Computer-aided conceptual design of surface-effect ships

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RÉSUMÉ

Description d'une technique récente de conception assistée par ordinateur d'aéroglisseurs à quilles latérales rigides. Il est fait appel à un modèle mathématique de synthèse comportant plus de 170 options d'entrée ainsi qu'à un système automatique de conception assistée par ordinateur comportant une table traçante.

Le procédé est décrit par le biais de plusieurs exemples de CAO, notamment d'un navire patrouilleur et d'un traversier rapide, tous deux de type à effet tunnel. Les auteurs montrent comment, en faisant appel à un modèle de synthèse représentant l'ensemble d'un navire, il est possible de sélectionner certaines variantes privilégiées, caractérisées soit par un coût minimal, soit par une puissance minimale, soit, enfin, par une charge maximale. Ils montrent également comment il est possible d'étudier une architecture donnée permettant d'éliminer les mouvements de tangage synchrones aux vitesses nominales par mer debout.

Les résultats obtenus ont servi à illustrer le procédé d'optimisation des cotes dimensionnelles d'un navire, longueur et bau, et montrent comment ce procédé permet de prendre en compte les changements dans les caractéristiques exigées ainsi que les variations dans les paramètres de conception tels la vitesse, l'état de mer, la charge et l'autonomie.

Des conceptions dotées de caractéristiques particulières sont données à titre d'exemple, accompagnées des prévisions de performances hors conditions nominales correspondantes et de dessins (voir figures 1 et 2).

COMPUTER-AIDED CONCEPTUAL DESIGN
OF
SURFACE-EFFECT SHIPS

BY

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ABSTRACT

A recent development for computer-aided design of rigid-sidehull Surface-Effect Ships (SES) is described. The approach uses a design-synthesis math model with over 170 input options and an AutoCAD computer with a drafting system.

The approach is described by way of several design examples including the design of an SES patrol craft and an SES high-speed passenger-car ferry. The paper shows how, by using a "whole-ship" design-synthesis model, preferred designs can be selected that feature either minimum cost, minimum power or maximum payload. The approach also shows how SES designs can be developed to avoid synchronous pitch motions at design speed in head seas.

Results are presented to illustrate the optimization of craft length and beam and how this is influenced by changing performance requirements including variations in speed, sea state, payload and range.

Specific requirements are selected for example designs for which off-design performance is presented along with drawings as shown, for example, in Figures 1 and 2.

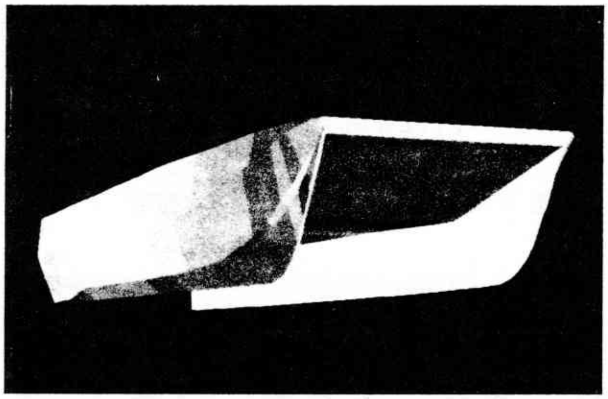


Figure 1. AutoCAD Perspective View of SES Hullform

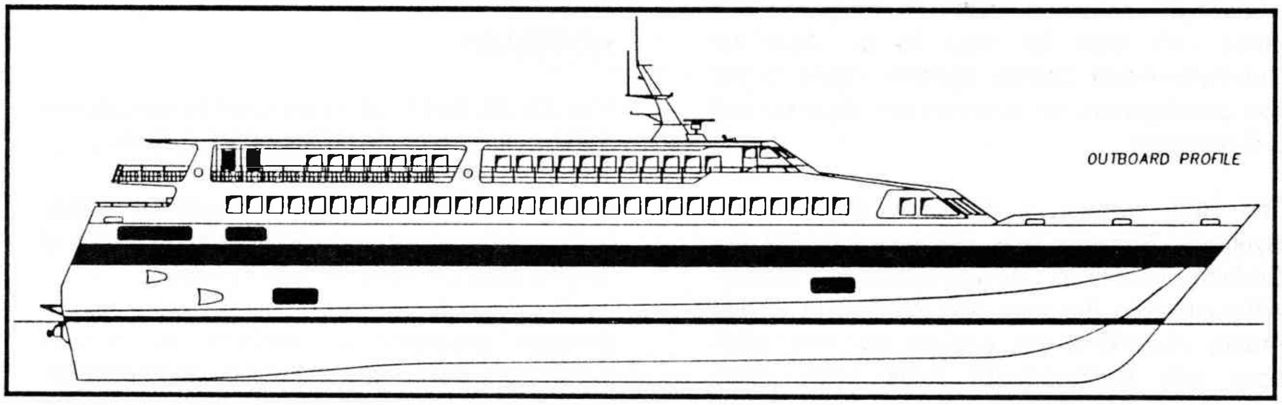


Figure 2. Outboard Profile of SES Passenger/Car Ferry

INTRODUCTION

A computer-aided-design capability for the early-stage design of Air-Cushion Vehicles (ACVs) and rigid-sidehull Surface-Effect Ships (SES) was developed at Band, Lavis & Associates, Inc. in 1979 (Reference 1). Developed originally to support an ACV project for the Canadian Government, the program was extensively expanded in capability and has since been used to support 19 additional design projects the majority of which were for the U.S. Navy. More recently, the basic program was restructured as four separate programs to permit the design of ACVs, SES, high-speed catamarans and monohulls as identified in Table 1.

Table 1. Design Synthesis Models

ADSM	ACV DESIGN-SYNTHESIS MODEL
SDSM	SES DESIGN-SYNTHESIS MODEL
CDSM	CATAMARAN DESIGN-SYNTHESIS MODEL
MDSM	MONOHULL DESIGN-SYNTHESIS MODEL

These programs run on an ALTOS 1409T/386 UNIX-based computer, the data output from which can be read by the Coast Design Inc. "AutoSHIP" software. This, in turn, provides faired hull lines for input to an AutoCAD Computer-Aided Design System, Figure 3, for the development of arrangement layouts and 3-D drawings.

The SES version of the BLA, Inc. Design-Synthesis Software was christened SDSM (for Surface-Effect-Ship Design-Synthesis Model). Although both the form and content of SDSM greatly resembles the original program, additions and improvements have been made including a new resistance routine, new design routines for waterjets and surface-piercing propellers, an improved structural-design routine and revised weight-estimating routines as identified in Table 2.

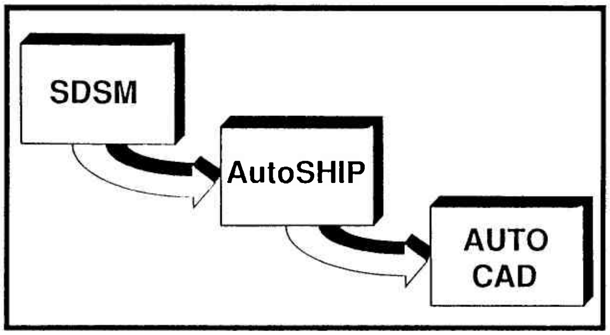


Figure 3. Integration of Computer Assets

Table 2. SDSM Revisions

- SES DESIGN-SYNTHESIS MODEL (SDSM)
  - DREA (1979 - 1980)
  - NAVSEA 501 (1981 - 1987)
  - DTRC CODE 16 (1987)
- RECENTLY REVISED ROUTINES
  - RESISTANCE: DTRC CODE 16 (CORRELATION: REVISED RESIDUAL DRAG)
  - WATERJET PUMP DESIGN (KAMEWA, INDUCER-TYPE, OPTIMIZED PUMPS)
  - SURFACE-PIERCING PROP DESIGN
  - STRUCTURAL DESIGN: SEA 501 (CORRELATION: LOADS, MATERIAL PROPERTIES, COMPONENT WEIGHTS)

APPROACH

The SDSM tool is normally used in conjunction with the design process illustrated in Table 3.

First, a parent hullform is selected by initially exploring the effect on resistance and stability of varying sidehull cross-sectional shapes.

Sidehull geometry is selected to provide satisfactory performance, stability and seakeeping based on prior experience. Figures 4 and 5 show the wide variety of sidehull shapes that have been used in prior designs. (Geometry "F," in Figure 5, was selected as the cross-section of the parent hull used in the studies presented here.)

