

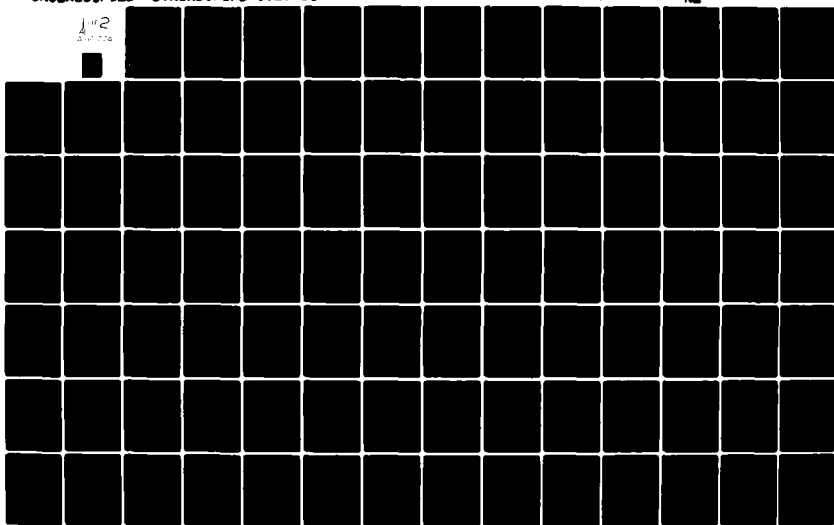
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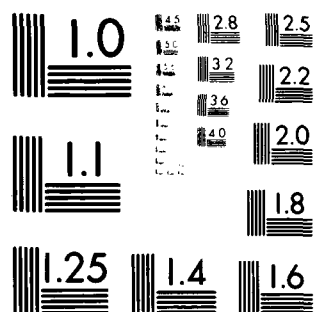
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DOCUMENTATION FOR SWATH SHIP RESISTANCE OPTIMIZATION PROGRAM (S--ETC(U)
SEP 81 T J NABLE, A W REED

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DOCUMENTATION FOR SWATH SHIP RESISTANCE OPTIMIZATION PROGRAM
(SWATHO) USER'S AND MAINTENANCE MANUAL by Toby J. Nagle and Arthur M. Reed

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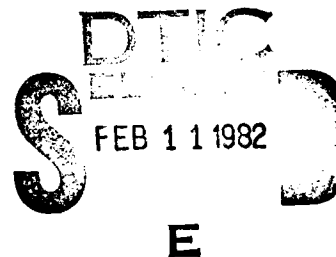


DOCUMENTATION FOR SWATH SHIP RESISTANCE
OPTIMIZATION PROGRAM (SWATHO) USER'S AND
MAINTENANCE MANUAL

Toby J. Nagle

and

Arthur M. Reed



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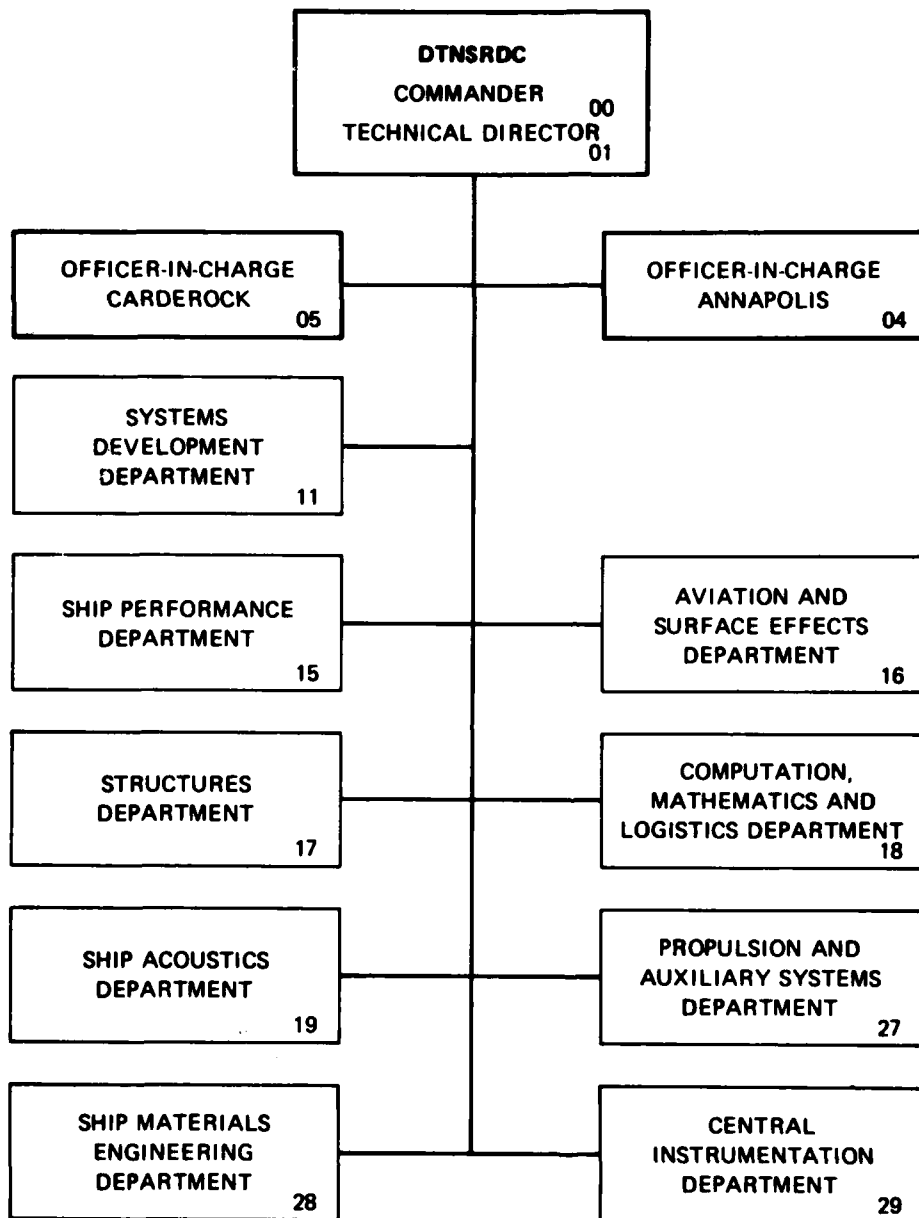
SHIP PERFORMANCE DEPARTMENT

September 1981

DTNSRDC/SPD-0927-03

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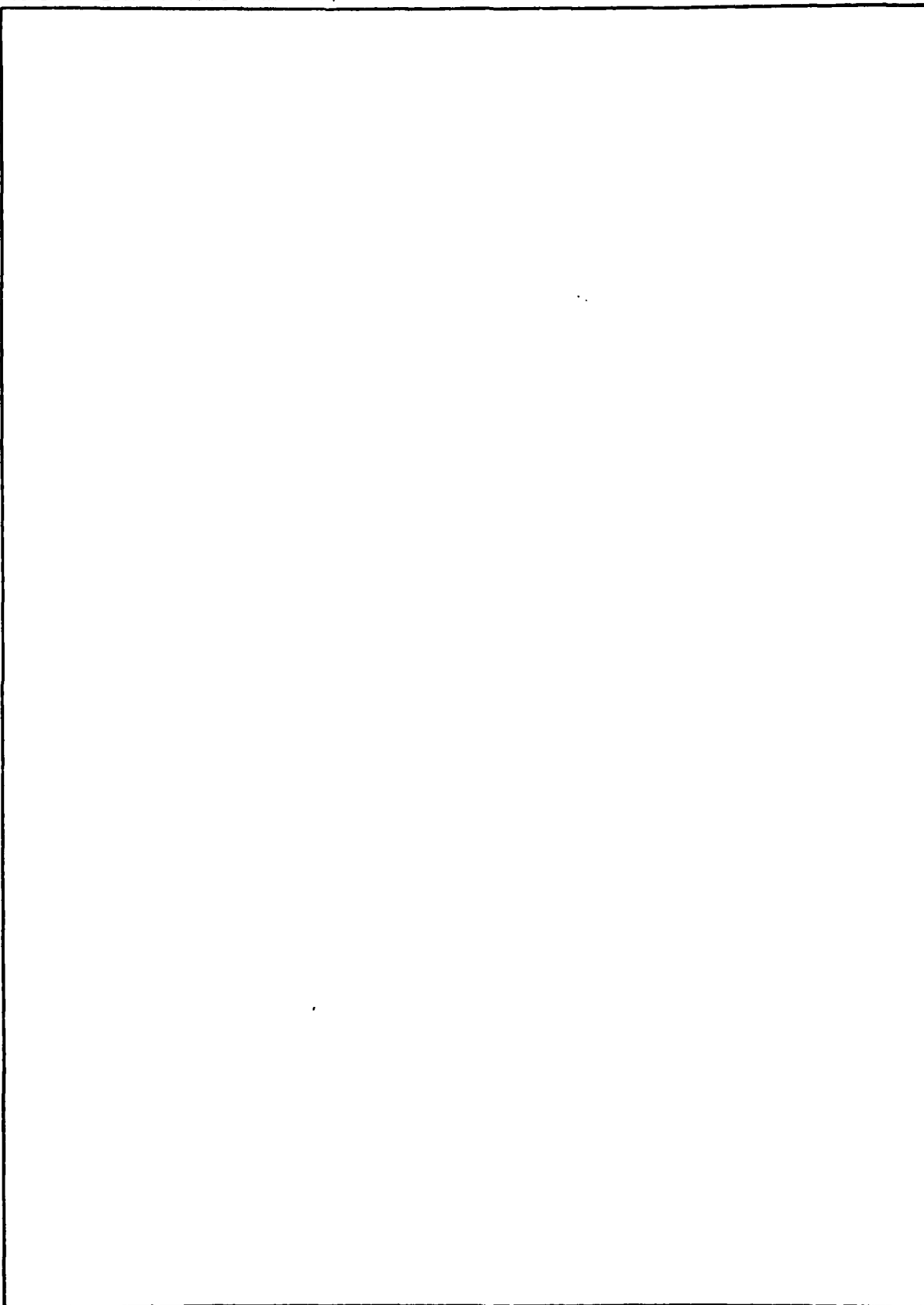
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NOMENCLATURE

<u>Symbol</u>	<u>Description</u>
$A(x)$	Body sectional area curve
A_o	Maximum section area of body
A_{Bm}	Symmetric coefficients of Chebychev series for body
A_{Sm}	Symmetric coefficients of Chebychev series for strut
A_w	Area of the waterplane
b	Half of the separation distance of the hulls
B_{Bm}	Anti-symmetric coefficients of Chebychev series for body
B_{Sm}	Anti-symmetric coefficients of Chebychev series for strut
C_A	Correlation allowance
C_F	Frictional resistance coefficient
C_{Fm}	Form drag coefficient
C_P	Body prismatic coefficient
C_{WP}	Waterplane coefficient
C_{IW}	Waterplane longitudinal inertia coefficient
g	Acceleration due to gravity
h_B	Maximum depth of submergence of axis of body
h_S	Maximum draft of strut
$J_n(\alpha)$	Bessel functions

NOMENCLATURE
(Continued)

<u>Symbol</u>	<u>Description</u>
L_B	Maximum length of body
L_S	Maximum length of strut
P_E	Effective power
R_n	Reynolds number
R_T	Total ship resistance
R_{WB}	Wave resistance due to one main body
R_F	Frictional resistance
R_{Fm}	Form drag
R_{WS}	Wave resistance due to one strut
R_{WSB}	Wave resistance due to the interaction of strut and main body
R_W	Wave resistance
S	Wetted surface
T (T_{max} also used)	Thickness at mid length of strut
$t(x)$	Strut half thickness function
T_{Bmn}	Auxiliary wave resistance function used in calculation of R_{WB}
T_{Smn}	Auxiliary wave resistance function used in calculation of R_{WS}

NOMENCLATURE
(Continued)

<u>Symbol</u>	<u>Description</u>
$T_{SB_{mn}}$	Auxiliary wave resistance function used in calculation of $R_{W_{SB}}$
$U_m(x)$	Chebyshev cosine series term (symmetric)
V	Velocity of ship
$V_m(x)$	Chebyshev sine series term (asymmetric)
$W_{B_{mn}}$	Auxiliary wave resistance function used in calculation of R_{W_B}
$W_{S_{mn}}$	Auxiliary wave resistance function used in calculation of R_{W_S}
$W_{SB_{mn}}$	Auxiliary wave resistance function used in calculation of $R_{W_{SB}}$
α	Variable of integration
ρ	Density of water
γ_{ob}	Dimensionless wave number related to body length and ship speed
γ_{os}	Dimensionless wave number related to strut length and ship speed
ζ	Variable of integration

ENGLISH/SI EQUIVALENTS

1 degree (angle)	= 0.01745 rad (radians)
1 foot	= 0.3048 m (meters)
1 foot per second (fps)	= 0.3048 m/sec (meters per second)
1 inch	= 25.40 mm (millimeters)
1 knot	= 0.5144 m/s (meters per second)
1 lb (force)	= 4.448 N (Newtons)
1 inch-lb - (Inch lbs)	= 0.1130 N·m (Newton-meter)
1 long ton (2240 pounds)	= 1.016 metric tons; or 1016 kilograms
1 horsepower	= 0.746 kW (kilowatts)

ABSTRACT

This report documents a computer program, SWATHO, which optimizes SWATH ship geometry, resulting in a minimum resistance and EHP for a specified speed of the ship. Contained in the report is a detailed description of the procedure for assembling the input deck for use on the CDC-6000 computer system at DTNSRDC, running the program on this system and understanding the output from the program. Also included are main program and subroutine descriptions as well as the theory behind the computations being performed.

ADMINISTRATIVE INFORMATION

This investigation was authorized under a direct funded block from the Naval Material Command (NAVMAT 08T2) under Program Element 62543N, Task Area ZF43-421-001, and administered by the David W. Taylor Naval Ship Research and Development Center (DTNSRDC), Work Unit 1500-102-30, and 1-1500-104-70.

INTRODUCTION

The computer program SWATHO, developed at DTNSRDC, optimizes SWATH ship geometry to arrive at minimum values of resistance and effective horsepower for a predetermined speed. The minimum values arrived at by the optimization are a result of initial ship geometry and constraints on the geometry as specified by the program user.

The calculations use standard EHP prediction methods accounting for frictional resistance, form drag, and wave resistance. Wave making predictions are made using the work of Lin and Day¹ on twin hull ships.

Contained in this report is a user manual which explains how to assemble the input deck as well as how to run the program on the CDC-6000 computer

¹References are listed on page 100

system at DTNSRDC. A description of the output and how to interpret it is also included along with an overview of how the main program works. Following the user's manual, a maintenance manual is presented, which contains a detailed description of the common blocks, functions and subroutines, and a tree diagram. The appendices contain a description of the objective and penalty functions used for minimization of effective power, a presentation of the theory behind the computational procedures for the resistance predictions, and an explanation of the relationships between Chebychev series and SWATH hullform coefficients.

This program will assist naval architects in finding a minimum resistance hull design which satisfies the given geometric constraints. The User's Manual portion of this document is intended to provide the user with the information needed to prepare input for the program, and with a description of the resulting output. The Maintenance Manual provides the documentation needed to understand the functioning of the program and its various subprograms, at a detailed enough level that changes could be made in the program if necessary.

USER'S MANUAL

PROGRAM DESCRIPTION

The Program SWATHO optimizes a SWATH ship geometry to obtain a minimum value of resistance and EHP for a specified speed of the ship. The program can be better understood if it is divided into four parts, each part having a specific purpose and result.

The first part of the program reads the input data that the user has prepared on cards; thus initializing the ship description as well as setting up the constraints. The array of scaling factors, which is used as the initial geometry, is optimized and initially set to 1 in this part. After each run, the values in the scaling array which correspond to the value of minimum EHP at that point are input to the next run of the program, keeping the rest of the INPUT cards the same. The actual description and format of the INPUT cards are found in the INPUT DESCRIPTION and INPUT EXAMPLE of this USER'S MANUAL.

The second part of the program actually performs the optimization of the EHP function. A detailed description of the method used and the actual subroutines which perform the optimization can be found in the MAINTENANCE MANUAL.

The third part of the program evaluates the objective function, thus finding intermediate values and a final value of EHP. A penalty function is also calculated in this part, based on any violation of constraints by the ship geometry at that time. Then more optimization is performed. This optimization cycle is repeated until the computational time is exceeded or sufficient convergence is reached.

The last part of the program outputs the initial ship description, intermediate curves and a design description, as well as resistance calculations over a range of speeds and other results of calculations. A detailed description of the output is found in the OUTPUT DESCRIPTION and OUTPUT EXAMPLE in the USER'S MANUAL.

INPUT DESCRIPTION

Diagrams showing the orientation of the geometry represented by the variables involved in this input description are found in Figure 1.

INPUT CARDS (Total number of input cards is 8)

1. The first card contains the alphanumeric title of the model.

Variable: TITLE (8)

Format: 8A10

1	11	21	31	41	51	61	71
TITLE (1)	TITLE (2)	TITLE (3)	TITLE (4)	TITLE (5)	TITLE (6)	TITLE (7)	TITLE (8)

2. Data on the second card are:

XL SI - Length of strut in ft

HSI - Draft of strut in ft

TSMAXI - Strut thickness in ft at XL SI/2

CWPI - Waterplane area coefficient

CLCFI - Waterplane moment coefficient

KG - Height of CG above baseline

Variable: XL SI, HSI, TSMAXI, CWPI, CLCFI, KG

Format: 6F10.6

1	11	21	31	41	51
XL SI	HSI	TSMAXI	CWPI	CLCFI	KG

3. Data on the third card are:

XLBI	-	Length of body in ft
BDIAI	-	Body diameter in ft at XLBI/2
BSI	-	Separation of hull centerlines
CSTRTI	-	Dist. of strut CL fwd of body CL
CPI	-	Body prismatic coefficient
CLCBI	-	Body moment coefficient

Variable: XLBI, BDIAI, BSI, CSTRTI, CPI, CLCBI

Format : 6F10.6

1	11	21	31	41	51
XLBI	BDIAI	BSI	CSTRTI	CPI	CLCBI

4-5 Data on the fourth and the fifth card are:

S - Array of scale factors

Variable: S

Format : 8 F10.6

1	11	21	31	41	51	61	71
S(1)	S(2)	S(3)	S(4)	S(5)	S(6)	S(7)	S(8)

1	11	21	31
S(9)	S(10)	S(11)	S(12)

6. Data on the sixth card is:

OPTSPD - Optimization speed in knots

Variable: OPTSPD

Format: F10.6

1

OPTSPD

7. Data on the seventh card are:

DISPMN	-	Minimum ship displacement in long tons
DFAC	-	Minimum draft/body diameter ratio
DRFTMX	-	Maximum draft of ship
WMAX	-	Maximum width of ship
XFWD	-	Minimum distance from body leading edge to strut leading edge
XAFT	-	Minimum distance from body trailing edge to strut trailing edge

Variable: DISPMN, DFAC, DRFTMAX, WMAX, XFWD, XAFT

Format: 6F10.4

1	11	21	31	41	51
DISPMN	DFAC	DRFTMAX	WMAX	XFWD	XAFT

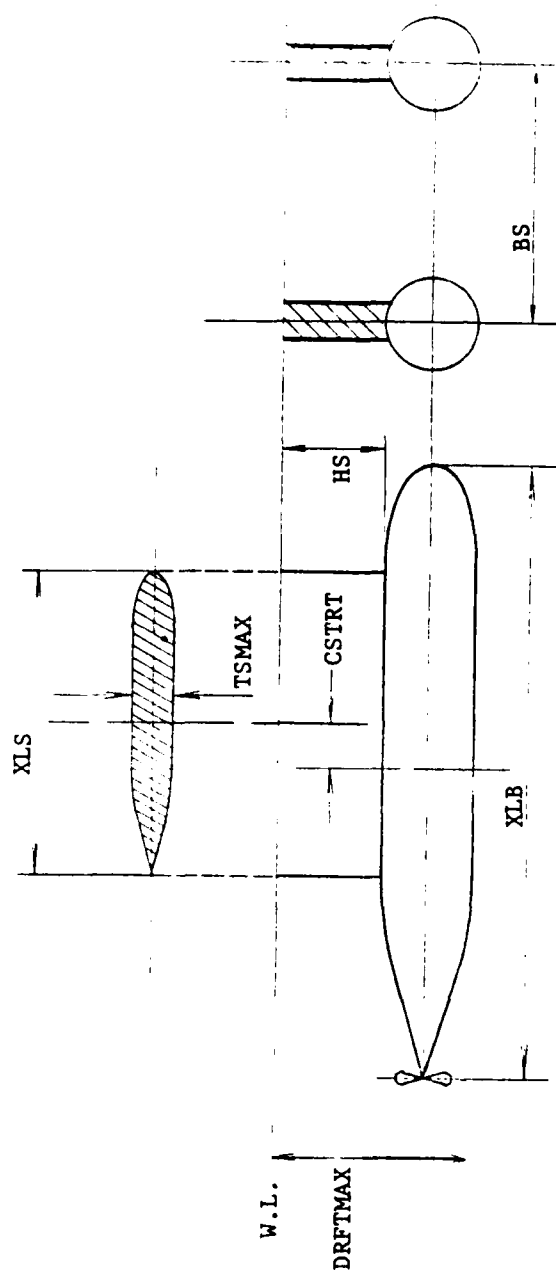
8. Data on the eighth card are:

MINGMT - Minimum TRANSVERSE GM
MINGML - Minimum LONGITUDINAL GM
LODMAX - Maximum body length over diameter ratio
LODMIN - Minimum body length over diameter ratio
TSMIN - Minimum strut thickness at 50 percent chord

Variable: MINGMT, MINGML, LODMAX, LODMIN, TSMIN

Format: 5F10.1

1	11	21	31	41
MINGMT	MINGML	LODMAX	LODMIN	TSMIN



SINGLE STRUT SWATH

Figure 1. SWATH SHIP BODY AND STRUT PROFILES (SWATHO)

INPUT EXAMPLE

Example of Input Data (Optimization):

1	11	21	31	41	51	61	71
TITLE (1)	TITLE (2)	TITLE (3)	TITLE (4)	TITLE (5)	TITLE (6)	TITLE (7)	TITLE (8)

SWATH OPTIMIZATION PROGRAM

1	11	21	31	41	51
XLSI	HSI	TSMAXI	CWPI	CLCFI	KG
210.	10.725	6.500	.8511	.014286	20.

