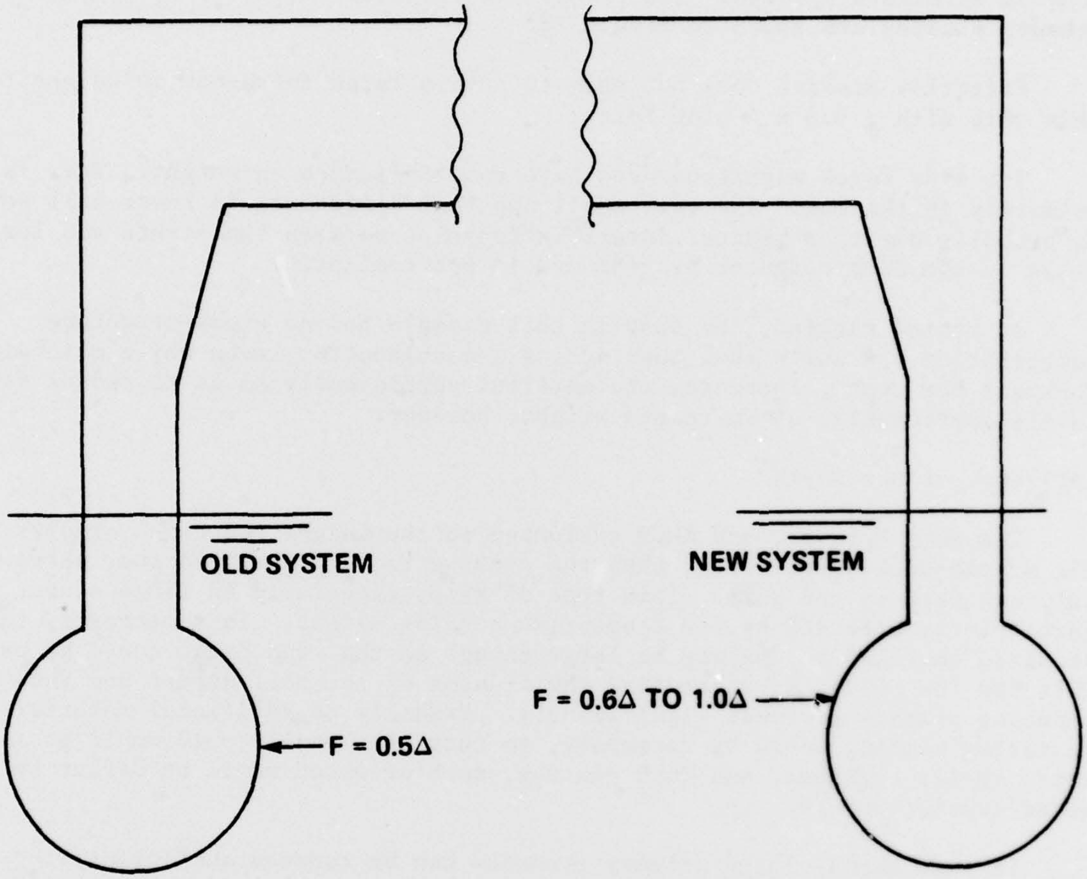

Figure 27— SWATH Side Force Estimating Schemes

A study of the significance of side force for the MCM was made. The version studied did not have a cross-structure doublebottom. The box depth was 10 feet (3 m).

On a SWATH design conducted at an earlier date, it was estimated that only 76% of its material would be effective in resisting transverse bending. Therefore, a study was made using the same MCM with a 0.5 x Δ side force and 75% effective breadth. The results of the side force and effective breadth studies are shown in Figure 28.

Effective breadth does not seem to have a large influence on weight for this ship with a 0.5 x Δ side force.

The side force magnitude does have some influence on weight. This is primarily in the box. The very small apparent difference in lower hull weight is probably due to numerical interrelationships between the struts and lower hulls in the SSDP computer program and is not realistic.

As stated earlier, the ship in this example had no cross-structure doublebottom. Results show that adding a doublebottom, even while maintaining constant box depth, increases the material sufficiently so as to reduce stress levels appreciably, at increased weight, however.

