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للأستاذ الدكتور محمد عبد الفتاح شامة

Published Papers (1974-1998)

on Ship Design and Economics

by

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1- "Structural and Economical Consequences of Ship Deflection", Seminar on the Application of Science & Technology in Marine Transport, A.M.T.A., J. Res. and Consultation Centre, July. (Egypt-1974), Shama, M. A.,

2- "Optimizing Hull Steel Weight for Overall Economic Transportation", Marine Week, May 2, (UK-1975), Shama, M. A.,

3- "The Cost of Irrationality in Ship Structural Design", PRADS. Int. Conference on Practical Design in Shipbuilding, SNAJ, Tokyo Oct. (Japan-1977), Shama, M. A.,

4- "Computer Design of Ships", Bull. Collage of Engineering, Basra University, (Iraq-1977), Shama, M. A.,

5- " Economical Consequences of Irrational Structural Design of Ships", Bull. Of Collage of Eng., Basra University, Vol.2, No.1, March, (Iraq-1977), Shama, M. A.,

6- "On the Rationalization of ship Structural Design", Schiff und Hafen, March, (Germany-1979), Shama, M. A.

7- "ON the Economics of Safety Assurance" Dept. of Naval Architecture and Ocean Engineering, Glasgow University, (UK-1979) Shama, M. A.,

8- "CADSUCS, the Creative CASD for the Concept Design of Container Ships", AEJ, Dec. (Egypt-1995), Shama, M. A., Eliraki, A. M. Leheta, H. W. and Hafez, K. A.,

9- "On the CASD of Container Ship; State of the Art", AEJ, Dec., (Egypt-1995) Shama, M. A., Eliraki, A. M. Leheta, H. W. and Hafez, K. A.,

10- "Assessment of Uncertainties of the Sea Margin", Maritime Research Journal, Sept., (Egypt-1998), Shama, M. A., Moniem, A. F. A. and Eweda, S.,

KG_{OF}	Vertical position of outfit center of gravity above the keel,	(m)
KG_S	Vertical position of hull steel center of gravity above the keel,	(m)
KG	Vertical position of center of gravity above the ship's keel,	(m)
KM_T	Height of transverse metacentre above the keel,	(m)
L_{APK}	Length of after peak,	(m)
LBP	Length between perpendiculars,	(m)
L_C	Length of container,	(m)
LCB	Longitudinal position of center of buoyancy, measured from amidship, positive values measured forward,	(m)
LCF	Longitudinal position of center of floatation of the load waterline, measured from amidship, positive values measured forward,	(m)
L_{ERM}	Length of engine room,	(m)
L_{FPK}	Length of forward peak,	(m)
L_{OP}	Length of open portion,	(m)
N_C	Number of containers to be specified by the owner,	(TEU)
N_{CH}	Number of containers within the holds,	(TEU)
N_{CD}	Number of containers above the deck,	(TEU)
NC_S	Actual number of containers to be enveloped within the form of the standard methodical series,	(TEU)
N_{HD}	Number of cargo holds,	(hold)
N_S	Number of transverse hatch openings amidship	
QPC	Quasi propulsive coefficient,	(–)
R	Trade route, to be specified by the owner,	(nm)
R_C	Number of rows of containers within the ship's central plane,	(TEU)
SAC	Sectional area ordinates expressed as a ratio of the maximum transverse immersed area,	(–)
S_C	Number of stacks of containers amidships,	(TEU)
SHP	Shaft horsepower,	(hp_m)
t	Thrust deduction fraction,	(–)
T_M	Moulded draught,	(m)
T_C	Number of tiers of containers amidships,	(TEU)
T_H	Periodic time of ship's heave,	(sec)
T_P	Periodic time of ship's pitch,	(sec)
T_R	Periodic time of ship's roll,	(sec)
V	Design speed, to be specified by the owner,	(knots)
W_C	Weight of containers,	(tonnes)
W_{FO}	Weight of fuel oil,	(tonnes)
W_{LG}	Light weight,	(tonnes)
$W_{M/C}$	Weight of machinery,	(tonnes)
W_{MIS}	Weight of miscellaneous items,	(tonnes)
W_{OF}	Weight of outfitting,	(tonnes)
W_S	Weight of steel,	(tonnes)
W	Weight of the design proposal,	(tonnes)
γ	Overall allowances at both sides of each container,	(m)
Δ	Full load displacement of the design proposal,	(tonnes)
δ	Overall allowances at both ends of each container,	(m)
η_H	Hull efficiency of the design proposal,	(–)
η_{RR}	Relative rotative efficiency of the design proposal,	(–)
η_{SH}	Shaft transmission efficiency of the design proposal,	(–)
η_{POPT}	Propeller optimum open water efficiency of the design proposal,	(–)
ω_t	Taylor's wake fraction,	(–)
∇	Volumetric displacement of the design proposal,	(m^3)

1. INTRODUCTION

The last three decades have seen a number of major developments concerning the field of ship design, but the one most far-reaching in its future influence has been the application of computers to this vital domain. The empirical formulae used in the various preliminary design estimations as well as the judgements and experience of the naval architect can be incorporated with the speed and precision of the computer to yield the best of both worlds. Also, using the computer to speed up the arduous iterative design procedures, it is possible to investigate and compare a considerable number of design variations within a reasonable time span. The applicability of the rudimentary developments in computer technology accompanied with simple illustrative flowcharts and mathematical models are demonstrated in [1]. In addition, references [2] and [3] furnish a good background for investigating the earlier developments which have taken place. However, in the days of the highly advanced digital computers, high technology hardware and rapid hunting of the software provide the most powerful tools to synthesize the proposed design with the aid of 2 as well as 3 dimensional graphics. Consequently, the ability to obtain a quick visualization of the proposed hull form, ship layout and/or stowage plan presents obvious advantages of any proposed tentative CASD-

(sub)system.

In light of the aforementioned, the underlying research is emphasized on the illustration of the capabilities of a most recently developed CASD-subsystem [4] for the concept design of container ships. Based on the number of containers (TEU), design speed (V) and trade route (R), as the whole input data that are required to realize the design, the proposed subsystem deals with the development of the principal particulars of container ships. The determination of the principal particulars of the cellular type container ship, clearly forms an important phase in the ship design spiral. Obviously, the principal particulars have a pronounced effect on many of the ship's characteristics, e.g., stability, container stowage coefficient and the designs' hydrodynamic requirements.

2. STATEMENT OF THE PROBLEM

In regard to the concept design of the cellular type container ship, a distinction must be made between two major groups of problems. The first concerns the unfeasiblity of applying traditional design methods to this unconventional ship type, whereas the second concerns the complexity of the internal constructional arrangement of this fine streamlined hull. A brief overview of these two problem groups will aid in distinguishing the principal differences between them.