Table 3. Design Approach

1. SELECT PARENT HULLFORM
   (BASED ON INITIAL RESISTANCE AND STABILITY ANALYSIS)
2. RUN SYNTHESIS MODEL AND VARY:
   - CUSHION LENGTH
   - PAYLOAD
   - SPEED
   - CUSHION BEAM
   - RANGE
   - DESIGN OPTIONS
3. SELECT CONFIGURATION HAVING MINIMUM
   - COST
   - POWER
   - WEIGHT
4. DEVELOP COMPLETE HULL LINES
5. CHECK HULLBORNE STABILITY
   (SELECT HULL SUB-DIVISIONS)
6. DEVELOP ARRANGEMENTS
7. SELECT ACTUAL SUBSYSTEMS
8. CHARACTERIZE SHIP OFF-DESIGN PERFORMANCE
   - SPEED, STABILITY, SEAKEEPING

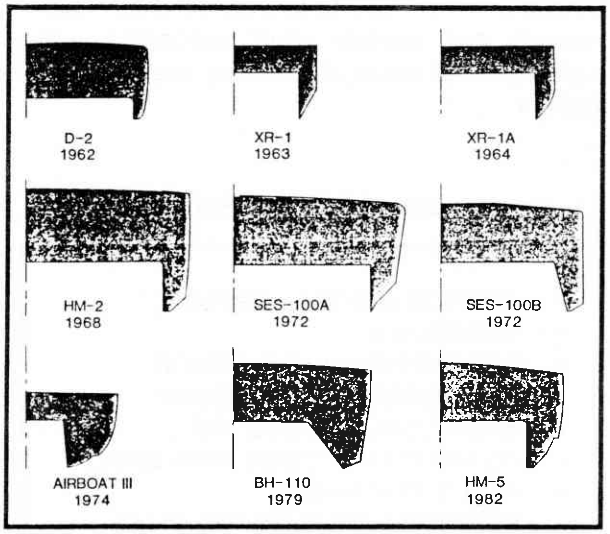


Figure 4. Early Trends in Sidehull Mid-Ship Sections

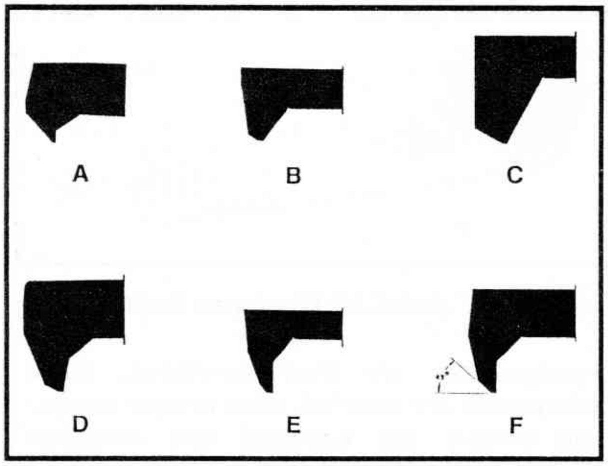


Figure 5. Recent Trends in Sidehull Midship Sections

Next, the synthesis model generates a series of conceptual SES designs which all meet the given requirements but which have different combinations of cushion length and beam and different types of subsystems.

From this series of designs a hullform configuration is usually selected that would result in maximum payload carrying capability or minimum cost.

The complete hull lines are then developed as shown in Figures 1, 6 and 7. Hullborne damaged stability is checked and the primary subdivisions selected.

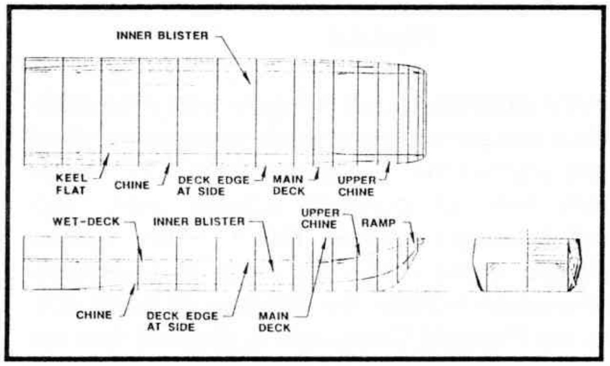


Figure 6. SES Body Plan

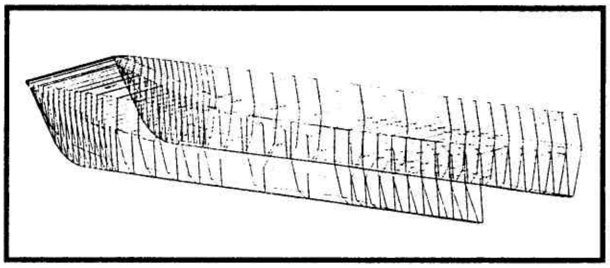


Figure 7. AutoCAD Wireframe Illustration

Arrangements are then developed, major subsystems are selected, more precise subsystem weights are estimated and off-design performance is characterized.

Figure 8 illustrates the process used to determine maximum payload carrying capability.

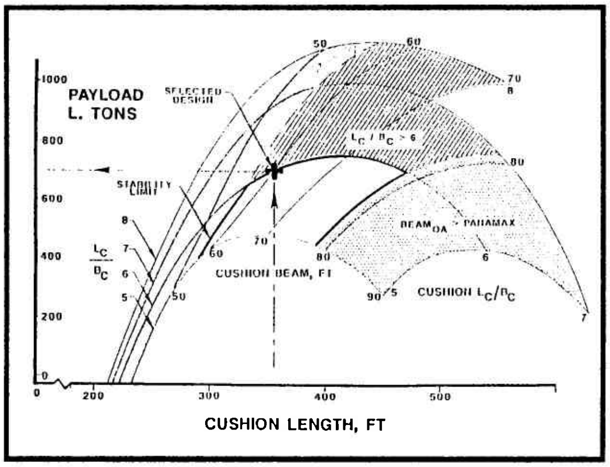


Figure 8. Typical Plot for Maximizing Payload

In the example shown in Figure 8 the propulsion plant and performance requirements were given and payload was plotted versus cushion length with lines of constant cushion beam and cushion-length-to-beam ratio. The various shaded areas define the limits of acceptable on-cushion stability, the limitation on beam due to the Panama Canal, and a practical limit on length-to-beam ratio. Within these limits a maximum payload could be found as shown.

SDSM SUBROUTINES

The basic form of the SDSM can be divided into three parts; input, synthesis and output. The SDSM input file may itself be divided into three parts. The first is mission requirements. In this part, all of the requirements for speed, environment, payload, range, endurance and margins are set. The second part of the input file involves individual subsystems. This section allows the user to identify specific elements to be used in the design synthesis. For example, the hull structure section includes a choice of aluminum or steel as the construction material and basic hullform geometry such as inner and outer deadrise angles of the sidehulls; the propulsion section allows a choice of marine diesel or gas-turbine prime movers, and a choice between waterscrew or waterjet propulsors. The last part of the SDSM input file is a program control section which allows the user to choose between several ways of running the program. For example, the user can choose a method of ship optimization which places a priority on minimum weight, minimum cost, minimum power or maximum payload.

The synthesis section of the program is subdivided into a main body, seven major subroutines and several other supporting subroutines. The major subroutines are shown in Table 4.

Table 4. SDSM Principal Subroutines

- CUSHION AND SEAL AIR FLOW
- RESISTANCE
- LIFT-SYSTEM AND FAN DESIGN
- PROPULSOR-SYSTEM DESIGN*
- ENGINE CHARACTERISTICS
- GEARBOX AND POWER TRAIN DESIGN
- HULL STRUCTURE
- SUBSYSTEM WEIGHTS AND SPACE

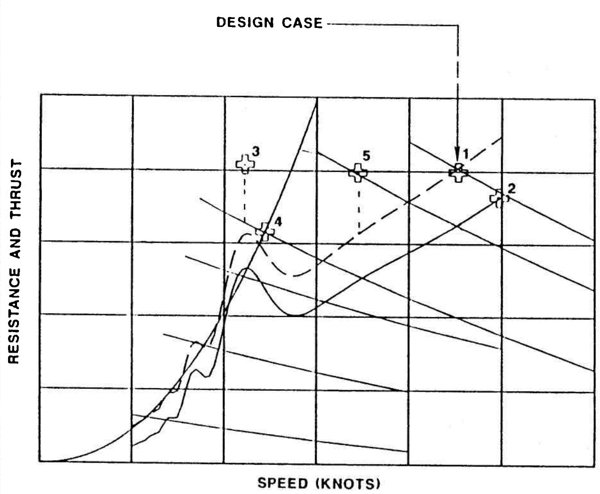
*OPTIMIZATION AVAILABLE

The last section of the SDSM uses the results from the synthesis routine and creates a detailed output that includes subsystem descriptions, thrust and drag characteristics and a SWBS weight breakdown to three digits for most weight groups.

An iterative computational sequence is used by the synthesis model to search for a balanced design. This is illustrated in Figure 9.

The procedure starts by specifying the input options including mission requirements at Step 1 (Figure 9) and then selecting the first combination of cushion planform length (L_C) and beam (B_C) to be investigated along with an initial guess at the gross weight at Step 2. This defines an initial shape and size from which to calculate, at Step 3, the lift-system air flow and at Step 4 the total drag and thrust required for up to eight design cases. These include calm-water speed, rough-water hump transit and cruise speed in rough water. A towing capability may also be included if required.

Next, at Step 5, the propulsors are sized to meet the most demanding of these thrust requirements. At Step 6, the lift fans are sized and the fan power determined. The lift system is also sized according to the most demanding of the design points. At Step 7, the engines and transmission are sized. The weights, space and cost requirements of the engines and transmission as well as major craft components, including the structure, payload and fuel load, are summarized as shown at Steps 8 and 9 of Figure 9.



