

REVIEW OF ADVANCED MARINE VEHICLES CONCEPTS

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SUMMARY

The objective of this paper is to present a review of developments of Advanced Marine Vehicles concepts, with emphasis on the basic techno-economic efficiency of fast passenger and high-value cargo ship designs. The presented work is based on the analysis of data of NTUA-SDL's Fast Marine Vehicles (FMV) techno-economic database. The collected techno-economic data have been systematically analysed, to assess the transport efficiency of various fast ship concepts and to conclude on the feasibility and viability of candidate designs for specific operational scenarios.

1. INTRODUCTION

During the past two decades the maritime community has witnessed a rapid technological evolution of Fast, Advanced Marine Vehicles (AMV) for various applications. In the commercial sector, considerable effort has been devoted worldwide to the development of new types of fast passenger and (to a lesser degree) high-value cargo ships, in an attempt to increase the share of waterborne transportation against other competing transportation modes in shortsea operations. Many operators have until now been reluctant to consider the introduction of advanced marine vehicles because of the difficulty in assessing their characteristics, the lack of proven operational records and last but not least the dramatic increase of fuel cost, particularly in the last years. As each AMV concept has its own optimal domain of application, wrong selection among the proposed concepts may become disastrous both for the image of the concept and for the viability of rather small operators.

An overview of developments of the various AMV concepts on the basis of the prime vehicle's weight counterbalance force is shown in the Appendix (Papanikolaou, 2002, updated). There it is noted that developments chronologically started from concepts in the upper left corner area (displacement ships, Archimedean hydrostatic weight balance force) and moved towards the right side and downwards with the introduction of more complex technologies. A comprehensive description of technological developments of AMV's has been recently issued by an international group of authorities (Lamb, 2004).

This paper focuses on a review of the basic characteristics of fast passenger ferry and high-value cargo ship designs, considering significant developments within and outside Europe. The technical and economic characteristics of AMVs, presented in the paper, derive from a recently developed techno-economic Fast Marine Vehicles (FMV) database by NTUA-SDL in the framework of an EU funded project (EFFISES, 2001-2005). The collected techno-economic data have been systematically analysed, in order to assess the transport efficiency of various fast ship concepts with the aim to assist the designer, shipowner or other interested parties in the evaluation of candidate technical solutions for specific operational scenarios. Empirical formulae relating major design

characteristics of various high-speed concepts have been derived based on regression analysis of the collected data (Papanikolaou et al, 2001). Emphasis has been placed in the assessment of two hybrid Air Lubricated Hull (ALH) EFFISES concepts, currently validated by open sea experiments of two scaled 9m prototypes (Papanikolaou et al., 2004). The main characteristics of the investigated EFFISES concepts are shown in Table 1.

2. PRESENTATION OF DATA SAMPLE

The NTUA-SDL FMV database considers techno-economic data of a significant portion of high-speed vehicles operating worldwide (sample size in June 2005: 657 registered vessels, Froude number over 0.70). The main source of data is both public domain information and confidential data of NTUA-SDL deriving from past and ongoing research in this area. Compared to commercially available relevant databases, it is characterized by the availability of a satisfactory set of data regarding ship weights (displacement, payload, deadweight and lightship weight) and building costs.

Figures 1 to 5 illustrate the main database menu with some main features of the database and the repartition of the collected data with respect to ship type, length, speed, etc.

The screenshot displays the 'FMV Database - Add a new Vessel' interface. It is divided into several sections: 'GENERAL INFORMATION' with fields for Ship ID, Name, and Type; 'MAIN CHARACTERISTICS' with fields for Loa, Lwl, B, and various hull parameters; 'MACHINERY and PROPULSION' with engine details; 'SHIP CAPACITY' with passenger and cargo options; 'SHIP SPEEDS' with speed and RPM data; and 'GENERAL COMMENTS' for additional notes. The interface includes a 'BACK TO CONTENTS' button and a status bar at the bottom.