Firstly, in the conventional methods of ship design, the alternatives to be investigated are usually generated using some rather simple relationships commonly represented graphically as design charts. However, accompanied to this rudimentary methodology are several drawbacks that make it difficult to arrive at the optimum design within the appropriate time span. The major handicaps of these classical methods are comprehensively delineated in the design literature, among those are [5], and [6]. Palpably, the classical approach of ship design is acceptable when treating missions and figures of merit for which the solution is tentatively known. It becomes, however, ineffective when faced with a novel design, where the designer should have a huge capability to generate and analyze the design alternatives that need to be considered if the correct design is to be reached.

Secondly, the design of the cellular type container ship is a 3-dimensional problem, where, the attainment of high container carrying capacity, expressed in terms of TEU, necessitates the design system to clearly address the coordinates of each element of the cargo-modules to be enveloped inside the streamlined hull. The container stowage plan is not only affected by the hydrodynamic configuration of the proposed hull but also, by its internal arrangement in terms of structural configuration, clearances allowed inboard/outboard the various elements of the cell guide system below deck, and stacking/lashing system on deck. In this context, it is important to mention that any minor changes in the proposed hull contour may entail some containers to be added/removed to/from the stowage plan, which in turn affects the operational economics of the proposed design throughout its expected life.

With reference to the aforementioned deficiencies, it is difficult to build up a complete figure for the whole critical design problems of this unconventional commercial ship type. However, in this research a great deal of effort was spent in delineating the major problems associated with the concept design of container ships. Important to mention also, is the drastical influence of the structural design considerations of this fully opened floating structure on the available stowage capacity of the design proposal. These considerations are not dealt with in the present paper, but are slated for future enhancements as the requirements of moving further around the design spiral for more and more refinements of the design proposal(s).

3. PROBLEM SOLUTION

The problem solution is logically divided into two principal stages. The first stage concerns the illustration of all principles/concepts/facts upon which the proposed solution is based. The second concerns the interpretation/mechanization of all these ship design keystones into an appropriate efficient and rather easy to interact package. Each of these stages is briefly discussed in sequel.

3.1. *Design Philosophy*

Based on the design methodology for linear dimension ships as discussed in [6], a rational approach for the determination of the aggregated dimensions is already suggested and conducted in [4]. 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, an engine room, aft peak, fore peak and side wing ways of approximately correct dimensions are added. The resultant projected configuration can be schematically represented as shown in Figure (1). A series of ships' particulars is furnished. The adjustment of the principal particulars according to the different design criteria (steel weight, powering, initial transverse stability and ship motions) is allowed for. Consequently, a family of ships, representing some tentative designs, was manifestly delineated. For the effort to illustrate efficiently and to allow the whole algorithm to be obvious, it is useful to clarify the conducted procedures by a logically designed flow diagram congenial with the proposed routine, as shown in Figure (2).

3.2. *Computer Implementation*

The aforementioned design methodology and its associated iteration techniques were mathematically modeled as separate computer programming modules, namely *CONT*, *WEIGHT*, *POWER*, *FORM*, *COUNT* and *HYDRO*. In addition, a customized automated specific version of a general drawing package was built. All program modules were incorporated together by a batch processing module (BPM) namely *CADSUCS* aiming at achieving an emulation to what is really a CASD-subsystem.

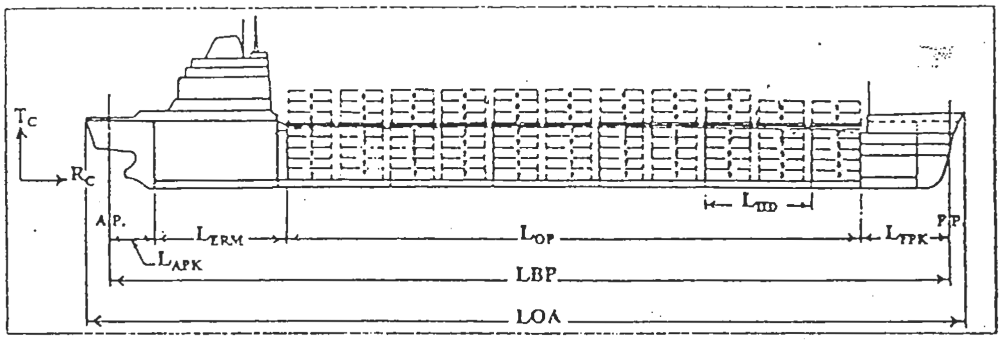

Figure (1 - a) Typical Profile Section at the Central Plane of a Conventional Type Container Ship Showing its Longitudinal Stowage Plan (R_C&T_C), [4].

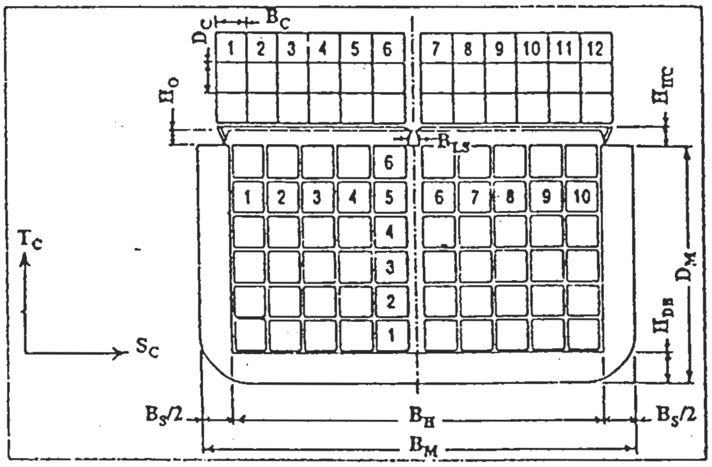

Figure (1 - b) Typical Midship Section of a Conventional Type Container Ship, Showing its Transverse Stowage Plan (S_C&T_C), [4].