1	11	21	31	41	51
XLBI	BDIAI	BSI	CSTRTI	CPI	CLCBI
260.	14.30	68.50	15.	.849	.01538

1	11	21	31	41	51	61	71
S(1)	S(2)	S(3)	S(4)	S(5)	S(6)	S(7)	S(8)
1.0154	.9900	0.9900	0.9783	-1.0	.9032	-1.0000	1.005

1	11	21	31
S(9)	S(10)	S(11)	S(12)
.9900	1.2500	1.0000	.5000

1
OPTSPD
20.

1	11	21	31	41	51
DISPMN	DFAC	DRFTMX	WMAX	XFWD	XAFT
2675.0	1.67	30.0	106.0	7.50	30.0

1	11	21	31	41
MINGMT	MINGML	LODMAX	LODMIN	TSMIN
30.00	30.00	20.00	16.00	5.0

OUTPUT DESCRIPTION

The first page of output consists of an echo print of the input including the S array of scaling factors. Following the array of scaling factors, NL and NF (value of counters in the optimization procedure) P (the penalty value), PEHP (the function to be minimized), and a repeat of the scaling factors (S array) are printed.

The second page of output consists of an intermediate plot of a body sectional area curve and strut waterplane outline curve where the symbols B and S stand for body and strut respectively. At the bottom of the plot, the values for the strut and body geometry are printed with the effective horsepower required for the design.

The third page of output lists values for intermediate design consisting of the symmetric and antisymmetric Chebychev coefficients for the body and strut and the wetted surface and ship geometry for the optimization speed. Also a table of speed-length ratios, wave resistance, frictional and residual resistance coefficients as well as the actual resistances and the EHP predicted is printed for the range of speeds from 10 to 26 knots.

The fourth page of output consists of a tabular listing of all of the scale factors of the S array corresponding to the strut and body geometric variables, as well as the penalty value and PEHP. The second difference array D(*) is printed out at the bottom of the listing. Also printed is NL, NF, PEHP and the values of the S array corresponding to a minimum PEHP so far. These S values are input by the user for the next run of the program. Often, when the execution time limit is exceeded, the output will stop in the middle of this tabular listing, in which case the minimum PEHP is found and the S array of scale factors are picked out from the table and used as input for the subsequent run.

The sequence of body sectional area curve and strut waterplane curve, intermediate design description, followed by tabular output is repeated until the time limit is exceeded or until convergence of the PEHP function is reached.

When the program has reached a prescribed degree of convergence, a final page is printed out, entitled "Wave Resistance for Strut and Body Geometric Characteristics." This page contains the optimum strut and body geometric characteristics, separation in feet, B/LB , strut centerline distance from body centerline (STRUT OFFSET), strut offset/ LB , the wave drag for strut and body and the frictional drag of body and strut. The coefficients of resistance as well as the minimum EHP calculated at certain speeds are also given.

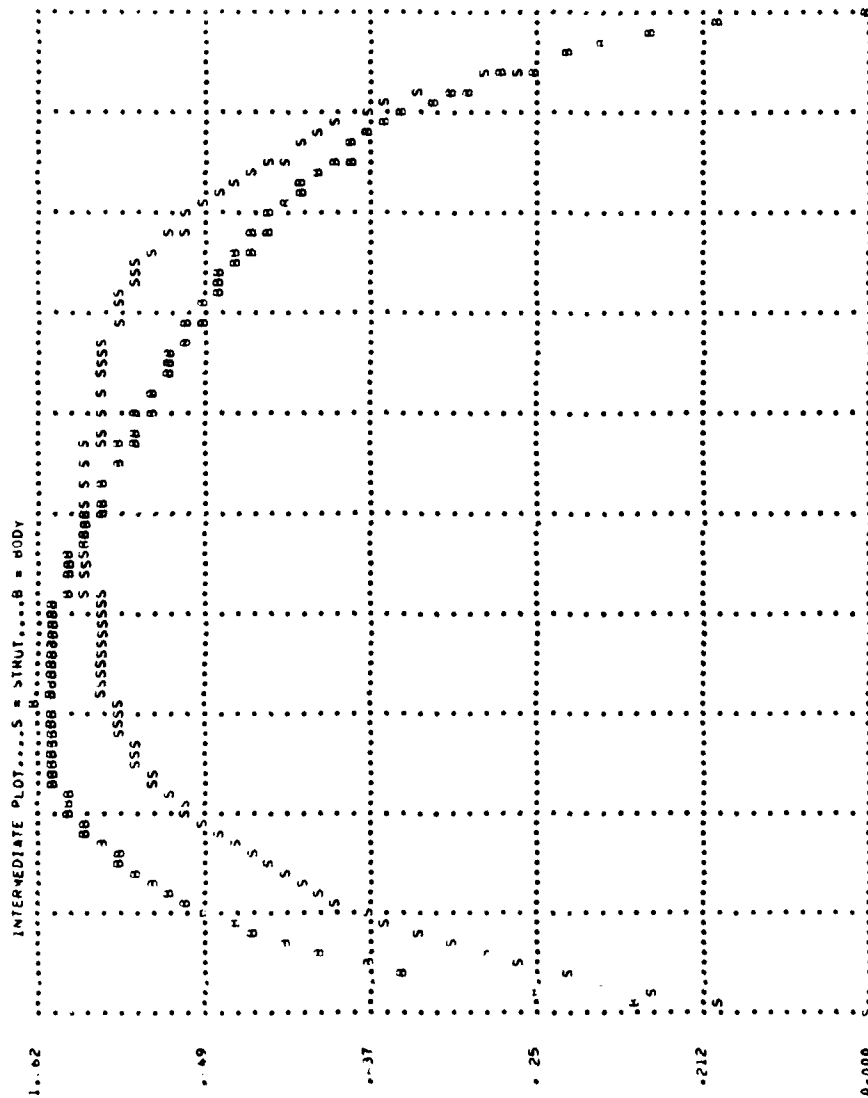
OUTPUT EXAMPLE

INITIAL S.	IP DESCRIPTION	
ALS	LENGTH OF STOUT IN FEET	= 210.0000
MS	DRAFT OF STOUT IN FEET	= 10.7250
TSMAK	MAX. STOUT THICKNESS IN FEET	= 0.5000
CSMP	WATERPLANE AREA COEFFICIENT	= .8511
CLYC	WATERPLANE MOMENT COEFFICIENT	= .0143
CLV	WATERPLANE INERTIA COEFFICIENT	= .0000E-01
KG	CG HEIGHT ABOVE BASELINE	= .2800E+02
KL8	LENGTH OF BODY IN FEET	= 260.0000
BOIA	BODY DIAMETER IN FEET AT ALB/2	= 14.3000
BS	SEPARATION OF HULL CENTERLINES	= 60.5000
CSSTR	DIST. OF STOUT CL FWD OF BODY CL	= 15.0000
CP	BODY HYDRASTATIC COEFFICIENT	= .6490
CLCM	BODY POSITIVE COEFFICIENT	= 0.154
OPTSPD	OPTIMIZATION SPEED IN KNOTS	= 2 0000

DISPNSN	MINIMUM SHIP DISPACEMENT LONG TONS =	2675.00
OPAC	MINIMUM SHIP DRAFT / BODY DIAMETER =	1.67
DRTXRA	MAXIMUM DRAFT OF SHIP IN FEET =	30.80
WMAA	MAXIMUM BREADTH OF SHIP IN FEET =	106.00
APUD	MINIMUM DIST. L.E.BODY TO L.E.STRUT =	7.50
XAFI	MINIMUM DIST. L.E.BODY TO T.E.STRUT =	30.00
GMI	MINIMUM TRANSVERSE GM	= 30.00
LONGI	MINIMUM LONGITUDINAL GM	= 30.00
LOOMA	MAXIMUM BODY LENGTH / BODY DIAMETER =	20.00
LOOMIN	MINIMUM BODY LENGTH / BODY DI-METER =	16.00
TSPIN	MINIMUM STRUT THICKNESS AT .5 CORD =	5.00
TS9000	.900000 .966333 1.000000 1.061062 -2.000000	-2.000000
TS2500		-2.000000

0	1	MIN F	K
LMIN EVALS			
		-3085400174E U4	
		1.025000	.980000
		-2.000000	1.022135
			.980000
			1.250000
			.980000
			1.061062
			.500000

BODY SECTIONAL AREA CURVE AND STRUT WATERPLANE OUTLINE CURVE FOR



$KL = 215.250040$ $MS = 10.510500$ $TMAX = 6.370000$ $CW = .024147$ $CLCF = 0.000000$ $CIVY = .063064$
 $CLCB = -.030760$ $L3 = 205.755100$ $BDIA = 14.157000$ $WS = 85.625000$ $CP = .049000$ $CSTRY = 7.500000$
 EFFECTIVE HUNSEPOWER REQUIRED FOR THIS DESIGN IS 3045.490

INTERMEDIATE DESIGN

STRUT CHEBYCHEV COEFFICIENTS - ASM 1.0493359 --0.0195361 --0.0297976
 STRUT CHEBYCHEV COEFFICIENTS - BSM 0.0000000 0.0000000 0.0000000
 BODY CHEBYCHEV COEFFICIENTS - ASM 1.0809604 --0.0809604 0.0000000
 BODY CHEBYCHEV COEFFICIENTS - BSM --0.1330036 0.0000000 0.0000000

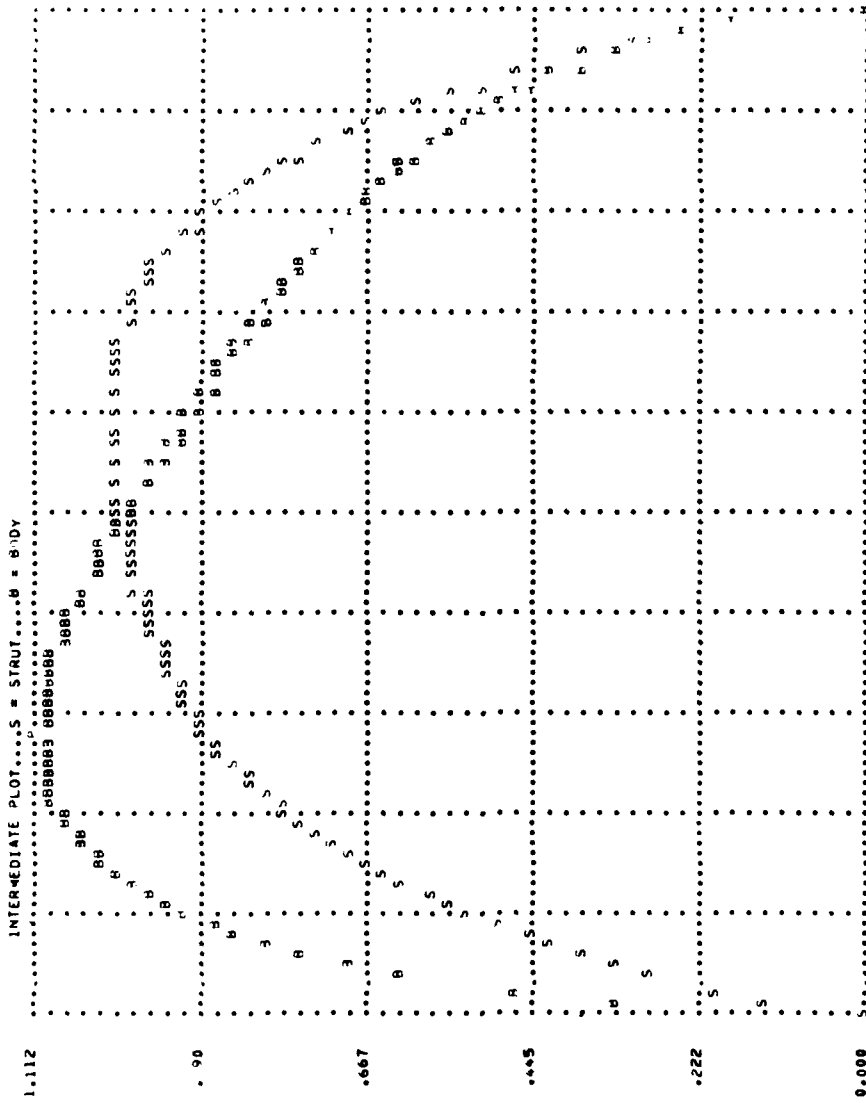
 STRUT WETTED SURFACE IN SQUARE FEET = 4530.83
 BODY WETTED SURFACE IN SQUARE FEET = 941.67
 TOTAL WETTED SURFACE IN SQUARE FEET = 14092.50

 LENGTH OF STRUT IN FEET = 215.2508
 DRAFT OF STRUT IN FEET = 10.5105
 MAX. ST. UT THICKNESS IN FEET = 6.3700
 WATERPLANE AREA COEFFICIENT = .8241
 WATERPLANE MOMENT COEFFICIENT = 0.0000
 WATERPLANE INERTIA COEFFICIENT = .9637
 LENGTH OF BODY IN FEET = 265.1551
 BODY DIAMETER IN FEET AT XLB/2 = 16.1576
 SEPARATION OF HULL CENTERLINES = 95.8250
 DIST. STRUT CL FWD OF BODY CL = 7.5000
 BODY PRISMATIC COEFFICIENT = .8490
 BODY MOMENT COEFFICIENT = .030~

 SHIP DISPLACEMENT IN LONG TONS = 2710.37 MIN. = 2675.00
 SHIP DR FT / 800 DIAMETER = 1.74 MIN. = 1.67
 DRAFT OF SHIP IN FEET = 24.67 MAX. = 30.00
 BREADTH OF SHIP IN FEET = 99.78 MAX. = 100.00
 DISTANCE L.E.BOD. TO L.L-STRUT = 17.75 MIN. = 7.50
 GMT / TR NSVERSE = 34.35 MIN. = 30.00
 GML (LONGITUDINAL) = 60.96 MIN. = 30.00
 BODY LENGTH / BODY DIA-ETER = 18.77 RANGE = 17.00-20.00
 STRUT THICKNESS AT 0.5 CHORD = 6.37 RANGE = 5.00-10.16

V-KTS V-F-S FM(S) FM(L) V-(K) V-(L) C_D C_{M2} C_W C_{FORM} CR CF CT RR-LBS RF-LBS RT-LBS EMP
 10.00 10.878 .203 .183 .582 .613 .210 -.032 .176 .500 .678 2.270 2.948 2708. 9072. 11780. 361.5
 12.00 20.254 .243 .219 .818 .736 .140 -.016 .124 .500 .624 2.228 2.852 3589. 12820. 16409. 604.3
 14.00 23.429 .294 .256 .954 .859 .216 -.066 .150 .500 .658 2.193 2.843 5091. 17179. 22269. 956.7
 16.00 27.005 .325 .292 .1091 .981 .879 .321 .150 .500 .678 2.164 3.864 17368. 22140. 30528. 1940.8
 18.00 30.368 .365 .329 .1227 1.104 1.006 .104 .902 .500 .678 2.139 3.541 18155. 27696. 45851. 2532.7
 20.00 33.756 .404 .365 1.363 1.227 .541 .144 .377 .451 1.028 2.117 3.145 16432. 33841. 50273. 3085.5
 22.00 37.132 .444 .402 1.500 1.350 .641 .244 .886 .848 1.733 2.098 3.031 33523. 40571. 74094. 5002.2
 24.00 40.507 .487 .438 1.636 1.472 .845 .558 1.543 .780 2.323 2.080 4.404 53177. 47881. 101358. 7464.9
 26.00 43.883 .527 .475 1.772 1.595 1.236 .640 1.876 .703 2.579 2.064 4.643 69659. 55766. 125474. 10007.2

BODY SECTIONAL AREA CURVE AND SHUT WATERPLANE OUTLINE CURVE FOR



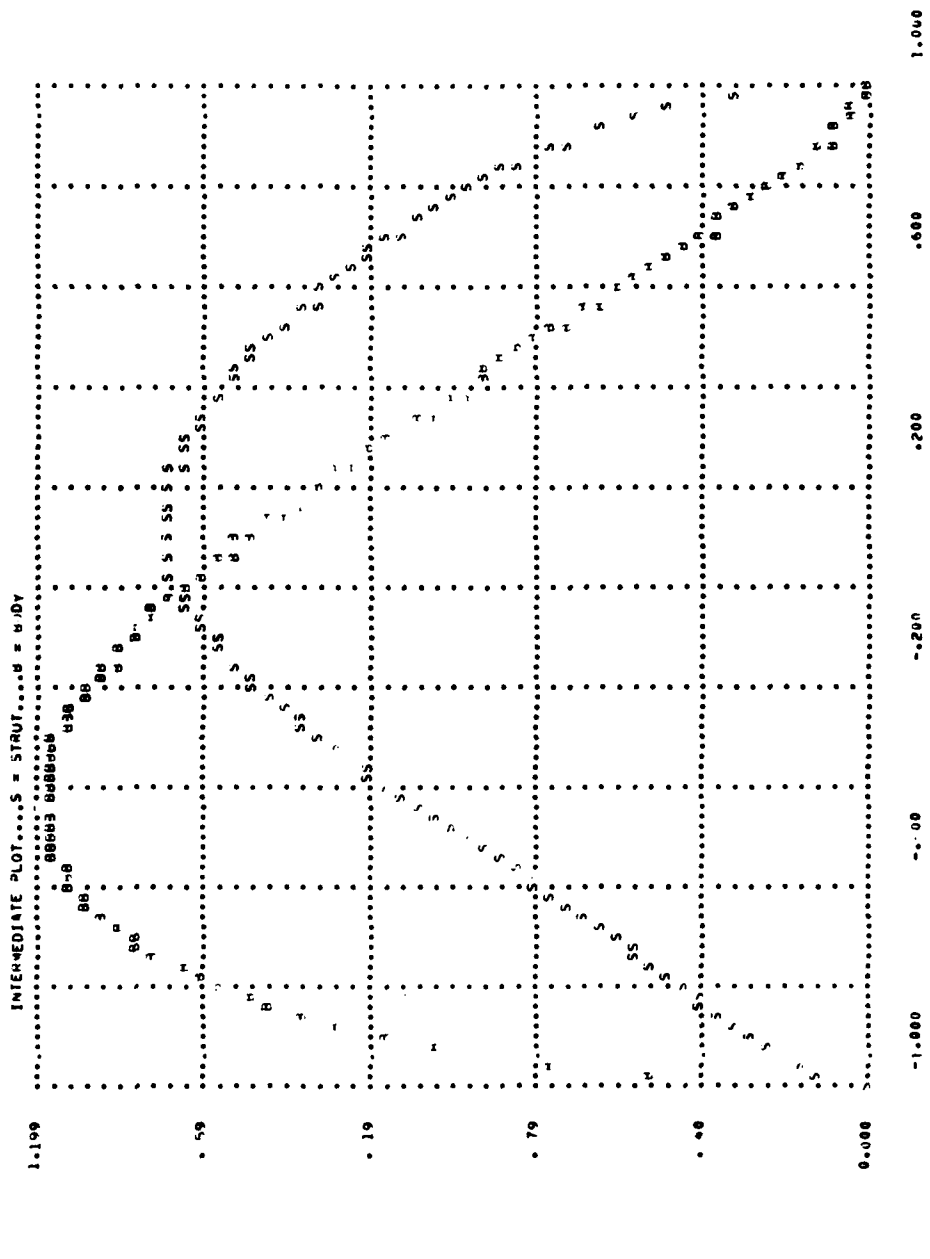
XLS = 219.450440 HS = 10.403250 TSWAR = 6.305000 CWP = .795661 CLCF = .014286 CLY = -.061112
 CLCB = -.0040140 WOA = 12.157000 BS = 84.940000 CLCP = .049000 CSTR = 15.000000
 EFFECTIVE HURSEPOWER REQUIRED FOR THIS DESIGN IS 2876.945