Figure 1

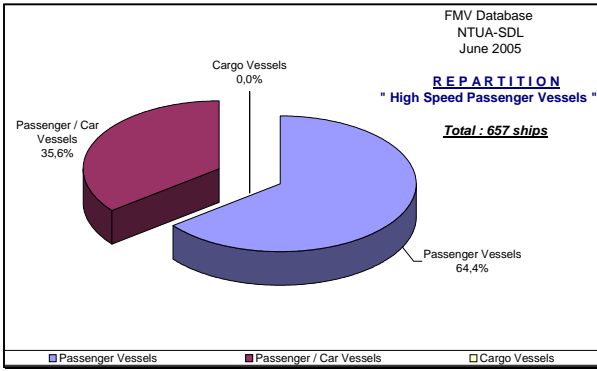


Figure 2

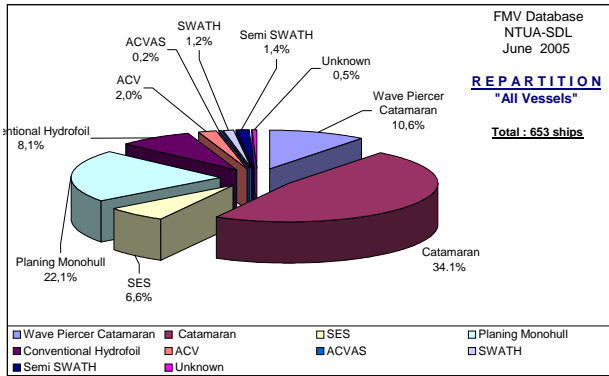


Figure 3

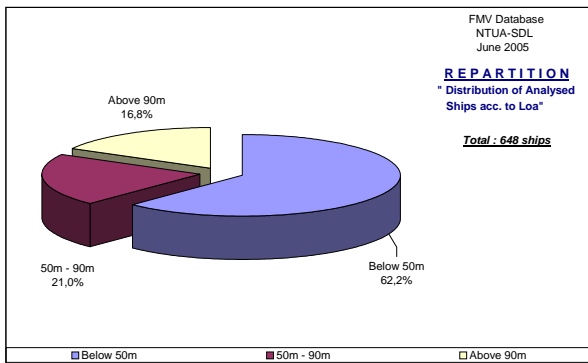


Figure 4

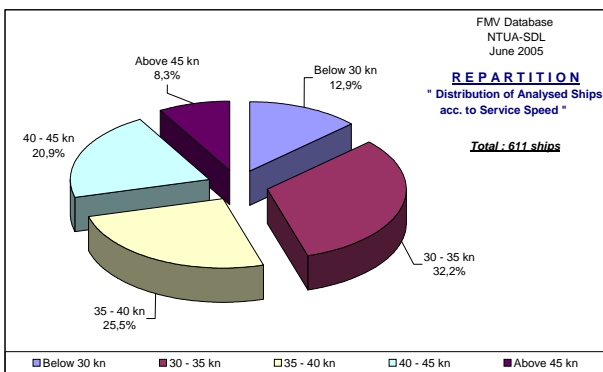


Figure 5

3. TRANSPORT EFFICIENCY ANALYSIS

The Transport Efficiency of a marine vehicle may be defined in various ways and a series of researchers have addressed this in the past. In the following, a review of past work is attempted and complemented by recent work of the author.

The Transport Efficiency may be defined as a function of the vessel's deadweight W_d (t), service speed V_s (kn) and total installed power P (kW) and is presented for a sample of AMVs in Figure 6.

$$E_1 = \frac{W_d \cdot V_s}{P} \quad (1)$$

The Transport Efficiency may be also defined with respect to the vessel's payload W_p (t) instead of deadweight, and is presented in Figure 7.

$$E_2 = \frac{W_p \cdot V_s}{P} \quad (2)$$

Comparing the transport efficiency of marine vehicles with that of alternative modes of transport (land- and airborne), it is very useful to employ the well known v. Karman-Gabrielli transport efficiency diagram. Akagi (1991) has re-plotted the original Karman-Gabrielli diagram, in terms of the reciprocal Transport Efficiency as a function of the total installed power P (PS), displacement W (t) and maximum speed V (km/h):

$$\frac{1}{E_3} = \frac{P}{W \cdot V} \quad (3)$$

and Akagi-Morishita (2001) added more recent developments of various transport vehicles. Figure 8 presents the reciprocal Transport Efficiency once more updated by sample data of the NTUA-SDL database, whereas Figure 9 is focusing on the performance of the marine vehicles only.

The reciprocal Transport Efficiency (specific power), may be based also on payload W_p (t):

$$\frac{1}{E_4} = \frac{P}{W_p \cdot V^2} \quad (4)$$

and is presented in Figure 10.

Akagi (1991) plotted the payload ratio (W_p/W) of various transport vehicles against their maximum speed (in km/h). This plot has been updated in Figure 11 by additions of the FMV-NTUA database. Akagi and Morishita (2001) also analyzed the Specific Power $1/E_2$ as:

$$\frac{P}{W_p \cdot V} = \frac{P}{W \cdot V} \cdot \frac{W}{W_d} \cdot \frac{W_d}{W_p} \quad (5)$$

and plotted each term separately. The deadweight and payload ratios against V , W and volumetric Froude number F_{∇} are plotted in Figures 12 – 20, as updated by the FMV-NTUA sample data.

Kenell (1998) introduced a transport factor:

$$TF = \frac{K_2 \cdot W}{SHP_{TI} / (K_1 \cdot V_K)} \quad (6)$$

where K_2 is a constant ($K_2= 2240$ lb/LT), W is ship's displacement in LT, SHP_{TI} is the total installed power in HP, K_1 is a constant ($K_1= 1.6878/550$ HP/lb-kn) and V_k is the design speed in kn. Figure 21 presents Kenell's transport factor vs. speed updated with the relevant FMV-NTUA database data.

Following Kennell's approach, the displacement and transport factor are decomposed as follows:

$$W = W_{ship} + W_{cargo} + W_{fuel} \quad (7)$$

$$TF = TF_{ship} + TF_{cargo} + TF_{fuel} \quad (8)$$

Where W_{ship} , W_{cargo} , W_{fuel} are the lightship, cargo and fuel oil weight respectively (in LT), and TF_{ship} , TF_{cargo} , TF_{fuel} are the transport factors, calculated for each weight group.

W_{ship} and W_{fuel} are obtained from the following equations:

$$W_{ship} = W - W_{cargo} - W_{fuel} \quad (9)$$

$$W_{fuel} = SFC_{avg} \cdot K_{SHP} \cdot SHP_{TI} \frac{R}{K_S \cdot V_K} \quad (10)$$

where SFC_{avg} is the average effective fuel consumption rate, K_{SHP} is the endurance power to design power ratio, R the range (in n.m.), K_S the endurance speed to design speed ratio.