Influence of Box Depth

The MCM, Frigate, and AMCM evaluated in the weight reduction studies were all single-deck ships (other than the cross-structure doublebottom, there is only one deck in the box). This type of ship, especially in large sizes, is particularly affected by the transverse bending moment. In some cases, the required enclosed volume may be large enough so that two decks could be used. This had the effect of separating the flanges of the hull girder and thus reducing primary stresses significantly. Probably no additional material for resisting bending would be necessary, so that the penalty paid would be in extra shell, bulkhead, and deck plating, much of which would be offset by reduced superstructure.

In some cases, large primary stresses can be reduced sufficiently on one-deck ships by increasing the deck height by one or two feet. A small penalty in shell and bulkheads is paid, but no additional material is needed in the upper and lower fibers and enclosed volume is increased.

Influence of ILS and Longitudinal Girders

Use of ILS and longitudinal girders tends to cause a large decrease in transverse material with a smaller increase in longitudinal material. As discussed previously, the decrease in transverse material can be counterproductive in ships with large primary stresses. The transverse material that was removed would otherwise have been available to resist bending. This was found to be unimportant in the steel ships studied with the 0.5 x Δ side force used. The best combination of longitudinal and transverse material should be studied on a ship case basis.

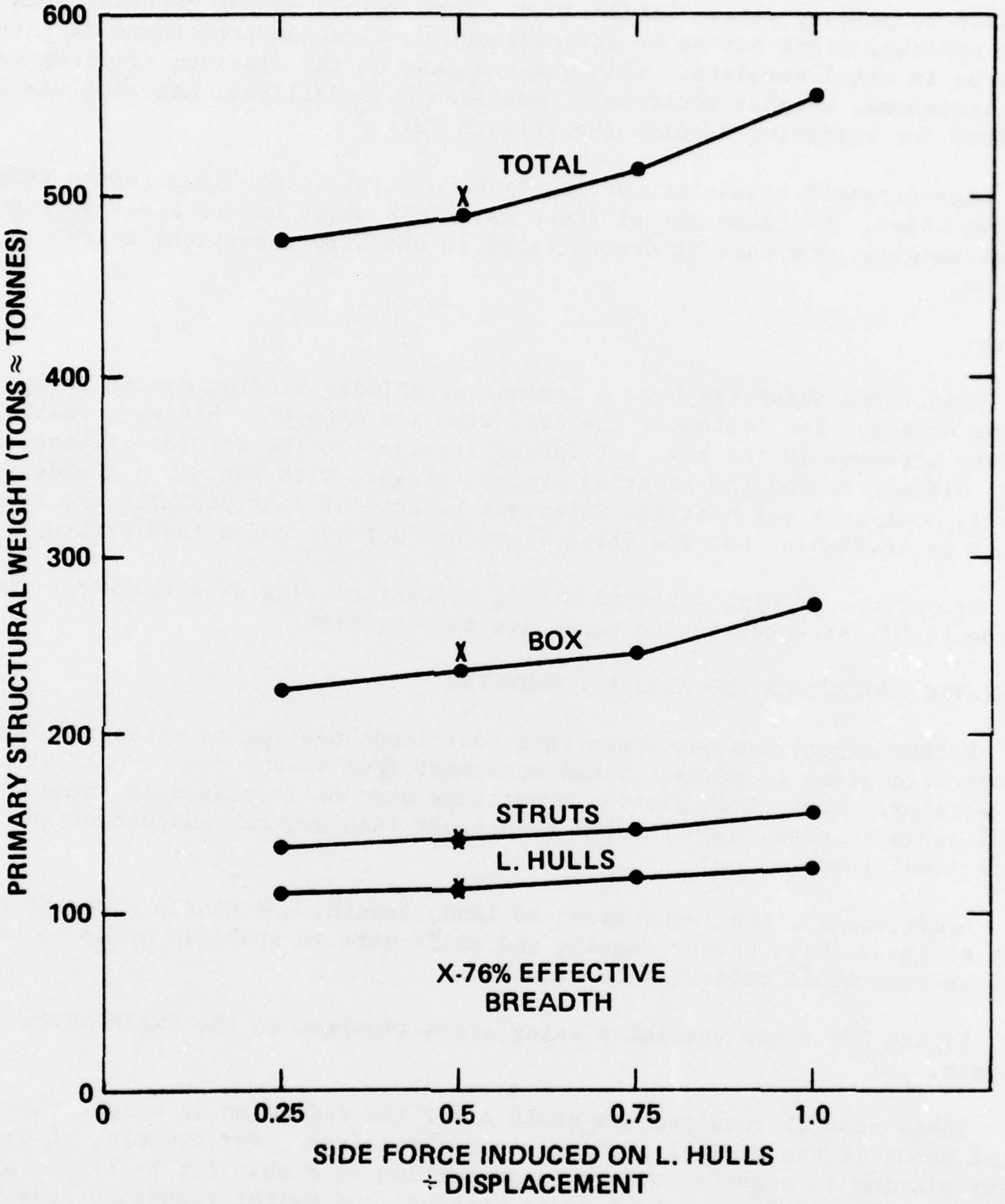

Figure 28 – SWATH MCM Ship (Δ = 2100T) Without Doublebottom Sensitivity of Primary Structural Weight to Lower Hull Side Force

Material Influences

Aluminum (5456) has less strength than steel. It is therefore more susceptible to primary stress limitations. Some weight saving methods (such as frame spacing) might not be as advantageous on aluminum structures as they might be in steel versions. This was the case on the aluminum frigate; in some instances, weights would have been less but additional material was required for resisting bending (See Figure 26).

