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USERS MANUAL FOR THE SHOP5 SYSTEM:
A Concept Exploration Model for
Monohull Frigates and Destroyers

J. L. Colwell

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A Concept Exploration Model for
Monohull Frigates and Destroyers**

James L. Colwell

November 1988

Approved by W. C. E. Nethercote

H / Hydronautics Section

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ABSTRACT

- 7 The SHOP5 System is a computer-aided ship design tool for monohull frigate and destroyer Concept Exploration. Its primary application is initializing the new-ship design process by determining the ship size, hull form and major systems best suited for the design requirements. Other uses include evaluating new technologies and performing specific parametric studies. The SHOP5 System incorporates three FORTRAN programs in a closed-loop system: program FIVPRE for defining and modifying ship descriptions and design requirements; program SHOP5 for computing ship characteristics; and program FIVPOS for examining design candidates using computer graphics. Design calculations include seakeeping in head seas, resistance, powering and range in calm water and in waves, propulsion and electrical system modeling, distribution of weight and volume components, preliminary intact and damaged stability analysis, and platform acquisition cost. Platform feasibility is assessed by user-definable design criteria which define goals for performance and capability. The SHOP5 ship description and design methodology are sufficiently flexible to define and analyse a wide variety of ship geometries, systems and missions.

RÉSUMÉ

Le système SHOP5 est un outil de conception assistée par ordinateur permettant de concevoir des modèles de frégates et destroyers monocoques. Son utilité principale consiste à amorcer le processus de conception en déterminant la taille du bateau, la forme de la coque et les principaux systèmes qui conviennent le mieux en fonction des exigences. Le système sert aussi à évaluer les nouvelles technologies et à réaliser l'analyse de certains paramètres particuliers. Le système SHOP5 est constitué de trois programmes FORTRAN qui font partie d'une boucle: le programme FIVPRE sert à définir et à modifier les descriptions et les exigences de calcul; le programme SHOP5 sert à déterminer les caractéristiques d'un navire; et le programme FIVPOS sert à évaluer les candidats en conception au moyen de l'infographie. Les calculs de conception tiennent compte de facteurs comme la tenue en mer houleuse, la résistance, le démarrage et le rangement en eaux calmes et dans les vagues, la modélisation de la propulsion et du système électrique, la distribution du poids et du volume des composants, l'analyse préliminaire de la stabilité en état intact ou endommagé et le coût d'acquisition de la plate-forme. La faisabilité de la plate-forme est analysée à partir de critères de calcul que l'utilisateur peut choisir et qui définissent les buts en termes de performance et de capacité. La méthodologie de description et de calcul de SHOP5 est suffisamment souple pour définir et analyser une vaste gamme de géométries de bateaux, de systèmes et de missions.

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NOTATION

Names in typewriter font and in square brackets, [...], define lineprinter notation.

AccHi	RMS vertical acceleration for zero percent crew effectiveness
AccLo	RMS vertical acceleration for one-hundred percent crew effectiveness
AccMax	seakeeping criterion, maximum vertical acceleration at station 4, $\ddot{z}_{maz}$
AK	cost factor
AP	after perpendicular $\equiv$ station 20
A_M	midship sectional area
avPgen	average ship service electrical power generated
A_W	waterplane area
B	maximum beam [B]
C	compartment standard of flooding (for damaged stability)
Ca	model-ship correlation allowance (resistance)
C_{App}	coefficient of appendage resistance, $C_{App} = R_{App}/\frac{1}{2}\rho S V^2$ [Capp]
C_B	block coefficient, $C_B = \nabla/L B T$ [Cb]
C_M	midship section coefficient, $C_M = A_M/B T = C_B/C_P$
CODAD	engine configuration; combined diesel and diesel
CODAG	engine configuration; combined diesel and gas turbine
CODOG	engine configuration; combined diesel or gas turbine
COGAG	engine configuration; combined gas turbine and gas turbine
COGOG	engine configuration; combined gas turbine or gas turbine
C_P	prismatic coefficient, $C_P = \nabla/A_M L$ [Cp]
CPP	controllable pitch propeller
CrM	Froude length/displacement ratio, $\mathbb{M} = L/\nabla^{\frac{1}{3}}$
C_W	waterplane coefficient, $C_W = A_W/L B$ [Cw]
DIAM	propeller diameter
D	midship hull depth [D]
DENS	hull material density, ρ_{hull}
DISP	full load displacement, Δ
Dstruc	structural hull depth (keel to strength deck)
dP_E	design margin on effective power, $P_E = P_E(1 + dP_E)$ [dPe]
dWi	margin for weight component 1

dWb	margin on W_{basic} , used for future growth margin
dVi	margin for volume component i
dVhull	special parameter for reducing SHOP5 estimate of hull volume
e	transport effectiveness $e = W_{combat}/\Delta \Pi$
e_{crew}	crew seakeeping effectiveness
$e_{crew(min)}$	seakeeping criterion, minimum e_{crew} [EffMin]
EffMin	seakeeping criterion, minimum e_{crew}
Ffp	freeboard at forward perpendicular
Fmod	factor on midship sectional modulus
F_{RB}	minimum midship freeboard for reserve buoyancy
F_{slam}	most probable maximum slam force
$F_{slam(max)}$	seakeeping criterion, maximum F_{slam} [SlmMax]
g	gravitational acceleration, 9.807 m/sec ² (32.174 ft/sec ²)
$\overline{GM}$	metacentric height (solid) [GM]
g.t.	gas turbine
H_w	significant waveheight, seakeeping [Hw]
$H_w(r)$	significant waveheight, powering and range
IGEN	MCI for ship service electrical generators
IAPPND	MCI for appendage resistance calculations
ICOST	MCI for cost factors
IENGIN	MCI for propulsion system configuration
IPROP	MCI for type of propeller
IRESID	MCI for residuary resistance databases
ISTRUC	MCI for structural materials
IVOLUM	MCI for sizing superstructure
ITTC	International Towing Tank Conference
$\overline{KG}$	vertical centre of gravity
KGb	$\overline{KG}$ for dWb
KGc	$\overline{KG}$ for Wcombat
$\overline{KG}_{max}$	design criterion, maximum intact $\overline{KG}$ [KGmax]
L	ship length between perpendiculars [L]
LCB	longitudinal centre of buoyancy

LCF	longitudinal centre of flotation
Lbulk	average bulkhead spacing
Ldamage	damaged length (percent of L open to flooding)
Lsuper	superstructure length (on upper deck)
$\mathbb{M}$	Froude length/displacement ratio, $\mathbb{M} = L/\nabla^{\frac{1}{3}}$ [CrM]
MCI	method control integer (see Table 2)
N	complement (number of accommodations) [N]
NPL	National Physical Laboratory (UK)
NRC FSS	National Research Council Fast Surface Ship (model series)
Nbulk	number of watertight bulkheads
Ndeck	number of internal decks
Ngen	number of ship service electrical generator sets
Nshaft	number of propeller shafts
N_{wet}	number of deck wetnesses per hour
$N_{wet(max)}$	seakeeping criterion, maximum N_{wet} [WetMax]
OPC	overall propulsive coefficient, $OPC = \eta_m \eta_h \eta_o$
P_E	effective power, $P_E = R_T V (1 + dP_E)$
P_{gen}	total installed ship service electrical generation power
P_i	installed power for an individual engine
P_I	total installed propulsion system power [Pins]
RMS	root mean square
R_{App}	appendage resistance
R_T	total resistance
R_{V_e}	design criterion, minimum range at V_E [R(Ve)]
S	wetted surface area
SFC	specific fuel consumption
SFCo	SFC at full power for an individual engine
SFCg	SFC of generators
SFCr	SFC for rubber engines
S1mMax	seakeeping criterion, maximum F_{slam}
SP	specific power $\Pi = R_T / \Delta OPC$
spW2	specific weight of entire propulsion system, $spW2 = W2/Pins$

spW2b	specific weight of propulsion system not including engines, $spW2b = (W2 - (W2a)N_{shaft})/P_{ins}$
spW3	specific weight of electrical systems, $spW3 = W3/P_{gen}$
SSPA	Swedish State Shipbuilding Experimental Tank
SSdens	superstructure material density, ρ_{super}
SSthck	average thickness of superstructure material, t_{1c} in Reference [1]
T	midship draft [T]
Tc	mission definition, relative time at V_C
Td	mission definition, relative time at V_D
Te	mission definition, relative time at V_E
To	wave modal period, seakeeping [To]
To(R)	wave modal period, powering and range [To(r)]
V	arbitrary ship speed
V_C	cruise speed (design requirement) [Vc]
V_{combat}	combat system volume [Vcombat]
V_{c(min)}	design criterion, minimum combat system volume [Vcombat]
V_D	design speed (design requirement) [Vd]
V_E	endurance speed (design requirement) [Ve]
V_f	fuel volume (tankage)
V_{hull}	volume enclosed by hull, $V_{hull} = V_{total} - V_{super}$
V_m	machinery volume
V_{MAX}	maximum calm water speed using installed power [Vmax]
V_{MAX(W)}	maximum speed in waves ($H_{W(R)}$) using installed power, not subject to seakeeping criteria [Vmax(w)]
V_n	personnel volume [Vn]
V_o	systems and outfit volume [Vo]
V_{super}	superstructure volume [Vsuper]
V_{s(max)}	maximum V_{super} [VsMax]
V_{s(min)}	minimum V_{super} [VsMin]
V_{total}	total enclosed volume [Vt]
V_W	seakeeping speed [Vw]
W_{basic}	basic ship weight, $W_{basic} = W_1 + W_2 + W_3 + W_5 + W_6$
W_{combat}	combat systems weight [Wc]

W_d	disposable loads weight [Wd]
WetMax	seakeeping criterion, maximum N_{wet}
W_f	fuel weight $W_f = \Delta - (W_{basic} + W_{combat} + W_d)$ [Wf]
W_1	structure weight [W1]
W_2	propulsion system weight, $W_2 = W_{2a} + W_{2b}$ [W2]
W_{2a}	weight of propulsion engines, includes acoustic isolation module [W2a]
W_{2b}	weight of gearing, shafting, intakes and exhaust, etc. [W2b]
W_3	ship service electrical system weight [W3]
W_5	auxiliary systems weight [W5]
W_6	outfit and furnishings weight [W6]
YIELD	hull material yield strength, σ_{yield}
$\ddot{z}_{max}$	maximum RMS vertical acceleration at station 4 [AccMax]
\$	platform acquisition cost
Δ	full load displacement [DISP]
η_h	qualified hull efficiency, $\eta_h = \eta_r(1 - t)/(1 - w)$
η_m	machinery efficiency
η_r	relative rotative efficiency
η_o	propeller open water efficiency
∇	displaced volume, $\nabla = \Delta/\rho$
Π	specific power $\Pi = R_T/\Delta OPC$ [SP]
σ_{yield}	hull material yield strength [YIELD]
ρ	water density
$\rho_{hul.}$	hull material density [DENS]
ρ_{super}	superstructure material density [SSdens]

1 Introduction

The SHOP5 System is a computer-aided ship design tool for monohull frigate and destroyer Concept Exploration. Its primary application is initializing the new-ship design process by determining the size, hull form and major systems of the ship or ships best suited for a particular mission. Other applications include evaluating the effects of new technologies and design requirements on ship characteristics, and performing parametric or comparative studies of a more specific nature.

The SHOP5 System consists of three FORTRAN programs which are arranged to allow rapid definition and analysis of many possible design candidates. Program FIVPRE is an interactive pre-processor for defining and modifying input, program SHOP5 is a stand-alone (batch) program for analysing the ship or ships defined by FIVPRE, and program FIVPOS is an interactive graphics post-processor for comparing design candidates generated by SHOP5.

SHOP5 calculates a variety of ship characteristics, including: deck wetness, vertical accelerations and slam force in head seas; resistance, powering and range in calm water and waves; propulsion and ship service electrical generation systems modeling and performance; ship weight and volume components; intact and damaged stability; and platform acquisition cost. The platform acquisition cost does not include any combat system or life-cycle costs, and is not sufficiently detailed for budgetary purposes; however, it is a useful, comparative parameter for performing design trade-offs. Platform feasibility is assessed by comparing ship characteristics with a variety of user-definable design requirements and criteria, including: combat system weight and volume; operational speeds and range; acceptable limits for seakeeping response parameters; and other criteria for structural integrity and static stability.

The SHOP5 ship description and design methodology are sufficiently flexible to define and analyse a wide variety of ship geometries, systems and missions. Most input parameters have pre-programmed, default values representative of contemporary NATO practice, and a variety of internal methods are available for many design calculations. All default values and most calculations can be modified or replaced by user-supplied input. Thus, the SHOP5 user should be familiar with the options for program input and have sufficient knowledge of the SHOP5 methodology to determine when default values and methods should be replaced by user-supplied input.

This Technical Communication describes the SHOP5 System operation, input and output. A brief summary of the traditional and contemporary design processes highlights some key problems which are overcome by the SHOP5 System, without sacrificing the desirable aspects of traditional design. The SHOP5 System structure and modes of operation are discussed and all input parameters are described. An overview of the SHOP5 design methodology summarizes important topics, including: the methods used to obtain a "balanced" ship; the dependence of SHOP5 calculations on contemporary practice; the comparative nature of the SHOP5 platform acquisition cost; and, the definition and usage of design margins. The SHOP5 System output structure is described, with emphasis on features for reducing the amount of program output which must be examined. Finally, the primary application for the SHOP5 System is illustrated by an example of design optimization, followed by a

brief discussion of other applications. The SHOP5 System technology base is documented in Reference 1.

2 Concept Exploration: Traditional vs Contemporary

The traditional design process can be illustrated as a spiral, as shown in Figure 1 [2]¹. The process begins by selecting a "basis ship", which is an existing ship whose capabilities closely match those required for the new design. The design progresses through three conceptual phases: Exploration, Development and Validation. Each phase considers the same general aspects of design, illustrated by the radial components in Figure 1, but the transition between design phases represents an increase in the level of detail and accuracy of both the ship description and design analysis. The primary goal of Concept Exploration is to initialize Concept Development by determining the ship size, hull form and major systems required to satisfy the design requirements. The end-product of this preliminary design process is the contract design, which defines the ship in sufficient detail to accurately estimate acquisition and operating costs, and to develop construction plans.

In the traditional context, the Concept Exploration phase is used to obtain the best variant of the basis ship for the current design requirements. This approach has a number of significant advantages: it has produced a long history of successful designs; it permits very rapid transition to the Concept Development phase; and it generally produces new designs whose performance is at least as good as the basis ship. On the other hand, there are significant problems associated with this process: it is often difficult to select an appropriate basis ship, especially when new systems or requirements are considered; there is no assurance of an "optimum" or "cost-effective" result, as the selection of a basis ship narrows the field of design possibilities at the very start of the design process; and, it constrains innovation.

The Concept Exploration Model (CEM), first reported in Reference 2, offers a solution to the problems associated with the traditional design process, while retaining its advantages. A CEM is a computer-based design tool which assists the naval architect in the earliest phase of ship design. A CEM separates the general design process into two functional stages; design synthesis and design analysis. Design synthesis is performed by the naval architect in defining ship geometry and systems for input to the CEM, and design analysis is performed by the CEM.

When using a CEM, the contemporary design process is essentially the same as the traditional process, with one major difference; the requirement to select a basis ship to initiate the process is eliminated. This does not mean that the capability to use a basis ship has been removed, rather, it is not required. The methods used by a CEM are sufficiently general to consider a wide range of design options, with reasonable confidence in the results. Since a basis ship is not required, the designer can consider a much larger field of possible design candidates, and since a CEM is a flexible design tool, the designer can employ a wide variety of contemporary, new, and anticipated future technologies. Also, a CEM can easily model existing ships, for direct comparison of new design candidates with established performance.

¹numerals enclosed in square brackets denote references

The basis ship still plays an important role in contemporary design. The characteristics of existing ships provide valuable guidance for defining initial CEM input, and many of the details required for the Concept Development ship description must be based on existing ships. A CEM allows the designer to select the best basis ship for Concept Development or to create a "hybrid" basis ship by combining systems from existing ships. Alternately, a CEM allows the designer to compare and/or combine contemporary and new technologies.

Another important difference in Concept Exploration between the traditional and contemporary design processes is the relative importance of seakeeping analysis. In the traditional process, seakeeping is the last step of design analysis, while in a CEM, seakeeping analysis is the first step after defining ship geometry. Of course, reliable seakeeping analysis methods have only been available for a relatively short time, but when first introduced, they were not given high priority. Thus, although the capability for meaningful seakeeping analysis has existed, it has not been an integral part of the design process. The shift in emphasis of seakeeping analysis is due to the realization that ships optimized for calm water performance often do not perform adequately in the typical, open-ocean environment.

The final difference between traditional and contemporary design considered here is the recent introduction of new platform types, including: SWATH ships; hydrofoils; Surface Effect Ships (SES); and, Air Cushion Vehicles (ACV). The Concept Exploration phase now has two major functions: first, to determine the platform type best suited to the design requirements; and then, to determine the ship size, hull form and major systems for input to the Concept Development phase. The traditional design process, with its dependence on a basis ship, cannot easily cope with different platform types. Indeed, using the traditional design process for new platform types forces the designer to enter the Concept Development level of design detail before a reasonable number of alternatives can be explored. For contemporary design, the CEM must be either sufficiently flexible to model all relevant platform types, or there must be more than one kind of CEM. At DREA, the latter approach has been used, resulting in a family of CEM's for different platform types, including; SWATH [3], hydrofoil [4], and SES/ACV [5].

3 Overview of the SHOP5 System

The name SHOP5 stands for "SHip Optimization, version 5"; however, it is important to appreciate that SHOP5 has no in-built optimization procedures. The design logic used in SHOP5 is relatively simple; given ship size, hull form, major systems and design requirements, SHOP5 calculates performance and capability. Optimization is an iterative and comparative process controlled by the user, as described in following sections.

3.1 Integrated SHOP5 System

The SHOP5 System is arranged to permit the rapid definition, analysis and inspection of many possible design candidates. A schematic view of the three SHOP5 System components is shown in Figure 2, where:

- FIVPRE is an interactive pre-processor for defining and modifying ship descriptions and design requirements for input to SHOP5;

- SHOP5 is a stand-alone (batch) program for analysing the ships defined by FIVPRE; and
- FIVPOS is an interactive graphics post-processor for inspecting ships output from SHOP5.

These three components are integrated into a closed-loop, user-friendly system which allows the designer to define ship descriptions, analyse their characteristics, inspect feasible design candidates, and then create new ship descriptions based on previous results.

3.2 Modes of Operation

SHOP5 has two modes of operation; SEARCH and DESCRIBE. The SEARCH mode allows the designer to define up to 800 ships for a single execution of SHOP5. As SHOP5 proceeds through its design calculations (analogous to traveling around the design spiral), the characteristics of each ship are compared with the design requirements and other criteria, and ships which do not satisfy these constraints are rejected. The characteristics of feasible ships are transferred to FIVPOS, where the designer uses computer graphics to inspect and compare the design candidates.

The DESCRIBE mode is different from the SEARCH mode in three respects: it only considers up to 11 individual ships; it does not reject ships; and it performs more detailed calculations for some design steps. The DESCRIBE mode is used to obtain more detailed output for individual ships and to model existing ships for comparison with design candidates generated by SHOP5. Also, it may be used to examine ships rejected in the SEARCH mode.

The term "closed-loop system" refers to the data flow from program FIVPOS to program FIVPRE. When using FIVPOS to examine design candidates generated by SHOP5 in the SEARCH mode, the user can select up to eleven ships for transfer to FIVPRE, where they are automatically inserted in a new DESCRIBE mode file. The user can immediately run SHOP5 using this file or, more often, use this file as a basis for a new SEARCH mode file.

4 SHOP5 Input

SHOP5 input consists of the ship description, design requirements, design criteria, and controls for design methodology. The ship description defines ship size, hull form, topside geometry, and major systems. The design requirements define the combat system and operational speeds, and for the SEARCH mode, the design criteria define goals for performance and capability. The controls for design methodology allow the designer to select options for the method used for particular design calculations, and to configure major ship systems.

With the SHOP5 System, program FIVPRE [6] is used to define all input. FIVPRE can be used in either a menu- or command-driven mode, and provides a comprehensive on-line help facility. The example on design optimization presented in Section 7 describes many of the features available in FIVPRE.

Table 1: Typical SEARCH Mode Variation of Required Input

Parameter	Low Value	High Value	Number of Values	(increment)
Δ (tonne)	3000.00	4000.00	6	200.00
$\mathbb{M}$	7.50	8.50	3	0.50
C_P	0.58	0.62	3	0.02
C_B	0.48	0.52	3	0.02
B/T	2.80	3.10	4	0.10

The remainder of this section describes the parameters used in the ship description, design requirements, design criteria, and controls for design methodology. A detailed summary of the SHOP5 input record structure is presented in Appendix A.

4.1 Ship Description

For input purposes, the ship description is divided into three categories; required input, optional input and method control integers. The required input consists of the following five parameters, which define ship size and underwater hull form.

1. Characteristic dimension, which can be either

- full load displacement, Δ (tonne:ton)
- length, L (m:ft)
- beam, B (m:ft), or
- draft, T (m:ft)

2. Froude length/displacement ratio, $\mathbb{M} = L/\nabla^{1/3}$

3. Prismatic coefficient, $C_P = \nabla/L A_M$

4. Block coefficient, $C_B = \nabla/L B T$, and

5. Beam/draft ratio, B/T .

In the DESCRIBE mode, each ship has explicit values for these parameters, and in the SEARCH mode, each parameter is defined as a range (i.e. low value, high value and number of values). For example, Table 1 defines 648 possible design candidates for the SEARCH mode.

4.1.1 Optional Input

The optional input parameters provide single-value definitions for a variety of geometric, system and design parameters, including design margins. Each optional input parameter has

a pre-programmed, default value or method which is representative of contemporary NATO practice. The designer can define replacement values for any or all of these parameters; otherwise, the defaults are used. Appendix B describes these optional input parameters, including their default values and options for user-supplied input. Details on the algorithms for calculating the optional input default values are provided in Reference 1.

Program FIVPRE allows the user to access each optional input parameter individually (command mode), or via a multi-level menu system.

4.1.2 Method Control Integers, MCI

The method control integers (MCI) control options for the SHOP5 design methodology and configure major systems or arrangement parameters, as shown in Table 2. The MCI's are similar to the optional input parameters, except they define items which have a substantial impact on the design methodology. Also, most MCI's accept variable amounts of user-supplied input to replace their default methods. In Table 2, the SHOP5 default methods are shown for values of 0 (zero), which are used unless explicitly redefined by user-supplied input. Program FIVPRE allows the user to change the MCI values individually or via a menu system. Five MCI's are directly associated with the ship description; ISTRUC, IPROP, IENGIN, IGEN, and IVOLUM. The applicability of the other MCI's for residuary resistance, appendage resistance and cost factors must be evaluated in terms of the ship description. Reference 1 describes the resistance and cost algorithms and defines their requirements for user-defined input.

4.2 Design Requirements

The design requirements are required input which define the following parameters:

- combat system weight, W_{combat}
- design speed, V_D
- cruise speed, V_C
- endurance speed, V_E
- seakeeping speed, V_W
- seakeeping significant wave height, H_W

The combat system weight includes all weapons, sensors, electronics, ammunition and aviation items, including aviation fuel. For new-ship design, the combat system is usually specified as part of the design requirements. When this information is not known, then a suitable value for W_{combat} can be determined by examining existing ships. Alternately, a number of W_{combat} values can be considered, by defining multiple sets of design requirements (different only in W_{combat}) and sequentially generating design candidates for each set of requirements. The combat system volume is considered as a design criterion, as explained in later sections.

Table 2: Method Control Integers, MCI.

NAME	VALUE	DESCRIPTION
IDIMEN Characteristic Dimension	0	full load displacement, Δ (tonne:ton)
	1	length between perpendiculars, L (m:ft)
	2	maximum beam, B (m:ft)
	3	midship draft, T (m:ft)
IRESID Residuary Resistance	0	NRC FSS
	1	Taylor, Hamburg C, or NPL/SSPA
IAPPND Appendage Resistance	0	SHOP5 method (assumed appendages)
	1	user-defined resistance coefficient
IPROP Propulsive Efficiency	0	SHOP5 method, controllable pitch
	1	SHOP5 method, fixed pitch
	2	user-defined OPC values
ISTRUC Structural Material	0	homogeneous
	1	hybrid
IENGIN Propulsion System	0	SHOP5 rubber engines
	1	user-defined rubber engines
	2	SHOP5 real engines
	3	user-defined real engines
IGEN Electrical Generation	0	SHOP5 diesel generators
	1	SHOP5 gas turbine generators
	2	user-defined generators
	3	integrated (propulsion system)
IVOLUM Superstructure Volume	0	$V_{combat} = f(V_{super})$
	1	$V_{super} = f(V_{combat})$
	2	$V_{super} = f(\overline{GM}/B)$
ICOST Cost Factors	0	SHOP5 method
	1	user-defined cost coefficients

The first three ship speeds, V_D , V_C and V_E , are used to calculate resistance, powering and range. Also, the required powers at V_D and V_C are used to select propulsion system components. Note that SHOP5 selects propulsion system components for required power in waves, using a sea state defined by optional input parameters for significant waveheight, $H_W(R)$, and wave modal period, $T_o(R)$. This significant waveheight has a default value of 3 metres and the default value for $T_o(R)$ is calculated for the North Atlantic [1].

The seakeeping speed, V_W , defines the minimum acceptable sustainable speed in waves, which is evaluated by comparing calculated seakeeping responses in deck wetness, vertical accelerations and slam force with user-definable seakeeping criteria, described later. The seakeeping significant waveheight, H_W , together with the seakeeping wave modal period, T_o (an optional input parameter), defines the sea state for seakeeping calculations. The seakeeping speed and waveheight are specified as required input to emphasize their importance to contemporary design.

4.3 Design Criteria

The following design criteria are used to assess platform feasibility in the SEARCH mode.