Figures 22 to 25 show the fuel transport factor vs. range and the trends of transport factors and various fractions thereof, as plotted by Kennell and updated by the FMV-NTUA database ships.

Hearn et al. (2001) used Kennell's transport factor to compare current technology catamarans, semi-SWATHs and wave-piercers against a defined Technology Barrier. Figure 26 shows an update of Hearn's diagram by data of the FMV-NTUA database ships.

Finally Wright (1990) examined the relation between BHP/Passenger and speed/length ratios for passenger crafts of about 200 passengers and calculated the Transport Efficiency of various high speed crafts. Wright's Transport Efficiency is defined as:

$$E_S = \frac{(W_{max} - LW) \cdot V_{C,0/0}}{P_C} \quad (10)$$

where W_{max} is the maximum displacement in t, LW the lightweight in t, $V_{c,0/0}$ the cruise speed in kn at 0/0 conditions (calm water, no wind) full load and P_c the cruise power in kW.

Wright's results, amended by FMV-NTUA data are presented in Figures 27 and 28.

4. CONCLUSIONS

The present state of the art of technological developments of Advanced Marine Vehicles allows the consideration of a wide variety of fast marine vehicle concepts, for various applications. The transport efficiency of the various investigated concepts clearly depends on design speed, route length, payload/displacement ratio and absolute vessel's size.

When considering commercial applications the selection of the optimal concept presumes the specification of an accurately defined operational scenario, following a market research with respect to the transport volume, market shares and the performance of alternative transport vehicles (speed and cost), including conventional vessels and, if applicable, airborne and land vehicles.

For the specified operational scenario alternative candidate AMV concepts may be assessed with respect to a variety of cost merit functions and design constraints. This assessment should include, along with the calm water performance of candidate concepts, their performance at service speed under the selected operational seaway conditions, characterizing the area of operation.

The Transport Efficiency analysis of the envisaged Air Lubricated Hull EFFISES prototype designs appears quite competitive compared to other types and modes of fast transport. If the preliminary design results of the EFFISES prototypes are confirmed by the planned open sea tests, it is believed that the envisaged ALH hybrid designs will represent an attractive alternative for the fast transportation of passengers and high-value cargo.

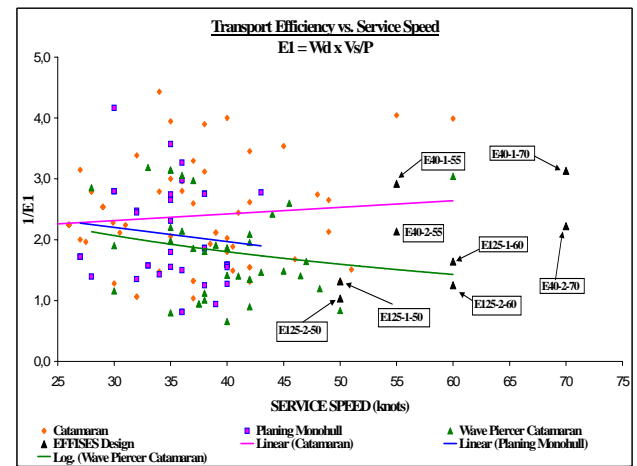


Figure 6

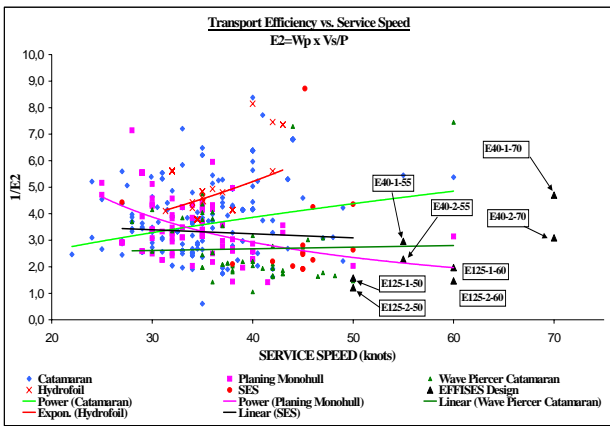


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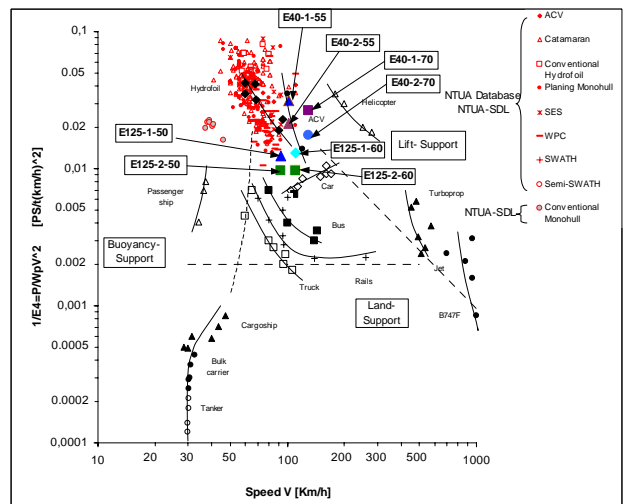


