A PROCEDURE TO EVALUATE THE FEASIBILITY OF NAVAL SHIP DESIGNS

by

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ABSTRACT

The utilization of computerized ship synthesis models to generate surface combatant conceptual designs has caused a lack of common-sense understanding of the factors effecting ship design and has resulted in the loss of manual ability to check the feasibility of these conceptual designs. A procedure is presented which simply and quickly checks the gross characteristics and weight allowances of a proposed design by comparison to already built or designed U.S. Navy surface combatants of all types. These comparisons are performed by defining relevant design parameters and utilizing graphs which show feasible regions for these parameters. The convenience of this procedure is illustrated by the performance of feasibility checks on two proposed designs.

Thesis Supervisor: Clark Graham
Title: Adjunct Professor of Marine Systems

ACKNOWLEDGEMENTS

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NOMENCLATURE

Δ = full load displacement, tons

∇ = total enclosed volume of hull and superstructure, cubic feet

SHP = maximum continuous installed propulsive power at V_s

SHPL = maximum continuous installed lift power at V_s

KW = installed electrical generation capacity, kilowatts

M = ship's complement, men

V_s = maximum continuous sustained speed in a 1.4 meter wave sea state, knots

V_c = cruise speed, knots

W1 = weight of SWBS category 100 (Hull Structure), tons

W2 = weight of SWBS category 200 (Propulsion Plant), tons

W3 = weight of SWBS category 300 (Electrical Plant), tons

W5 = weight of SWBS category 500 (Auxiliary Systems), tons

W567 = weight of SWBS category 567 (Lift System--includes fans, fan engines, and seals for SES/ACV's; includes foil lift systems for hydrofoils), tons

W6 = weight of SWBS category 600 (Outfit and Furnishings), tons

WCREW = weight of SWBS loads F10 (Crew Personal Effects) + F30 (Stores) + F52 (Potable Water), tons

WFUEL = weight of ship's fuel used for propusion, lift, and electrical power generation, tons

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CHAPTER 1

INTRODUCTION

Computer based ship synthesis models are used to generate many, if not most, surface combatant conceptual designs. As a result of this reliance on computers, naval architects, marine engineers, and ship design managers have less common-sense understanding of the factors affecting surface ship design than they had prior to the use of computers. At the same time there has been a decrease in the number of personnel capable of manually producing and checking conceptual designs.

This thesis introduces a simple procedure for graphically checking the validity of proposed Navy surface combatant ship designs. Basically, the procedure compares the characteristics of proposed ship designs to those of Navy ships which have already proven to be feasible. This procedure consists of a series of individual characteristic feasibility checks.

In the first section of this paper the ship's characteristics to be checked are selected. Then the methodology is developed for checking these individual characteristics and for checking the overall design feasibility. Next, parameters involving these characteristics are defined and the graphs used for comparing values of these parameters are presented. Finally, as an illustration of the use of the procedure and graphs, two proposed designs are checked for feasibility.

CHAPTER 2

PROCEDURE

This chapter describes a procedure for checking the feasibility of a proposed Navy surface combatant design. It is applicable to monohull, small-waterplane-area-twin-hull (SWATH), hydrofoil, surface effect ship (SES), air cushion vehicle (ACV), and planing type ships. The first section of this chapter tells what characteristics of a proposed design will be checked and presents the procedure developed for checking them. The second section discusses the application of this procedure.

Section 2.1 - Characteristic Selection and Development of the Procedure

The procedure presented here is at the lowest level of detail possible and still maintain the significance of the feasibility checks. This was done to make checking a design simple, quick, and easy. Gross ship characteristics and Ship Work Breakdown Structure (SWBS) weights(1) at the single digit level are checked. The configuration (i.e. dimensions and shape) of the ship is not checked. Nothing to do with payload is checked, but it is assumed that a typical military payload is to be carried by the proposed design.[1]

[1]Where payload is defined as SWBS categories 400 and 700 and all payload related loads.

One of the basic requirements for the feasibility of a design is to have the capacity to provide the volume, energy, and crew required to support the payload and satisfy the mobility requirements (range and speed) specified in the ship's Top Level Requirements (TLR). To check the gross capacities of the ship, checks of total ship enclosed volume (∇), installed propulsive shaft horsepower (SHP) at sustained speed, installed lift shaft horsepower (SHPL) required at sustained speed, installed electrical power generation capacity (KW), and crew size (M) are made.

In order to make these capacity checks the proposed design's full load displacement (Δ) is taken as the given measure of the proposed design's size and is not allowed to vary. Additionally the following requirements and characteristics of the proposed design are inputted: ship type, propulsor type, and the design's values of the characteristics to be checked. These checks and the information required to make them are summarized in the upper section of the Procedure Flow Chart (Figure 1).

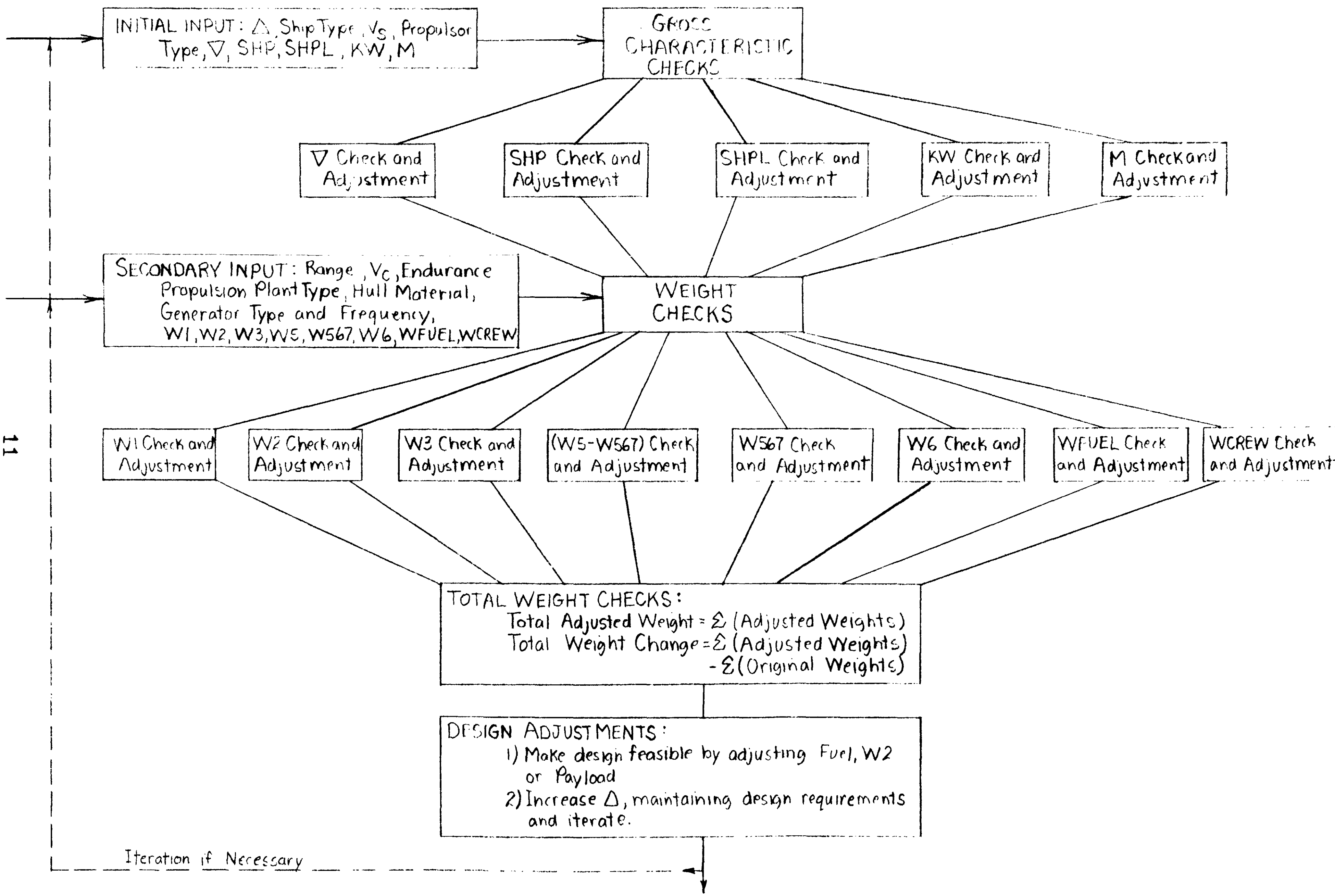

Figure 1. Procedure Flow Chart

After these five capacities are checked and adjusted, the proposed design's weight allowances needed to provide these required capacities are checked. The weights checked are all those not associated with payload. Weights are checked instead of volume because most high performance Navy surface ships are weight limited instead of volume limited.[1] The weights checked are listed in Table 1 by function and SWBS category. The abbreviation for each weight is also included.

TABLE 1

WEIGHT CHECKS

SWBS Weight Group	Abbreviation	Function
100	W1	hull structure
200	W2	propulsion plant
300	W3	electrical plant
567	W567	lift system: --including fans, fan engines and seals for SES/ACV; --including foil system for hydrofoils.
500-567	W5-W567	auxiliary system, not including the lift system
600	W6	outfit and furnishings
F10+F30+F52	WCREW	crew related loads
part of F40	WFUEL	ship's fuel weight, not including payload related fuel.

[1]Time constraints did not permit a check of volume in this thesis. However, it is recommended that this work be extended to include volume checks.

To check the weights in Table 1 the additional ship characteristics listed below are required:

TABLE 2

SECONDARY INPUT

- Range
- Cruise Speed (V_c)
- Endurance
- Propulsion Plant Type
- Hull Material
- Generator Type
- Generator Frequency
- Reduction Gear Type
- The designer's values of the weights listed in Table 1.

The weight checks in Table 1 and the secondary information requirements in Table 2 are summarized in the middle section of the Procedure Flow Chart.

In general the tests indicated in the Procedure Flow Chart check whether there is too little, enough, or too much capacity or weight allowance given the ship's input characteristics. However, in the case of the total enclosed volume (∇) check, it is assumed that all the volume specified is required. Therefore this characteristic is only adjusted upward. This is done primarily because more detailed volume checks are required to get an accurate check on volume. Values for the other capacities are adjusted upward or downward, as appropriate. In most cases engineers tend to be optimistic so that underdesign is more of a problem than conservatism.

Section 2.2 - Use of Procedure

The checks outlined above can be utilized in a variety of ways, ranging from individual spot checks of a particular design characteristic to a procedure which involves all the checks and looks at the overall feasibility of the proposed design.

The first case is the simplest, involving merely checking the characteristic of interest as indicated on the flow chart to find out whether there is enough capacity or weight in a particular area. If a capacity is checked, then the procedure can be carried one step further to get the weight impact of the revised capacity characteristic.

Overall design feasibility can be checked by running through the entire procedure outlined on both pages of the flow chart. An abbreviated procedure would be to assume that all the proposed design's capacity characteristics are acceptable, and just carry out all the weight checks shown on the second page. In any case, where all the weight checks are performed, it is important to look at the overall impact as indicated at the end of the flow chart. It may be that the additional weight required by some weight groups is cancelled by the reduced weight in others. A second possibility is that several characteristics or weights are just marginally acceptable. In this case a more detailed engineering analysis may be required to check the overall feasibility of the design.

In some cases it may be that additional weight is required to make the design feasible. If the required additional weight is not too great, there are several ways the proposed design can be modified to make it feasible without changing the full load displacement:

1) The payload that the design is to carry can be reduced by the amount of additional weight required.
2) The fuel carried by the design can be decreased, resulting in a proportionate decrease in range.
3) The installed shaft horsepower can be lowered, resulting in a slower maximum speed and a reduced propulsion plant weight to compensate for the additional weight requirement.

Any one or any combination of these modifications can be employed. In making a modification it is important to look at the design and make the adjustments which are "least damaging" overall.

For some proposed designs the additional weight required is so large that a minor adjustment is not feasible, or the design requirements are inflexible so that no decrease in performance is acceptable. In these cases the displacement of the design must be arbitrarily increased and the procedure shown used iteratively as a design tool to get a feasible design.

Section 2.3 - Summary and Conclusions

A procedure for checking the feasibility of Navy surface ship designs has been developed. This procedure can be utilized to check the gross characteristics and weights of surface combatant ships of different types. In addition to checking overall design feasibility, the above procedure can also be used for spot checking the feasibility of individual characteristics of a given design. With relatively little modification this procedure can be utilized as a design tool to get a gross ship size estimate.

CHAPTER 3

GRAPHS UTILIZED BY THE PROCEDURE

This chapter provides the graphs which are used to estimate the feasible range of values for a proposed design's gross characteristics and weight estimates as introduced in Chapter 2 and shown on the Procedure Flow Chart. Discussion and explanation is provided with each graph. Conclusions drawn from the graphs are summarized at the end of the chapter.

Section 3.1 - Presentation of Graphs

For each characteristic there is a discussion section which explains on what key variables the characteristic depends, and introduces the plots utilized to show a feasible range of values for the parameter involving the characteristic. Observations and trends based on analysis of the graphs have been listed, followed by an explanation of these trends.

The points plotted on each graph represent actual built or designed U.S. Navy ships.[1] If only designed, the designs have been carried far enough to demonstrate technical

[1]No points are plotted on the curves used for checking SHP or WFUEL because of the classified nature of speed and range information. Feasibility bands are drawn, however, based on actual data.

feasibility. The different types of ships are differentiated on the graphs by the use of the symbols in Table 3. The darkened-in symbols represent the two designs which are checked in Chapter 4.