STRUT C-BEYCHEV COEFFICIENTS - ASM	1.0130674	-0.2255921	-0.3556995
STRUT C-BEYCHEV COEFFICIENTS - BSM	0.0578907	0.0000000	0.0000000
BODY C-BEYCHEV COEFFICIENTS - ABM	1.0899804	-0.0899804	0.0000000
BODY C-BEYCHEV COEFFICIENTS - BSM	-0.1995057	0.0000000	0.0000000
STRUT WETTED SURFACE IN SQUARE FEET	4570.77		
BODY WETTED SURFACE IN SQUARE FEET	9565.80		
TOTAL WETTED SURFACE IN SQUARE FEET	14136.56		
LENGTH OF STRUT IN FEET	219.4509		
DRAFT OF STRUT IN FEET	10.4033		
MAX. ST UT THICKNESS IN FEET	0.3050		
WATERPLANE AREA COEFFICIENT	.7957		
WATERPLANE MOMENT COEFFICIENT	.0143		
WATERPLANE INERTIA COEFFICIENT	.0611		
LENGTH OF BODY IN FEET	265.7551		
BODY DI WETER IN FEET AT X.0/2	14.1570		
SEPARATION OF MUL CENTERLINES	84.9400		
DIST. STRUT CL P.D OF BODY CL	1.0000		
BODY PRISMATIC COEFFICIENT	.8490		
BODY MOMENT COEFFICIENT	.0461		
SHIP DI PLACEMENT IN LONG TONS	2686.11	MIN. =	2675.00
DRAFT OF FT / BOD DIAMETER	1.73	MIN. =	1.07
DRAFT OF SHIP IN FEET	4.50	MIN. =	30.00
DIAMETER OF SHIP IN FEET	9.910	MIN. =	106.00
DISTANCE L.E. BOD TO L.C. STRUT	9.15	MIN. =	7.50
HEIGHT (TR NVERSE)	32.77	MIN. =	30.00
SWL (LONGITUDINAL)	59.45	MIN. =	30.00
BODY LENGTH / BODY DIAMETER	10.00	RANGE =	1.00-20.00
STRUT T THICKNESS AT 0.5 CMOD	6.33	RANGE =	5.00-14.10

V-F-15	V-F-5	FN(15)	FN(1)	V-(15)	V-(1)	CM1	CM2	CM	CM04	CR	CF	CT	RR-1BS	RR-BS	EMO
10.00	10.00	.201	.183	.615	.613	.282	.002	.057	.500	.780	2.269	3.049	3128	9035	375.1
12.00	12.02	.214	.196	.810	.806	.153	.005	.047	.500	.857	2.127	2.827	3216	9055	375.1
14.00	14.00	.224	.206	.810	.806	.153	.005	.047	.500	.857	2.127	2.827	3216	9055	375.1
16.00	16.05	.231	.213	.845	.841	.093	.003	.035	.500	.857	2.127	2.827	3216	9055	375.1
18.00	18.00	.241	.226	1.080	.981	.500	.307	.098	.500	1.350	2.127	2.827	3216	9055	375.1
20.00	20.00	.262	.249	1.215	1.104	.844	.634	.080	.500	1.350	2.127	2.827	3216	9055	375.1
22.00	22.10	.285	.265	1.350	1.227	.844	.634	.080	.500	1.350	2.127	2.827	3216	9055	375.1
24.00	24.12	.302	.282	1.485	1.350	.844	.634	.080	.500	1.350	2.127	2.827	3216	9055	375.1
26.00	26.17	.322	.302	1.620	1.472	.844	.634	.080	.500	1.350	2.127	2.827	3216	9055	375.1
28.00	28.22	.342	.322	1.755	1.595	1.076	.617	.103	.711	2.000	2.089	2.827	3216	9055	375.1
30.00	30.27	.362	.342	1.890	1.719	1.308	.617	.103	.711	2.000	2.089	2.827	3216	9055	375.1
32.00	32.32	.382	.362	2.025	1.842	1.540	.617	.103	.711	2.000	2.089	2.827	3216	9055	375.1
34.00	34.37	.402	.382	2.160	1.964	1.772	.617	.103	.711	2.000	2.089	2.827	3216	9055	375.1
36.00	36.42	.422	.402	2.295	2.086	2.004	.617	.103	.711	2.000	2.089	2.827	3216	9055	375.1
38.00	38.47	.442	.422	2.430	2.208	2.236	.617	.103	.711	2.000	2.089	2.827	3216	9055	375.1
40.00	40.52	.462	.442	2.565	2.330	2.468	.617	.103	.711	2.000	2.089	2.827	3216	9055	375.1
42.00	42.57	.482	.462	2.700	2.452	2.700	.617	.103	.711	2.000	2.089	2.827	3216	9055	375.1
44.00	44.62	.502	.482	2.835	2.574	2.932	.617	.103	.711	2.000	2.089	2.827	3216	9055	375.1
46.00	46.67	.522	.502	2.970	2.696	3.164	.617	.103	.711	2.000	2.089	2.827	3216	9055	375.1
48.00	48.72	.542	.522	3.105	2.818	3.396	.617	.103	.711	2.000	2.089	2.827	3216	9055	375.1
50.00	50.77	.562	.542	3.240	2.940	3.628	.617	.103	.711	2.000	2.089	2.827	3216	9055	375.1
52.00	52.82	.582	.562	3.375	3.062	3.860	.617	.103	.711	2.000	2.089	2.827	3216	9055	375.1
54.00	54.87	.602	.582	3.510	3.184	4.092	.617	.103	.711	2.000	2.089	2.827	3216	9055	375.1
56.00	56.92	.622	.602	3.645	3.306	4.324	.617	.103	.711	2.000	2.089	2.827	3216	9055	375.1
58.00	58.97	.642	.622	3.780	3.428	4.556	.617	.103	.711	2.000	2.089	2.827	3216	9055	375.1
60.00	60.02	.662	.642	3.915	3.550	4.788	.617	.103	.711	2.000	2.089	2.827	3216	9055	375.1

At this point numerous iterations have been omitted for a more concise report presentation.

BODY SECTIONAL AREA CURVE AND STRUT WATERPLANE OUTLINE CURVE FOR



XLS = 227.195260 MS = 9.814414 TMAX = 12.405406 CUB = .687000 C.CF = .048590 CLTY = .055834
 CLCH = -.05753 L3 = 272.623200 DUA = 13.663097 BSI = 75.226498 CP = .759745 CSTRAT = 15.232826
 EFFECTIVE HURSEPOWER REQUIRED FOR THIS DESIGN IS 2247.592

INTERMEDIATE DESIGN

STRUT C-BEYCHEV COEFFICIENTS - ASM
 STRUT C-BEYCHEV COEFFICIENTS - RSM
 BODY C-BEYCHEV COEFFICIENTS - ABM
 BODY C-BEYCHEV COEFFICIENTS - BBM

STRUT WETTED SURFACE IN SQUARE FEET = 447.34
 BODY WETTED SURFACE IN SQUARE FEET = 7499.13
 TOTAL WETTED SURFACE IN SQUARE FEET = 12170.47

LENGTH OF STRUT IN FEET = 227.0953

DRAFT OF STRUT IN FEET = 9.9144

MAX. ST. JT THICKNESS IN FEET = 12.4854

WATERPLANE AREA COEFFICIENT = .6879

WATERPLANE MOMENT COEFFICIENT = 0.466

WATERPLANE INERTIA COEFFICIENT = 0.558

LENGTH OF BODY IN FEET = 27.6233

BODY DIAMETER IN FEET AT L/8/2 = 13.6636

SEPARATION OF HULL CENTERLINES = 75.2265

DIST. STRUT CL F.D OF BODY CL = 15.2328

BODY PRISMATIC COEFFICIENT = .7497

BODY MOMENT COEFFICIENT = .1055

SHIP DISPLACEMENT IN LONG TONS = 2831.55

SHIP DR FT / HOD DIAMETER = 1.72

DRAFT OF SHIP IN FEET = 23.49

BREADTH OF SHIP IN FEET = 98.89

DISTANCE L.E.-HOD TO L.L.-STRUT = 7.5

GMT (TR VSWERSE) = 47.57

GML (LONGITUDINAL) = 105.22

BODY LENGTH / BODY DIAMETER = 19.9

STRUT THICKNESS T 0.5 CHORD = 12.44

MIN. = 267.500
 MAX. = 1.7
 MIN. = 30.00
 MAX. = 10.500
 MIN. = 7.50
 MAX. = 30.00
 MIN. = 30.00
 RANGE = 16.00-20.00
 RANGE = 5.00-13.66

V-KTS	V-F S	FN(S)	FN(L)	V-(K5)	V-(L3)	C4	CM2	CW	CFOR4	CR	CF	CT	MR-LBS	RF-LBS	RT-LBS	EMP
10.00	16.878	.197	.180	.564	.609	.575	.222	.797	.500	1.297	2.264	3.561	4475.	7813.	12248.	377.1
12.00	20.254	.237	.216	.696	.727	.655	-.156	.697	.500	.597	2.222	2.819	2986.	11042.	14010.	515.9
14.00	23.629	.274	.252	.829	.848	.786	-.037	.509	.500	.809	2.188	2.597	5474.	14796.	20270.	870.9
16.00	27.005	.312	.288	1.062	.969	.916	.189	.374	.500	.874	2.159	3.033	7724.	19070.	26794.	1315.6
18.00	30.380	.350	.324	1.327	1.070	.983	.064	.447	.500	.947	2.134	3.081	10589.	23857.	34445.	1902.7
20.00	33.756	.388	.358	1.600	1.211	1.179	-.156	.623	.518	.941	2.112	2.853	14770.	29151.	46621.	2247.6
22.00	37.132	.426	.396	1.860	1.332	1.262	.384	1.006	.855	1.861	2.092	3.953	21080.	34949.	66059.	4457.7
24.00	40.507	.464	.433	2.125	1.454	1.253	.681	2.134	.808	2.942	2.075	5.017	56476.	41246.	99722.	7344.5
26.00	43.883	.511	.469	1.725	1.575	1.676	1.029	2.705	.726	3.431	2.059	5.491	80051.	48040.	128090.	10219.9

SWATH OPTIMIZATION PROGRAM - G.W.L.G.M.T - AUGUST 1980

STRUT CHEBYCHEV COEFFICIENTS - ASM	.6758110	.0934144	.0307747
STRUT CHEBYCHEV COEFFICIENTS - BSM	.1632157	0.0000000	0.0000000
RODY CHEBYCHEV COEFFICIENTS - ABM	.9673380	.0326620	0.0000000
BODY CHEBYCHEV COEFFICIENTS - BBM	-.4091957	0.0000000	0.0000000

STRUT WETTED SURFACE IN SQUARE FEET	=	4471.34
BODY WETTED SURFACE IN SQUARE FEET	=	7699.13
TOTAL WETTED SURFACE IN SQUARE FEET	=	12170.47

LENGTH OF STRUT IN FEET	=	227.953
DRAFT OF STRUT IN FEET	=	9.8144
MAX. STRUT THICKNESS IN FEET	=	12.4854
WATERPLANE AREA COEFFICIENT	=	.6879
WATERPLANE MOMENT COEFFICIENT	=	.0466
WATERPLANE INERTIA COEFFICIENT	=	.0558
LENGTH OF BODY IN FEET	=	272.6233
BODY DIAMETER IN FEET AT X _{B/2}	=	13.6636
SEPARATION OF HULL CENTERLINES	=	75.2265
DIST. STRUT CL F.D OF BODY CL	=	15.2328
BODY PRISMATIC COEFFICIENT	=	.7597
BODY MOMENT COEFFICIENT	=	.1058

SHIP DISPLACEMENT IN LONG TONS	=	2831.55	MIN. =	2675.00
SHIP DRAFT / BODY DIAMETER	=	1.72	MIN. =	1.47
DRAFT OF SHIP IN FEET	=	23.44	MAX. =	30.00
BREADTH OF SHIP IN FEET	=	88.89	MAX. =	106.00
DISTANCE L.E.BODY TO L.C.STRUT	=	7.54	MIN. =	7.50
GMT (TRANSVERSE)	=	47.57	MIN. =	30.00
GML (LONGITUDINAL)	=	105.22	MIN. =	30.00
BODY LENGTH / BODY DIAMETER	=	19.94	RANGE =	16.00-20.00
STRUT THICKNESS T 0.5 CHORD	=	12.49	RANGE =	5.00-13.66

WAVE RESISTANCE CALCULATIONS FOR SWATH OPTIMIZATION PROGRAM - GML-64T - AUGUST 1980
STRUT GEOMETRIC CHARACTERISTICS

XLS 227.09 260 MS = 9.814-14 TSMAX = 12.485406
GAMA08 12.824521 FROUDS = .197453 MS/LS = .043217

BODY GEOMETRIC CHARACTERISTICS

XLB 272.621260 HB = 16.646217 AX = 146.629250
GAMA08 15.394578 FROUDS = .180213 HB/LB = .061059

SEPARATION DISTANCE IN FEET = 75.226 B/LB = .276

STRUT CL FROM BODY CL IN FEET = 15.233 STRUT OFFSET/LB = .056

WETTED SURFACES ARE FOR A DEMI-HULL

SHIP SPEED IS 16.878 FPS. 10.000 KNOTS, STRUT V-L RATIO = .66 BODY V-L RATIO = .606

RESISTANCES IN POUNDS ARE FOR A DEMI-HULL

STRUT WAVE DRAG IN POUNDS = .1673367E+04

R15/(RHO/2*WTSJRF**2) = .405E-03

BODY WAVE DRAG IN POUNDS = .1-29978E+03

R18/(RHO/2*WTSJRF**2) = .047E-03

STRUT-BODY WAVE DRAG IN LBS = .1471757E+3

R15H/(RH/2*WTSUNF**2) = .043E-03

STRUT INTERFERENCE DRAG LBS = .5235560E+03

R12S/(RH/2*WTSUNF**2) = .094E-03

BODY INTERFERENCE DRAG LBS = .1159055E+2

R12H/(RH/2*WTSUNF**2) = .003E-03

STRUT-BODY INTERFERENCE DRAG LBS = .4305955E+03

R12SH/(RH/2*WTSUNF**2) = .125E-03

STRUT FRICTION DRAG IN LBS = .2905115E+04

RFS/(RHO/2*WTSJRF**2) = .042E-03

BODY FRICTION DRAG IN LBS = .900005E+04

RFR/(RHO/2*WTSJRF**2) = 1.422E-03

CF TOTAL = .7913200E+04
CF TOTAL = 2.264E-03

WT = .1220799E+05
CT = 3.501E-03
END = 377.005

WAVE RESISTANCE CALCULATIONS FOR SWATH OPTIMIZATION PROGRAM - GML-64T - AUGUST 1980
STRUT GEOMETRIC CHARACTERISTICS

XLS 227.09-260 HS = 9.814+14 TSMAX = 12.485406
GAMA08 8.90-91H FROUDS = .236744 HS/LS = .043217

BODY GEOMETRIC CHARACTERISTICS

XLB 272.62326 HB = 16.646217 AX = 146.629250
GAMA08 10.691374 FROUDS = .216256 HB/LB = .061059

SEPARATION DISTANCE IN FEET = 75.226 B/LB = .276

STRUT CL FROM BODY CL IN FEET = 15.233 STRUT OFFSET/LB = .056

WETTED SURFACES ARE FOR A DEMI-HULL

SHIP SPEED IS 20.254 FPS, 12.000 KNOTS, STRUT V-L RATIO = .79 BODY V-L RATIO = .727

RESISTANCES IN POUNDS ARE FOR A DEMI-HULL

STRUT WAVE DRAG IN POUNDS = .2968083E-04
R1S/(RHO/2*WTSURF**2) = .577E-03

BODY WAVE DRAG IN POUNDS = .5416044E-03
R1H/(RHO/2*WTSURF**2) = .109E 03

STRUT-BODY WAVE DRAG IN LBS = -.2140786E+04
R1S4/(RH /2*WTSURF**2) = -.431E-03
CWL TOT = .255E-03

STRUT INTERFERENCE DRAG LBS = .6620352E+03
R12S/(RH /2*WTSURF**2) = .133E-03

BODY INTERFERENCE DRAG LBS = .1731256E+01
R12H/(RH /2*WTSURF**2) = .000E-03

STRUT-BODY INTERFERENCE DRAG LBS = -.1448918E+04
R12S3/(RHO/2*WTSURF**2) = -.292E-03

CW2 TOT = -.000E-03
CW TOT-L
CD .097E-03
WR .597E-04
2968481F.04

STRUT FRICTION DRAG IN LBS = .4104764E 04
RFS/(RHO/2*WTSURF**2) = .82E-03
BODY FRICTION DRAG IN LBS = .937138E+04
RFB/(RHO/2*WTSURF**2) = 1.394E-03

RF TOTAL = .1104191E+05
CF TOTAL = 2.222E-03

RT = .1401034E+05
CT = 2.819E-03
FWD = 515.929

WAVE RESISTANCE CALCULATIONS FOR SWATH OPTIMIZATION PROGRAM - GML.G41 - AUGUST 1980
 STRUT GEOMETRIC CHARACTERISTICS

XLS 227.03 260 HS = 9.814-14 TSMAX = 12.445406
 GAMMA05 6.53123 FROUDS = .276435 -S/LS = .043217

BODY GEOMETRIC CHARACTERISTICS

XLB 272.62126 HB = 16.446217 AX = 146.629250
 GAMMA08 7.85 887 FROUDS = .252249 M-LB = .061059

SEPARATION DISTANCE IN FEET = 75.226 B/LB = .270

STRUT CL FROM BODY CL IN FEET = 15.233 STRUT OFFSET/LB = .050

SETTLED SURFACES ARE FOR A DEMI-KULL

SHIP SPEED IS 23.004 FPS. 14.000 KNOTS. STRUT V-L RATIO = .929 BODY V-L RATIO = .848

RESISTANCES IN POUNDS ARE FOR A DEMI-KULL

STRUT WAVE DRAG IN POUNDS = .3118388E+04
 R1S/(RHO/2*WTSJRFV**2) = .461E-03

BODY WAVE DRAG IN POUNDS = .1314265E+04
 R1H/(RHO/2*WTSJRFV**2) = .194E-03

STRUT-BODY WAVE DRAG IN LBS = -.2 92432E+04
 R1S-/(RM /2*TSURFV**2) = -.304E-03

STRUT INTERFERENCE DRAG LBS = .146887E+03
 R12S/(RM /2*TSURFV**2) = .024E-03

BODY INTERFERENCE DRAG LBS = .3169488E+02
 R12-/(RM /2*TSURFV**2) = .005E-03

STRUT-BODY IN PRINCE D-16 LB = -.4468674E+03
 R12S3/(RM/2*WTSJRFV**2) = -.069E-03

STRUT FRICTION DRAG IN LBS = .5499577E+04
 RFS/(RHO/2*WTSJRFV**2) = .613E-03
 BODY FRICTION DRAG IN LBS = .296922E+04
 RPH/(RHO/2*WTSJRFV**2) = 1.374E-03

CW2 TOT = -.037E-03

CW TOTAL = .309E-03
 CR = .809E-03
 CR = .5473931E+04

WF TOTAL = .1479650E+05
 CF TOTAL = 2.188E-03

RT = .2027043E+05
 CT = 2.997E-03
 EMP = 870.862

CW1 TOT = .344E-03

WAVE RESISTANCE CALCULATIONS FOR SWATH OPTIMIZATION PROGRAM - GML-64T - AUGUST 1980
STRUT GEOMETRIC CHARACTERISTICS

XLS 227.09-250 MS = 9.814-14 TSMAX = 12.485406
GAMA05 5.004579 FROUDS = .315925 MS/LS = .043217

BODY GEOMETRIC CHARACTERISTICS

XLB 272.624260 MB = 16.646217 AX = 146.629250
GAMA08 6.01 898 FROUD- = .288341 M-L/LB = .061059

SEPARATION DISTANCE IN FEET = 75.226 B/LB = .270

STRUT (L FROM BODY CL IN FEET = 15.233 STRUT OFFSET/LB = .056

WETTED SURFACES ARE FOR A DEMI-HULL

SHIP SPEED IS 27.005 FPS. 10.000 KNOTS, STRUT V-L RATIO = 1.062 BODY V-L RATIO = .949

RESISTANCES IN POUNDS ARE FOR A DEMI-HULL

STRUT WAVE DRAG IN POUNDS = .4194254E-04
R15/(RHO/2*WTSJRFV**2) = .475E-03

BODY WAVE DRAG IN POUNDS = .2863267E-04
R18/(RHO/2*WTSJRFV**2) = .324E-03

STRUT-BODY WAVE DRAG IN LBS = .5418042E-04
R15+/(RHO/2*WTSURFV**2) = -.613E-03

STRUT INTERFERENCE DRAG LBS = -.178875E-02
R125/(RHO/2*WTSURFV**2) = -.005E-03

BODY INTERFERENCE DRAG LBS = .447801E-03
R12+/(RHO/2*WTSURFV**2) = .094E-03

STRUT-BODY INTERFERENCE DRAG LB = .4438478E-03
R1253/(RHO/2*WTSURFV**2) = .095E-03

STRUT FRICTION DRAG IN LBS = .7086923E-04
RFS/(RHO/2*WTSJRFV**2) = .402E-03

BODY FRICTION DRAG IN LBS = .1198307E-03
RFS/(RHO/2*WTSJRFV**2) = 1.356E-03

CW1 TOT = .186E-03

CW2 TOT = .189E-03

CW TOTAL = .374E-03
CH = .874E-03
RR = .7723617E+04

RF TOTAL = .1906999E+05
CF TOTAL = 2.150E-03

RT = .20793361E+05
CT = 3.033E-03
FHP = 1315.55A

WAVE RESISTANCE CALCULATIONS FOR SWATH OPTIMIZATION PROGRAM - GML,GMT - AUGUST 1980
 STRUT GEOMETRIC CHARACTERISTICS

XLS 227.09+260 HS = 9.814+14 TSMAX = 12.485406
 GAMAOS 3.958186 FROUDS = .355+16 MS/LS = .043217

BODY GEOMETRIC CHARACTERISTICS

XLB 272.62+260 HB = 16.646217 AX = 146.629250
 GAMAOS 4.751722 FROUDS = .324384 MH/LB = .061059

SEPARATION DISTANCE IN FEET = 75.226 B/LB = .276

STRUT CL FROM BODY CL IN FEET = 15.233 STRUT OFFSET/LB = .056

WETTED SURFACES ARE FOR A DEMI-HULL

SHIP SPEED IS 30.380 FPS. 1=0.000 KNOTS. STRUT V-L RATIO = 1.19 BODY V-L RATIO = 1.090

RESISTANCES IN POUNDS ARE FOR A DEMI-HULL

STRUT WAVE DRAG IN POUNDS = .3419516E+04
 215/(RHO/2*WTSJRF+V**2) = .351E-03

BODY WAVE DRAG IN POUNDS = .3704998E+04
 218/(RHO/2*WTSJRF+V**2) = .331E-03

STRUT-BODY WAVE DRAG IN LBS = -.3340301E+04
 2154/(RHJ/2*WTSURF+V**2) = -.299E-03

STRUT INTERFERENCE DRAG LBS = -.1892274E+03
 2125/(RH /2*WTSURF+V**2) = -.017E-03

BODY INTERFERENCE DRAG LBS = .3174303E+03
 2124/(RHJ/2*WTSURF+V**2) = .024E-03

STRUT-BODY INTERFERENCE DRAG -B = .5456097E+03
 21253/(RH0/2*WTSURF+V**2) = .052E-03

STRUT FRICTION DRAG IN LBS = .0864598E+04
 2FS/(RHO/2*WTSJRF+V**2) = .793E-03
 BODY FRICTION DRAG IN LBS = .1499190E+05
 2FB/(RHO/2*WTSJRF+V**2) = 1.341E-03

