A PARAMETRIC METHOD FOR CHARACTERIZING THE DESIGN SPACE OF HIGH SPEED CARGO SHIPS

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SUMMARY

This paper presents a parametric investigation into meeting high speed cargo requirements. A five-parameter method is derived and discussed. The five parameters are:

- Ship Lift/Drag ratio
- Weight of Power
- Weight of Cargo Carriage Capability
- Overall Propulsive Coefficient
- Specific Fuel Consumption

A design space is derived using assumed values for these five parameters. Then the five-parameter method is used to analyze an existing ship, and to derive a sealift ship based on this parent. The ships thus derived are compared to the design space initially developed. Finally, another use for the parametric is explored, by using it to investigate the limiting values bounding the desired design space.

This method offers a very rapid tool for determining if a proposed design is worth pursuing further. It can be used to evaluate claims of 'breakthrough' performance, in order to decide whether the claim has merit. It is most emphatically NOT a design method. Rather it is a tool for indicating where, in the universe of ship concepts, a satisfactory design might be found.

The method has proven to be a useful tool for gaining insight into a complex problem.

NOMENCLATURE

D	Drag: the resistance of the ship
EHP	Effective Horsepower
Fn_{vol}	Volumetric Froude number: $Fn_{vol} = V / \sqrt{(g\,(\Delta_{vol})^{1/3})}$
g	Gravitational constant (9.8 m/s^2)
HSSL	High Speed Sea Lift (Pronounced "Hustle")
L	Lift: the weight of the ship
LT	Long Tons (2240 pounds, about 1017 kg)
MCR	Maximum Continuous Rating
ONR	Office of Naval Research
OPC	Overall Propulsive Coefficient OPC = EHP / SHP
SFC	Specific Fuel Consumption
SHP	Shaft Horsepower
V	Ship speed in meters per second
Vk	Ship speed in knots
Δ_{vol}	Displaced volume in cubic meters

1. INTRODUCTION

In 2005-2006 the US Navy's Office of Naval Research (ONR) contracted with Alion Science & Technology to assist in exploring the feasibility of high speed military sealift, under a program designated "HSSL." The question was intentionally left somewhat vague, so that researchers would enjoy the freedom to follow the most fruitful pathways. The requirements were also made deliberately demanding, in order to provoke innovation.

The requirements were as follows:

- 3600 LT payload
- 43 knot speed
- 5000 nautical mile range

ONR's stated goal is to accomplish the above mission with a ship of less than 560 feet length and 12,000 tons displacement. In the analyses that follow the reader will find a recurring theme of attaining the 12,000 ton displacement, or at least measuring how close to it one can get.

There is no shortage of concepts for high speed cargo ships. Instead, what is needed is a means for sorting through the myriad possibilities, and determining where the most fruitful avenues of exploration lie.

In this vein, the author developed a parametric methodology aimed specifically at helping to answer the question "Where must I make a breakthrough, in order to attain the HSSL desired level of performance?"

This paper will introduce the method, and will explore some but not all of the possible ramifications and applications of the method. Some of these uses include:

- Use as a "lie detector" to detect claims that are well above the current state of the art
- Use as a predictive tool, to tell one where they will end up if they simply stick with the current state of the art

- Use as a thought-provoking tool, to nudge me toward the exploration of concepts not normally entertained in naval architecture.

The present paper will describe the parametric methodology, and will show some of the analyses that it makes possible.

2. LIMITATIONS

The parametric method presented in this paper is a tool for sorting through the Gordian knot of high speed cargo concepts. But like the sword that Alexander the Great used to cut that knot, it lacks a certain subtlety, and has limits that must be realized.

For example, consider that the entire mission will be described using three parameters of payload, speed, and range. Note that this requirement set includes no information about the space required for the cargo, nor for the systems required to handle the cargo, nor for the environmental conditions of the transit. This is not because these factors are unimportant. Rather, their absence should highlight to the reader just how "top level" the parametric analysis really is.

The author admits to some hesitation in presenting this methodology, because there will be some of his colleagues who reject any utility for such very-high-level and simplistic tools. To those who are of this opinion I suggest that you please feel free to pass this by. I am in no way suggesting that "everybody should think like me." But if you do think like me, then I think you may enjoy this tool.

3. PARAMETRIC FRAMEWORK

The five parameters used in this method are as follows:

- Lift to Drag Ratio: What is the highest total vehicle L/D I can attain?
- Propulsor Efficiency: What is the highest propulsor efficiency I can obtain?
- Specific Fuel Consumption: What is the lowest fuel consumption I can attain?
- Weight of Power: What is the lightest propelling machinery I can find?
- Weight of Cargo Carrying Capacity: What is the minimum weight of the ship's structure, manning, auxiliary systems, and other components which are endemic to the carriage of cargo.