High-strength steels are obviously beneficial in highly stressed ships. In some cases, judicious use of these materials where needed can save significant weight. One case is demonstrated in the Struts section, which follows.

Struts

Some large ships can have a dominating primary bending moment influence in the struts. For instance, the CVA, with its deep box, has very small primary stresses in the box, but larger stresses in the struts. (These, however, did not exceed the limiting primary stress, with the 0.5 x Δ side force.) This is most critical near the waterline because at that position the bending moment is increasing but the strut flare has not yet begun (See Figure 29).

Proper use of high strength steel, thicker plating or a thicker strut in the highly stressed region can solve this problem.

BALLISTIC PROTECTION AND AIRCRAFT HANDLING

Recent experience has shown that additional plating is often required in specific areas to protect vital equipment from damage due to ballistic projectiles. Very often plating scantlings must be increased in these local areas to sizes much thicker than those required for support of the usual local loads.

Additionally, the requirement to land, launch, and handle aircraft on many of these ships causes plating and stiffeners in specific areas to be heavier than would otherwise be required.

Figure 30* shows special plating areas required on the SWATH ANVCE Frigate.

These special requirements could alter the reduction in weight that might occur if the special plating was not required. For example, if special heavy plating is required over a large portion of a ship for ballistic protection, the size of frames, best frame spacing, and weight reduction possible through use of the best frame spacing could differ from that predicted for the ship without special plating. In such cases, detailed specific studies would be necessary for determination of the true primary structural weight.

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*From a report of higher classification by Stevens and Lamb.