TABLE 3

DATA POINT SYMBOL KEY

△ monohulls

□ hydrofoils

▽ planing and semi-planing ships

○ surface effect ships and air cushion vehicles (SES's and ACV's)

◇ small-waterplane-area-twin-hull ships (SWATH's)

For each plot all data points are drawn on a single plot to show differences, if any, between different types of ships. Where appropriate and where enough points exist, bands are drawn, by type of ship to show the range of values for the particular parameter. In cases where there is no noticeable difference between ship types only one band is drawn. Even in the cases of planing ships and SWATH's where no bands are drawn because of the lack of data points, the few known designs are plotted so that they can be compared to the other ship types. As more of these types of ships are designed and built, more points can be added and more bands drawn.

3.1.1 Characteristic ∇

∇ = total volume enclosed by the ship's hull and superstructure.

Discussion

The volume of a ship is determined by the volume required by the components that make up the ship. Components which have the most significant effect are the main propulsion plant and lift system, the habitability and maintainability volume requirements, the amount of tankage for ship's fuel, and the payload volume. Since individual volume estimates for each of these components are not made, volume is based on the overall size of the ship as reflected in the full load displacement. In an effort to maintain a level plot, density ($\frac{\Delta}{\nabla}$) was chosen instead of volume for the ordinate. The abscissa of Δ was chosen so that any density variation with ship size could be observed.

Observations and Trends

- There is considerable variation in ship density between ship types. Monohulls are the most dense; hydrofoils and planing ships slightly less dense; and SES/ACV about one half the density of monohulls. A fairly narrow band of density can be drawn for each ship type.

- There is no noticeable change in density with size or time for any of the ship types.

- Within the monohull ship type there is considerable variation with propulsion plant type. The more recent monohulls have considerably lower density than older ships of the same type.

- The monohull at about 80,000 tons displacement has relatively low density.

- The large SES's have very low densities even for surface effect ships.

Explanation of Trends

- The observed differences between ship types are explained by basic differences between ship types: Monohulls are volume limited; therefore volume and not weight is most carefully controlled, resulting in relatively high densities. Most high performance ships are weight limited because they lift their weight to reduce drag at high speeds. Volume is not critical so they have lower densities. In contrast to monohulls they generally have aluminum hulls to save weight.

- The variation between high performance types is also explainable. SES/ACV's require large cushion areas and hense have large internal areas. Additionally, they employ very undense lift systems with great amounts of air ducting along with relatively undense gas turbine propulsion plants with waterjet propulsors. Hydrofoils have dense foil systems which keep them, in general, above planing craft.

- Densities within a ship type stay relatively constant with size because the weight and volume allocations to different functions usually stay relatively constant.

- The densities of the gas turbine powered monohulls are less than the steam powered ships because gas turbine plants are less dense than steam plants and because these ships carry less dense payload and also have more habitability volume.

- The large monohull, an aircraft carrier, is less dense because of the nature of its payload and the large open aircraft maintenance areas.

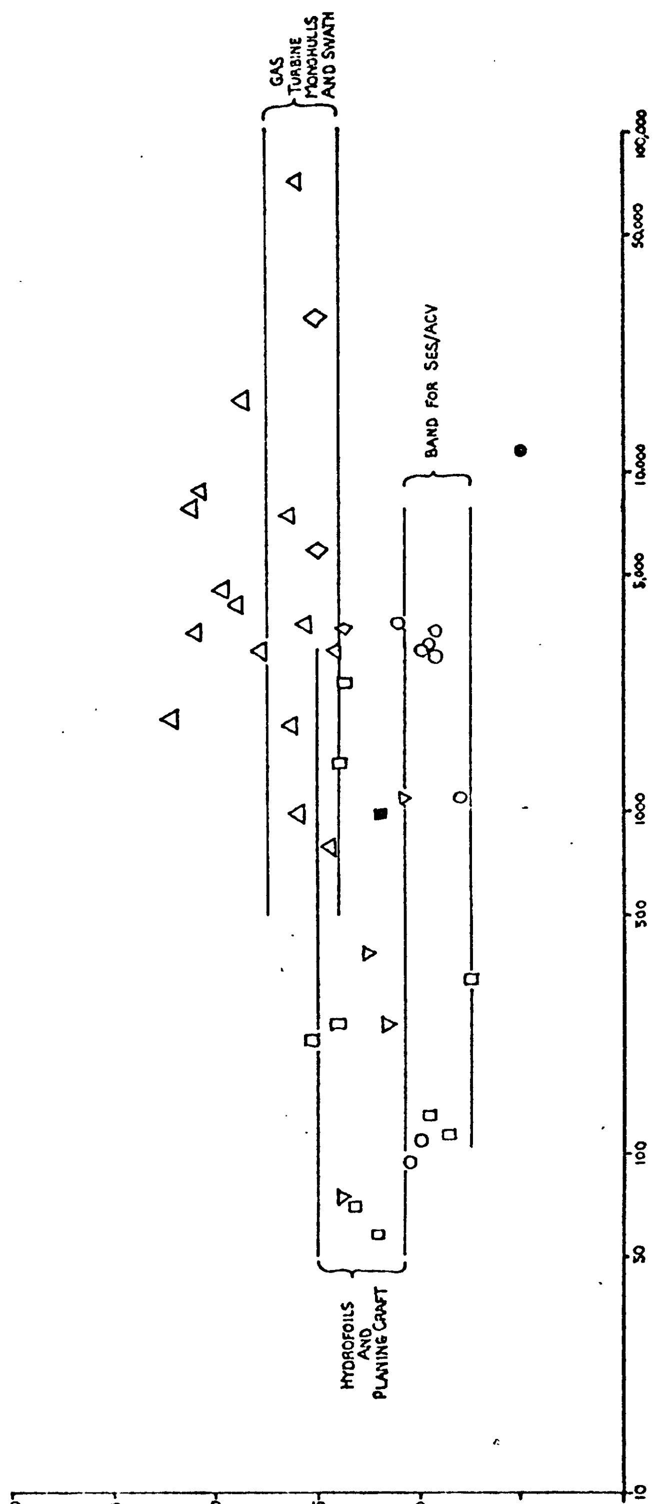

FIGURE 2. $\frac{\Delta}{\nabla}$ versus Δ

3.1.2 Characteristics: SHP and SHPL

SHP = total propulsive shaft horsepower required at V_s

SHPL = total lift shaft horsepower required at V_s

Discussion

SHP is a complex function of ship type, size, and shape, and V_s. In general the horsepower required increases faster than the maximum speed no matter what type of ship is being considered. SHP/Δ versus Δ was plotted so that any variation with size could be noticed. Contours of speed are indicated on this plot.

SHPL is primarily a function of the SES/ACV's weight (Δ). It also varies with the ship's speed because leakage losses increase as waves are encountered at a faster rate.

Observations

- All monohulls have slow speed, subcavitating propellers and fine hulls with approximately the same shapes.

- All hydrofoils have submerged foils.

Trends

SHP/Δ varies a great deal with ship type. The trends for each ship type are as follows:

Monohulls

- For a given speed SHP/Δ decreases as Δ increases.
- For a given size SHP/Δ increases faster than V_s increases.
- SHP/Δ doesn't change significantly with time or technology.

Hydrofoils

- For a given speed SHP/Δ decreases slightly as Δ increases.
- For a given size SHP/Δ increases faster than V_s increases.
- SHP/Δ doesn't change significantly with time or technology.

SES/ACV

- For a given speed SHP/Δ decreases rapidly as Δ increases.
- There are not enough data points to confidently state other trends.
- SHPL/Δ appears to stay relatively constant as displacement increases.

Planing/Semi-Planing

- There are not enough data points to state trends.

Explanation of Trends

Monohulls: The observed trends are easily explained by classic ship resistance theory as found in PNA.[2]

Hydrofoils: According to a simplified explanation of hydrofoil drag by Mandel[3] SHP/Δ is a constant at different values of Δ at constant speed. A more sophisticated analysis by Mao[4] indicates that SHP/Δ for a submerged foil hydrofoil is a complex function of many variables and decreases slightly with Δ.

SES/ACV: The explanation and plots presented by Mandel[5] confirm the slope and magnitudes of the bands presented.

Planing/Semi-Planing: According to Mandel[6] semi-planing hull resistance per ton decreases significantly with Δ and planing resistance per ton stays about the same as Δ increases.

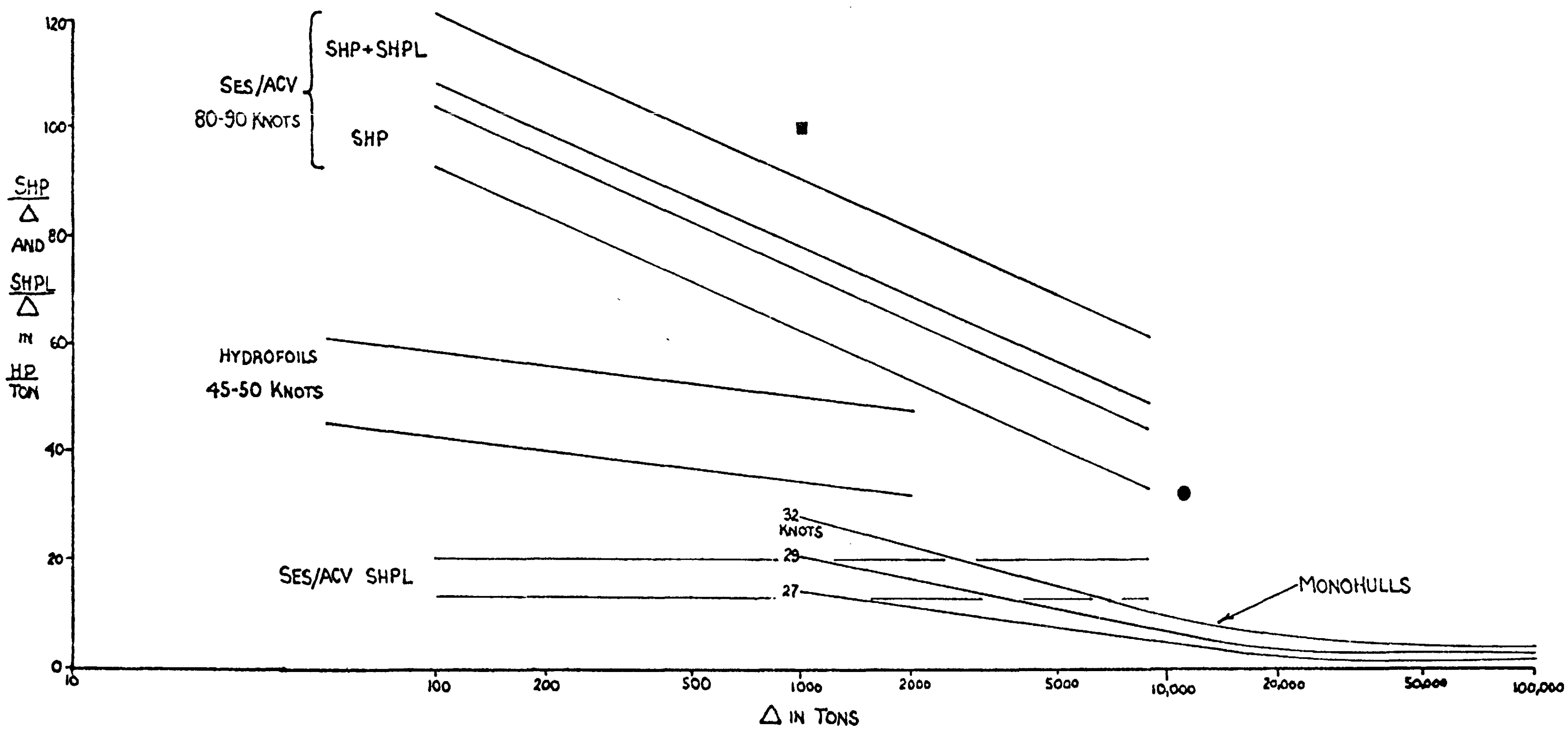

FIGURE 3. $\frac{SHP}{\Delta}$ AND $\frac{SHPL}{\Delta}$ versus Δ

3.1.3 Characteristic: KW

KW = installed electrical power generation capacity, kilowatts.

Discussion

The amount of installed electrical power generation capacity depends primarily on the size of the ship, as measured by both Δ and ∇ , and on the electrical power requirements of the payload. KW/Δ was picked as the ordinate, and Δ as the abscissa in order to see any variation with size. Since it is difficult to measure payload electrical power requirements directly, an effort to see any trend in payload KW requirements with time is undertaken by including the launch or design date with each point.

Observations and Trends

- There is no obvious difference in KW between vehicles of different types.

- In general the more recently launched ships have the highest KW/ton. There is, however, a great deal of scatter, particularly in the smaller ships.

- In general the KW/ton decreases with size.

Explanation of Trends

- The higher KW/ton on the more recent ships is caused by the higher electrical power requirements of the payload items on these ships.

- KW/ton is not dependent on ship type because most of the electrical load depends on the volume of the ship and the requirements of the payload.

- The scatter in the smaller ship sizes is caused by the great variance in the amount of payload carried. Many of the small hydrofoils are essentially experimental and carry little military payload.

- For ships with the same weight fraction of military payload, the KW/ton decreases with size for two reasons:
  (1) smaller ships have a greater proportion of their electrical load going to non-payload items;
  (2) the manning/ton decreases with size so that electrical power/ton required for crew decreases with size.

- The indicated band is drawn based on the electrical requirements of only the most recent and most militarized (least experimental) designs. This band is felt to be reasonable for the present and near future. In any event, KW/ton requirements are not expected to go down in the future.