Figure 10

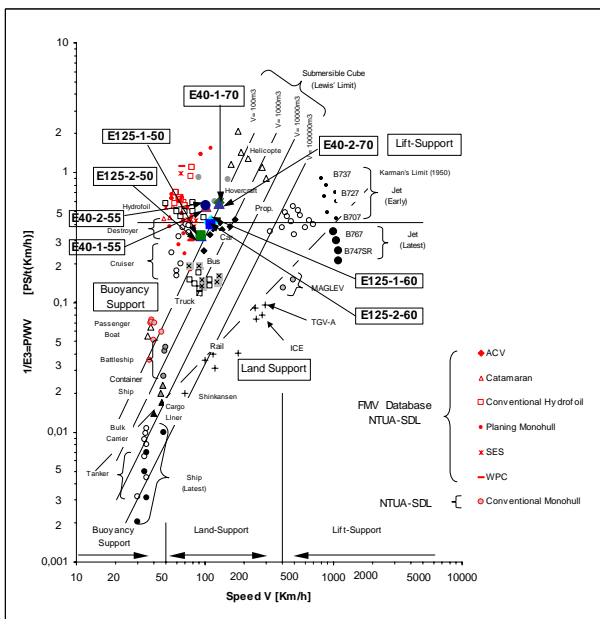


Figure 8

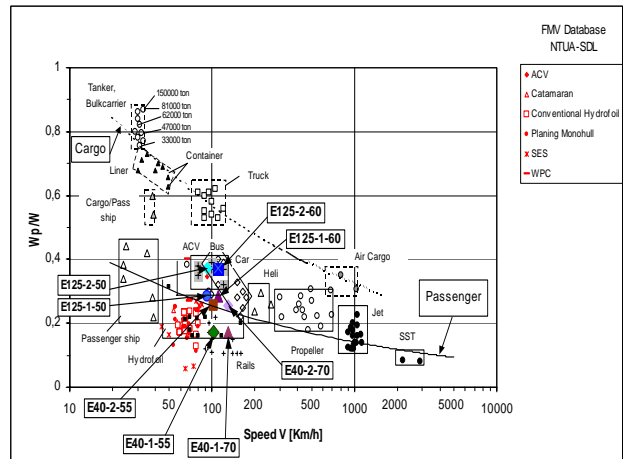


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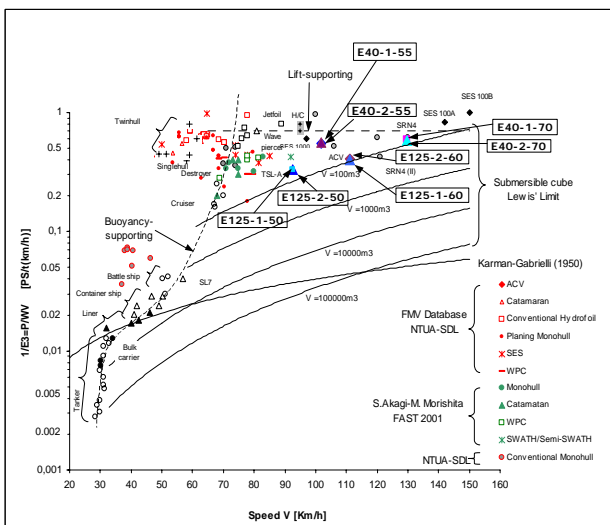


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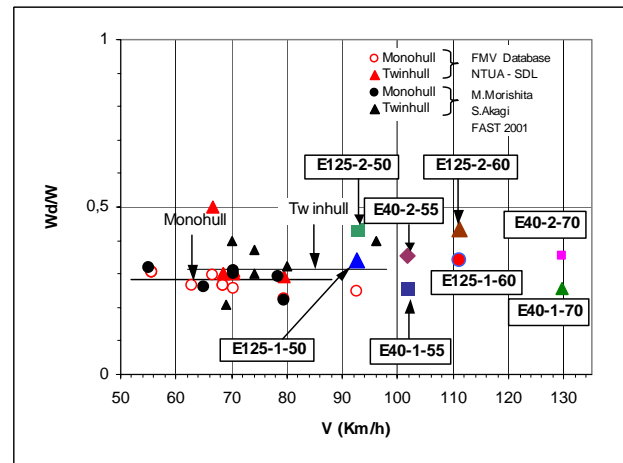


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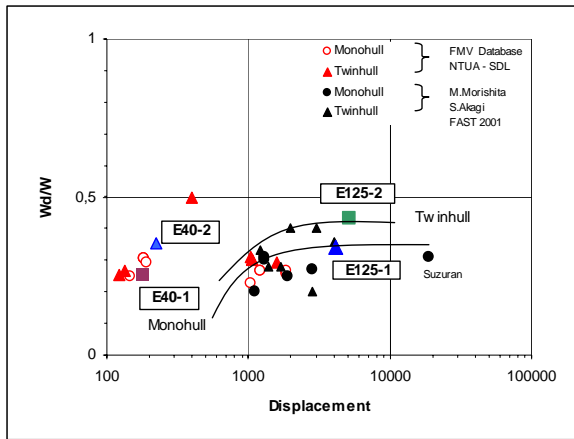


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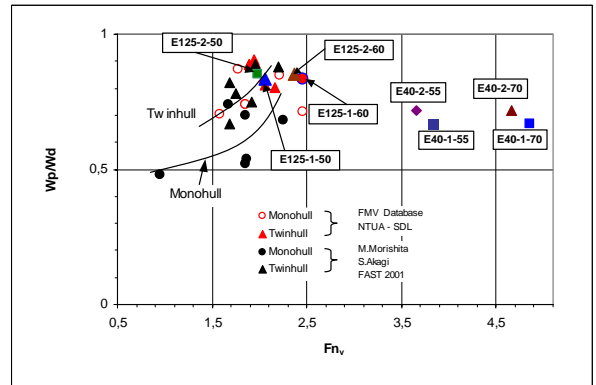


