ON THE CASD OF CONTAINER SHIPS: STATE OF THE ART

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ABSTRACT

The subject matter of the present paper is to concentrate on the applicability of various design approaches for the design of container ships. A survey of the conventional as well as the rational design approaches that have been previously suggested and conducted for the design of this type of commercial ships is briefly demonstrated. It is shown that, the current design approaches will not provide the appropriate tools for a radically new ship design synthesis in the future. Therefore, a more rationalized and sophisticated design routine for a newly open and creative design of this sensitive type of commercial ships was proposed. A CASD-subsystem namely CADSUCS based on the proposed rational design routine in conjunction with the appropriate design iteration techniques is used in constructing a series of decisive tentative design charts. These design charts can be a keystone in assessing/checking the principal particulars for container ships at the concept design stage. Finally, for the whole effort to be demonstrated efficiently, the results obtained are analyzed and the conclusions are presented.

Keywords: CASD, Container Ships.

Nomenclature

B_m or B	Moulded breadth of the vessel,	(m)
b	Total width of the longitudinal deck strips,	(mm)
b_i	Transverse distance between hatchways,	(mm)
BM_T	Transverse metacentric radius at the load water line,	(m)
C_B	Block coefficient based on length between perpendiculars	
CN	Cubic number,	(m^3)
D_M or D	Moulded depth of the ship amidships,	(m)
DWT	Deadweight,	(tonnes)
GM_T	Transverse metacentric height above the center of gravity,	(m)
KG	Vertical position of center of gravity above the ship's keel,	(m)
LBP or L	Length between perpendiculars,	(m)
N_C	Number of containers to be specified by the owner,	(TEU)
N_{CH}	Number of containers within the holds,	(TEU)
P_B	Brake power,	(hp)
R	Trade route, to be specified by the owner,	(nm)
R_C	Number of rows of containers within the ship's central plane,	(TEU)
S_C	Number of stacks of containers amidships,	(TEU)
t_d	Thickness of deck plating,	(mm)
T_M or T	Moulded draught,	(m)
T_C	Number of tiers of containers amidships,	(TEU)
V	Design speed, to be specified by the owner,	(knots)
V_S	Service speed,	(knots)
W_{LG}	Light weight,	(tonnes)
W_S	Weight of steel,	(tonnes)
α_i	Load factor of the deck between hatchways, (to be obtained from the NK rule)	
β	$1-2b/B-\Sigma(\alpha_i b_i)/B$	
Δ	Full load displacement of the design proposal,	(tonnes)

1. INTRODUCTION

Ship design, as currently practiced, is largely based on ship types, and also is governed by the nature of the available infrastructure necessary to design ships. However, in regard to container ships, there are two principal design approaches commonly in use for their design. Firstly, the conventional approach in which the design process is based on plots of data gathered from the existing world fleet of container ships to reflect the current trends in design practice. Unfortunately, this does not result in reliable designs due to the deficiencies discussed later, but it serves as a good yardstick for the consequent design phases. Secondly, the modular/linear design approach, in which the principal particulars that satisfy the specified owner requirements are estimated, partly based on the number of unit size containers to be carried, and partly based on detailed information that are not broadly available for each ship designer.

Having reached this multidimensional level of complexity, a rational design technique based on the modular/linear design approach was proposed. The proposed design technique would give the ship designer the ability to explore, in the early design stage, many layouts of the main design areas and to break away from past practice. Such technique may even show that there are benefits in substantially altering some/all of the ship's principal particulars to get a better containers' stowage distribution.

Finally, aiming at producing quick and accurate results, a most recently developed CASD-subsystem based on the proposed rational design technique and utilizing the available capabilities of the PC's, is used in constructing a series of design charts. The latter may be used in assessing and/or checking the principal particulars for the ship type under consideration at the earlier design stages. The underlying subsystem was developed to manipulate nearly detailed principal particulars of container ships based on the number of containers (TEU's), design speed (V) and trade route (R), all of which are specified by the owner.

2. ART OF SHIP DESIGN

It has been known that the design of a ship is often described as iterative procedures in which compromises between various conflicting design requirements have to be executed and in which the naval architect, by repeating a series of sequential tasks, with ever increasing design accuracy, arrives at some optimum dimensions and configuration of the design [1]. Therefore, care must be taken in selecting the number of design alternatives to be investigated and the mode of investigation so as to satisfy the governing constraints. Traditionally, many authors have from time to time referred to the so-called design spiral when describing the iterative design procedures graphically, in which the steps involved in the design process are illustrated as iterative steps working from the specified owner requirements to a detailed design, as shown in Figure (1). Some authors show it turning right [2], others turning left [3], sometimes the spiral winds inward [4], thus suggesting the convergence of the process towards a unique solution, sometimes it winds outwards [5], probably to indicate the fact that with increasing accuracy also the amount of necessary design procedures increases. Beyond that, in light of [6], and [7], the computer serves as an information storage as well as management system, and in this respect has important implications for the ship designer. Palpably, computers offer an opportunity to increase the number of parameters to be considered in the iterative design steps. Therefore, using the computer speeds up the tedious iterative design procedures, and makes it possible to investigate and compare a considerable number of design alternatives on a reasonable time scale.

3. DESIGN PHILOSOPHY OF CONTAINER SHIPS

As understood from [8], from the aspect of determining appropriate principal dimensions, ships are divided into three main categories:

i. The deadweight designs.
ii. The capacity designs.
iii. The linear dimension designs.