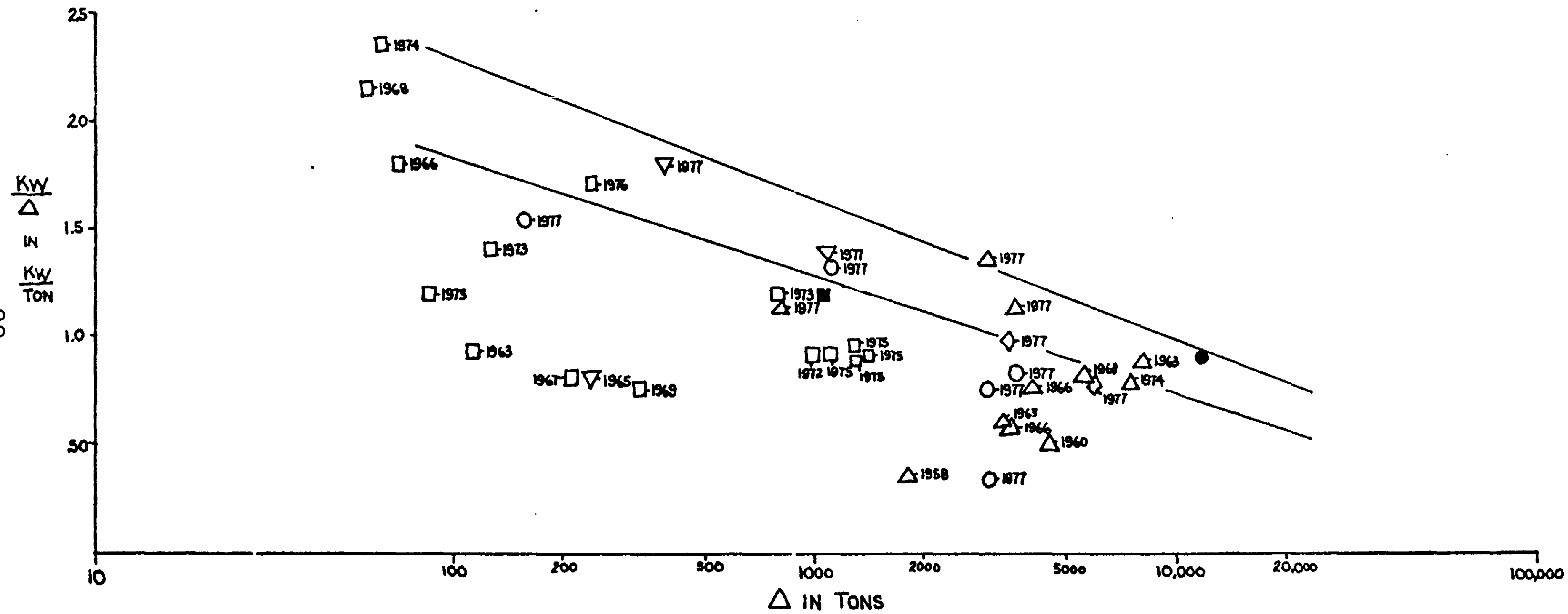

FIGURE 4. $\frac{KW}{\Delta}$ versus Δ

3.1.4 Characteristic: M

M = manning

Discussion

A ship's manning requirements depend primarily on three things: the size of the ship (Δ), the manpower requirements of the ship's payload, and the manning philosophy at the time of the ship's design. Manning philosophy includes the degree of automation, amount of onboard maintenance and personnel requirements for watch stations and standard Navy evolutions. To see the variation of manning with ship size M/Δ was plotted versus Δ. Launch or design date is included with each point in an effort to observe a trend in manning philosophy and payload manpower requirements with time.

Observations and Trends

- Manning per ton decreases as ship size increases.

- For a given ship size manning per ton has decreased for the more recent designs.

- There are no apparent differences in manning per ton between different ship types.

Explanation of Trends

- The basic downward trend of manning per ton can be explained as follows. Small ships need a minimum number of men to man standard Navy positions on the bridge, and for radar and line handling, etc. This is a more or less fixed number independent of the ship's size or type so a rapid downward slope of the manning per ton curve at low displacements is expected. As ships get larger, a few more specialized personnel are added to operate and maintain additional payload items; the proportion of people added, primarily for payload and payload related support services, would be expected to be about constant.

- The shift from a higher to a lower trend line with time refects changes in manning philosophy (degree of onboard maintenance and degree of automation).

- The band drawn on the graph reflects the most recent manning philosophy, and is expected to be suitable for present and near future designs. Later manning per ton may be even lower as manning philosophy changes.

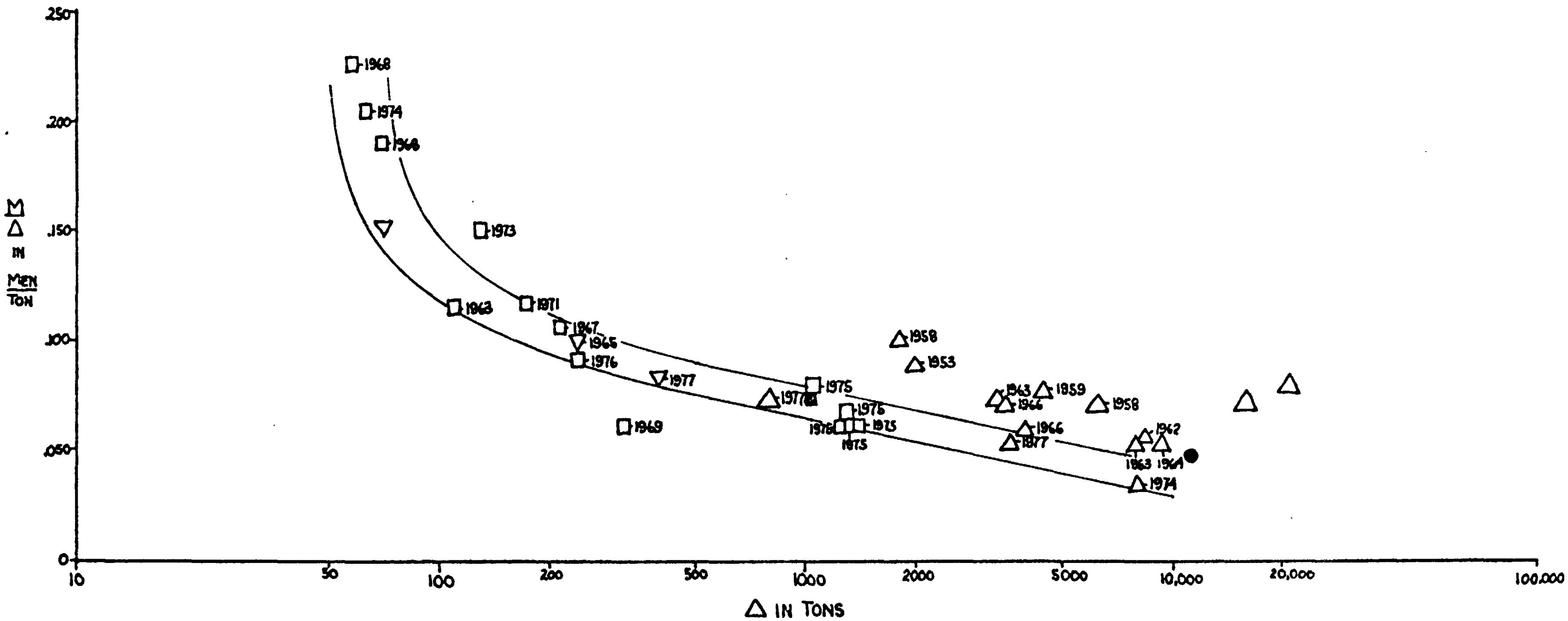

FIGURE 5. $\frac{M}{\Delta}$ versus Δ

3.1.5 Characteristic: W1

W1 = weight of SWBS category 100 (hull structure).

Discussion

W1 is a function of the size of the ship as reflected in both Δ and ∇. The plating and structure included encloses the hull volume and gives the ship the strength to resist the bending moment and point loads the ship sees. The applied loads, and the ability to resist these loads as well as Δ and ∇, are all functions of the ship type and configuration. The weight of the structure also depends on the weight and strength characteristics of the hull material (generally steel or aluminum).

The plots chosen are Δ/∇ versus $W1/\Delta$ and $W1/\Delta$ versus Δ. The first plot was chosen because W1 varies both with Δ and ∇ and Heller and Clark have shown the usefulness of utilizing a plot in which lines with constant structural density ($W1/\nabla$) and hull structural weight fraction ($W1/\Delta$) are on a single plot.[7] $W1/\Delta$ versus Δ was plotted so that any variation of $W1/\Delta$ with size could be seen.

Observations and Trends

- All monohulls have steel hulls and most have aluminum deckhouses. Most other ship types have aluminum construction.

- All currently built aluminum hulled ships fall in a structural density band of 2 to 4 lbs/ft^3. All currently built steel ships fall in a structural density band of 5 to 8 lbs/ft^3.

- On the $W1/\Delta$ versus Δ plot there are distinctive bands for each ship type.

- There is no discernible trend with size except for very small ships (less than 100 tons) where the structural weight fraction increases because a minimum thickness of metal must be used for weldability.

Explanation of Trends

- The bands of weight fraction for different types of ships observed on the second graph are a result of the different densities of the different types of ships. For aluminum and steel ships a certain amount of metal is needed just to enclose and stiffen the ship's volume, and additional metal is required to provide the resistance to bending moment necessary.

- The larger displacement monohulls have high values of weight fraction because their weights include armor and ballistic protection.