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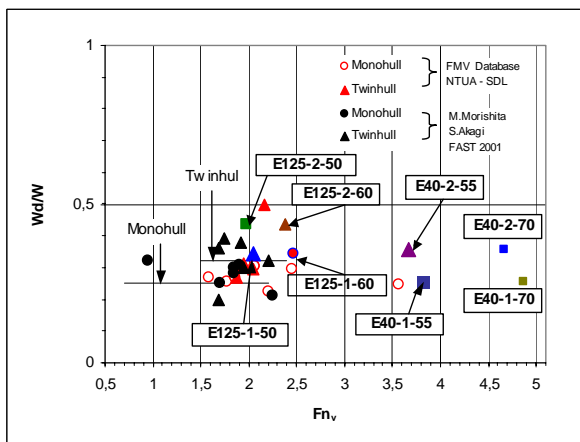


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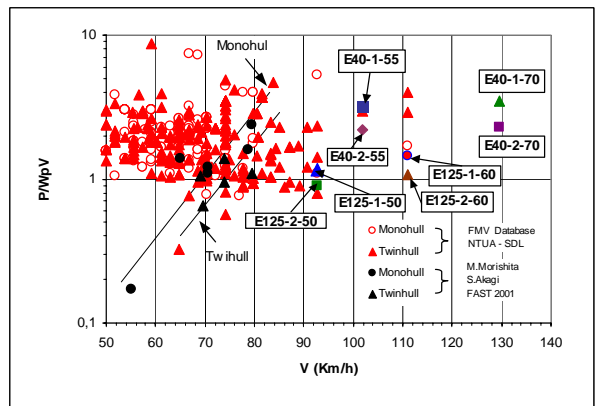


Figure 18

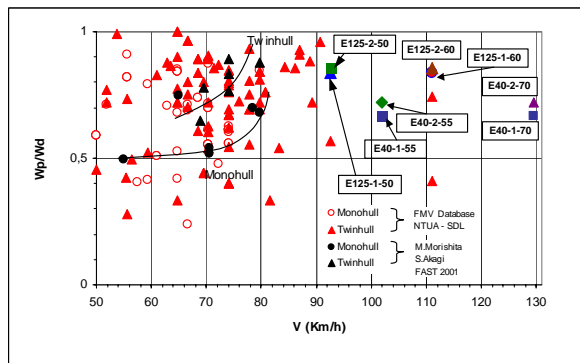


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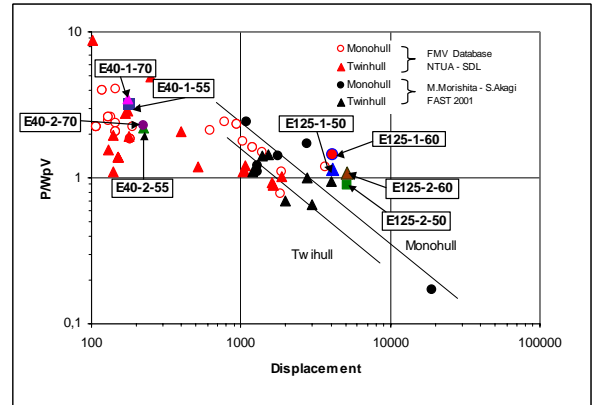


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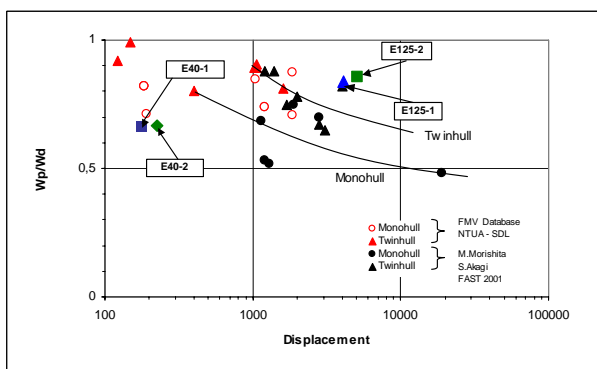


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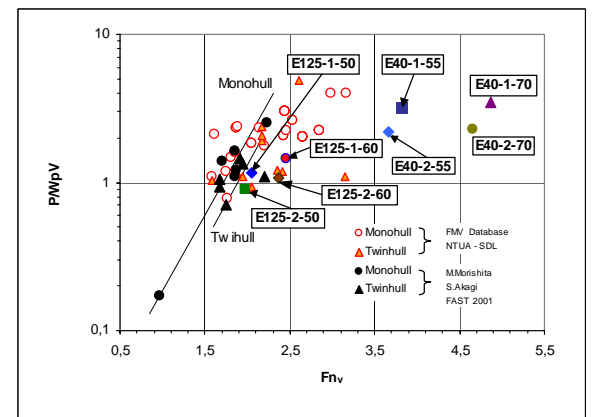