Each of these items is the subject of further discussion below.

3.1 L/D CURVE

Certainly one of the parameters of primary importance in the analysis of a fast sealift ship is the resistance of the ship. In 1989 I presented historical data that suggests that the boundary of the state of the art of ship resistance performance can be described by the equation:

$$L/D = 55\ Fn_{vol}^{-2.5}$$

A slightly more accurate formulation is

$$L/D = 5 + 40\ Fn_{vol}^{-3.0}$$

This reduces to:

$$Drag = Displ / (5 + 40 / Fn_{vol}^{3})$$

Where Fn_{vol} is the vessel's volumetric Froude number.

This equation is plotted in Figure 1, and is hereinafter referred to as the "Best Practices Curve." Also included on that figure are data points representing a handful of widely different ship types, which illustrate the goodness of fit of the Best Practices Curve equation.

The Best Practices Curve is not a model of physics. It is, instead, an approximate description of the observed frontier or apparent state of the art. It does not state that a ship of Fn=X must have L/D as given, but rather that it could have that L/D, provided that the right choice is made for other parameters such as hull type, length, etc.

Further, L/D is not a metric of ship "goodness." Instead, it is more accurate to think of it as an extremely simple ship resistance prediction formula. For the HSSL project a better measure of ship goodness is ship displacement.

Also, note that the Best Practices equation uses arguments that are surprisingly round numbers: 5, 4, and 3. This is intentional and serves two purposes: It results in an equation that is easy to remember, while at the same time the very roundness of the numbers reminds the user that this is not intended to be a high fidelity model, just a useful one.

One value of this L/D curve is that it introduces the fact that resistance depends upon size. In 1997 in an earlier look at sealift I proposed a 40-knot L/D of 20, but as Figure 1 shows, it is easy to exceed that value – substantially – by making the vessel large enough. Indeed, according to the Best Practices Curve an L/D of 100 is attainable, at 43 knots, if the vessel displacement is approximately 700,000 tons. Unfortunately at this size, even with L/D=100 the required power would be over 3.5 Million horsepower.

Clearly this latter is an absurd example, or at least one that lies outside the boundaries of the ONR HSSL project. However in Section 4 below I will return to more realistic explorations of the impacts of this dependency.

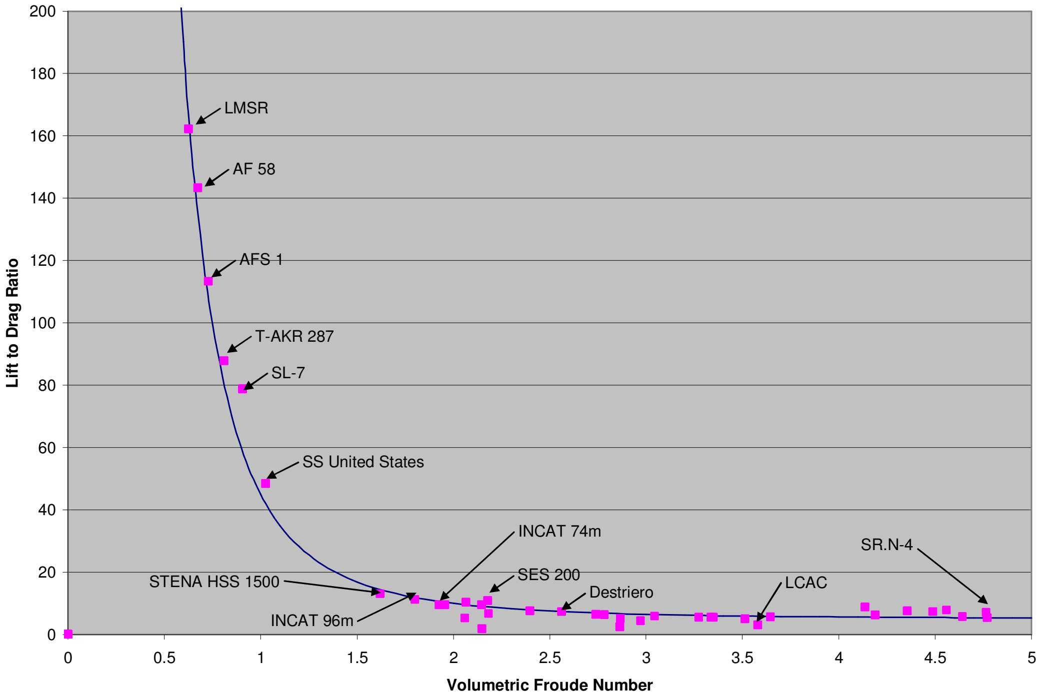


Figure 1 – Best Practices Curve "Observed Frontier" of ship Lift/Drag ratio, including selected named data points

Finally, note that the Best Practices Curve is not a perfect fit of the data: There are some ships that exceed the curve. I note this, and will return to this in the later examples wherein I exploit these points.