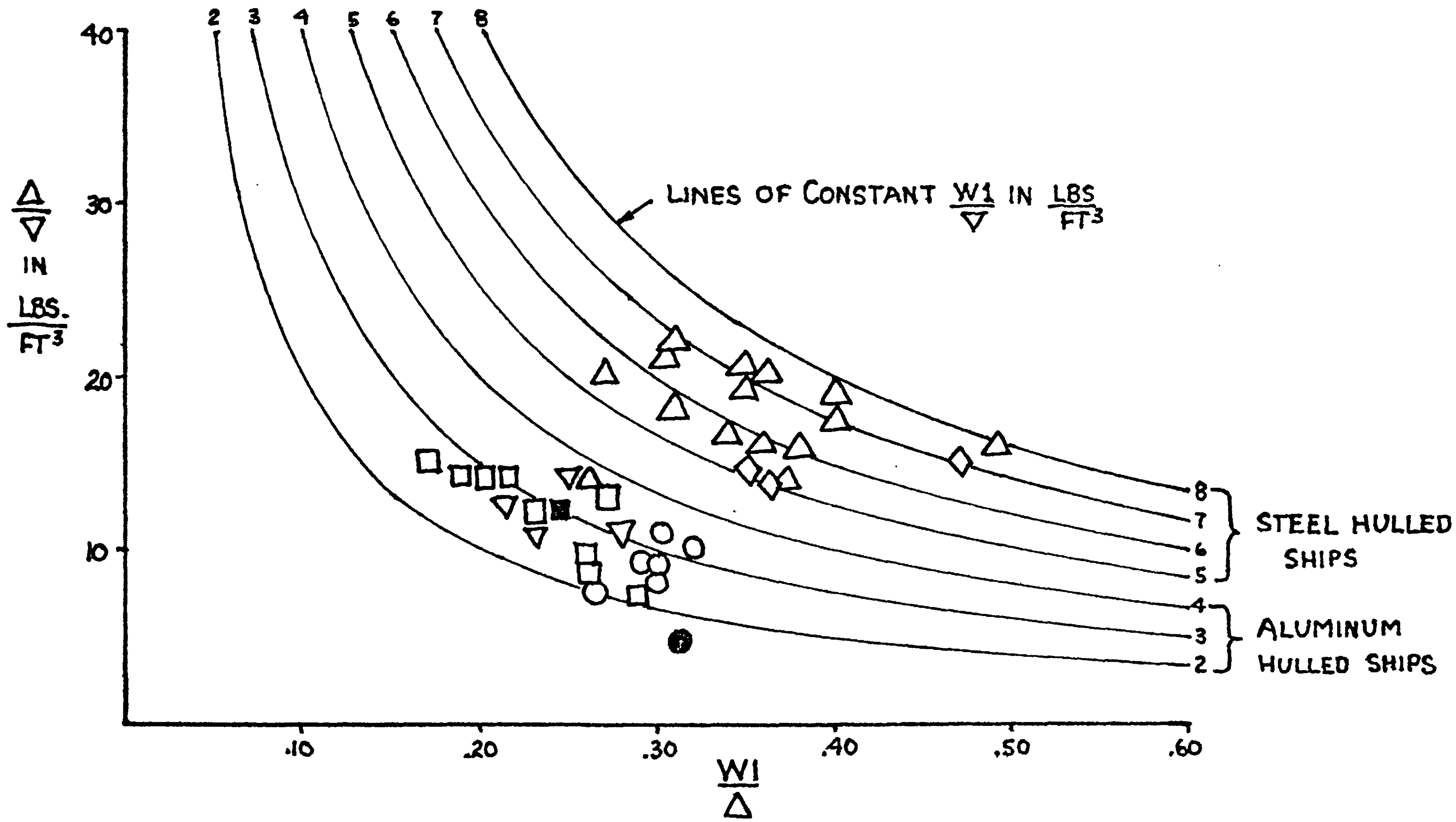

FIGURE 6. $\frac{\Delta}{\nabla}$ versus $\frac{W1}{\Delta}$

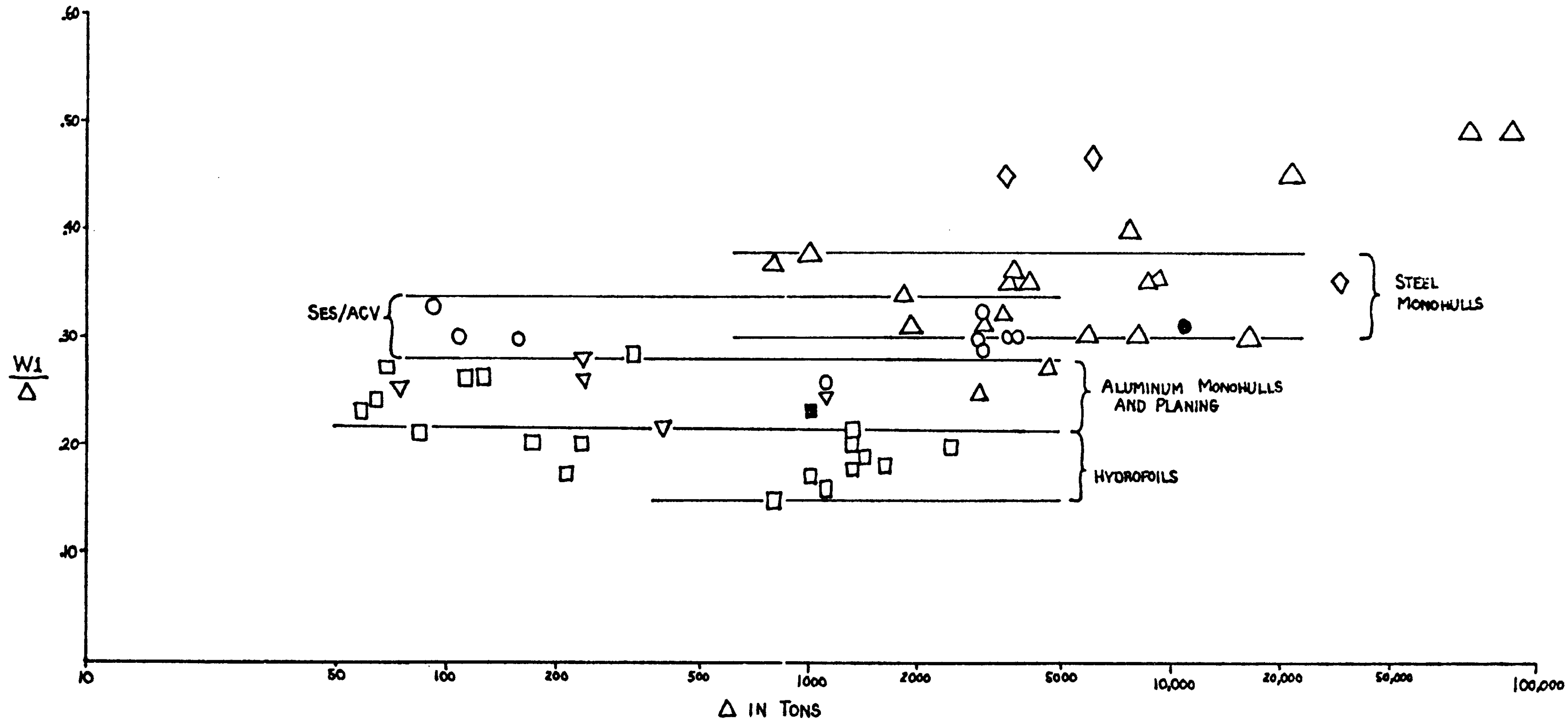

FIGURE 7. $\frac{W1}{\Delta}$ versus Δ

3.1.6 Characteristic: W2

W2 = weight of propulsion plant for all ships.

Discussion

W2 is a function of the power of the propulsion plant and the characteristics of the propulsion plant. Those characteristics which have a particular impact are: the types of prime mover (steam, diesel or gas turbine), the propulsor type (subcavitating propeller, supercavitating propeller, waterjet, or air propeller), the propulsor RPM, and the reduction gear type (conventional or planetary). Of the characteristics, power is the easiest to measure and the ratio W2/SHP in lbs/HP is commonly used so it was chosen as a parameter to plot. SHP was chosen as abscissa so that any economy of scale could be detected. An additional plot, SHP/Δ versus $W2/\Delta$ with lines of constant W2/SHP, was chosen because it graphically shows the impact on propulsive weight fraction of SHP/ton (an indicator of capacity) and W2/SHP (an indicator of design efficiency).

Observations and Trends

- As expected, W2/SHP varies greatly with type of propulsion plant, type of propulsor, and RPM of propulsor. The regions for each are indicated on the graphs.

- There appears to be only a little economy of scale for gas turbine plants. This may be a result of technological advances as well as actual economies of scale.

- The propulsion plants of monohulls and SWATH's generally weigh more than those of hydrofoils, SES/ACV's, and planing ships.

Explanation of Trends

- Above 20,000 horsepower there is little economy of scale for gas turbines, because of the present single engine maximum size limit. For higher horsepowers, multiples of existing gas turbines must be used because larger engines do not yet exist.

- Because hydrofoils, SES/ACV's, and planing ships are weight-limited instead of volume-limited, they utilize propulsion plants with lighter weight components (waterjets, high RPM supercavitating propellers). In addition, weight saving design standards are used aboard these high performance ships.

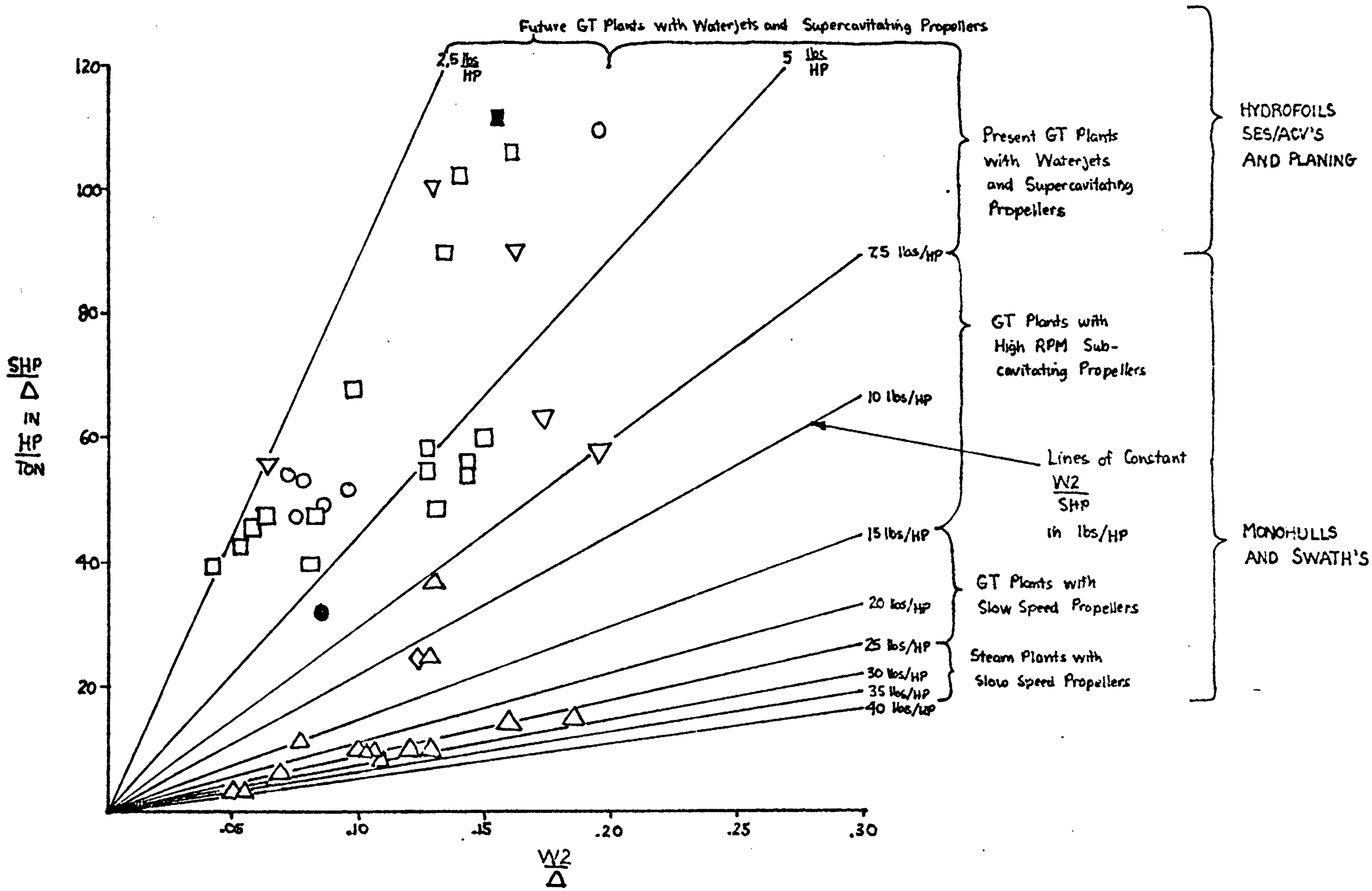

FIGURE 8. $\frac{SHP}{\Delta}$ versus $\frac{W2}{\Delta}$

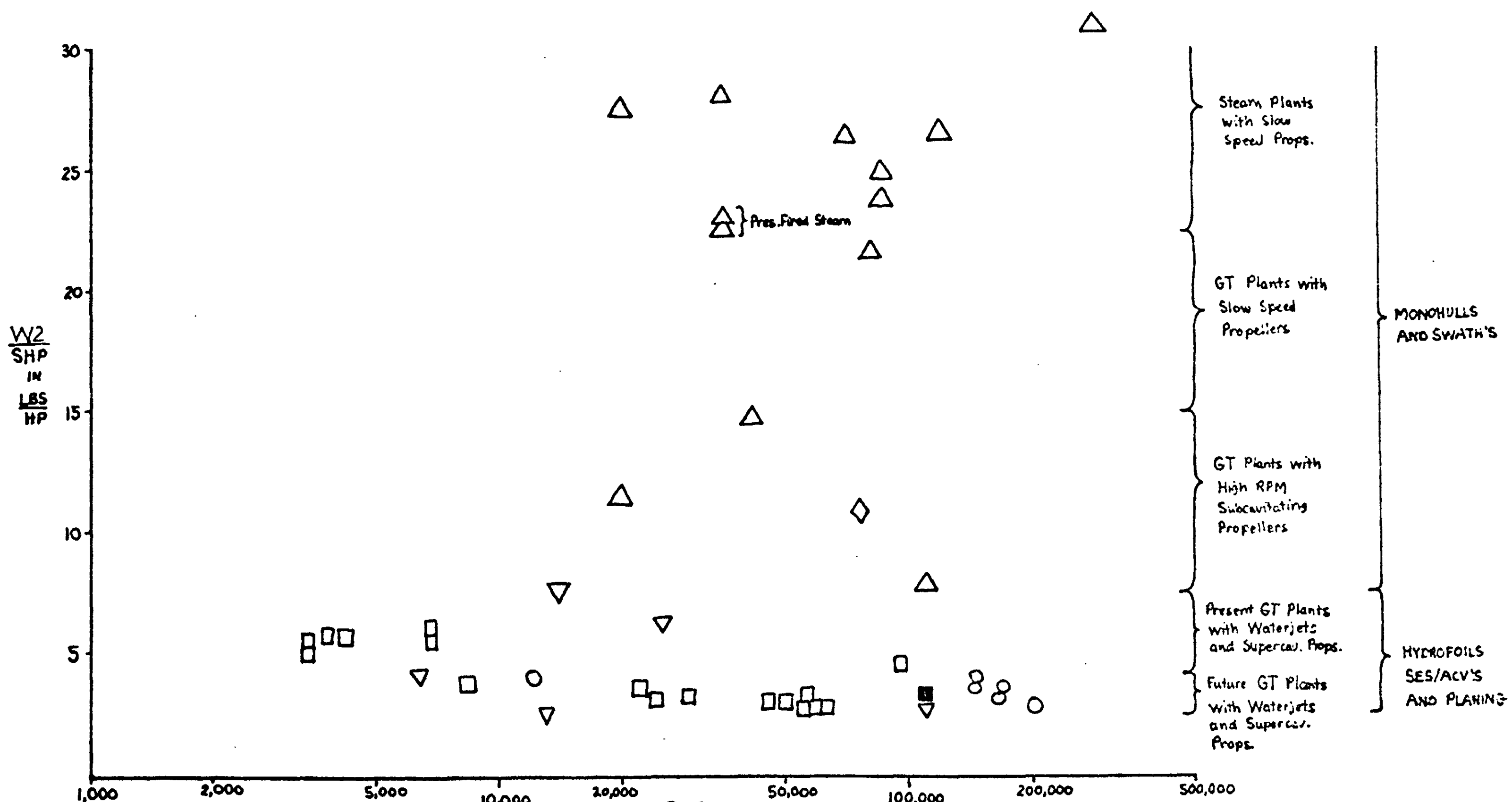

FIGURE 9. $\frac{W2}{SHP}$ versus SHP

3.1.7 Characteristic: W3

W3 = weight of SWBS category 300 (electrical plant).

Discussion

W3 is made up of the electric power generators and the electrical power distribution system (including lighting). It therefore is a function both of the size and type of generators and the volume over which the power must be distributed. W3/KW versus KW was plotted to check the variation of W3 with KW and see if any economy of scale existed. In addition KW/Δ versus $W3/\Delta$ with lines of constant W3/KW was plotted because it shows the impact on electrical weight fraction of KW/ton and W3/KW.

Observations and Trends

- As expected W3/SHP varies greatly with the type of generator prime mover and the frequency of the power generated. The frequency seems to make more difference than the type of prime mover, possibly because the generator weight is the predominant part of the whole generator set weight.

- The electrical plants of monohulls and SWATH's generally weigh more than those of hydrofoils, SES/ACV's, and planing ships.

- There appears to be little economy of scale for either gas turbine or diesel generators.

Explanation of Trends

- By Gibbs and Cox' study[8] about two-thirds of W3 is related directly and linearly to KW; the rest being related to ∇.

- Four hundred Hertz electrical systems are incorporated on many high performance ships because these systems save weight. Monohulls and SWATH's, being volume limited instead of weight-limited, use heavier 60 Hertz systems.