1. SET INPUT OPTIONS.
2. SELECT L_C AND B_C AND ASSUME INITIAL GROSS WEIGHT.
3. CALCULATE AIR FLOWS.
4. CALCULATE DRAG & THRUST FOR DESIGN CASES.
5. SIZE PROPULSORS AND DETERMINE PROPULSION POWER.
6. SIZE LIFT FANS AND DETERMINE FAN POWER.
7. SIZE ENGINES AND TRANSMISSION SYSTEM.
8. CALCULATE ALL WEIGHT COMPONENTS.
9. CALCULATE SPACE COMPONENTS.
10. ADJUST GROSS WEIGHT AND REPEAT FROM STEP 3 TO FIND BALANCED DESIGN.
11. OUTPUT SUMMARY OF RESULTS.
12. REPEAT STEPS 2 THROUGH 11 WITH NEW L_C AND B_C.
13. SELECT L_C AND B_C FOR LEAST COST, POWER, OR MAX. PAYLOAD, ETC.
14. OUTPUT DETAILED RESULTS.
15. REPEAT FROM STEP 1 THROUGH 14 FOR NEXT SET OF OPTIONS.

Figure 9. SES Design Synthesis Procedure

The full-load gross weight found by this method is then used instead of the initial guess for gross weight at Step 2 and the sequence of Steps 3 through 10 is repeated iteratively until successive gross weights at Step 10 are close to being equal. A summary of the performance and characteristics of the balanced design is then made available at Step 11.

Next, the iterative Steps 2 through 10 are repeated with new values for L_C and B_C. The results are then compared at Step 13 to select the L_C and B_C combination which results in maximum payload, minimum weight, minimum cost or minimum total power.

RESISTANCE

Calculations are performed by SDSM to predict resistance both on and off cushion.

To verify the accuracy of the updated SDSM in predicting SES resistance on-cushion, several runs were made using inputs corresponding to existing models. The modified drag algorithms were correlated against results from SES models of L_C/B_C of 3.8 and 4.7. These correlations are presented as Figures 10 and 11. As is shown, the SDSM drag routine agrees reasonably well with model test result.

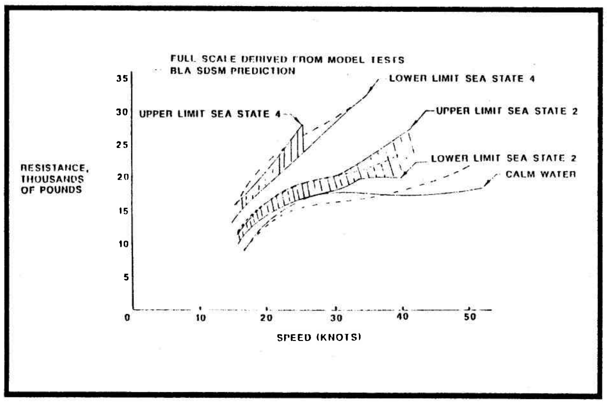


Figure 10. Comparison of SDSM and Model Test Results, L_C/B_C = 3.8

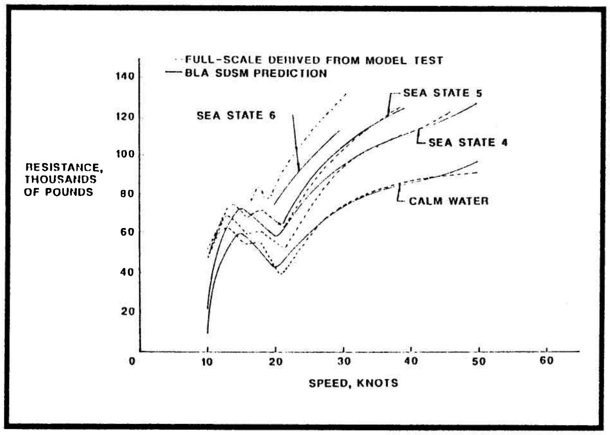


Figure 11. Comparison of SDSM and Model Test Results, L_C/B_C = 4.7

STRUCTURE

The new structural design routine is designated STRUCT. The primary purpose of the STRUCT subroutine, Figure 12, is to provide an estimate of the structural weight (W100) of the ship. To accomplish this, a substantial structural design calculation is carried out leading to estimates of the plating thicknesses of the shell, the wet-deck, the main and lower decks and longitudinal and transverse bulkheads. The weights of shell and deck stiffeners are determined by empirical relationships derived from analysis of typical plate/stiffener combinations. A similar procedure is followed for transverse frames and longitudinal girders. Consequently, no scantlings are given for structural components other than plate. Empirical formulae are used to estimate the weights of foundations and superstructure. Structural weights are calculated at the three digit SWBS level.

PROPULSION

The user may specify the type of propulsor, such as specifying KaMeWa pumps for water-jets, or let the program make its own selection.

Figure 13 shows an example of how the SDSM selects a waterjet pump when ship weight is allowed to vary to maintain a balanced whole-ship design. The ordinate on this figure is the product of thrust power and system weight. The abscissa is propulsive coefficient. System weight is defined as propulsion group 200 weight less lift-system weight plus total fuel weight.

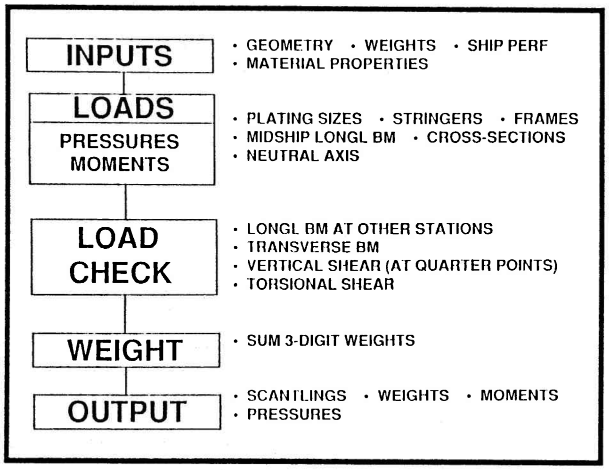


Figure 12. Hull Structure Design

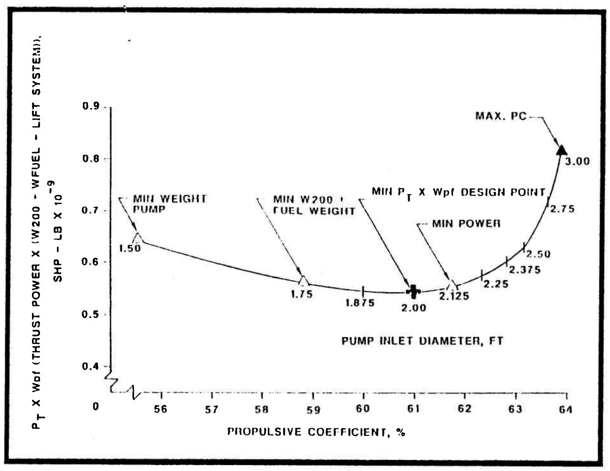


Figure 13. Waterjet Optimization With Respect to PC

On this basis, Figure 13 shows that the SDSM does not pick the pump with maximum propulsive coefficient (PC), but the one with the least product of system weight and required power. Figure 13 also shows pumps that would have been chosen using other optimization criteria.

Figure 14 provides another look at the effect of pump size and optimization criteria. The figure shows, again, the product of thrust power and system weight plotted this time against power. From this plot it can be seen that the minimum power pump is very close to the pump selected by the SDSM.

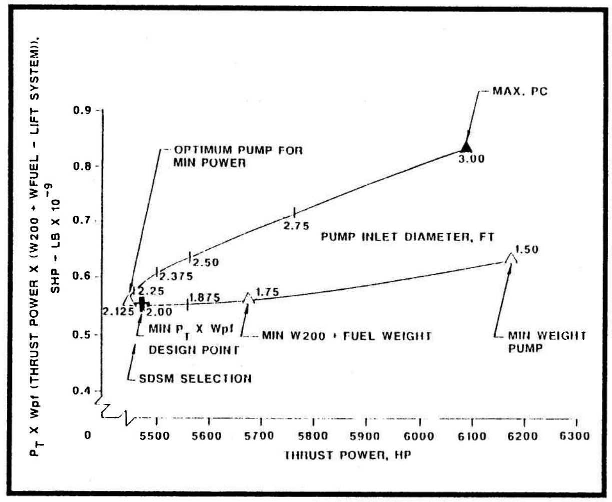


Figure 14. Waterjet Optimization With Respect to Thrust Power

LIFT SYSTEM

The lift-system subroutine is used to develop an air-supply system that will meet the requirements for seal flow and cushion flow, and, if required, the air flow needed for engine supercharging, maneuvering, and a ride-control system.

The user has a number of input variables at his disposal by which he may influence the design of a craft's lift system. They consist of the maximum number of fans, maximum fan diameter, maximum value of fan tip speed, fan inlet orientation, and air-distribution arrangement. Reasonable values of maximum allowable fan diameter depend in part upon craft geometry. Maximum tip speeds tend to be limited to about 500 feet per second, beyond which unacceptably high loads develop within the fans. The number and type of fans are selected to comply with diameter and tip-speed limitations and flow requirements.