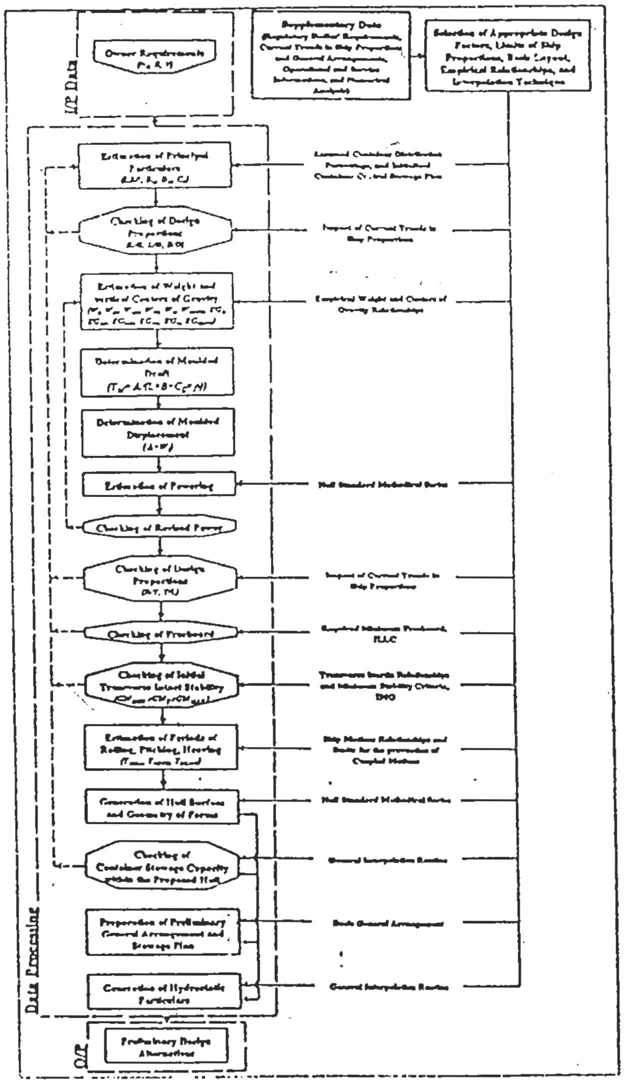

Figure (2) Logical Flow Diagram Showing the Layout of CADSUCS-Subsystem, [4].

The proposed subsystem is not an optimization routine but, is still considered to belong to the preliminary design stage. It produces several design alternatives all of which satisfy the specified owner requirements and the associated technical constraints. Economical considerations have not been taken into account. All capabilities as well as the intermodal linking between the various modules of CADSUCS-subsystem are schematically presented by a systematically designed flow diagram as shown in Figure (3). A comprehensive illustration for the whole routine was furnished in [4]. However, a brief description of the skeletal structure of the proposed CASD-subsystem and some information concerning the methods used in the application modules are arranged in hierarchical order, in accordance with the logical layout of the ship design spiral as follows:

i. Module *CONT*: for the estimation of the principal particulars and all corresponding ship proportions, based on the design technique of linear dimension ships. The output of each individual run presents four design alternatives with different container distribution arrangements between holds and hatch covers. The particulars/proportions of the design alternatives are audited against common range of current design trends, adequate powering, appropriate transverse initial intact stability, acceptable tentative ship motions and adequate container stowage capacity.
ii. Module *WEIGHT*: for the estimation of the weight groups of container ships, based on the empirical formulae devised from a large fleet of this unconventional ship type.
iii. Module *POWER*: for the estimation of both the resistance and propulsion characteristics, based on the mathematical representation for the model testing experimental results of the SSPA cargo liner methodical series. In addition, based on the mathematical representation of the NSMB standard propeller methodical series data, a preliminary design of the congenial propeller was performed. The propeller giving maximum overall propulsion efficiency, permitting appropriate under water immersion and maintaining the minimum permissible stern aperture clearances is adopted.

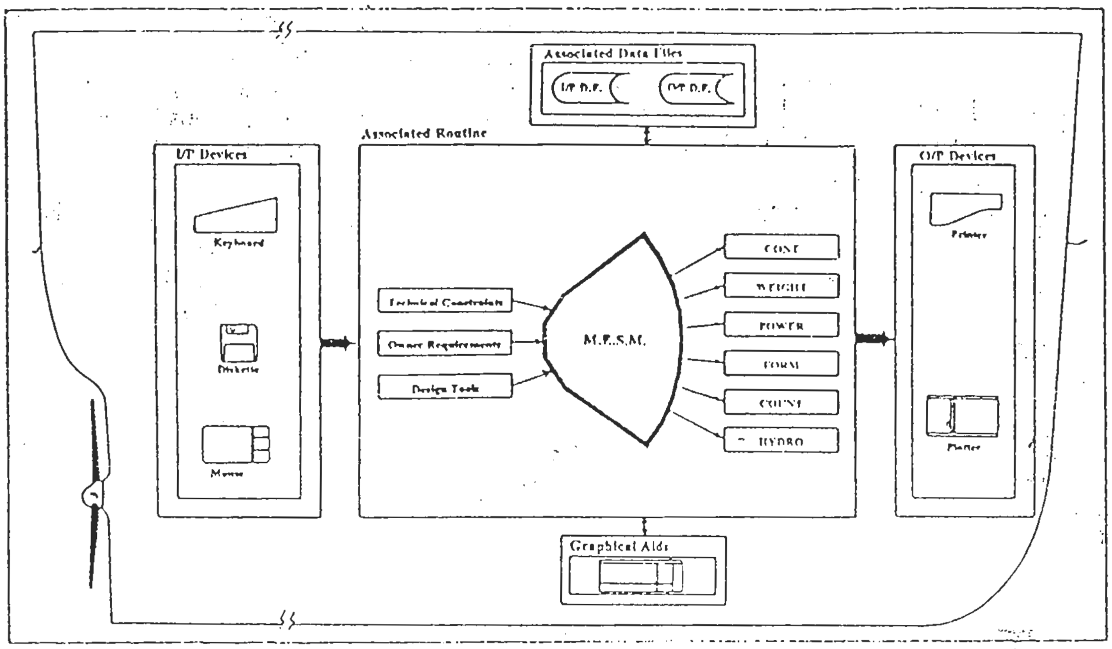

Figure (3) Schematic Representation of CADSUCS-Subsystem, [4].

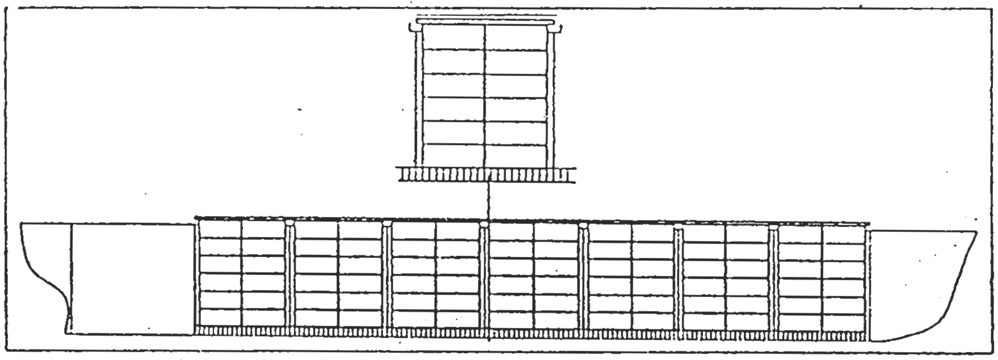

Figure (4 - a) Arrangement of Compartmentation and Stowage Plan of Containers, Section through Central Plane of Profile, Design "A", [4].