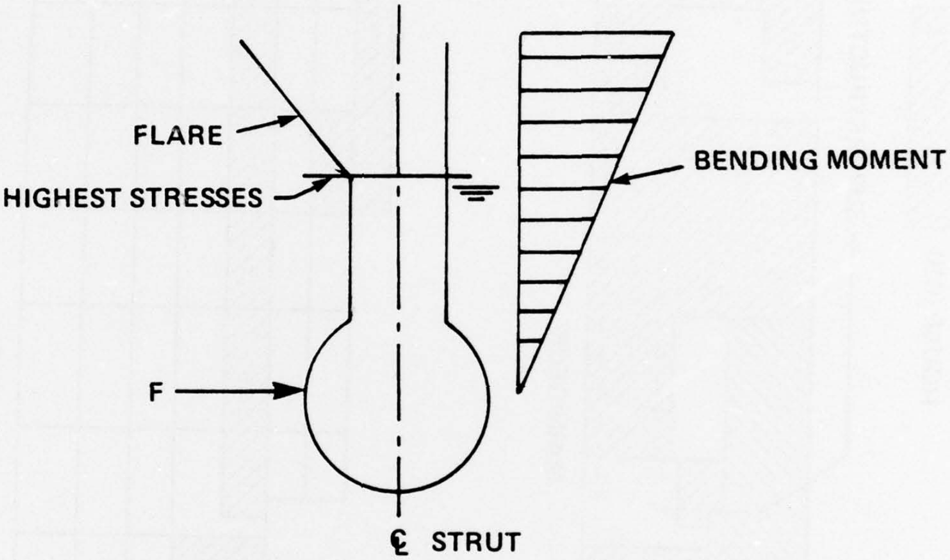

Figure 29 - Strut Bending Moment Buildup

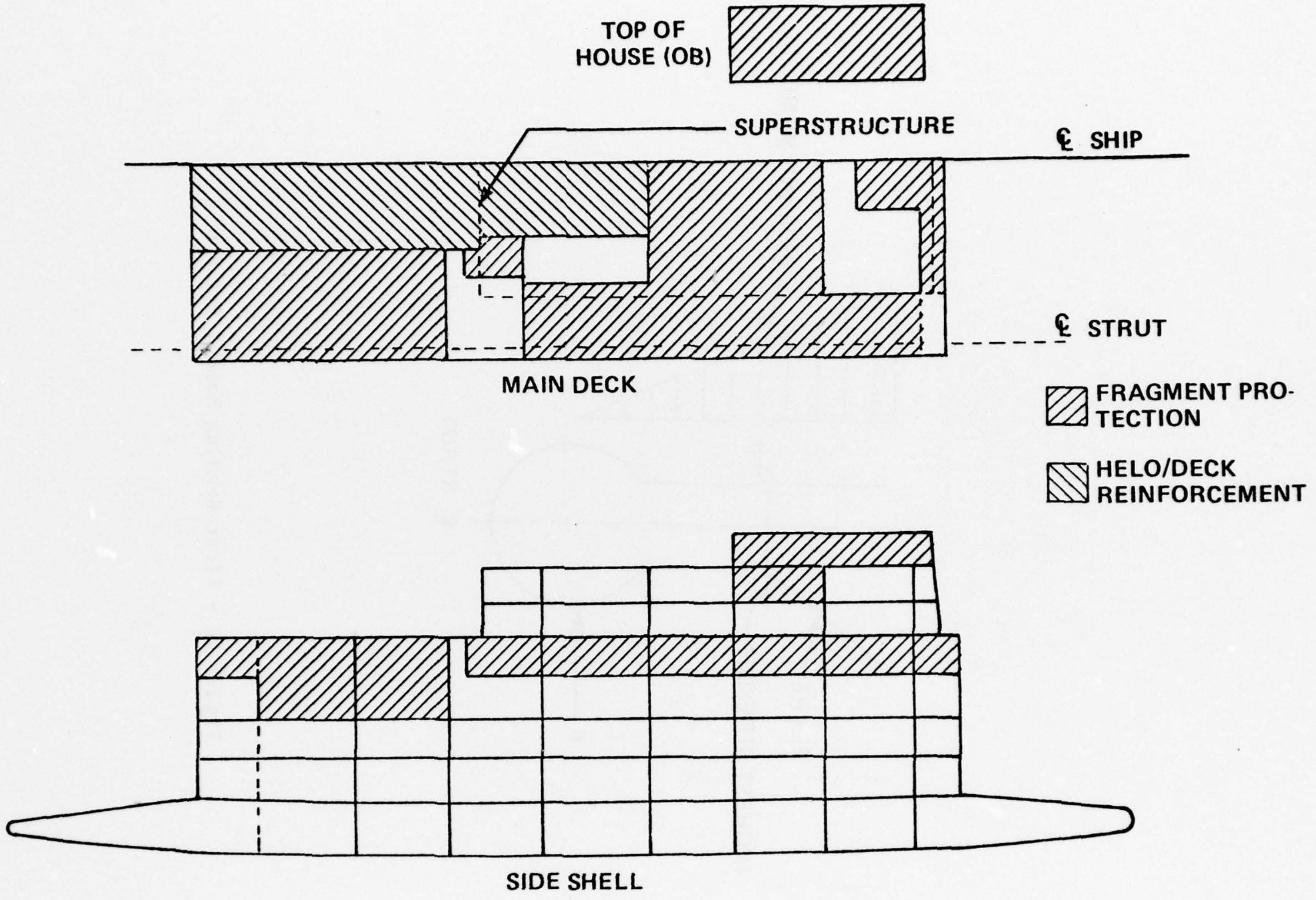

Figure 30 Aluminum Frigate Special Plating Areas (From a Report of Higher Classification by Stevens and Lamb)

COST COMMENTS

The benefits of weight savings cannot be examined alone. The cost of including these savings must also be studied.