In addition, as the design deadweight of most container ships can be obtained at a draught less than that obtainable with type-B freeboard, deadweight can not be used directly to determine the tentative design of a container ship. Moreover, as container ships usually carry a substantial percentage of their cargo on deck, it is not possible to base their design on the required cargo capacity as this is indeterminate. Evidently, the principal dimensions of container ships are determined primarily by the unit size of the containers they carry which, in turn, classify container ships as linear dimension designs. Here, parenthetically, as discussed in [9], there is a widely-held but erroneous belief that the ship's main dimensions are purely determined by the number of container positions, preferably below deck, but the fact is that a container ship has almost flexible stowage space in the vertical direction, with the stacking height limited by the following considerations (arranged from the importance point of view):

i. Stability considerations, (transverse intact stability).
ii. Strength considerations, (structural design of the ship's double bottom as well as hatch covers, both primary and secondary structural elements).
iii. Nautical considerations, (ship motions and seakeeping performance).
iv. Visibility considerations, (angle of sight and sight domain).
v. Permissible height considerations, (height under shore gantry crane).

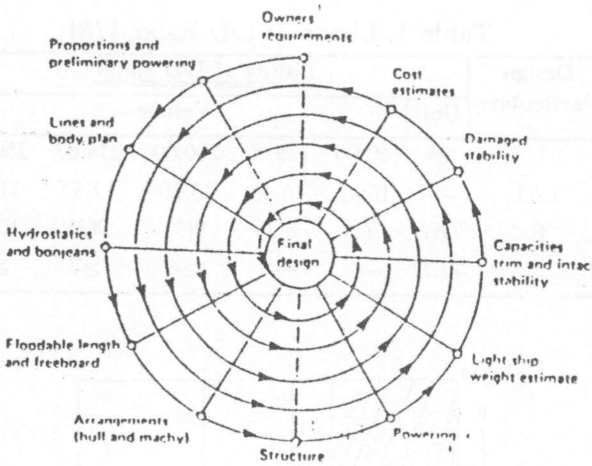

Figure (1) Design Spiral for All Merchant Ships, [*10*].

3.1. *Conventional Design Approach*

In the classical approach of ship design, the design alternative to be investigated is usually generated using some rather simple relationships (derived from the census trend imposed by the existing designs of the over all world fleet of cellular type container ships), commonly represented graphically as design charts, such as those published in [10]. However, the major disadvantages of this approach as has been discussed in [11] can be summarized as follows:

i. The information used for preparing these design charts may not represent optimum ships.
ii. The set of constraints which govern the principal dimensions of the ship may vary considerably as they depend on some controlling factors, among them are the trade route, the calling ports, etc.
iii. Design charts are based on both certain general arrangements and configurations which may not conform with the required design.
iv. The design criteria, technical and/or economical, may not be identical to the required criteria.

Palpably, the classical approach of ship design is acceptable when treating missions and figures of merit (objective functions) for which the solution is well known. It becomes, however, ineffective when faced with a novel design, where the designer should have a huge capability to generate and analyze the alternatives that need to be considered if the correct solution is to be found.

Faced with these problems, a newly developed approach that overcomes the deficiencies of the classical one was sought in [12] and [13]. The proposed approach is based upon a rational concept, namely the aggregated dimensions. The concept of aggregated dimensions is not a new one but was adopted before in several researches, and has proved its applicability for the capacity carriers as in [14] and [15], and also for the deadweight carriers as in [16]. Currently, this concept is realized for the linear dimension designs as already conducted in [17].

3.2. *Rational Design Approach*

A first approach was introduced in [8], in which both the moulded breadth (B_M) and the moulded depth (D_M) are the first dimensions to be fixed, determining the number of containers which could be carried inside the midship section of the ship. Finally, the length of the ship is then adjusted to envelope the appropriate under deck container capacity according to both the economically and technically (techno-economic feasibility) desirable ship proportions (L/B, L/D, B/T, etc.). Of course, speed affects the number of containers' rows along the length, because of its severe influence on both the block coefficient and the machinery power, thus on the configuration of the engine room compartment but, these may be regarded as second order effects. In addition, the effect of range is minimal and could be ignored at this preliminary design stage. Figure (2) gives the product (tiers x rows) at a given under deck container capacity as well as service speed as was given in the same reference [8].

A second approach was introduced in [18], in which the moulded breadth (B_M) and the moulded depth (D_M) of the ship may be uniquely determined by the number of stacks (S_C) as well as the number of tiers (T_C) of the containers stowed in a hold amidships. Finally, the length of the ship is to be adjusted to satisfy both the requirements imposed by the classification society (the subjective author has used the N.K. class) concerning longitudinal strength and current design trends in ships' proportions. Figures (3) through (5) as well as Table (1), as given by the same author, can be used in the preliminary design of container ships.

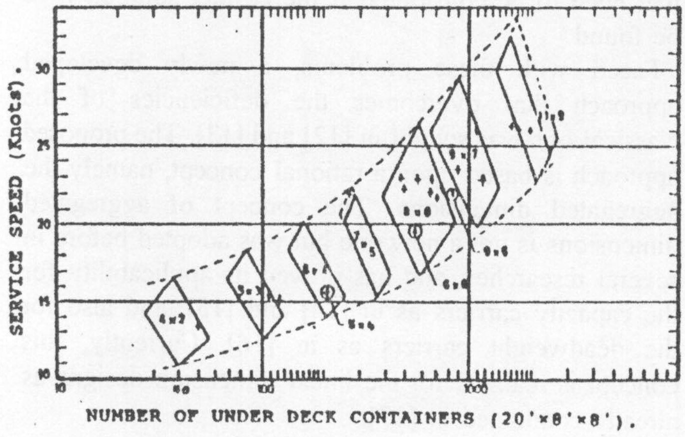

Figure (2) V_S Versus N_{CH} for Various Ranges of $S_C \times T_C$, [8].