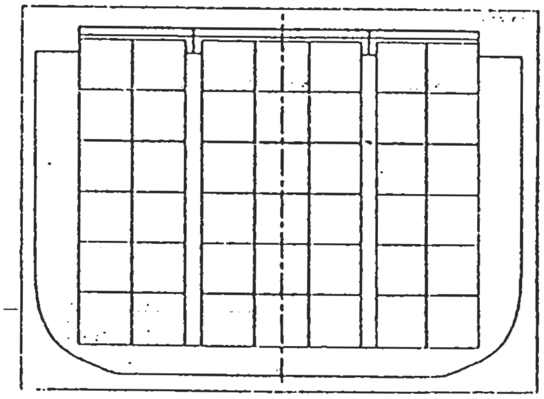

Figure (4 - b) Arrangement of Main Stowage Bays of Containers, Section through Mid-Ship, Design "A", [4].

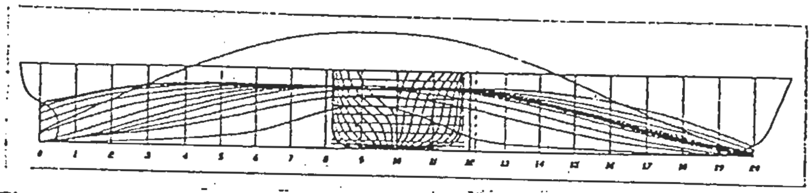

Figure (4 - c) Lines Plan and Sectional Area Curve, Design "A", [4].

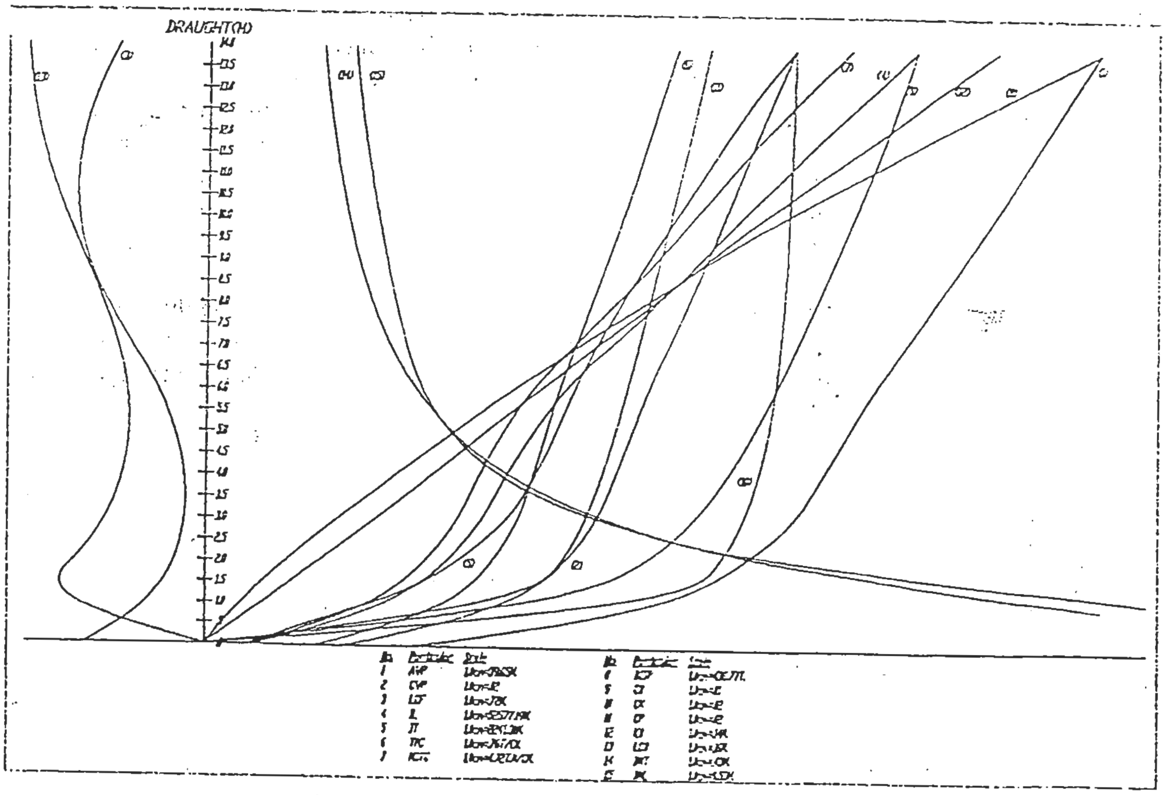

Figure (4 - d) Hydrostatic Particulars, Design "A", [4].

iv. Module *FORM*: for the generation of the hull form, based on the mathematical representation for the model testing experimental results of the SSPA cargo liner methodical series.

v. Module *COUNT*: for checking the validity of the suggested design approach by counting the number of the below deck stowed containers, facilitating any geometrical modifications to be conducted on the hull of the design proposals. The main purpose of these geometrical modifications is to achieve a hull form appropriate to accommodate the required containers.

vi. Module *HYDRO*: for the development of all hydrostatic particulars for the individual designs. These particulars are obtained at certain specified justifiable intervals. The latter were adopted to investigate/examine the mutual relationships between the different particulars and also, to check the results that are obtained with respect to the existing ship design packages (if possible).

vii. A customized automated specific version of general drawing package providing the graphical support subsystem and presenting the means to display the graphical representation of the output results. The graphical representation module has used the spline curves/surfaces as the basis for the development of all associated resultant graphics. Unfortunately, the use of spline technique needs more computer time/configuration than the parabolic one which is the price for better accuracy.

So far the present routine has used the SSPA cargo liner methodical series for the hull surface generation. However, the technique herein is still applicable to any other hull form having its hydrodynamic controlling parameters within the current design trend of container ships.

4. CRITERIA FOR SOLUTION SELECTION

It is well-known that, there are several weighing criteria that may be helpful in assessing the most suitable design alternative(s). These criteria are grouped under two main headings. Firstly, for example the operational criteria, including propelling power, transverse intact stability, periods of ship motions and windage area. Secondly, the economical criteria, including capital as well as operational costs, required freight rate, etc.. Although each design criterion has a unique/interrelated influence on the principal particulars of the proposed design, only the operational criteria are considered while developing the proposed problem solution. However, it is difficult to simultaneously satisfy the requirements of all criteria, but the design alternatives are developed to a point where these criteria can be weighed against each other and the most suited designs are selected.

Unequivocally, if the proposed design satisfies the technical constraints, economical power requirements that in turn satisfy the required speed, adequate stability and good periods of ship motions, and also provides a reasonable container stowage space, it may be considered as technically feasible. However, important to mention is that these technically feasible designs may not be economically the optimum solution. Obviously, in order to obtain the global optimum design, the seakeeping performance, capital and running costs must be assessed over the specified trade route.