Figure 20

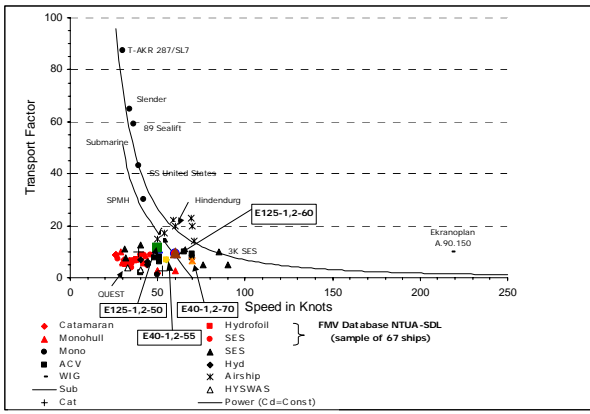


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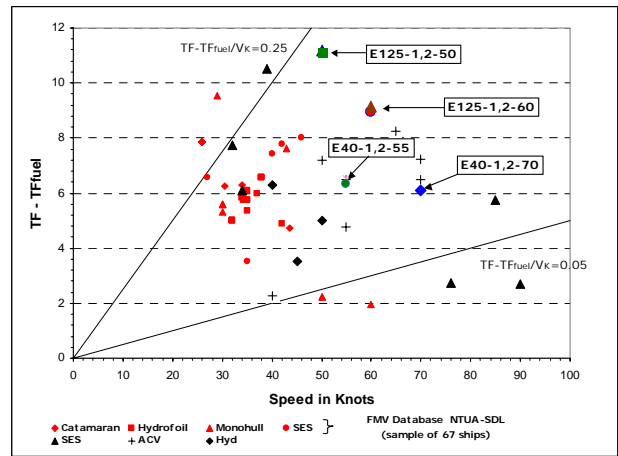


Figure 25

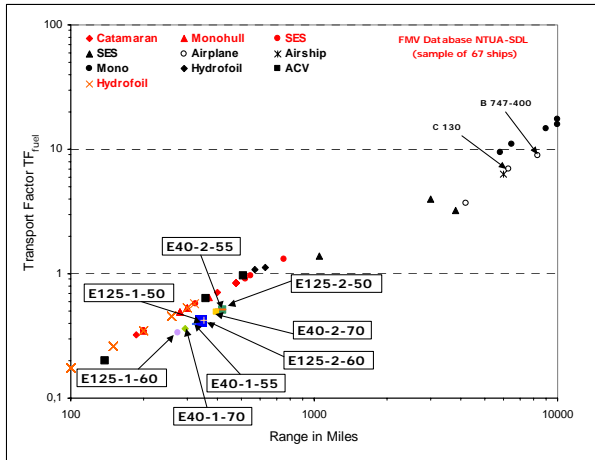


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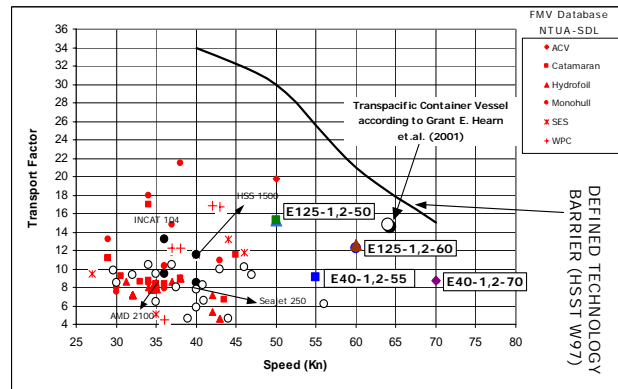


Figure 26

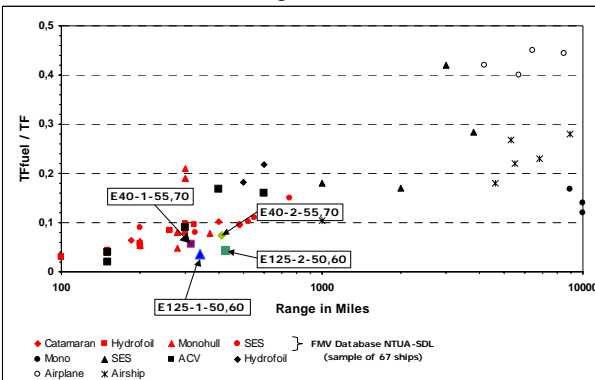


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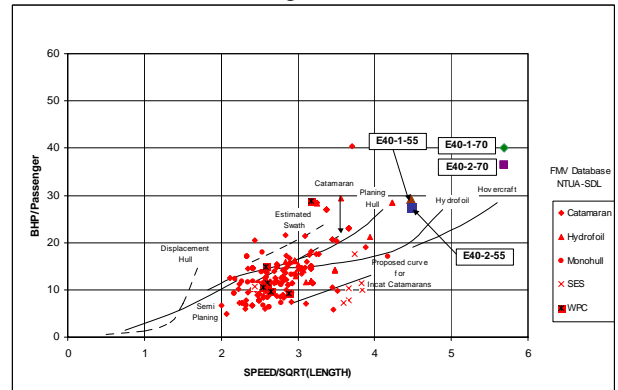