3.2 THE WEIGHT OF FUEL

In addition to the L/D curve, the next key parameter is the weight of fuel. This is reduced to two component parts: the propulsive efficiency of the ship and the fuel efficiency of the powerplant.

I begin with the overall propulsive coefficient OPC. As used herein this is defined as the ratio of Effective Power (EHP) divided by total installed Shaft Horsepower (SHP.) Further, by "total installed" I refer to the installed Maximum Continuous Rating, and not merely to that fraction of MCR about which the plant is balanced. Thus in a Navy powerplant I would calculate OPC based on the MCR, even though the MCR has been picked so that speed is attained on 80% MCR.

This lumping of the MCR margin into the OPC results in OPC values which are lower than expected, by the amount of the MCR margin. However, a counterbalancing effect is that will also tend to result in SFC (Specific Fuel Consumption) rates which are better than expected, by the same fraction (because I will calculate the Observed SFC as if the ship was using 100% power.) The two effects balance each other out, but it is important to know that this margin is buried in the soup, and that in later more detailed analyses one may want to strain it out.

The values of OPC that are held to be State of the Art are depicted in Figure 2 taken from Reference (a). As may be seen this curve uses dimensional speed as the ordinate, which is appropriate for a propulsor. The curve suggests that an OPC of 0.60 might be median for propellers (including both surface-piercing and fully submerged types) and OPC=0.7 might be median for waterjets.

The second half of the weight of fuel is the overall fuel consumption of the machinery, on a specific or per-horsepower-hour basis. For this the starting point is to again describe the state of the art by collecting SFC (Specific Fuel Consumption) data from commercial sources such as engine catalogs.

Because of the power levels that will be required for HSSL, I have looked only at gas turbine engines. Figure 3 shows the SFC reported for a variety of modern turbines in Navy service, plotted against their output power (Navy rating). Also included is a projection representing my estimate of what level of SFC performance might be attained by future larger engines – via a simple a visual extension of the line.

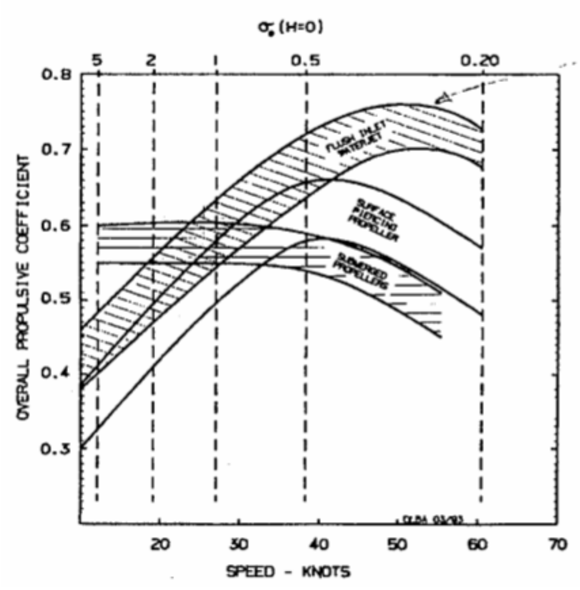


Figure 2 - 1997 State of the Art limits of Overall Propulsive Coefficient (from Donald L Blount Assoc.)

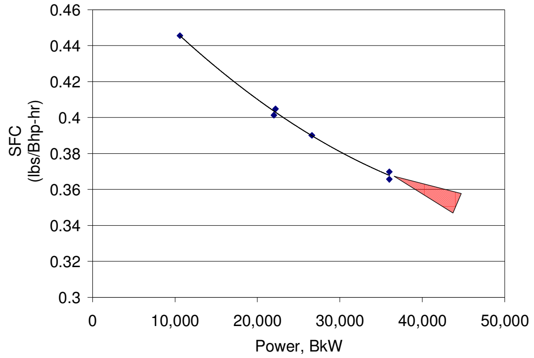


Figure 3 – Propulsion Gas Turbine Engines, SFC versus Power, Current and Future Engines