CW1 TOT = .383E-03

CW2 TOT = .064E-03

CW TOT-L = .447E-03
 CQ = .947E-03
 RR = .1058875E+05

RF TOTAL = .2385650E+05
 CF TOTAL = 2.134E 03

RT = .3444525E+05
 CT = 3.081E-03
 EMP = 1902 655

WAVE RESISTANCE CALCULATIONS FOR SWATH OPTIMIZATION PROGRAM - GML-647 - AUGUST 1980
 STRUT GEOMETRIC CHARACTERISTICS

KLS 227.09-260 MS = 9.614-14 TSMAX = 12.485406
 GAMAS 3.20-130 FROUDS = .394907 MS/LS = .043217

BODY GEOMETRIC CHARACTERISTICS

KLH 272.623260 MB = 16.646217 AX = 140.629250
 GAMAB 3.844895 FROUD = .360427 M-LB = .061059

SEPARATION DISTANCE IN FEET = 75.226 R/LB = .276

STRUT CL FROM BODY CL IN FEET = 15.233 STRUT OFFSET/LH = .056

WETTED SURFACES ARE FOR A DEMI-FULL

SHIP SPEED IS 33.756 FPS. 20,000 KNOTS. STRUT V-L RATIO = 1.32 BODY V-L RATIO = 1.211

RESISTANCES IN POUNDS ARE FOR A DEMI-FULL

STRUT WAVE DRAG IN POUNDS = .7487906E-04
 $R_{1S}/(RHO/2*WTSJRFV**2)$ = .542E-03

BODY WAVE DRAG IN POUNDS = .4461345E-04
 $R_{1H}/(RHO/2*WTSJRFV**2)$ = .323E-03

STRUT-BODY WAVE DRAG IN LBS = -.9473140E-04
 $R_{1S}/(RHO/2*WTSURFV**2)$ = -.686E-03

STRUT INTERFERENCE DRAG LBS = .522414E-04
 $R_{12S}/(RH/2*WTSURFV**2)$ = .233E-03

BODY INTERFERENCE DRAG LBS = .4761470E-03
 $R_{12B}/(RH/2*WTSURFV**2)$ = .062E-03

STRUT-BODY INTERFERENCE DRAG LBS = -.6234378E-04
 $R_{12SB}/(RHO/2*WTSURFV**2)$ = -.452E-03

STRUT FRICTION DRAG IN LBS = 1043070E-07
 $R_{FS}/(RHO/2*WTSJRFV**2)$ = .785E-03
 BODY FRICTION DRAG IN LBS = .1832024E-03
 $R_{FB}/(RHO/2*WTSJRFV**2)$ = 1.327E-03

CW1 TOT = .179E-04

CW2 TOT = -.156E-03

CW TOT L = .023E-03
 CB = .541E-03
 -R = .7469982E-04

RF TOTAL = .2915094E-05
 CF TOTAL = 2.112E-13

RT = .3662092E-05
 CT = 2.653E-03
 EMP = 2247.597

WAVE RESISTANCE CALCULATIONS FOR SWATH OPTIMIZATION PROGRAM - GML-04T - AUGUST 1980
STRUT GEOMETRIC CHARACTERISTICS

XLS 227.095260 MS = 9.81414 TSMAX = 12.485406
GAMA05 2.669695 FROUDS = .434397 MS/LS = .043217

BODY GEOMETRIC CHARACTERISTICS

XLH 272.621260 HB = 16.046217 AX = 146.629250
GAMA08 3.180905 FROUDS = .396669 HR/LB = .061059

SEPARATION DISTANCE IN FEET = 75.226 B/LB = .276

STRUT CL FROM BODY CL IN FEET = 15.233 STRUT OFFSET/LH = .056

WETTED SURFACES ARE FOR A DEMI-HULL

SHIP SPEED IS 37.112 FPS, 22.000 KNOTS, STRUT V-L RATIO = 1.460 BODY V-L RATIO = 1.332

RESISTANCES IN POUNDS ARE FOR A DEMI-HULL

STRUT WAVE DRAG IN POUNDS = .1314653E+05
R1S/(RHO/2*WTSJRFV**2) = .787E-03

BODY WAVE DRAG IN POUNDS = .0128567E+04
R1R/(RHO/2*WTSJRFV**2) = .407E-03

STRUT-BODY WAVE DRAG IN LBS = -.11080232E+05
R1SH/(RHO/2*WTSURFV**2) = -.652E-03

STRUT INTERFERENCE DRAG LBS = .5694433E-04
R12S/(RH/2*WTSURFV**2) = .341E-03

BODY INTERFERENCE DRAG LBS = .3911885E-04
R12H/(RHO/2*WTSURFV**2) = .234E-03

STRUT-BODY INTERFERENCE DRAG LB = -.3196314E-04
R12S3/(RHO/2*WTSURFV**2) = -.191E-03

STRUT FRICTION DRAG IN LBS = .1208356E-05
RFS/(RHO/2*WTSJRFV**2) = .777E-03

BODY FRICTION DRAG IN LBS = .2196530E-05
RFR/(RHO/2*WTSJRFV**2) = 1.315E-03

CW1 TOT = .622E-03

CW2 TOT = .384E-03

CW TOTAL = 1.006E-03

CR = 1.861E-03

RR = .3107990E-05

RF TOTAL = .3494884E+05

CF TOTAL = 2.092E-03

RT = .6602874E+05

CT = 3.953E-03

END = 4457.734

WAVE RESISTANCE CALCULATIONS FOR SWATH OPTIMIZATION PROGRAM - GMLGNT - AUGUST 1980
STRUT GEOMETRIC CHARACTERISTICS

XLS 227.09-260 MS = 9.81E-14 TSMAX = 12.485406
GAMA08 2.224579 FROUDS = .473888 MS/LS = .043217

BODY GEOMETRIC CHARACTERISTICS

XLM 272.629260 HB = 16.646217 AK = 146.629250
GAMA08 2.679843 FROUDS = .432512 M/LB = .061059

SEPARATION DISTANCE IN FEET = 75.226 B/LB = .276

STRUT CL FROM BODY CL IN FEET = 15.233 STRUT OFFSET/LB = .056

WETTED SURFACES ARE FOR A DEMI-HULL

SHIP SPEED IS 40.507 FPS, 2.000 KNOTS, STRUT V-L RATIO = 1.593 BODY V-L RATIO = 1.454

RESISTANCES IN POUNDS ARE FOR A DEMI-HULL

STRUT WAVE DRAG IN POUNDS = .1811587E-05
RIS/(RHO/2*WTSJRFV**2) = .911E-03

BODY WAVE DRAG IN POUNDS = .1304392E-05
RIS/(RHO/2*WTSJRFV**2) = .658E-03

STRUT-BODY WAVE DRAG IN LBS = -.6247330E-04
RIS/(RHO/2*WTSURFV**2) = -.314E-03

STRUT INTERFERENCE DRAG LBS = .5497737E-04
RIS/(RHO/2*WTSURFV**2) = .302E-03

BODY INTERFERENCE DRAG LBS = .7014915E-04
RIS/(RHO/2*WTSURFV**2) = .353E-03

STRUT-BODY INTERFERENCE DRAG LBS = .4492953E-04
RIS/(RHO/2*WTSURFV**2) = .226E-03

STRUT FRICTION DRAG IN LBS = .1532164E-05
RIS/(RHO/2*WTSJRFV**2) = .771E-03
BODY FRICTION DRAG IN LBS = .2592460E-05
RIS/(RHO/2*WTSJRFV**2) = 1.304E-03

CW1 TOT = 1.253E-03

CW2 TOT = .881E-03
CW TOTAL = 2.134E-03
CR = 2.942E-03
RR = .5847572E-05

RF TOTAL = .4124629E-05
CF TOTAL = 2.074E-03

RT = .9972201E-05
CT = 5.017E-03
EMP = 7344.472

WAVE RESISTANCE CALCULATIONS FOR SWATH OPTIMIZATION PROGRAM - GML,GMF - AUGUST 1980
STRUT GEOMETRIC CHARACTERISTICS

XLS 227.09-260 MS = 9.814+14 TSMAX = 12.485406
GAMAUS 1.89+119 F30UDS = .5133/9 -S/LS = .043217

BODY GEOMETRIC CHARACTERISTICS

XLB 272.62+260 MB = 16.646+17 AX = 146.629250
GAMA08 2.277452 F30UDN = .468555 M-L/LB = .061059

SEPARATION DISTANCE IN FEET = 75.226 B/LB = .276

STRUT (L FROM BODY CL IN FEET = 15.233 STRUT OFFSET/LH = .056

WETTED SURFACES ARE FOR A DEMI-HULL

SHIP SPEED IS 43.883 FPS, 20.000 KNOTS, STRUT V-L RATIO = 1.72~ BODY V-L RATIO = 1.575

RESISTANCES IN POUNDS ARE FOR A DEMI-HULL

STRUT WAVE DRAG IN POUNDS = .2166027E+05
R1S/(RHO/2*WTSJRF**2) = .924E-03

BODY WAVE DRAG IN POUNDS = .1726300E+05
R1H/(RHO/2*WTSJRF**2) = .740E-03

STRUT-BODY WAVE DRAG I LBS = .1774093E+03
R1S1/(RHJ/2*WTSURF**2) = .008E-03

STRUT INTERFERENCE DRAG LBS = .4982214E+04
R12S/(RH /2*WTSURF**2) = .214E-03

BODY INTERFERENCE DRAG LBS = .8673783E+04
R12H/(RH /2*WTSURF**2) = .372E-03

STRUT-BODY INTERFERENCE DRAG LBS = .1035771E+05
R12S3/(RHO/2*WTSURF**2) = .444E-03

STRUT FRICTION DRAG IN LBS = .1744376E+05
RFS/(RHO/2*WTSJRF**2) = .765E-03
BODY FRICTION DRAG IN LBS = .3019593E+05
RPH/(RHO/2*WTSJRF**2) = 1.294E-03

CW1 TOT = 1.676E-03

CW2 TOT = 1.029E-03

CW TOTAL = 2.705E-03
CR = 3.431E-03
RR = .005050E-05

RF TOTAL = .4883969E+05
CF TOTAL = 2.050E-03

RT = .1280902E+06
CT = 5.491E-03
EMP = 10219.920

JOB CONTROL FOR SWATHO

The Fortran code file of SWATHO is stored on a DTNSRDC Computer Center disk pack. To access the disk pack and make use of the program the following directions should be followed.

One must first set up an account with the DTNSRDC Computer Center and acquire a user ID. A Computer Center Reference Manual will provide the user with a further explanation of the Job Setup Control cards.

1. To get the program from the disk pack to a permanent file:

```
JOB CARD
CHARGE CARD
PAUSE. JOB REQUIRES DV4865.
MOUNT,VSN=DV4865,SN=CHRELIB.
REQUEST,LOG,*PF.
ATTACH,OLDPL,OPTSWATH,ID=CHRE,SN=CHRELIB.
UPDATE(P,F)
FTN(I=COMPILE,R=3)
CATALOG,LOG,USER'S NAME OF FILE,ID=USER ID
7/8/9
6/7/8/9
```

2. To run the program which is stored on the user's permanent file:

```
JOB CARD
CHARGE CARD
ATTACH,USER'S NAME OF FILE,ID=USER ID.
FIRST SEVEN LETTERS OF NAME OF FILE (PL=50000)
7/8/9
INPUT CARDS
6/7/8/9
```

The user's permanent file which is set up with the catalog card in Part 1 will be purged after 30 days of inactivity.

MAINTENANCE MANUAL

This part of the report contains a description of the main program, SWATHO and the subroutines directly called by it as well as descriptions of how other important subroutines fit together. Also included in this manual are descriptions of the common blocks, functions and subroutines and a functional listing of the functions and subroutines.

INTRODUCTION

The main program, SWATHO, first calls subroutine INPUT. Subroutine INPUT reads the input cards prepared by the user. The strut geometric characteristics, waterplane area and moment coefficients as well as the height of the CG above the baseline are read. Next, the body geometric characteristics, separation of hull centerlines, placement of the strut centerline in relation to the body centerline and the body prismatic and moment coefficients are read. Following that the S array of scaling factors, the optimization speed and limiting values are read.

After returning from INPUT the program calls PRAXIS, the optimization routine, which is described in detail in the following pages of this report.

Upon the completion of the optimization by PRAXIS, the subroutine SCALE is called which sets up an array of current working values of X, each member of the array corresponding to one of the ship geometric characteristics. The X array is calculated by multiplying S by XI where the S's are the scale factors and the XI's are the initial values of the ship geometry. Both S and XI are read by subroutine INPUT. Initially the members of the S array all have values of 1 and then, on subsequent runs, the S's correspond to the lowest value of EHP so far encountered by the user in the output from the previous run of the program. All of the initial variables are left unchanged.

Subroutine CHEB, called by the main program next, calculates the Chebychev coefficients for the ship as well as the wetted surface of the body and strut.* It also calls another subroutine, PCHEB, which plots the strut waterplane and body sectional area curves.

LISTEX is then called and values of ship geometry, etc. are listed to display the proximity of the solution to the extreme limits.

* See Appendix C for a discussion of the relationship between the Chebychev coefficients and the hullform coefficients.

Function EHP is lastly called at which time final design resistance and power is output. Whether the program gets this far is contingent upon how much time the computer is given for the computations.

Subroutine PRAXIS accomplishes the optimization of the objective function, EHP. PRAXIS finds the minimum of a function using the principal axis method as implemented by Brent.² The arguments of the subroutine are TO, HO, N, IPRIN, X, F, and FMIN. PRAXIS attempts to find this minimum such that if X0 is the true local minimum near X, then $NORM(X-X0) = TO + \text{SQUARE ROOT}(\text{MACHEP}) * NORM(X)$, where MACHEP is the machine precision, the smallest number such that $1 + \text{MACHEP} > 1$, and TO is the tolerance.

The values of TO, HO, N and IPRIN are set in the data statement in SWATHO. The value of MACHEP should be 2^{*-47} (about 7.105 E-15) on the CDC 6000 series for single precision arithmetic or 16^{*-13} (about 2.23 E-16) for double precision on the IBM 370 system. HO is the maximum step size, and should be set to about the maximum distance from the initial guess to the minimum. This value of HO affects the initial rate of convergence, in the current program $HO = .25$. N is the number of variables upon which the function depends, in this case $N = 12$. N must be at least 2. IPRIN controls the printing of intermediate results of the optimization.

X is an array which contains a guess of a point of minimum and an estimated point of minimum, on entry and return, respectively. $F(X,N)$ is the function to be minimized, in our case it is PEHP. F needs to be a real function declared EXTERNAL in the calling program. FMIN is set to the minimum value of F that is found.

The approximating quadratic form is

$$Q(X') = F(X,N) + \frac{1}{2} * (X' - X) \text{ TRANSPOSE } * A * (X' - X).$$

Here A is $\text{INVERSE}(V\text{-Transpose}) * D * \text{INVERSE}(V)$ where $V(*,*)$ is the matrix of search directions and $D(*)$ is the array of second differences.

PRAXIS in operation proceeds as follows. PRAXIS calls PRMIN which minimizes the function along first direction $V(*,J)$. PRMIN then calls function PRLIN which is a function of one real variable, which it minimizes. Function RANDUM is called and a random number is returned to PRAXIS to avoid resolution valleys. PRMIN continues to minimize the PRLIN function in different directions. PRQUAD is then

called and this subroutine tries a quadratic extrapolation in case minimization is being done in a curved valley. PRAXIS then calls PRFIT to find principal values and directions of the quadratic forms and PRSORT is called to sort the eigenvalues and eigenvectors. PRPRIN prints out the scaling factor on the first page of the output as is described in the output section of the USER's manual and VCPRINT prints the second difference array.

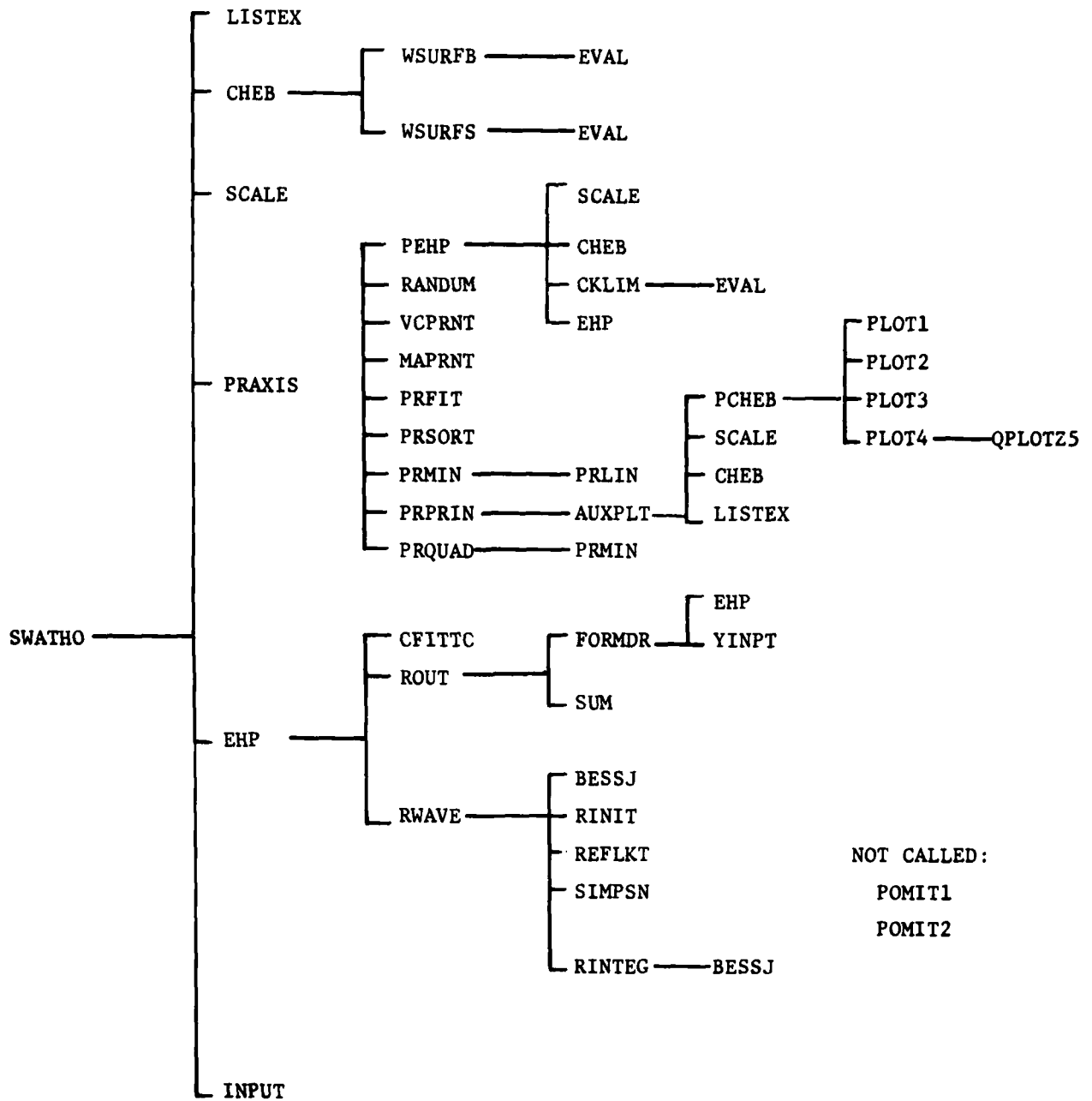
The optimization procedure is performed on the function PEHP. PEHP gets its value from the EHP calculated by the function by that name and a penalty P, so that $PEHP = (1 + P) * EHP$. P is determined from an array calculated in subroutine CKLIM. CKLIM uses the constraints determined by subroutine INPUT to check the current ship values for violation of these constraints. The checking procedure is quantified with an array GG of violation coefficients, in the following way. The current value of ship displacement is multiplied by a member of a scaling array, ALPHA, given in a data statement in CKLIM. This results in a violation coefficient GG(1) for displacement. Nineteen of these coefficients are calculated and this array of GG(I)'s is used in function PEHP. Since $GG(I) > 0$ means that the constraint is violated whereas $GG(I) < 0$ means that the constraint is satisfied, the function PEHP totals up all of the GG(I)'s greater than zero and this becomes the value of P, used to calculate PEHP. For further details on penalty functions see Appendix A.