5. CASE STUDY

The use of the proposed CADSUCS-subsystem is illustrated by the design of a cellular type container ship, given the data shown in Table (1) as the owner requirements. The principal results of the basic design alternatives (A, B, C, D) are presented numericall Table (2) and graphically represented in Figure (4). numerical results concerning the detailed de particulars are tabulated in Appendix (I). Importan mention here is that, these results do not give optimum designs but, are intended to give illustration of the input and output of the propc subsystem. The resultant design alternatives can compared to each other and ranked by means of a m function consisting of one or more parameters v certain specified weighing factors reflecting the ef of operational criteria and/or economical criteria, e Graphical representation of the output greatly impro the interpretation of the results. Also, comparisons v built ships are misleading, as ships are fully cust built and ship owners have wide diversification requirements. Eventually, it is fairly obvious that procedures developed, while working well, reache level of complexity that is beyond the available time is not possible, however, to simplify the procedures a further and still hope to produce meaningful results.

6. SENSITIVITY ANALYSIS

This section illustrates the use of CADSUC subsystem in a sensitivity analysis in which it is prov that the design methodology considered functic consistently. In this analysis, four additional designs a generated each having the same basic owr requirements as that used in case study, section 5. Tv of these additional designs differ in the number container rows (± 1 TEU) whereas the other tv designs differ in the number of container stacks (± TEU). Although, the proposed analysis may be carrie out considering some/all of the basis designs, it is waste of time and/or effort to consider all desi alternatives (A, B, C, D) as they would lead to t same inference. Therefore, consider only design "A" be the talking paper for the proposed analysis.

Table 1. Owner Requirements, [4].

Owner Requirements	Unit	Value
N_C	*T.E.U.*	600
R	*n.m.*	2500.00
V	*Knots*	18.00

Table 2. Principal Particulars, [4].

Principal Particulars	Unit	Design Alternatives			
		A	B	C	D
LBP	*m*	125.52	125.52	125.52	125.52
B_M	*m*	22.98	24.96	24.96	28.60
D_M	*m*	15.41	15.45	15.45	15.53
T_M	*m*	7.90	6.95	6.85	6.37
FB_B	*m*	7.50	8.50	8.60	9.16
FB_T	*m*	1.80	1.80	1.80	1.80
Δ	*tonne*	13356.96	14330.77	14572.21	15670.64
DWT	*tonne*	8151.14	8228.65	8275.20	8352.93
W_L	*tonne*	5205.82	6102.13	6297.00	7317.71
BHP	hp_m	8012.98	10706.51	12328.04	15023.51

6.1. *Effect of Variation in Number of Container Rows*

In regard to the principal particulars shown in Table (3) as well as the detailed design particulars tabulated in Appendix (II), the most obvious effect of changing container rows is the change in ship length that varies partly to envelop the corresponding multiple number of TEU, partly to adopt an integer number of transverse frame spacing, and partly to accommodate the partial/multiple lengths of the propulsion engine(s). The effect of varying the number of container rows is to be considered, however, both number of stacks and number of tiers are constrained. Principally, as the number of container rows are altered the ship's length is directly varied.

Table 3. Principal Particulars.

Principal Particulars	Unit	Effect of Variation in Container Rows, (Design A)		
		R_C	$R_C + (L_C + \delta)$	$R_C - (L_C + \delta)$
LBP	*m*	125.52	134.49	116.71
B_M	*m*	22.98	22.50	22.96
D_M	*m*	15.41	15.40	14.04
T_M	*m*	7.90	7.61	6.936
FB_B	*m*	7.50	7.78	7.11
FB_T	*m*	1.80	1.98	1.61
Δ	*tonne*	13356.96	13593.69	12857.86
DWT	*tonne*	8151.14	8129.93	8149.10
W_L	*tonne*	5205.82	5463.76	4708.76
BHP	hp_m	8012.98	7278.86	7949.57

Table 4. Principal Particulars.

Principal Particulars	Unit	Effect of Variation in Container Stacks, (Design A)		
		S_C	$S_C + (B_C + \gamma)$	$S_C - (B_C + \gamma)$
LBP	*m*	125.52	125.52	125.52
B_M	*m*	22.98	24.96	21.28
D_M	*m*	15.40	15.45	15.15
T_M	*m*	7.90	7.84	8.34
FB_B	*m*	7.50	7.61	6.81
FB_T	*m*	1.80	1.80	1.80
Δ	*tonne*	13356.96	13557.91	13101.22
DWT	*tonne*	8151.14	8158.83	8146.99
W_L	*tonne*	5205.82	5499.08	4954.23
BHP	hp_m	8012.98	8280.47	7876.35

The principal influences of this variation may be summarized as follows:

i. As the length of the vessel varies, the block coefficient is inversely varied, in order to approximately maintain the same under-deck container stowage capacity. However, the number of containers which can be carried is partly dependent on local variations in the shape of the hull. Therefore, in order to improve the under-deck container carrying capacity, as shown in Table (II-3), the block coefficient of the design proposal is directly varied with the ship's length.

ii. As the length of the vessel varies, the propulsion power is inversely varied, provided that all the resistance governing parameters are maintained constant or even slight variation in any of them is allowed for as shown in Table (3). The result is that, a different engine of different dimensions is required to be installed in order to cope with the altered power. However, as already mentioned before, improving the container carrying capacity may necessitate minor variations in the block coefficient. The latter inversely affects the design draft that is necessary to provide the required immersed volume as well as improving proper propeller clearances.

iii. Varying the ship's length, while retaining and/or directly altering the fineness/fullness of the proposed hull, will result in a corresponding direct variation in the hull steel weight as shown in Table (II-4). Variation in hull steel weight means direct variation in the initial cost (material and construction costs) as well as the operational cost and thus cause inverse variation in the revenue through the corresponding variation in the container carrying capacity.