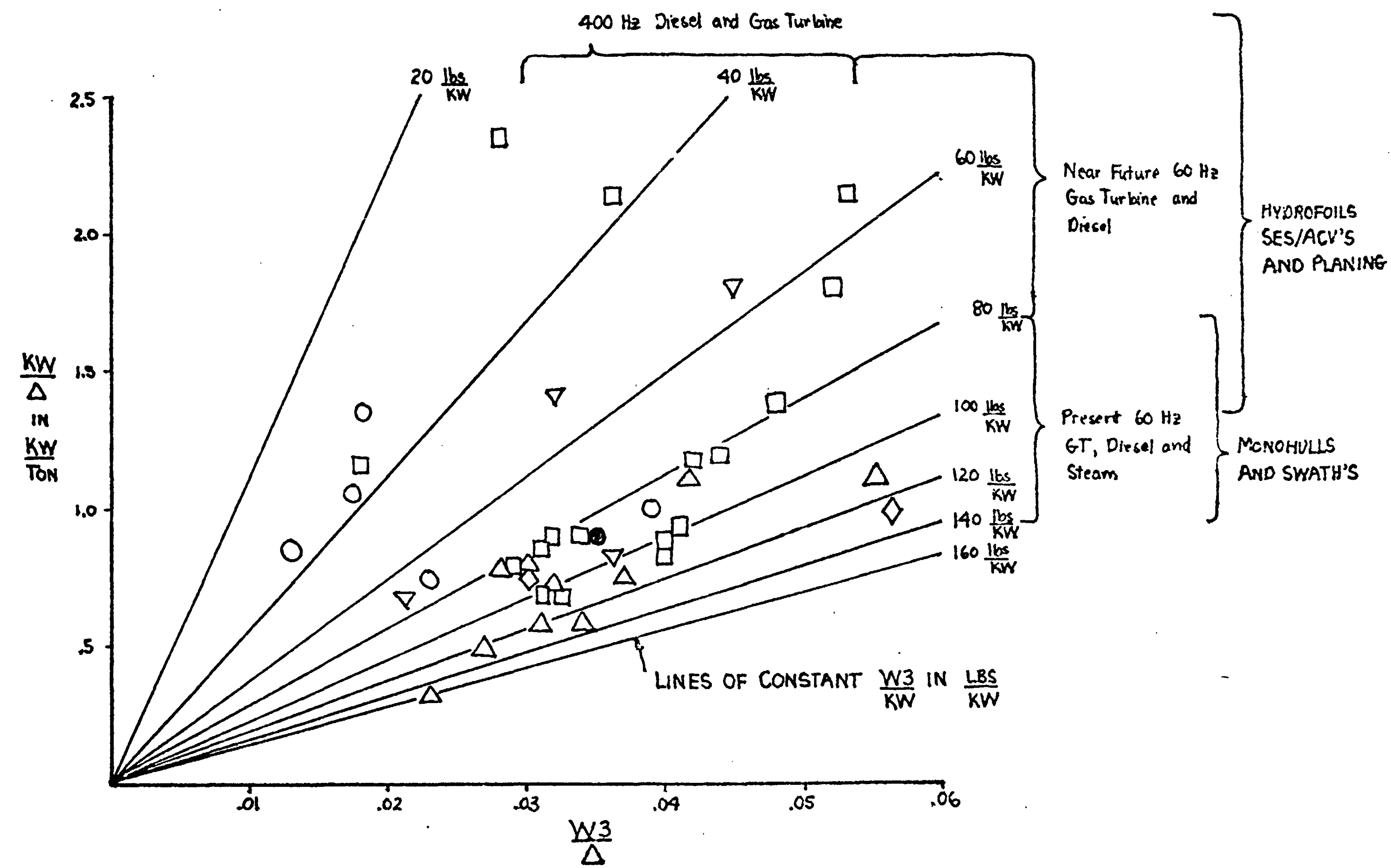

FIGURE 10. $\frac{KW}{\Delta}$ versus $\frac{W3}{\Delta}$

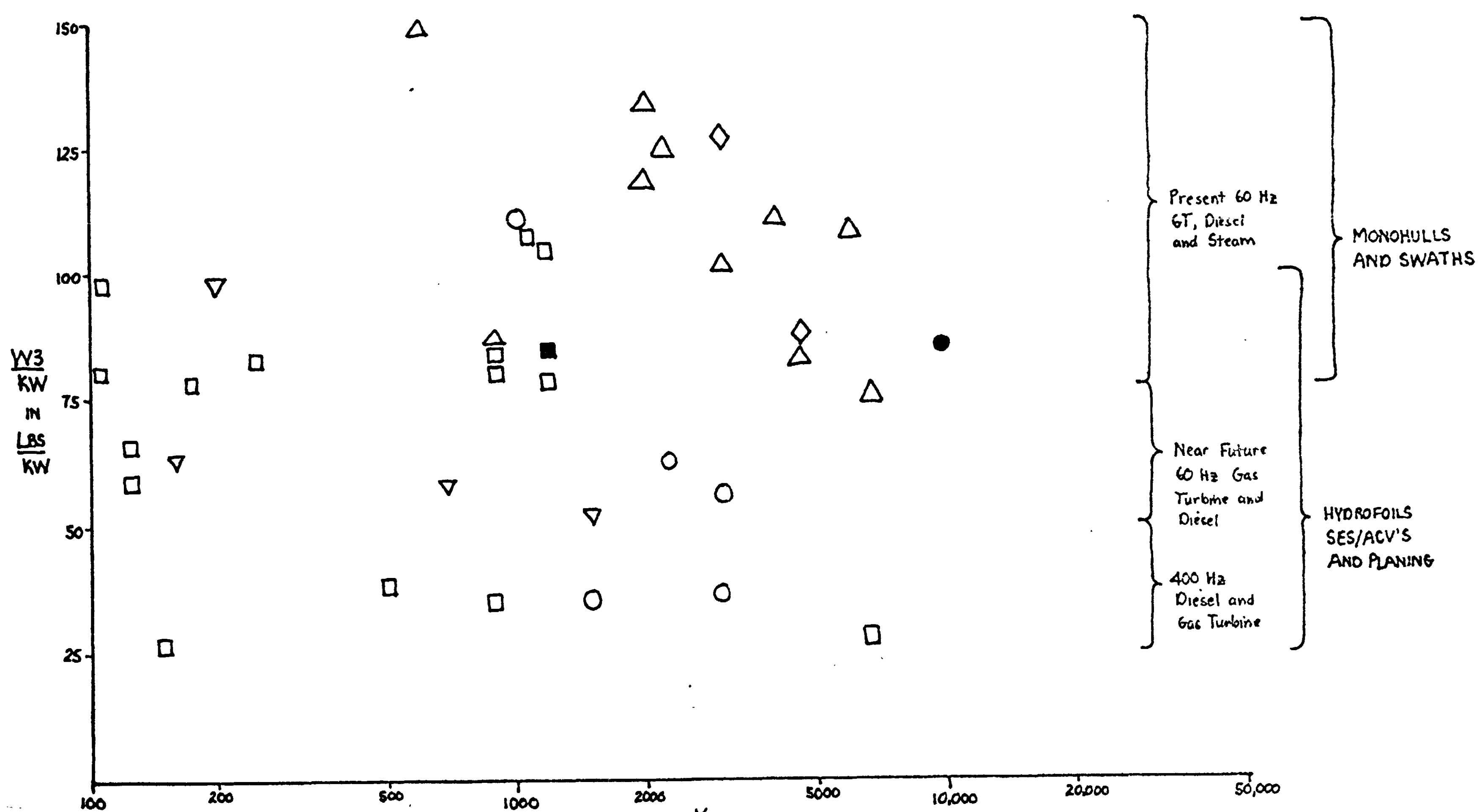

FIGURE 11. $\frac{W3}{KW}$ versus KW

3.1.8 Characteristic: (W5-W567)

(W5-W567) = (weight of SWBS category 500 [auxiliary systems])

- (weight of lift system).

Discussion

(W5-W567) is made up of two types of systems: those such as firemain, fuel transfer, anchor handling, and steering that depend on overall ship size and therefore vary with Δ and ∇ ; and those that vary with the ship's manning such as heating, air conditioning, distilling plant and lifeboats.[9]

Two plots were chosen: the first, Δ/∇ versus (W5-W567)/Δ with lines of constant (W5-W567)/∇ , to show variation of (W5-W567)/Δ with both ship density and auxiliary system density; and the second, (W5-W567)/Δ versus Δ , to show any decrease in auxiliary system weight per ton with increasing ship size.

Observations and Trends

- High performance ships have consistently lower auxiliary system weight fractions and auxiliary system densities than monohulls.

- There is some economy of scale for both high performance ships and monohulls.

Explanation of Trends

- Monohull points reflect the use of standard, heavy auxiliary system components. High performance ships use lightweight equipment in the areas of mooring, anchoring, and lifeboats, to mention only a few examples.

- High performance ships have different habitability standards which necessitate less air conditioning and other support systems.

- For all ship types M/Δ decreases as Δ increases so that the portion of (W5-W567) which depends on manning contributes to the slight decrease in $(W5-W567)/\Delta$ with size.