In an effort to reduce the weight of advanced craft, many extreme techniques can be implemented. Non-standard plating thicknesses, extremely close frame spacing (under 1 ft (0.3 m)), lightening holes in stiffeners, and exotic materials, etc. could all be used. These could cause an increase in cost, however, and were not studied.

Use of closer frame spacing, ILS, and addition of longitudinal girders could cause an increase in cost, primarily through increased labor cost required for installation of a larger number of pieces. This is not believed to be as significant as the possible increased cost due to such things as lightened stiffeners, or titanium construction, for example.

HY80 and HY100 cause an increase in cost due to material prices. Labor costs may also increase due to a larger number of ILS's. It might be best to conduct a detailed study to determine the portions of the ship in which HY80 and HY100 would permit the greatest reduction in weight. These materials would then be used only in such critical areas.

The advantage of using any of the weight saving measures examined in this study must be balanced against its cost for the particular ship application. This is a judgment decision which ultimately rests with the designer.

Some of the expected additional labor cost for including a greater number of structural pieces in the ship to reduce weight can be offset by expected characteristics of SWATH construction. A very large proportion of a SWATH's structure is composed of flat or single-curvature stiffened panels. These are especially suitable for semi-automatic fitting and welding which, in an appropriately equipped shipyard, can significantly reduce construction labor costs.

DETAILED STRUCTURAL DESIGN

Use of a simple structural weight-estimating algorithm such as that included in the SSM is quite valuable in the early stages of design when it is being iterated for preliminary sizing estimates. However, as the design proceeds, more precise estimates of structural weight are desired. These can only be had through use of detailed design techniques and such tools as SSDP. The SSDP can be used to evaluate the effect of such things as special plating, and can vary many of the design parameters to yield the combination with the lowest primary structural weight consistent with cost and other requirements.

CONCLUSIONS

A. Primary structural weight can usually be reduced (10%-20% relative to the base SSM) through varying frame spacing, using intermediate lateral supports, applying high strength steels, and using longitudinal girders and short transverse spans. The particular techniques used on any ship and the possible savings will depend on many ship-related factors and will vary from ship to ship. However, for early design, these savings can be predicted and should be incorporated in the SWATH Synthesis Model.

B. Computer programs which are used to estimate structural weight should allow flexibility in the number and location of major structural elements such as decks, cross-structure doublebottom, and bulkheads. The decision to include any of these and the number to be included should be based on actual arrangements, safety, stability, and structural requirements rather than on preprogrammed instructions.

C. While local loads continue to drive SWATH structural weight, transverse bending is of increasing importance. The magnitude of this moment is derived from the ship's geometry. The amount of material required to resist this is based on the ship's geometry, material of construction, and framing system used. This influence should be examined on a case basis.

D. The NAVSEC SWATH Synthesis Model, with proposed modifications, is a valuable tool in the early (feasibility) phase of SWATH design. The best combination of loads, structural arrangement, frame spacing, and materials will vary from ship to ship. Therefore, after the approximate ship size is determined using the SSM, the SWATH version of the Structural Synthesis Design Program should be exercised using these variations to estimate the weight (conceptual design).

ACKNOWLEDGMENTS

The support of Mr. L. Benen, NAVSEA 0321, in recognizing the need for this work is appreciated.

The author is also grateful to N. Nappi, F. Lev, and R. Walz (DTNSRDC/1730) for their assistance with the SSDP and their general aid in this project. Special thanks go to E. Aroone and C. Kennel (NAVSEA/6114) for their assistance and review of this work, and to G. Lamb (DTNSRDC/1110) for providing the configurations and many suggestions for weight-saving. The supervision and review of this work by G. Elmer (DTNSRDC/1102) and S. Hawkins (1170) is appreciated.

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