Figure 27

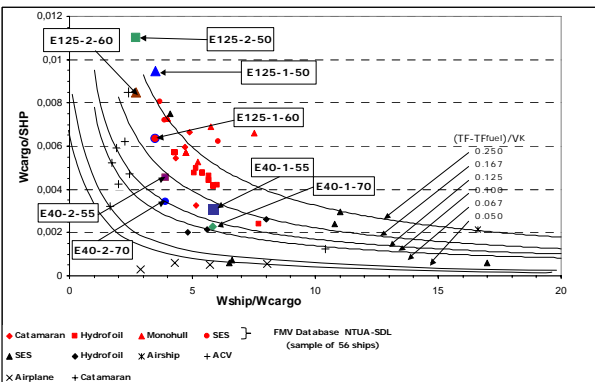


Figure 24

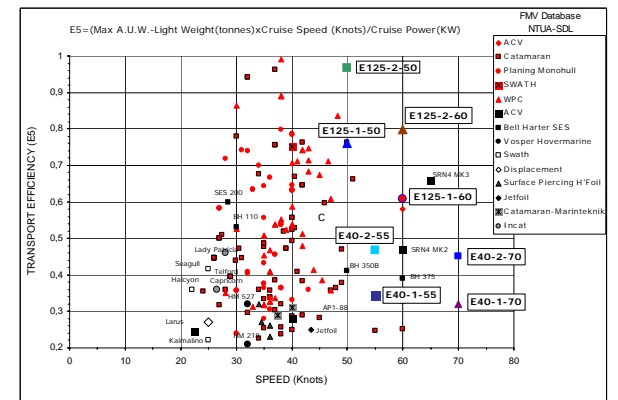


Figure 28

Ship Characteristics	E40-1-55	E40-1-70	E40-2-55	E40-2-70
LOA	40 m			
LBP	36 m			
B	16 m			
D	4.30 m			
Displacement	175 tons		225 tons	
Lightship	130 tons		145 tons	
Deadweight	45 tons		80 tons	
Payload	30 tons		57.5 tons	
Fuel	10 tons		17 tons	
Pass. Capacity	247 – 342			
Car Capacity	0			
Truck Capacity	0			
Speed	55 Kn	70 Kn	55 Kn	70 Kn
Total Power	7227 kW	9874 kW	9353 kW	12440 kW
Consumption (M.E)	240 gr/kW/h			
Ship Characteristics	E125-1-50	E125-1-60	E125-2-50	E125-2-60
LOA	125 m			
LBP	118 m			
B	45 m			
D	12.80 m			
Displacement	4100 tons		5125 tons	
Lightship	2700 tons		2900 tons	
Deadweight	1400 tons		2225 tons	
Payload	1170 tons		1900 tons	
Fuel	150 tons		230 tons	
Pass. Capacity	1500			
Car Capacity	150 – 400			
Truck Capacity	25 – 0			
Speed	50 Kn	60 Kn	50 Kn	60 Kn
Total Power	92000 kW	138000 kW	115000 kW	167000 kW
Consumption (M.E)	250 gr/kW/h			