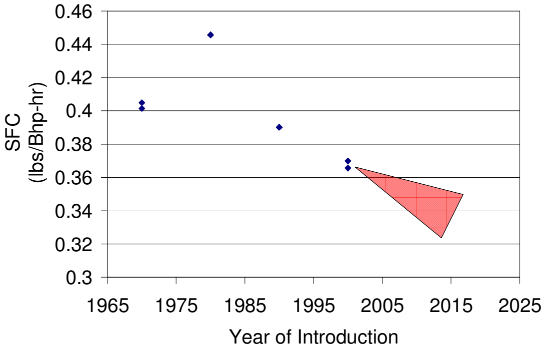


Figure 4 – Propulsion Gas Turbine Engines, SFC versus Year of Introduction, Current and Future Engines

The engines presented in Figure 3 also represent a evolution over time. In Figure 4 I have presented the same family of engines, but here I have plotted the SFCs versus the engine's date of entry into service. The same trend of steady improvement is seen, but it appears possible to deduce that future engines might be even better than predicted on Figure 3, perhaps as low as the lower corner of the red triangle on Figure 4.

In consideration of this data, whereas the first investigation conducted below will use an SFC value of 0.40 lbs/hp, it appears reasonable that SFC might be as low as 0.36 to 0.33.

3.3 THE WEIGHT OF POWER

The L/D Best Practices Curve provides a prediction of how much power might be needed to move a given weight of ship. This power prediction can be used to generate a prediction of fuel weight for that ship given an assumed range.

But what of the weight of the power source itself? Detailed investigation of this will take place during a later section of this paper, but as a starting point let me assume a value of 10 pounds per horsepower. That is to say that a 100,000 hp propulsion plant, including all of its components *including propulsors* may be expected to weigh about one million pounds, or ~450 tons.

In Section 4 below I will present analysis of an existing ship design which yields a real-world values of this parameter near the range of 8 to 10 lbs / hp. I will also explore the impacts of some variations of this parameter upon the total ship feasibility picture.

3.4 THE WEIGHT OF CARGO CARRYING CAPACITY

In addition to propelling machinery the ship must encompass structure, crew, auxiliary systems, and so forth.

At the highest conceptual level I envision this as a sort of "bag" that is placed around the cargo. It seems reasonable, then, to attempt to model the weight of these parts of the ship by a multiplier on the cargo weight. Thus, for example, I may find that it takes one pound of ship to hold each pound of cargo, and thus the multiplier would be 1 lbs / lb. (Note that weight of the cargo is not included in the numerator in this definition.)

4. ILLUSTRATIVE EXAMPLES

Up to this point I have introduced a conceptual model of the ship design space, based on five simple parameters:

- L/D Ratio
- OPC
- SFC
- Parameter "Weight of Power"
- Parameter "Cargo Carriage Multiplier"

Let me now explore these parameters and their effect upon the design space as a whole.

4.1 ANALYSIS OF THE HSSL

Firstly, let me consider the case put forward in ONR's "HSSL" program. The goal here was to define the characteristics of a hypothetical 12,000 LT 43 knot ship. The requirement was for a speed of 43 knots and a range of 5,000 nautical miles, with a desired cargo capacity of 3600 LT.

Let me assign the following values to the five parameters:

- L/D per Best Practices Curve
- OPC of 0.6
- SFC of 0.40 lbs/hp-hr
- Weight of Power of 10 lbs / hp
- Cargo Carriage Multiplier of 2 lbs / lb

These values yield the results presented in Table 1.

As may be seen, the ship in Table 1 only carries some 1500 tons of cargo, less than half of the HSSL project goal. At first glance this suggests that it will take a ship of 28,000 tons or more to meet ONR's goal.

Table 1 - First analysis of the HSSL by the present Parametric Method

(1)	Full Load Displacement	12,000	LT
(2)	Vk	43	knots
(3)	Fnvol	1.482	
(4)	L/D	17.28	
(5)	Rt	1,555,138	lbs
(6)	EHP	205,126	hp
(7)	OPC	0.6	
(8)	SHP	341,876	hp
(9)	SFC	0.4	lbs/hp-hr
(10)	Range	5,000	miles
(11)	Fuel Weight	15,901,204	lbs
(12)	Fuel Weight	7,099	LT
(13)	Displacement minus Fuel	4,901	LT
(14)	Wt of Power	10	lbs/hp
(15)	Machinery Weight	1,526	LT
(16)	Weight available for Cargo & Cargo Carriage	3,375	LT
(17)	Cargo Carriage Multiplier	2	lbs/lb
(18)	Cargo Carriage Weight	2,250	LT
(19)	Cargo Load	1,125	LT
	SUMMARY		
	Machinery Weight	1,526	LT
	Cargo Carriage Weight	2,250	LT
	Light Ship Weight	3,776	LT
	Fuel Weight	7,099	LT
	Cargo Load	1,125	LT
	Full Load Displacement	12,000	LT