- range at endurance speed, R_{V_e}
- number of deck wetnesses per hour, $N_{wet(max)}$
- RMS vertical acceleration/g at station 4², $\ddot{z}_{max}$
- slam force/displacement ratio, $F_{slam(max)}$
- crew seakeeping effectiveness, $e_{crew(min)}$ (percent)
- overall propulsive coefficient, OPC_{min}
- vertical centre of gravity, $\overline{KG}_{max}$ (m:ft)
- combat system volume, $V_c(min)$ (m³:ft³)

The range at endurance speed must be defined by user-supplied input, and all other design criteria have default values or methods which can be replaced by user-supplied input. As each design candidate progresses through the SEARCH mode design process, it is compared with these criteria; when a criterion is violated, the ship is rejected and the next design candidate is considered. For initial runs in the SEARCH mode, it is not unusual for most or all ships to be rejected for violating design criteria. In this case, it is often useful to temporarily reduce the dominant design criteria values, and examine the less capable ships to identify trends that may suggest a path to acceptable ships.

The range criterion, R_{V_e} , defines the minimum acceptable range at endurance speed, V_E . When more than one range criterion is defined for a particular mission, then R_{V_e} and

²The station numbering convention used by SHOP5 has station 0 at the forward perpendicular and station 20 at the after perpendicular.

V_E should model the condition most likely to be dominant, and other range criteria can be rapidly assessed using the computer graphics available in program FIVPOS.

The four seakeeping criteria are used in both the SEARCH and DESCRIBE modes. Their default values are, respectively, 60 deck wetnesses per hour, 0.20 gravities, 0.20 for the slam force/displacement ratio, and 50 percent for crew effectiveness. In the SEARCH mode, the seakeeping behaviour of each design candidate is evaluated for the seakeeping speed and significant waveheight (design requirements), and when a seakeeping criterion is violated, the ship is rejected. In the DESCRIBE mode, SHOP5 calculates the ship speed at which each criterion is violated.

The design criterion OPC_{min} is evaluated at endurance speed, and provides a convenient method for early rejection of ships with very low propulsive efficiency. The default value for OPC_{min} is 0.60 (60 percent).

By default, the design criterion $\overline{KG}_{max}$ is the maximum, intact transverse vertical centre of gravity for positive stability in the damaged condition. This parameter can be redefined by user-supplied input as either a fixed value or as a fraction of midship hull depth (i.e. $\overline{KG}_{max} = 10$ (m) or $\overline{KG}_{max}/D = 0.60$). When a ship's intact $\overline{KG}$ exceeds $\overline{KG}_{max}$, the ship is rejected. Another rejection criterion is the minimum midship freeboard for reserve buoyancy in the damaged condition, F_{RB} . This criterion is not listed above, as it cannot be re-defined by the user. The damaged condition is defined by the standard of compartmentation, C , which is an optional input parameter with a default value of 3 (i.e. three adjacent compartments flooded). This parameter can be redefined by user-supplied input as either the number of compartments flooded or as a fraction of ship length open to flooding.

The minimum acceptable combat system volume, $V_{c(min)}$, has a default value equal to 12.5 percent of total enclosed volume (i.e. $V_{c(min)}/V_{total} = 0.125$). Since this parameter is of major importance and varies dramatically with mission and combat system components, it is recommended that user-supplied input be provided for $V_{c(min)}$ whenever possible.

Finally, three conditions can lead to rejected ships in both the SEARCH and DESCRIBE modes.

- The derived midship coefficient ($C_M = A_M/BT = C_B/C_P$) is outside the allowable range for the residuary resistance database.
- The calculated thrust loading coefficient (see Reference 1) is outside the allowable range for the propeller open water database.
- An internal or user-supplied real-engine database cannot produce an adequate propulsion system, which usually indicates that the design speed power requirements exceed the capability of the systems available.

5 Overview of Design Methodology

For each ship, the following calculations are performed sequentially.

- geometry

- seakeeping
- resistance, propulsive efficiency and required power
- propulsion system selection and performance
- ship service electrical generation system performance
- total enclosed volume
- weight components
- range
- stability
- volume components
- platform acquisition cost

The "arrangements" and "structure" design steps shown in Figure 1 are not included above, as they are not considered in sufficient detail to warrant separate status. In SHOP5, arrangements are considered in two stages: the ship description defines geometry and major system configurations; and the weight, volume, and stability algorithms contain empirical relations based on contemporary NATO frigates and destroyers. The key arrangement parameter calculated by SHOP5 is the combat system volume, V_{combat} . This parameter is a measure of the internal space available for combat systems; however, the actual arrangement of spaces is not considered. Similarly, key structural geometries are defined by the ship description, and the algorithm for structural weight, W_1 , incorporates criteria for longitudinal strength and minimum material thicknesses; otherwise, structures *per se* are not considered.

5.1 Balancing Weight and Volume Components

One of the most important aspects of the SHOP5 design process is the method used to achieve a "balanced" design. Ship weight components are balanced by the definition of fuel weight, W_f .

$$W_f = \Delta - (W_1 + W_2 + W_3 + W_5 + W_6 + W_d + W_{combat})$$

where Δ is the full load displacement, W_1 is structural weight, W_2 is the propulsion system weight, W_3 is electrical systems weight, W_5 is auxiliary systems weight, W_6 is outfit and furnishings weight, W_d is the disposable loads weight, and W_{combat} is the combat system weight.

The full load displacement is defined by the ship description and combat system weight is defined as a design requirement; the remaining weight components are estimated using empirical methods described in Reference 1. The fuel weight is a major factor in determining range, which is used as a design criterion in the SEARCH mode; any ships with insufficient

range at endurance speed are rejected. SHOP5 estimates W_f for eleven existing NATO frigates and destroyers to within a maximum error of 3.2 percent of displacement (average of 0.2 percent, standard deviation of 2.2 percent). More details are presented in Reference 1, including a tabular summary of estimating errors for all weight components.

Similarly, the balance of volume components is achieved by the definition of combat system volume, V_{combat} .

$$V_{combat} = V_{total} - (V_m + V_o + V_n + V_f)$$

where V_{total} is the total enclosed volume, V_m is machinery volume, V_o is outfit and systems volume, V_n is personnel volume, and V_f is fuel volume.

The total enclosed volume, V_{total} , is defined by the ship description and other volume components are estimated using methods discussed in Reference 1. Thus, the combat system volume is the sum of spaces not required for any other ship functions. In the SEARCH mode, V_{combat} is compared with the user-definable minimum acceptable combat system volume, $V_{c(min)}$; all ships with insufficient V_{combat} are rejected. SHOP5 estimates V_{combat} for eleven existing NATO frigates and destroyers to within a maximum error of 3.2 percent of V_{total} (average of 0.5 percent, standard deviation of 1.9 percent). More details are presented in Reference 1, including a tabular summary of estimating errors for all volume components.

5.2 Defining Total Enclosed Volume

The total enclosed volume is separated into two components, hull volume, V_{hull} , and superstructure volume, V_{super} .

$$V_{total} = V_{hull} + V_{super}$$

For an individual ship, V_{hull} is defined by underwater and topside geometries, and so it is fixed by the ship description; however, there are three options for determining V_{super} (controlled by method control integer IVOLUM, see Table 2).

1. V_{super} is fixed (defined by optional input parameter V_{super})
2. V_{super} is sized to suit a target value for V_{combat}
3. V_{super} is sized to suit a target value for the metacentric height/beam ratio, $\overline{GM}/B$

For the last two options, user-definable minimum and maximum superstructure volumes constrain the variation of V_{super} . In both cases, the minimum superstructure volume serves as a starting point for determining the required V_{super} to satisfy the goal for V_{combat} or $\overline{GM}/B$. In the SEARCH mode, ships are rejected when they cannot satisfy the target value for V_{combat} or $\overline{GM}/B$ within the allowable variation of V_{super} . Reference 1 describes these options in more detail.

The designer must exercise caution when using the SEARCH mode, as SHOP5 only considers volume, not deck area. Since the SHOP5 default method for defining midship

Table 3: Global Limits on Displacement and Hull Form Coefficients

Displacement, Δ :	2000 to 10,000 tonnes
Length/displacement ratio, $\mathcal{M}$:	5.5 to 10.0
Prismatic coefficient, C_P :	0.55 to 0.75
Block coefficient, C_B :	0.35 to 0.65
Beam/draft ratio, B/T :	2.5 to 4.5

hull depth varies with draft and length, it is possible to gain substantial volume through variations in hull depth without significant gains in deck area. It is usually desirable to relate internal volume to deck area by defining a fixed hull depth (see optional input parameter 1 in Appendix B). In this case, variation of internal volume for ships with common hull depth is directly proportional to internal deck area.

The algorithm for estimating V_{hull} assumes a continuous upper deck. In most cases, this is a good assumption but when it is not valid, it is possible to model a discontinuous upper deck, using procedures described in later sections.

5.3 SHOP5 Limits

Table 3 defines the global limits imposed on SHOP5.

Additional constraints on midship sectional area coefficient, C_M , vary according to which method is used for calculating residuary resistance, as described in Reference 1.

The SHOP5 design methodology combines databases derived from model test results and theoretical analyses with empirical equations based on contemporary practice and historical trends. In general, the database approach is used for performance parameters which are primarily dependent on hull form, such as seakeeping and residuary resistance. Ideally, these methods should be used only by interpolation, but the global limits on SHOP5 generally exceed the original limits of the SHOP5 databases. These methods have robust extrapolation procedures which produce reasonable results outside of the original scope of the database; however, validation of these results is difficult due to a lack of data. The SHOP5 user should be familiar with these database algorithms (described in Reference 1) and should use intelligent caution when comparing "radical" hull forms with contemporary practice.

5.4 Dependence on Contemporary Practice

When SHOP5 is used with all defaults for the optional input and method control integers, the resulting ship description is an average of existing NATO practice for such items as hull depth, size and type of appendages and other geometric and system parameters. As the designer replaces SHOP5 defaults with "real" or different data, then the ship description generally follows one of two trends: either converging on the contemporary design practice

of a particular nation, or diverging from existing practice because of new systems or radical geometries.

When the ship description or design requirements are significantly different from contemporary practice, the designer is responsible for determining which SHOP5 methods are applicable and which methods should be replaced or modified by user-supplied input. For example, consider a diesel-electric propulsion system, with the diesel engines located on the highest internal deck level. This system diverges from the SHOP5 defaults in two key areas: its physical characteristics are different in terms of weight, space and performance, and the location of diesel engines high in the hull is a departure from contemporary arrangements practice. This system is best modeled by a user-supplied, real engine database, for which the user defines the type (diesel), available power, specific fuel consumption, and weight of one or more engines. Also, this option accepts user-supplied input to define a propulsion system specific weight and vertical centre of gravity. This specific weight accounts for gearing, shafting and other propulsion system components not included in the engine weight. The weight of the electric motors can be defined as an addition to either the engine weight or the propulsion system specific weight, depending on whether motor weight is fixed or varies with installed power. The absence of significant gearbox weight and shafting is also considered by adjusting the propulsion system specific weight. Other weight differences, such as abnormally heavy foundations or significantly more rafting than normal, should be defined in the appropriate weight margin categories (see Appendix B). The system weight and performance description is completed by selecting a CODAD (Combined Diesel And Diesel) propulsion system configuration. Next, the designer must determine whether the total space required for this system is different from a contemporary system, as assumed by SHOP5. When significant differences are expected, then the total machinery volume can be defined with the user-supplied propulsion system volume/installed power ratio, V_m/P_I or the SHOP5 volume estimate can be increased using the margin on machinery volume. This system's atypical vertical weight distribution is explicitly modeled with the user-defined propulsion system vertical centre of gravity.

This example illustrates the flexibility of SHOP5 input for modeling non-standard systems, but it also emphasizes that when a new system is used, the designer must have reasonable knowledge of the system characteristics.

5.5 Using Cost as a Comparative Parameter

As stated earlier, the SHOP5 platform acquisition cost is only valid for comparative purposes. This must be qualified further by stating that the SHOP5 default cost factors used to estimate platform acquisition cost (see Reference 1) should only be used for comparing ships with equivalent technology of systems and construction. The default cost factors are derived from historical data with a bias towards recent practice, and these factors are valid for the SHOP5 options which do not require user-supplied input to describe new systems. For example, the relative costs of gas turbine vs diesel engines are considered, but propulsion system cost for the diesel-electric system described above would not be modeled properly. Thus, the platform acquisition cost for diesel-electric ships estimated using default cost factors would be valid for trade-off studies considering only diesel-electric ships, but would not be valid for direct comparison with ships using different propulsion systems.

5.6 Design Margins

When using SHOP5, it is useful to consider four types of design margins: future growth, design and construction (D & C), assurance, and modeling. The first three types are well recognized [7], while the modeling margin is peculiar to SHOP5, as it accounts for items not considered by the SHOP5 algorithms (e.g. extra foundations and rafting for the example diesel-electric system). Future growth margins allow flexibility for refit and modernization programs, or account for items identified for installation but not available in the time-frame of ship acquisition. D & C margins account for uncertainties in the hull form definition and estimating errors or changes to requirements for propulsion, weights, volumes, and stability. Assurance margins are applied to ensure that the ship has adequate capability to meet the design requirements.

SHOP5 defines explicit margins for resistance, powering, weights and volumes through the optional input parameters (see Appendix B). Other margins can be implicitly defined by incorporating them in the appropriate input parameters. The recommended procedures for defining margins are discussed in Reference 1, but a few special considerations are discussed here.

Two commonly used assurance margins for the propulsion system are:

1. increasing the required propulsion power to account for the effects of hull fouling and sea state on fuel consumption and range; and,
2. reducing the available engine power to determine maximum sustainable speed.

The first of these margins should never be used with SHOP5; the effects of significant hull fouling should be modeled by adjusting the ship-model correlation allowance, C_A (an optional input parameter), and the effects of sea state are explicitly considered in SHOP5 by calculating the added power in waves. The second margin for determining maximum sustainable speed should be used with caution, as sustainable speed is usually limited by sea state, not power. When this approach must be used, it should be done by defining a user-supplied engine database with engine powers which incorporate the assurance margin. In this case, the design speed (a design requirement) is used as the minimum acceptable sustainable speed.

The SHOP5 range calculations incorporate two assurance margins which cannot be re-defined by the user. These are a five percent reduction in the available fuel weight to account for fuel trapped in tank bottoms and piping systems, and a five percent increase in propulsion system fuel consumption to account for engine degradation in service.

A special note regarding the SHOP5 weight and volume algorithms is necessary, as these algorithms are based on existing, real ship data. Thus, the SHOP5 algorithms include the D & C and assurance margins on weight and volume used for the design and construction of these ships. This does not mean that these weight and volume margins should not be used with SHOP5, but it does indicate that they should be chosen carefully and verified in the Concept Development design phase.

6 SHOP5 Output

This section provides a brief overview of the SHOP5 System output structure. More details are presented later in the example on design optimization and in the appendices. Figure 3 shows the relationship between SHOP5 System input and output. The SHOP5 input prepared using FIVPRE is written to a disk file which is automatically read when SHOP5 is executed. Also, the user can store a copy of the current input in the FIVPRE library for retrieval at a later time. Every time SHOP5 is executed, it produces lineprinter output to summarize all program input, as well as describe the characteristics of feasible ships generated by SHOP5. When the graphical post-processor FIVPOS is used, SHOP5 writes a ship data file on disk, which forms the input for FIVPOS. Every time that FIVPOS is executed, it produces lineprinter output to summarize its input and provide details of the ships rejected by SHOP5. When in FIVPOS, the user can select ships to form the basis for new input to SHOP5 (via FIVPRE), and/or receive lineprinter output describing these ships.

Since the SHOP5 System is used iteratively, the process of generating design candidates can produce a very large amount of lineprinter output; however, the SHOP5 System Program Control menu provides a solution, as follows.

SHOP5 System: Program Control

- ```

1. Run FIVPRE
2. Run SHOP5
3. Run FIVPOS
4. Lineprinter Control
5. Editor
6. Help
99. EXIT
```

Enter NUMBER =>

Menu item 4 controls where all lineprinter output is sent; by default, all SHOP5 System lineprinter output is written on a disk file called DATA. The user can re-route this output to the "real" lineprinter by selecting the appropriate option associated with menu item 4. Menu item 5 allows the user to invoke an editor to inspect the contents of DATA. This editor is automatically started by the executive menu system, and requires only four or five simple commands to view all or selected parts of the DATA file. Thus, the great majority of user-program interaction is done at the terminal, and paper output is only used to record milestones in the design process.

Currently, this executive menu is only available for the VAX/VMS operating system (Digital Equipment Corporation), although its functions can be easily duplicated on most computers. This menu provides a convenient environment for using the SHOP5 System, but it is not required. All functions performed by the SHOP5 System, except for the graphics used in FIVPOS, are written in FORTRAN. The SHOP5 System Installation Guide [8] provides details on hardware and software requirements.

## 7 Design Optimization: An Example

The first steps in using the SHOP5 System are to define the ship description, design requirements and criteria, and determine which SHOP5 methods are appropriate for the current problem. At this stage the key consideration for the ship description is to decide which SHOP5 default parameters are suitable and which should be replaced by user-supplied input. The optimum design candidate is located by an iterative process in which the designer initially considers a wide range of ship sizes and hull forms. The field of possible candidates rapidly narrows, and the designer enters a refinement process in which ship description parameters are varied to assess second-order effects. Often, more than one design candidate appears viable, and so the designer may perform a final selection process in which cost/performance trade-offs determine the optimum candidate. Alternately, it is reasonable to identify more than one design candidate for further examination in the Concept Development phase. This is especially true when the success of a particular design depends on a new and possibly high risk technology. In this case, it is reasonable to have an optimum "advanced" design candidate and an optimum "back-up" candidate using contemporary technologies, just in case the advanced technology is not available or does not perform as expected. Also, the best choice for major ship systems (e.g. engine configuration) or overall arrangements (e.g. relative superstructure size) may not be clear in the Concept Exploration phase. In this case, the designer may not be able to eliminate a particular ship on the basis of Concept Exploration analysis, as key decisions cannot be made until more detailed studies are completed (e.g. noise vs speed or vulnerability vs arrangements).

When using the SHOP5 System, the designer is responsible for all design decisions and for appropriate selection of design candidates. The designer must decide how to configure the ship description and how to modify the SHOP5 methodology, based on personal design experience and particular requirements for the current problem. The SHOP5 default values and methods provide a good starting point, but they must be modified or replaced when they are not suitable.

Major features of the SHOP5 System are now illustrated by an example design problem, which also reflects the iterative and comparative process used for design optimization.

### 7.1 Design Philosophy

An appropriate design philosophy guides the designer in configuring and selecting design candidates by defining the relative importance of particular ship characteristics. For this exercise, the design philosophy is, in order of precedence, minimize platform acquisition cost, operational costs and technological risk, maximize survivability, minimize detectability, and maximize sustained speed in waves. SHOP5 does not explicitly consider all of these topics, but their relative importance provides valuable guidance for defining and changing the SHOP5 input. Also, the variation of key SHOP5 output parameters provides insight into the relative merits of the design candidates. For example, if combat systems and personnel are fixed, then relative fuel consumption is a fairly accurate measure of relative operational costs.

## 7.2 Example Design Requirements

The following design requirements and constraints are considered:

- Range in 3 metre waves:
  - 2500 n. miles at 30 knots
  - 4500 n. miles at 20 knots
  - 5000 n. miles at 15 knots
- Combat system weight 375 tonnes
- Combat system volume 2900 m<sup>3</sup>
- 50 tonnes weight margin for future growth
- Accomodation spaces of 16 m<sup>3</sup> per person
- Minimum sustainable speed of 20 knots in 5 metre waves, with:
  - maximum of 30 deck wetnesses per hour
  - maximum RMS vertical acceleration of 0.20 gravities, at station 4
  - maximum slam force/displacement of 0.20

## 7.3 Other Constraints and Decisions

Acceptable intact stability is defined by the metacentric height/beam ratio,  $\overline{GM}/B$ , with a minimum of 0.095 and of maximum 0.105. Damaged stability is assessed using the SHOP5 method, with the damaged condition defined by 15 percent of length open to flooding. This design uses all-steel construction. An initial midship hull depth of 10 metres will be used for all design candidates, which permits direct comparison of internal space and deck area. This hull depth can be varied to suit individual circumstances, and so it is not truly a design constraint, but it is a convenient assumption which reduces the variations that SHOP5 may consider initially.

The method for estimating complement size will be reduced from the SHOP5 default of  $N = \Delta^{2/3}$  to  $N = 0.88\Delta^{2/3}$  to model the (arbitrary) contemporary practice of the host navy.

Since the type of propulsion system is not defined by the design requirements, the designer must decide which systems are appropriate. Given the design philosophy stated above, only twin shaft propulsion systems with gas turbine main engines and, when required, diesel or gas turbine cruise engines will be used. Thus, only the following twin-shaft propulsion system configurations will be considered.

- One gas turbine per shaft, with cross-connected gearing
- COGAG (COmbined Gas turbine And Gas turbine)

- COGOG (Combined Gas turbine Or Gas turbine)
- CODOG (Combined Diesel Or Gas turbine)

The notation used for combined configurations defines, respectively, the type of cruise engine, type of gearbox ("AND" or "OR") and type of main engine. Since minimizing technological risk is a major consideration for this design, the CODAG configuration is not considered. This omission does not imply that the CODAG configuration is impractical, it simply reflects the fact that no contemporary frigate-sized ships use this type of propulsion system, and so technological risk may be significant.

Ship's service electrical requirements will be provided by four, 1000 kW diesel generator sets.

These requirements and constraints represent the first level of design goals for this platform; further constraints will be enforced and evaluated in later phases of design. This is especially true of constraints associated with the combat system. It is possible to introduce simple constraints such as a minimum acceptable length for arranging on-deck systems, but these cannot be truly evaluated until the internal and external layout (arrangements) are defined, which is usually the second step after using SHOP5 (the first is to define the hull form in more detail).

## 7.4 Starting the SHOP5 Design Process

For this example, the goal is to identify the most cost-effective design candidate which satisfies all of the design requirements. In order to simplify this task, each type of propulsion system is considered separately, and then the best design candidates for each system are compared.

### 7.4.1 The First Input File: SEARCH Mode

The immediate task is to define an input file which reflects the design constraints and decisions noted above. The SHOP5 input cannot explicitly model all design constraints defined for this exercise, and so the designer must choose which constraints are pre-set and which are evaluated later (using FIVPOS). For example, three combinations of speed/range requirements are defined, while SHOP5 provides only one design criterion for range. For this exercise, the 4500 nautical mile range at 20 knots is explicitly modeled, and the other two range criterion are assessed when selecting design candidates.

The first input file should define a sufficiently wide variation of ship size and hull form coefficients to produce at least a few feasible design candidates in the SEARCH mode. Once this is accomplished, then the characteristics of these design candidates will guide the designer's selection of subsequent ship size and hull form parameters. The initial variation in ship size and hull form coefficients are shown in Table 4.

The important aspects of this design example are discussed in the following text, but most details are contained in the appendices, as follows. Appendix C shows the first steps in the design process, in which the initial input file is defined for the COGAG propulsion

Table 4: Initial Variation of Displacement and Hull Form Coefficients

| Parameter        | Low Value | High Value | Number of Values | (increment) |
|------------------|-----------|------------|------------------|-------------|
| $\Delta$ (tonne) | 3500.00   | 4500.00    | 6                | 200.00      |
| $M$              | 7.00      | 9.00       | 5                | 0.50        |
| $C_P$            | 0.59      | 0.59       | 1                | -           |
| $C_B$            | 0.49      | 0.49       | 1                | -           |
| $B/T$            | 2.80      | 3.20       | 5                | 0.10        |

system and subsequently modified to "home-in" on desirable trends observed in FIVPOS graphics. Appendix D shows the final steps in the design process, in which desirable ships have been defined, but a few minor changes are required to satisfy all design requirements. Also, Appendix D contains the FIVPOS and SHOP5 lineprinter output for the COGAG design candidate. Appendix E lists the SHOP5 output parameters that can be examined graphically in FIVPOS.

The initial input file defined in Appendix C defines a total of 44 parameters. An absolute minimum of 29 parameters is required for the SEARCH mode, which includes a title, six program control integers, fifteen parameters to define the variation of size and hull form coefficients (as shown above), and seven mission-definition parameters (speeds, range, etc.). The other 15 parameters are user-supplied input which either replaces a SHOP5 default value (e.g. hull depth = 10 m), or defines a non-default method (e.g. superstructure is sized for the combat system requirements).

This initial input file is defined in a menu-driven mode, using the FIVPRE command "NEW". When this command is given, the user is forced to supply acceptable input for each of the 29 required input parameters, and is provided menus which access all other input parameters. The NEW mode is most useful for creating a new file from scratch; otherwise, the user would modify an existing file by using explicit commands (e.g. change freeboard) and/or by invoking individual, menu-driven procedures (e.g. change optional input). FIVPRE provides abbreviation recognition and ambiguity resolution, as well as complete on-line help.

#### 7.4.2 The First Run

The initial input file defines a total of 150 potential design candidates, but the first execution of SHOP5 indicates that only eight ships satisfy the design requirements that are explicitly modelled. FIVPOS is used to examine these ships and, as shown in Figure 4, none of them satisfy the requirement for 2,500 nautical mile range at design speed (30 knots). Before modifying the initial input to produce ships with greater range at design speed, examining other FIVPOS parameters reveals some interesting trends. Figure 5 shows significant variation in platform acquisition cost corresponding to changes in installed propulsion power. Other FIVPOS graphs shown in Appendix C indicate that superstructure volume and fuel

Table 5: Variation of Parameters For Second SEARCH Mode Input

| Parameter        | Low Value | High Value | Number of Values | (increment) |
|------------------|-----------|------------|------------------|-------------|
| $\Delta$ (tonne) | 4500.00   | 4500.00    | 1                | -           |
| $\mathbb{M}$     | 8.00      | 8.50       | 6                | 0.10        |
| $C_P$            | 0.57      | 0.61       | 3                | 0.02        |
| $C_B$            | 0.47      | 0.51       | 3                | 0.02        |
| $B/T$            | 2.80      | 3.2        | 5                | 0.10        |

consumption decrease significantly with increasing  $\mathbb{M}$ . The relatively low-cost design candidates shown in Figure 5 have values of  $\mathbb{M}$  of 7.5, 8.0 and 8.5. Since all of these ships have the same displacement of 4,500 tonnes, this represents a significant variation in length.