4. DEVELOPMENT OF CASD-(SUB)SYSTEMS

The last three decades show significant progress concerning the application of electronic computers to the field of ship design. Their value and use in this important field was highly recognized, and most of the several computational tasks have been greatly simplified by the development of appropriate computer programs. Many computer programs were developed to handle the problems associated with integrated CASD systems. In most programs, data are obtained from input unit(s), calculations made by the computer according to the empirical formulae as well as the designers' proposed decisions incorporated in the underlying program and the results placed at the output unit(s). Therefore, the main effort of the ship designer becomes the preparation of the input data and the analysis of the output results. However, the validity of any program generated results is dependent upon:

i. The assumptions on which the underlying program is based.
ii. The scope and quality of the input data to be processed.
iii. The quality and degree of sophistication of the basic empirical relationships.

Table 1. Limits of L/D Ratio, [*18*].

Design Particulars	Limits of L/D Ratio					
	Unit	Values				
L	*m*	150.00	175.00	200.00	214.67	250.00
L/D	---	16.45	16.45	13.20	12.55	11.65
R	*TEU*	7(1)	8(2)	9(3)	9(3)	10(2)
S	*TEU*	-----	-----	≥6	≥7	≥8

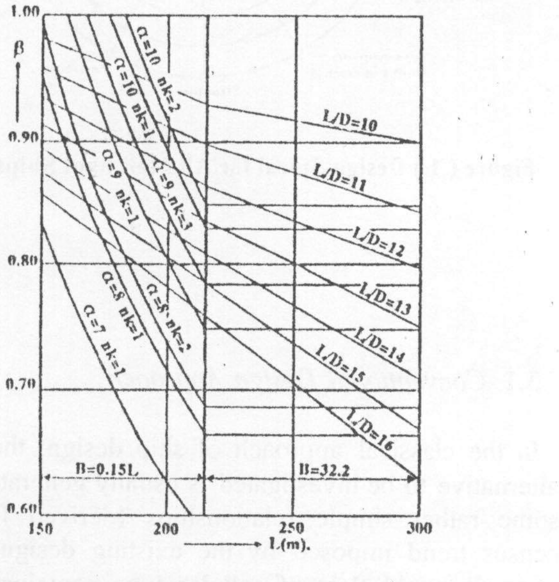

Figure (3) B Versus LBP at Constant L/D, R_C and N_{CH}, [*18*].

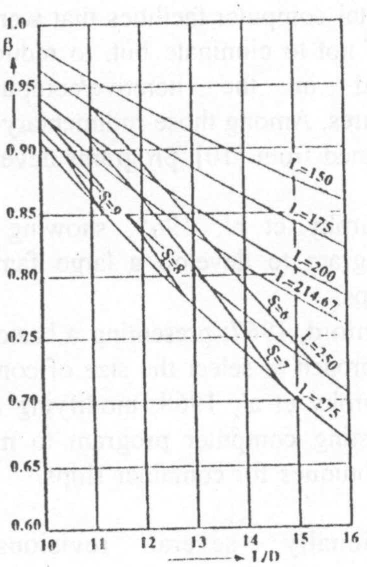

Figure (4) B Versus L/D at Constant LBP and S_C, [*18*].

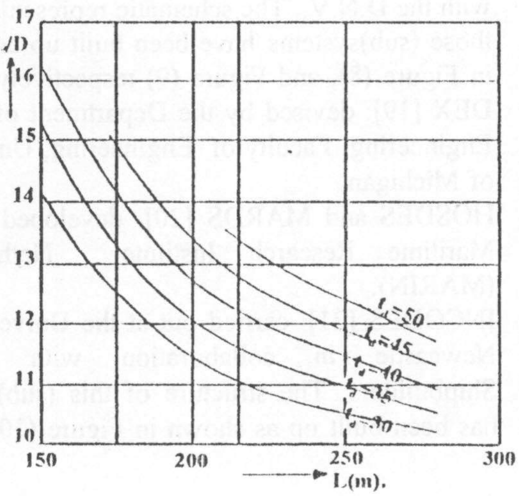

Figure (5) Limits of L/D Ratio, [*18*].

Fundamentally, different types of computer programs for preliminary ship design can be encountered. These programs either:

i. Vary certain design parameters (LBP, C_B, etc.) and iterate around the design spiral making trial and error variations to seek an optimum design; economical considerations being the most common, as shown in Figure (6). This would result in a large family of technical solutions to the specified mission requirements. The final decision then emerges from the iteration and/or optimization technique incorporated in the routine.

ii. Perform a search on a set of possible design solutions, where data for all ships calculated during the search may be represented graphically in a matrix form as a function of the most relevant design parameters (L/B, B/T, C_B, etc.). The latter are selected to cover reasonable combinations and/or proportions for the owner's requirements, as shown in Figure (7).