Other important subroutines have not been mentioned yet. Subroutine RWAVE, called by Function EHP, computes the auxiliary wave resistance functions T and W as explained in Appendix B, using the Chebychev expansions calculated in subroutine CHEB, as discussed in Appendix C. Subroutine RINTEG integrates these auxiliary functions with subroutine INIT initializing the arrays. The symmetric matrices of T and W are reflected by subroutine REFLKT. Using the Chebychev coefficients, subroutine WSURFB determines the wetted surface of the body of revolution and WSURFS determines the wetted surface of the strut.

Subroutine ROUT is called by function EHP, it computes values of Froude number and speed-length ratio as well as wave resistance coefficients and frictional drag coefficients and returns the value of EHP to function EHP. It also prints the intermediate and final design values. Which one of these is printed is determined by the value of KEY. If KEY = 0 no output is printed, instead only the computations in ROUT are performed. If KEY = 1 the optimization is complete and just the final design is printed. If KEY = 2 when ROUT gets to the output section,

the intermediate results are printed. The different values of KEY are set in the subroutines which call FUNCTION EHP which in turn calls ROUT; KEY is set to 0 in PEHP, 1 in SWATHO and 2 in AUXPLOT.

Figure 2 - TREE DIAGRAM OF SWATH PROGRAM



FUNCTIONAL LISTING OF FUNCTIONS AND SUBROUTINES

<u>Subroutine Name</u>	<u>Description</u>
AUXPLT	Prints titles and labels for body sectional area and waterplane curves
BESSJ	Evaluates Bessel function
CHEB	Determines Chebychev coefficients for body and strut
CKLIM	Checks for violation of geometric constraints
INPUT	Reads in initial values of ship geometry and constraints
LISTEX	Lists various values of the design to see how close to the limits the solution lies
MAPRNT	Prints columns of matrix
PCHEB	Plots body sectional area curve and waterplane outline curve
PLOT1	Sets up spacing and determines values of the axes for printer plot
PLOT2	Establishes formula for computing location in the image region where the point will be plotted, in the printer plot
PLOT3	Assigns an alpha character to each point to be plotted on the printer plot
PLOT4	Prints image of completed graph on the printer
POMIT1	Causes certain grid lines on printer plot to be deleted
POMIT2	Causes values at grid lines to be deleted
PRAXIS	Finds the minimum of the objective function using the principal axis method
PRFIT	Fits points to a quadratic curve
PRMIN	Minimizes the objective function, F, in one dimension
PRPRIN	Prints intermediate results and calls the routine which does the printer plotting

FUNCTIONAL LISTING OF FUNCTIONS AND SUBROUTINES (CONT)

<u>Subroutine Name</u>	<u>Description</u>
PRQUAD	Looks for minimum of F along a quadratic curve
PRSORT	Sorts the elements of a matrix to find the eigenvalues and eigenvectors
QPLOTZ5	Calculates scaling information to label the plot
REFLECT	Reflects matrices of auxiliary wave resistance functions
RINIT	Initializes the auxiliary wave resistance function matrices to zero
RINTEG	Evaluates the integrand of the auxiliary wave resistance function
ROUT	Calculates EHP, wave resistance coefficients and constants, and also prints the intermediate and final design results
RWAVE	Computes the auxiliary wave resistance functions
SCALE	Calculates working values of ship geometry
SIMPSN	Sets up Simpson's multipliers for numerical integration by Simpson's rule
SUM	Computes the components of wave resistance as a matrix multiplication involving the Chebychev coefficients and the auxiliary wave resistance function matrices
VCPRINT	Depending on the option; prints the second difference array, scale factors, value of quadratic, and value of the objective function as part of the optimization
WSURFB	Determines surface area of a body of revolution given by Chebychev coefficients
WSURFS	Determines surface area of strut whose thickness distribution is given by Chebychev coefficients

FUNCTIONAL LISTING OF FUNCTIONS AND SUBROUTINES (CONT)

<u>Function Name</u>	<u>Description</u>
CFITTC	Determines frictional resistance coefficient from ITTC line
EHP	Calculates body constants and frictional drag coefficients
EVAL	Evaluates the Chebychev series
FORMDR	Evaluates form drag coefficients
PEHP	The objective function to be minimized by PRAXIS
PRLIN	Function of one variable minimized by PRAXIS
RANDUM	Returns a random number which creates random steps during the optimization
YINTP	Interpolates through a set of discrete data

COMMON BLOCK DESCRIPTIONS

COMMON/COEFS

PURPOSE: COEFS stores the values of the Chebychev coefficients for the strut and body

<u>NAME</u>	<u>TYPE</u>	<u>LENGTH</u>	<u>DEFINITION</u>
ASM	R	(3)	Coefficients of Chebychev Sine Series for strut
BSM	R	(3)	Coefficients for Chebychev Cosine Series for strut
ABM	R	(3)	Coefficients of Chebychev Sine Series for body
BBM	R	(3)	Coefficients of Chebychev Cosine Series for body
MMAX	I		Maximum order of Chebychev Series

COMMON/ EXTLIM

PURPOSE: EXTLIM defines and stores physical constants and geometric parameters

<u>NAME</u>	<u>TYPE</u>	<u>DEFINITION</u>
DISPMN	R	Minimum ship displacement in long tons
DFAC	R	Minimum draft/body diameter ratio
DRFTMX	R	Maximum draft of ship
WMAX	R	Maximum width of ship
XFWD	R	Minimum distance from body L.E. to strut L.E.
XAFT	R	Minimum distance from body T.E. to strut T.E.
MINGMT	R	Minimum GMT (transverse GM)
MINGML	R	Minimum GML (longitudinal GM)
LODMAX	R	Maximum length over diameter ratio
LODMIN	R	Minimum length over diameter ratio
TSMIN	R	Minimum strut thickness at 50 percent chord
KG	R	Height of center of gravity of ship above baseline

COMMON/INITL

PURPOSE: Store initial values of ship geometry

<u>NAME</u>	<u>TYPE</u>	<u>DEFINITION</u>
XL SI	R	Length of strut in ft.
HSI	R	Draft of strut in ft.
TSMAXI	R	Max. strut thickness in ft.
CWPI	R	Waterplane area coefficient
CLCFI	R	Waterplane moment coefficient
CIYYI	R	Waterplane inertia coefficient
CLCBI	R	Body moment coefficient
XLBI	R	Length of body in ft.
BDIAI	R	Body diameter in ft. at XLB/2
BSI	R	Separation of hull centerlines
CPI	R	Body prismatic coefficient
CSTRTI	R	Dist. of strut CL fwd of body CL
VBI	R	Initial displaced volume of the body in cubic ft.
VSI	R	Initial displaced volume of the strut in cubic ft
KBI	R	Initial height of center of buoyancy above the baseline
BMLI	R	Initial longitudinal metacentric height
IYYI	R	Waterplane moment of inertia

COMMON/NOCHG

PURPOSE: Checks whether certain ship geometry variables change or not.

<u>NAME</u>	<u>TYPE</u>	<u>LENGTH</u>	<u>DEFINITION</u>
LL	I	6	LL(1) thru LL(6) represents positions in WORKVL of XLS, BS, HS, XLB, BDJA CSTRT. In the data statement in SWATHO they are assigned values; LL(1) = 1, LL(2) = 10, LL(3) = 2, LL(4) = 8, LL(5) = 9, LL(6) = 1
SS	R	6	Holds array of scale factors corresponding to the six ship geometry variables in the LL array
SAME	L		Variable which indicates whether scaling variables have changed or not.

COMMON/OMEGA

PURPOSE: OMEGA stores the values of variables and constants for evaluation of auxiliary wave resistance functions and ship resistance coefficients

<u>NAME</u>	<u>TYPE</u>	<u>DEFINITION</u>
VMFPS	R	Speed of ship (feet per second)
GAMAOS	R	γ_{os}
GAMAOB	R	γ_{ob}
GOSQ	R	$(\gamma_{os})^2$
HSOLS	R	Ratio of draft to length of strut
HBOLB	R	Ratio of draft to length of body
WETS	R	Wetted surface area of strut (ft ²)
WETB	R	Wetted surface area of body (ft ²)
WTSURF	R	Total wetted surface area (ft ²)
SEP	R	$2b (\gamma_{os} L_s)$
PHIS	R	$\frac{2(h_s)}{L_s \gamma_{os}}$
PHIB	R	$\frac{2(h_b)}{L_b \gamma_{ob}}$
RATIOI	R	γ_{ob}/γ_{os}
CFS	R	Frictional drag coefficient of strut
CFB	R	Frictional drag coefficient of body

COMMON/PHYSICO

PURPOSE: PHYSICO stores physical constants

<u>NAME</u>	<u>TYPE</u>	<u>DEFINITION</u>
RHO	R	Density of water
GNU	R	Kinematic viscosity of water
G	R	Acceleration due to gravity
PI	R	Ratio of circumference to diameter of a circle
DELCF	R	Correlation allowance
KTFPS	R	Conversion factor for changing ft/sec into knots

COMMON/PRCOMM

PURPOSE: Used by optimization subroutines to transmit values
amongst themselves

<u>NAME</u>	<u>TYPE</u>	<u>DEFINITION</u>
FX	R	Function to be minimized
LDT	R	Used in step size computations
DMIN	R	The square of the machine precision
NF	I	Function evaluation counter
NL	I	One dimensional search counter

COMMON/PSI

PURPOSE: PSI stores the values of the variables and constants used in integration routines

<u>NAME</u>	<u>TYPE</u>	<u>DEFINITION</u>
NPTSZ	I	Number of integration steps from γ_{os} to $\gamma_{os}+1$
PTSAF	R	Scaling factor of step size in integrating from α_{max} to α_{smax}
EXPN	R	Empirical constant for integration to stop
NALMAX	I	Maximum number of integration steps from $\gamma_{os}+1$ to α_{max}
NAL	I	Counter of integration steps
ALFA	R	Integration variable (α)
ALSMAX	R	Maximum of α for integration

Comments: Values of NPTSZ, PTSAF, EXPN, NALMAX and ALSMAX are assigned in data statement in SWATHO

COMMON/Q

PURPOSE: Used by optimization subroutines to transmit function representations amongst themselves

<u>NAME</u>	<u>TYPE</u>	<u>DEFINITION</u>
V	R	Matrix to define directions for linear search
Q0	R	Variables which define the plane for the quadratic search
Q1	R	
QA	R	Variables which define a parabolic space curve
QB	R	
QC	R	
QD0	R	Variables used in QA, QB, QC to define quadratic curve
QD1	R	
QF1	R	Value of function defined by QA, QB, QC

COMMON/SPEEDS

PURPOSE: Stores speeds at which resistance calculations are made

<u>NAME</u>	<u>TYPE</u>	<u>LENGTH</u>	<u>DEFINITION</u>
NSPEED	I		Number of speeds
SPEED	R	20	Speeds in feet per second

COMMON/XRPLOTF

PURPOSE: XRPLOTF stores the values of variables for the plotting routines

<u>NAME</u>	<u>TYPE</u>	<u>DEFINITION</u>
XL	R	Value of abscissa at left-most grid line
XH	R	Value of abscissa at right-most grid line
YL	R	Value of ordinate at bottom grid line
YH	R	Value of ordinate at top grid line
XI	R	Increment of divisions along the abscissa
YI	R	Increment of divisions along the ordinate
YMOV	R	Ordinate index increment number of array GRAF
XMOV	R	Abscissa index increment number of array GRAF

COMMON/XRPLTG

PURPOSE: XRPLTG stores the values and characters of variables for the plotting routines

<u>NAME</u>	<u>TYPE</u>	<u>LENGTH</u>	<u>DEFINITION</u>
GRAF	I	(11,204)	Array containing the image to be plotted

COMMON/ XRPLQT

PURPOSE: XRPLQT stores the constants and characters for the plotting routines

<u>NAME</u>	<u>TYPE</u>	<u>DEFINITION</u>
I, II	I	Ordinate scale factor is 10^I
J, JJ	I	Number of digits following ordinate decimal point
K, KK	I	Abcissa scale factor is 10^K
L, LL	I	Number of digits following abcissa decimal point
A, NHL	I	Integer number of horizontal grid lines
G, NSBH	I	Integer number of spaces beyond each horizontal grid line to next grid line
C, NVL	I	Integer number of vertical grid lines
D, NSBV	I	Integer number of spaces beyond each vertical grid line to next grid line
E, HCHAR		Horizontal grid character
F, VCHAR		Vertical grid character
M, IX, ISX	I	Number of horizontal spaces
N, IY, ISY	I	Number of vertical spaces
V	L	Logical variable = TRUE when maximum and minimum values of the ordinate are determined
H	L	Logical variable = TRUE when maximum and minimum values of the abcissa are determined

COMMON/WORKVL

PURPOSE: WORKVL stores the working values of the ship geometry

<u>NAME</u>	<u>TYPE</u>	<u>DEFINITION</u>
XLS	R	Length of strut in ft.
HS	R	Draft of strut in ft.
TSMAX	R	Max strut thickness in ft.
CWP	R	Waterplane area coefficient
CLCF	R	Waterplane moment coefficient
CIYY	R	Waterplane inertia coefficient
CLCB	R	Body moment coefficient
XLB	R	Length of body in ft.
BDIA	R	Body diameter in ft. at XLB/2
BS	R	Separation of hull centerlines
CP	R	Body prismatic coefficient
CSTRT	R	Dist. of strut CL fwd of body CL
AX	R	Maximum body cross-sectional area in sq. ft.
HB	R	Body centerline submergence
DISP	R	Displacement of total ship in long tons
AWP	R	Waterplane area of one strut
NLOC	I	Switch indicating presence of second strut
CSTRT2	R	Dist. of strut CL fwd of body CL
OVMFPS	R	Optimization speed in ft/sec

COMMON/WORKVL (CONT)

<u>NAME</u>	<u>TYPE</u>	<u>DEFINITION</u>
KB	R	Height of center of buoyancy above baseline
BML	R	Longitudinal metacentric height
BMT	R	Transverse metacentric height

SUBROUTINE AND FUNCTION DESCRIPTIONS

NAME:	SUBROUTINE AUXPLT
PURPOSE:	Prints title and values for ship geometry on the body sectional area and waterplane outline curve. Subroutine PCHEB prints the actual curve
CALLING SEQUENCE:	Call AUXPLT (S, N, HP)
ARGUMENTS:	S - Scaling values for each of the variables N - The number of variables upon which the function depends HP - Horsepower
COMMON BLOCKS:	INITL, NOCHG, PHYSCO, SPEEDS
SUBROUTINES CALLED:	SCALE, CHEB, LISTEX, PCHEB, EHP
CALLED BY:	PRPRIN

NAME:	SUBROUTINE BESSJ
PURPOSE:	SUBROUTINE BESSJ evaluates the Bessel function from order 0 to order N
CALLING SEQUENCE:	CALL BESSJ (X, N, VJ)
ARGUMENTS:	X - Argument of the Bessel function N - Maximum order of the Bessel function VJ - Array holding (N+1) values of the Bessel function of order zero up to N, where VJ(1) = $J_0(X)$. . . VJ(N+1) = $J_N(X)$
COMMON BLOCKS:	NONE
SUBROUTINE CALLED:	NONE
CALLED BY:	RINTEG, RWAVE

NAME:	FUNCTION CFITTC
PURPOSE:	Function CFITTC determines the frictional resistance coefficient based on the ITTC correlation line
CALLING SEQUENCE:	C = CFITTC (RN)
ARGUMENT:	RN - Reynolds number at test condition
COMMON BLOCKS:	NONE
SUBROUTINE CALLED:	NONE
CALLED BY:	Function EHP
COMMENTS:	$C = \frac{0.075}{(\log_{10} (RN) - 2)^2}$

NAME:	SUBROUTINE CHEB
PURPOSE:	Determines Chebychev coefficients for the ship, and calculates wetted surface of body and strut
CALLING SEQUENCE:	CALL CHEB (TITLE, KEY)
ARGUMENTS:	TITLE - Label printed on output KEY - Variable used to skip or include the printed output.
COMMON BLOCKS:	COEFS, OMEGA, PHYSCO, WORKVL
SUBROUTINES CALLED:	WSURFB, WSURFS
CALLED BY:	SWATHO, PEHP, AUXPLT

NAME:	SUBROUTINE CKLIM
PURPOSE:	Checks for violation of constraints and scales penalties by the values in the array ALPHA
CALLING SEQUENCE:	CALL CKLIM (GG, NGG)
ARGUMENTS:	GG - actual amount of violation NGG - number of values to be checked for violation
COMMON BLOCKS:	COEFS, EXTLIM, WORKVL
SUBROUTINES CALLED:	EVAL
CALLED BY:	Function PEHP

NAME:	FUNCTION EHP
PURPOSE:	Calculates body constants and frictional drag coefficients and calls ROUT to calculate EHP
CALLING SEQUENCE:	EH = EHP (SPEED, TITLE, KEY)
ARGUMENTS:	SPEED - Speed of ship in feet per second TITLE - Label printed on output KEY - Variable to skip or include the printed output
COMMON BLOCKS:	NOCHG, OMEGA, PHYSCO, WORKVL
SUBROUTINES CALLED:	ROUT, RWAVE, CFITTC
CALLED BY:	SWATHO, AUXPLT, PEHP

NAME:	FUNCTION EVAL
PURPOSE:	Evaluates the Chebychev series $F(x) = \sum_{M=1}^{MAX} A(M)*U(M,X) + B(M)*V(M,X)$
CALLING SEQUENCE:	EV = EVAL (X,A,B,MAX)
ARGUMENTS:	X - Arguments of the Chebychev series A - Coefficients of the Chebychev Cosine series B - Coefficients of the Chebychev Sine series MAX - Maximum order of the Chebychev series
COMMON BLOCKS:	NONE
SUBROUTINES CALLED:	NONE
CALLED BY:	CKLIM, WSURFB, WSURFS
COMMENTS:	$U_M(X) = \cos \{(2M-1)(\theta)\}$ $V_M(X) = \sin 2M\theta$ $\theta = \sin^{-1}(X)$

NAME:	FUNCTION FORMDR
PURPOSE:	Function FORMDR evaluates the form drag coefficient
CALLING SEQUENCE:	FOR = FORMDR (VL)
ARGUMENT:	VL = Speed-length ratio of ship based on strut length
COMMON BLOCKS:	NONE
SUBROUTINE CALLED:	FUNCTION YINTP
CALLED BY:	ROUT
COMMENTS:	