### 7.5 Defining the "Optimum" Design Candidate

In general, after the first few "feasible" ships are generated, the process of identifying "optimum" design candidates is greatly simplified by reducing the range of parameter variations considered at any particular time. In this case, it is useful to consider the relatively short and long hull forms as different potential design solutions, and to examine them independently. The search for a COGAG ship with a relatively long hull form is initiated within FIVPOS by selecting the right-most ship in Figures 4 and 5 ( $\mathbb{M} = 8.5$ ) for transfer to FIVPRE. When program FIVPRE is executed, a DESCRIBE mode file is automatically produced to model the ship or ships transferred from FIVPOS (if no ships are transferred, then the user can either modify an existing file using ENTER and CHANGE or create a NEW one). In this case, the displacement and hull form coefficients of the transferred ship are:  $\Delta = 4500(t)$ ,  $\mathbb{M} = 8.50$ ,  $C_P = 0.59$ ,  $C_B = 0.49$ , and  $B/T = 3.20$ . The DESCRIBE mode file created by FIVPRE for this ship is converted back to the SEARCH mode using a procedure shown in Appendix C and a new set of geometric variations (called the "search space") is defined, as shown in Table 5.

In Table 5, displacement is held constant and finer variations in  $\mathbb{M}$  are used. Also, variations in  $C_P$  and  $C_B$  are introduced to examine combinations not considered initially. The purpose of this file is to determine which combination of hull form coefficients provides the greatest range at design speed for the relatively long, COGAG ship. Figure 6 shows some of the 105 ships generated by this input file. Ship number 91 has the greatest range at design speed, and so it is used as a basis for subsequent input files which model ships with larger displacements and, hopefully, greater range at design speed.

Figure 7 shows the range at design speed for ships generated later in this example, from which ship number 20 is selected as the optimum design candidate for the long hull, COGAG configuration. Additional information on this ship is contained in Appendix D, including its lineprinter output from both FIVPOS and SHOP5 in the DESCRIBE mode.

The general procedure described above for the long, COGAG ship was repeated for

Table 6: Design Candidates, All Requirements Satisfied

| SHIP                          | A1        | B1        | C1        | D1        | E1        | F1        |
|-------------------------------|-----------|-----------|-----------|-----------|-----------|-----------|
| $\Delta$ (tonne)              | 4380      | 4460      | 4550      | 4600      | 4620      | 4660      |
| N                             | 236       | 238       | 242       | 243       | 244       | 246       |
| \$                            | 1.00      | 1.07      | 0.98      | 1.05      | 1.08      | 1.08      |
| $R_{30}$ (n. mile)            | 2515      | 2529      | 2501      | 2516      | 2514      | 2504      |
| $R_{20}$ (n. mile)            | 5520      | 5307      | 5305      | 6402      | 5997      | 5724      |
| $R_{15}$ (n. mile)            | 6693      | 7228      | 6982      | 8926      | 8055      | 6988      |
| $\mathbb{M}$                  | 8.35      | 8.30      | 9.05      | 8.25      | 8.35      | 7.65      |
| $L$ (m)                       | 135.5     | 135.5     | 148.7     | 136.1     | 138.0     | 126.7     |
| $V_{super}$ (m <sup>3</sup> ) | 2710      | 2608      | 2450      | 2739      | 3031      | 4091      |
| $P_{I(main)}$ (kW)            | 2 x 18650 | 2 x 18650 | 2 x 11940 | 2 x 18650 | 2 x 18650 | 2 x 11940 |
| $P_{I(cruise)}$ (kW)          | -         | 2 x 4775  | 2 x 4775  | 2 x 5370  | 2 x 4775  | 2 x 11940 |
| Configuration                 | X-connect | COGOG     | COGAG     | CODOG     | COGAG     | COGAG     |
| $FC_{20}$ (t/hour)            | 2.65      | 2.76      | 2.70      | 2.31      | 2.71      | 3.12      |
| $V_{MAX(5m)}$                 | 23.0      | 21.1      | 26.1      | 21.8      | 24.6      | 21.6      |
| $V_{MAX(3m)}$                 | 30.2      | 30.9      | 30.0      | 30.1      | 31.8      | 30.7      |

other engine configurations and hull forms, resulting in the six design candidates shown in Table 6. These design candidates are arbitrarily listed in order of increasing displacement, and the relative platform acquisition cost of ship A1 is used to normalize costs for all other ships. The maximum speeds shown at the bottom of this table,  $V_{MAX(5m)}$  and  $V_{MAX(3m)}$ , are, respectively, the maximum speed in 5 metre waves as limited by the seakeeping criteria and the maximum speed in 3 metre waves as limited by available propulsion power. Note that ship E1 is the long, COGAG design candidate described above and in Appendices C and D. Also, ship F1 is derived from the short, COGAG ships mentioned earlier and shown at the left-hand side of Figures 4 and 5.

At this stage, the designer should be able to select one or two of these design candidates for further definition and analysis in the Concept Development phase. This selection would be based on the relative importance of ship characteristics with respect to the design philosophy and other factors which cannot be assessed by a CEM (e.g. availability of particular engines, compatibility with existing systems, fleet maintenance practice, etc.). This selection is not made here, but a few general observations are made.

These design candidates illustrate that platform acquisition cost does not necessarily

Table 7: Design Candidates, 2000 n. mile Range at 30 knots.

| SHIP                                 | A2        | B2        | C2        | D2        | E2        | F2        | A3        |
|--------------------------------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| $\Delta$ (tonne)                     | 4200      | 4280      | 4120      | 4420      | 4350      | 4440      | 4100      |
| N                                    | 229       | 232       | 226       | 237       | 235       | 238       | 225       |
| \$                                   | 1.00      | 1.07      | 0.96      | 1.05      | 1.07      | 1.08      | 0.99      |
| $R_{30}$ (n. mile)                   | 2005      | 2018      | 2083      | 2042      | 2007      | 2046      | 2005      |
| $R_{20}$ (n. mile)                   | 4748      | 4597      | 4521      | 5805      | 4954      | 5254      | 4542      |
| $R_{15}$ (n. mile)                   | 5493      | 5944      | 5937      | 7260      | 6587      | 6190      | 5367      |
| $\textcircled{M}$                    | 8.20      | 8.30      | 8.85      | 8.30      | 8.20      | 7.50      | 8.40      |
| $L$ (m)                              | 131.2     | 133.7     | 140.7     | 135.1     | 132.8     | 122.3     | 133.3     |
| $V_{\text{super}}$ (m <sup>3</sup> ) | 4153      | 3625      | 1805      | 3773      | 3381      | 4752      | 2996      |
| $P_{I(\text{main})}$ (kW)            | 2 x 18650 | 2 x 18650 | 2 x 11940 | 2 x 18650 | 2 x 18650 | 2 x 11940 | 2 x 18650 |
| $P_{I(\text{cruise})}$ (kW)          | -         | 2 x 4775  | 2 x 4775  | 2 x 5370  | 2 x 4775  | 2 x 11940 | -         |
| Configuration                        | X-connect | COGOG     | COGAG     | CODOG     | COGAG     | COGAG     | X-connect |
| $FC_{20}$ (t/hour)                   | 2.47      | 2.57      | 2.63      | 2.07      | 2.69      | 3.00      | 2.57      |
| $V_{\text{MAX}(5\text{ m})}$         | 22.8      | 23.5      | 23.6      | 24.0      | 23.5      | 21.6      | 23.5      |
| $V_{\text{MAX}(5\text{ m})}$         | 30.1      | 30.1      | 30.0      | 30.0      | 31.5      | 30.0      | 30.2      |

increase with increasing displacement and length. The variation of cruise and main engines has a significant effect on platform acquisition cost. For example, consider ships A1 and C1; ship C1 is 170 tonnes heavier and 13.2 metres longer, but has lower platform acquisition cost due to its lower installed propulsion power.

By comparing the performance of the design candidates with the original requirements, it is apparent that the 2500 nautical mile range requirement at 30 knots is dominant. This became obvious early in the design process, as the displacement of ships otherwise acceptable had to be increased significantly to obtain sufficient fuel. Thus, the designer may feel that these design requirements are unbalanced, and it may be worth investigating the effects of reducing the required range at design speed. This option was investigated by reducing the design-speed range requirement to 2000 nautical miles, and the results are shown in Table 7. These ships are essentially scaled-down versions of those shown in Table 6, and are listed in the corresponding order.

In most cases, there is no significant reduction in platform acquisition cost between the two groups of design candidates, but the generally lower fuel consumption at cruise speed (20 knots) and reduced complement will provide significant reductions in future operational costs.

The last ship shown in Table 7, labelled A3, is a variant of ship A2 which is included to illustrate how decisions made by the designer in controlling the design process affect the

design solution. Ship A2 was derived from A1 by simply reducing displacement and length to match the reduced range at design speed. Since volume requirements remain constant (except for a small difference due to reducing complement), the superstructure volume of A2 is significantly larger than for A1 (4153 m<sup>3</sup> vs 2710 m<sup>3</sup>). A different approach was used to generate ship A3, in which displacement was reduced but length was held approximately constant. In this case, ships A1 and A3 have approximately the same superstructure volume and the relatively low resistance of A3 with respect to the shorter A2 results in a lower displacement for A3.

The final comments on these design candidates concerns another aspect of the impact of designer's decisions on the design solution. Ships C1 and C2 were generated by increasing ship length until the powering requirements could be satisfied by relatively low installed power; however, it was not possible to generate these ships without changing the SHOP5 default calculations for the number of internal bulkheads,  $N_{bulk}$ , and waterplane coefficient,  $C_W$ . Originally, all likely candidates for this long hull form were rejected by SHOP5 for exceeding the maximum vertical centre of gravity for positive stability in the damaged condition,  $\overline{KG}_{max}$  (described in Reference 1). This criterion was temporarily by-passed by defining a large user-supplied value for  $\overline{KG}_{max}$  of 10.0 metres, and so ships generated from subsequent input files were effectively not limited by this criterion. With this constraint removed, a number of design candidates were generated and the FIVPOS graphics showed that many had adequate intact stability. Thus, if the damaged stability characteristics of these ships could be improved without degrading other performance parameters, it should be possible to generate acceptable design candidates. This was done by increasing  $N_{bulk}$  from the default value of 16 to 17, and by increasing  $C_W$  from the default of 0.728 to 0.768. Subsequent runs of SHOP5 with these modified values for  $N_{bulk}$  and  $C_W$  produced design candidate C1, which also satisfies the  $\overline{KG}_{max}$  criterion. An additional change was necessary before ship C2 could be generated, as the minimum superstructure volume used in the procedure for sizing the superstructure produced over-large superstructures for these ships, causing inadequate intact stability due to relatively high vertical centres of gravity. The FIVPOS graphics for these ships showed that these ships had excess combat system volume, which indicated that it may be possible to increase  $\overline{GM}/B$  by reducing superstructure volume, and still satisfy the combat system requirements. This was done by defining a reduced value for the minimum superstructure volume, and resulted in ship C2.

This entire design exercise, including investigating the reduced design-speed range requirement was performed by a single person in three days. Thus, the designer can rapidly initialize more detailed design by selecting one (or more) of the ships from Table 6, and can also indicate that significant savings in operational costs are possible if the design-speed range requirement is reduced.

## 8 Other uses for the SHOP5 System

Most of this documentation assumes that SHOP5 is being used to initialize the new-ship design process; however, it is a useful tool for other purposes, including:

- evaluating the effects of new or different technologies on ship size, performance and relative cost <sup>3</sup> ;
- evaluating the relative impact of design requirements and design practice (i.e. margins, methodology, etc.) on the ship platform;
- initial evaluation of design proposals or major refit/modernization programs;
- comparative naval architecture [9];
- initializing and/or performing specific parametric studies (e.g. [10]); and,
- in conjunction with other CEMs, evaluating the relative merits of the monohull frigate/destroyer for anticipated future requirements.

Of course, the level of detail used by SHOP5 means that it does not perform all calculations required for these purposes, but it is a useful tool in all cases. For example, the process of modeling a design proposal or foreign ship with SHOP5 rapidly highlights any anomalies (i.e. standard of accommodations, machinery space vs installed power, propulsive efficiency vs contemporary practice, etc.).

## 9 Concluding Remarks

The SHOP5 System provides a fast, flexible and user-friendly design tool for Concept Exploration design of monohull frigates and destroyers. The system has three major components; program FIVPRE for defining and modifying input, program SHOP5 for analysing the ships described by the input, and program FIVPOS for examining the characteristics of feasible design candidates using computer graphics.

The design logic used in SHOP5 is relatively simple; given ship size, hull form, major systems and design requirements, SHOP5 calculates performance and capability, including: deck wetness, vertical accelerations, and slam force in head seas; resistance, powering and range in calm water and waves; propulsion and electrical generation systems modeling and performance; distribution of weight and volume components; preliminary intact and damaged stability analysis; and a platform acquisition cost. This cost does not include any combat system or future operating costs, and is not sufficiently detailed for budgetary purposes; however, it is a valuable comparative parameter for performing design trade-offs.

The SHOP5 input consists of the ship description, design requirements and design criteria. Most of these parameters have pre-programmed default values representative of contemporary NATO practice, which can be redefined by user-supplied input for cases when the defaults are not appropriate. SHOP5 can be used in either a SEARCH or DESCRIBE mode. In the SEARCH mode, the designer specifies a range of ship sizes and underwater hull form coefficients, which defines a multi-dimensional search space. Each combination of ship size and hull form coefficients produces a possible design candidate, and up to 800

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<sup>3</sup>SHOP5 does not explicitly consider operating costs, but it does provide key information, especially fuel consumption.

can be considered on a single execution of the program. When an individual ship does not satisfy all design criteria, then it is rejected and the next possible ship is considered. The characteristics of feasible ships are transferred to program FIVPOS, where the designer uses computer graphics to examine and select possible design candidates. The closed-loop structure of the SHOP5 System allows the user to transfer ship data from FIVPOS to FIVPRE, where they are arranged to form a new input file for SHOP5. This file can be used immediately to examine the selected ships in the DESCRIBE mode, or it can be modified to form a new SEARCH mode input file. In the DESCRIBE mode, more detailed calculations are performed for up to eleven individual ships and no ships are rejected. This mode is used to model existing ships for direct comparison with design candidates generated by SHOP5 and to examine ships rejected in the SEARCH mode.

The primary application for SHOP5 is to initialize the new-ship design process by determining the size, hull form and major systems of the ship or ships best suited for the design requirements. The iterative process used for design optimization was illustrated by generating a number of design candidates for a typical frigate mission. Also, this example emphasized the designer's responsibility for configuring suitable input and selecting appropriate design candidates. All SHOP5 input parameters and algorithms for design calculations were described in detail, with special attention to the options for replacing input parameter default values and internal calculations with user-supplied input.

Other uses for the SHOP5 System include assessing the effects of new or different technologies, design requirements and design practice on performance and capability, initial evaluation of design proposals and major refit or modernization programs, comparative naval architecture, performing special parametric studies, and examining future requirements.

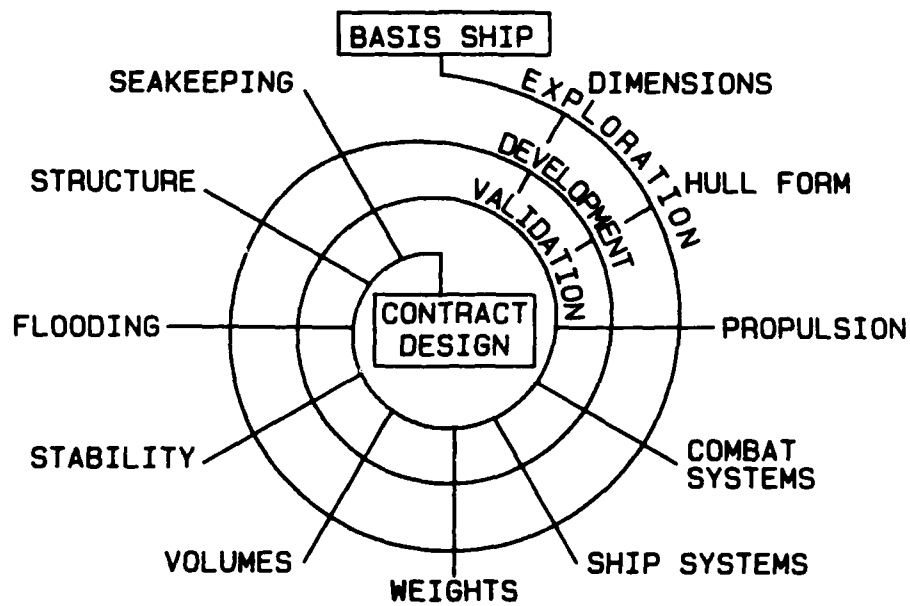


Figure 1: Traditional Design Spiral

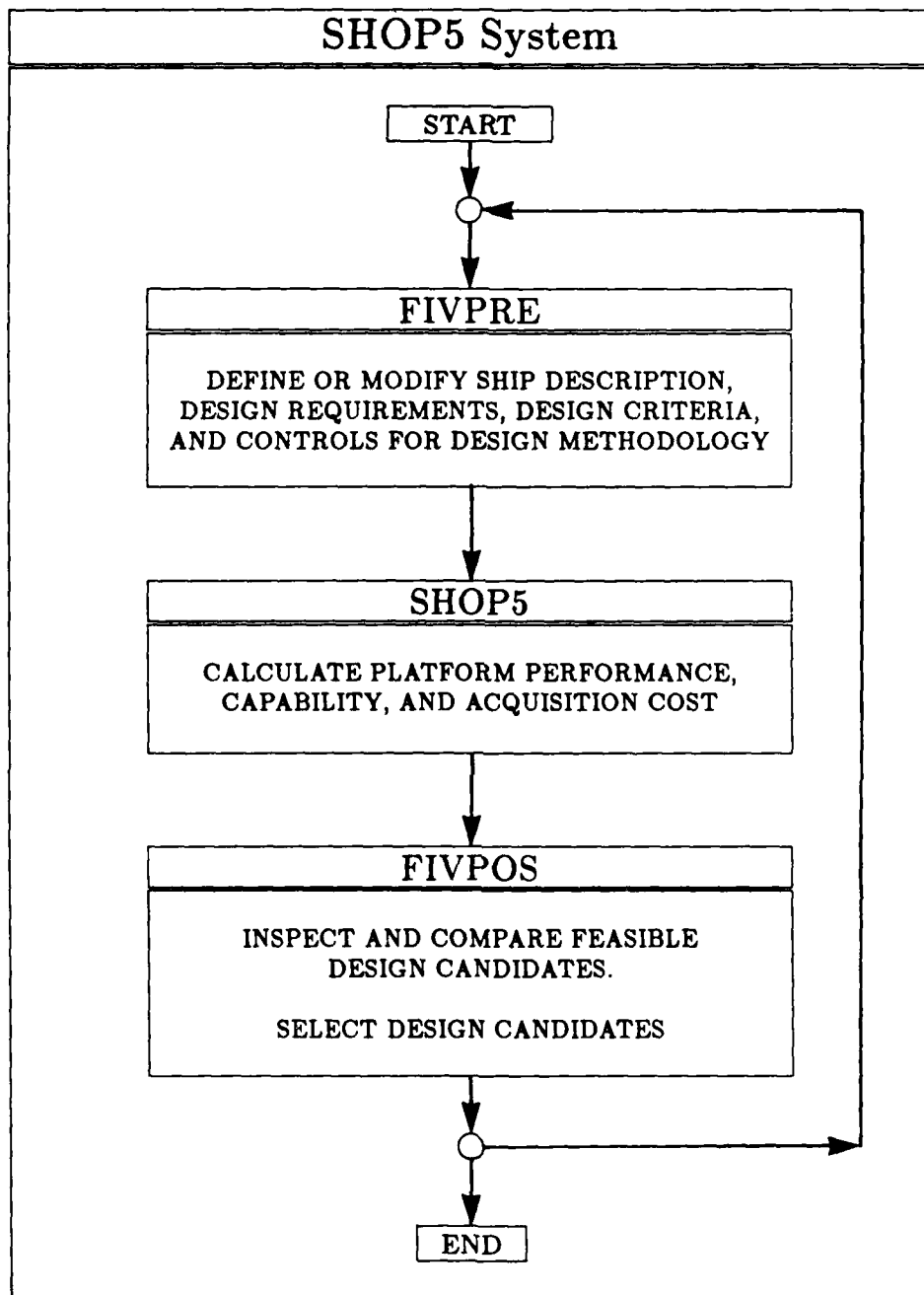


Figure 2: SHOP5 System Programs

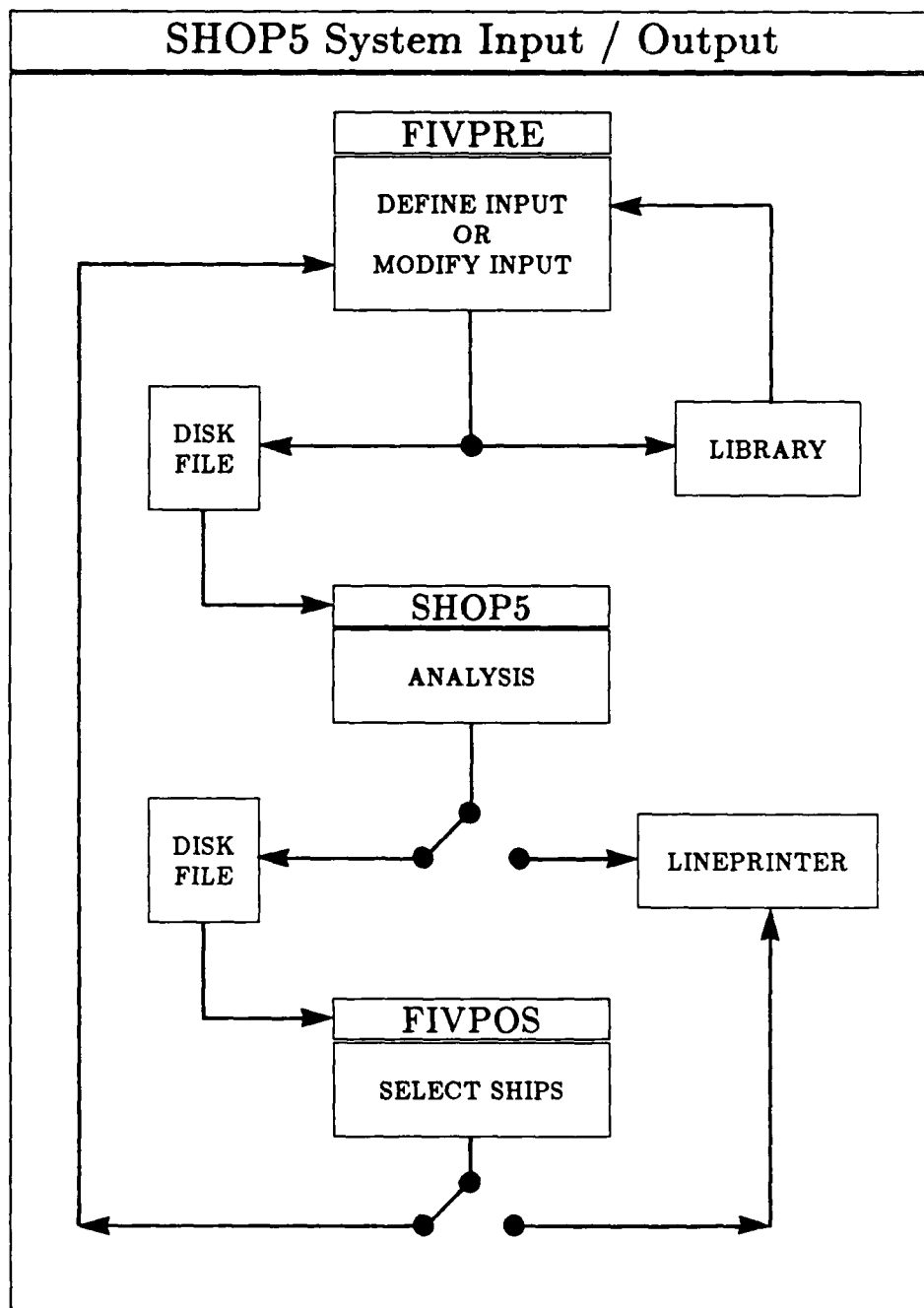


Figure 3: SHOP5 System Input and Output



Figure 4: Range at Design Speed, 'First-Run' Ships

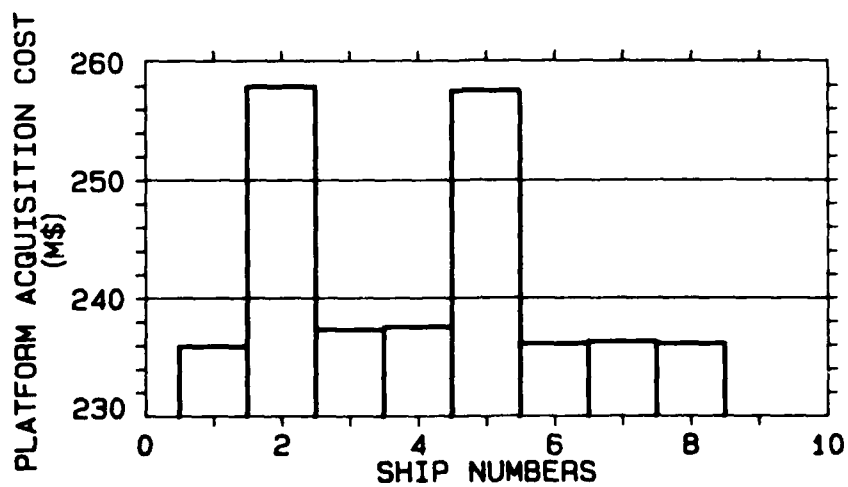


Figure 5: Platform Acquisition Cost, First-Run Ships

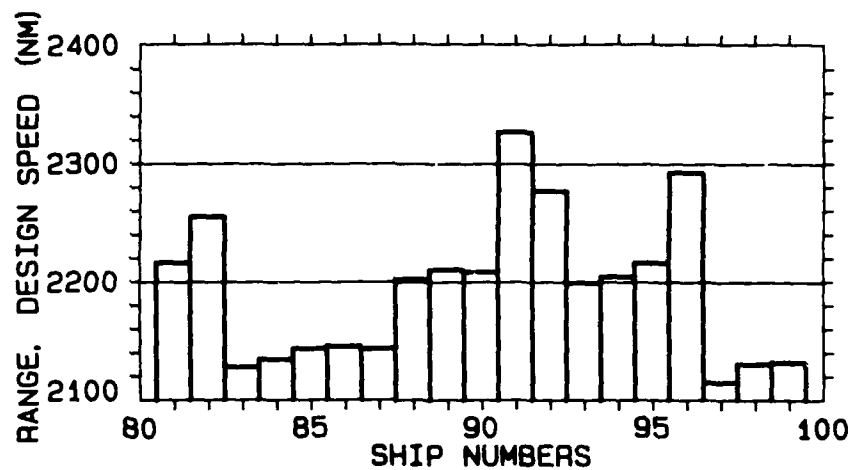


Figure 6: Range at Design Speed, 'Second-Run' Ships

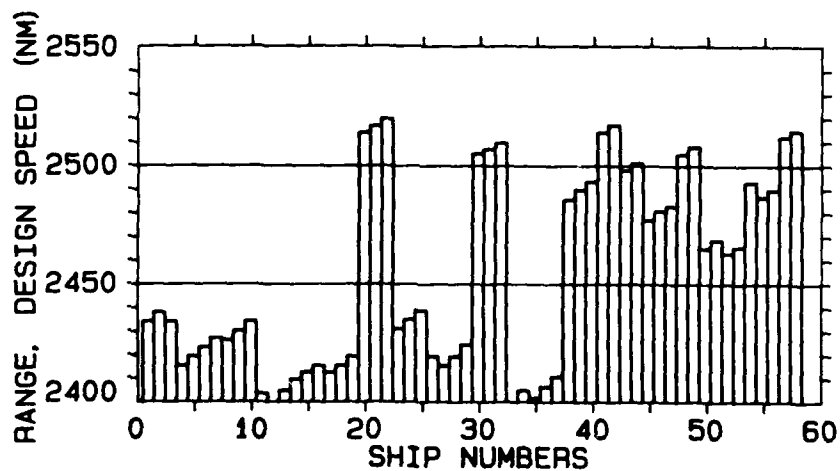


Figure 7: Range at Design Speed, 'Final-Run' Ships

## Appendix A: SHOP5 Input Records

### Overview of SHOP5 Input Records

The SHOP5 input parameters are arranged in the following records.