The type and the number of fans are calculated within the subroutine to satisfy the air flow and pressure requirements. The program selects the most appropriate fan type from among centrifugal fans, mixed flow fans, single-stage axial fans and multi-stage axial fans. The number of fans, the type of fan, the number of stages (if axial), the fan diameter, tip speed and the total power and weight are output along with a number of non-dimensional performance characteristics.

POWER PLANT

There are a number of inputs which the user may select to indicate the type and number of engines to be used by the SDSM for a given craft. These include the technology year, engine type, number of lift and propulsion engines, and gearbox mesh efficiency. This allows the user to indicate whether the craft is to have closed-cycle gas turbine, open-cycle gas turbine, diesel or rotary engines. The technology year indicates the year in which the craft is expected to be built and is used to account for likely improvements in technology levels between the point of design and the time of actual construction. The SDSM, working upon the assumption of either a separate or an integrated lift-propulsion system, will choose a set number of engines of equal power which together will meet the maximum power requirements of the craft. The user may wish to vary the number of engines to result in a power required per engine which is met by engines already on the market. However, when doing this, the user must remember that varying the number of engines will also affect craft weight and all other associated craft characteristics.

COST

There are four principal inputs which specifically apply to the COST subroutine. These are: year of construction start, number of craft in buy, number of operational sorties per year, and a factor to account for other missions. These inputs are used to calculate acquisition cost per craft, direct operating cost for the fleet per year, indirect operating cost for the fleet per year, annual fleet depreciation and total annual fleet cost. Note that cost estimates for commercial procurement are estimated to be significantly less than those for military procurement.

WEIGHT

Table 5 summarizes the basic methods used to find subsystem weights.

Table 5. Basis of Weight Estimation

SWBS		
1	STRUCTURE	THEORETICAL/EMPIRICAL
2	PROPULSION	THEORETICAL/EMPIRICAL
3	ELECTRICAL	EMPIRICAL
4	C^3N	EMPIRICAL
5	AUXILIARY	EMPIRICAL
6	OUTFIT & FURNISHING	EMPIRICAL
7	ARMAMENT	GIVEN
F	LOADS	THEORETICAL/GIVEN

Weights for SWBS groups 1 and 2, which together can represent at least 60% of the ship's empty weight, are calculated theoretically from first principles with some empirical adjustments.

Weights for groups 3 thru 6 are estimated from relatively simple algorithms derived from fitting trend lines, or curves, through empirical data.

Groups 7 and the loads are usually derived as a combination of given and calculated weights.

Tables 6 through 13 show some of the results obtained by running SDSM for one set of requirements.

Table 6 shows the geometry and hydrostatic characteristics of the craft selected by the

SDSM as representing the least cost solution from a wide range of craft lengths and beams.

Table 6. SDSM Geometry and Hydrostatic Output

GEOMETRY AND HYDROSTATIC CHARACTERISTICS

OUTPUT DATA FOR MIN.WEIGHT, MAX.PAYLOAD, MIN.POWER, OR MIN. COST CASE

SES GEOMETRY:-

PRESS/LENGTH	LENGTH/BEAM	CUSH/LENGTH	CUSH.BEAM	BOW RADIUS	STRN RADIUS
-	-	FEET	FEET	FEET	FEET
1.145	4.335	150.000	34.600	NA	NA
	SEAL PERIM.	CUSH.AREA	CUSH.PRESS	PSEAL/PCUSH	SEAL PRES.
	FEET	SQ FT	PSF	-	PSF
	69.200	5190.000	171.801	1.040	178.67250
CUSH DENS.	CUSH.HEIGHT	HMP FROUDE#	HUMP SPEED	TROUGH FR.#	TROUGH SPD
SLUG/CU.FT	FEET	-	FT/SEC	-	FT/SEC
0.002	12.110	0.844	58.656	0.434	30.127
2ND.HMP.FR.#	2ND.HMP SPD	CB DRAFT	HB DRAFT	OAL.	OAB.
-	FT/SEC	FEET	FEET	FEET	FEET
0.400	27.786	2.684	11.743	173.543	46.796
BEVEL ANGLE	BEVEL DEPTH	SH BUOYANCY	SIDEHULL VOL.	TOTAL VOL.	
DEGREES	FEET	%	CU.FEET	CU.FEET	
80.000	10.500	13.114	18468.0	100365.0	

Table 7 shows the dynamic stability characteristics obtained for on-cushion operation. The table shows the index of heave stability, heave and pitch damped natural frequencies, and the index for stable roll when turning and when operating in resonant beam seas.

Table 7. SDSM Dynamic Stability Output

DYNAMIC STABILITY CHARACTERISTICS - ON CUSHION

HEAVE STABILITY INDEX#1	HEAVE STABILITY INDEX#2	HEAVE FREQUENCY CPS#1	HEAVE FREQUENCY CPS#2	TURN STABILITY INDEX -	RESONANT BEAM SEA STABILITY INDEX
0.471	0.523	1.106	1.244	2.230	1.779
HEAD-SEA* HEAVE TUNING FACTOR FOR PIERSON MOSKOWITZ SPECTRA -	ENCOUNTER* SPECTRA AVERAGE MODAL PERIOD SEC	ENCOUNTER* SPECTRA AVERAGE ENCOUNTER FREQUENCY CPS	PITCH NATURAL FREQUENCY CPS	HEAD-SEA* PITCH TUNING FACTOR FOR PIERSON-MOSKOWITZ SPECTRA -	SPEED/ WAVE HT. KT/FT
0.581	1.384	0.723	0.242	2.983	30/4.1

*AT 30 KNOTS

Table 7 also shows the heave and pitch tuning factors so that a judgement can be made as to how close the principal design operating condition is to resonant motion.

Tables 8 and 9 show the parameters of the selected waterjet pumps and lift system, respectively.

Table 8. SDSM Waterjet Design Data Output

WATERJET PARAMETERS

1 VELOCITY	SIG.WAVE HT	PROP THRST	PROP DIAM	TIP SPEED	INLET V RAT
FT/SEC	FEET	LB	FEET	FT/SEC	-
50.634	0.000	44533.190	3.728	126.815	0.654
	# OF PROPS	JET EXIT VEL.	INLET DRAG	HEAD DVLPD	TOT.THRPWR
	-	FT/SEC	LB	FEET	HP
	2.000	111.380	94.257	164.905	7724.263
	INLET AREA	JET FLOW RATE			SUCT. SPECIFIC SPEED
	SQ. FEET	CUF T/SEC	GPM		RPM*SQT(GPM)/FT^.75
	5.612	180.136	80838.760		8425.672
	PUMP SPECIFIC SPEED	PROP COEFF	PUMP SPEED	POS SUC HD	INLT HD CF
	RPM*SQT(GPM)/FT^.75	-	RPM	(NET) FT	-
	7138.131	0.531	649.689	61.359	0.858
	NOZZLE HGT	PUMP EFF	NOZL EFF	JET WEIGHT	SH BEAM RQD
	FEET	-	-	LB	FT
	3.301	0.895	0.995	37470.390	5.02
	NOZZLE DIA	PMP INLT.DIA	SH BEAM AVAIL		
	FEET	FEET	FEET		
	1.435	3.500	5.02		

Table 9. SDSM Lift System Design Data Output

LIFT SYSTEM

NO.OF FANS	RAM HEAD	RAM REC.CFT	EYE LOSS CF	DIST LOS CF	PSI/PHI SL
#	PSF	-	-	-	-
4.000	2.828	0.330	0.014	0.009	- 0.169
PSI/PHI CT	NO.STAGES	DES.PSIT	DESIGN PHI	SPEC.SPEED	DEYE/DFAN
-	#	-	-	-	-
- 0.297	1.000	0.880	0.148	0.424	0.637
TIP SPEED	FAN TYPE	FLOW/FAN	FAN PR RISE	FAN DIAM	DES.EFFY
FT/SEC	-	CFS	PSF	FEET	-
456.740	3.000	1111.551	202.463	4.571	0.844
	WBS248				
TOT.FAN PWR	TOT.FAN WT	LFTSYS EFFY			
HP	LB	-			
1939.453	5092.490	0.716			

FAN TYPE:- CENTRIFUGAL

Table 10 shows details of the mechanical power transmission for propulsion. A similar type of result is produced for the lift-system power transmission.

Table 11 shows an example of the weight estimated for the hull structure while Table 12 shows similar details for the weight of the propulsion system.

Weights for SWBS groups 3 through 7 are also provided in a similar manner.

Table 13 shows the output provided to describe cost. These costs are for design and construction and represent estimates for the cost of the "first of class" for the construction month and year specified (in this case, January 1988). The costs shown assume U.S. shipyard construction and military procurement. They include the cost of documentation and spares but not the cost of RDT&E if required.