I can explore whether this is true by expanding the analysis to a range of assumed displacements, and generating a family of results which are presented in Figure 5 as a graph of Full Load Displacement versus Cargo Load. Of course, all of these predictions are dependent upon my assumptions for L/D, SFC, and OPC.

By these results I see that it is not necessary to grow all the way to 28,000 tons to carry the desired 3600 LT of cargo, but rather this goal corresponds to a displacement of 24,200 LT. This is due to the magnifying effect of the L/D curve, wherein the bigger ship benefits from an improved L/D, as alluded to earlier.

But what if the Cargo Carriage Multiplier is other than 2? This parameter is probably the least defensible of my assumptions, so it makes sense to consider a fairly wide range of possible values.

Similarly, I might also consider a range of possible values for specific fuel consumption, say between 0 and 0.5 lbs / hp-hr.

Figure 6 depicts a surface wherein the Cargo Carriage Multiplier varies from 1 to 11, and SFC varies from 0 to 0.5. In this figure the plotted value of displacement corresponds to a cargo weight of 3600 LT. The same design space is plotted in Figure 7, but this time instead of Full Load Displacement I depict the required installed horsepower. Finally, Figure 8 shows again the same space, but depicts the required fuel load.

The arithmetic for Table 1 is as follows:

(1)	Input
(2)	Input
(3)	Calculated from (1) & (2)
(4)	From Best Practices Curve
(5)	(1)/(4)*2240
(6)	calculated from (5) & (2)
(7)	Assumed
(8)	(6) / (7)
(9)	Assumed
(10)	Input
(11)	(8)*(9)*(10)/(2)
(12)	(11) / 2240
(13)	(1) - (12)
(14)	Assumed
(15)	(14)*(8)/2240
(16)	(13) - (15)
(17)	Assumed
(18)	(19) * (17)
(19)	(16) - (18)

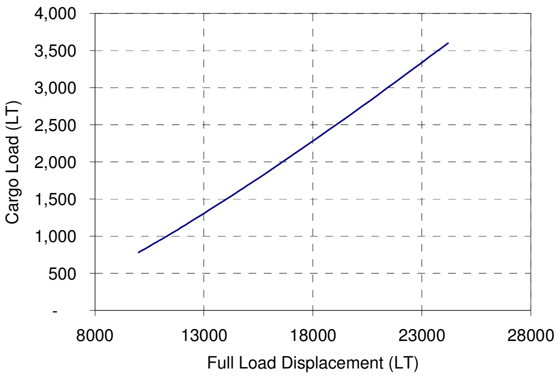


Figure 5 - Trend of Cargo Capacity with increasing Ship Size, corresponding to Table 1.

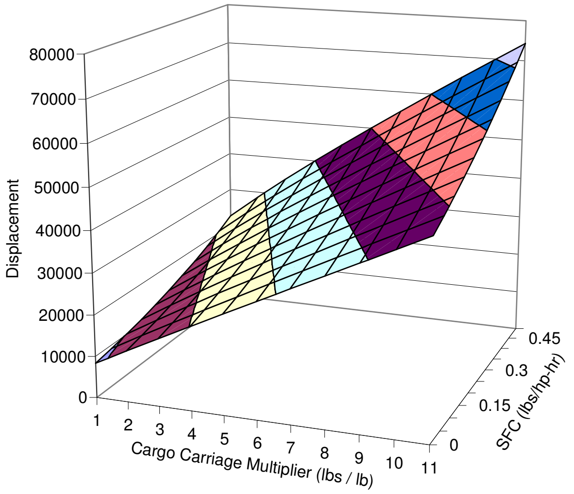


Figure 6 - Map of first-look HSSL Ship Size, (Corresponds to 3600 LT cargo, 43 kts, 5000 nmi range, OPC = 60%, L/D per Best Practices Curve, Weight of Power = 10 lbs / shp. Cargo Carriage Multiplier from 1 to 11 lbs/lb, SFC from 0 to 0.5 lbs/hp-hr)