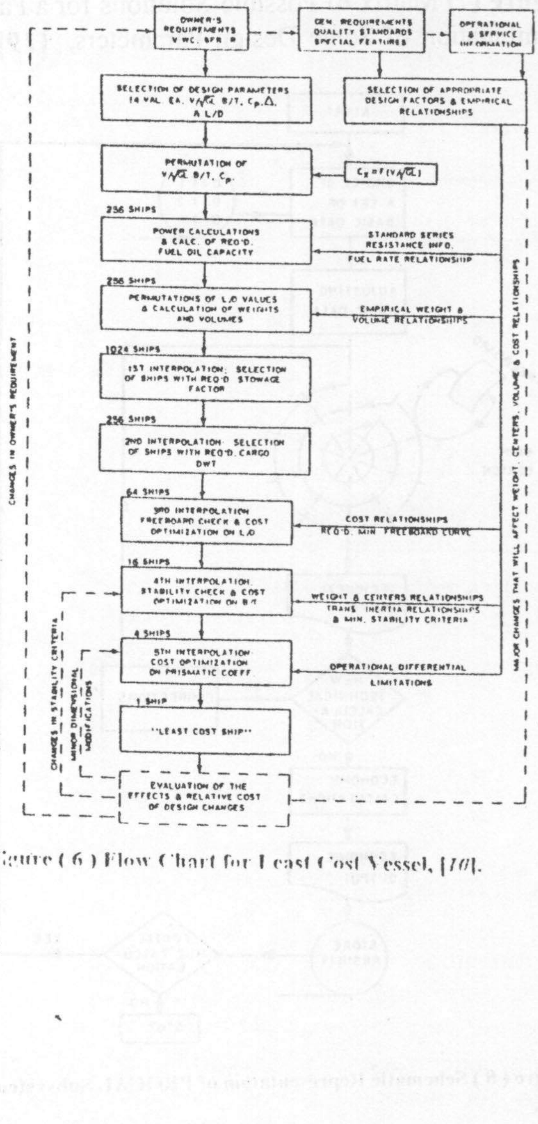

Figure (6) Flow Chart for Least Cost Vessel, [*10*].

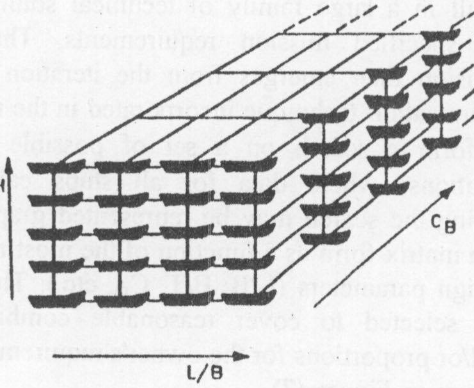

Figure (7) Matrix of Possible Solutions for a Particular Combination of Some Design Parameters, [*19*].

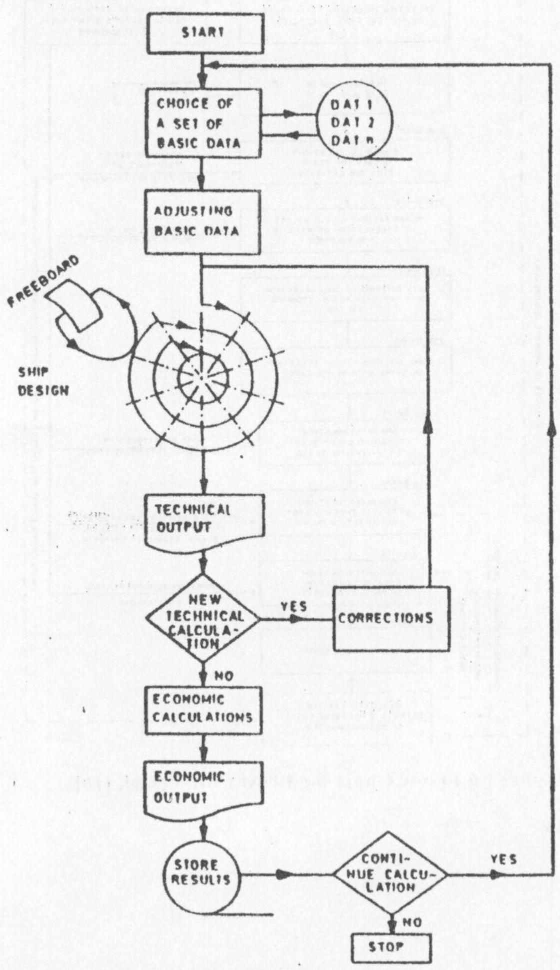

Figure (8) Schematic Representation of PROCAL Subsystem, [*19*].

Many attempts had been made before, aiming at using the digital computer facilities that were available at the time, if not to eliminate but, to reduce the hard work involved in the iterative/computational design procedures. Among those rudimentary implementations as obtained from [10], programs developed by:

i. Murphy et al, 1965; showing a logical flow diagram to develop a large family of container ships.
ii. Benford, 1967; presenting a basic computer-aided approach to select the size of container ships.
iii . Murphy et al, 1968; modifying and updating an existing computer program to match the design techniques for container ships.

Occasionally, several revisions have been implemented in those programs aiming at developing what is really a CASD-(sub)systems. Among the latter are:

i. PROCAL and FLEET [19]: devised by the Ship Research Institute of Norway in co-operation with the D.N.V.. The schematic representation of those (sub)systems have been built up as shown in Figure (8), and Figure (9) respectively.
ii. DEX [19]: devised by the Department of Ocean Engineering, Faculty of Engineering, University of Michigan.
iii. HOSDES and MARDS [20]: developed by the Maritime Research Institute, Netherlands (MARIN).
iv. INCODES [21]: carried out at the University of Newcastle in collaboration with British Shipbuilders. The structure of this (sub)system has been built up as shown in Figure (10).