6.2. *Effect of Variation in Number of Container Stacks*

With reference to the underlying principal particulars collected in Table (4) as well as the detailed particulars grouped in Appendix (III), the sensible influence of varying the number of container stacks is the variation in ship's breadth that varies partly to envelop the corresponding multiple number of TEU, partly to provide sufficient tankage capacity for the purposes of adjusting the transverse intact stability, storing of consumable liquids and transverse spotting of suspended containers, and partly to furnish sufficient strength for the worst loading condition of static/dynamic combined longitudinal, transverse, and warping incentivenesses. The influence of varying the number of container stacks is to be considered, however, both number of rows and number of tiers are constrained. In this respect, any variation in the number of container stacks results in direct proportional variation in the ship's breadth. The principal effects of this variation may be summarized as follows:

i. The resistance is directly varied resulting in a corresponding direct variation in the power requirements as shown in Table (4).

ii. The design draft inversely varies with the breadth. Small drafts restrict the maximum propeller principal dimensions. This usually means lower propulsive efficiency as shown in Table (III-7). In essence, the last disadvantage is not present when the propulsion unit calls for a high propeller speed which reduces the diameter.

iii. The hull steel weight is directly varied as the ship's breadth is altered. The reason is that, any variation in the ship's breadth entails an inverse variation in the scantlings of the bottom and/or deck materials. In fact, any variation in the ship's breadth may impose an inverse variation in its depth in order to approximately maintain a reasonable container carrying capacity. However, as the number of tiers is constrained, a considerable variation in the block coefficient is allowed for.

iv. According to the pin-points that are presented in i through iii, the production costs would be directly varied through an observed range .

v. A considerable variation in the ship's breadth results in direct variation in its initial transverse intact stability as shown in Table (III-5). Evidently, any variation in the ship's breadth results in an inverse variation in KB (in proportion to the draft). Whereas, BM directly varies (in proportion to the cube of the second moment of the waterplane area). The resultant variation in BM has a considerably greater effect than the variation in KB. Therefore, the initial stability GM is thus directly varied for two reasons. Firstly, the metacenter M shifts upwards/downwards, and the center of gravity G shifts downwards/upwards respectively, both with respect to the keel.

vi. The ratio of container stowage coefficient (CSC) as obtained from the cross-sectional area curve ranges between 0.50 and 0.60. The given ratio is based on an assumed constant height of the double bottom. The larger ratio reflects the fullness of the design proposal, and/or the minimum cupboard space is included. Whereas, the smaller one reflects the fineness of the design proposal and/or the increased cupboard space.

vii. Considering a constant block coefficient, a high container stowage coefficient can best be attained by keeping the side strip of the deck abreast the hatches as narrow as possible. However, there are practical limits on the magnitude of this figure. Therefore, in relation to the ship's breadth, the breadth of the longitudinal deck strip inversely varies as the size of the ship.

7. CONCLUSIONS

The present paper has focused on illustrating the capabilities of a newly proposed CASD-subsystem for the cellular type container ship. Unequivocally, a brief investigation of the principal conclusions from this work are as follows:

i. The proposed CASD-subsystem is considered as a comprehensive subsystem for the conceptual design of the cellular type container ships. In addition, it produces several design alternatives all of which satisfy the specified owner requirements as well as the associated technical constraints.

The proposed CASD-subsystem is established in separate functional modules, smoothly interconnected through a main executive supervisor program (MESM). Therefore, it could be easily extended for future purposes to cover other design requirements.

The proposed CASD-subsystem is based on the standard TEU containers. However, other standard container modules could easily be incorporated in the routine.

The proposed CASD-subsystem may be regarded as a sophisticated base for a larger comprehensive CASD-system that takes account of strength and economic considerations.

The use of the graphical aids in the proposed CASD-subsystem has obvious advantages at the concept design phase where it would allow continuous visualization and hence checking of the design proposals at each design stage.

The realization of the subsystem has been fulfilled because of the availability of the present computer facilities (hardware and software) as well as the adoption of the modular format.

FUTURE AMENDMENTS

he present developments of CADSUCS-subsystem ncemed with the construction of an infrastructure for ophisticated container ship design package. The latter ty be used in developing an integrated and/or vanced ship design software. Future amendments uld be done in the following areas:

The conversion of the subsystem from FORTRAN to the C language, for a more user friendly interaction as well as reducing the size of the subsystem coding.

ii. The addition of subjective subroutines as follows:
   - More resistance and propulsion estimation methods.
   - Detailed stability calculation.
   - Freeboard calculation.
   - Calculation of longitudinal, transverse, torsional and/or local strength.
   - Checking of the rules of the classification societies.
   - Optimization for structural design considerations.
   - Optimization for economic considerations.

REFERENCES

[1] M.A. Shama, "Use of Computers in Ship Design", In Arabic, *General Lecture, the Marine Scientific Society*, Department of Naval Architecture and Marine Engineering, Faculty of Engineering, Alexandria University, Alexandria, Egypt, pp. 7-34, 1967.

[2] R. Taggart (Editor), *Ship Design and Construction*, *S.N.A.M.E. Publications*, pp.(1-49, 51-96, 105-137, 419-473), 1980.

[3] K.J. Rawson, "Maritime System Design Methodology", *Symposium on Advances in M.T.*, Trondheim, 1979.

[4] K.A. Hafez, "A Computer-Aided Design Subsystem for Container Ships", *M. Sc. Thesis*, Department of Naval Architecture and Marine Engineering, Faculty of Engineering, Alexandria University, Alexandria, Egypt, February 27, 1995.

[5] D. Andrews, "Creative Ship Design", *R.I.N.A. Transactions*, pp. 447-470, 1981.

[6] G.M. Watson and A. W. Gilfillan, "Some Ship Design Methods", *R.I.N.A. Transactions*, vol. 119, pp. 279-305, July 1977.

[7] H. Schneekluth, *Ship Design for Efficiency and Economy*, Butterworths, London, pp. (1-40, 205-242), 1987.

APPENDIX "I"

TABULATED PRESENTATION FOR THE DETAILED O/P RESULTS OF THE BASIC DESIGNS OF CADSUCS-SUBSYSTEM

Table I-1. Initial Guess for Stowage Arrangements, [4].

Stowage Arrangements	Unit	Design Alternatives			
		A	B	C	D
N_{CH}	*TEU*	300	360	420	480
N_{CD}	*TEU*	300	240	180	120
R_C	*TEU*	14	14	14	14
S_C	*TEU*	7	8	8	9
T_C	*TEU*	6	6	6	6

Table I-2. Design Parameters, [4].

Design Parameters	Unit	Design Alternatives			
		A	B	C	D
F_N	------	0.261	0.261	0.261	0.261
L/B	------	5.46	5.03	5.03	4.39
L/D	------	8.15	8.12	8.12	8.08
B/D	------	1.49	1.62	1.62	1.84
B/T	------	2.91	3.59	3.64	4.49
D/T	------	1.95	2.22	2.26	2.44
T/L	------	0.06	0.06	0.05	0.05
$L/\nabla^{1/3}$	------	5.33	5.21	5.18	5.06
DWT/Δ	------	0.61	0.57	0.57	0.53
$V^3\times\Delta^{2/3}/SHP$	------	409.73	321.38	282.23	243.09

Table I-3. Coefficients of Forms, [4].

Coefficients of Forms	Unit	Design Alternatives			
		A	B	C	D
C_B	------	0.57	0.64	0.66	0.67
C_M	------	0.96	0.98	0.98	0.98
C_W	------	0.71	0.76	0.77	0.77
CP_T	------	0.59	0.66	0.67	0.68
CP_L	------	0.81	0.85	0.86	0.86

Table I-4. Aggregated Weights, [4].