|           |                                           |
|-----------|-------------------------------------------|
| Record 1  | Title                                     |
| Record 2  | Program Control Integers (PCI)            |
| Record 3  | Primary Input (PRIM)                      |
| Record 4  | Method Control Integers (MCI)             |
| Record 5  | Optional Input Parameters (OPT)           |
| Record 6  | Design/Seakeeping Criteria (CRIT)         |
| Record 7  | Appendage Resistance Coefficient (IAPPND) |
| Record 8  | Overall Propulsive Coefficients (IPROP)   |
| Record 9  | Superstructure Material (ISTRUC)          |
| Record 10 | Propulsion System (IENGINE)               |
| Record 11 | Electrical Generation System (IGEN)       |
| Record 12 | Superstructure Size Variations (IVOLUM)   |
| Record 13 | Cost Factors (ICOST)                      |

Uppercase letters in (...) brackets define names recognized by FIVPRE for invoking parameter-access menus. For example, the FIVPRE command CHANGE MCI invokes the menu for changing method control integers. Records 1, 2 and 3 are required input. Records 4, 5 and 6 are optional and one or more of Records 7 through 13 may be required to define additional input for Record 4.

The following descriptions of the SHOP5 input records use the SHOP5 lineprinter notation for all parameter names, which is also used on-screen by FIVPRE and FIVPOS, and on all SHOP5 System lineprinter output. The Notation section at the front of this Technical Memorandum has separate entries for parameters whose lineprinter notation is significantly different from that used in the text.

When using program FIVPRE, some of the SHOP5 input parameters are defined automatically, and so the user does not have explicit knowledge of all required input. The differences between the on-screen input structure used by FIVPRE and the on-disk input structure required by SHOP5 are only important when the user is defining or modifying an input file without using FIVPRE. In this case, Appendices A and B provide complete documentation of the SHOP5 input record structure.

An example input file is presented in Table A.9 at the end of this appendix.

**Record 1: Title**

**TITLE** Maximum of 80 characters, first line of file

## Record 2: Program Control Integers

|        |                                                                                                                                                                                                                                                                                                                     |
|--------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| MODE   | Defines type of mode: SEARCH or DESCRIBE<br>0 SEARCH mode<br>n DESCRIBE mode, n = number of ships, $1 \leq n \leq 11$                                                                                                                                                                                               |
| UNITS  | Defines type of units for input and output $0 \leq \text{UNITS} \leq 3$<br>0 Input FPS, Output FPS<br>1 Input METRIC, Output FPS<br>2 Input FPS, Output METRIC<br>3 Input METRIC, Output METRIC                                                                                                                     |
| IPOST  | Will post-processor (FIVPOS) be used?<br>0 NO post-processor not used<br>1 YES post-processor will be used<br><u>Notes:</u> (a) in SEARCH mode, if IPOST = 0, define ILPT = 1<br>if IPOST = 1, define ILPT = 0<br>(b) in DESCRIBE mode, define IPOST = 0                                                            |
| ILPT   | Will SEARCH mode ship data be written to lineprinter ?<br>0 NO ship data not written to lineprinter<br>1 YES ship data written to lineprinter, one page per ship<br><u>Notes:</u> (a) summary of input always written to lineprinter<br>(b) see Note (a) for IPOST, above.<br>(c) in DESCRIBE mode, define ILPT = 1 |
| LEGEND | Will a legend of abbreviations accompany the lineprinter output ?<br>0 NO legend not written<br>1 YES legend written to lineprinter                                                                                                                                                                                 |
| NCON   | number of method control integers redefined (see Record 4)                                                                                                                                                                                                                                                          |
| NOPT   | number of optional input parameters redefined (see Record 5)                                                                                                                                                                                                                                                        |
| NLIM   | number of design criteria redefined (see Record 6)                                                                                                                                                                                                                                                                  |

**Order of input:** eight integers on one line.

### Record 3: Primary Input

The primary input define the characteristic dimension, underwater hull form and design requirements. These input are separated into two sub-records; Record 3A for the SEARCH mode and Record 3B for the DESCRIBE mode.

### Record 3A: SEARCH Mode Primary Input

Only used when program control integer MODE = 0 (Record 2).

|       |                                                  |
|-------|--------------------------------------------------|
|       | Characteristic dimension: (see IDIMEN, Record 4) |
| XXXlo | low value                                        |
| XXXhi | high value                                       |
| I1    | number of values, $1 \leq I1 \leq 11$            |
|       | Length/Displacement ratio, $\bar{M}$ :           |
| CrMlo | low value                                        |
| CrMhi | high value                                       |
| I2    | number of values, $1 \leq I2 \leq 11$            |
|       | Prismatic coefficient:                           |
| CPlo  | low value                                        |
| CPhi  | high value                                       |
| I3    | number of values, $1 \leq I3 \leq 11$            |
|       | Block Coefficient:                               |
| CBlo  | low value                                        |
| CBhi  | high value                                       |
| I4    | number of values, $1 \leq I4 \leq 11$            |
|       | Beam/Draft ratio:                                |
| B/Tlo | low value                                        |
| B/Thi | high value                                       |
| I5    | number of values, $1 \leq I5 \leq 11$            |

Note: maximum total number of ships is 800 (i.e.  $\prod_{i=1}^5 I_i \leq 800$ )

|       |                                                            |
|-------|------------------------------------------------------------|
| R(Ve) | Minimum acceptable range (n. miles) at endurance speed, Ve |
| Wc    | Combat systems weight (t:ton)                              |
| Vd    | Design speed (knots)                                       |
| Vc    | Cruise speed (knots)                                       |
| Ve    | Endurance speed (knots)                                    |
| Vw    | Seakeeping speed (knots)                                   |
| Hw    | Seakeeping significant wave height (m:ft)                  |

Order of input: XXXlo XXXhi I1  
 CrMlo CrMhi I2  
 Cplo Cphi I3  
 Cblo Cbhi I4  
 B/Tlo B/Thi I5  
 R(Ve) Wc Vd Vc Ve Vw Hw

**Record 3B: DESCRIBE Mode Primary Input**

Only used when program control integer MODE > 0 (Record 2).

XXX Characteristic dimension (see IDIMEN, Record 4)  
 CrM Length/Displacement ratio, (M)  
 Cp Prismatic coefficient  
 Cb Block coefficient  
 B/T Beam/Draft ratio  
 Wc Combat systems weight (t:ton)  
 Vd Design speed (knots)  
 Vc Cruise speed (knots)  
 Ve Endurance speed (knots)  
 Vw Seakeeping speed (knots)  
 Hw Seakeeping significant wave height (m:ft)

Notes: (a) number of ships = MODE (Record 2)  
 (b) every ship requires explicit input for each parameter

| <u>Order of input:</u> | XXX  | CrM | Cp   | Cb   | B/T  | Wc  | Vd | Vc | Ve | Vw | Hw |
|------------------------|------|-----|------|------|------|-----|----|----|----|----|----|
| for example:           | 4000 | 8.5 | 0.60 | 0.49 | 2.95 | 350 | 32 | 20 | 15 | 20 | 5  |
| (MODE = 3)             | 4200 | 8.5 | 0.60 | 0.49 | 2.95 | 350 | 32 | 20 | 15 | 20 | 5  |
|                        | 4400 | 8.5 | 0.60 | 0.49 | 2.95 | 350 | 32 | 20 | 15 | 20 | 5  |

### Record 4: Method Control Integers

Only used when program control integer NCON > 0 (Record 2).

I Integer descriptor number of MCI being redefined

J(I) Integer value of MCI(I)

Notes: (a) Acceptable I and J(I) values are shown in Table A.1, below.

| Table A.1: Method Control Integers |                                    |      |                                              |                  |
|------------------------------------|------------------------------------|------|----------------------------------------------|------------------|
| I                                  | Name                               | J(I) | Option                                       | Additional Input |
| 1                                  | IDIMEN<br>Characteristic Dimension | 0    | displacement (t:ton)                         | no               |
|                                    |                                    | 1    | length (m:ft)                                | no               |
|                                    |                                    | 2    | beam (m:ft)                                  | no               |
|                                    |                                    | 3    | draft (m:ft)                                 | no               |
| 2                                  | IRESID<br>Residuary Resistance     | 0    | NRC FSS                                      | no               |
|                                    |                                    | 1    | other SHOP5 database                         | no               |
| 3                                  | IAPPND<br>Appendage Resistance     | 0    | SHOP5                                        | no               |
|                                    |                                    | 1    | user-defined                                 | Record 7         |
| 4                                  | IPROP<br>Propulsive Efficiency     | 0    | SHOP5 CPP                                    | no               |
|                                    |                                    | 1    | SHOP5 fixed pitch                            | no               |
|                                    |                                    | 2    | user-defined OPCs                            | Record 8         |
| 5                                  | ISTRUC<br>Structural Material      | 0    | homogeneous                                  | no               |
|                                    |                                    | 1    | hybrid                                       | Record 9         |
| 6                                  | IENGIN<br>Propulsion System        | 0    | SHOP5 rubber engines                         | no               |
|                                    |                                    | 1    | user-defined rubber engines                  | Record 10A       |
|                                    |                                    | 2    | SHOP5 real engines                           | Record 10B       |
|                                    |                                    | 3    | user-defined real engines                    | Record 10C       |
| 7                                  | ICONFG<br>Engine Configuration     | 0    | fixed configuration                          | no               |
|                                    |                                    | 1    | variable configuration                       | Record 10D       |
| 8                                  | IGEN<br>Electrical Generation      | 0    | SHOP5 diesel                                 | no               |
|                                    |                                    | 1    | SHOP5 gas turbine                            | no               |
|                                    |                                    | 2    | user-defined                                 | Record 11        |
|                                    |                                    | 3    | SHOP5 integrated                             | no               |
| 9                                  | IVOLUM<br>Superstructure Volume    | 0    | V <sub>super</sub> fixed                     | no               |
|                                    |                                    | 1    | V <sub>super</sub> = f(V <sub>combat</sub> ) | Record 12        |
|                                    |                                    | 2    | V <sub>super</sub> = f(GM/B)                 | Record 12        |
| 10                                 | ICOST<br>Cost Factors              | 0    | SHOP5                                        | no               |
|                                    |                                    | 1    | user-defined                                 | Record 13        |

(b) IDIMEN and ICONFG are not explicitly defined as method control integers in FIVPRE.

Order of input: I J

for example: 1 1 (i.e. characteristic dimension: length)

(NCON = 3) 6 2 (i.e. propulsion system: SHOP5 real engines)

7 1 (i.e. electrical generators: SHOP5 gas turbines)

### Record 5: Optional Input Parameters

Only used when program control integer NOPT > 0 (Record 2).

I Integer descriptor number of parameter being redefined

X(I) Real or integer value of parameter(I)

Note: see Appendix B (page 48) for values of I and X(I).

Order of input: I X(I)  
for example: 1 10 (i.e. D = 10 m)  
(NOPT = 4) 5 220 (i.e. N = 220)  
8 -15 (i.e. L<sub>damage</sub>/L = 15)  
41 -16 (i.e. V<sub>n</sub>/N = 16 m<sup>3</sup>/person)

### Record 6: Design Criteria

Only used when program control integer NLIM > 0 (Record 2).

I Integer descriptor number of criterion being redefined

X(I) Real or integer value of criterion(I)

Notes: (a) Acceptable input for I and X(I) are shown in the Table A.2, below.

| Table A.2: Redefinable Design Criteria |         |                    |                                                            |
|----------------------------------------|---------|--------------------|------------------------------------------------------------|
| I                                      | Name    | Default            | User-Supplied Input, X(I)                                  |
| 1                                      | WetMax  | 60 wetness/hour    | WetMax = X(I)                                              |
| 2                                      | AccMax  | 0.20 gravities     | AccMax = X(I)                                              |
| 3                                      | SlmMax  | 0.20               | SlmMax = X(I)                                              |
| 4                                      | EffMin  | 50.0 percent       | EffMin = X(I)                                              |
| 7                                      | OPCmin  | 0.60               | OPCmin = X(I)                                              |
| 10                                     | KGmax   | calculated         | X(I) > 0 ⇒ KGmax = X(I)<br>X(I) < 0 ⇒ KGmax/D =  X(I)      |
| 11                                     | Vcombat | Vcombat/Vt = 0.125 | X(I) > 0 ⇒ Vcombat = X(I)<br>X(I) < 0 ⇒ Vcombat/Vt =  X(I) |

(b) The missing I values in Table A.2 are for design criteria that cannot be redefined by user-supplied input (e.g. minimum freeboard for reserve buoyancy).

Order of input: I X  
for example: 1 30 (i.e. WetMax = 30)  
(NLIM = 2) 11 2900 (i.e. Vcombat = 2900 m<sup>3</sup>)

### Record 7: Appendage Resistance Coefficient

Only used when method control integer IAPPND = 1 (Record 4).

Capp      Appendage resistance coefficient, dimensionless

Note: input must be defined; input of zero gives Rapp = 0

### Record 8: Overall Propulsive Coefficients

Only used when method control integer IPROP = 2 (Record 4).

OPC(Vd)    Overall propulsive coefficient at design speed

OPC(Vc)    Overall propulsive coefficient at cruise speed

OPC(Ve)    Overall propulsive coefficient at endurance speed

Note: input must be defined for all parameters; no defaults available.

|                        |         |         |         |
|------------------------|---------|---------|---------|
| <u>Order of input:</u> | OPC(Vd) | OPC(Vc) | OPC(Ve) |
| for example:           | 0.615   | 0.654   | 0.682   |

### Record 9: Superstructure Material

Only used when method control integer ISTRUC = 1 (Record 4).

SSdens      Density of superstructure material (t/m<sup>3</sup>:ton/ft<sup>3</sup>)  
Default (SSdens = 0): aluminum, SSdens = 2.81 t/m<sup>3</sup> (0.075 ton/ft<sup>3</sup>)

SStkck      Average thickness of superstructure material (m:ft)  
Default (SStkck = 0): aluminum, SStkck = 0.016 m (0.053 ft)

Note: input must be defined for both parameters; enter zero for default(s).

|                        |        |        |                                                          |
|------------------------|--------|--------|----------------------------------------------------------|
| <u>Order of input:</u> | SSdens | SStkck |                                                          |
| for example:           | 0.0    | 0.020  | (i.e. SSdens = 2.81 t/m <sup>3</sup> , SStkck = 0.020 m) |

### Record 10: Propulsion System

Only used when method control integer  $IENGINE > 0$  and/or  $ICH00S = 1$  (Record 4).  
The propulsion system sub-record structure is defined in Table A.3, below.

| Table A.3: Propulsion System Sub-Records |            |                                   |
|------------------------------------------|------------|-----------------------------------|
| $IENGINE = 1$                            | Record 10A | user-defined rubber engines       |
| $IENGINE = 2$                            | Record 10B | SHOP5 real engine database        |
| $IENGINE = 3$                            | Record 10C | user-defined real engine database |
| $ICONFG = 1$                             | Record 10D | variable engine configuration     |

### Record 10A: User-Defined Rubber Engines

Only used when method control integer  $IENGINE = 1$  (Record 4).

**SpW2** Propulsion system specific weight,  $W2/Pins$  (kg/kW:lb/HP)  
Default ( $SpW2 = 0$ ): SHOP5 rubber engines, approximates COGOG

**KG2** Propulsion system vertical centre of gravity (m:ft)  $-[KG2/D]$   
Default ( $KG2 = 0$ ):  $KG2/D = 0.4$

**Nsfc** Number of (SFCr,  $P/Pins$ ) data-pairs input below,  $0 \leq Nsfc \leq 11$   
Default ( $Nsfc = 0$ ): SHOP5 rubber engines, approximates COGOG  
and SFCr(I) and  $P/Pins(I)$  not input.

**SFCr(I)** Specific fuel consumption (kg/kW-hr:lb/HP-hr) at power ratio  $P/Pins(I)$   
Note: SFCr(1) must be full power SFC, SFCo

**$P/Pins(I)$**  Power ratio (operating power/installed power) for SFCr(I)  
Notes: (a)  $P/Pins(1)$  must = 1.00 (i.e. full power)  
(b)  $P/Pins$  values must be in descending order  
(i.e.  $P/Pins(I+1) < P/Pins(I)$ )

|                        |                   |                                  |             |
|------------------------|-------------------|----------------------------------|-------------|
| <u>Order of input:</u> | <b>SpW2</b>       | <b>KG2</b>                       | <b>Nsfc</b> |
|                        | <b>SFCr(1)</b>    | <b><math>P/Pins(1)</math></b>    |             |
|                        | <b>SFCr(2)</b>    | <b><math>P/Pins(2)</math></b>    |             |
|                        | ...               | ...                              |             |
|                        | <b>SFCr(Nsfc)</b> | <b><math>P/Pins(Nsfc)</math></b> |             |

|              |      |      |   |
|--------------|------|------|---|
| for example: | 5.36 | -0.3 | 4 |
|              | 0.20 | 1.00 |   |
|              | 0.23 | 0.80 |   |
|              | 0.28 | 0.60 |   |
|              | 0.38 | 0.40 |   |

### Record 10B: SHOP5 Real Engines

Only used when method control integer IENGINE = 2 (Record 4).

ITYPE      Type of engine configuration per shaft,  $1 \leq \text{ITYPE} \leq 6$

- 1   Single gas turbine
- 2   COGAG
- 3   COGOG
- 4   CODAG
- 5   CODOG
- 6   CODAD

IDBASE      Engine data base selection,  $0 \leq \text{IDBASE} \leq 1$

- 0   1980 engine data base, see Table A.4
- 1   1995 engine data base, see Table A.5

| Table A.4: 1980 Engine Data Base |        |        |        |                                       |                                       |          |       |
|----------------------------------|--------|--------|--------|---------------------------------------|---------------------------------------|----------|-------|
| Name                             | Type   | $P_i$  |        | $SFC_o$                               |                                       | $W_{2a}$ |       |
|                                  |        | (kW)   | (HP)   | $\left(\frac{kg}{kW \cdot hr}\right)$ | $\left(\frac{lb}{HP \cdot hr}\right)$ | (tonne)  | (ton) |
| LM 2500                          | g.t.   | 18,650 | 25,000 | 0.23                                  | 0.38                                  | 15.65    | 15.40 |
| Spey                             | g.t.   | 11,936 | 16,000 | 0.24                                  | 0.39                                  | 9.30     | 9.15  |
| DDA 570                          | g.t.   | 4,774  | 6,400  | 0.28                                  | 0.46                                  | 2.27     | 2.23  |
| Pielstick                        | diesel | 5,371  | 7,200  | 0.23                                  | 0.38                                  | 42.98    | 42.30 |
| MTU                              | diesel | 3,730  | 5,000  | 0.23                                  | 0.38                                  | 33.83    | 33.30 |

| Table A.5: 1995 Engine Data Base |        |        |        |                                       |                                       |          |       |
|----------------------------------|--------|--------|--------|---------------------------------------|---------------------------------------|----------|-------|
| Name                             | Type   | $P_i$  |        | $SFC_o$                               |                                       | $W_{2a}$ |       |
|                                  |        | (kW)   | (HP)   | $\left(\frac{kg}{kW \cdot hr}\right)$ | $\left(\frac{lb}{HP \cdot hr}\right)$ | (tonne)  | (ton) |
| LM 5000                          | g.t.   | 44,760 | 60,000 | 0.21                                  | 0.34                                  | 35.15    | 34.60 |
| FT 9                             | g.t.   | 33,570 | 45,000 | 0.21                                  | 0.35                                  | 21.09    | 20.76 |
| LM 2500                          | g.t.   | 22,380 | 30,000 | 0.22                                  | 0.37                                  | 15.65    | 15.40 |
| Spey                             | g.t.   | 17,904 | 24,000 | 0.23                                  | 0.38                                  | 9.30     | 9.15  |
| DDA 570                          | g.t.   | 5,968  | 8,000  | 0.28                                  | 0.46                                  | 2.27     | 2.23  |
| Pielstick                        | diesel | 7,460  | 10,000 | 0.23                                  | 0.38                                  | 42.98    | 42.30 |
| MTU                              | diesel | 4,476  | 6,000  | 0.23                                  | 0.38                                  | 33.83    | 33.30 |

Order of input:    ITYPE    IDBASE

for example:      2            0            (i.e. COGAG configuration, 1980 data base)

## Record 10C: User-defined Real Engines

**Only used when method control integer IENGIN = 3 (Record 4).**

**ITYPE**      Type of engine configuration per shaft,  $1 \leq \text{ITYPE} \leq 6$

- 1 Single gas turbine
- 2 COGAG
- 3 COGOG
- 4 CODAG
- 5 CODOG
- 6 CODAD

**SpW2b**      **Specific weight of propulsion system not including engines**

$$SpW2b = (W2 - (W2a)Nshaft) / Pins \text{ (kg/kW:lb/HP)}$$

**Default (SpW2b = 0):** Nshaft = 2, SpW2 = 7.72 kg/kW (12.7 lb/HP)

**Nshaft = 1, SpW2 = 7.30 kg/kW (12.0 lb/HP)**

**KG2      Propulsion system vertical centre of gravity (m:ft) - [KG2/D]**

**Default (KG2 = 0):**  $KG2/D = 0.4$

**Nturb**      Number of gas turbine engines,  $0 \leq \text{Nturb} \leq 8$

NAME(I) Name of engine(I), maximum 16 characters

**P<sub>1</sub>(I)**      **Full power of engine(I) (kW:HP)**

**SFCo(I)** Full power specific fuel consumption of engine(I) (kg/kW-hr:lb/HP-hr)

**W2a(I)**      **Weight of engine(I) (t:ton), includes acoustic isolation module**

**Ndies**      Number of diesel engines,  $0 \leq \text{Ndies} \leq 4$

**NAME(I)**    Name of engine(I), maximum 16 characters

**P1(I) Full power of engine(I) (kW:HP)**

**SFCo(I)** Full power specific fuel consumption of engine(I) (kg/kW-hr:lb/HP-hr)

**W2a(I)**      **Weight of engine(I) (t:ton), includes acoustic isolation module**

**Notes:** (a) ITYPE, SpW2b, KG2, Nturb and Ndis must be input. If Nturb and/or Ndis is zero, corresponding NAME, Pi, SFCO and W2a are not input.