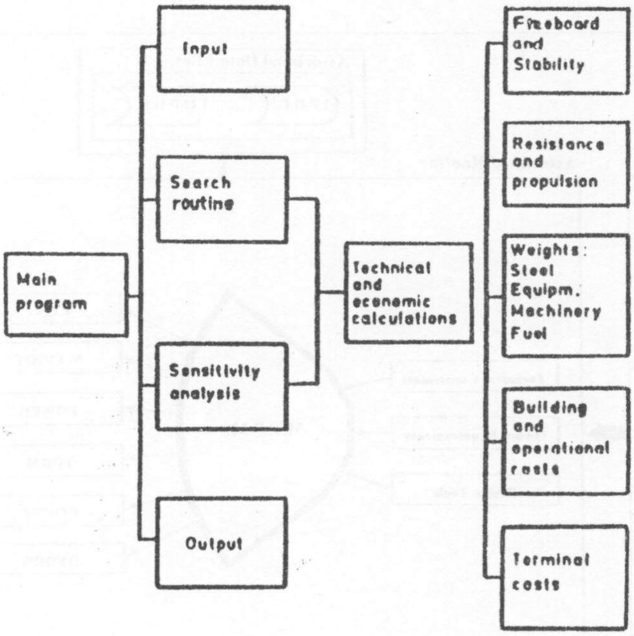

Figure (9) Schematic Representation of FLEET Subsystem, [*19*].

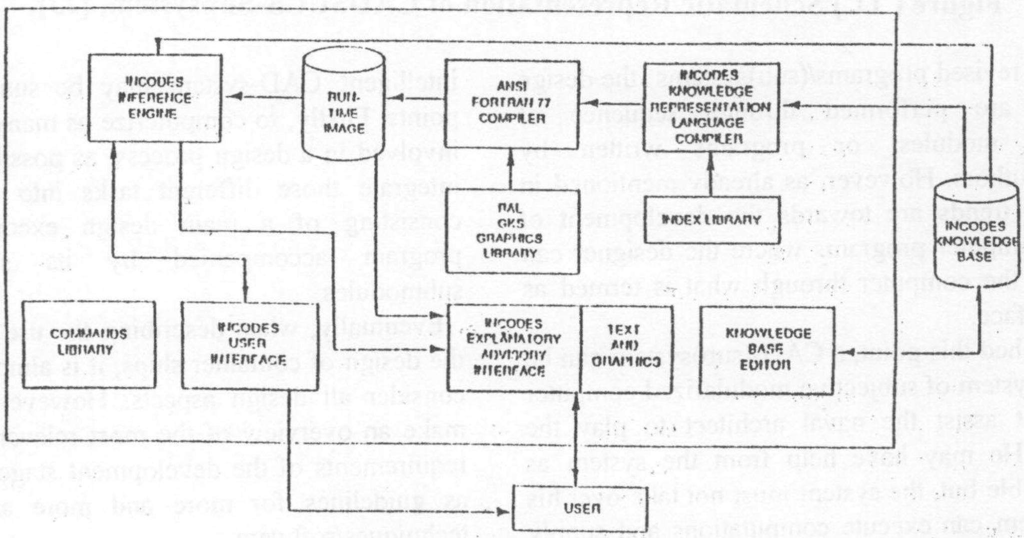

Figure (10) Skeletal Structure of INCODES Expert System Shell, [*21*].