Aggregated Weights	Unit	Design Alternatives			
		A	B	C	D
W_S	*tonne*	3278.55	3853.69	3933.29	4545.68
W_{OF}	*tonne*	1096.24	1190.59	1190.59	1363.98
$W_{M/C}$	*tonne*	513.30	685.42	788.80	961.42
W_{LG}	*tonne*	5205.82	6102.13	6297.00	7317.71
W_C	*tonne*	7800.00	7800.00	7800.00	7800.00
W_{FO}	*tonne*	231.14	355.20	308.65	432.93
W_{MIS}	*tonne*	120.00	120.00	120.00	120.00
DWT	*tonne*	8151.14	8228.65	8275.20	8352.93
W	*tonne*	13356.96	14330.77	14572.21	15670.64
KG_S	*m*	8.19	8.13	8.11	8.19
KG_{OF}	*m*	14.15	14.19	14.19	14.27
$KG_{M/C}$	*m*	7.24	7.26	7.26	7.30
KG_C	*m*	16.44	14.69	13.51	12.72
KG_{FO}	*m*	5.70	5.72	5.72	5.75
KG_{MIS}	*m*	7.70	7.73	7.73	7.77
KG	*m*	12.62	11.40	10.72	10.21

Table I-5. Initial Transverse Intact Stability Criteria, [4].

Initial Stability Criteria	Unit	Design Alternatives			
		A	B	C	D
KB	*m*	4.37	3.77	3.70	3.43
BM_T	*m*	9.13	12.36	12.57	17.75
KM_T	*m*	13.50	16.13	16.27	21.18
KG	*m*	12.62	11.40	10.72	10.21
GM_T	*m*	0.88	4.73	5.54	10.96

Table I-6. Particulars of Ship Motions, [4].

Particulars of Ship Motions	Unit	Design Alternatives			
		A	B	C	D
T_R	*sec.*	15.81	8.01	7.56	6.09
T_P	*sec.*	6.86	6.83	6.80	7.05
T_H	*sec.*	7.48	7.55	7.57	7.73
T_R/T_P	------	2.30	1.17	1.11	0.86
T_R/T_H	------	2.11	1.06	1.00	0.79
T_P/T_H	------	0.92	0.90	0.90	0.91

Table I-7. Propulsion Performance, [4].

Propulsion Performance	Unit	Design Alternatives			
		A	B	C	D
ω_t	------	0.27	0.30	0.31	0.31
t	------	0.20	0.21	0.22	0.23
η_H	------	1.09	1.13	1.13	1.11
η_{RR}	------	1.01	1.01	1.01	1.01
η_{SH}	------	0.98	0.98	0.98	0.98
η_{POPT}	------	0.56	0.53	0.52	0.51
QPC	------	0.62	0.60	0.59	0.57
P/D	------	0.99	0.91	0.90	0.87
D_{POPT}	*m*	4.41	4.75	4.90	5.12
P	*m*	4.36	4.35	4.39	4.47

Table I-8. Actual Container Carrying Capacity, [4].

Check	Unit	Design Alternatives			
		A	B	C	D
NC_S	*TEU*	283	340	396	451
Dif. %	------	-5.67	-5.56	-5.71	-6.04

APPENDIX "II"

TABULATED PRESENTATION FOR THE DETAILED O/P RESULTS OF THE CONJUGATE DESIGNS (DIFFERENT NUMBER OF ROWS) OF CADSUCS-SUBSYSTEM

Table II-1. Stowage Arrangements.

Stowage Arrangements	Unit	Effect of Variation in Container Rows. (Design A)		
		R_C	$R_C + (L_C + \delta)$	$R_C - (L_C + \delta)$
N_{CH}	*TEU*	300	300	300
N_{CD}	*TEU*	300	300	300
R_C	*TEU*	14	15	13
S_C	*TEU*	7	7	7
T_C	*TEU*	6	6	6

Table II-2. Design Parameters.

Design Parameters	Unit	Effect of Variation in Container Rows, (Design A)		
		R_C	$R_C + (L_C + \delta)$	$R_C - (L_C + \delta)$
F_N	-----	0.261	.252	0.263
L/B	-----	5.46	5.98	5.08
L/D	-----	8.15	8.74	8.31
B/D	-----	1.49	1.46	1.64
B/T	-----	2.91	2.96	3.31
D/T	-----	1.95	2.02	2.02
T/L	-----	0.06	0.06	0.06
$L/\nabla^{1/3}$	-----	5.33	5.68	5.02
DWT/Δ	-----	0.61	0.60	0.63
$V^3\times\Delta^{2/3}/SHP$	-----	409.73	456.36	402.64

Table II-3. Coefficients of Forms.

Coefficients of Forms	Unit	Effect of Variation in Container Rows, (Design A)		
		R_C	$R_C + (L_C + \delta)$	$R_C - (L_C + \delta)$
C_B	-----	0.57	0.58	0.67
C_M	-----	0.96	0.97	0.97
C_W	-----	0.71	0.71	0.72
CP_T	-----	0.59	0.60	0.61
CP_L	-----	0.81	0.81	0.82

Table II-4. Aggregated Weights.

Aggregated Weights	Unit	Effect of Variation in Container Rows, (Design A)		
		R_C	$R_C + (L_C + \delta)$	$R_C - (L_C + \delta)$
W_S	*tonne*	3278.55	3514.39	3181.72
W_{OF}	*tonne*	1096.24	1149.71	1018.27
$W_{M/C}$	*tonne*	513.30	466.19	508.77
W_{LG}	*tonne*	5205.82	5463.76	4708.76
W_C	*tonne*	7800.00	7800.00	7800.00
W_{FO}	*tonne*	231.14	209.93	229.10
W_{MIS}	*tonne*	120.00	120.00	120.00
DWT	*tonne*	8151.14	8129.93	8149.10
W	*tonne*	13356.96	13593.69	12857.86
KG_S	*m*	8.19	8.12	9.42
KG_{OF}	*m*	14.15	14.05	12.98
$KG_{M/C}$	*m*	7.24	7.24	6.60
KG_C	*m*	16.44	16.24	16.10
KG_{FO}	*m*	5.70	5.70	5.20
KG_{MIS}	*m*	7.71	7.70	7.02
KG	*m*	13.22	12.43	13.78

Table II-5. Initial Transverse Intact Stability Criteria.

Initial Stability Criteria	Unit	Effect of Variation in Container Rows, (Design A)		
		R_C	$R_C + (L_C + \delta)$	$R_C - (L_C + \delta)$
KB	*m*	4.39	4.21	3.76
BM_T	*m*	9.28	9.09	9.21
KM_T	*m*	13.67	13.30	12.97
KG	*m*	13.22	12.43	13.78
GM_T	*m*	0.45	0.87	-0.81

Table II-6. Particulars of Ship Motions.