(b) Order of input and example input are on next page.

|                        |             |             |            |
|------------------------|-------------|-------------|------------|
| <u>Order of input:</u> | ITYPE       | SpW2b       | KG2        |
|                        | Nturb       |             |            |
|                        | NAME(1)     |             |            |
|                        | Pi(1)       | SFCo(1)     | W2a(1)     |
|                        | NAME(2)     |             |            |
|                        | Pi(2)       | SFCo(2)     | W2a(2)     |
|                        | ...         |             |            |
|                        | ...         | ...         | ...        |
|                        | NAME(Nturb) |             |            |
|                        | Pi(Nturb)   | SFCo(Nturb) | W2a(Nturb) |
|                        | Ndies       |             |            |
|                        | NAME(1)     |             |            |
|                        | Pi(1)       | SFCo(1)     | W2a(1)     |
|                        | NAME(2)     |             |            |
|                        | Pi(2)       | SFCo(2)     | W2a(2)     |
|                        | ...         |             |            |
|                        | ...         | ...         | ...        |
|                        | NAME(Nturb) |             |            |
|                        | Pi(Ndies)   | SFCo(Ndies) | W2a(Ndies) |

|              |                |      |       |
|--------------|----------------|------|-------|
| for example: | 5              | 7.2  | -0.35 |
|              | 3              |      |       |
|              | BIG TURBINE    |      |       |
|              | 20000.         | 0.20 | 25.0  |
|              | MEDIUM TURBINE |      |       |
|              | 15000.         | 0.22 | 12.0  |
|              | SMALL TURBINE  |      |       |
|              | 7500.          | 0.24 | 3.0   |
|              | 2              |      |       |
|              | BIG DIESEL     |      |       |
|              | 10000.         | 0.21 | 45.5  |
|              | SMALL DIESEL   |      |       |
|              | 4000.          | 0.21 | 30.0  |

### Record 10D: Variable Engine Configuration

Only used when method control integer ICH00S = 1 (Record 4).

This option should be used with caution, see Reference 1 for further comments.

**IHIAR** Integer descriptor of engine configuration hierarchy,  $0 \leq \text{IHIAR} \leq 3$

- 0 SHOP5 noise hierarchy, see Table A.6
- 1 SHOP5 gearing hierarchy, see Table A.6
- 2 SHOP5 powering hierarchy, see Table A.6
- 3 User-defined hierarchy, see NHIAR(I), below.

| Table A.6: SHOP5 Hierarchies |         |        |
|------------------------------|---------|--------|
| Noise                        | Gearing | Power  |
| CODAD                        | CODAG   | COGAG  |
| CODAG                        | COGAG   | CODAG  |
| COGAG                        | COGOG   | COGOG  |
| CODOG                        | CODOG   | CODOG  |
| COGOG                        | CODAD   | CODAD  |
| Single                       | Single  | Single |

**NHIAR(I)** Integer descriptors of user-defined engine configuration hierarchy,

- Notes:
- (a) NHIAR values only input when IHIAR = 3
  - (b) When used, six values for NHIAR must be input
  - (c) NHIAR integer descriptors shown in Table A.7

| Table A.7: Hierarchy Descriptors |                            |
|----------------------------------|----------------------------|
| NHIAR                            | Configuration<br>per shaft |
| 1                                | Single gas turbine         |
| 2                                | COGAG                      |
| 3                                | COGOG                      |
| 4                                | CODAG                      |
| 5                                | CODOG                      |
| 6                                | CODAD                      |

Order of input: IHIAR

NHIAR(1) NHIAR(2) NHIAR(3) NHIAR(4) NHIAR(5) NHIAR(6)

for example: 3

6 5 4 3 2 1

### Record 11: Electrical Generation System

Only used when method control integer IGEN = 2 (Record 4).

SpW3      Specific weight of electrical systems (kg/kW:lb/kW)  
             $SpW3 = W3/P_{gen}$   
            Default (SpW3 = 0): SHOP5 diesel generators

KG3      Electrical systems vertical centre of gravity (m:ft) -[KG3/D]  
            Default (KG3 = 0): SHOP5 calculation

SFCg      Specific fuel consumption of generators (kg/kW-hr:lb/kW-hr)  
            Default (SFCg = 0): SHOP5 diesel generators

Order of input:   SpW3   KG3   SFCg

for example:   50.0   -0.75   0.0

### Record 12: Superstructure Size Variations

Only used when method control integer IVOLUM > 0 (Record 4).

VsMin      Minimum superstructure volume (m<sup>3</sup>:ft<sup>3</sup>) -[VsMin/Vt]  
            Default (VsMin = 0): SHOP5 calculation, assumes hangar

VsMax      Maximum superstructure volume (m<sup>3</sup>:ft<sup>3</sup>) -[VsMax/Vt]  
            Default (VsMax = 0): SHOP5 calculation

GM/B      Target value for metacentric height/beam ratio, see note (a).  
            Default (GM/B = 0): GM/B = 0.10

Notes:   (a)   GM/B only input when IVOLUM = 2.  
            (b)   When IVOLUM = 1, target value for combat systems volume is defined by  
                Vcombat, design criterion (Record 6).

Order of input:   VsMin   VsMax   GM/B   (assume IVOLUM = 2)

for example:   1750.   -0.32   0.08

### Record 13: Cost Factors

Only used when method control integer ICOST = 1 (Record 4).

NCOST      Number of cost factors being redefined

I            Integer descriptor of cost factor being defined,  $1 \leq I \leq 16$

AK(I)      New value of cost factor(I)

Note: Table A.8 shows the cost categories for each value of I and also shows the SHOP5 default AK(I) values. See Reference 1 for information on the cost estimating equations and units of cost factors.

| Table A.8: Cost Factors |                                          |                  |
|-------------------------|------------------------------------------|------------------|
| I                       | Cost Category                            | Default<br>AK(I) |
| 1                       | Hull structure                           | 18.00            |
| 2                       | Superstructure,      MCI ISTRUC = 0      | 18.00            |
|                         | ISTRUC = 1                               | 40.00            |
| 3                       | Not used by SHOP5                        | -                |
| 4                       | Diesel engines                           | 1.25             |
| 5                       | Gas turbine engines                      | 3.25             |
| 6                       | Electrical systems                       | 150.00           |
| 7                       | Auxiliary systems                        | 90.00            |
| 8                       | Outfit and furnishings                   | 65.00            |
| 9                       | Shipyard construction                    | 1.00             |
| 10                      | Design and engineering, lead ship        | 0.50             |
| 11                      | Design and engineering, follow-on ship   | 0.05             |
| 12                      | Construction services                    | 0.40             |
| 13                      | Shipyard profit, lead ship               | 1.15             |
| 14                      | Shipyard profit, follow-on ship          | 1.15             |
| 15                      | Miscellaneous surcharges, lead ship      | 1.33             |
| 16                      | Miscellaneous surcharges, follow-on ship | 1.28             |

Order of input:    NCOST

                      I(1)      AK(1)

                      I(2)      AK(2)

                      ...

                      I(NCOST)    AK(NCOST)

for example:    3

                      1            15.5

                      7            75.0

                      13          1.01

### Example Input File

Table A.9 contains an example input file which defines input for most of the SHOP5 input records. This example input file is the same as the first file produced in the design optimization example in Appendix C. The ".....Record (i)" notation in Table A.9 is only included for identifying individual input records; it is not normally present.

Table A.9: Example Input File

|                                         |           |       |       |       |       |      |   |       |  |             |
|-----------------------------------------|-----------|-------|-------|-------|-------|------|---|-------|--|-------------|
| DESIGN OPTIMIZATION, COGAG CONFIG. .... |           |       |       |       |       |      |   |       |  | Record (1)  |
| 0                                       | 3         | 1     | 0     | 0     | 2     | 6    | 2 | ..... |  | Record (2)  |
| 3500.000                                | 4500.000  |       | 8     |       | ..... |      |   |       |  | Record (3A) |
| 7.000                                   | 9.000     |       | 5     |       |       |      |   |       |  | " "         |
| 0.590                                   | 0.590     |       | 1     |       |       |      |   |       |  | " "         |
| 0.490                                   | 0.490     |       | 1     |       |       |      |   |       |  | " "         |
| 2.800                                   | 3.200     |       | 5     |       |       |      |   |       |  | " "         |
| 4500.00                                 | 375.00    | 30.00 | 20.00 | 20.00 | 20.00 | 5.00 |   |       |  | " "         |
| 6                                       | 2         | ..... |       |       |       |      |   |       |  | Record (4)  |
| 9                                       | 11        |       |       |       |       |      |   |       |  | " "         |
| 1                                       | 10.0000   |       | ..... |       |       |      |   |       |  | Record (5)  |
| 5                                       | -0.8800   |       |       |       |       |      |   |       |  | " "         |
| 8                                       | -0.1500   |       |       |       |       |      |   |       |  | " "         |
| 19                                      | 4000.0000 |       |       |       |       |      |   |       |  | " "         |
| 33                                      | 50.0000   |       |       |       |       |      |   |       |  | " "         |
| 41                                      | -16.0000  |       |       |       |       |      |   |       |  | " "         |
| 1                                       | 30.0000   |       | ..... |       |       |      |   |       |  | Record (6)  |
| 11                                      | 2900.0000 |       |       |       |       |      |   |       |  | " "         |
| 2                                       | 0         | ..... |       |       |       |      |   |       |  | Record (10) |
| 2                                       | -0.3000   |       | ..... |       |       |      |   |       |  | Record (12) |

## Appendix B: Optional Input Parameters

SHOP5 uses a total of 44 optional input parameters to define details of geometry, systems, environment and design margins. Each optional input parameter has a default value or method which is used when the parameter is not explicitly re-defined by the user. The algorithms used to calculate the defaults are described in Reference 1.

This appendix describes the optional input parameters, including; names, descriptions, units and defaults. Most names are either a standard symbol (e.g.  $C_w$  for waterplane coefficient) or descriptive abbreviation (e.g.  $N_{shaft}$  for number of propeller shafts). The names are shown in the lineprinter format, which is also used on-screen by FIVPRE and FIVPOS, and on the SHOP5 and FIVPOS lineprinter output. When using program FIVPRE to prepare the SHOP5 input file, individual optional input parameters can be accessed using the CHANGE command (abbreviation C). The parameter is identified by entering either its name or part of its description (e.g. C CW or C WAT COEF).

This appendix uses the following format to describe each parameter.

I   name        description (units)   -[negative definition]  
                 default value or method, and special notes

where I is the integer descriptor number defined in Record 5, Appendix A.

As indicated above, many of the optional input parameters accept either positive or negative input. In most cases, negative input defines a non-dimensional form of the parameter. For example (in metric units), input of 10 for midship hull depth, D, defines  $D = 10$  metres; whereas, input of -12 defines the ratio  $L/D = 12$ . When negative input changes the definition of a parameter, then two names are shown. For example, consider the margin on personnel volume,  $dV_n$ , which has the following description.

41  $dV_n$         Margin on personnel volume,  $V_n$  ( $m^3:ft^3$ )   -[ $V_n/N$ ]  
      $V_n/N$         Standard of Accomodation ( $m^3/person:ft^3/person$ )  
                  $V_n/N$  is not a margin

This parameter has two definitions: for positive input, it is a margin,  $dV_n$  ( $m^3:ft^3$ ), which is added to the SHOP5 estimate for personnel volume,  $V_n$ ; for negative input, it is the standard of accomodation (personnel volume/person ratio),  $V_n/N$  ( $m^3/person:ft^3/person$ ). For example (in metric units), input of 200 for  $dV_n$  defines  $dV_n = 200 m^3$ , and the SHOP5 estimate for  $V_n$  is increased by  $200 m^3$ . Conversely, input of -16 for  $dV_n$  defines  $V_n = 16 N$  ( $m^3/person$ ), and the SHOP5 algorithm for estimating  $V_n$  is not used.

The optional input parameters are grouped in categories defined by the FIVPRE menu shown below. This menu provides indirect access to all of the optional input parameters, and is used by the commands NEW and CHANGE OPTIONAL INPUT (i.e. C OPT).

#### OPTIONAL INPUT

- 1 GEOMETRY AND COMPLEMENT
- 2 SEAKEEPING
- 3 POWERING AND MACHINERY
- 4 STRUCTURE
- 5 WEIGHT AND STABILITY
- 6 VOLUME
- 7 MISSION

#### GEOMETRY AND COMPLEMENT

- 1 D Midship hull depth (m:ft)  $-[L/D]$   
Default:  $D = T + 0.04 L$
- 2 Cw Waterplane coefficient  
Default:  $Cw = 0.78 C_p + 0.33$
- 3 LCB Longitudinal centre of buoyancy (m:ft)  $-[LCB/L]$   
Default:  $LCB/L = 0.515$
- 4 LCF Longitudinal centre of flotation (m:ft)  $-[LCF/L]$   
Default:  $LCF/L = 0.557$
- 5 N Complement (accommodations)  $-[N/DISP^{2/3}]$   
Default:  $N/DISP^{2/3} = 1.0$  (person/t)
- 6 Ndeck Number of internal decks (m:ft)  $-[Dstruc]$   
Dstruc Hull depth to strength deck (m:ft)  
Default:  $Ndeck = D/2.59 - 1$  (m)
- 7 Nbulk Number of watertight compartments  $-[Lbulk]$   
Lbulk Average bulkhead spacing (m:ft)  
Default:  $Nbulk = SHOP5$  calculation
- 8 C Standard of compartmentation  $-[Ldamage/L]$   
Ldamage Flooded length (note, defined as  $Ldamage/L$ )  
Default:  $C = 3$
- 9 Lsuper Superstructure length (m:ft)  $-[Lsuper/L]$   
Default:  $Lsuper/L = 0.55$

## SEAKEEPING

- 
- 10 Ffp      Freeboard at FP (m:ft)     $-[Ffp/L]$   
             Default:  $Ffp/L = 0.093 - 0.00021 L$
- 11 To        Wave modal period, seakeeping (sec)  
             Default:  $To = f(Hw)$ , winter North Atlantic
- 12 AccHi     RMS vertical acceleration for zero percent crew effectiveness  
             Default:  $AccHi = 0.25$  (gravities)
- 13 AccLo     RMS vertical acceleration for 100 percent crew effectiveness  
             Default:  $AccLo = 0.05$  (gravities)

## POWERING AND MACHINERY

- 
- 14 Ca        Model-ship correlation allowance  
             Default:  $Ca = 0.0005$
- 15 dPe       Design margin on effective power,  $Pe$   
              $Pe = (1 + dPe) Rt V$   
             Default:  $dPe = 0.10$  (i.e. 10 percent)
- 16 DIAM      Propeller diameter (m:ft)     $-[DIAM/T]$   
             Default:  $DIAM/T = 1.0$  for  $Nshaft = 2$   
                      $DIAM/T = 1.1$  for  $Nshaft = 1$
- 17 Nshaft    Number of propeller shafts  
             Default:  $Nshaft = 2$
- 18 Ngen       Number of ship service electrical generators  
             Default:  $Ngen = 4$
- 19 Pgen       Electrical power installed (kW)     $-[Pgen/DISP]$   
             Default:  $Pgen/DISP = 1.0$  (kW/t)
- 20 avPgen    Average cruising electrical power (kW)     $-[avPgen/Pgen]$   
             Default:  $avPgen/Pgen = 0.25$
- 21 Hw(r)     Significant wave height for powering and range (m:ft)     $-[Hw(r)/L]$   
             Default:  $Hw(r) = 3.0$  (m)
- 22 To(r)     Wave modal period for powering and range (sec)  
             Default:  $To(r) = f(Hw(r))$ , winter North Atlantic

## STRUCTURE

- 23 YIELD Yield strength of hull material (ton/in<sup>2</sup>:t/cm<sup>2</sup>)  
Default: steel, YIELD = 2.835 t/cm<sup>2</sup> (18.0 ton/in<sup>2</sup>)
- 24 DENS Density of hull material (ton/ft<sup>3</sup>:t/m<sup>3</sup>)  
Default: steel, DENS = 7.858 t/m<sup>3</sup> (0.219 ton/ft<sup>3</sup>)
- 25 Fmod Factor on structural modulus  
Fmod multiplies midship sectional modulus  
Default: Fmod = 1.0

## WEIGHT AND STABILITY All default values for weight margins are zero.

- 26 dW1 Margin on structural weight, W1 (ton:t) -[dW1/W1]
- 27 dW2 Margin on machinery weight, W2 (ton:t) -[dW2/W2]
- 28 RAFT Margin on engine rafting (ton:t) -[RAFT/W2]
- 29 GEAR Margin on gear box weight (ton:t) -[GEAR/Pins]
- 30 dW3 Margin on electrical systems weight, W3 (ton:t) -[dW3/W3]
- 31 dW5 Margin on auxiliary systems weight, W5 (ton:t) -[dW5/W5]
- 32 dW6 Margin on outfit and furnishings weight, W6 (ton:t) -[dW6/W6]
- 33 dWb Margin on Wbasic, (ton:t) -[dWb/Wb]  
Wbasic = W1 + W2 + W3 + W5 + W6  
Use dWb for future growth margin
- 34 dWd Margin on disposable loads weight, Wd (ton:t) -[dWd/Wd]
- 35 KGb Vertical centre of gravity of dWb (m:ft) -[KGb/D]  
Default: KGb/D = 0.65
- 36 KGc Vertical centre of gravity of Wcombat (m:ft) -[KGc/D]  
Default: KGc/D = 1.00

VOLUME All default values for volume margins are zero.

-----

- 37  $V_{super}$  Superstructure volume ( $m^3:ft^3$ )  $-[V_{super}/V_t]$   
 $V_{super}$  only used when method control integer IVOLUM = 0  
 Default:  $V_{super}/V_t = 0.30$
- 38  $dV_m$  Margin on machinery volume,  $V_m$  ( $m^3:ft^3$ )  $-[V_m/Pins]$   
 $V_m/Pins$  Propulsion system volume/installed power ratio ( $m^3/kW:ft^3/HP$ )  
 $V_m/Pins$  is not a margin
- 39  $dV_o$  Margin on outfit and systems volume,  $V_o$  ( $m^3:ft^3$ )  $-[V_o/V_t]$   
 $V_o/V_t$  Outfit and systems volume/Total enclosed volume ratio (dimensionless)  
 $V_o/V_t$  is not a margin
- 40  $dV_b$  Margin on  $V_{basic}$  ( $m^3:ft^3$ ),  $V_{basic} = V_m + V_o$   $-[dV_b/V_t \text{ or } dV_{hull}]$   
 $dV_{hull}$  Reduction in calculated hull volume ( $m^3:ft^3$ ),  
 $0 < \text{input} \Rightarrow dV_b, V_{basic} = V_m + V_o + dV_b$   
 $-1 \leq \text{input} \leq 0 \Rightarrow dV_b/V_t, V_{basic} = V_m + V_o + V_t|dV_b/V_t|$   
 $\text{input} < -1 \Rightarrow dV_{hull}, V_{hull} = V_{hull} - |dV_{hull}|$   
 $dV_{hull}$  is not a margin
- 41  $dV_n$  Margin on personnel volume,  $V_n$  ( $m^3:ft^3$ )  $-[V_n/N]$   
 $V_n/N$  Standard of Accomodation ( $m^3/person:ft^3/person$ )  
 $V_n/N$  is not a margin

MISSION

-----

- 42  $T_d/T$  Normalized time at design speed,  $V_d$   
 Default:  $T_d/T = 0.05$
- 43  $T_c/T$  lizedtime at cruise speed,  $V_c$   
 Default:  $T_d/T = 0.30$
- 44  $T_e/T$  Normalized time at endurance speed,  $V_e$   
 Default:  $T_d/T = 0.65$

## Appendix C: Design Optimization Example, Session 1

This example terminal session demonstrates using FIVPRE to define a new SHOP5 input file and illustrates the iterative process of running SHOP5, examining ships with FIVPOS and re-defining the initial input to home-in on a desirable design candidate. None of the ships generated on the initial run have sufficient range at 30 knots, but some interesting trends regarding platform acquisition cost, range and superstructure volume are evident.

Most program menus for controlling input are shown only once; however, editorial comments indicate where text has been omitted. Editorial comments are delimited as follows,

---<editorial comments>---

All user-supplied input follows a "=" prompt. When no input is shown after this prompt, then the user has simply pushed the Return\_key (i.e. "null" input), and a default response is used. The default response (or action) is defined within <...> brackets in the prompt-line. When no default response is defined, then null input means "preserve the current value".

```
SHOP5 System: Program Control

1 Run FIVPRE
2 Run SHOP5
3 Run FIVPOS
4 Lineprinter Control
5 Edit
6 Help
99 EXIT
```

Enter NUMBER => 1

```

FIVPRE, Pre-processor for SHOP5

```

reading library file.....

FIVPRE: enter command => NEW

Enter TITLE => design optimization, COGAG config.

Program Control Integers (PCI)

```

MODE

0 SEARCH
1 DESCRIBE
```

MODE ? <SEARCH> =>

#### UNITS

0 Input: FPS Output: FPS  
1 Input: metric Output: FPS  
2 Input: FPS Output: metric  
3 Input: metric Output: metric

UNITS ? <metric-metric> =>

#### POST-PROCESSOR

0 NO, Post-processor (FIVPOS) will NOT be used  
1 YES, Post-processor will be used

POST-PROCESSOR ? <Yes> =>

#### LEGEND

0 NO Legend  
1 Legend of SHOP5 abbreviations written on lineprinter

LEGEND ? <No> =>

#### Characteristic Dimension (XXX)

0 Displacement (full load)  
1 Length  
2 Beam  
3 Draft

Enter selection <Displacement> =>

#### Primary Input (PRIM)

|                                |                     |      |
|--------------------------------|---------------------|------|
| DISP; Displacement (t:ton)     | Minimum =>          | 3500 |
|                                | Maximum =>          | 4500 |
|                                | Number of values => | 6    |
| CrM; Length/Displacement Ratio | Minimum =>          | 7    |
|                                | Maximum =>          | 9    |
|                                | Number of values => | 5    |
| Cp; Prismatic Coefficient      | Minimum =>          | .59  |
|                                | Maximum =>          | .59  |
| Cb; Block Coefficient          | Minimum =>          | .49  |
|                                | Maximum =>          | .49  |
| B/T; Beam/Draft Ratio          | Minimum =>          | 2.8  |
|                                | Maximum =>          | 3.2  |
|                                | Number of values => | 5    |

#### Design Requirements

R(Ve); Range at Endurance Speed => 4500  
Wcombat; Combat System Weight (t:ton) => 375  
Vd; Design Speed (kt) => 30  
Vc; Cruise Speed (kt) => 20  
Ve; Endurance Speed (kt) => 20  
Vw; Seakeeping Speed (kt) => 20  
Hw; Seakeeping Wave Height (m:ft) => 5

```

Method Control Integers (MCI)

1 IRESID; Residuary Resistance
2 IAPPND; Appendage Resistance
3 IPROP; Propeller Type or OPC Values
4 ISTRUC; Hull/Superstructure Material
5 IENGIN; Propulsion System
6 IGEN; Ship Service Electrical Generators
7 IVOLUM; Superstructure Sizing Method
8 ICOST; Cost Factors

Enter selection <exit> => 5

Propulsion System (IENGIN)

0 SHOP5 Rubber Engines
1 User-Supplied Rubber Engines
2 SHOP5 Real Engines
3 User-Supplied Real Engines

Enter selection => 2

Engine Data Base

0 1980 Engine Data Base
1 1996 Engine Data Base

Enter selection <1980> =>

Engine Configuration (ITYPE)

1 Single gas turbine
2 COGAG (COMbined Gas And Gas)
3 COGOG (COMbined Gas Or Gas)
4 CODAG (COMbined Diesel And Gas)
5 CODOG (COMbined Diesel Or Gas)
6 CODAD (COMbined Diesel And Diesel)

Enter selection => 2

Engine Configuration Selection

0 SHOP5 must use this Configuration
1 SHOP5 may change Configuration (not recommended)

Enter selection <must use> =>

---<omit MCI menu, select IVOLUM>---

Volume Components (IVOLUM)

0 Vcombat = f(Vsuper)
1 Vsuper = f(Vcombat)
2 Vsuper = f(GM/B)

Enter selection => 1

** WARNING **
You have changed the method for calculating superstructure
volume, Vsuper. Vsuper is now determined by the target
value for combat system volume, Vcombat (design criterion).

```

**\*\* INFORMATION \*\***

The following constraints on  $V_{super}$  are now active.

$V_{sMin}$ ; minimum Superstructure Volume =  $f(L, B, D, N_{deck}, Pins)$

$V_{sMax}$ ; maximum Superstructure Volume =  $f(L_{super}, B, D, N_{deck})$

Note: the current default value for  $V_{sMax}$  permits fairly wide variation of  $V_{super}$ . You can reduce the number of design candidates by defining a more rigorous constraint.

CHANGE  $V_{sMin}$  or  $V_{sMax}$  ? <Yes> =>

**Superstructure Volume Constraints**

1  $V_{sMin}$ ; minimum Superstructure Volume.

2  $V_{sMax}$ ; maximum Superstructure Volume.