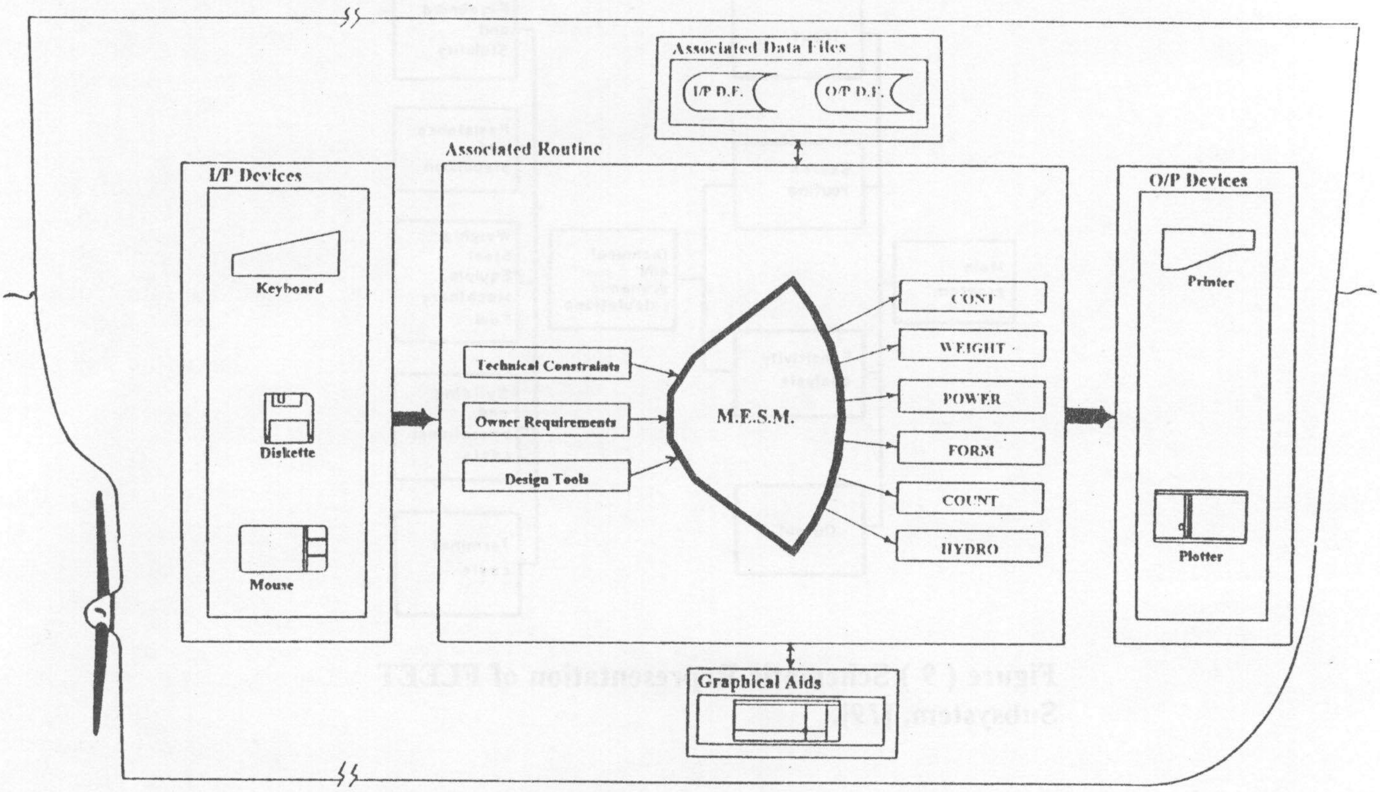

Figure (11) Schematic Representation of CADSUCS-Subsystem, [*23*].

In all these revised programs/(sub)systems, the design calculations are performed through sequence of programmed modules, or programs written by specialized authors. However, as already mentioned in [21], present trends are towards the development of interactive computer programs where the designer can interact with the computer through what is termed as the user interface.

Having reached this point, a CAD-(sub)system can be defined as a system of subjective modularized computer programs, that assist the naval architect to play the central role. He may have help from the system as much as possible but, the system must not take over his job. The system can execute computations and supply information, but it should not take decisions on its own. Also, the system must be user friendly and easy to interact, i.e., minimum time span is spent in achieving the subjective proposal.

A fascinating view of future CAD-systems has been demonstrated by [22], declaring that the goals of any intelligent CAD-system may be summarized in two points. Firstly, to computerize as many individual tasks involved in a design process, as possible. Secondly, to integrate those different tasks into a single system consisting of a main design executive supervisor program accompanied by its subprograms or submodules.

Eventually, when describing the use of computers in the design of container ships, it is almost impossible to consider all design aspects. However, it is useful to make an overview of the most relevant wishes and/or requirements of the development stages. They will act as guidelines for more and more advanced design techniques/software.

5. DEVELOPMENT OF A NOVEL CASD-SUBSYSTEM

Based on the design methodology for linear dimension designs, a more rational approach was introduced and conducted in [17]. In this approach, the length, breadth, and depth of the under-deck container's stowage plan are the first dimensions to be fixed, deciding the number of containers that could be carried within the mid-ship section as well as inside the central plane of the ship. In order to give a complete configuration for the principal dimensions (LBP, B_M, D_M), an engine room, aft peak, fore peak and side wing ways of approximately correct dimensions (from the existing fleet of the cellular type container ships and conforming to the requirements of the classification societies) are added. This results in the development of a basis for what is really a CASD-subsystem, namely CADSUCS. The latter was further amended and extended through comprehensive sensitivity analysis as presented in [23]. All capabilities and the intermodal linking between the various modules of the CADSUCS-subsystem are schematically presented by the flow-diagram shown in Figure (11).

6. PARAMETRIC STUDY

The present subsection demonstrates the use of the CADSUCS-subsystem in conducting a parametric study in which it is essential that the design methodology, technique and empirical formulae that were incorporated in it, function consistently. The analysis are carried-out for some principal relationships, basically drawn for constant/variable ship speed (V) and number of containers (N_C), but with constant trade route (R). Important to mention is that the technical design parameters are considered as the governing parameters, whereas the economical ones are slated for future subsystem upgrading.

6.1. *Effect of Altering Ship Speed*

In regard to the preliminary design chart as shown in Figure (I-1), the most obvious effect of varying the ship speed is the direct variation in its length in proportional with the hydrodynamic parameter namely Froude number. In essence, there are two principal causes for this variation:

i. The block coefficient is inversely varied in proportion with both the reciprocal of the Froude number and the length-breadth ratio which, in turn, causes an inverse variation in the container carrying capacity. The latter could be maintained by directly altering the size of the hull envelope through direct variation of the ship length. In this respect, comparing with the influence of the ship length on the container carrying capacity, both the breadth and the depth has a minor effect.

ii. The required engine output is inversely varied, therefore, an engine with directly varied length margin has to be fitted to provide the altered power at the varied design speed. This in turn requires an engine room with directly varied length margin which results in a direct variation in the ship length.