Table 10. SDSM Propulsion Transmission Data Output

PROPULSION TRANSMISSION SYSTEM

FAN SPEED RPM 1908.209	PROP/SPEED RPM 1024.623	ENGINE RPM RPM 1325.716	OFST.GB.RPM RPM 1325.716	OFST.GRATIO - 1.294	OFST.GB.PWR HP 5960.673
BEV.GRATIO - 0.000	BEV.GB.RPM RPM 0.000	EBV.GB.PWR HP 0.000	EBV.PIN.RPM RPM 0.000	PBV.GB.PWR HP 0.000	PBV.PIN.RPM RPM 0.000
# FANS/PROP # 0.000	FAN SHFT.PR HP 0.000	OFST.GB.WT LB 3041.958	EBEV.GB.WT LB 0.000	PBEV.GB.WT LB 0.000	
PROP.SHFT.WT LB 0.000	TRAN.SHF.WT LB 0.000	ENG.SHFT.WT LB 145.087	MAIN SHF.WT LB 1275.778	FAN SHFT.WT LB 48.374	WBS244 TOT.BERG.WT LB 528.562
WBS243 SHAFT WT LB 2841.730	W242 COUPLING WT LB 1176.439	WBS241 TOT.GB.WT LB 6083.916	WBS240 TOT.TRAN.WT LB 48101.030	WBS262 GB.LUB.WT LB 1056.536	

OFFSET GEARBOX WITH 1. STAGE

Table 11. SDSM Structure Weights

GROUP 1 WEIGHT DETAILS

W111 25.204	W113 2.184	W114 1.325	W115 1.221		
W116 8.142	W117 16.086	W119 3.814		W110 57.976	
W121 3.789	W122 10.783	W123 0.586		W120 15.158	
W131 22.253	W132 18.822	W133 0.000	W134 0.000		
W136 0.000				W130 41.075	
W141 3.542				W140 3.542	
				W150 8.204	
W161 0.486	W163 0.000	W164 0.000	W167 3.261		
W168 0.153	W169 0.000			W160 3.900	
W171 0.412				W170 0.412	
W181 0.000	W182 2.990	W183 0.375	W184 0.347		
W185 0.264	W186 1.115	W187 0.000		W180 5.091	
W197 0.000	W199 0.000			W190 0.000	
					W100 135.359

Table 12. SDSM Propulsion - System Weights

GROUP 2 WEIGHT DETAILS

W234 42.155				W230	
W241 3.126	W242 0.613	W243 1.432	W244 0.266		
W245 0.000	W246 0.000	W247 16.728	W248 2.273	W240 24.438	
W251 0.558	W252 0.462	W256 4.767	W259 3.310	W250 9.096	
W261 0.902	W262 0.549			W260 1.451	
W298 12.096	W299 0.190			W290 12.285	
					W200 89.426

Table 13. SDSM Cost Output

COST BREAKDOWN ($)

GROUP 100 COST MIL 2.5621	GROUP 200 COST MIL 5.3449	GROUP 300 COST MIL 0.7465	GROUP 400 COST MIL 1.0801
GROUP 500 COST MIL 5.0399	GROUP 600 COST MIL 2.5717	GROUP 700 COST MIL 0.0371	GROUP 800* COST MIL 10.2106
			ACQUISITION RCU 1ST OF CLASS, MIL (FY88) 27.5929
			ACQUISITION COST DOC., SPARES MIL (FY88) 34.4911

*INCLUDES: DESIGN AND INTEGRATION (GROUP 800) PLUS ASSEMBLY & SUPPORT SERVICES (GROUP 900)

DOES NOT INCLUDE COST OF WEAPONS

CONCEPT SELECTION

The selection of a preferred concept is usually made with the objective of meeting the specified requirements at minimum cost.

Often a customer has some idea of what cost can be afforded but no idea of what this will buy in terms of performance. Before committing to preliminary design it is therefore helpful to show the trade-off between cost and performance. This is where a tool, such as the SDSM, is extremely valuable, particularly if the customer also wishes to examine the impact of design options such as waterjets instead of marine screws, steel versus aluminum-alloy hulls and diesel versus gas-turbine propulsion.

To examine the variation of cost with performance it is essential that balanced designs be developed and their cost compared over a range of requirements. For the example presented here a large number of patrol-craft designs were developed by the SDSM for each combination of requirements from which one least-cost solution could be found. The cost of each least-cost solution could then be compared within the range of requirements of interest.

Figure 15 is a typical carpet plot showing first-of-class cost versus cushion length and the ratio of length-to-beam for one combination of requirements (payload = 35 tons, range = 500 nm and speed = 35 knots in sea state 3). One such plot was produced for each combination of requirements.

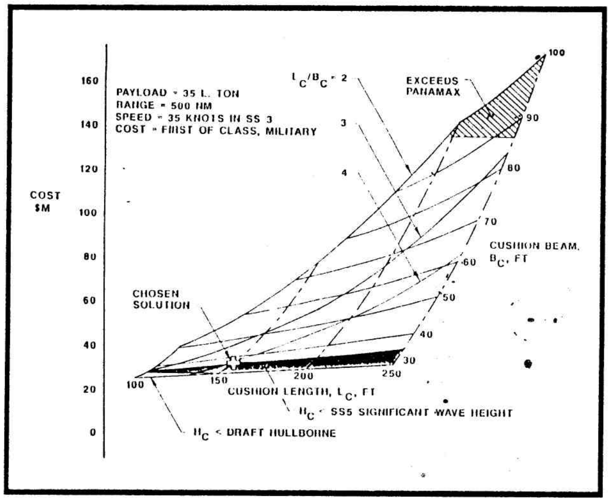


Figure 15. Example Cost Versus Craft Length and Beam

The upper limit of the envelope is the lowest length-to-beam ratio examined at a value of 2.0. The lower limit of the envelope is the highest length-to-beam ratio examined at a value of 6.5.

The left-hand side of the envelope is defined by a minimum cushion length of 100 feet and the righthand side of the envelope is defined by a maximum cushion length of 250 feet.

Within this envelope internal limits for maximum beam (panamax), stability and wet-deck immersion can be defined.

One additional limit was examined. This limit is where a transition from a single diesel engine per propulsor to multiple diesels or a gas turbine were found to be necessary.

This last criterion was not intended to be used as a general criterion, and most of the time it was not a factor in selecting minimum cost solutions.

In some of the extreme value cases, i.e., ranges of 1000 nm or more and a speed of 40 knots, no solutions could be found for single diesel engines.

From plots such as this, the minimum cost point could be selected for each set of requirements.

Figures 16 through 18 present the cost of all of the least cost solutions for payloads of 15, 25 and 35 L. tons, respectively. Each figure shows the sensitivity of cost to variations in forward speed capability (in sea-state 3) and variations in endurance range.

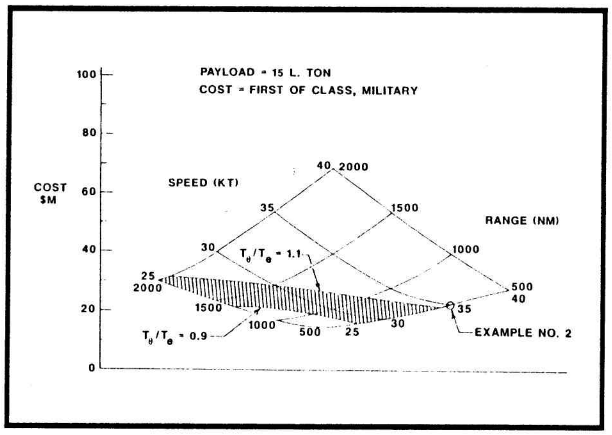


Figure 16. Cost Versus Speed and Range (15 L. Ton Payload)

The example plot of cost versus length and beam, shown in Figure 15, resulted in only one point on Figure 18 corresponding to 35 knots and 500 n miles.

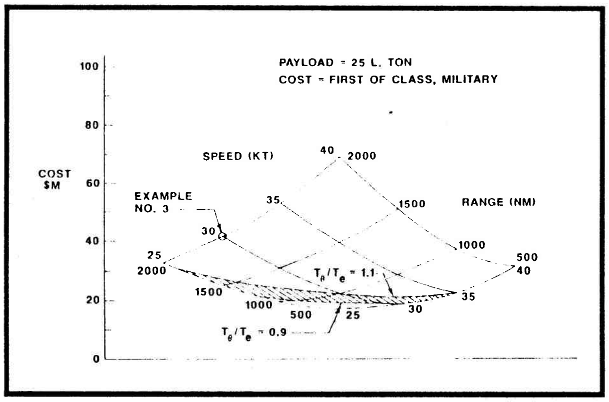


Figure 17. Cost Versus Speed and Range (25 L. Ton Payload)

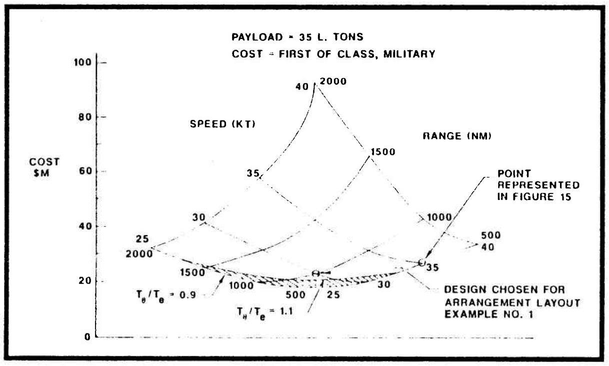


Figure 18. Cost Versus Speed and Range (35 L. Ton Payload)

Note that the increase in cost associated with increasing speed from 35 to 40 knots is quite substantial in Figure 18, particularly if range is also increased. Note also that a 40-knot speed in sea-state 3 would result in a calm-water speed well in excess of 50 knots for all of these designs.