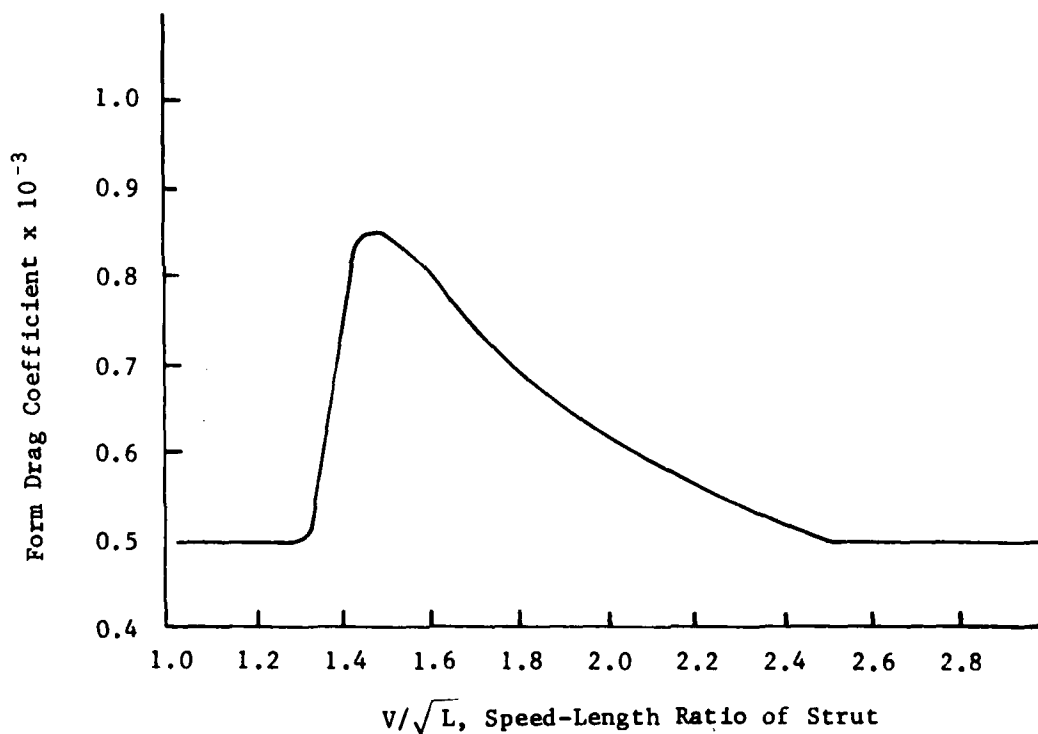


Figure 3. FORM DRAG COEFFICIENT

NAME:	SUBROUTINE INPUT
PURPOSE:	Reads into common block/INITL/the initial values of ship geometry and constraints, concurrently defining array XI. It then prints the starting point, along with an echo of the input values
CALLING SEQUENCE:	CALL INPUT (TITLE, S, OPTSPD)
ARGUMENTS:	TITLE - Label printed on output S - Scale factors OPTSPD - Optimization speed in knots
COMMON BLOCKS:	EXTLIM, INITL
SUBROUTINES CALLED:	NONE
CALLED BY:	SWATHO

NAME:	SUBROUTINE LISTEX
PURPOSE:	Lists various constraint values so that it can be determined how close to the extreme limits this solution lies
CALLING SEQUENCE:	CALL LISTEX
ARGUMENTS:	NONE
COMMON BLOCKS:	EXTLIM, PHYSCO, WORKVL
SUBROUTINES CALLED:	NONE
CALLED BY:	SWATHO, AUXPLT

NAME:

SUBROUTINE MAPRNT

PURPOSE:

Prints the columns of the NxN Optimization
matrix V with a heading as specified by OPTION

CALLING SEQUENCE:

CALL MAPRNT (OPTION, V, M, N)

ARGUMENTS:

OPTION = 1 LABELS NEW DIRECTION
 2 LABELS PRINCIPAL AXES

V - Logical variable = TRUE

M - The maximum step size

N - Number of variables

COMMON BLOCKS:

NONE

SUBROUTINES CALLED:

NONE

CALLED BY:

PRAXIS

NAME:	SUBROUTINE PCHEB
PURPOSE:	Subroutine PCHEB plots by line printer the body sectional area curve and waterplane outline curve from the given Chebychev coefficients
CALLING SEQUENCES:	CALL PCHEB (AS, BS, AB, BB, NN, TITLE)
ARGUMENTS:	AS - Coefficients of Chebychev Sine Series for strut (Symmetric) BS - Coefficients of Chebychev Cosine Series for strut (Antisymmetric) AB - Coefficients of Chebychev Sine Series for body (Symmetric) BB - Coefficients of Chebychev Cosine Series for body (Antisymmetric) NN - Dimension of AS, BS, AB, BB TITLE- Array containing the alphanumeric characters of the title of the project.
COMMON BLOCKS:	NONE
SUBROUTINES CALLED:	PLOT1, PLOT2, PLOT3, PLOT4
CALLED BY:	AUXPLT

NAME:	FUNCTION PEHP
PURPOSE:	PEHP is the objective function to be minimized by PRAXIS
CALLING SEQUENCE:	PE = PEHP (S,N)
ARGUMENTS:	S - Array of scale factors being optimized N - Maximum order of the Bessel function
COMMON BLOCKS:	OMEGA, WORKVL
SUBROUTINES CALLED:	SCALE, CHEB, CKLIM, EHP
CALLED BY:	PRAXIS

NAME:	SUBROUTINE PLOT1
PURPOSE:	Subroutine PLOT1 sets up spacing and determines the values of the axes
CALLING SEQUENCE:	CALL PLOT1 (NSCALE, A, B, C, D, E, F)
ARGUMENTS:	NSCALE - Integer array defined as follows: NSCALE (1) - I, if printed, values of the ordinate are $10 \times I$ times the actual values NSCALE (2) - J, if printed, values of the ordinate are $10 \times J$ times the actual values NSCALE (3) - K, if printed, values of the abscissa are $10 \times K$ times the actual values NSCALE (4) - L, if printed, values of the abscissa are $10 \times L$ times the actual values A - Integer number of horizontal grid lines B - Integer number of spaces between each horizontal grid line C - Integer number of vertical grid lines D - Integer number of spaces between each vertical grid line E - Horizontal grid character F - Vertical grid character
COMMON BLOCK:	XRPLQT
SUBROUTINE CALLED:	NONE
CALLED BY:	PCHEB

NAME:	SUBROUTINE PLOT2
PURPOSE:	Subroutine PLOT2 examines the minimum and maximum values of the abscissa and the ordinate and establishes an internal formula for computing location in the image region corresponding to the point to be plotted
CALLING SEQUENCE:	CALL PLOT2 (XMAX, XMIN, YMAX, YMIN, NSCLI)
ARGUMENTS:	XMAX - Value of abscissa at rightmost grid line XMIN - Value of abscissa at leftmost grid line YMAX - Value of ordinate at top grid line YMIN - Value of ordinate at bottom grid line NSCLI - Logical flag (should be FALSE, if PLOT1 has not been called and standard grid is desired)
COMMON BLOCKS:	XRPLTF, XRPLTQ, XRPLTG
SUBROUTINE CALLED:	NONE
CALLED BY:	PCHEB

NAME:

SUBROUTINE PLOT3

PURPOSE:

Subroutine PLOT3 assigns an alpha-character to each point to be plotted

CALLING SEQUENCE:

CALL PLOT3 (PCHAR, X, Y, SDATA, FDATA, DDATA)

ARGUMENTS:

PCHAR - Plotting character
X - Array containing the X coordinates to be plotted
Y - Array containing the Y coordinates to be plotted
SDATA - Integer position in the arrays of the first ordered pair to be plotted
FDATA - =1 if each point from SDATA to DDATA is to be plotted
=2 if every other point is to be plotted
=3 if every third point is to be plotted
DDATA - Integer position in the array of the last ordered pair to be plotted

COMMON BLOCKS:

XRPLOTF, XRPLOTG

SUBROUTINE CALLED:

NONE

CALLED BY:

PCHEB

NAME:	SUBROUTINE PLOT4
PURPOSE:	Subroutine PLOT4 prints the image of the completed graph on the printer, including the values of the abscissa and the ordinate at the grid lines outside the bottom and left edge of the graph
CALLING SEQUENCE:	CALL PLOT4 (MCHAR, NCHAR)
ARGUMENTS:	MCHAR - Single dimension array containing alpha characters to be plotted at the left of the graph NCHAR - Number of valid characters in MCHAR
COMMON BLOCKS:	XRPLTF, XRPLTG, XRPLTQ
SUBROUTINE CALLED:	QPLOTZ5
CALLED BY:	PCHEB

NAME:	SUBROUTINE POMIT1
PURPOSE:	To cause certain grid lines on graph to be deleted, depending upon which arguments are labeled TRUE
CALLING SEQUENCE:	CALL POMIT1 (T, B, L, R)
ARGUMENTS:	T = top line on graph B = bottom line on graph L = left line on graph R = right line on graph
COMMON BLOCKS:	XRPL0TC, XRPL0TQ
SUBROUTINES CALLED:	NONE
CALLED BY:	Main program
COMMENTS:	This subroutine is part of a plotting package and is included in this program only to keep this package intact

NAME:	SUBROUTINE POMIT2
PURPOSE	Causes horizontal and/or vertical values at grid lines to be deleted
CALLING SEQUENCE:	CALL POMIT2 (ARG)
ARGUMENTS:	ARG ARG = 1 values of abscissa at grid lines deleted ARG = 2 values of ordinate at lines deleted ARG = 3 both sets of values deleted.
COMMON BLOCKS:	XRPLQTQ
SUBROUTINES CALLED:	NONE
CALLED BY:	Main program
COMMENTS:	This subroutine is part of a plotting package and is included in this program only to keep this package intact

NAME: SUBROUTINE PRAXIS

PURPOSE: Finds the minimum of the function $F(X,N)$ of n variables using the principal axis method. The gradient of the function is not required.

CALLING SEQUENCE: CALL PRAXIS (TO, HO, N, IPRIN, X, F, FMIN)

ARGUMENTS:

TO	-	is a tolerance
HO	-	is the maximum step size
N	-	the number of variables upon which the function depends (must be at least two)
IPRIN	-	controls the printing of intermediate results
X	-	contains on entry a guess of the point of minimum, on return the estimated point of minimum
F	-	the function to be minimized
FMIN	-	is set to the minimum found

COMMON BLOCKS: PRCOMM, Q

SUBROUTINES CALLED: PRPRIN, PRMIN, PRQUAD, MAPRNT, PRFIT, PRSORT, VCPRT, RANDUM, PEHP

CALLED BY: SWATHO

COMMENTS: The approximating quadratic form is:

$$s(X') = F(X,N) + \frac{1}{2} * ((X' - X) - \text{Transpose } *A* (X - X'))$$

X is the best estimate of the minimum
A is Inverse (V-Transpose) *D* Inverse (V)
V(**) is matrix of search directions
D(*) is array of second differences

NAME:	SUBROUTINE PRFIT
PURPOSE:	An improved version of MINFIT restricted to $M = N, P = 0$. The singular values of the array AB are returned to Q, and AB is overwritten with the orthogonal matrix V such that $U \text{ DIAG } (Q) = AB.V$, where U is another orthogonal matrix.
CALLING SEQUENCE:	CALL PRFIT (M, N, MACHEP, TOL, AB, Q)
ARGUMENTS:	M - is the maximum step size N - the number of variables upon which the function depends MACHEP - is the machine precision, the smallest number such that $1 + \text{MACHEP} > 1$. MACHEP should be 2^{*-47} (about 7.105 E-15) for single precision arithmetic on the CDC 6000 system or 16^{*-13} (about 2.23 D-16) for double precision on the IBM 370 system. TOL - Tolerance AB - Array for which singular values are to be determined Q - Where the original values of the array are to be stored.
COMMON BLOCKS:	NONE
SUBROUTINES CALLED:	NONE
CALLED BY:	PRAXIS

NAME:	FUNCTION PRLIN
PURPOSE:	PRLIN is the function of one real variable L that is minimized by the subroutine PRMIN
CALLING SEQUENCE:	PR = PRLIN (N, J, L, F, X, NF)
ARGUMENTS:	N - Number of variable J - Defines direction for search/ minimization in the V matrix L - The single variable in the rotated coordinate system upon which the function is assumed to vary quadratically F - The function to be minimized X - Coordinate of the initial point in the quadratic space NF - The function evaluation counter
COMMON BLOCKS:	Q
SUBROUTINES CALLED:	NONE
CALLED BY:	PRMIN

NAME:	SUBROUTINE PRMIN
PURPOSE:	Minimizes F from X in the direction V(*,J) unless J is less than 2, when a quadratic search is made in the plane, defined by Q0, Q1, X
CALLING SEQUENCE:	CALL PRMIN (N, J, NITS, D2, X1, F1, FK, F, X, T, MACHEP, H)
ARGUMENTS:	N - is the number of variables upon which the function depends. J - Defines direction for search/minimization in the V matrix. NITS - Controls the number of times an attempt will be made to halve the interval D2 - is either zero or an approximation to half F X1 - is estimate of the distance from X to the minimum along V (*, J) F1 - PRLIN (N, J, X1, F, X, NF) FK - Logical operator F - The function to be minimized X - Coordinate of the initial point in the quadratic space T - Tolerance MACHEP - Machine precision H - Step size
COMMON BLOCKS:	PRCOMM, Q
SUBROUTINES CALLED:	PRLIN
CALLED BY:	PRAXIS, PRQUAD

NAME:	SUBROUTINE PRPRIN
PURPOSE:	PRPRIN prints intermediate optimization results including the number of function evaluations, function value, and current coordinates
CALLING SEQUENCE:	CALL PRPRIN (N,X, IMPRIN)
ARGUMENTS:	N - the number of variables upon which the function depends X - contains on entry a guess of the point of minimum, on return the estimated point of minimum. IPRIN - controls the printing of intermediate results
COMMON BLOCKS:	PRCOMM
SUBROUTINES CALLED:	AUXPLT
CALLED BY:	PRAXIS

NAME :	SUBROUTINE PRQUAD
PURPOSE:	Looks for the minimum of F along a quadratic curve defined by Q_0 , Q_1 , X, in case minimization is being done in a curved valley
CALLING SEQUENCE:	CALL PRQUAD (N, F, X, T, MACHEP, H)
ARGUMENTS:	N - Number of variable F - The function to be minimized X - Coordinate of the initial point in the quadratic space H - Step size
COMMON BLOCKS:	PRCOMM, Q
SUBROUTINES CALLED:	PRMIN
CALLED BY:	PRAXIS

NAME:	SUBROUTINE PRSORT
PURPOSE:	Sorts the elements of D(N) into descending order and moves the corresponding columns of V(N,N) resulting in eigenvalues and eigenvectors
CALLING SEQUENCE:	CALL PRSORT (M, N, D, V)
ARGUMENTS:	M - The maximum step size N - Number of variables D - Second difference array V - Matrix of search directions
COMMON BLOCKS:	NONE
SUBROUTINES CALLED:	NONE
CALLED BY:	PRAXIS

NAME:	SUBROUTINE QPLOTZ5
PURPOSE:	Subroutine QPLOTZ5 calculates the scaling information needed to generate the format to label the left-hand side of the printer plot.
CALLING SEQUENCE:	CALL QPLOTZ5 (PDQ)
ARGUMENT:	PDQ-scaling factor for ordinate plot
COMMON BLOCKS:	XRPLOTF, XRPLOTQ
SUBROUTINES CALLED:	NONE
CALLED BY:	PLOT4

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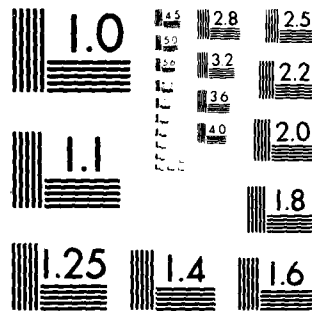
DAVID W TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT CE--ETC F/G 20/4
DOCUMENTATION FOR SHATH SHIP RESISTANCE OPTIMIZATION PROGRAM (S--ETC(U)
SEP 81 T J NABLE, A M REED
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MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963-A

NAME:

FUNCTION RANDUM

PURPOSE:

To avoid resolution valleys, by making random steps on a periodic basis, Function RANDUM returns a random number uniformly distributed in (0,1)

CALLING SEQUENCE:

RA = RANDUM (NAUGHT)

ARGUMENTS:

NAUGHT - number used to initialize the random number generator

COMMON BLOCKS:

NONE

CALLED BY:

PRAXIS

NAME:	SUBROUTINE REFLKT
PURPOSE:	Subroutine REFLKT defines the lower half of the symmetrical matrices T and W, the auxiliary wave resistance integrals, by reflection about the diagonal of the matrix.
CALLING SEQUENCE:	CALL REFLKT
ARGUMENTS:	NONE
COMMON BLOCKS:	AUX, COEFS
SUBROUTINE CALLED:	NONE
CALLED BY:	RWAVE

NAME:	SUBROUTINE RINIT
PURPOSE:	Subroutine RINIT initializes the auxiliary wave resistance matrices, T and W, to zero
CALLING SEQUENCE:	CALL RINIT
ARGUMENT:	NONE
COMMON BLOCKS:	AUX, COEFS
SUBROUTINE CALLED:	NONE
CALLED BY:	RWAVE

NAME: SUBROUTING RINTEG

PURPOSE: Subrouting RINTEG evaluates the integrand for T and W functions.

CALLING SEQUENCE: CALL RINTEG (ALFA, B, D, NLOC2, WTINT, SEPCOS, SQ)

ARGUMENTS:

ALFA	-	Integrating variable
B	-	CSTRT1(I)/XLS
D	-	CSTRT2(I)/XLS
NLOC2	-	Flag indicating the presence of a second strut
NLOC2	=	0 if single strut
	=	1 if tandem strut
WTINT	-	Weighting constant for the integrand
SEPCOS	-	Value of the cosine function in the integrand
SQ	-	Value of the integrand

$$\frac{1}{(\alpha^2 - \gamma^2)^{1/2}}$$

COMMON BLOCKS: AUX, OMEGA, COEFS, WORKVL

SUBROUTINE CALLED: BESSJ

CALLED BY: RWAVE

COMMENTS: Integrals used in calculations are of the form:

$$\int_{\gamma_{os}}^{\gamma_{os} + 1} \frac{d\alpha}{\sqrt{\alpha^2 - \gamma_{os}^2}} f(\alpha) + \int_{\gamma_{os} + 1}^{\infty} \frac{d\alpha}{\sqrt{\alpha^2 - \gamma_{os}^2}} f(\alpha)$$

For the first integral we use the substitution: $\alpha = \gamma_{os} + \zeta^2$ where $d\alpha = 2\zeta d\zeta$.

Therefore the first integral becomes $\int_0^1 \frac{2d\zeta}{\sqrt{2\gamma_{os} + \zeta^2}} f(\gamma_{os} + \zeta^2)$.

Where the function $f(\alpha)$ takes the form of $E_s^2(\alpha) J_m(\alpha) J_n(\alpha)$

where the order of the Bessel functions is determined by which auxiliary function is to be evaluated.

NAME:	SUBROUTINE ROUT
PURPOSE:	Calculates EHP, and wave resistance coefficients, frictional drag coefficients, speed constants, and prints the intermediate and final design results
CALLING SEQUENCE:	CALL ROUT (TITLE, EHP, KEY)
ARGUMENTS:	TITLE - label printed on output EHP - effective horsepower of the ship KEY - variable used to skip or print output
COMMON BLOCKS:	OMEGA, PHYSCO, WORKVL
SUBROUTINES CALLED:	SUM, FORMDR
CALLED BY:	Function EHP
COMMENTS:	The type of output from ROUT is determined by the value of KEY, which is set in the subroutines which call EHP. If KEY = 0 (set in PEHP) no output is printed and ROUT just does computations; if KEY = 1 (set in SWATHO) the optimization is complete and the final design values are printed; if KEY = 2 (set in AUXPLOT) the intermediate design results are printed

NAME: SUBROUTINE RWAVE

PURPOSE: Subroutine RWAVE computes the auxiliary wave resistance functions T and W.