6.2. *Effect of Altering Number of Containers*

Considering the preliminary design charts that are shown in Figure (I-2) through Figure (I-6), any variation in the number of containers, while retaining constant design speed, would result in a corresponding direct/inverse variation in the principal characteristics of the design alternative(s). The influences of changing the number of containers could be confined to two principal effects, (any other effects may be considered as consequences of these two principal effects), the variation in the ship length and/or its breadth. A detailed overview of these variations was furnished in [23]. However, the principal influences are grouped in Table (II-1) and Table (II-2). In addition, below is a brief discussion of the various tendencies that could be indicated from the areas of concern outlined in the underlying routine.

i. If the number of containers is varied in a large index, this variation could be absorbed through direct variation in the ship length and may be associated with separate and/or collective variation of the breadth, depth, and/or block coefficient. However, if the number of containers is varied in a small index that could be absorbed through the direct variation in the ship fineness/fullness, there is no need for varying the ship length and/or breadth. Figure (I-6) shows the behavior of the ship's cubic number versus the number of containers.

ii. The choice of the appropriate policy of variation depends on whether the required variation in the number of containers could be enveloped by separate/collective variation in one or more of the principal dimensions. In addition, the ship's principal dimensions may be further slightly varied to adjust a particular proportion (L/B, B/D, B/T) within the current trends of the world fleet of container ships.

iii. The deadweight is directly varied with the number of containers. Obviously, the weight of the latter constitutes the greatest portion from the deadweight component. The weight of fuel oil may be decreased/increased in direct proportion with the propulsion power. The power variation may be caused not only by the inverse variation in the ship breadth but also, by the direct variation in its length, depending on whether any or both particular(s) be varied to accommodate the difference in the number of containers. However, the resultant variation in the weight of containers has a considerably greater effect than the variation in the weight of fuel oil. Also, the variation of the weight of miscellaneous items may be considered as of second order effect, and hence, its effect may be neglected in relation to the effect of the other deadweight components.

iii. As already discussed in ii, similar explanation could be furnished for searching the influence of variation of the number of containers on both the deadweight coefficient and the loaded displacement.

iv. The observed scatters in the different graphs are due to the step function that control the mathematical relationships between the central under-deck container stowage planes and the corresponding principal dimensions. However, this step-wise behavior may be considered as second order effect when absorbing the variation in the multiple number of TEU's as a corresponding slight variation in the breadth of the side wing ways.

7. CONCLUSIONS

The present paper has touched upon many aspects of ship design that are used in the design of container ships as well as the developments that have occurred in the application of the available computer facilities to the field of ship design. Unequivocally, a brief investigation of the principal conclusions that may be aggregated from the work conducted in this paper are furnished as follows:

i. Although conventional design approaches are likely to be applied more in the design process, until a comprehensive philosophy of design is developed, this application will have to be in a case by case manner.

ii. In regard to the discussed design techniques/routines, a comprehensive design technique was pursued. Such a technique is open and responsive to new creative designs whilst including the essential design constraints (technical and or economical).

iii. The determination of the principal particulars of container ships using the available published data for the existing world fleet of container ships does not necessarily give optimum design alternatives for a projected container ship satisfying a certain mission.

iv. The principal dimensions of container ships may be determined primarily as a function of the unit size of cargo modules that could be enveloped within the streamlined hull of the ship.

v. The proposed approach enables shipyards or individual naval architects to conduct the concept design stage quickly and more efficiently.

vi. The adoption of the present computer facilities (hardware and software) offers an opportunity to increase the number of design parameters to be considered in the iterative design procedures.

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APPENDIX "I"
PRELIMINARY DESIGN CHARTS FOR CELLULAR TYPE CONTAINER SHIPS

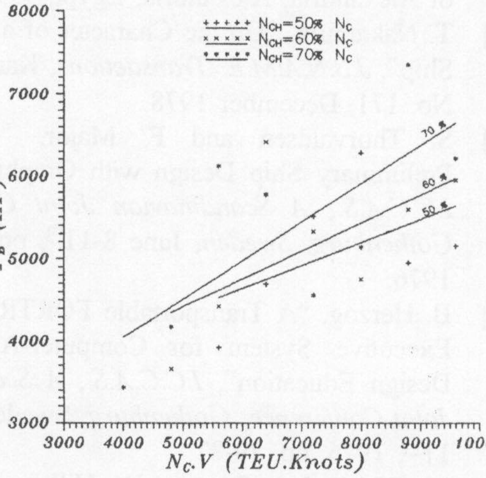

Figure (I-1). Brakepower Versus Number of Containers × Speed at Constant Range.

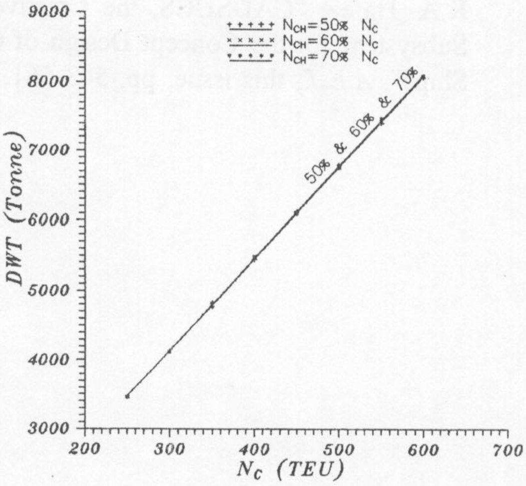

Figure (I-2). Deadweight Versus Number of Containers at Constant Speed and Range.