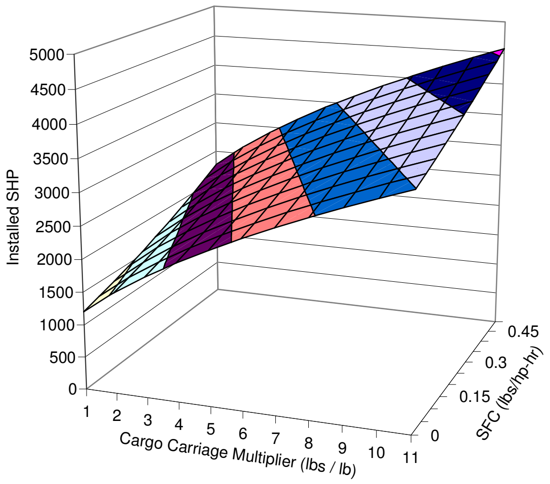


Figure 7 - HSSL Installed Power
(Same family of ships as Figure 5.)

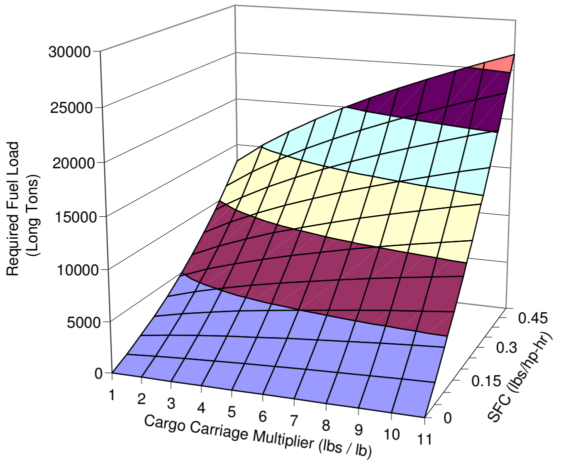


Figure 8 - HSSL Required Fuel Load for 5000 mile range (Same family of ships as Figure 5)

From maps of this type we can gain enough insight to direct our further research efforts. For example, specific to the HSSL program, if the the goal is find a ship of 12,000 LT displacement that can carry 3600 LT of cargo across 5000 miles at 43 knots, then the following statements can be made with some confidence:

The solution must lie (subject to the assumptions made up to this point) along a line demarked by the following two endpoints:

- ○ SFC = 0.39; Cargo Carriage Multiplier = 0.0 (Which is the limit because it allows no weight for structure and ship systems)
- ○ SFC = 0; Cargo Carriage Multiplier = 1.9 (Which is the limit because it allows no weight for fuel)
- ○ The midpoint of this line lies at SFC = ~0.20 ; Cargo Carriage Multiplier = 1.0

Alternatively, we need to make a breakthrough in the L/D value, or in the Weight of Power. A separate calculation (not detailed in this paper, but using the same methodology,) investigated this effect. If the Best Practices Curve maps the state of the art, then one can carry about 1500 tons of cargo on a 12,000 LT ship. To reach 3600 LT of cargo would require a 6x improvement in the state of the art for L/D.

The effect of these insights upon the HSSL research program is clear:

- Investigate ways to reduce the Cargo Carriage Multiplier
- Investigate ways to reduce the Weight of Power
- Investigate ways to make substantial improvements in the L/D state of the art

I shall now continue to demonstrate the use of this parametric method, by showing how I use it to explore these questions.

4.1 ANALYSIS OF EXISTING SHIPS

In the paragraphs below I have collected actual data on a real-world vessel, and subjected this ship to analysis by the parametric relationships above. Of course, in the actual HSSL program I would expand this to include several different parent ships – the present analysis is only illustrative.

Via this analysis I observe what sort of values for L/D, SFC, Power/Weight ratio, and Cargo Weight Ratio are observed in the real world. Then, with those real-world parameters, I estimate what an ONR HSSL Sealift Ship would “look like” if it were derived from the given real-world parent.

The input data for the parent ships consists of weight, power, and dimensional data taken from public sources. This is collected into the form of the parameters discussed above.

Note that the Observed SFC is calculated based on the assumption that all of the reported fuel is used to cover the reported range at the reported speed. Similarly, the L/D Observed assumes that all of the reported power is used to attain the reported speed. Thus if the designer of the parent ship has included power margins, range allowances, and so forth, these have been ‘rolled up’ into the derived parameters.

Once the five parameters have been calculated, one then compares the observed performance with the performance that would be predicted by the best Practices Curve. This yields an L/D “correction factor” that I will assume represents some intrinsic characteristic of the parent ship.