Also shown on Figures 16 through 18 is the applicable range (shaded area) of pitch-motion tuning factors from 0.9 to 1.1. This is used to ensure that, at design conditions, any selected craft will avoid pitch resonance during head-sea operation.

CONCEPTUAL DESIGN ARRANGEMENTS

To develop design-layout drawings for a craft designed by the SDSM it is necessary to first convert the hullform generated by the SDSM into a format which can be read by AutoSHIP and AutoCAD. This is accomplished by passing the SDSM hydrostatic and geometric output data (along with some of the geometric input data) through a post-processing program. This post processor generates hull offsets which are in turn used as input to AutoSHIP. The hull offsets produced by the post processor program can also be used with SHCP, for example, to do detailed hullborne stability analysis. The AutoSHIP program is used to complete the hull lines and to ensure that they are fair. Finally, the resulting hull produced by AutoSHIP is passed to AutoCAD where arrangement drawings can be developed.

PATROL CRAFT EXAMPLES

The requirements for each of the three patrol craft selected for example layout drawings are identified in Figures 16, 17 and 18, respectively. Their outboard profiles are shown in Figure 19. Selections of the deck plans for Example No. 1 (Figure 18) are shown in Figures 20 through 22.

This craft is approximately 174 ft in length, has a beam of 47 ft and displaces 471 L. tons at full load.

Figure 20 is a planview showing the general arrangements of the main deck, featuring the boat ramp aft, and the accommodation located amidships.

Figure 21 is a planview showing the general arrangements of the second deck. This features the location of the crew stateroom, mess deck, lounge and galley, etc.

The basic machinery plant consists of two diesel propulsion engines and two inducer-type waterjet propulsors.

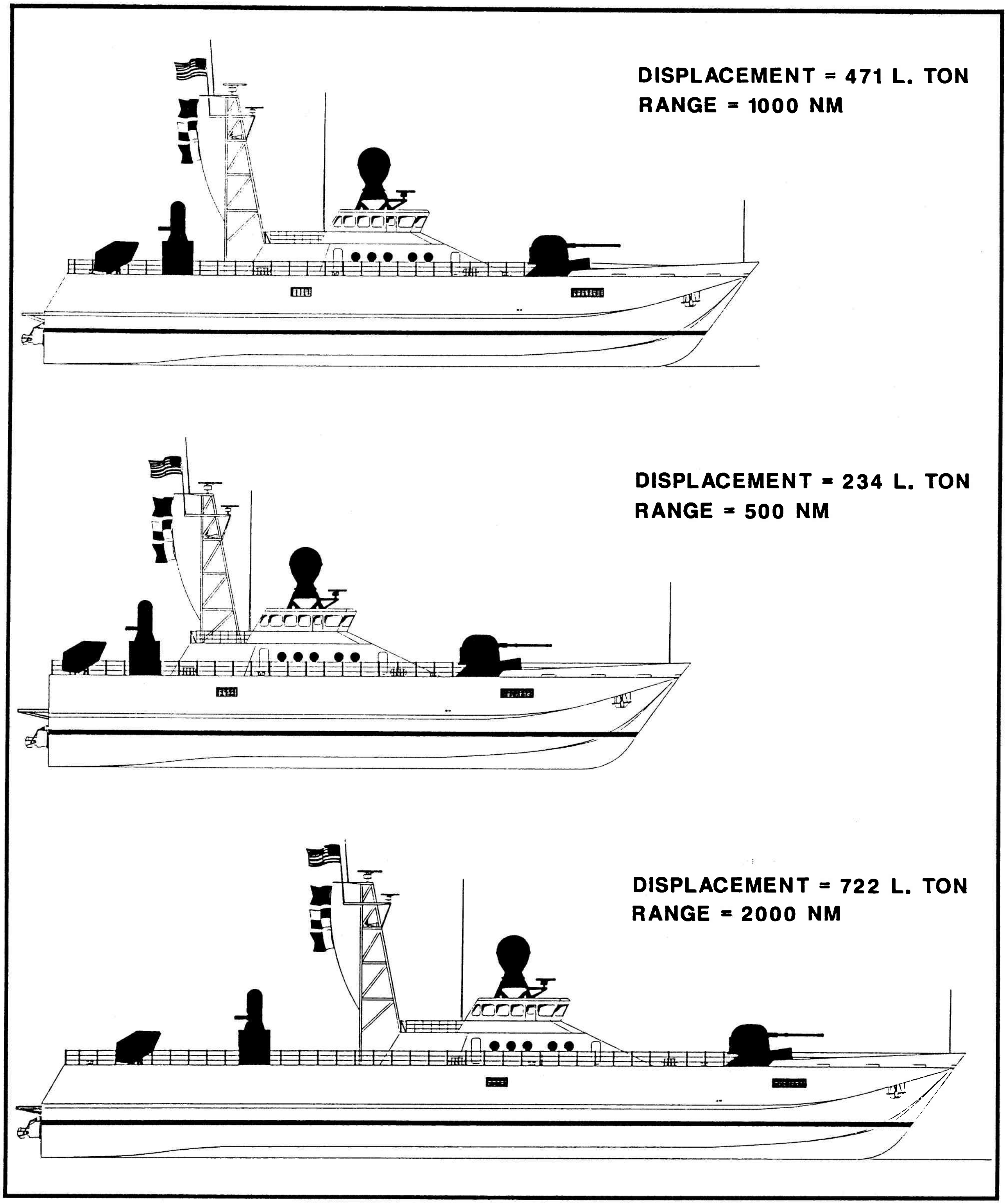


Figure 19. Outboard Profile of Example Patrol Craft

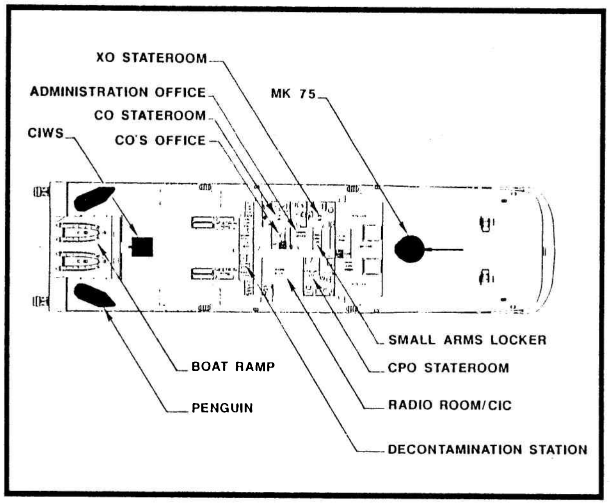


Figure 20. Layout of Main Deck

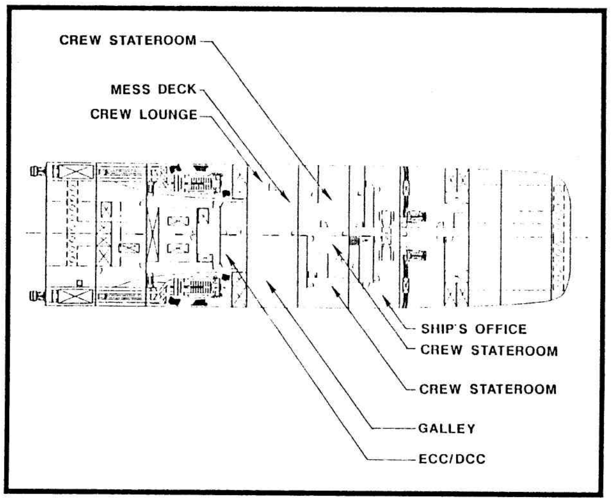


Figure 21. Layout of Second Deck

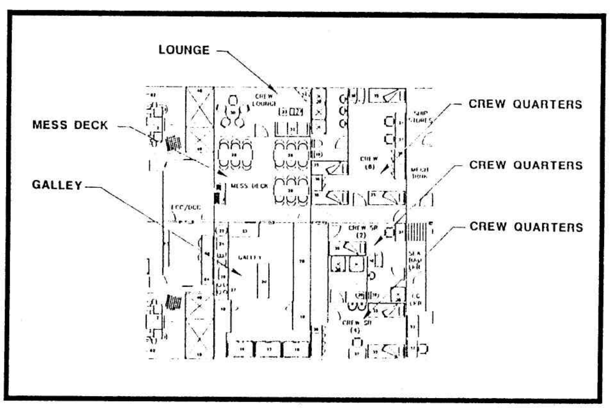


Figure 22. Layout of Crew Quarters

Each main propulsion diesel has been segregated from the other by a longitudinal, watertight bulkhead. The longitudinal subdivision isolates the engines and gearboxes for both fire protection and acoustic damping.