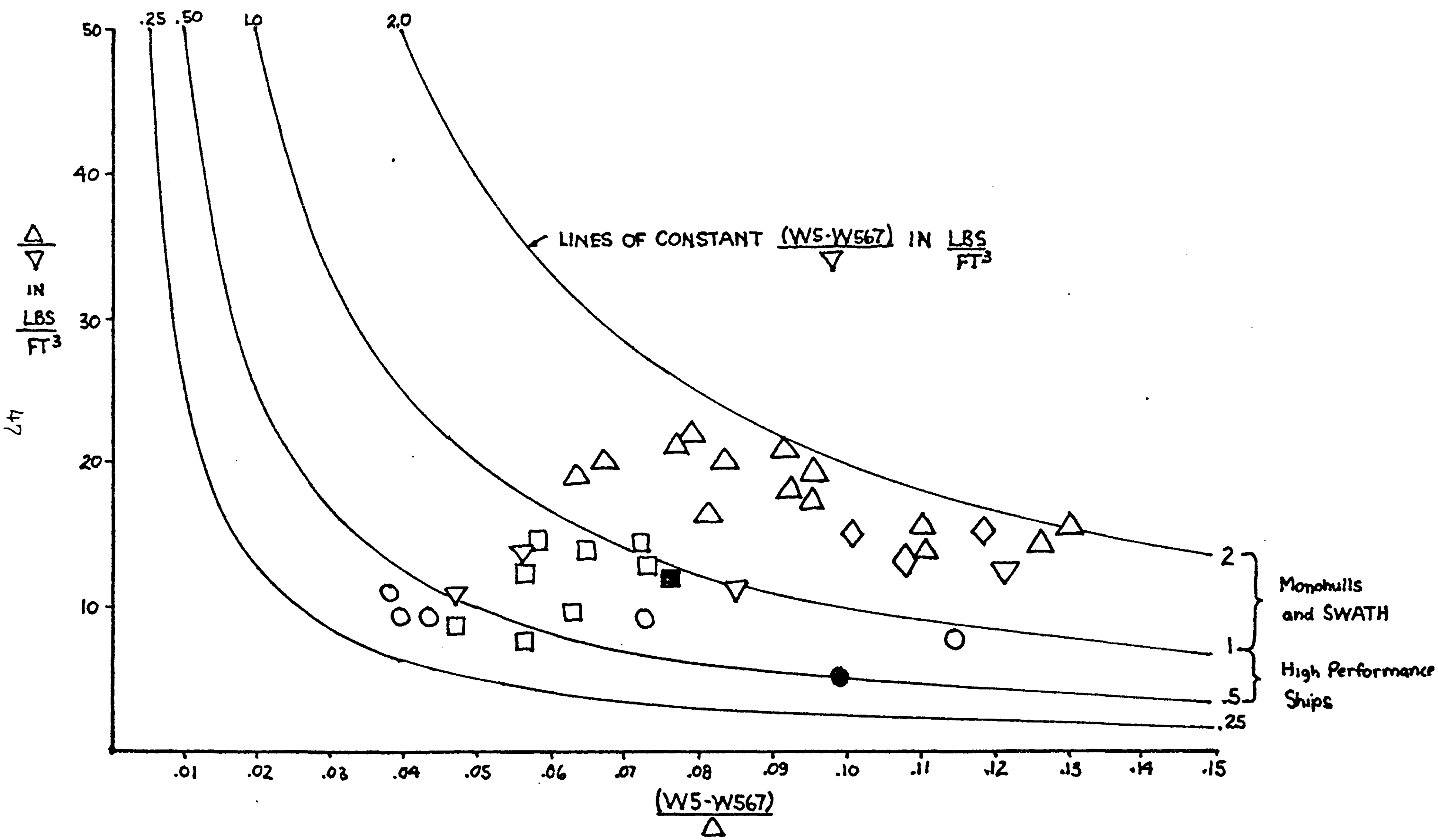

FIGURE 12. $\frac{\Delta}{\nabla}$ versus $\frac{(W5\text{-}W567)}{\Delta}$

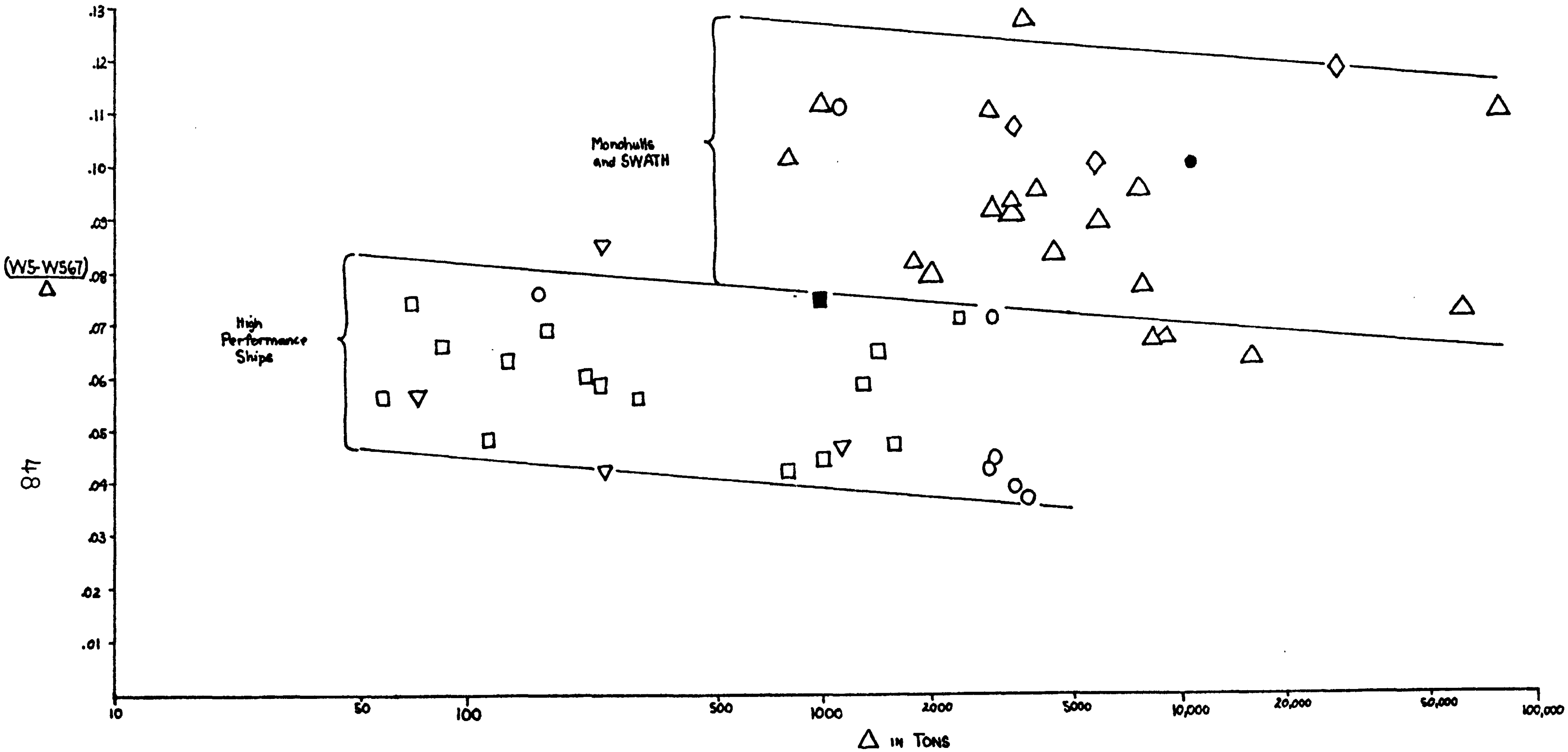

FIGURE 13. $\frac{(W5-W567)}{\Delta}$ versus Δ

3.1.9 Characteristic: W567

W567 = weight of lift system.

Discussion

W567 includes different components for different types of ships. For hydrofoils the lift system is made up of the foils, struts and associated retraction mechanisms. Since the weight of these items is directly related to the weight of the ship they lift, the plot $W567/\Delta$ versus Δ is utilized.

For ACV's and SES's W567 includes fans, fan engines and seals. In this case most of the weight is a function of the shaft horsepower required to lift the ship. Since this shaft horsepower is one of the gross characteristics checked earlier, the weight per horsepower is checked here.

Observations and Trends

Hydrofoils

- The foil system weight fraction remains nearly constant with increasing displacement.

SES/ACV

- The weight of W567 per horsepower decreases slightly as horsepower increases.

Explanation of Trends

Hydrofoils

- Most sources feel that the foil system weight fraction should increase with displacement because the foil area increases linearly with the ship's displacement, assuming constant foil loading.[10] However, the lift developed by the foils is strongly influenced by their configuration and other factors, so that their weight fraction does not have to increase faster than ship displacement. In addition, W567 includes the strut and other components whose weight fraction stays constant or decreases with displacement.

SES/ACV

- As with propulsion, for powers in excess of 20,000 SHP, multiples of existing gas turbines are used. Therefore, above this horsepower little economy of scale is expected.

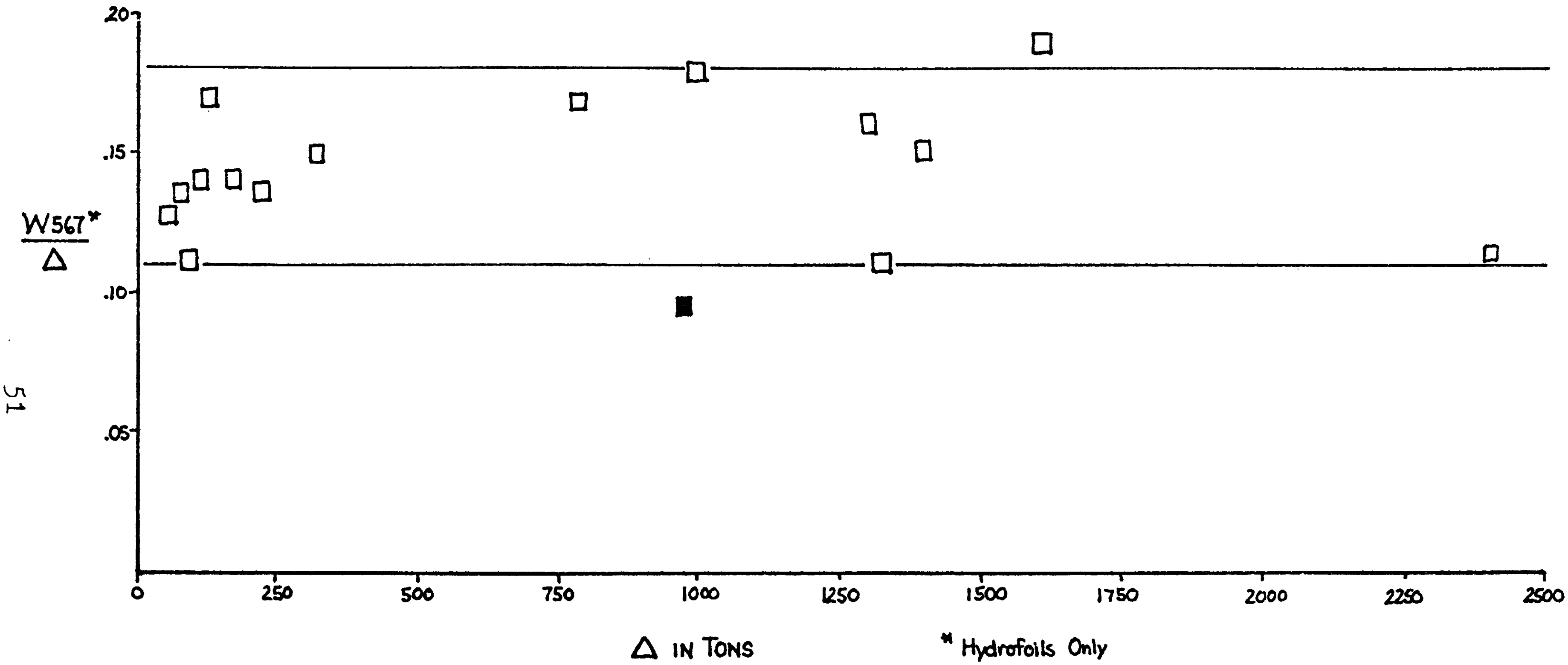

FIGURE 14. $\frac{W567}{\Delta}$* versus Δ

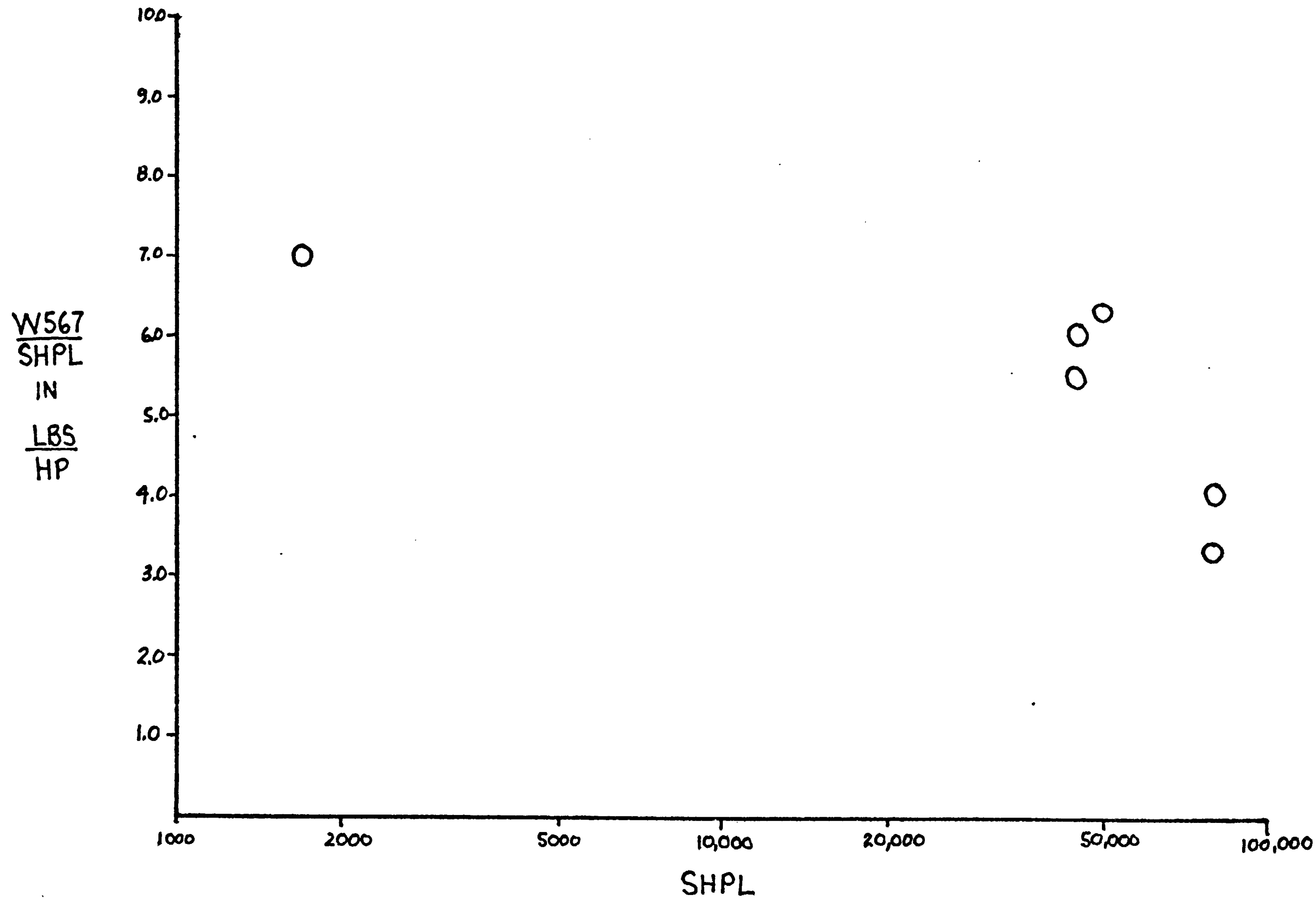

FIGURE 15. $\frac{W567}{SHPL}$ versus SHPL

3.1.10 Characteristic: W6

W6 = weight of SWBS category 600 (outfit and furnishings).

Discussion

Like (W5-W567), W6 is made up of two types of items, those depending primarily on ship's size and those that are a function of manning. According to studies by Boeing,[11] and by Gibbs and Cox,[12] between 65% and 80% of W6 depends primarily on ship size as reflected by Δ or ∇ . For the same reasons as in (W5-W567), two plots were chosen:

Δ/∇ versus $W6/\Delta$ with lines of constant $W6/\nabla$;

and $W6/\Delta$ versus Δ .

Observations and Trends

- High performance ships have consistently lower outfit and furnishings weight fractions than monohulls. They also have consistently lower outfit and furnishings densities than conventional monohulls.

- There appears to be some economy of scale with Δ for both high performance ships and monohulls.

Explanation of Trends

- Because of the nature of the items in W6 the only explanation for the overall lighter weights and densities is the use of lighter weight materials and a lower habitability standard.

- The economy of scale with larger size is because items such as ship fittings, rails, stanchions, floorplates, ladders, and deck covering vary more with area (or $\Delta^{2/3}$) than linearly with displacement or volume.