Armed with these now six parameters I can introduce a new set of assumed range, speed, and cargo weight, and can from the parameters derive the characteristics of such a ‘scale-up’ of the parent ship.

Allow me to illustrate this with a fast car ferry.

4.2 ANALYSIS OF PACIFICAT

The Pacificat is an INCAT-Designed 122m catamaran ferry, of which three sisterships were built by Catamaran Ferries International. The Pacificat data set represents a highly-credible best commercial practice multihull. The key input values are as follows:

Table 2 – Pacificat Input Parameters

Parent:	**PacifiCat**	
Length	400	feet
Weight of Power	136	LT
Total Light Ship	1,331	LT
Fuel	57	LT
"Cargo"	466	LT
Full Load	1,855	LT
Installed Power	34,866	SHP
Full Speed	32.00	knots
Fn_{vol}	1.50	
OPC	0.65	-
Range	260	nautical miles
Speed at Range	32.0	knots

These may be analyzed according to the parametric methodology and yield the following derived values:

Table 3 – Pacificat Derived Data

Parent:	**PacifiCat**	
Weight of Power	8.72	lbs/hp
Cargo Carriage Multiplier	2.56	lbs/lb
SFC	0.451	lbs/hp-hr
OPC	0.650	-
Observed L/D	17.99	-
Predicted L/D	16.73	-
L/D multiplier	1.08	(obs / pred)

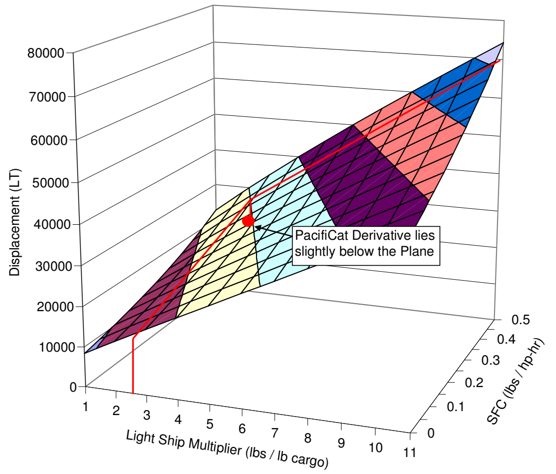
Thus, for one real-world commercial craft, the weight of Cargo Carriage is less than 3, the weight of power is less than 9 lbs / hp, and the L/D ratio exceeds the Best Practices Curve’s prediction by 8%.

The next step, then, is to estimate what the characteristics would be for a HSSL ship based on this parent, but sized to carry 3600 LT of cargo across 5,000 nautical miles at 43 knots. Note that in this derivation I assume that the L/D multiplier may be applied equally. In other words, if the ship was 8% better than Best Practices Curve at the input point, then it will be the same amount better at 43 knots. The weight parameters (Cargo Carriage Multiplier, Weight of Power Multiplier, SFC, (and OPC) are similarly assumed not to change between the parent and the offspring.

The resulting HSSL parameters are given in Table 4. Here, as we see, the result is a 26,000 LT ship, requiring half a million horsepower. This represents about a 2.5x linear scale-up of the Pacificat, and thus a ship of 960 feet length.

Table 4 - Parameters of a HSSL based upon Pacificat

Parent:	PacifiCat	
Cargo	**3,600**	LT
Weight of Cargo Carriage	**9,228**	LT
Weight of Power	**1,813**	LT
Fuel	**11,080**	LT
Full Load Displacement	**25,721**	LT
Length	**960**	feet
Range	**5,000**	nmi
Speed	**43**	knots
Fn-vol	**1.31**	
L/D-raw	**22.99**	
L/D-adjusted	**24.72**	
Resist	**2,331,051**	lbs
EHP	**307,470**	hp
SHP	**473,031**	hp



PacifiCat Derivative lies slightly below the Plane

Figure 8 – PacifiCat-Derived HSSL plotted on design space from Figure 5.

Note that this result is quite consistent with the result generated parametrically earlier. Earlier we saw that a ship carrying 3600 LT tons of cargo might be expected to be about 24,000 tons at best practice. That conclusion was based on arbitrarily assumed values for power to weight ratio and cargo carriage multiplier. Here, using the real-world PacifiCat as a parent, we find that we can attain a slightly higher power to weight ratio, but a somewhat inferior cargo carriage multiplier. The L/D value lies just about on the curve, and the SFC and OPC are also about as expected. Thus the net effect balances the change in Cargo Carriage Multiplier and Weight of Power to yield a ship very near the originally expected displacement.