Exhausts exit through the stern. The general arrangement has been configured so that vertical stacks can easily be added if desired.

A service tank is located on the centerline and is sized for 8 to 10 hours at full power.

A central control room has been located forward of the engine space with windows to view each main engine compartment. The control room will also serve as a safe haven in the event of an engine-room fire.

All fuel tanks are in the lower sidehulls.

Lift fans and engines are located forward to reduce the losses associated with long ducting. One fan feeds the bow seal through a plenum that is integral to the inner-bottom structure. The second fan feeds the cushion directly.

An auxiliary cross duct has been added to the inner bottom to cross-connect the two lift fans. Should one fan system fail the other system can be used to feed both the cushion and the bow seal. The forepeak is used to distribute air to the bow seal.

A ride-control system (RCS) has also been incorporated. Forward vents penetrate through the inner bottom. Aft ports come through the sidehull blister forward of each main diesel engine.

In later design phases a study could be made to determine if the forward RCS vents could also serve as low-speed bow thrusters.

The stern seal is fed from the cushion through a boost fan. Once again, the inner bottom is used for the distribution plenum. The bow seal is a conventional bag-and-finger seal and the stern seal is a multi-loop configuration.

Generally, living areas have been located as close to the center of motion as possible while still segregating them from noise and vibration sources. As with all ships, some compromises have been made in both areas.

Enlisted crew are housed on the second deck, isolated from the engine room by the galley and mess deck, Figure 22. Berthing spaces are divided into 2-, 4-, and 8-person compartments to allow maximum flexibility for mixed-gender crews.

Habitability standards exceed U.S. Navy and NATO standards.

The CPOs and officers are housed on the main deck. The CO's stateroom is located adjacent to the pilothouse ladder for easy access.

A decontamination station is located aft, on the centerline of the deckhouse. It has been arranged so that it can be sealed off when not in use without impeding normal traffic flow.

A small-arms locker is located next to the executive officer's stateroom. Hard structure is used for the small-arms locker rather than joiner material for security reasons.

Ample space has been allowed for a combat information center and radio room. Arrangement of this space is dependent on the weapons suite.

Two rigid-hull inflatable boats are stowed on and launched from a stern ramp. The stern ramp is integral with the hull. A detailed stability analysis has not yet been carried out for this arrangement.

Liferaft canisters are located in four separate locations and sized so that any two can be lost and still retain 100% capacity.

The pilothouse has more than ample space for chart tables, radio equipment and ship controls. The pilothouse size is basically a resultant of deckhouse size. There are open bridge wings (with controls) port, starboard and aft. Without stacks there is excellent visibility all around from the pilothouse.

A mast has been added that is integral with both the hull and deckhouse structure.

The weapons system is a notional system shown to represent a deck gun, forward, and a closed-in weapons system (CIWS) and a small missile system, aft.

Ample deck space is available, as well as payload, for a wide variety of system. Large, flat deck areas also provide large arc's of fire.

It has been assumed that the ship also carries machine guns and a standard array of small arms, in addition to the weapons suite.

OFF-DESIGN PERFORMANCE OF PATROL CRAFT

Figure 23 shows predicted vertical acceleration as a function of craft longitudinal station and sea state. The forward speed used for each sea state corresponds to the predicted speed at maximum continuous power.

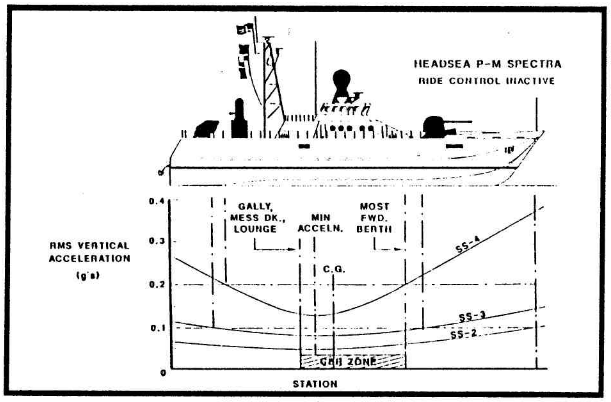


Figure 23. Seakeeping Assessment of Example No. 1

The seakeeping prediction is based on subscale model data without ride control for head-seas only, which is the worst seakeeping situation. From this it can be seen that the pilothouse and habitable quarters have been located close to the station of least motion.

Figure 24 shows propulsion power versus forward speed and sea state. At maximum continuous power the craft is capable of 44 knots in calm water and 22 knots in sea-state 5.

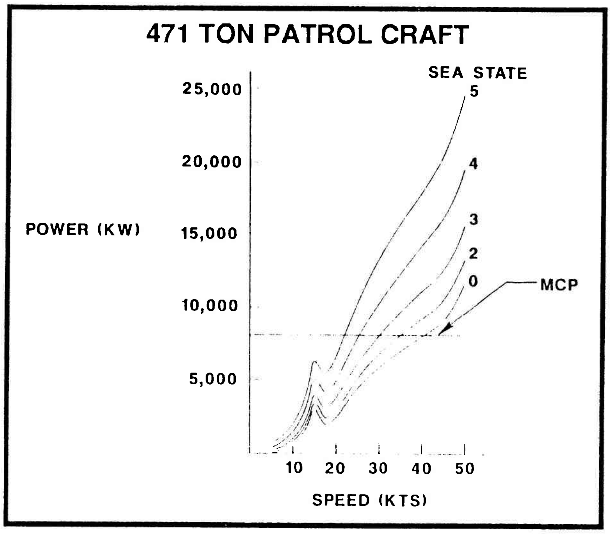


Figure 24. Power Versus Speed and Sea State for Example No. 1

SES CAR-FERRY EXAMPLE

A similar approach was used for the design of a commercial SES car ferry (Reference 2). Figure 25 shows the results of using the SDSM program to explore the cost impact of changing craft speed and length for a craft required to carry a payload of 90 L. tons over a range of 240 n. miles. For this study a calm-water speed of 60 knots was eventually selected as the affordable speed and the concept design shown in Figures 26 and 27 was developed.

This design features a RO/RO automobile deck with a vehicle ramp fore and aft. The underside of the bow ramp supports the entire bow seal. It is assumed that the ship will dock at dedicated terminals designed to mate with either the bow or the stern ramp. The automobiles can be loaded and off-loaded in either direction. The passenger accommodation is shown here on two decks although a more economical, single-deck arrangement could also be designed. The characteristics listed in Table 14 are identified by the SDSM program.

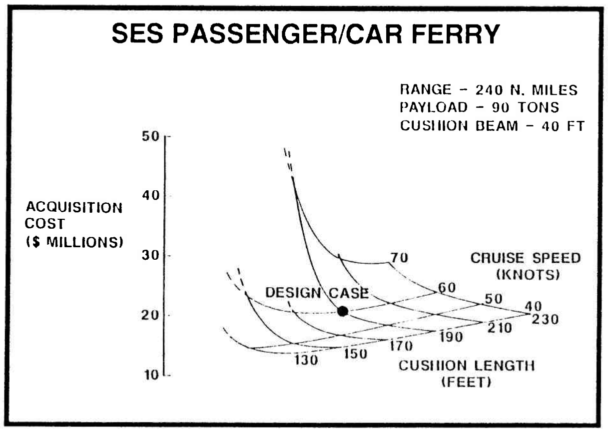


Figure 25. Cost Versus Speed and Cushion Length

The required propulsion power is about 8000 hp per side. This requirement could be conveniently met by using two Avco Lycoming TF40 gas turbines (which have a maximum continuous rating of 4000 shp). These two TF40s would have to be geared together to drive one waterjet on each side hull.

The total lift power required is 3600 hp. The lift system consists of two units. One unit is located forward on the port side and one is located aft on the starboard side. Each unit consists of one gas turbine driving two double-width, double-inlet (DWDI) centrifugal fans. In the case of the forward unit, one fan feeds the bow seal and one feeds the cushion; in the case of the aft unit, one fan feeds the stern seal and one feeds the cushion. The lift gas turbines could also be Avco Lycoming engines such as the TF-25 with a maximum continuous rating of 2500 shp.