Enter selection <exit> => 2

$V_{sMax}$ ; maximum Superstructure Volume =  $f(L_{super}, B, D, N_{deck})$

$V_{sMax}$ ; maximum  $V_{super}$  (m<sup>3</sup>:ft<sup>3</sup>) - [ $V_{sMax}/V_t$ ] => -0.30

---<omit  $V_{sMin}/V_{sMax}$  menu, select Exit>---

---<omit MCI menu, select Exit>---

**Optional Input (OPT)**

1 Geometry and Complement

2 Seakeeping

3 Powering and Machinery

4 Structure

5 Weight and Stability

6 Volume

7 Mission

Enter selection <exit> => 1

**Geometry and Complement**

1 D; Midships Hull Depth

2  $C_w$ ; Waterplane Coefficient

3 LCB; Longitudinal Centre of Buoyancy

4 LCF; Longitudinal Centre of Flotation

5 N; Complement

6  $N_{deck}$ ; Number of Internal Decks [.OR.  $D_{struc}$ ]

7  $N_{bulk}$ ; Number of Watertight Compartments

8 C; Standard of Compartmentation [.OR.  $L_{damage}$ ]

9  $L_{super}$ ; Superstructure Length

Enter selection <exit> => 1

Current Value (Default) =  $D = T + 0.04 L$

D; Midship Hull Depth (m:ft) - [ $L/D$ ] => 10

---<omit Geometry and Complement menu, select N (complement)>---

Current Value (Default) =  $N/(DISP^{(2/3)}) = 1.0$

N; Complement  $-[N/DISP^{(2/3)}] \Rightarrow -0.88$

---<omit Geometry and Complement menu, select C>---

Current Value (Default) = 3 Compartments

C; Standard of Compartmentation  $-[L_{damage}/L] \Rightarrow -0.15$

---<omit Geometry and Complement menu, select Exit>---

---<omit OPT menu, select Powering and Machinery>---

#### Powering and Machinery

- 1 Ca; Model-Ship Correlation Allowance
- 2 dPe; Design Margin on Effective Power
- 3 DIAM; Propeller Diameter
- 4 Nshaft; Number of Propeller Shafts
- 5 Ngen; Number of Electrical Generators
- 6 Pgen; Electrical Power Installed
- 7 avPgen; Average Cruise Electrical Power
- 8 Hw(r); Significant Wave Height (range)
- 9 To(r); Wave Modal Period (range)

Enter selection <exit>  $\Rightarrow$  6

Current Value (Default) =  $Pgen/DISP = [-]1.0$

Pgen; Installed Generator Power (kW)  $-[Pgen/DISP] \Rightarrow 4000$

---<omit Powering and Machinery menu, select Exit>---

---<omit OPT menu, select Weightand Stability>---

#### Weight and Stability

- 1 dW1; Margin on Hull Structure Weight
- 2 dW2; Margin on Propulsion Machinery Weight
- 3 RAFT; Margin on Engine Rafting
- 4 GEAR; Margin on Gear Box
- 5 dW3; Margin on Electrical Weight
- 6 dW5; Margin on Auxiliaries Weight
- 7 dW6; Margin on Outfit & Furnishing Weight
- 8 dWb; Margin on Basic Weight (future growth)
- 9 dWd; Margin on Disposable Weight
- 10 KGb; VCG of Margin on Basic Weight
- 11 KGc; VCG of Combat System Weight

Enter selection <exit>  $\Rightarrow$  8

Current Value (Default) = 0.0

dWb; MARGIN Wb, Basic Weight (t:ton)  $-[dWb/Wb] \Rightarrow 50$

---<omit Weight and Stability menu, select Exit>---

---<omit OPT menu, select Volume>---

Volume  
-----  
1 Vsuper; Superstructure Volume  
2 dVm; Margin on Machinery Volume [.OR. Vm/Pins]  
3 dVo; Margin on Outfit Volume [.OR. Vo/Vt]  
4 dVb; Margin on Basic Volume [.OR. dVhull]  
5 dVn; Margin on Personnel Volume [.OR. Vn/N]  
  
Enter selection <exit> => 5  
  
Current Value (Default) = 0.0  
  
dVn; MARGIN Personnel Volume (m3:ft3) -[Vn/N] => -16.  
  
---<omit Volume menu, select Exit>---  
---<omit OPT menu, select Exit>---

#### Design Criteria (CRIT)

-----  
1 WetMax; Number of Deck Wetness/Hour  
2 AccMax; Vertical Acceleration (Stn 4)  
3 SImMax; SIm Force/Displacement  
4 EffMin; Crew Seakeeping Effectiveness  
5 OPCMin; OPC at Endurance Speed  
6 KGmax; Vertical Centre of Gravity  
7 Vcombat; Combat System Volume  
  
Enter selection <exit> => 1  
  
Current Value (Default) = 60.0 (per hour)  
  
WetMax; Maximum Deck Wetnesses/Hour => 30  
  
---<omit CRIT menu, select Vcombat>---  
  
Current Value (Default) = Vcombat/Vt = [-]0.125  
  
Vcombat; Combat System Volume (m3:ft3) -[Vcombat/Vt] => 2900  
  
---<omit MCI menu, select Exit>---  
  
\*\* Input complete \*\*

FIVPRE: enter command => all ---<i.e. show all>---

#### Title

DESIGN OPTIMIZATION, COGAG CONFIG.

#### Program Control Integers (PCI)

-----  
MODE = Search  
Input/Output UNITS = Input: metric Output: metric  
POST-PROCESSOR ? = Yes  
LINEPRINTER OUTPUT ? = No  
LEGEND OF ABBREVIATIONS ? = No

# Primary Input (PRIM)

|                                | Minimum  | Maximum  | Number |
|--------------------------------|----------|----------|--------|
| DISP; Displacement (t:ton)     | 3500.000 | 4500.000 | 6      |
| CrM; Length/Displacement Ratio | 7.000    | 9.000    | 5      |
| Cp; Prismatic Coefficient      | 0.590    | 0.590    | 1      |
| Cb; Block Coefficient          | 0.490    | 0.490    | 1      |
| B/T; Beam/Draft Ratio          | 2.800    | 3.200    | 5      |

|                                          |   |          |
|------------------------------------------|---|----------|
| R(Ve); Range at Endurance Speed (n.mile) | = | 4500.000 |
| Wcombat; Combat System Weight (t:ton)    | = | 375.000  |
| Vd; Design Speed (kt)                    | = | 30.000   |
| Vc; Cruise Speed (kt)                    | = | 20.000   |
| Ve; Endurance Speed (kt)                 | = | 20.000   |
| Vw; Seakeeping Speed (kt)                | = | 20.000   |
| Hw; Seakeeping Wave Height (m:ft)        | = | 5.000    |

## Method Control Integers (MCI)

IDIMEN; Characteristic Dimension; Displacement  
 IRESID; Residuary Resistance; NRC Fast Surface Ship series (FSS)  
 IAPPND; Appendage Resistance; SHOP5 Calculations  
 IPROP; Propeller Type/OPC Values; SHOP5 Calculations, C.P. Propeller  
 ISTRUC; Structure; Homogenous, same material for hull and superstructure  
 \*IENGIN; Propulsion System; SHOP5 Engine Data Base  
 Engine Selection; Must Use Selected Engine Configuration  
 IGEN; Generators; SHOP5 Diesel Generators  
 \*IVOLUM; Volumes;  $V_{super} = f(V_{combat})$   
 ICOST; Cost Factors; SHOP5 Cost Factors (1977 Dollars)

## User-Supplied Optional Input (OPT)

D; Midship Hull Depth (m:ft) -  $[L/D] = 10$   
 N; Complement -  $[N/DISP^{(2/3)}] = -0.880$   
 C; Standard of Compartmentation -  $[L_{damage}/L] = -0.150$   
 Pgen; Installed Generator Power (kW) -  $[Pgen/DISP] = 4000$   
 dWb; MARGIN Wb, Basic Weight (t:ton) -  $[dWb/Wb] = 50$   
 dVn; MARGIN Personnel Volume (m3:ft3) -  $[Vn/N] = -16$

## User-Supplied Design Criteria (CRIT)

WetMax; Max. Number of Deck Wetness/Hour = 30.0  
 Vcombat; Minimum Combat System Volume (m3:ft3) = 2900.0

## Propulsion System (IENGIN); SHOP5 Engine Data Base

ITYPE; Type of engine configuration = COGAG  
 1980 Engine Data Base

Volumes (IVOLUM);  $V_{super} = f(V_{combat})$

VsMin; minimum Superstructure Volume =  $f(L, B, D, N_{deck}, Pins)$   
 VsMax/Vt; maximum Superstructure Volume/total Volume = 0.300

FIVPRE: enter command => z ---<i.e. exit>---

**\*\* WARNING \*\***

You have not SAVED the current file.  
Exit anyway ? <No> =>

FIVPRE: enter command => sa opt1

writing to file OPT1.....  
writing to file FIVIN.....

FIVPRE: enter command => z        ---<i.e. exit>---

saving library file.....

**\*\* FIVPRE Finished \*\***

-----  
---<Note: lines across the page denote execution of a different  
program, accessed through the SHOP5 System Program Control  
menu; subsequent display of this menu are omitted.

**\*\* SHOP5 RUNNING, PLEASE WAIT \*\***

---<00 min. 28 sec. CPU time, VAX 11/750>---

-----  
FIVPOS, Post-processor for SHOP5  
-----

Title: DESIGN OPTIMIZATION, COGAG CONFIG.

8 ships generated.

reading Summary of Rejected Ships....

reading ship data....

**SUMMARY OF REJECTED SHIPS**  
-----

| CONSTRAINT                 | REJECTED |
|----------------------------|----------|
| Deck Wetness               | 16       |
| Vertical Acceleration      | 28       |
| Slam Force                 | 0        |
| Seakeeping Effectiveness   | 0        |
| Midship Freeboard          | 0        |
| Midship Coefficient        | 0        |
| OPC at Endurance Speed     | 0        |
| Engines                    | 0        |
| Range at Endurance Speed   | 63       |
| Vertical Centre of Gravity | 35       |
| Combat System Volume       | 0        |

142 out of 150 ships were REJECTED.

COMMAND MENU

- 1 SELECT PARAMETER
- 2 Re-plot
- 3 Define Window
- 4 Select Ships for Lineprinter
- 5 Select Ships for Transfer to FIVPRE
- 6 Summary of Rejected Ships
- 7 Define Terminal Type
- 8 HELP
- 9 EXIT

Enter selection => 1

PARAMETER CATEGORIES

- 1 Primary Input
- 2 Dimensions and Complement
- 3 Geometric Ratios and Coefficients
- 4 Cost
- 5 Range
- 6 Weight Components
- 7 Volume Components
- 8 Stability
- 9 Seakeeping
- 10 Resistance and Propulsion

Enter selection <exit> => 5

Range

- 27 R(Vd) Range at Design Speed
- 28 R(Vc) Range at Cruise Speed
- 29 R(Ve) Range at Endurance Speed
- 30 R(M) Mission Range
- 31 R(Vd)/Wf Range at Design Speed/Fuel Weight
- 32 R(Vc)/Wf Range at Cruise Speed/Fuel Weight
- 33 R(Ve)/Wf Range at Endurance Speed/Fuel Weight
- 34 R(M)/Wf Mission Range/Fuel Weight

Enter selection <exit> => 27

PARAMETER DEFINITION

- 1 PLOT
- 2 Divide By:
- 3 Select Another Parameter
- 4 Show Selected Parameters
- 5 Reset Selected Parameters
- 6 HELP

Enter selection <exit> => 1

---<see Figure 4 in the main text>---

---<Notes: - All subsequent references to the FIVPOS menus shown above are omitted.  
- See Appendix E for a listing of the FIVPOS parameters.  
- Subsequent graphs for these ships are Figure 5 in the main text and Figures C.1 through C.3

---<on COMMAND menu, select Transfer Ships>---

-----  
SELECT SHIPS FOR TRANSFER TO FIVPRE  
-----

To select individual ships, enter each SHIP NUMBER on a separate line.

To select a range of ships, enter two SHIP NUMBERS on the same line, separated by a blank or comma.

Enter SHIP NUMBER(S) <exit> => 8

Enter SHIP NUMBER(S) <exit> =>

---<on COMMAND menu, select Exit>---

writing Summary of Rejected Ships to lineprinter.....

saving graphs for Re-Plot command.....

saving ships for FIVPRE.....

\*\* FIVPOS Finished \*\*

-----  
FIVPRE, Pre-processor for SHOP5  
-----

reading library file.....

reading ships from FIVPOS.....

Primary Input (PRIM), Geometry

---<automatic display>---

Disp 4500.0

CrM 8.50

Cp 0.590

Cb 0.490

B/T 3.200

FIVPRE: enter command => c mode

---<i.e. CHANGE MODE>---

MODE

0 SEARCH

1 DESCRIBE

MODE ? <SEARCH> =>

Mode Change: DESCRIBE to SEARCH

1 Restore most recent SEARCH mode file

2 Select DESCRIBE mode ship to initialize search space

3 Define search space from scratch.

4 Cancel mode-change

Enter selection <Restore SEARCH> => 2

Rv(e); Range at Endurance Speed => 4500

Primary Input (PRIM)

|                                | Minimum  | Maximum  | Number |
|--------------------------------|----------|----------|--------|
| DISP; Displacement (t:ton)     | 4500.000 | 4500.000 | 1      |
| CrM; Length/Displacement Ratio | 8.500    | 8.500    | 1      |
| Cp; Prismatic Coefficient      | 0.590    | 0.590    | 1      |
| Cb; Block Coefficient          | 0.490    | 0.490    | 1      |
| B/T; Beam/Draft Ratio          | 3.200    | 3.200    | 1      |

R(Ve); Range at Endurance Speed (n.mile) = 4500.000  
Wcombat; Combat System Weight (t:ton) = 375.000  
Vd; Design Speed (kt) = 30.000  
Vc; Cruise Speed (kt) = 20.000  
Ve; Endurance Speed (kt) = 20.000  
Vw; Seakeeping Speed (kt) = 20.000  
Hw; Seakeeping Wave Height (m:ft) = 5.000

FIVPRE: enter command => c crm

|                                | Minimum      | Maximum        | Number                |
|--------------------------------|--------------|----------------|-----------------------|
| CrM; Length/Displacement Ratio | 8.500        | 8.500          | 1                     |
| CrM; Length/Displacement Ratio | Minimum => 8 | Maximum => 8.5 | Number of values => 6 |

FIVPRE: enter command => c cp

|                           | Minimum        | Maximum        | Number                |
|---------------------------|----------------|----------------|-----------------------|
| Cp; Prismatic Coefficient | 0.590          | 0.590          | 1                     |
| Cp; Prismatic Coefficient | Minimum => .57 | Maximum => .61 | Number of values => 3 |

FIVPRE: enter command => c cb

|                       | Minimum        | Maximum        | Number                |
|-----------------------|----------------|----------------|-----------------------|
| Cb; Block Coefficient | 0.490          | 0.490          | 1                     |
| Cb; Block Coefficient | Minimum => .47 | Maximum => .51 | Number of values => 3 |

FIVPRE: enter command => c b/t

|                       | Minimum        | Maximum        | Number                |
|-----------------------|----------------|----------------|-----------------------|
| B/T; Beam/Draft Ratio | 3.200          | 3.200          | 1                     |
| B/T; Beam/Draft Ratio | Minimum => 2.8 | Maximum => 3.2 | Number of values => 5 |

FIVPRE: enter command => sa ---<i.e. SAVE>---

Enter FILE NAME <FIVIN only> =>

writing to file FIVIN.....

FIVPRE: enter command => z

saving library file.....

\*\* FIVPRE Finished \*\*

-----  
\*\* SHOP5 RUNNING, PLEASE WAIT \*\*

---<00 min. 57 sec CPU time, VAX 11/750>---

-----  
FIVPOS, Post-processor for SHOP5  
-----

Title: DESIGN OPTIMIZATION, COGAG CONFIG.

105 ships generated.

reading Summary of Rejected Ships....

reading ship data.... 10 20 30 40 50 60 70 80 90 100

SUMMARY OF REJECTED SHIPS  
-----

| CONSTRAINT                 | REJECTED |
|----------------------------|----------|
| Deck Wetness               | 0        |
| Vertical Acceleration      | 0        |
| Slam Force                 | 0        |
| Seakeeping Effectiveness   | 0        |
| Midship Freeboard          | 0        |
| Midship Coefficient        | 90       |
| OPC at Endurance Speed     | 0        |
| Engines                    | 0        |
| Range at Endurance Speed   | 0        |
| Vertical Centre of Gravity | 75       |
| Combat System Volume       | 0        |

165 out of 270 ships were REJECTED.

COMMAND MENU  
-----

- 1 SELECT PARAMETER
- 2 Re-plot
- 3 Define Window
- 4 Select Ships for Lineprinter
- 5 Select Ships for Transfer to FIVPRE
- 6 Summary of Rejected Ships
- 7 Define Terminal Type
- 8 HELP
- 9 EXIT

Enter selection => 2      ---<i.e. Re-Plot>---

|    | Parameter(s)                                          |
|----|-------------------------------------------------------|
| 1  | FC(Vc) Fuel Consumption, Cruise Speed                 |
| 2  | Vsuper Superstructure Volume                          |
| 3  | CrM Length/Displacement Ratio (Circle M)              |
| 4  | P.A. \$ Platform Acquisition Cost (lead ship)         |
| 5  | R(Vd) Range at Design Speed                           |
| 6  | GM/B Metacentric Height/Beam                          |
| 7  | Pins Total Installed Power                            |
| 8  | Vmax(w) Maximum Speed in Waves (limited by Pins only) |
| 9  | R(Ve) Range at Endurance Speed                        |
| 10 | KG/KGmax KG/maximum KG for Damaged Stability          |
| 11 | ..ratio (Vsuper) / (Vtotal)                           |
| 12 | B/T Beam/Draft Ratio                                  |
| 13 | Cb Block Coefficient                                  |
| 14 | Cp Prismatic Coefficient                              |
| 15 | DISP Displacement                                     |

Enter selection <exit> => 5

---<see Figure C.4>---

---<on COMMAND menu, select Define Window>---

#### WINDOW DEFINITION

The window is defined by low and high ship numbers, corresponding to left and right sides of the window.

The window definition is preserved until reset.

Enter SHIP NUMBER: LOW => 81,99

---<on COMMAND menu, select Re-Plot>---

---<on Re-Plot menu, select item 1 (most recent plot)>---

---<see Figure 7 in main text>---

---<on COMMAND menu, select Transfer Ships>---

#### SELECT SHIPS FOR TRANSFER TO FIVPRE

To select individual ships, enter each SHIP NUMBER on a separate line.

To select a range of ships, enter two SHIP NUMBERS on the same line, separated by a blank or comma.

Enter SHIP NUMBER(S) <exit> => 90,92

Enter SHIP NUMBER(S) <exit> =>

---<on COMMAND menu, select Exit, omit exit messages>---

\*\* FIVPOS Finished \*\*

#### FIVPRE, Pre-processor for SHOP5

reading library file.....

reading ships from FIVPOS.....

Primary Input (PRIM), Geometry

---<automatic display>---

SHIP      1      2      3  
          [90]    [91]    [92]

Disp 4500.0 4500.0 4500.0  
CrM    8.40    8.40    8.50  
Cp     0.610   0.610   0.570  
Cb     0.490   0.510   0.470  
B/T    3.200   3.200   3.200

FIVPRE: enter command => c mode

MODE

0 SEARCH  
1 DESCRIBE

MODE ? <SEARCH> =>      ---<i.e. Return only = SEARCH mode>---

Mode Change: DESCRIBE to SEARCH

- 1 Restore most recent SEARCH mode file
- 2 Select DESCRIBE mode ship to initialize search space
- 3 Define search space from scratch.
- 4 Cancel mode-change

Enter selection <Restore SEARCH> => 2

Which ship ? Enter SHIP NUMBER or ? <exit> => 2

Rv(e); Range at Endurance Speed => 4500

Primary Input (PRIM)

---<automatic display>---

|                                | Minimum  | Maximum  | Number |
|--------------------------------|----------|----------|--------|
| DISP; Displacement (t:ton)     | 4500.000 | 4500.000 | 1      |
| CrM; Length/Displacement Ratio | 8.400    | 8.400    | 1      |
| Cp; Prismatic Coefficient      | 0.610    | 0.610    | 1      |
| Cb; Block Coefficient          | 0.510    | 0.510    | 1      |
| B/T; Beam/Draft Ratio          | 3.200    | 3.200    | 1      |

R(Ve); Range at Endurance Speed (n.mile) = 4500.000  
Wcombat; Combat System Weight (t:ton) = 375.000  
Vd; Design Speed (kt) = 30.000  
Vc; Cruise Speed (kt) = 20.000  
Ve; Endurance Speed (kt) = 20.000  
Vw; Seakeeping Speed (kt) = 20.000  
Hw; Seakeeping Wave Height (m:ft) = 5.000

FIVPRE: enter command => c crm

---<omit re-definition of Primary Input, new values shown below>---

|                                | Minimum  | Maximum  | Number |
|--------------------------------|----------|----------|--------|
| DISP; Displacement (t:ton)     | 4520.000 | 4560.000 | 3      |
| CrM; Length/Displacement Ratio | 8.350    | 8.450    | 3      |
| Cp; Prismatic Coefficient      | 0.590    | 0.620    | 3      |
| Cb; Block Coefficient          | 0.500    | 0.520    | 3      |
| B/T; Beam/Draft Ratio          | 3.100    | 3.300    | 3      |

FIVPRE: enter command => sa ---<i.e. SAVE>---

Enter FILE NAME <FIVIN only> =>

writing to file FIVIN.....

FIVPRE: enter command => z

\*\* FIVPRE Finished \*\*

-----  
 \*\* SHOP5 RUNNING, PLEASE WAIT \*\*

---<00 min. 54 sec. CPU time, VAX 11/750>---

-----  
 FIVPOS, Post-processor for SHOP5  
 -----

Title: DESIGN OPTIMIZATION, COGAG CONFIG.

129 ships generated.

reading Summary of Rejected Ships....

reading ship data.... 10 20 30 40 50 60 70 80 90 100  
 110 120

SUMMARY OF REJECTED SHIPS  
 -----

| CONSTRAINT                 | REJECTED |
|----------------------------|----------|
| Deck Wetness               | 0        |
| Vertical Acceleration      | 0        |
| Slam Force                 | 0        |
| Seakeeping Effectiveness   | 0        |
| Midship Freeboard          | 0        |
| Midship Coefficient        | 81       |
| OPC at Endurance Speed     | 0        |
| Engines                    | 0        |
| Range at Endurance Speed   | 0        |
| Vertical Centre of Gravity | 33       |
| Combat System Volume       | 0        |

114 out of 243 ships were REJECTED.

---<End of Appendix C>---

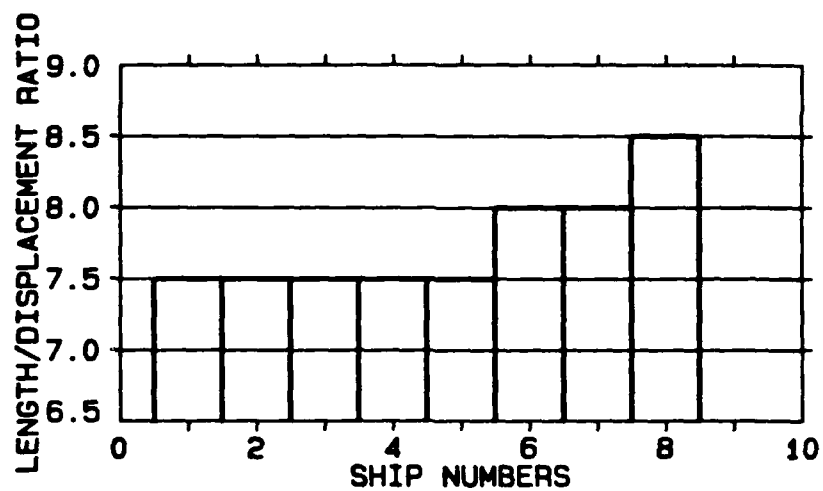


Figure C.1: Length Displacement Ratio, First-Run Ships



Figure C.2: Superstructure Volume, First-Run Ships

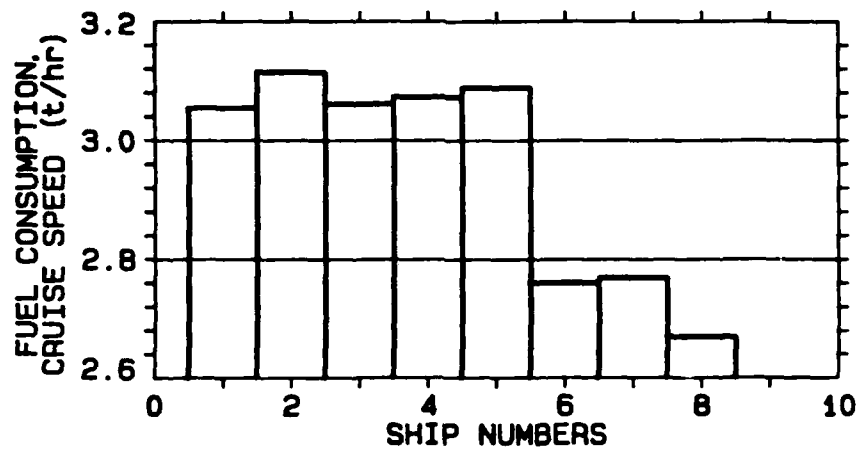


Figure C.3: Fuel Consumption at Cruise Speed, First-Run Ships

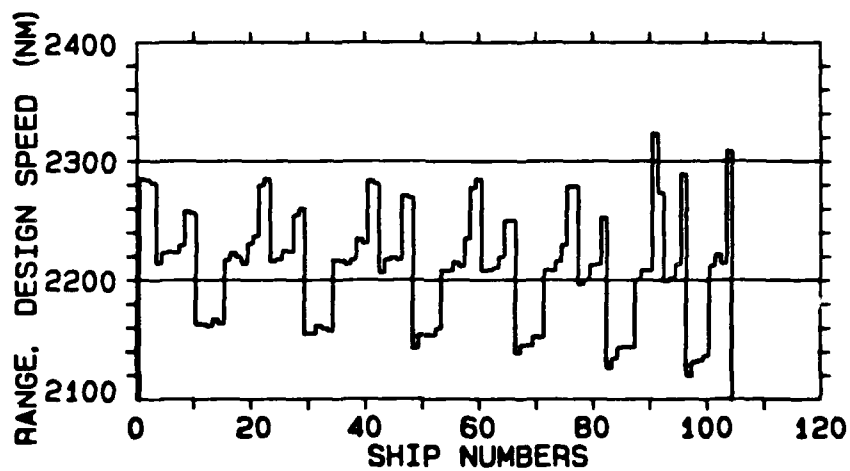


Figure C.4: Range at Design Speed, Second-Run Ships

## Appendix D: Design Optimization Example, Session 2

The trends shown in Appendix C lead towards the design candidate selected in this appendix. The relative merits of this ship are illustrated by examining FIVPOS graphics and lineprinter output. The SHOP5 DESCRIBE mode lineprinter output for this ship is also included.

This terminal session is presented using the same format as Appendix C.

FIVPOS, Post-processor for SHOP5

Title: DESIGN OPTIMIZATION, COGAG CONFIG.