Note that in terms of the design plane, this means that the PacifiCat lies on the predicted plane. Figure 8 is an illustration showing where this Pacificat derivative lies on the HSSL design plane. Because the observed L/D is close to Best Practices Curve's prediction, but the Power to Weight ratio is less than 10, the resulting spot is below the design plane.

4.3 ANALYSIS OF LIMITS

In Section 4.2 I presented an analysis of one parent craft, and I used the parametric method to extrapolate this parent to the HSSL mission requirements. Now I wish to use the method in a different way, to determine what values our parent would have to possess, to give us the HSSL that we desire.

Let us assume that the desire is to complete the HSSL mission with a ship of no more than 12000 LT.

I will end the paper by telling you about a graph that I wish I could present, but don't know how to draw: We can expand the 'line' in Section 4.1 into a sort of hyper-cube, which defines the boundaries of the space of 12,000 LT HSSL ships, in a five-dimensional space. Table 5 presents the coordinates of two three-dimensional planes in that space. Figure 9 is a hand-drawn plot of those planes.

The two planes represent 12000 LT ships, the lower plane being ships that have L/D as predicted by the Best Practices Curve, the upper plane being ships that have half the resistance of the Best Practices Curve (i.e. twice the L/D.)

What this tells us is as follows:

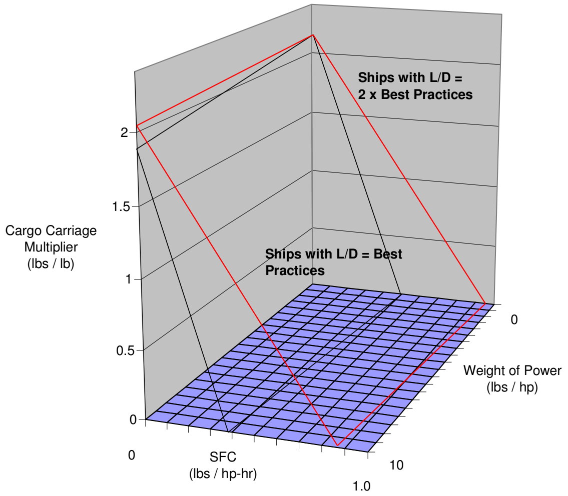
Improvements in Weight of Power are surprisingly unimportant. A move along the Weight of Power axis doesn't require much change in Cargo Carriage Multiplier or SFC in order to stay on the plane. Cargo Carriage Multiplier and SFC are (relatively) more important.

A change in either Cargo Carriage Multiplier or SFC demands a change in the other. The only way to increase Cargo Carriage Multiplier, while staying on the 12000 LT plane, is to decrease the SFC, and vice versa.

Changes in Resistance (via OPC or L/D) can be traded against large changes in SFC. Reducing resistance permits increasing fuel consumption, without changing displacement. This seems obvious. What is less obvious is that there is very little effect upon Cargo Carriage Multiplier. Changes in resistance don't seem to make much change in the range of "acceptable" Cargo Carriage Multiplier values.

Table 5 - Boundaries of two planes limiting the HSSL design space

Corner	Weight of Power	Cargo Carriage Multiplier	SFC	k L/D
A	10	0	0.39	100%
B	10	1.9	0	100%
C	0	0	0.475	100%
D	0	2.3	0	100%
E	10	0	0.86	200%
F	10	2.1	0	200%
G	0	0	0.95	200%
H	0	2.3	0	200%



Many other conclusions could be drawn, but I return to my theme that my purpose is not to talk about the HSSL mission, but rather about the parametric method. I believe that I have shown that this method can be a useful tool for breaking a complex problem into very simple parts, giving us insights into the shape of the design space as a result of that, and thus finally permitting us to manage and focus our further engineering efforts, for maximum programmatic effectiveness.

5. CONCLUSIONS

The paper has introduced a five-parameter method, using parameters that align with traditional naval architecture thought, to yield a tool for mapping of an entire design space.

The method is simple and powerful, in that it permits rapid identification of how innovative one must be, or how conservative one can afford to be, in order to attain various performance levels.

The method is a framework upon which other advances can be built. For example, I have used this method to study the effect of alternative power upon merchant ships, by appropriate changes in the SFC and "weight of power" parameters.

The method is most emphatically not a design method. There is no guarantee that any given set of parametric values is attainable in real life. But by defining the values that must be attained in order to achieve a given mission capability, the method becomes a powerful tool for managing and directing the design task.

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7. REFERENCES

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8. AUTHOR'S BIOGRAPHY

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