Table 1

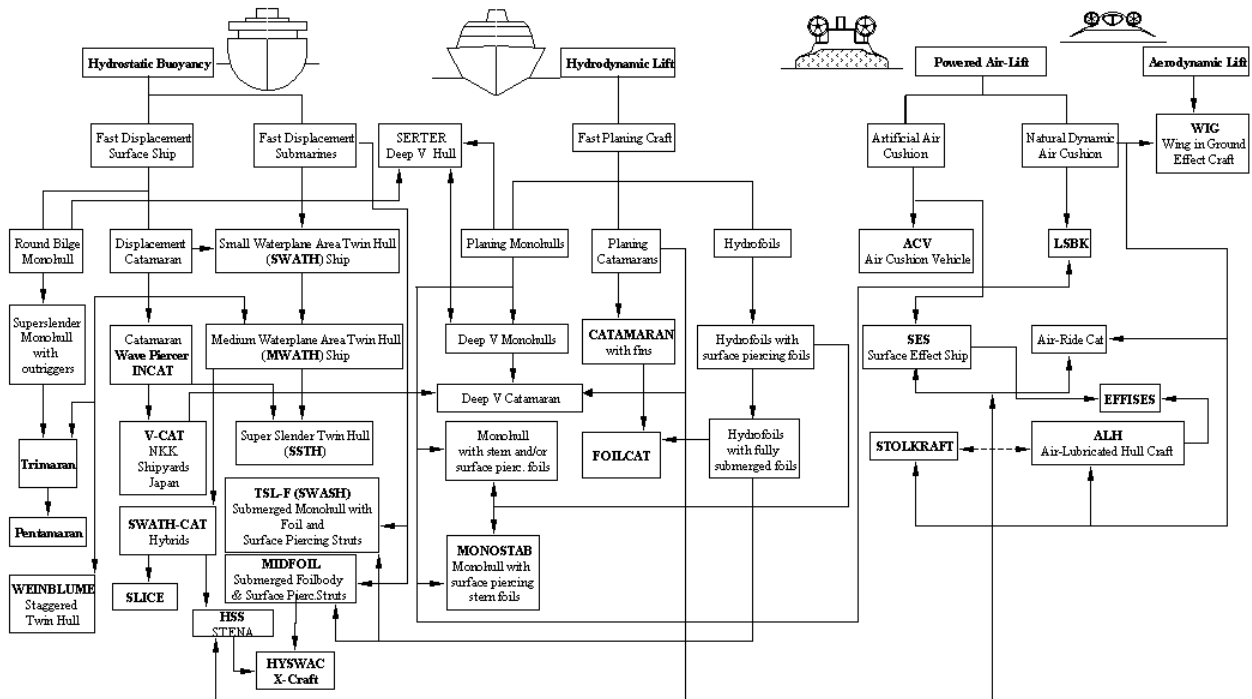
5. ACKNOWLEDGMENTS

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APPENDIX A



Comments on Chart of Advanced Marine Vehicles and Explanation of Used Acronyms

1. ACV: Air Cushion Vehicle - Hovercraft, excellent calm water and acceptable seakeeping (limiting wave height), limited payload capacity.
2. ALH: Air Lubricated Hull, various developed concepts and patents, see type STOLKRAFT.
3. Deep V: ships with **Deep V** sections of semi-displacement type acc. to E. Serter (USA) or of more planing type, excellent calm water and payload characteristics, acceptable to good seakeeping, various concepts AQUASTRADA (RODRIQUEZ, Italy), PEGASUS (FINCANTIERI, Italy), MESTRAL (BAZAN, Spain), CORSAIR (LEROUX & LOTZ, France).
4. EFFISES: Hybrid ALH twin hull with powered lift, patented by SES Europe A.S. (Norway)
5. FOILCAT: Twin hull (catamaran) hydrofoil craft of KVAERNER (Norway), likewise MITSUBISHI (Japan), excellent seakeeping (but limiting wave height) and calm water characteristics, limited payload.
6. HYSWAC – X-Craft: Hybrid SWATH with midfoil, prototypes currently tested by US Navy
7. LWC: Low Wash Catamaran, twin hull superslender semi-displacement catamaran with low wave-wash signature of FBM Marine Ltd. (United Kingdom), employed for river and closed harbour traffic.
8. LSBK: Längs Stufen- Bodenkanalboot- Konzept, optimized air-lubricated twin hull with stepped planing demihulls, separated by tunnel, aerodynamically generated cushion, patented in Germany.
9. MIDFOIL: Submerged Foil-body and surface piercing twin struts of NAVATEK-LOCKHEED (USA).
10. MONOSTAB: Semi-planing monohull with fully submerged stern fins of RODRIQUEZ (Italy).
11. MWATH: Medium Waterplane Area Twin Hull Ship, as type SWATH, however with larger waterplane area, increased payload capacity and reduced sensitivity to weight changes, worse seakeeping.
12. PENTAMARAN: Long slender monohull with four outriggers, designs by Nigel Gee and IZAR (Spain).
13. SES: Surface Effect Ship, Air Cushion Catamaran Ship, similar to ACV type concept, however w/o side skirts, improved seakeeping and payload characteristics.
14. SLICE: Staggered quadruple demihulls with twin struts on each side, acc. to NAVATEK-LOCKHEED (USA), currently tested as prototype.
15. SSTH: Superslender Twin Hull, semi-displacement catamaran with very slender long demihulls of IHI shipyard (Japan), similar to type WAVEPIERCER.
16. STOLKRAFT: Optimized air-lubricated V-section shape catamaran, with central body, reduced frictional resistance characteristics, limited payload, questionable seakeeping in open seas, patented by STOLKRAFT (Australia)
17. Superslender Monohull with Outriggers: Long monohull with two small outriggers in the stern part, EUROEXPRESS concept of KVAERNER-MASA Yards (Finland), excellent calm water performance and payload characteristics, good seakeeping in head seas.
18. SWATH Hybrids: SWATH type bow section part and planing catamaran astern section (STENA's HSS of Finyards, Finland, AUSTAL hybrids, Australia), derived from original type SWATH & MWATH concepts.
19. SWATH: Small Waterplane Area Twin Hull Ship, synonym to SSC (Semi-Submerged Catamaran of MITSUI Ltd.), ships with excellent seakeeping characteristics, especially in short period seas, reduced payload capacity, appreciable calm water performance.
20. TRICAT: Twin hull semi-displacement catamaran with middle body above SWL of FBM Marine Ltd. (United Kingdom).
21. TRIMARAN: Long slender monohull with small outriggers at the center, introduced by Prof. D. Andrews - UCL London (United Kingdom), currently tested as large prototype by the UK Royal Navy (TRITON), similarities to the Superslender Monohull with outriggers concept of KVAERNER-MASA.
22. TSL-F - SWASH: Techno-Superliner Foil version developed in Japan by shipyard consortium, submerged monohull with foils and surface piercing struts.
23. V-CAT: Semi-displacement catamaran with V section shaped demihulls of NKK shipyard (Japan), as type WAVEPIERCER.
24. WAVEPIERCER: Semi-displacement catamaran of INCAT Ltd. (Australia), good seakeeping characteristics in long period seas (swells), good calm water performance and payload characteristics.
25. WEINBLUME: Displacement catamaran with staggered demihulls, introduced by Prof. H. Söding (IfS-Hamburg-Germany), very good wave resistance characteristics, acceptable seakeeping and payload, name to the honor of late Prof. G. Weinblum.
26. WFK: Wave Forming Keel High Speed Catamaran Craft, employment of stepped planing demihulls, like type LSBK, but additionally introduction of air to the planing surfaces to form lubricating film of micro-bubbles or sea foam with the effect of reduction of frictional resistance, patented by A. Jones (USA)
27. WIG: Wing In Ground Effect Craft, various developed concepts and patents, passenger/cargo carrying and naval ship applications, excellent calm water performance, limited payload capacity, limited operational wave height, most prominent representatives the ECRANOPLANS of former USSR.

Development of Basic Types and Hybrids of Advanced Marine Vehicles