CALLING SEQUENCE: CALL RWAVE (B, D, NLOC2)

ARGUMENTS: B -CSTRT1(I)/XLS
D -CSTRT2(I)/XLS
NLOC2 -Flag indicating the presence of a second strut

NLOC2 = $\begin{cases} 0 & \text{if single strut} \\ 1 & \text{if tandem struts} \end{cases}$

COMMON BLOCKS: AUX, OMEGA, PSI, COEFS, PHYSCO, WORKVL

SUBROUTINES CALLED: RINIT, SIMPSN, RINTEG, BESSJ, REFLKT

CALLED BY: FUNCTION EHP

COMMENTS:

Integrals evaluated by RWAVE:

$$T_{S_{mn}} = (2m-1) (2n-1) \int_{\gamma_{os}}^{\infty} \frac{d\alpha}{\alpha^2 \sqrt{\alpha^2 - \gamma_{os}^2}} E_s^2(\alpha) J_{2m-1}(\alpha) J_{2n-1}(\alpha)$$

$$W_{S_{mn}} = (2m) (2n) \int_{\gamma_{os}}^{\infty} \frac{d\alpha}{\alpha^2 \sqrt{\alpha^2 - \gamma_{os}^2}} E_s^2(\alpha) J_{2m}(\alpha) J_{2n}(\alpha)$$

$$T_{B_{mn}} = (2m-1) (2n-1) \int_{\gamma_{os}}^{\infty} \frac{\alpha^2 d\alpha}{\sqrt{\alpha^2 - \gamma_{os}^2}} E_B^2(\beta) J_{2m-1}(\beta) J_{2n-1}(\beta)$$

$$W_{B_{mn}} = (2m) (2n) \int_{\gamma_{os}}^{\infty} \frac{\alpha^2 d\alpha}{\sqrt{\alpha^2 - \gamma_{os}^2}} E_B^2(\beta) J_{2n}(\beta)$$

$$T_{SB_{mn}} = (2m-1) (2n-1) \int_{\gamma_{os}}^{\infty} \frac{d\alpha}{\sqrt{\alpha^2 - \gamma_{os}^2}} E_s(\alpha) E_B(\beta) J_{2m-1}(\alpha) J_{2n-1}(\beta)$$

$$W_{SB_{mn}} = (2m) (2n) \int_{\gamma_{os}}^{\infty} \frac{d\alpha}{\sqrt{\alpha^2 - \gamma_{os}^2}} E_s(\alpha) E_B(\beta) J_{2m}(\alpha) J_{2n}(\beta)$$

NAME:	SUBROUTINE SCALE
PURPOSE:	Creates current working values X, by $X = S * XI$, where S is the scale factor, and XI is the vector of initial values.
CALLING SEQUENCE:	CALL SCALE (S, N)
ARGUMENTS:	S - scaling value for each of the variables N - number of variable
COMMON BLOCK:	INITL, NOCHG, PHYSCO, WORKVL
SUBROUTINES CALLED:	NONE
CALLED BY:	SWATHO, PEHP, AUXPLT

NAME:	SUBROUTINE SIMPSN
PURPOSE:	Subroutine SIMPSN sets up Simpson's multipliers for numerical integration by Simpson's rule.
CALLING SEQUENCE:	CALL SIMPSN (NPTS, SIMP)
ARGUMENTS:	NPTS - Number of integration steps SIMP - Array containing the Simpson's multipliers
COMMON BLOCKS:	NONE
SUBROUTINE CALLED:	NONE
CALLED BY:	RWAVE
COMMENT:	These values are used to integrate the auxiliary wave resistance integrals, T and W, for values of the integral between γ_{os} and $\gamma_{os} + 1$

An example of one of these integrals in the range γ_{os} to $\gamma_{os} + 1$ is

$$\int_{\gamma_{os}}^{\gamma_{os}+1} \frac{d\alpha}{\sqrt{\alpha^2 - \gamma_{os}^2}} f(\alpha) = \int_0^1 \frac{2d\zeta}{\sqrt{2\gamma_{os} + \zeta^2}} f(\gamma_{os} + \zeta^2)$$

NAME:

SUBROUTINE SUM

PURPOSE:

Subroutine SUM computes the sums for the wave resistance from the Chebychev coefficients and the auxiliary wave resistance functions, T and W

$$\sum_{m=1}^M \sum_{n=1}^N (A_m A_n T_{mn} + B_m B_n W_{mn})$$

COMMENTS: where A_m and B_m are the symmetric and antisymmetric Chebychev coefficients for the strut or body, and T_{mn} and W_{mn} are the auxiliary wave resistance functions for various hull-strut combinations

CALLING SEQUENCE:

CALL SUM (SUM1S, SUM1B, SUM1SB, SUM12S, SUM12B, SUM12SB)

ARGUMENTS:

SUM1S - Partial sum for strut 1
SUM1B - Partial sum for body 1
SUM1SB - Partial sum for interaction between strut 1 and body 1
SUM12S - Partial sum for interaction between strut 1 and strut 2
SUM12SB - Partial sum for interactions between strut 1 and body 2 or strut 2 and body 1

COMMON BLOCKS:

AUX, COEFS

SUBROUTINE CALLED:

NONE

CALLED BY:

ROUT

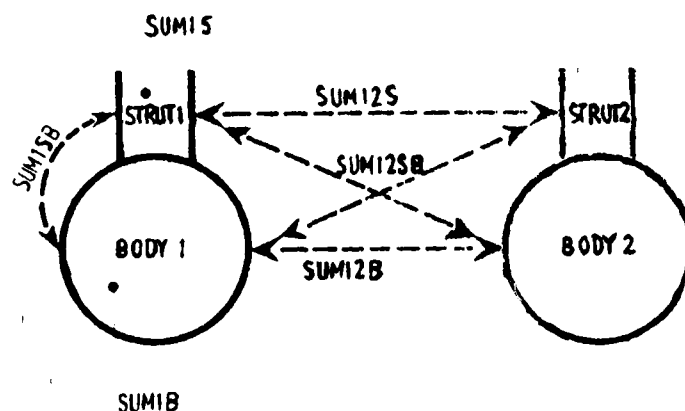


Figure 4 - Body-Strut Configuration

NAME:	SUBROUTINE VCPRINT
PURPOSE:	With certain input options, this subroutine prints a vector of given length using two of several formats
CALLING SEQUENCE:	CALL VCPRINT (OPTION, V, N)
ARGUMENTS:	OPTION = 1 Prints the Second Difference Array = 2 Prints the Scale Factors = 3 Prints the value of the approximating quadratic form = 4 Prints the value of X V = Matrix of search directions N = Number of variable
COMMON BLOCKS:	NONE
SUBROUTINES CALLED:	NONE
CALLED BY:	PRAXIS

NAME:	SUBROUTINE WSURFB
PURPOSE:	Determine surface area of body of revolution whose sectional area is given by Chebychev coefficients
CALLING SEQUENCE:	CALL WSURFB (AREA)
ARGUMENTS:	AREA - Surface area of a body (ft ²)
COMMON BLOCKS:	COEFS, PHYSCO, WORKVL
SUBROUTINES CALLED:	FUNCTION EVAL
CALLED BY:	CHEB

NAME:	SUBROUTINE WSURFS
PURPOSE:	Determines surface area of a strut whose thickness distribution is given by Chebychev coefficients
CALLING SEQUENCE:	CALL WSURFS (AREA)
ARGUMENTS:	AREA - Wetted surface area of a strut (ft ²)
COMMON BLOCKS:	COEFS, WORKVL
SUBROUTINES CALLED:	FUNCTION EVAL
CALLED BY:	CHEB

NAME:	FUNCTION YINTP
PURPOSE:	Function YINTP interpolates through a set of discrete data, using quadratic interpolation.
CALLING SEQUENCE:	YTP = YINTP (XZ, X, Y, N) XA - Point to be interpolated X - Array of ordinate data Y - Array of abscissa data N - Number of data points
COMMON BLOCKS:	NONE
SUBROUTINE CALLED:	NONE
CALLED BY:	FORMDR
COMMENTS:	Uses linear interpolation

REFERENCES

1. Lin, W. C. and W. G. Day, Jr., "The Still Water Resistance and Propulsion Characteristics of Small-Waterplane Area Twin-Hull (SWATH) Ships," AIAA/SNAME Advanced Marine Vehicles Conferences. Paper No. 74-325, (1974).
2. Brent, Richard P., "Algorithm for Finding Zeroes and Extrema of Functions without Calculating Derivatives," Stanford University Report, CS-71-198, 1971

APPENDIX A
OBJECTIVE AND PENALTY FUNCTIONS

APPENDIX A - OBJECTIVE AND PENALTY FUNCTIONS

The program SWATHO is designed to determine the geometry of a SWATH ship which yields the minimum effective power for a given speed. Thus the objective function is the effective power. However, this is an over simplification of the problem, in that the solution to the problem must also satisfy a number of constraints. That this is so is intuitively obvious if one considers that the ship with minimum power for a given speed is that ship with zero length and volume, and therefore zero resistance. Thus an obvious constraint is that the ship contain at least some minimum volume.

The subroutine PRAXIS, which is used to perform the minimization, is a program designed for use in unconstrained minimization problems. This dictates that a modified objective function be employed, which takes into account the fact that constraints are or are not violated. To meet this requirement, an external constraint method was employed, where the functions $g_i(\underline{x})$ were defined to be greater than zero when the i^{th} constraint was violated, and less than zero when the i^{th} constraint was satisfied. Using these g_i 's, the modified objective function was defined as:

$$\text{PEHP} = \text{EHP}(1 + \sum_i \text{Max}(g_i(\underline{x}), 0)).$$

In all of the above definitions, the vector $\underline{x}$ is the vector of parameters defining the ship's geometry.

This definition of the objective function results in the addition of no penalty to the objective function internal to the region where the constraints are satisfied, and results in the addition of a penalty exterior to the region where the constraints are satisfied. This gives rise to the description of this as an external constraint method.

There are a total of nineteen penalty functions which are applied to the problem of minimizing the resistance of a SWATH ship. These constraints/penalty functions are as follows:

1. Minimum displacement constraint

$$g_1 = (\text{DISPMN} - \text{DISP})\alpha_1$$

where DISPMN is the minimum ship displacement as input by the user and DISP is the current ship displacement at that iteration of the calculations.

2. Minimum draft-diameter ratio constraint

$$g_2 = \left[\text{Draft Factor} \times \text{BDIA} - (\text{HS} + \text{BDIA}) \right] \alpha_2$$

where the Draft Factor is the minimum draft to diameter ratio, BDIA is the body diameter at half of the length of the body and HS is the draft of the strut.

3. Maximum draft constraint

$$g_3 = (\text{HS} + \text{BDIA} - \text{DRFTMAX}) \alpha_3$$

where DRFTMAX is the maximum draft of the ship as input by the user.

4. Maximum beam constraint

$$g_4 = (\text{BS} + \text{BDIA} - \text{WMAX}) \alpha_4$$

where BS is the separation of the hull centerlines and WMAX is the maximum beam of the ship as specified by the user.

5. Hull overlap constraint

$$g_5 = (\text{BDIA} - \text{BS}) \alpha_5$$

6. Strut-hull Nose clearance constraint

$$g_6 = (\text{XFWD} + \text{CSTRT} + \text{XLS}/2 - \text{XLB}/2) \alpha_6$$

where XFWD is the minimum distance from the body leading edge to the strut leading edge, CSTRT is the distance of the strut forward of the body centerline, XLS is the length of the strut and XLB is the length of the body.

7. Strut-hull tail clearance constraint

$$g_7 = (\text{XAFT} - \text{XLB}/2 + \text{XLS}/2 - \text{CSTRT}) \alpha_7$$

where XAFT is the minimum distance from body trailing edge to strut trailing edge.

8. Minimum transverse GM constraint

$$g_8 = \left[\text{MINGMT} - (\text{KB} + \text{BMT} - \text{KG}) \right] \alpha_8$$

where MINGMT is the minimum transverse GM, KB is the distance of the center of buoyancy from the baseline, BMT is the transverse metacenter and

KG is the distance of the center of gravity from the baseline.

9. Minimum longitudinal GM constraint

$$g_9 = \left[\text{MINGML} - (\text{KB} + \text{BML} - \text{KG}) \right] \alpha_9$$

where MINGML is the minimum longitudinal GM and BML is the longitudinal metacenter.

10. Body offsets greater than zero constraint

$$g_{10} = \int_{-1}^1 dx \left[|b(x)| - b(x) \right] \alpha_{10}$$

where $b(x)$ represents the body offsets

11. Strut offsets greater than zero constraint

$$g_{11} = \int_{-1}^1 dx \left[|t(x)| - t(x) \right] \alpha_{11}$$

where $t(x)$ represents the strut offsets

12. Maximum length-diameter ratio check

$$g_{12} = (\text{XLB} - \text{LODMAX} \times \text{BDIA}) \alpha_{12}$$

where LODMAX is the maximum body length over diameter ratio.

13. Minimum length-diameter ratio check

$$g_{13} = (\text{LODMIN} \times \text{BDIA} - \text{XLB}) \alpha_{13}$$

where LODMIN is the minimum body length over diameter ratio.

14. Strut minimum thickness constraint

$$g_{14} = (\text{TSMIN} - \text{TSMAX}) \alpha_{14}$$

where TSMIN is the minimum strut thickness at 50% chord and TSMAX is the strut thickness in the current iteration of the calculations.

15. Strut thickness-body diameter constraint

$$g_{15} = (\text{TSMAX} - \text{BDIA}) \alpha_{15}$$

16. Positive strut length constraint

$$g_{16} = (-\text{XLS}) \alpha_{16}$$

17. Positive body length constraint

$$g_{17} = (-\text{XLB}) \alpha_{17}$$

18. Maximum body offset constraint

$$g_{18} = (b_{\max} - 1.2 \text{ BDIA})\alpha_{18}$$

where $b_{\max}$ is the maximum body offset. This constraint insures a reasonable value for the maximum body offset.

19. Maximum strut thickness constraint

$$g_{19} = (t_{\max} - 1.2 \text{ TSMAX})\alpha_{19}$$

where $t_{\max}$ is the maximum possible value of strut thickness. This constraint insures a reasonable value for the maximum strut thickness.

In all of the above penalty functions, the constraints α_i are chosen so that a constraint violation of ten percent results in a value of g_i around 10^4 .

Of the above penalty functions, eleven are constraints imposed by the program user to insure that the optimum vehicle meets some minimum set of criteria such as minimum displacement and transverse and longitudinal GM. These user specified constraints are the constraints numbered 1, 2, 3, 4, 6, 7, 8, 9, 12, 13, and 14.

The other eight constraints are constraints imposed by the program to insure that the geometry of the vehicle is reasonable. Examples of these would be constraints to insure that the lengths of the body and strut are positive, and constraints to insure that the offsets of the strut and body are all positive. The numbers of these constraints are 5, 10, 11, 15, 16, 17, 18, and 19.

APPENDIX B

COMPUTATIONAL PROCEDURE FOR SWATH
RESISTANCE PREDICTION

APPENDIX B - COMPUTATIONAL PROCEDURE FOR SWATH RESISTANCE PREDICTION

The main purpose of the SWATHO program is to minimize the power required to propel a SWATH ship in a calm sea at constant speed. For a ship moving at speed V and experiencing a total drag force R_T the effective horsepower required is:

$$P_E = \frac{R_T V}{550}.$$

The total drag is comprised of three components: frictional resistance (R_F), wave-making resistance (R_W), and form drag (R_{FM}). That is:

$$R_T = R_F + R_W + R_{FM}.$$

The frictional resistance and form drag are caused by the motion of the hull through a viscous fluid. The wave-making resistance is due to the energy that must be supplied by the ship to the wave system created on the free surface. However, wave-making resistance and form drag are usually grouped together under the title of residuary resistance.

FRICTIONAL RESISTANCE

Frictional resistance is the single largest component of the resistance of a SWATH ship. Frictional resistance is calculated in the traditional fashion of naval architects, using the ITTC model ship correlation line to determine a frictional resistance coefficient (C_F). However, for a SWATH ship, the frictional drag of the hulls and struts are calculated separately based on their respective Reynolds numbers. Thus we have that the frictional resistance coefficient is given by the formula:

$$C_F = \frac{0.075}{(\log_{10} Rn - 2)^2}$$

and the frictional resistance of the hulls and struts are given by:

$$R_{F_{Hull}} = \frac{1}{2} \rho S_{Hull} V^2 C_{F_{Hull}}$$

and

$$R_{F_{Strut}} = \frac{1}{2} \rho S_{Strut} V^2 C_{F_{Strut}}.$$

In calculating the total frictional resistance, a correlation allowance (C_A) of 0.0005 is also included in the total, so we have that:

$$R_F = R_{F_{Hull}} + R_{F_{Strut}} + \frac{1}{2}\rho (S_{Hull} + S_{Strut})V^2 C_A.$$

FORM DRAG

Form drag (R_{FM}) is usually defined as the viscous component of the drag due to the shape of body, i.e., the difference between the total viscous drag, and the viscous drag of the equivalent flat plate of the same length. However, in the case of the SWATH resistance programs, the form drag has been determined in a much more empirical fashion.

SWATH form drag has been defined as the difference between the experimentally determined residuary resistance of a hull form and the theoretically derived wave resistance for that same hull form. Such a difference was calculated for both SWATH 3 and SWATH 4 based on bare hull resistance results,¹ and plotted as a function of strut speed-length ratio. A curve was then faired through the data, Figure 3 (p. 69). Due to the scatter in the data a decision was made not to allow the form drag coefficient go below 0.0005; this can be seen on Figure 3. The form drag coefficient, determined from Figure 3, is converted to full scale form drag, using the traditional formula and the total wetted surface:

$$R_{FM} = \frac{1}{2}\rho SV^2 C_{FM}.$$

WAVE-MAKING RESISTANCE

The wave-making resistance of a ship is not easily predicted from empirical relations or from gross ship features. Experience has shown that two ships of similar form may differ significantly in their measured total resistance due to differences in the wave-making resistance component. Wave-making resistance is a function of the fine details of ship form, and is best studied through mathematical analysis.

Lin and Day¹ investigated the problem of wave-making resistance for twin-hull ships. The mathematical problem is formulated within the context of the linearized thin-ship theory. In their investigations, the potential flow around such a ship is represented by sheet distributions of sources.

The computer program SWATHO documented in this user's manual is devoted primarily to the implementation of numerical procedures for the prediction of the

wave-making resistance of SWATH ships following the theory developed by Lin and Day. The remainder of this appendix will be devoted to the discussion of the essential details involved in the numerical procedure utilized in the wave-making resistance predictions.

Based on the analysis of Lin and Day, the wave resistance is expressed as follows:

$$R_S = \left(\frac{\pi}{2} \rho g T^2 L_S \gamma_{os} \right) \times \sum_{m=1}^M \sum_{n=1}^M \left\{ A_{Sm} A_{Sn} T_{Smn} + B_{Sm} B_{Sn} W_{Smn} \right\},$$

$$R_B = \left(\frac{2\pi\rho g A_0^2}{L_S \gamma_{os}} \right) \sum_{m=1}^M \sum_{n=1}^M \left\{ A_{Bm} A_{Bn} T_{Bmn} + B_{Bm} B_{Bn} W_{SBmn} \right\}$$

$$R_{SB} = (2\pi\rho g A_0^2 T) \sum_{m=1}^M \sum_{n=1}^M \left\{ A_{Sm} A_{Bn} T_{SBmn} + B_{Sm} B_{Bn} W_{SBmn} \right\}$$

where T , L_S , and h_S are the maximum thickness, length, and draft of the strut, respectively; A_0 , L_B , and h_B are the maximum section area, length, and depth of submergence of the axis of the body.

In the above equations, R_S , R_B , and R_{SB} represent the wave resistance due to one strut, one main body, and the intersection between strut and main body, respectively. Hence, the wave resistance of a SWATH ship becomes

$$R_W = 2(R_S + R_B + R_{SB}).$$

Also in the above equations, A_{Sm} and B_{Sm} are the Chebychev coefficients for the strut, A_{Bm} and B_{Bm} are the Chebychev coefficients for the hull, and T_{SMmn} , T_{SBmn} , T_{Bmn} , W_{Smn} , W_{SBmn} , and W_{Bmn} are the auxiliary wave resistance functions. The auxiliary wave resistance functions are defined as follows:

$$\left. \begin{array}{c} \frac{T_{Smn}}{(2m-1)(2n-1)} \\ \frac{W_{Smn}}{(2m)(2n)} \end{array} \right\} = \int_{\gamma_{os}}^{\infty} \frac{d\alpha}{\alpha^2 \sqrt{\alpha^2 - \gamma_{os}^2}} D\left(\alpha, \frac{2b}{L_S}, \gamma_{os}\right) \times E_S^2(\alpha) \left\{ \begin{array}{c} J_{2m-1}(\alpha) J_{2n-1}(\alpha) \\ J_{2m}(\alpha) J_{2n}(\alpha) \end{array} \right\}$$

$$D = 1 + \cos \frac{2b}{L_S} \frac{2}{\gamma_{os}} \alpha \sqrt{\alpha^2 - \gamma_{os}^2},$$

$$E_S = 1 - e^{-2(h_S/L_S)(\alpha^2/\gamma_{os})},$$

$$\gamma_{os} = \frac{gL_S}{(2U^2)},$$

$$\left. \begin{array}{l} \frac{T_{Bmn}}{(2m-1)(2n-1)} \\ \frac{W_{Bmn}}{(2m)(2n)} \end{array} \right\} = \int_{\gamma_{os}}^{\infty} d\alpha \frac{\alpha^2}{\sqrt{\alpha^2 - \gamma_{os}^2}} D\left(\alpha, \frac{2b}{L_S}, \gamma_{os}\right)$$

$$\times E_B(\beta) \begin{Bmatrix} J_{2m-1}(\beta) & J_{2n-1}(\beta) \\ J_{2m}(\beta) & J_{2n}(\beta) \end{Bmatrix}$$

$$E_B = e^{-2(h_B/L_B)(\beta^2/\gamma_{OB})},$$

$$\gamma_{OB} = \frac{gL_B}{(2U^2)},$$

$$\beta = \left(\frac{\gamma_{OB}}{\gamma_{os}}\right) \alpha,$$

and

$$\left. \begin{array}{l} \frac{T_{SBmn}}{(2m-1)(2n-1)} \\ \frac{W_{SBmn}}{(2m)(2n)} \end{array} \right\} = \int_{\gamma_{os}}^{\infty} \frac{d\alpha}{\sqrt{\alpha^2 - \gamma_{os}^2}} D\left(\alpha, \frac{2b}{L_S}, \gamma_{os}\right)$$

$$\times E_S(\alpha) E_B(\beta) \begin{Bmatrix} J_{2m-1}(\alpha) & J_{2n-1}(\beta) \\ J_{2m}(\alpha) & J_{2n}(\beta) \end{Bmatrix}$$

where $J_m(\alpha)$ is a Bessel function of the first kind, defined as follows:

$$J_m(\alpha) = \frac{2}{\pi} \int_0^{\pi/2} \cos(\alpha \sin t) \cos(mt) dt.$$

NUMERICAL INTEGRATION METHODS FOR AUXILIARY WAVE RESISTANCE FUNCTION EVALUATION

The range of integration for the auxiliary wave resistance functions is divided into three intervals of integration: $[\gamma_{os}, \gamma_{os} + 1]$, a "central region" and the "tail" region. A detailed discussion of these intervals and the integration procedure for each interval follows.