83 ships generated.

reading Summary of Rejected Ships....

reading ship data.... 10 20 30 40 50 60 70 80

### SUMMARY OF REJECTED SHIPS

| CONSTRAINT                 | REJECTED |
|----------------------------|----------|
| Deck Wetness               | 0        |
| Vertical Acceleration      | 0        |
| Slam Force                 | 0        |
| Seakeeping Effectiveness   | 0        |
| Midship Freeboard          | 0        |
| Midship Coefficient        | 54       |
| OPC at Endurance Speed     | 0        |
| Engines                    | 0        |
| Range at Endurance Speed   | 0        |
| Vertical Centre of Gravity | 79       |
| Combat System Volume       | 0        |

133 out of 216 ships were REJECTED.

### COMMAND MENU

- 1 SELECT PARAMETER
- 2 Re-plot
- 3 Define Window
- 4 Select Ships for Lineprinter
- 5 Select Ships for Transfer to FIVPRE
- 6 Summary of Rejected Ships
- 7 Define Terminal Type
- 8 HELP
- 9 EXIT

Enter selection => 2

|             | Parameter(s)                                  |
|-------------|-----------------------------------------------|
| 1 P.A. \$   | Platform Acquisition Cost (lead ship)         |
| 2 CrM       | Length/Displacement Ratio (Circle M)          |
| 3 GM/B      | Metacentric Height/Beam                       |
| 4 R(Vd)     | Range at Design Speed                         |
| 5 FC(Vc)    | Fuel Consumption, Cruise Speed                |
| 6 Vsuper    | Superstructure Volume                         |
| 7 Pins      | Total Installed Power                         |
| 8 Vmax(w)   | Maximum Speed in Waves (limited by Pins only) |
| 9 R(Ve)     | Range at Endurance Speed                      |
| 10 KG/KGmax | KG/maximum KG for Damaged Stability           |
| 11 ..ratio  | (Vsuper) / (Vtotal)                           |
| 12 B/T      | Beam/Draft Ratio                              |
| 13 Cb       | Block Coefficient                             |
| 14 Cp       | Prismatic Coefficient                         |
| 15 DISP     | Displacement                                  |

Enter selection <exit> => 4

---<see Figure D.1>---  
 ---<Define Window for ships 61 to 79 and then Re-Plot>---  
 ---<see Figure D.2>---  
 ---<Transfer Ships 69, 70 and 71 to FIVPRE>---  
 ---<Exit from FIVPOS, omit exit messages>---

---

FIVPRE, Pre-processor for SHOP5

---

reading library file.....  
 reading ships from FIVPOS.....

Primary Input (PRIM). Geometry

---

---<automatic display>---

| SHIP | 1<br>[69] | 2<br>[70] | 3<br>[71] |
|------|-----------|-----------|-----------|
| Disp | 4620.0    | 4620.0    | 4620.0    |
| CrM  | 8.35      | 8.35      | 8.35      |
| Cp   | 0.595     | 0.595     | 0.595     |
| Cb   | 0.505     | 0.505     | 0.505     |
| B/T  | 3.150     | 3.150     | 3.150     |

FIVPRE: enter command => c mode

---<omit re-definition of Primary Input, new values shown below>---

|                                | Minimum  | Maximum  | Number |
|--------------------------------|----------|----------|--------|
| DISP; Displacement (t:ton)     | 4620.000 | 4620.000 | 1      |
| CrM; Length/Displacement Ratio | 8.350    | 8.450    | 3      |
| Cp; Prismatic Coefficient      | 0.585    | 0.595    | 3      |
| Cb; Block Coefficient          | 0.495    | 0.505    | 3      |
| B/T; Beam/Draft Ratio          | 2.950    | 3.250    | 7      |

FIVPRE: enter command => sa ---<i.e. SAVE>---

---<omit SAVE and EXIT from FIVPRE>---

-----  
\*\* SHOP5 RUNNING, PLEASE WAIT \*\*

---<00 min. 39 sec CPU time, VAX 11/750>---

-----  
FIVPOS, Post-processor for SHOP5  
-----

Title: LONG COGAG

58 ships generated.

reading Summary of Rejected Ships....

reading ship data.... 10 20 30 40 50

SUMMARY OF REJECTED SHIPS  
-----

| CONSTRAINT                 | REJECTED |
|----------------------------|----------|
| Deck Wetness               | 0        |
| Vertical Acceleration      | 0        |
| Slam Force                 | 0        |
| Seakeeping Effectiveness   | 0        |
| Midship Freeboard          | 0        |
| Midship Coefficient        | 63       |
| OPC at Endurance Speed     | 0        |
| Engines                    | 0        |
| Range at Endurance Speed   | 0        |
| Vertical Centre of Gravity | 68       |
| Combat System Volume       | 0        |

131 out of 189 ships were REJECTED.

---<omit FIVPOS menus>---

---<see Figure 7 in main text and Figures D.4 through D.7>---

---<select ships 18 to 24 for lineprinter output, see Table D.1>---

---<select ship 20 for transfer to FIVPRE>---

---<omit Exit from FIVPOS>---

-----  
FIVPRE, Pre-processor for SHOP5  
-----

reading library file.....

reading ships from FIVPOS.....

Primary Input (PRIM), Geometry

---<automatic display>---

Disp 4620.0  
CrM 8.35  
Cp 0.595  
Cb 0.505  
B/T 3.150

FIVPRE: enter command => c tit

---<i.e. CHANGE TITLE>---

Enter TITLE => long cogag

FIVPRE: enter command => sa s1

--<i.e. SAVE (as file) S1>---

writing to file S1.....

writing to file FIVIN.....

FIVPRE: enter command => z

saving library file.....

\*\* FIVPRE Finished \*\*

-----  
\*\* SHOP5 RUNNING, PLEASE WAIT \*\*

---<00 min. 05 sec CPU time>---

-----  
---<see Table D.2 for SHOP5 DESCRIBE mode output on this ship>---

---<End of Appendix D>---

Table D.1: FIVPOS LINEPRINTER OUTPUT FOR SHIPS 18 THROUGH 24

FIVPOS  
SHIP'S POST-PROCESSOR

14:09:08 29-JAN-88

LONG COGAC

| REJECTION CRITERIA VIOLATIONS |      |        |        |        |        |       |       |        |       |       |         |    |
|-------------------------------|------|--------|--------|--------|--------|-------|-------|--------|-------|-------|---------|----|
| DISP                          | CRH  | WetMax | AccMax | SlmMax | EffMin | FmMin | OPMin | ENGINE | RANGE | KQmax | Vcombat |    |
| TONNE                         |      | 1      | 2      | 3      | 4      | 5     | 6     | 7      | 8     | 9     | 10      | 11 |
| 4620.0                        | 8.35 | 0      | 0      | 0      | 0      | 0     | 21    | 0      | 0     | 0     | 20      | 0  |
| 8.40                          | 0    | 0      | 0      | 0      | 0      | 0     | 21    | 0      | 0     | 0     | 22      | 0  |
| 8.45                          | 0    | 0      | 0      | 0      | 0      | 0     | 21    | 0      | 0     | 0     | 26      | 0  |

SUMMARY OF REJECTED SHIPS

| CRITERIA | REJECTS |
|----------|---------|
| MetLim   | 0       |
| AccLim   | 0       |
| SlmLim   | 0       |
| EffLim   | 0       |
| Fm Lim   | 0       |
| Cm Lim   | 63      |
| OPCLim   | 0       |
| ENGINE   | 0       |
| RANGE    | 0       |
| KQLim    | 68      |
| VolLim   | 0       |

| REJECTION CRITERIA |        |             |
|--------------------|--------|-------------|
| NUMBER             | NAME   | LIMIT VALUE |
| 1                  | MetLim | 30.         |
| 2                  | AccLim | 0.200       |
| 3                  | SlmLim | 0.200       |
| 4                  | EffLim | 50.         |
| 5                  | Fm Lim |             |
| 6                  | Cm Lim |             |
| 7                  | OPCLim | 0.600       |
| 8                  | ENGINE | 4500.       |
| 9                  | RANGE  |             |
| 10                 | KQLim  | 2900.       |
| 11                 | VolLim |             |

## SHIP NUMBERS =&gt;

|                   | 18        | 19        | 20        | 21        | 22        | 23        | 24        |
|-------------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| <b>DIMENSIONS</b> |           |           |           |           |           |           |           |
| Displacement      | 4620.000  | 4620.000  | 4620.000  | 4620.000  | 4620.000  | 4620.000  | 4620.000  |
| Length            | 137.922   | 137.922   | 137.922   | 137.922   | 137.922   | 137.922   | 137.922   |
| Beam              | 14.461    | 14.573    | 14.276    | 14.389    | 14.501    | 14.377    | 14.490    |
| Draft             | 4.519     | 4.484     | 4.532     | 4.497     | 4.462     | 4.564     | 4.528     |
| Hull Depth        | 10.000    | 10.000    | 10.000    | 10.000    | 10.000    | 10.000    | 10.000    |
| Wetted Surface    | 2058.971  | 2063.262  | 2029.649  | 2035.175  | 2040.702  | 2057.309  | 2061.600  |
| Circle M          | 8.350     | 8.350     | 8.350     | 8.350     | 8.350     | 8.400     | 8.400     |
| <b>HULL FORM</b>  |           |           |           |           |           |           |           |
| Cp                | 0.595     | 0.595     | 0.595     | 0.595     | 0.595     | 0.585     | 0.585     |
| Cb                | 0.500     | 0.500     | 0.500     | 0.505     | 0.505     | 0.495     | 0.495     |
| B/T               | 3.200     | 3.250     | 3.150     | 3.200     | 3.250     | 3.150     | 3.200     |
| <b>WEIGHTS</b>    |           |           |           |           |           |           |           |
| Structure         | 1629.935  | 1625.827  | 1629.774  | 1625.576  | 1621.482  | 1633.754  | 1629.538  |
| Propulsion        | 397.594   | 397.594   | 397.594   | 397.594   | 397.594   | 397.594   | 397.594   |
| Electrical        | 244.941   | 244.941   | 244.941   | 244.941   | 244.941   | 244.941   | 244.941   |
| Auxiliary         | 472.773   | 473.566   | 471.688   | 472.490   | 473.280   | 472.154   | 472.960   |
| Outfit/Furnish.   | 355.807   | 355.807   | 355.807   | 355.807   | 355.807   | 355.807   | 355.807   |
| Disposable Loads  | 196.474   | 196.601   | 196.522   | 196.652   | 196.779   | 196.351   | 196.482   |
| Fuel              | 897.477   | 900.664   | 898.675   | 901.941   | 905.117   | 894.400   | 897.679   |
| Combat Systems    | 375.000   | 375.000   | 375.000   | 375.000   | 375.000   | 375.000   | 375.000   |
| <b>VOLUMES</b>    |           |           |           |           |           |           |           |
| TOTAL             | 16866.951 | 16912.273 | 16805.227 | 16850.813 | 16895.918 | 16831.711 | 16877.600 |
| SUPERSTRUCTURE    | 2950.445  | 2862.158  | 3031.096  | 2942.694  | 2854.854  | 3077.901  | 2989.312  |
| HULL              | 13916.506 | 14050.115 | 13774.131 | 13908.119 | 14041.064 | 13753.811 | 13888.288 |
| Machinery         | 3779.379  | 3818.438  | 3715.300  | 3754.469  | 3793.335  | 3750.182  | 3789.628  |
| Personnel         | 3872.000  | 3872.000  | 3872.000  | 3872.000  | 3872.000  | 3872.000  | 3872.000  |
| Outfit/Systems    | 5150.294  | 5152.418  | 5151.093  | 5153.269  | 5155.384  | 5148.245  | 5150.430  |
| Fuel              | 1165.277  | 1169.416  | 1166.833  | 1171.073  | 1175.197  | 1161.283  | 1165.540  |
| Combat Systems    | 2900.000  | 2900.000  | 2900.000  | 2900.000  | 2900.000  | 2900.000  | 2900.002  |
| Resistance        | 134.812   | 134.965   | 128.063   | 128.319   | 128.578   | 133.470   | 133.618   |
| OPC               | 0.624     | 0.622     | 0.628     | 0.626     | 0.625     | 0.626     | 0.625     |
| <b>DESIGN</b>     |           |           |           |           |           |           |           |
| Speed             | 10.081    | 10.103    | 9.701     | 9.727     | 9.751     | 9.987     | 10.005    |
| Fuel Consumption  | 2416.324  | 2419.758  | 2514.399  | 2516.929  | 2519.588  | 2430.880  | 2435.367  |
| Range             | 44.915    | 44.990    | 42.136    | 42.257    | 42.380    | 44.030    | 44.103    |
| Resistance        | 0.642     | 0.642     | 0.644     | 0.641     | 0.643     | 0.643     | 0.643     |
| <b>CRUISE</b>     |           |           |           |           |           |           |           |
| Speed             | 2.825     | 2.830     | 2.712     | 2.718     | 2.725     | 2.781     | 2.786     |
| Fuel Consumption  | 5749.111  | 5759.081  | 5996.524  | 6004.309  | 6011.079  | 5818.635  | 5830.550  |
| Range             | 44.915    | 44.990    | 42.136    | 42.257    | 42.380    | 44.030    | 44.103    |
| Resistance        | 0.642     | 0.641     | 0.644     | 0.643     | 0.643     | 0.643     | 0.643     |
| <b>ENDURANCE</b>  |           |           |           |           |           |           |           |
| Speed             | 2.825     | 2.830     | 2.712     | 2.718     | 2.725     | 2.781     | 2.786     |
| Fuel Consumption  | 5749.111  | 5759.081  | 5996.524  | 6004.309  | 6011.079  | 5818.635  | 5830.550  |
| Range             | 5222.083  | 5230.879  | 5444.792  | 5451.608  | 5457.693  | 5280.197  | 5290.839  |
| Resistance        | 0.051     | 0.052     | 0.049     | 0.049     | 0.049     | 0.051     | 0.051     |
| <b>MISSION</b>    |           |           |           |           |           |           |           |
| Transport Eff.    | 1.448     | 1.444     | 1.525     | 1.519     | 1.514     | 1.466     | 1.463     |
| Specific Power    | 31.359    | 31.336    | 31.769    | 31.740    | 31.714    | 31.458    | 31.439    |
| <b>ENGINES</b>    |           |           |           |           |           |           |           |
| Max. Speed        | 46848.801 | 46848.801 | 46848.801 | 46848.801 | 46848.801 | 46848.801 | 46848.801 |
| Installed Power   | 18650.000 | 18650.000 | 18650.000 | 18650.000 | 18650.000 | 18650.000 | 18650.000 |
| Main Engines      | 4774.400  | 4774.400  | 4774.400  | 4774.400  | 4774.400  | 4774.400  | 4774.400  |
| Cruise Engines    |           |           |           |           |           |           |           |
| Configuration     |           |           |           |           |           |           |           |
| <b>STABILITY</b>  |           |           |           |           |           |           |           |
| GM                | 1.648     | 1.743     | 1.471     | 1.564     | 1.657     | 1.611     | 1.611     |
| GM <sub>C</sub>   | 1.483     | 1.578     | 1.305     | 1.398     | 1.492     | 1.352     | 1.445     |
| KC                | 5.516     | 5.504     | 5.525     | 5.512     | 5.500     | 5.533     | 5.520     |
| K <sub>max</sub>  | 5.641     | 5.687     | 5.530     | 5.574     | 5.620     | 5.544     | 5.588     |
| <b>SEAKEEPING</b> |           |           |           |           |           |           |           |
| Deck Wetness      | 7.116     | 6.986     | 7.410     | 7.270     | 7.137     | 6.864     | 6.735     |
| Vertical Accn/g   | 0.166     | 0.165     | 0.167     | 0.166     | 0.166     | 0.165     | 0.164     |
| Slam Force/Disp.  | 0.059     | 0.061     | 0.062     | 0.064     | 0.067     | 0.064     | 0.046     |
| Effectiveness     | 67.796    | 68.081    | 67.255    | 67.556    | 67.846    | 68.201    | 68.493    |
| Complement        | 242.000   | 242.000   | 242.000   | 242.000   | 242.000   | 242.000   | 242.000   |
| P.A. Cost (lead)  | 237.107   | 237.088   | 237.043   | 237.023   | 237.004   | 237.149   | 237.129   |

TABLE D.2: SHOP5 LINEPRINTER OUTPUT FOR SHIP 20

SHOP5  
DREA CONCEPT EXPLORATION MODEL  
FOR MONITORING FRIGATES AND DESTROYERS

14:08:08 29-JAN-88

LONG OOCAG

MODE = 1 INOUT = 3 IPOST = 0 ILPT = 1  
ILECND = 0 NOON = 2 NOPTN = 6 NLIM = 2

DESCRIBE MODE

1 SHIP

| INDEPENDENT VARIABLES |        |       |       |      |       |         |      |      |      | REQUIREMENTS |      |      |      |      |      |  |  |  |  |
|-----------------------|--------|-------|-------|------|-------|---------|------|------|------|--------------|------|------|------|------|------|--|--|--|--|
| DISP                  | CIRCLE | M     | Qp    | Qb   | B/T   | Wcombat | Vd   | Vc   | Vv   | KTS          | KTS  | Vv   | KTS  | Hv   | m    |  |  |  |  |
| 4620.00               | 8.35   | 0.595 | 0.505 | 3.15 | 375.0 | 30.0    | 20.0 | 20.0 | 20.0 | 20.0         | 20.0 | 20.0 | 20.0 | 20.0 | 5.00 |  |  |  |  |

METHOD CONTROL INTEGERS FOR CURRENT EXECUTION

| NUMBER | NAME   | VALUE | DESCRIPTION                                |
|--------|--------|-------|--------------------------------------------|
| 1      | IDIMEN | 0     | CHARACTERISTIC DIMENSION = DISPLACEMENT    |
| 2      | IRESID | 0     | RESIDUARY RESISTANCE: NRC FSS SERIES       |
| 3      | IAPPND | 0     | SHOP5 APPENDANCE RESISTANCE CALCULATIONS   |
| 4      | IPROP  | 0     | SHOP5 OPC CALCULATIONS, C.P. PROPELLER     |
| 5      | ISTRUC | 0     | HOMOGENEOUS HULL AND SUPERSTRUCTURE        |
| 6      | IENGIN | 2     | SHOP5 ENGINE DATA BASE                     |
| 7      | ICHOO  | 0     | MUST USE SELECTED ENGINE CONFIGURATION     |
| 8      | ICEN   | 0     | SHOP5 DIESEL GENERATORS                    |
| 9      | IVOLUM | 1     | SUPERSTRUCTURE VOLUME: Vsuper = f(Vcombat) |
| 10     | ICOST  | 0     | SHOP5 COST CALCULATIONS (1977 DOLLARS)     |

SEAFIGHTING CRITERIA : MetMax = 30. AccMax = 0.200 SImMax = 0.200 E fMin = 50.

COMBAT SYSTEM VOLUME: Vcombat = 2900.00 m3

OPTIONAL INPUT: VALUES FOR CURRENT CALCULATIONS

| NUMBER | NAME   | VALUE                          | DESCRIPTION                                               | UNITS                  |
|--------|--------|--------------------------------|-----------------------------------------------------------|------------------------|
| 1      | D      | 10.0000                        | MIDSHIP HULL DEPTH                                        | m                      |
| 2      | Cv     | 0.695 Cp + 0.335               | WATERPLANE COEFFICIENT                                    |                        |
| 3      | LCB    | LCB/L = 0.515                  | LONGITUDINAL CENTRE OF BUOYANCY                           |                        |
| 4      | LCE    | LCE/L = 0.557                  | LONGITUDINAL CENTRE OF FLOTATION                          |                        |
| 5      | N      | N/DISP <sup>2/3</sup> = 0.8800 | COMPLEMENT (Accommodations)                               |                        |
| 6      | Ndeck  | D/2.59 - 1                     | NUMBER OF INTERNAL DECKS                                  |                        |
| 7      | Nbulk  | f(L,L/B)                       | NUMBER OF WATERTIGHT BULKHEADS                            |                        |
| 8      | C      | DAMAGE/L = 0.1500              | FRACTION OF SHIP LENGTH OPEN TO FLOODING                  |                        |
| 9      | Leaper | Leaper/L = 0.55                | SUPERSTRUCTURE LENGTH                                     | m                      |
| 10     | Ftp    | Ftp/L = f(L)                   | FREEBOARD AT FORWARD PERPENDICULAR                        | m                      |
| 11     | Ton    | NORTH ATLANTIC                 | WAVE MODAL PERIOD FOR SEAKEEPING                          | sec                    |
| 12     | AccH1  | AccH1 = 0.05 (g)               | VERTICAL ACCELERATION/g, 0% CREW EFFECTIVENESS            | sec <sup>2</sup>       |
| 13     | AccLo  | AccLo = 0.25 (g)               | VERTICAL ACCELERATION/g, 100% CREW EFFECTIVENESS          | sec <sup>2</sup>       |
| 14     | Ca     | 0.0005                         | MODEL-SHIP CORRELATION ALLOWANCE                          |                        |
| 15     | dPe    | 0.10                           | MARGIN ON EFFECTIVE POWER, Pe = (1-dPe)R <sup>0.4</sup> V |                        |
| 16     | DIAM   | DIAM/T = 1.0                   | PROPELLER DIAMETER                                        | m                      |
| 17     | Nshaft | 2                              | NUMBER OF PROPELLER SHAFTS                                |                        |
| 18     | Ngen   | 4                              | NUMBER OF ELECTRICAL GENERATORS                           |                        |
| 19     | Pgen   | 4000.0000                      | ELECTRICAL POWER INSTALLED                                | kW                     |
| 20     | avPgen | avPgen = Pgen/4                | AVERAGE ELECTRICAL POWER FOR RANGE                        | kW                     |
| 21     | Hor    | 3.00                           | SIGNIFICANT WAVE HEIGHT FOR RANGE                         | m                      |
| 22     | Tor    | NORTH ATLANTIC                 | WAVE MODAL PERIOD FOR RANGE                               | sec                    |
| 23     | YIELD  | 2.835                          | YIELD STRENGTH OF HULL MATERIAL                           | t/cm <sup>2</sup>      |
| 24     | DENS   | 7.858                          | DENSITY OF HULL MATERIAL                                  | t/m <sup>3</sup>       |
| 25     | Fmod   | 1.0                            | FACTOR FOR STRUCTURAL MODULUS                             |                        |
| 26     | RAFT   | 0.0                            | MARGIN: MAIN ENGINE RAFTING                               | t                      |
| 27     | GEAR   | 0.0                            | MARGIN: on W2 for GEAR BOX WEIGHT                         | t                      |
| 28     | dW1    | 0.0                            | MARGIN: on W1 (HULL STRUCTURE)                            | t                      |
| 29     | dW2    | 0.0                            | MARGIN: on W2 (PROPULSION MACHINERY)                      | t                      |
| 30     | dW3    | 0.0                            | MARGIN: on W3 (ELECTRICAL)                                | t                      |
| 31     | dW5    | 0.0                            | MARGIN: on W5 (AUXILIARIES)                               | t                      |
| 32     | dW6    | 0.0                            | MARGIN: on W6 (OUTFIT & FURNISHING)                       | t                      |
| 33     | dWb    | 50.0000                        | MARGIN: on Wbasic (BASIC WEIGHT)                          | t                      |
| 34     | dWd    | 0.0                            | MARGIN: on Wd (DISPOSABLE LOADS WEIGHT)                   | t                      |
| 35     | KCb    | KCb/D = 0.65                   | VCG OF EXTRA BASIC WEIGHT                                 | m                      |
| 36     | KCc    | KCc/D = 1.00                   | VCG OF COMBAT SYSTEM WEIGHT                               | m                      |
| 37     | Vsuper | Calculated                     | SUPERSTRUCTURE SIZED FOR COMBAT SYSTEMS                   | m <sup>3</sup>         |
| 38     | dVm    | 0.0                            | MARGIN: on Vm (MACHINERY VOLUME)                          | m <sup>3</sup>         |
| 39     | dVo    | 0.0                            | MARGIN: on Vo (SYSTEMS AND OUTFIT VOLUME)                 | m <sup>3</sup>         |
| 40     | dVb    | 0.0                            | MARGIN: Vbasic (BASIC VOLUME)                             | m <sup>3</sup>         |
| 41     | Vn/N   | Vn/N = 16.00                   | VOLUME PER PERSON                                         | m <sup>3</sup> /person |
| 42     | Td/T   | 0.05                           | NORMALIZED TIME AT DESIGN SPEED                           |                        |
| 43     | Tc/T   | 0.30                           | NORMALIZED TIME AT CRUISE SPEED                           |                        |
| 44     | Te/T   | 0.65                           | NORMALIZED TIME AT ENDURANCE SPEED                        |                        |

INPUT RECORD (10) : PROPULSION SYSTEM  
CONFIGURATION = COCAG  
1980 ENGINES  
MUST USE SELECTED ENGINE CONFIGURATION

INPUT RECORD (12) : SUPERSTRUCTURE VOLUME CONSTRAINTS  
Vmin: minimum Superstructure Volume = calculated.  
Vmax/Vt: maximum Superstructure Volume/total Volume = 0.3000

\*\*\*\*\* SHIP NUMBER 1 \*\*\*\*\*

GENERAL

DISPLACEMENT = 4620.00 t  
 LENGTH = 137.92 m  
 BEAM = 14.28 m  
 DRAFT = 4.53 m  
 FREBOARD = 5.47 m  
 DEPTH = 10.00 m  
 WETTED AREA = 2029.6 m<sup>2</sup>  
 VOLUME DISP. = 4506.5 m<sup>3</sup>

FORM COEFFICIENTS

C<sub>M</sub> = 8.350  
 L/B = 9.661  
 B/T = 3.150  
 L/D = 13.792  
 C<sub>R</sub> = 7.560  
 DLR = 49.076

MISCELLANEOUS

N = 242  
 Ndeck = 2.9  
 Nbulk = 16  
 SIQNA = 1.36  
 Kt/J2 = 0.174  
 J = 1.09  
 RPM = 173.3  
 ITYPE = 2  
 Lauper = 75.9 m  
 Pgen = 4000. kW  
 wPgen = 1000. kW  
 SFCgen = 0.249 kg/kW-HR  
 Plus = 46849. kW  
 DIAM = 4.53 m