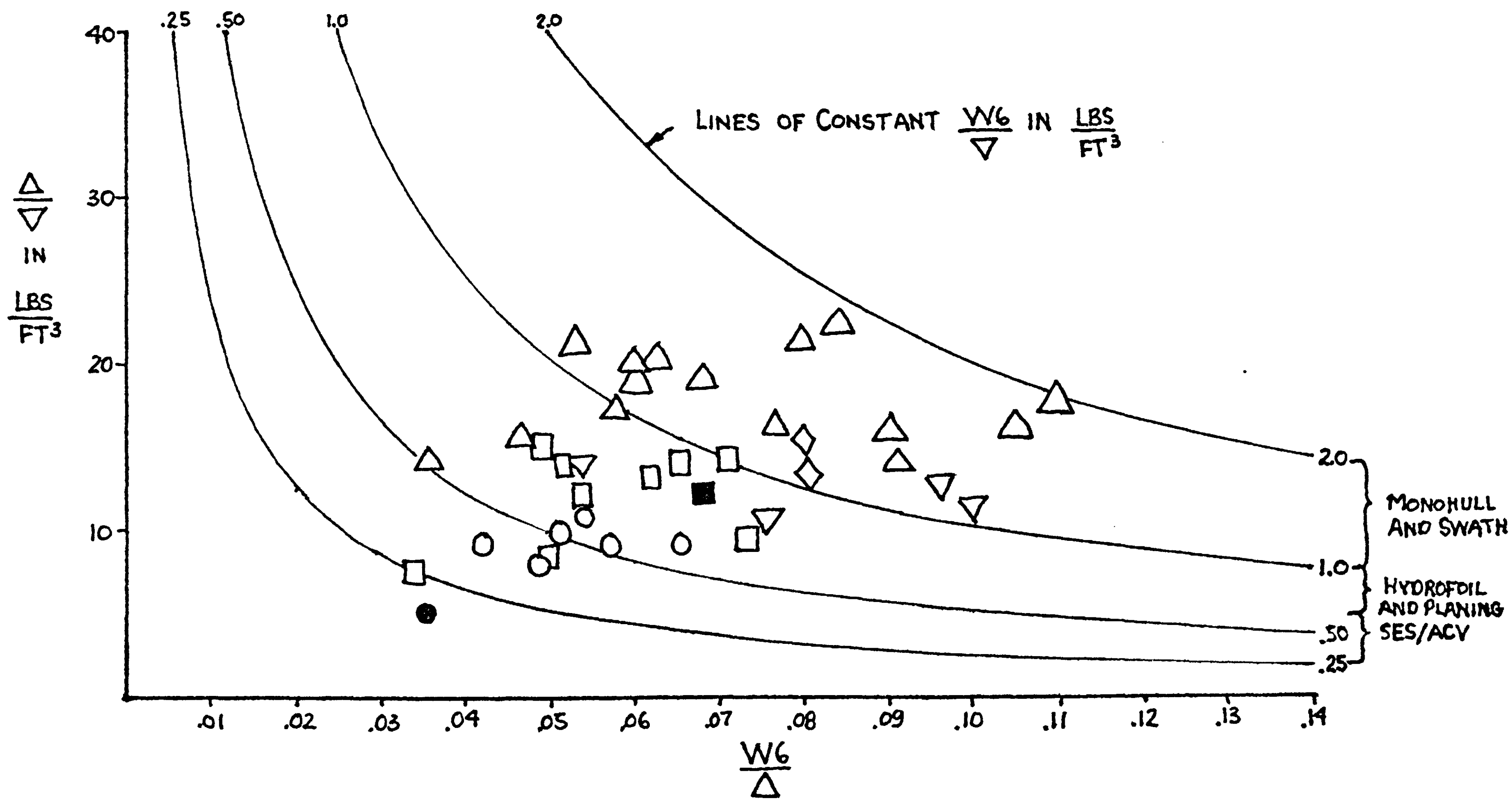

FIGURE 16. $\frac{\Delta}{\nabla}$ versus $\frac{W6}{\Delta}$

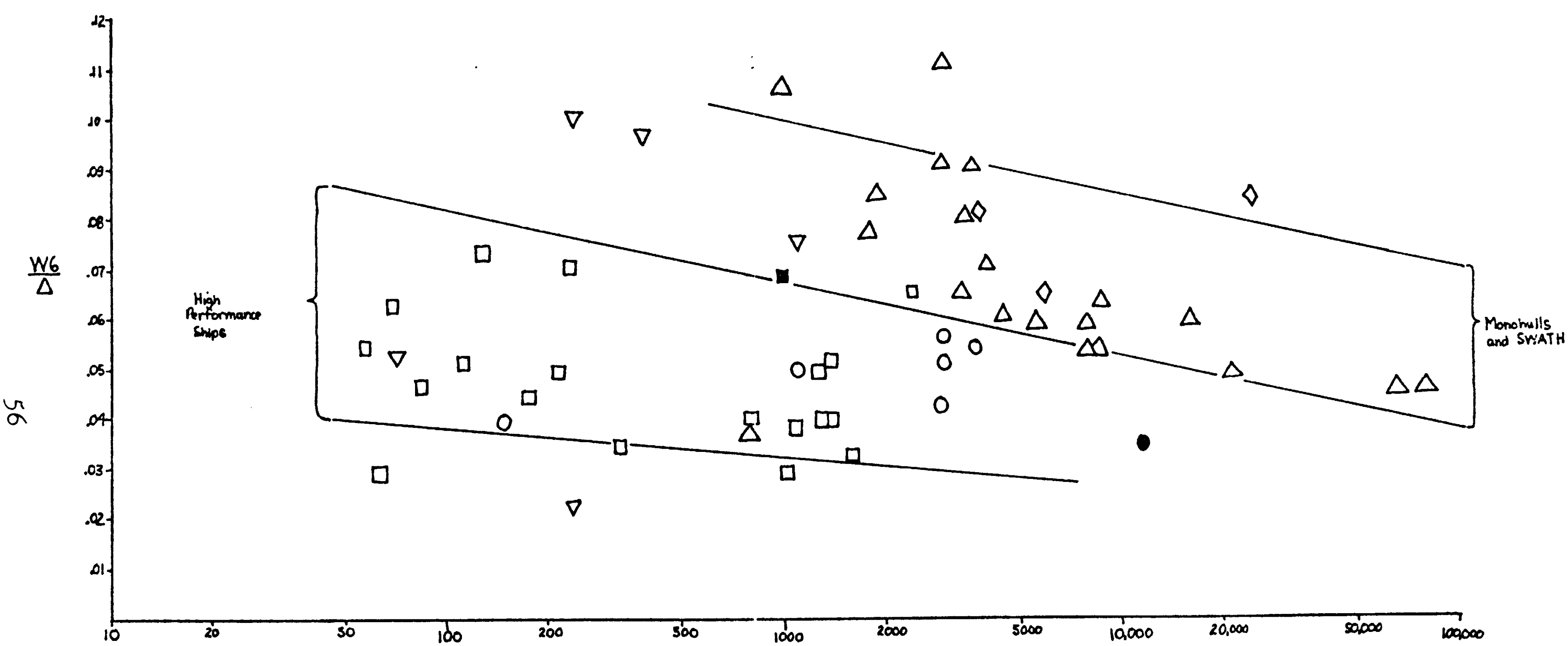

FIGURE 17. $\frac{W6}{\Delta}$ versus Δ

3.1.11 Characteristic: WFUEL

WFUEL = weight of ship's fuel used for propulsion, lift and electrical power generation.

Discussion

The weight of fuel carried by a ship is a complex function of the ship's type, size, cruise speed, range and propulsion plant characteristics. In an attempt to get an estimate of fuel required by a given type of ship, the weight of fuel for each ship has been divided by the ship's displacement and range to give pounds of fuel required per ton of displacement and per nautical mile of range. It was felt that dividing by the range would eliminate differences in fuel fractions resulting solely from range differences between ships of the same type. This left cruise speed as the major remaining variable. To take care of this, speed bands are indicated for each type of ship. An abscissa of Δ was used to show any decrease in fuel required per ton per nautical mile as displacement increased.

Observations and Trends

- As expected there are definite differences between ship types. Also, higher cruise speed requires more fuel per ton per mile. There are enough hydrofoil and monohull points to draw bands for these two types of ships.

- Definite economies of scale exist for both hydrofoils and monohulls.

Explanation of Trends

- The explanation is similar to that presented for installed SHP. Fuel consumption is dependent on propulsion plant SHP and fuel consumption at cruise speed.

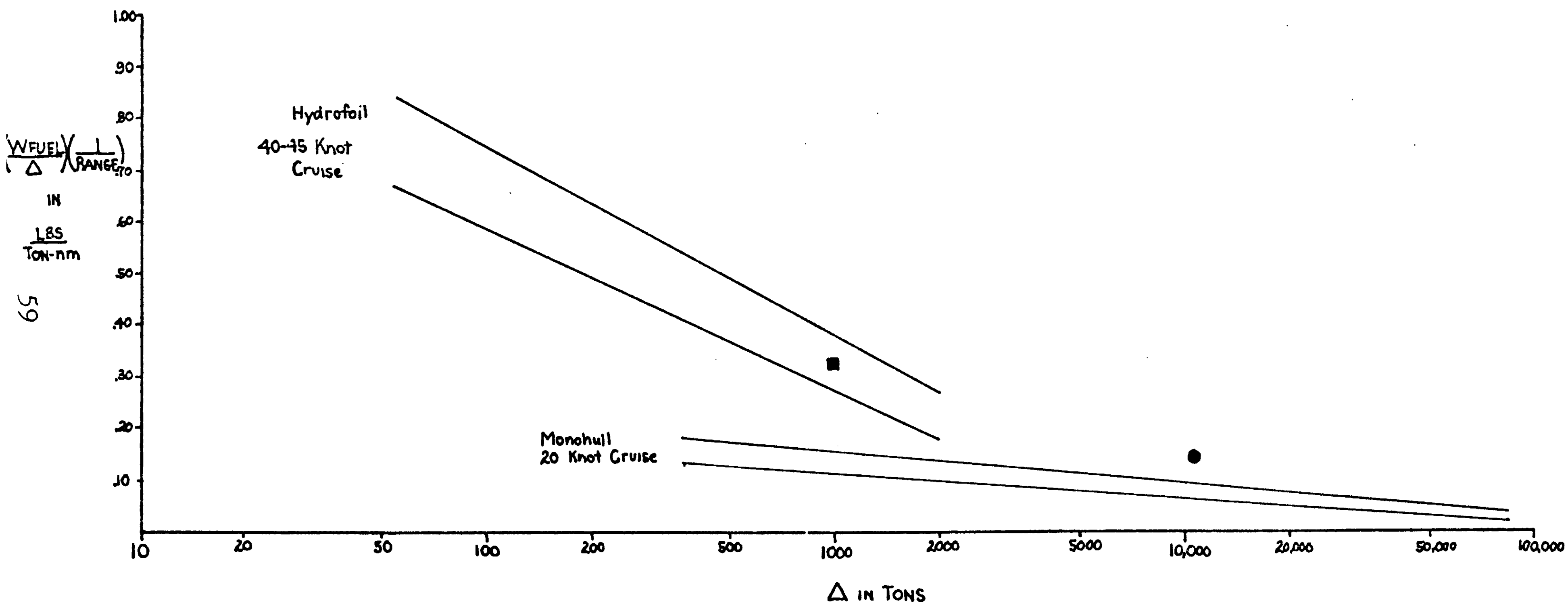

FIGURE 18. $\left(\frac{W_{FUEL}}{\Delta}\right)\left(\frac{1}{RANGE}\right)$ versus Δ

3.1.12 Characteristic: WCREW

WCREW = SWBS load F10 (crew personal effects) + F30 (stores) + F52 (potable water).

Discussion

WCREW is a function of a ship's manning and endurance requirement. The plot WCREW/M versus M was chosen to see if any economy of scale existed.

Observations and Trends

- There is considerable scatter for ships with small crews.

- For larger crew sizes there is a relatively narrow band and no apparent economy of scale.

Explanation of Trends

- The smaller ships have a wide variation in endurance requirements. The nuclear ships and very large ships generally have a longer endurance requirement.