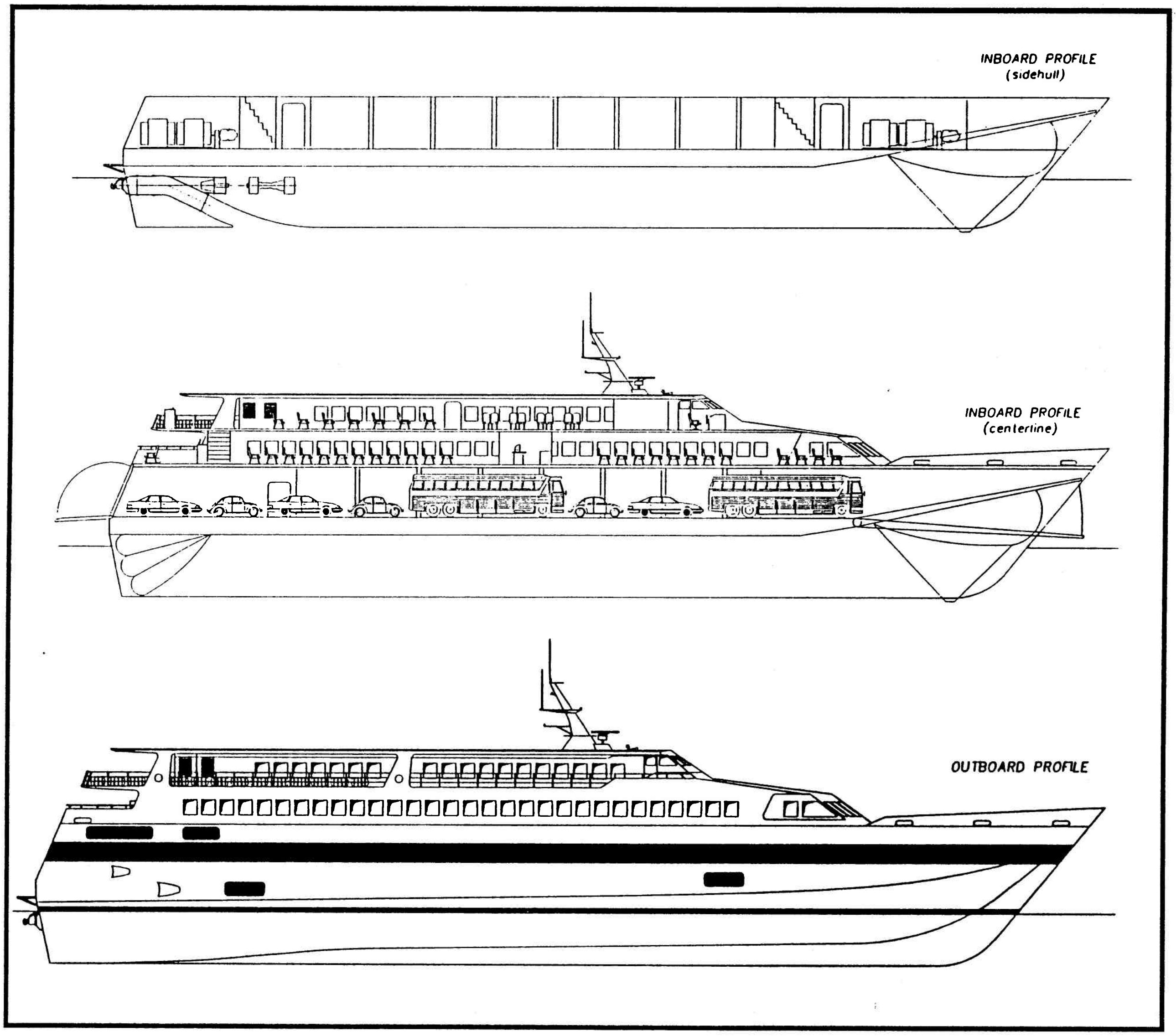


Figure 26. Profile of Conceptual SES Car Ferry (Range 240 NM, Payload 90 T, Design Speed 60 Knots)

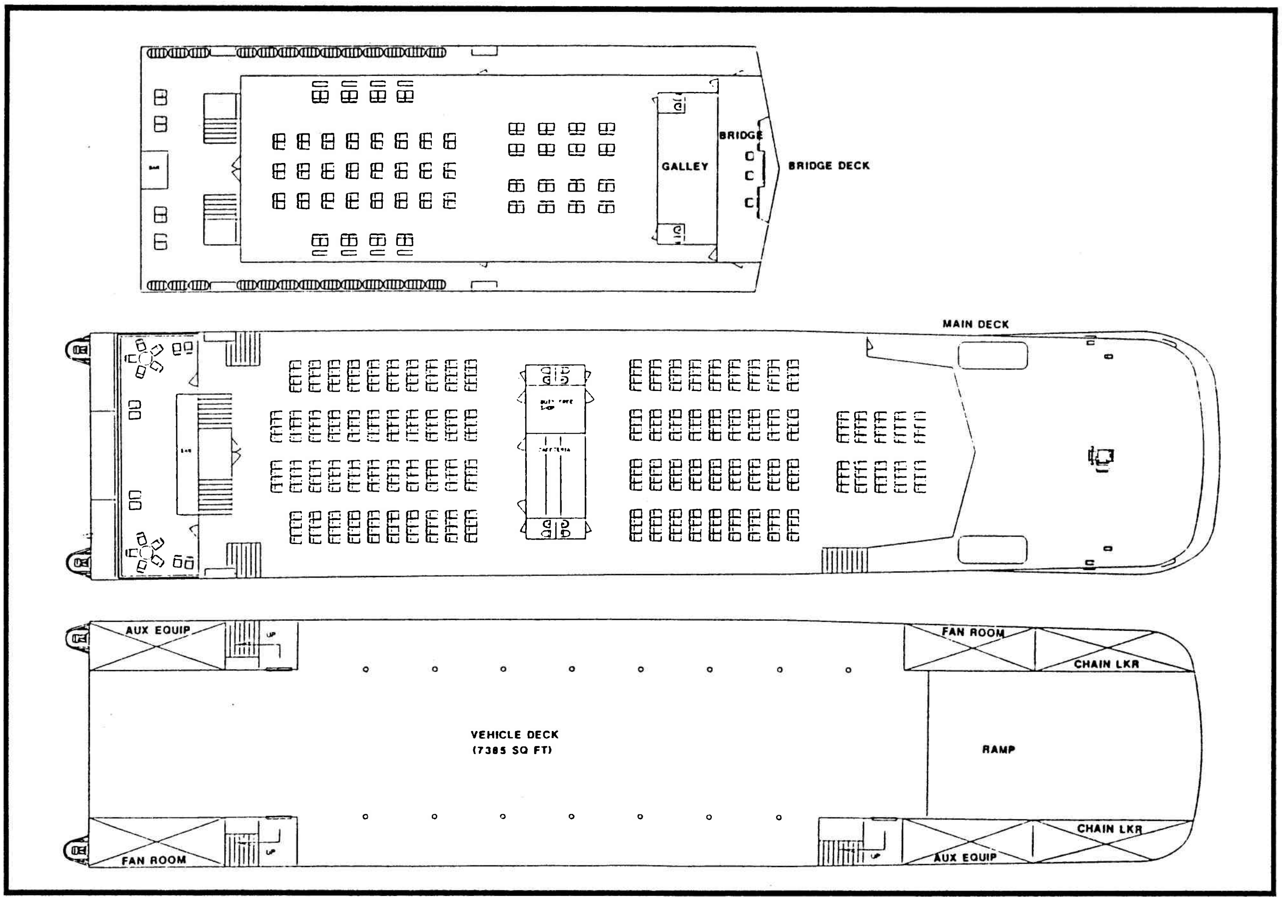


Figure 27. Deck Plans of Conceptual SES/Passenger Car Ferry (Range 240 NM, Payload 90 T, Design Speed 60 Knots)

Table 14. Leading Particulars of Passenger/Car Ferry

GROSS WEIGHT, Δ	436 L. TONS
CUSHION LENGTH, L_C	190 FT
CUSHION BEAM, B_C	40 FT
CUSHION PRESSURE, P_C	114 PSF
WET-DECK HEIGHT, H_C	14 FT
L_C/B_C	4.75
P_C/L_C	0.6
OVERALL LENGTH	219 FT
WATERLINE LENGTH - CUSHIONBORNE	198.6 FT
WATERLINE LENGTH - HULLBORNE	204.9 FT
OVERALL BEAM	50.4 FT
WATERLINE BEAM - CUSHIONBORNE	48.2 FT
WATERLINE BEAM - HULLBORNE	50.2 FT
DRAFT - CUSHIONBORNE	1.8 FT
DRAFT - HULLBORNE	7.6 FT

SUMMARY AND CONCLUSIONS

The paper describes a capability that has been in continuous development for over 9 years, to conduct computer-aided, early-stage design of ACVs, SES, and high-speed catamarans and monohulls. Examples are given for its application to SES design that show how the trade-off between cost and craft performance may be examined prior to a further stage of design.

Work is currently underway that uses this capability to provide a comparison between ACVs, SES, catamarans and monohulls for various missions. Reference 2 provides such a comparison for SES and ACVs as commercial ferries.

In this way, any inconsistencies between design assumptions, practices, standards, margins or procedures, that invariably occur with such comparisons, may be avoided by using a similar methodology.

Future near-term development of the SDSM is expected to include the results of recent work sponsored by NAVSEA 05R to improve SES resistance and seakeeping predictions. New resistance and seakeeping prediction tools have been developed using multiple-linear regression of a very extensive data base of SES model test results, that provide for greater flexibility in exploring the effects of sidehull geometry and operating conditions and which can easily be incorporated into a design synthesis model.

ACKNOWLEDGEMENTS

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2. "Computer-Aided Design of Air Cushion Vehicles and Surface Effect Ships," by E. G. U. Band and D. R. Lavis, to be presented at the Advanced Marine Vehicle Conference, Shanghai, Peoples Republic of China, November 1-4, 1988.