CALM WATER RESISTANCE AND PROPULSION

| * SPEED * FROUDE * NUMBER | * FRICTIONAL * RESIDUARY * RESISTANCE * TOTAL * POWER * EFFECTIVE * OPC * REQUIRED * FUEL * RANGE * |
|---------------------------|-----------------------------------------------------------------------------------------------------|
| * KTS *                   | * t *                                                                                               |
| * 30.0 *                  | * 0.42 *                                                                                            |
| * 20.0 *                  | * 0.28 *                                                                                            |

POWERING IN WAVES, H<sub>wr</sub> = 3.00 m , Tor = 10.03 sec

| * SPEED * FROUDE * NUMBER | * ADDED * FRICTIONAL * RESIDUARY * RESISTANCE * TOTAL * POWER * EFFECTIVE * OPC * REQUIRED * FUEL * RANGE * |
|---------------------------|-------------------------------------------------------------------------------------------------------------|
| * KTS *                   | * t *                                                                                                       |
| * 30.0 *                  | * 0.42 *                                                                                                    |
| * 20.0 *                  | * 0.28 *                                                                                                    |

WEIGHTS

W1 = 1629.77 t  
 W2 = 397.59 t  
 W3 = 244.94 t  
 W5 = 471.69 t  
 W6 = 355.81 t  
 W6b = 50.00 t  
 Wloads = 3149.80 t  
 Wcombat = 1470.20 t  
 Wd = 375.00 t  
 Wf = 196.52 t

VOLUMES

Vhull = 13774. m<sup>3</sup>  
 Vsuper = 3031. m<sup>3</sup>  
 Vm = 3715. m<sup>3</sup>  
 Vo = 5151. m<sup>3</sup>  
 Vb = 0. m<sup>3</sup>  
 Vloads = 8866. m<sup>3</sup>  
 Vcombat = 7939. m<sup>3</sup>  
 Vn = 2900. m<sup>3</sup>  
 Vf = 3872. m<sup>3</sup>  
 TOTAL = 16805. m<sup>3</sup>

STABILITY

GM = 1.47 m  
 GMf = 1.31 m  
 KB = 2.76 m  
 BM = 4.24 m  
 KG = 5.53 m  
 Kmax = 5.53 m  
 KCC = 10.00 m  
 Erb = 1.38 m  
 TAU = 10.12 sec

SEAKEEPING

Hw = 5.00 m  
 Tos = 12.07 sec  
 Ww = 20.00 m  
 Wwet = 7. m  
 Accn = 0.167 m/s<sup>2</sup>  
 Fslam = 0.062 m/s<sup>2</sup>  
 S EFF = 67.3 %  
 Ffp = 8.83 m/s  
 Vwet = 30.00 m/s  
 Vvacn = 24.63 m/s  
 Vslam = 25.40 m/s  
 Veff = 26.99 m/s

MISSION

Td/T = 0.050  
 Te/T = 0.300  
 Te/T = 0.650  
 Vman = 20.50 m/s  
 Rmsnw = 6095.3 m  
 Rmsnw = 5444.8 m  
 Teff = 1.525 sec  
 SP = 0.049 m/s  
 Vmax = 32.50 m/s  
 Vmaxw = 31.77 m/s

COST

C1 = 6.9  
 C2 = 22.4  
 C3 = 11.9  
 C4 = 12.1  
 C5 = 7.0  
 C6 = 60.3  
 C7C = 90.6  
 C7C = 45.3  
 C8 = 4.1  
 C9C = 178.2  
 C10C = 126.1  
 C10C = 237.0  
 C10C = 162.7

| COCAG  | ENGINE<br>CONFIGURATION<br>PER SHAFT | TYPE    | INSTALLED<br>POWER<br>kW | REQUIRED<br>POWER<br>kW | SPECIFIC<br>FUEL CON.<br>kg/kw-hr | WEIGHT<br>t |
|--------|--------------------------------------|---------|--------------------------|-------------------------|-----------------------------------|-------------|
| CRUISE | DDA 570                              | TURBINE | 4774                     | 4317                    | 0.285                             | 2.3         |
| MAIN   | LM 2500                              | TURBINE | 18650                    | 13854                   | 0.245                             | 15.6        |

TABLE OF RESISTANCE, POWER, AND RANGE

| TABLE OF RESISTANCE, POWER, AND RANGE |                  |                          |                           |       |             |                         |                           |                          |                      |                         |                           |                           |
|---------------------------------------|------------------|--------------------------|---------------------------|-------|-------------|-------------------------|---------------------------|--------------------------|----------------------|-------------------------|---------------------------|---------------------------|
| CALM WATER                            |                  |                          |                           |       |             |                         |                           |                          |                      |                         |                           |                           |
| SPEED<br>KTS                          | FROUDE<br>NUMBER | TOTAL<br>RESISTANCE<br>t | EFFECTIVE*<br>POWER<br>kW | QFC   | POWER<br>kW | REQUIRED<br>POWER<br>kW | FUEL<br>CONSUMPT.<br>t/hr | RANGE<br>CALM<br>N MILES | ADDED<br>POWER<br>kW | REQUIRED<br>POWER<br>kW | FUEL<br>CONSUMPT.<br>t/hr | RANGE<br>WAVES<br>N MILES |
| 10.0                                  | 0.140            | 9.10                     | 506.                      | 0.646 | 783.        | 1041.                   | 0.921                     | 8824.                    | 356.                 | 1139.                   | 1.003                     | 8110.                     |
| 11.0                                  | 0.154            | 11.01                    | 673.                      | 0.646 | 1041.       | 1351.                   | 0.980                     | 9124.                    | 404.                 | 1444.                   | 1.072                     | 8341.                     |
| 12.0                                  | 0.168            | 13.10                    | 873.                      | 0.646 | 1351.       | 1719.                   | 1.051                     | 9283.                    | 461.                 | 1812.                   | 1.156                     | 8439.                     |
| 13.0                                  | 0.182            | 15.39                    | 1111.                     | 0.646 | 1719.       | 2151.                   | 1.135                     | 9313.                    | 530.                 | 2249.                   | 1.256                     | 8417.                     |
| 14.0                                  | 0.196            | 17.87                    | 1390.                     | 0.646 | 2151.       | 2678.                   | 1.233                     | 9230.                    | 610.                 | 2761.                   | 1.372                     | 8294.                     |
| 15.0                                  | 0.210            | 20.77                    | 1730.                     | 0.646 | 2678.       | 3306.                   | 1.354                     | 9010.                    | 704.                 | 3382.                   | 1.514                     | 8055.                     |
| 16.0                                  | 0.224            | 24.02                    | 2135.                     | 0.646 | 3306.       | 4033.                   | 1.497                     | 8692.                    | 810.                 | 4116.                   | 1.681                     | 7737.                     |
| 17.0                                  | 0.238            | 27.58                    | 2604.                     | 0.646 | 4033.       | 4888.                   | 1.663                     | 8313.                    | 930.                 | 4963.                   | 1.875                     | 7374.                     |
| 18.0                                  | 0.252            | 31.55                    | 3154.                     | 0.645 | 4888.       | 5990.                   | 1.857                     | 7879.                    | 1062.                | 5950.                   | 2.100                     | 6971.                     |
| 19.0                                  | 0.266            | 36.58                    | 3861.                     | 0.645 | 5990.       | 7271.                   | 2.109                     | 7326.                    | 1207.                | 7197.                   | 2.384                     | 6480.                     |
| 20.0                                  | 0.280            | 42.14                    | 4682.                     | 0.644 | 7271.       |                         | 2.401                     | 6773.                    | 1364.                | 8635.                   | 2.712                     | 5997.                     |
| 21.0                                  | 0.294            | 48.23                    | 5626.                     | 0.643 | 8751.       |                         | 2.738                     | 6139.                    | 1532.                | 10284.                  | 3.085                     | 5514.                     |
| 22.0                                  | 0.308            | 54.08                    | 6610.                     | 0.642 | 10292.      |                         | 3.137                     | 5443.                    | 1710.                | 12002.                  | 3.467                     | 5039.                     |
| 23.0                                  | 0.322            | 59.71                    | 7629.                     | 0.642 | 11887.      |                         | 3.602                     | 4642.                    | 1896.                | 13783.                  | 3.851                     | 4571.                     |
| 24.0                                  | 0.336            | 65.68                    | 8757.                     | 0.641 | 13655.      |                         | 4.181                     | 3767.                    | 2089.                | 15744.                  | 4.235                     | 4109.                     |
| 25.0                                  | 0.350            | 71.99                    | 9998.                     | 0.641 | 15609.      |                         | 4.885                     | 2869.                    | 2286.                | 17896.                  | 4.619                     | 3652.                     |
| 26.0                                  | 0.364            | 81.46                    | 11765.                    | 0.639 | 18426.      |                         | 5.710                     | 2012.                    | 2486.                | 20912.                  | 5.003                     | 3200.                     |
| 27.0                                  | 0.378            | 91.73                    | 13759.                    | 0.636 | 21640.      |                         | 6.710                     | 1372.                    | 2686.                | 24326.                  | 5.387                     | 2747.                     |
| 28.0                                  | 0.392            | 102.85                   | 15998.                    | 0.633 | 25256.      |                         | 7.903                     | 7403.                    | 2884.                | 28139.                  | 5.771                     | 2294.                     |
| 29.0                                  | 0.406            | 114.93                   | 18516.                    | 0.631 | 29355.      |                         | 9.388                     | 5480.                    | 3075.                | 32430.                  | 6.155                     | 1841.                     |
| 30.0                                  | 0.420            | 128.06                   | 21343.                    | 0.628 | 33998.      |                         | 11.077                    | 3687.                    | 3257.                | 37256.                  | 6.539                     | 1388.                     |

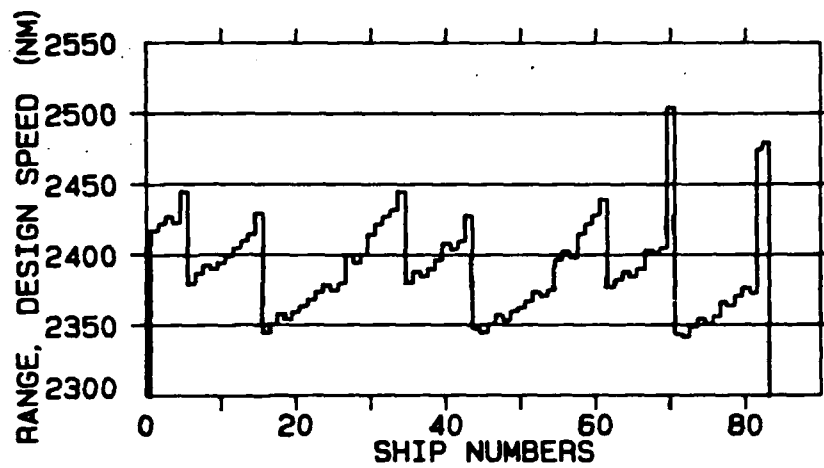


Figure D.1: Range at Design Speed

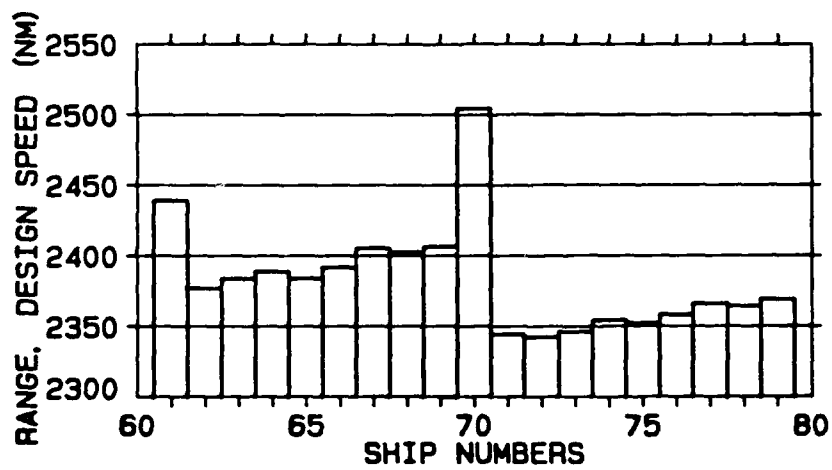


Figure D.2: Range at Design Speed, Ships 61 to 79

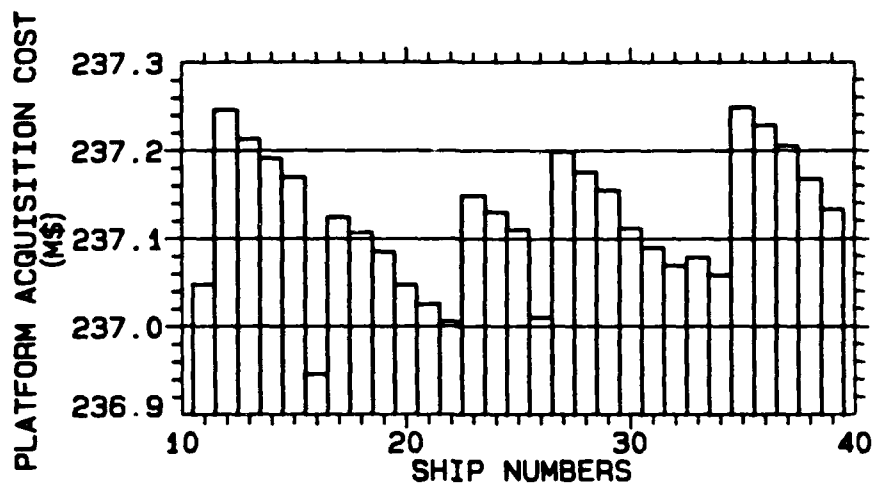


Figure D.3: Metacentric Height/Beam Ratio, Final-Run Ships

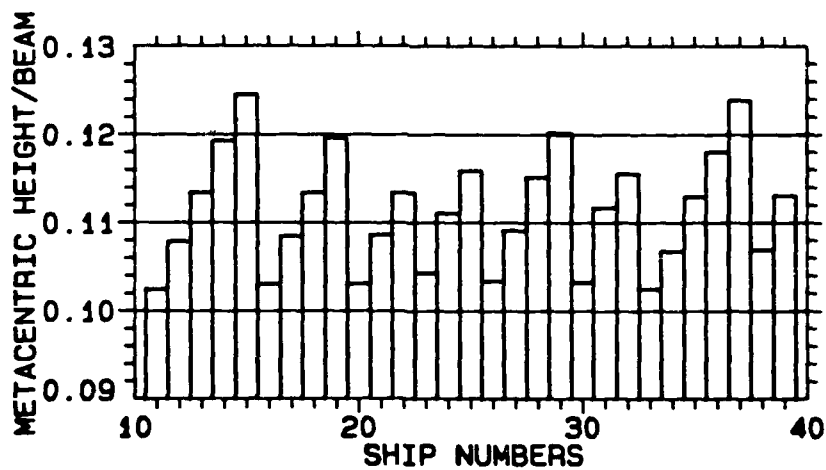


Figure D.4: Platform Acquisition Cost, Final-Run Ships

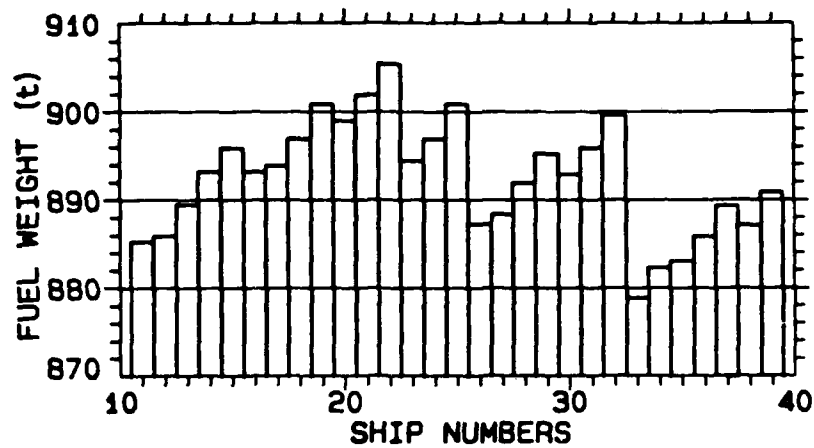


Figure D.5: Fuel Weight, Final-Run Ships

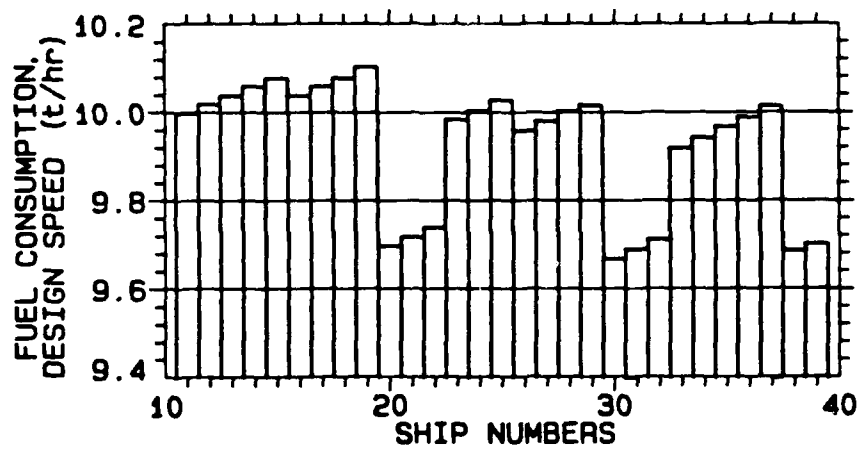


Figure D.6: Fuel Consumption at Design Speed, Final-Run Ships

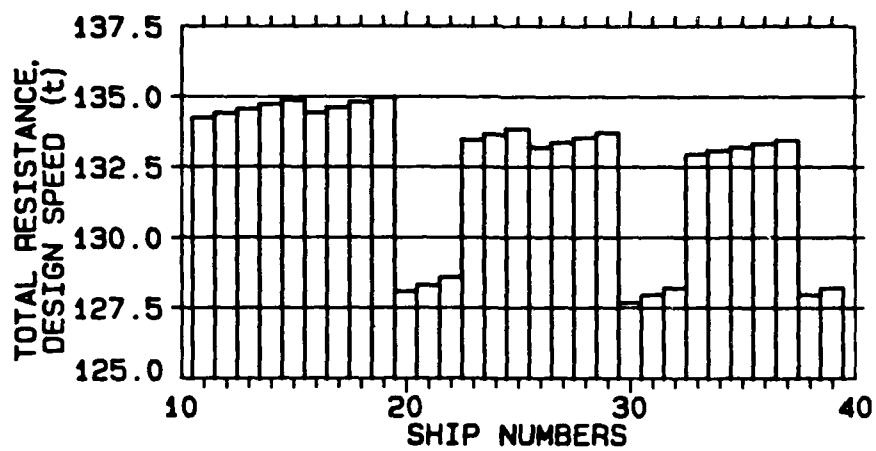


Figure D.7: Total Resistance at Design Speed, Final-Run Ships

## Appendix E: FIVPOS Parameters

The FIVPOS parameters are listed in groups corresponding to the categories used on the FIVPOS parameter-access menu. Note that each parameter has a unique integer descriptor, and that the SHOP5 lineprinter notation is used for all parameter names.

### Primary Input

|   |      |                                |
|---|------|--------------------------------|
| 1 | DISP | Displacement                   |
| 2 | CrM  | Length/Displacement Ratio, (M) |
| 3 | Cp   | Prismatic Coefficient          |
| 4 | Cb   | Block Coefficient              |
| 5 | B/T  | Beam/Draft Ratio               |

### Dimensions and Complement

|    |        |                       |
|----|--------|-----------------------|
| 6  | L      | Length                |
| 7  | B      | Beam                  |
| 8  | T      | Draft                 |
| 9  | D      | Hull Depth            |
| 10 | S      | Wetted Surface        |
| 11 | Vtotal | Total Enclosed Volume |
| 12 | Vsuper | Superstructure Volume |
| 13 | Vhull  | Hull Volume           |
| 14 | VOL    | Displaced Volume      |
| 15 | N      | Complement            |

### Geometric Ratios and Coefficients

|    |     |                           |
|----|-----|---------------------------|
| 16 | L/B | Length/Beam Ratio         |
| 17 | L/T | Length/Draft Ratio        |
| 18 | L/D | Length/Hull Depth Ratio   |
| 19 | Cw  | Waterplane Coefficient    |
| 20 | Cm  | Midship Coefficient       |
| 21 | DLR | Displacement/Length Ratio |

### Cost

|    |            |                                       |
|----|------------|---------------------------------------|
| 22 | P.A. \$    | Platform Acquisition Cost (lead ship) |
| 23 | \$/DISP    | P.A. Cost/Displacement                |
| 24 | \$/Vtotal  | P.A. Cost/Total Enclosed Volume       |
| 25 | \$/Wcombat | P.A. Cost/Combat Systems Weight       |
| 26 | \$/Vcombat | P.A. Cost/Combat Systems Volume       |

### Range

|    |          |                                      |
|----|----------|--------------------------------------|
| 27 | R(Vd)    | Range at Design Speed                |
| 28 | R(Vc)    | Range at Cruise Speed                |
| 29 | R(Ve)    | Range at Endurance Speed             |
| 30 | R(M)     | Mission Range                        |
| 31 | R(Vd)/Wf | Range at Design Speed/Fuel Weight    |
| 32 | R(Vc)/Wf | Range at Cruise Speed/Fuel Weight    |
| 33 | R(Ve)/Wf | Range at Endurance Speed/Fuel Weight |
| 34 | R(M)/Wf  | Mission Range/Fuel Weight            |

### Weight Components

|    |         |                              |
|----|---------|------------------------------|
| 35 | W1      | Structure Weight             |
| 36 | W2      | Propulsion System Weight     |
| 37 | W3      | Electrical Systems Weight    |
| 38 | W5      | Auxiliary Systems Weight     |
| 39 | W6      | Outfit and Furnishing Weight |
| 40 | Wd      | Disposable Loads Weight      |
| 41 | Wf      | Fuel Weight                  |
| 42 | Wcombat | Combat Systems Weight        |

### Volume Components

|    |         |                           |
|----|---------|---------------------------|
| 43 | Vm      | Machinery Volume          |
| 44 | Vn      | Personnel Volume          |
| 45 | Vo      | Outfit and Systems Volume |
| 46 | Vf      | Fuel Volume               |
| 47 | Vcombat | Combat Systems Volume     |

### Stability

|    |          |                                       |
|----|----------|---------------------------------------|
| 48 | GM       | Metacentric Height                    |
| 49 | GM/B     | Metacentric Height/Beam               |
| 50 | GMf      | Fluid Metacentric Height              |
| 51 | GMf/B    | Fluid Metacentric Height/Beam         |
| 52 | KG       | Vertical Centre of Gravity            |
| 53 | KG/D     | Vertical Centre of Gravity/Hull Depth |
| 54 | KG/KGmax | KG/maximum KG for Damaged Stability   |
| 55 | Tau      | Natural Roll Period (unappended)      |

### Seakeeping

|    |        |                                          |
|----|--------|------------------------------------------|
| 56 | Nwet   | Number of Deck Wetnesses                 |
| 57 | Accn   | RMS Vertical Acceleration/g at Station 4 |
| 58 | Fslam  | Slam Force/Displacement                  |
| 59 | S(Eff) | Crew Seakeeping Effectiveness            |

### Resistance and Propulsion

|    |         |                                                 |
|----|---------|-------------------------------------------------|
| 60 | Rt(Vd)  | Total Resistance, Design Speed                  |
| 61 | Rt(Vc)  | Total Resistance, Cruise Speed                  |
| 62 | Rt(Ve)  | Total Resistance, Endurance Speed               |
| 63 | OPC(Vd) | Overall Propulsive Coefficient, Design Speed    |
| 64 | OPC(Vc) | Overall Propulsive Coefficient, Cruise Speed    |
| 65 | OPC(Ve) | Overall Propulsive Coefficient, Endurance Speed |
| 66 | FC(Vd)  | Fuel Consumption, Design Speed                  |
| 67 | FC(Vc)  | Fuel Consumption, Cruise Speed                  |
| 68 | FC(Ve)  | Fuel Consumption, Endurance Speed               |
| 69 | Pins    | Total Installed Power                           |
| 70 | Pmain   | Installed Power of Main Engines                 |
| 71 | Pcruise | Installed Power of Cruise Engines               |
| 72 | Vm/Pins | Machinery Volume/Total Installed Power          |
| 73 | Vmax(w) | Maximum Speed in Waves (limited by Pins only)   |
| 74 | e       | Transport Effectiveness                         |
| 75 | SP      | Specific Power                                  |

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| 4. AUTHORS (Last name, first name, middle initial. If military, show rank, e.g. Doe, Maj. John E.)<br><br>Colwell, James L.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                                                                                                                             |                                                                                                                             |
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The SHOP5 System is a computer-aided ship design tool for monohull frigate and destroyer Concept Exploration. Its primary application is to initialize the new-ship design process by determining the ship size, hull form and major systems best suited for the design requirements. Other uses include evaluating new technologies and performing specific parametric studies. The SHOP5 System incorporates three major FORTRAN programs in a closed-loop system; program FIVPRE for defining and modifying ship descriptions and design requirements, program SHOP5 for computing ship characteristics, and program FIVPOS for examining design candidates using computer graphics. Design calculations include sea-keeping in head seas, resistance, powering and range in calm water and in waves, propulsion and electrical system modeling, distribution of weight and volume components, preliminary intact and damaged stability analysis, and platform acquisition cost. Platform feasibility is assessed by user-definable design criteria which define goals for performance and capability. The SHOP5 ship description and design methodology are sufficiently flexible to define and analyse a wide variety of ship geometries, systems and missions. Most input parameters have pre-programmed, default values representative of contemporary NATO practice and a variety of internal methods are available for many design calculations. All default values and most calculations can be modified or replaced by user-supplied input.

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SHOP5  
Naval Architecture  
Computer-Aided Ship Design (CASD)  
Concept Exploration Model (CEM)  
Feasibility Design  
Warship  
Frigate  
Destroyer

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