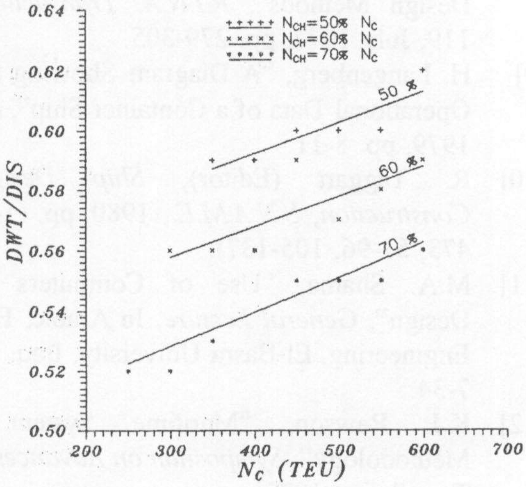

Figure (I-3). Deadweight Coefficient Versus Number of Containers at Constant Speed and Range.

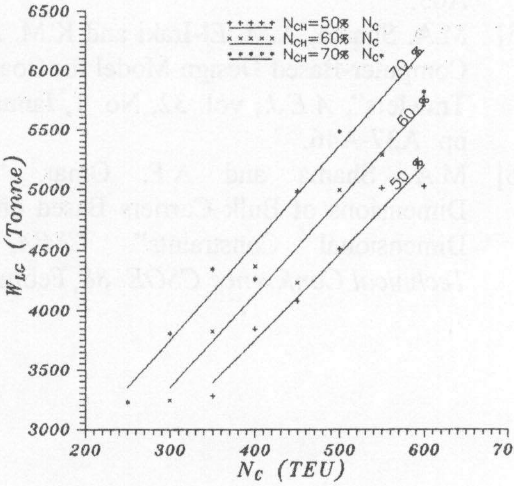

Figure (I-4). Lightweight Versus Number of Containers at Constant Speed and Range.

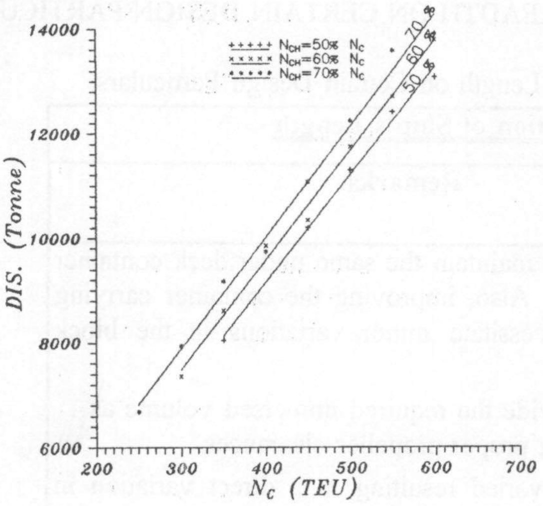

Figure (I-5). Full Load Displacement Versus Number of Containers at Constant Speed and Range.

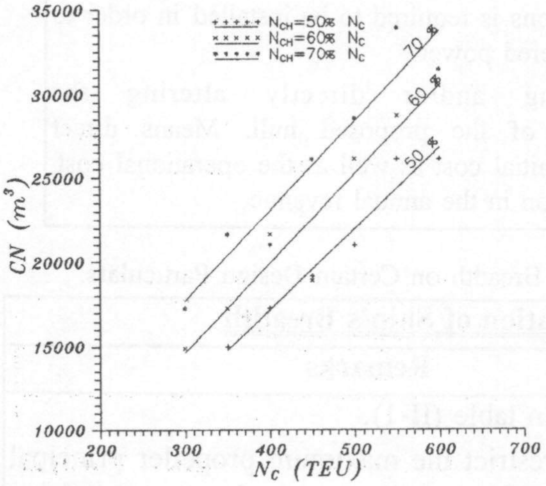

Figure (I-6). Cubic Number Versus Number of Containers at Constant Speed and Range.

APPENDIX "II"
EFFECT OF VARIATION OF SHIP'S LENGTH AND BREADTH ON CERTAIN DESIGN PARTICULARS

Table (II-1). Effect of Variation of Ship's Length on Certain Design Particulars.

Design Particulars	**Effect of Variation of Ship's Length**	
	Proportionality	**Remarks**
C_B	Inverse	To approximately maintain the same under deck container stowage capacity. Also, improving the container carrying capacity may necessitate minor variations in the block coefficient.
T	Direct	Necessary to provide the required immersed volume as well as improving proper propeller clearances.
D_M	Direct/Inverse	May be slightly varied resulting in a direct variation in the vertical center of gravity KG, i.e., it may be considered of minor effect.
P_B	Inverse	Provided that all the resistance governing parameters are maintained constant or even slight variation in any of them is allowed for. Therefore, a different engine of different dimensions is required to be installed in order to cope with the altered power.
W_S	Direct	While retaining and/or directly altering the fineness/fullness of the proposed hull. Means direct variation in the initial cost as well as the operational cost, i.e., direct variation in the annual revenue.

Table (II-2). Effect of Variation of Ship's Breadth on Certain Design Particulars.

Design Particulars	**Effect of Variation of Ship's Breadth**	
	Proportionality	**Remarks**
C_B	Inverse	The same as in table (II-1).
T	Inverse	Small drafts restrict the maximum propeller principal dimensions. This usually means lower propulsive efficiency. This disadvantage is not present when the propulsion unit calls for a high propeller speed which reduces the diameter
D_M	Direct/Inverse	The same as in table (II-1).
P_B	Direct	The same as in table (II-1).
W_S	Direct	Any variation in the ship's breadth entails an inverse variation in the scantlings of the bottom and/or deck materials.
GM_T	Direct	The metacenter M shifts upwards/downwards, and the center of gravity G shifts downwards/upwards respectively, both are with respect to the keel.