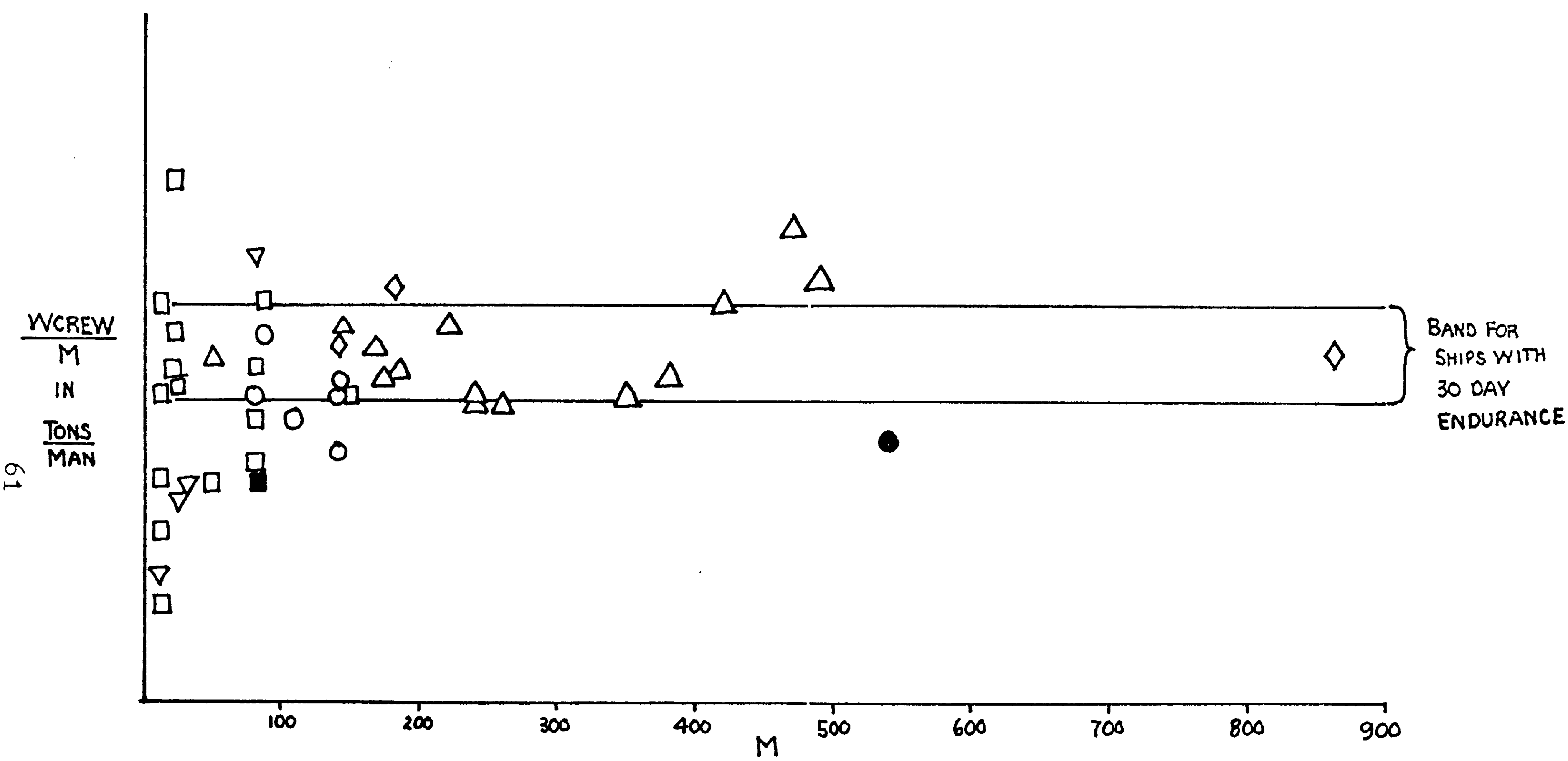

FIGURE 19. $\frac{W_{CREW}}{M}$ versus M

TABLE 4 Summary of Graph Utilization

	Characteristic	Parameter	Applicable Graph
GROSS CHARACTERISTICS	∇	$\frac{\Delta}{\nabla}$	$\frac{\Delta}{\nabla}$ versus Δ
	SHP and SHPL	$\frac{SHP}{\Delta}$ and $\frac{SHPL}{\Delta}$	$\frac{SHP}{\Delta}$ and $\frac{SHPL}{\Delta}$ versus Δ
	KW	$\frac{KW}{\Delta}$	$\frac{KW}{\Delta}$ versus Δ
	M	$\frac{M}{\Delta}$	$\frac{M}{\Delta}$ versus Δ
WEIGHT ESTIMATES	W1	$\frac{W1}{\Delta}$	$\frac{\Delta}{\nabla}$ versus $\frac{W1}{\Delta}$ with lines of constant $\frac{W1}{\nabla}$ [1]
	W2	$\frac{W2}{\Delta}$	$\frac{SHP}{\Delta}$ versus $\frac{W2}{\Delta}$ with lines of constant $\frac{W2}{SHP}$ [1]
	W3	$\frac{W3}{\Delta}$	$\frac{KW}{\Delta}$ versus $\frac{W3}{\Delta}$ with lines of constant $\frac{W3}{KW}$ [1]
	(W5-W567)	$\frac{(W5-W567)}{\Delta}$	$\frac{\Delta}{\nabla}$ versus $\frac{(W5-W567)}{\Delta}$ with lines of constant $\frac{(W5-W567)}{\nabla}$ [1]
	W567 (hydrofoils)	$\frac{W567}{\Delta}$	$\frac{W567}{\Delta}$ versus Δ
	W567 (SES/ACV)	$\frac{W567}{SHPL}$	$\frac{W567}{SHPL}$ versus SHPL
	W6	$\frac{W6}{\Delta}$	$\frac{\Delta}{\nabla}$ versus $\frac{W6}{\Delta}$ with lines of constant $\frac{W6}{\nabla}$ [1]
	WFUEL	$\left(\frac{WFUEL}{\Delta}\right)\left(\frac{1}{Range}\right)$	$\left(\frac{WFUEL}{\Delta}\right)\left(\frac{1}{Range}\right)$ versus Δ
	WCREW	$\frac{WCREW}{M}$	$\frac{WCREW}{M}$ versus M

[1] It is important to remember that these graphs are entered with an ordinate value which has already been checked and therefore remains constant. Where necessary the weight fraction is changed in order to move into the desired feasible band

Section 3.2 - Summary of Graph Utilization

Table 4 summarizes the parameters and graphs utilized for each of the characteristic and weight checks. It is important to remember that the design bands indicated on the graphs are not ironclad boundaries. They should not be blindly used and weights should not be changed without first looking for an explanation. Only if there is no explanation should an adjustment be made.

Section 3.3 - Summary and Conclusions Drawn From Graphs

This chapter has presented graphs based on existing designs which show definite feasible regions for parameters used to estimate both gross ship characteristics and weights. These graphs show that, even though ship characteristics are affected by a large number of variables, relationships between a few basic variables can be meaningfully shown graphically. More specifically, these graphs show that:

(1) The values of the following characteristics are independent of the type of ship: M, KW, and WCREW.

(2) Differences between values of ∇ , SHP, W567, and WFUEL result from inherent differences between ship types.

(3) The lighter weights of W1, W2, W3, W5, and W6 on high performance ships result from the use of

lighter weight components and different design standards. These components and standards are incorporated because these ships are weight-limited and not volume-limited.

CHAPTER 4

EXAMPLES OF THE USE OF THE PROCEDURE AND GRAPHS

This chapter illustrates the use of the procedure and graphs presented in Chapters 2 and 3. Two proposed designs (Fast Hydrofoil and Large SES) are checked for feasibility, and the results of these checks are compared with the results of more detailed engineering feasibility checks performed by another activity.

Section 4.1 - Example Feasibility Checks

The input characteristics of the two proposed designs are shown on the Input Data Sheet as shown in Table 5. This sheet summarizes the information shown as primary and secondary input in the Procedure Flow Chart. The actual checking procedure is reflected in the Design Check Sheets which are shown filled out for the proposed designs in Tables 6 and 7. In each case the proposed parameter value is compared with the feasible range from the appropriate graph and either modified or accepted. Notes on marginal values are entered in the right column. Total weight changes are shown at the bottom of the page.

The first Design Check Sheet (Table 6) for the Fast Hydrofoil illustrates a proposed design in which only minor adjustments are necessary. The second sheet (Table 7) for Large SES shows a requirement for an additional 1465 tons

TABLE 5. INPUT DATA SHEET

SHIP	FAST HYDROFOIL	LARGE SES
Δ	983 MT	11,345 MT
∇	179,871 ft^3	5,050,354 ft^3
Year	Far future	Far future
Hull Mat'l	Aluminum	
M	79	540
Main Prop.		
Type	GT	GT
Propulsor		Waterjet
SHP	100,000	240,000 to 300,000[1]
Lift System		
Type	Foils	Fans
SHPL	—	60,000 to 120,000[1]
Electrical		
Type	2 Diesel @ 500 KW + 150 KW EDG	3 GT @ 3,300 KW
Frequency	400 Hz	60 Hz
KW	1150 KW	9,900 KW
Performance		
V_S	Well above 50	Well below 80
V_C	Average	Well below 80
Range@V_C	Average	Long
Endurance	Short	Average
Wt. Breakdown		
W1	229	3511
W2	152	764
W3	44	380
WS-W567	74	1122
W567	93.1	202
W6	67	400
WFUEL	199	2719
WCREW	26.	208.

1 Large SES has an integrated propulsion/lift fan system. One or two of the six 60,000 SHP gas turbines are normally devoted to lift power.

GROSS CHARACTERISTIC CHECKS

Characteristic	Parameter	Parameter Values: Calculated Design Value	Parameter Values: Acceptable Range From Graph	Parameter Values: Adjusted Value	Comments
∇	Δ/∇	120	.11 - 15	OK	
SHP	SHP/Δ	103	—	OK	High speed hydrofoil. Appears OK by comparison
SHPL	SHPL/Δ	N.A	—	—	
KW	KW/Δ	1.19	1.35-1.60	1.35	
M	M/Δ	.081	.065-.080	OK	

INPUTS TO WEIGHT CHECKS

WEIGHT CHECKS

Weight Group	Parameter	Calculated Design Value	Acceptable Range From Graph	Adjusted Value	Calculated New Weight	Input Old Weight	Weight Change	Comments
100	W1/∇	Not Req'd	2-3	Not Req'd	OK	OK	0	
	W1/Δ	.233	.17-.34	OK				
200	W2/SHP	Not Req'd	2.5-5.0	Not Req'd	OK	OK	0	
	W2/Δ	.155	.125-.225	OK				
300	W3/KW	Not Req'd	25-50	Not Req'd	(.031)(983) = 31 tons	44 tons	-13 tons	Enter $\frac{KW}{\Delta}$ versus $\frac{W3}{\Delta}$ with KW/Δ = 1.35 from above
	W3/Δ	.044	.016-.031	.031				
500-567	$\frac{W5-W567}{\nabla}$	Not Req'd	.5-1.0	Not Req'd	OK	OK	0	
	$\frac{W5-W567}{\Delta}$	.075	.042-.083	OK				
567 (hydrofoils)	W567/Δ	.0947	.11-.17	.11	(.11)(.983) = 108 tons	93.1 tons	+15 tons	Not retractable so design value may be OK
567 (SES/ACV)	W567/SHPL	N.A.	—	—	—	—	—	
600	W6/∇	Not Req'd	.5-1.0	Not Req'd	OK	OK	0	
	W6/Δ	.068	.042-.083	OK				
CREW	WCREW/M	.32	.44-.58	OK See Comment	OK	OK	0	OK because of short endurance
FUEL	$\frac{WFUEL}{\Delta}$ $\frac{1}{Range}$		.26-.37	OK	OK	OK	0	
				Weight Totals			+2 tons	Ship is basically OK.

TABLE 6 DESIGN CHECK SHEET - FAST HYDROFOIL

GROSS CHARACTERISTIC CHECKS

Characteristic	Parameter	Parameter Values: Calculated Design Value	Parameter Values: Acceptable Range From Graph	Parameter Values: Adjusted Value	Comments
∇	Δ/∇	4.95	7.5 - 11	use 4.95	4.95 seems low even for an aircraft carrying SES
SHP	SHP/Δ	21.1-26.4	—	OK	Lower speed requirement
SHPL	SHPL/Δ	5.3-10.6	13-20	OK See Comment	should make power OK
KW	KW/Δ	.88	.65 - .90	OK	
M	M/Δ	.0483	.025 - .04	use .0483	use high design value because of aircraft carrier type ship

INPUTS TO WEIGHT CHECKS

WEIGHT CHECKS

Weight Group	Parameter	Calculated Design Value	Acceptable Range From Graph	Adjusted Value	Calculated New Weight	Input Old Weight	Weight Change	Comments
100	W1/∇	Not Req'd	2 - 3	Not Req'd	(.40)(11,345) = 4538 tons	3511	+1027	W1 driven up by very low density (high volume)
	W1/Δ	.31	.40 - .60	.40				
200	W2/SHP	Not Req'd	2.5-5.0	Not Req'd	(.06)(11,345) = 681	764	- 83	When looked at with the lift system (W567), propulsion seem somewhat conservative
	W2/Δ	.067	.025 - .06	.06				
300	W3/KW	Not Req'd	60-80	Not Req'd	(.032)(11,345) = 363	380	-17	
	W3/Δ	.033	.024 - .032	.032				
500-567	(W5-W567)/∇	Not Req'd	.30 - .75	Not Req'd	OK	1122	0	
	(W5-W567)/Δ	.099	.066 - .150	OK				
567 (hydrofoils)	W567/Δ	NA	—	—	—	—	—	
567 (SES/ACV)	W567/SHPL	3.7-7.4	3.5-6	OK		202	0	
600	W6/∇	Not Req'd	.35 - .75	Not Req'd	(.080)(11,345) = 908	400	+508	W6 driven up by low density (high volume)
	W6/Δ	.035	.080 - .140	.080				
CREW	WCREW/M	.38	.44 - .58	.44	(.44)(540) = 238	208	+ 30	
FUEL	(WFUEL/Δ)(1/Range)	Not Specified	—	—	Assume OK	2719	—	
				Weight Totals			+1465 tons	Major modifications required to make this ship feasible

TABLE 7. DESIGN CHECK SHEET - LARGE SES

of weight allowance. This design can be made feasible by employing the three modifications mentioned in Section 2.2. However, the changes required are so great that they would not normally be made. Instead, a totally new design should be drawn up.

Section 4.2 - Comparison of Results

The two proposed designs used as examples in Section 4.1 and other proposed designs were analyzed for feasibility by performing a detailed engineering analysis, and also by utilizing the procedure and graphs presented in this thesis.[1] For each design checked, similar results were obtained. Both methods consistently highlighted the same characteristics as questionable or infeasible, although in some cases the magnitude of additional weight required was different.

Section 4.3 - Conclusions

- The procedure presented here for checking the feasibility of a design is easy and quick to use.

- The procedure is convenient because it utilizes plots which can be taken and used anywhere.

[1] The engineering analysis was not done as part of this thesis and is not included here.

- Depending on the amount of infeasibility found in a proposed design, the design may be able to be adjusted to yield a feasible design, or the whole design may have to be reiterated to yield a feasible result.

- In checks of a number of conceptual designs the procedure yielded the same results as did a more detailed engineering analysis.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

- The graphical procedure for checking the feasibility of Navy surface ship types presented in this thesis is simple, quick, and meaningful. It helps an engineer or manager understand the basic factors affecting the design of any type of surface ship, whether it be a monohull, SWATH, hydrofoil, SES, ACV, or planing ship.

- The graphs developed for utilization by this procedure illustrate that:

  (1) The values of the following ship characteristics are independent of the type of ship: M, KW, and WCREW.

  (2) Differences between the values of ∇ , SHP, W567, and WFUEL result from inherent differences between ship types.

  (3) The lighter weights of W1, W2, W3, W5, and W6 on high performance ships (compared to monohulls and SWATH's) result from the use of lighter weight components and different design standards. These components and standards are incorporated because these ships are weight-limited instead of volume-limited as are monohulls and SWATH's.

Recommendations

- The procedure should be expanded to include more detailed volume checks because weight groups 100, 500, and 600 are strongly influenced by a ship's enclosed volume.

- Additional points should be added to the graphs as more ships of the newer types are designed and built. This will enable additional feasibility bands to be drawn.

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