Particulars of Ship Motions	Unit	Effect of Variation in Container Rows, (Design A)		
		R_C	$R_C + (L_C + \delta)$	$R_C - (L_C + \delta)$
T_R	*sec*	15.81	16.16	32.87
T_P	*sec*	6.86	6.77	7.11
T_H	*sec*	7.48	7.38	7.74
T_R/T_P	------	2.30	2.39	4.62
T_R/T_H	------	2.11	2.19	4.25
T_P/T_H	------	0.92	0.92	0.92

Table II-7. Propulsion Performance.

Propulsion Performance	Unit	Effect of Variation in Container Rows, (Design A)		
		R_C	$R_C + (L_C + \delta)$	$R_C - (L_C + \delta)$
ω_t	------	0.27	0.28	0.24
t	------	0.20	0.18	0.18
η_H	------	1.09	1.14	1.08
η_{RR}	------	1.01	1.01	1.01
η_{SH}	------	0.98	0.98	0.98
η_{POPT}	------	0.56	0.56	0.54
QPC	------	0.62	0.65	0.60
P/D	------	0.989	0.993	0.966
D_{POPT}	*m*	4.41	4.32	4.23
P	*m*	4.36	4.29	4.09

Table II-8. Actual Container Carrying Capacity.

Check	Unit	Effect of Variation in Container Rows, (Design A)		
		R_C	$R_C + (L_C + \delta)$	$R_C - (L_C + \delta)$
NC_S	*TEU*	283	287	274
Dif. %	------	-5.67	-4.33	-8.67

APPENDIX "III"

TABULATED PRESENTATION FOR THE DETAILED O/P RESULTS OF THE CONJUGATE DESIGNS (DIFFERENT NUMBER OF STACKS) OF CADSUCS-SUBSYSTEM

Table III-1. Stowage Arrangements.

Stowage Arrangements	Unit	Effect of Variation in Container Stacks, (Design A)		
		S_C	$S_C + (B_C + \gamma)$	$S_C - (B_C + \gamma)$
N_{CH}	*TEU*	300	300	300
N_{CD}	*TEU*	300	300	300
R_C	*TEU*	14	14	14
S_C	*TEU*	7	8	6
T_C	*TEU*	6	6	6

Table III-2. Design Parameters.

Design Parameters	Unit	Effect of Variation in Container Stacks, (Design A)		
		S_C	$S_C + (B_C + \gamma)$	$S_C - (B_C + \gamma)$
F_N	------	0.261	0.261	0.261
L/B	------	5.46	5.03	5.90
L/D	------	8.15	8.12	8.29
B/D	------	1.49	1.62	1.41
B/T	------	2.91	3.18	2.55
D/T	------	1.95	1.97	1.82
T/L	------	0.06	0.06	0.07
$L/\nabla^{1/3}$	------	5.33	5.29	5.37
DWT/Δ	------	0.61	0.60	0.62
$V^3 \times \Delta^{2/3}/SHP$	------	409.73	402.43	411.50

Table III-3. Coefficients of Forms.

Coefficients of Forms	Unit	Effect of Variation in Container Stacks, (Design A)		
		S_C	$S_C + (B_C + \gamma)$	$S_C - (B_C + \gamma)$
C_B	------	0.57	0.54	0.70
C_M	------	0.96	0.96	0.97
C_W	------	0.71	0.68	0.72
CP_T	------	0.59	0.57	0.61
CP_L	------	0.81	0.79	0.81

Table III-4. Aggregated Weights.

Aggregated Weights	Unit	Effect of Variation in Container Stacks, (Design A)		
		S_C	$S_C + (B_C + \gamma)$	$S_C - (B_C + \gamma)$
W_S	*tonne*	3278.55	3442.48	3435.13
W_{OF}	*tonne*	1096.24	1190.59	1015.01
$W_{M/C}$	*tonne*	513.30	530.39	504.09
W_{LG}	*tonne*	5205.82	5499.08	4954.23
W_C	*tonne*	7800.00	7800.00	7800.00
W_{FO}	*tonne*	231.14	238.83	226.99
W_{MIS}	*tonne*	120.00	120.00	120.00
DWT	*tonne*	8151.14	8158.83	8146.99
W	*tonne*	13356.96	13657.91	13101.22
KG_S	*m*	8.19	8.29	8.10
KG_{OF}	*m*	14.15	14.19	13.92
$KG_{M/C}$	*m*	7.24	7.26	7.12
KG_C	*m*	16.44	16.42	16.54
KG_{FO}	*m*	5.70	5.72	5.61
KG_{MIS}	*m*	7.70	7.73	7.58
KG	*m*	12.62	12.57	13.72

Table III-5. Initial Transverse Intact Stability Criteria.

Initial Stability Criteria	Unit	Effect of Variation in Container Stacks, (Design A)		
		S_C	$S_C + (B_C + \gamma)$	$S_C - (B_C + \gamma)$
KB	*m*	4.37	4.38	4.50
BM_T	*m*	9.13	10.82	8.25
KM_T	*m*	13.50	15.20	12.75
KG	*m*	12.62	12.57	13.72
GM_T	*m*	0.88	2.63	-0.97

Table III-6. Particulars of Ship Motions.

Particulars of Ship Motions	Unit	Effect of Variation in Container Stacks, (Design A)		
		S_C	$S_C + (B_C + \gamma)$	$S_C - (B_C + \gamma)$
T_R	*sec*	15.81	9.32	36.00
T_P	*sec*	6.86	7.06	7.30
T_H	*sec*	7.48	7.52	8.18
T_R/T_P	------	2.30	1.32	4.93
T_R/T_H	------	2.11	1.24	4.40
T_P/T_H	------	0.92	0.94	0.89

Table III-7. Propulsion Performance.

Propulsion Performance	Unit	Effect of Variation in Container Stacks, (Design A)		
		S_C	$S_C + (B_C + \gamma)$	$S_C - (B_C + \gamma)$
ω_t	------	0.27	0.25	0.27
t	------	0.20	0.20	0.18
η_H	------	1.09	1.06	1.12
η_{RR}	------	1.01	1.01	1.01
η_{SH}	------	0.98	0.98	0.98
η_{POPT}	------	0.56	0.57	0.54
QPC	------	0.62	0.61	0.64
P/D	------	0.989	1.005	1.01
D_{POPT}	*m*	4.41	4.42	4.82
P	*m*	4.36	4.44	4.87

Table III-8. Actual Container Carrying Capacity.

Check	Unit	Effect of Variation in Container Stacks, (Design A)		
		S_C	$S_C + (B_C + \gamma)$	$S_C - (B_C + \gamma)$
NC_S	*TEU*	283	306	263
Dif. %	-----	-5.67	+2.00	-12.33