INTEGRATION PROCEDURE FOR THE INTERVAL $[\gamma_{os}, \gamma_{os} + 1]$

In the region of γ_{os} the integrands do not behave well, but they are nevertheless integrable. This is due to the presence of $\sqrt{\alpha^2 - \gamma_{os}^2}$ in the denominator. This may be easily handled by utilizing the substitution:

$$\alpha = \gamma_{os} + \zeta^2$$

where

$$d\alpha = 2\zeta d\zeta.$$

This substitution will be utilized in the region $[\gamma_{os}, \gamma_{os} + 1]$. It eliminates the square-root singularity by giving

$$\int_{\gamma_{os}}^{\gamma_{os}+1} \frac{d\alpha}{\sqrt{\alpha^2 - \gamma_{os}^2}} f(\alpha) = \int_0^1 \frac{2d\zeta}{\sqrt{2\gamma_{os} + \zeta^2}} f(\gamma_{os} + \zeta^2).$$

Investigating the behavior of the integrands as functions of ζ in the region $0 \leq \zeta \leq 1$ shows that they are very well behaved and a simple numerical integration scheme with about 30 points will yield excellent results.

INTEGRATION PROCEDURE FOR THE CENTRAL REGION

The central region of the numerical integration starts at $\alpha = \gamma + 1$ and continues until $E_B(\beta)$ reaches a very small fraction of its initial value,

$$E_B(\beta_{init}) = E_B \left[\frac{(\gamma_{os} + 1)\gamma_{OB}}{\gamma_{os}} \right].$$

The fraction is given as $10^{-\epsilon}$, so

$$\frac{\exp \left\{ -2 \frac{h_B}{L_B} \frac{\beta_{max}^2}{\gamma_{OB}} \right\}}{\exp \left\{ -2 \frac{h_B}{L_B} \frac{(\gamma_{os} + 1)^2 \gamma_{OB}}{\gamma_{os}^2 \gamma_{OB}} \right\}} = 10^{-\epsilon} = \exp(-2.3026\epsilon).$$

Hence,

$$\alpha_{max} = \frac{L_S}{L_B} \beta_{max} = \sqrt{\left(\frac{2.3026\epsilon \gamma_{os}}{2 \frac{h_B}{L_B} \frac{L_B}{L_S}} \right)} + (\gamma_{os} + 1)^2.$$

The justification of this choice for α_{max} , and the effect of the choice of ϵ , will be discussed in the next section.

In order to implement an effective and economical numerical integration scheme, it is necessary to investigate the behavior of the integrands within this central region. The requirement is to provide at least several points of the integrand for each full cycle of its oscillation. Hence, a conservative estimate of behavior will be an estimate of more rapid oscillation than actually exists.

The Bessel functions are approximated as

$$J_\nu(z) \approx \sqrt{\frac{2}{\pi z}} \cos\left(z - \frac{\nu\pi}{2} - \frac{\pi}{4}\right)$$

for $|z| \gg 1$ and $|z| \gg |\nu|$.

for smaller Z , the behavior will be less oscillatory, so this represents a conservative estimate for all Z . This assumption results in

$$J_{\mu}(\alpha)J_{\nu}(\alpha) \approx \begin{cases} \frac{1}{\pi\alpha} [\cos(2\alpha+\psi) + 1] & \frac{\mu-\nu}{2} \text{ even} \\ \frac{1}{\pi\alpha} [\cos(2\alpha+\psi) - 1] & \frac{\mu-\nu}{2} \text{ odd} \end{cases}$$

where the case of $(\mu-\nu)$ odd will never occur due to the form of the integrands.

The other combinations of Bessel functions are found as

$$J_m(\alpha)J_n(\beta) \sim \frac{1}{\pi\sqrt{\alpha\beta}} \cos(\alpha+\beta)$$

$$J_m(\beta)J_n(\beta) \sim \frac{1}{\pi\beta} \cos(2\beta),$$

where the phase angles, a slow oscillation in the first case, and a constant term in the second case, have all been ignored. Since β is generally greater than α , but of the same order of magnitude, a conservative estimate gives the variation of all of the above as

$$J_m J_n \sim \frac{1}{\pi\alpha} \cos(2\beta) = \frac{1}{\pi\alpha} \cos\left(\frac{2L_B}{L_S} \alpha\right).$$

The term $[\sqrt{\alpha^2 - \gamma_{os}^2}]$ behaves as $[\alpha]$ for $\alpha \gg \gamma_{os}$, and is better behaved for smaller α . This conservative estimate will be used for the occurrence of this term at the beginning of each integrand. However, the substitution will not be made in the term

$$D(\alpha) = \cos\left[\frac{2}{\gamma_{os}} \frac{2b}{L_S} \alpha \sqrt{\alpha^2 - \gamma_{os}^2}\right],$$

which occurs in all of the two-hull integrands, since that would result in considerably less economical numerical integration.

The terms $E_B(\beta)$ and $E_S(\alpha)$ contain decreasing exponentials and are not oscillatory and are quite well-behaved, and so will not affect the spacing of points for the numerical integration.

Therefore, the integrand for $T_{12S_{mn}}$ and $W_{12S_{mn}}$ behave like

$$\frac{d\alpha}{\pi\alpha^4} E_S^2(\alpha) \cos\left(2 \frac{L_B}{L_S} \alpha\right) \cos\left[\frac{2}{\gamma_{os}} \frac{2b}{L_S} \alpha \sqrt{\alpha^2 - \gamma_{os}^2}\right],$$

those for $T_{12B_{mn}}$ and $W_{12B_{mn}}$ behave like

$$\frac{d\alpha}{\pi} E_B^2\left(\frac{L_B}{L_S} \alpha\right) \cos\left(2 \frac{L_B}{L_S} \alpha\right) \cos\left[\frac{2}{\gamma_{os}} \frac{2b}{L_S} \alpha \sqrt{\alpha^2 - \gamma_{os}^2}\right], \text{ and}$$

those for $T_{12SB_{mn}}$ and $W_{12SB_{mn}}$ behave like

$$\frac{d\alpha}{\pi\alpha^2} E_B\left(\frac{L_B}{L_S} \alpha\right) E_S(\alpha) \cos\left(2 \frac{L_B}{L_S} \alpha\right) \cos\left[\frac{2}{\gamma_{os}} \frac{2b}{L_S} \alpha \sqrt{\alpha^2 - \gamma_{os}^2}\right].$$

The single-hull terms ($T_{S_{mn}}, W_{S_{mn}}, T_{B_{mn}}, W_{B_{mn}}, T_{SB_{mn}}, W_{SB_{mn}}$) are similar but without the $\cos\left[\frac{2}{\gamma_{os}} \frac{2b}{L_S} \alpha \sqrt{\alpha^2 - \gamma_{os}^2}\right]$ term.

Based on the behavior shown above, the most rapid oscillation of the integrands is like

$$\cos\left[2 \frac{L_B}{L_S} \alpha\right] \cos\left[\frac{2}{\gamma_{os}} \frac{2b}{L_S} \alpha \sqrt{\alpha^2 - \gamma_{os}^2}\right].$$

In the vicinity of $\alpha = \bar{\alpha}$, $\cos[f(\alpha)]$ behaves like $\cos\left[\left(\frac{df(\alpha)}{d\alpha}\right)_{\alpha=\bar{\alpha}}\right]$ and hence

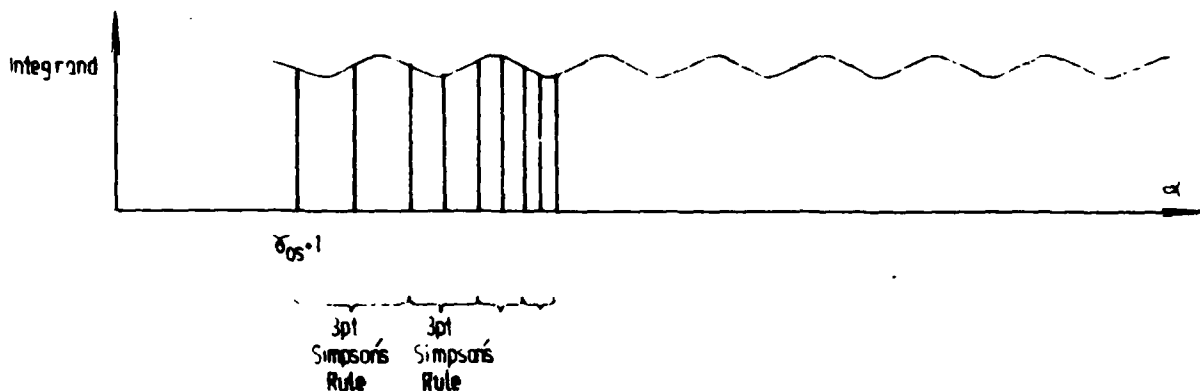
$$\begin{aligned} & \cos\left[2 \frac{L_B}{L_S} \alpha\right] \cos\left[\frac{2}{\gamma_{os}} \frac{2b}{L_S} \sqrt{\alpha^2 - \gamma_{os}^2} + \frac{\bar{\alpha}^2}{\sqrt{\alpha^2 - \gamma_{os}^2}} \alpha\right] \\ & \approx \cos\left[\left(2 \frac{L_B}{L_S} + \frac{2}{\gamma_{os}} \frac{2b}{L_S} \frac{2\bar{\alpha}^2 - \gamma_{os}^2}{\sqrt{\alpha^2 - \gamma_{os}^2}}\right) \alpha\right]. \end{aligned}$$

If the accuracy desired from the numerical integration scheme requires P points per cycle, then the step size S (distance between points) in the vicinity of $\bar{\alpha} = \alpha$ is

$$S = \left[\frac{\frac{2\pi}{P}}{2 \frac{L_B}{L_S} + \frac{2}{\gamma_{OS}} \frac{2b}{L_S} \frac{2\alpha^2 - \gamma_{OS}^2}{\sqrt{\alpha^2 - \gamma_{OS}^2}}} \right]$$

This step size will decrease with increasing α but will be smaller for larger hull centerline spacing b . Hence, if computations are made for various values of b for the same sample points, the step size should be based on the largest value of b .

The numerical integration scheme chosen for the central region is a modified Simpson's rule in which all steps are not equal. For this method, a step size is computed at a given α (starting first with $\gamma_{OS} + 1$), using the last equation. Then an integral is taken over an interval equal to two of these step sizes, using a three-point Simpson's rule. A new step size is computed for the α at the end of that interval, and the process is repeated until $\alpha_{\max}$ is reached or exceeded. The concept may be visualized as shown below.



This economizes on samples (points) where the integrand does not vary quickly, and uses more densely spaced points where necessary.

All of the approximations made in this section have been only for the purpose of choosing the step sizes for the numerical integration. The samples taken, which are multiplied by appropriate weights added to obtain the numerical evaluation of the integral, are all found using the actual integrands.

INTEGRATION PROCEDURE FOR THE TAIL

It should be noted that the criterion for the end of the "central region," and hence the beginning of the "tail," is that $E_B(\beta)$ reach a very small percentage of its original value. This will insure that any integrand which includes $E(\beta)$ will have long ceased to contribute significantly to the result. The body-alone and strut-body integrals ($T_B, W_B, T_{12B}, W_{12B}, T_{SB}, W_{SB}, T_{12SB}$ and W_{12SB}) can therefore be assumed complete at the conclusion of the "central region" numerical integration.

The strut-alone terms (T_S, W_S, T_{12S} , and W_{12S}) are not complete, however. The integrand for these terms decreases only like α^{-4} . The utilization of the "central region" numerical integration scheme until this integrand were very small would be quite accurate but exceptionally expensive, especially due to the constantly decreasing (with increasing α) step size required for that scheme. Hence, a more economical scheme must be developed, accepting the resulting loss of accuracy.

The single-hull strut-alone terms (T_S and W_S) are easily handled since they do not include the highly oscillatory term

$$D(\alpha) = \cos \left[\frac{2}{\gamma_{os}} \frac{2b}{L_S} \alpha \sqrt{\alpha^2 - \gamma_{os}^2} \right].$$

The behavior of the integrands for these terms is like

$$\frac{d\alpha}{\pi\alpha^4} E_S^2(\alpha) \cos(2\alpha),$$

which allows the use of a simple numerical integration scheme with constant step size

$$S = \frac{\pi}{P}$$

where P is the desired number of points per cycle.

The above method is still not very economical due to the large region over which the integral must be taken, due to the relatively slowly decreasing α^{-4} envelope in which the integrand oscillates. A more economical method is to approximate the integrand asymptotically, and analytically integrate the approximate integrand from a given value to infinity. The obvious simplification is to assume that $E_S(\alpha) \approx 1$, which is an excellent approximation, because $E_S(\alpha)$ approaches unity as $E_B(\beta)$ approaches zero. The approximation is hence assured by the condition that

determined the end of the "central region." In addition to $E_S(\alpha)$, the Bessel functions must also be approximated. We use the approximation

$$J_\nu(a) \approx \sqrt{\frac{2}{\pi\alpha}} \cos\left(Z - \frac{\nu\pi}{2} - \frac{\pi}{4}\right)$$

for $|\alpha| \gg 1$ and $|\alpha| \gg |\nu|$.

If $|\alpha|$ is not enough greater than $|\nu|$ at the beginning of the tail, a special "base of tail" numerical integration is done for T_S and W_S using step size $S = \pi/P$ (as discussed on the previous page). This is done over a region from the start of the "tail" until α is large enough for the above asymptotic approximation to yield an accurate result. The above asymptotic approximation gives

$$J_\mu(\nu)J_\nu(\mu) \approx \begin{cases} \frac{1}{\pi\alpha} [\cos(2\alpha+\psi) + 1] & \frac{\mu-\nu}{2} \text{ even} \\ \frac{1}{\pi\alpha} [\cos(2\alpha+\psi) - 1] & \frac{\mu-\nu}{2} \text{ odd} \end{cases}$$

where the case of $(\mu-\nu)$ odd will never occur due to the form of the integrands. The integrands therefore consist of a constant term and an oscillatory term. The contribution of the constant term to the integral, using the above approximations, is

$$\int_{\alpha_A}^{\infty} \frac{d\alpha}{\pi\alpha^3 \sqrt{\alpha^2 - \gamma_{os}^2}} = \frac{1}{2\pi\gamma_{os}^3} \arcsin\left(\frac{\gamma_{os}}{\alpha_A}\right) - \frac{\sqrt{\alpha_A^2 - \gamma_{os}^2}}{2\pi\gamma_{os}^2 \alpha_A^2}.$$

When α_A is much greater than γ_{os} , this expression will not provide an accurate solution since it will be the difference of two very similar values. For $R = \gamma_{os}/\alpha_A \gg 1$, the result is

$$\begin{aligned} \frac{1}{2\pi\gamma_{os}^3} \left[R + \frac{1}{6} R^3 + \frac{3}{40} R^5 + \dots \right] - \frac{1}{2\pi\gamma_{os}^3} \left[R - \frac{1}{2} R^3 - \frac{1}{8} R^5 + \dots \right] \\ = \frac{1}{3\pi\alpha_A^3} \left[1 + \frac{3}{10} R^2 + \dots \right]. \end{aligned}$$

The simplified form

$$\frac{1}{3\pi\alpha_A^3}$$

will therefore be accurate to about $2n$ decimal places if R is 10^{-n} . Likewise, the exact solution will lose $2n$ decimal places in the subtraction of the two parts when R is 10^{-n} . Hence, for a computer with about 16 decimal place accuracy, the simplified form is used whenever $R < 10^{-4}$.

The analytic integration of part of the integrands for T_S and W_S shown in the preceding paragraph depends on a large enough α_A for sufficiently accurate approximation of the Bessel functions. Hence, the simple numerical integration shown must be utilized to fill in the gap if the "central region" ends before such a sufficiently large α_A is reached.

The oscillatory components of the integrands for T_S and W_S in the region of analytic integration of the asymptotic approximations have been ignored in this formulation, as their contribution is assumed to be negligible.

The integrals for T_{12S} and W_{12S} were not carried past the end of the "central region" due to their highly oscillatory integrands, which made the contribution from further computation both uneconomical, and not critical to the final values of T_{12S} and W_{12S} . This is, however, not as good an approximation as those previously noted in the above development. As a result, errors of as much as 2% can be expected in the computation of wave drag due to interference between the two struts.

APPENDIX C

RELATIONSHIPS BETWEEN CHEBYCHEV SERIES AND SWATH
HULLFORM COEFFICIENTS

APPENDIX C - RELATIONSHIPS BETWEEN CHEBYCHEV SERIES AND SWATH HULLFORM COEFFICIENTS

CHEBYCHEV SERIES

In the wave resistance integrals, geometry of strut and body are represented by a special form of Chebychev series. In SWATHO, the Chebychev coefficients are approximated from various statistical moments of strut and body. The Chebychev series representation of hull and body geometries are discussed below. Let

$$x = \sin \theta, -\frac{\pi}{2} \leq \theta \leq \frac{\pi}{2}.$$

Define the fundamental functions of the Chebychev series as follows:

$$\begin{aligned} U_m(x) &= \cos(2m-1)\theta \\ &= \cos[(2m-1)\sin^{-1}x] \end{aligned}$$

$$\begin{aligned} V_m(x) &= \sin 2m\theta \\ &= \sin[2m \sin^{-1}x], \quad m = 1, 2, \dots, m. \end{aligned}$$

The strut half-thickness and the body sectional-area functions can be represented by finite sums of the fundamental Chebychev series as follows:

$$\begin{aligned} t(x) &= \sum_{m=1}^M [A_{sm} U_m(x) + B_{sm} V_m(x)] \\ &= \sum_{m=1}^M [A_{sm} \cos(2m-1)\theta + B_{sm} \sin 2m\theta] \end{aligned}$$

and

$$\begin{aligned} A(x) &= \sum_{m=1}^M [A_{bm} U_m(x) + B_{bm} V_m(x)] \\ &= \sum_{m=1}^M [A_{bm} \cos(2m-1)\theta + B_{bm} \sin 2m\theta] \end{aligned}$$

Through use of the orthogonality of the series, the following inversion formulas are obtained:

$$\begin{aligned} A_{Sm} &= \frac{2}{\pi} \int_{-1}^1 dx \frac{t(x)U_m(x)}{\sqrt{1-x^2}} \\ &= \frac{2}{\pi} \int_{-\pi/2}^{\pi/2} d\theta t(\sin \theta) \cos[(2m-1)\theta], \end{aligned}$$

$$\begin{aligned} B_{Sm} &= \frac{2}{\pi} \int_{-1}^1 dx \frac{t(x)V_m(x)}{\sqrt{1-x^2}} \\ &= \frac{2}{\pi} \int_{-\pi/2}^{\pi/2} d\theta t(\sin \theta) \sin(2m\theta), \end{aligned}$$

$$A_{Bm} = \frac{2}{\pi} \int_{-\pi/2}^{\pi/2} d\theta A(\sin \theta) \cos(2m-1)\theta,$$

and

$$B_{Bm} = \frac{2}{\pi} \int_{-\pi/2}^{\pi/2} d\theta A(\sin \theta) \sin 2m\theta.$$

INVERSE PROCEDURE FOR DETERMINING THE CHEBYCHEV COEFFICIENTS

The geometric coefficients of a SWATH ship's form can be shown to be closely related to the Chebychev coefficients of the strut and body.

These coefficients of form are easily obtained at the preliminary design stage and, thus, can be used to approximate the Chebychev coefficients. In the following example, the waterplane coefficient, C_{WP} , can be used to find A_{S1} .

By definition, the waterplane area is

$$A_W = 2 \int_{-L_S/2}^{L_S/2} dx t(x)$$

where $t(x)$ is the thickness function of the strut. Let

$$x = \frac{L_s}{2} \xi, \quad dx = \frac{L_s}{2} d\xi, \quad \xi = \frac{1}{L_s/2} x, \quad t(x) = t_{\max} \cdot t(\xi).$$

Thus,

$$\begin{aligned} A_W &= \frac{L_s}{2} t_{\max} \int_{-1}^1 d\xi t(\xi) \\ &= \frac{L_s}{2} t_{\max} \int_{-1}^1 d\xi \left[\sum_1^M A_{sm} U_m(\xi) + B_{sm} V_m(\xi) \right] \\ &= \frac{L_s}{2} t_{\max} \left[\sum_1^M A_{sm} \int_{-1}^1 U_m(\xi) d\xi + \sum_1^M B_{sm} \int_{-1}^1 V_m(\xi) d\xi \right]. \end{aligned}$$

Making the substitution,

$$x = \sin \theta, \quad dx = \cos \theta d\theta,$$

we obtain:

$$\begin{aligned} A_W &= \frac{L_s}{2} t_{\max} \left[\sum_1^M A_{sm} \int_{-\pi/2}^{\pi/2} d\theta \cos(2m-1)\theta \cos \theta \right. \\ &\quad \left. + \sum_1^M B_{sm} \int_{-\pi/2}^{\pi/2} d\theta \sin 2m\theta \cos \theta \right]. \end{aligned}$$

The second integral is odd and, therefore, it is identically zero. Hence

$$\begin{aligned} A_W &= \frac{L_s t_{\max}}{2} \sum_1^M A_{sm} \int_{-\pi/2}^{\pi/2} d\theta [\cos(2m-1)\theta \cos \theta] \\ &= \frac{L_s t_{\max}}{2} \sum_1^M A_{sm} \int_{-\pi/2}^{\pi/2} d\theta [\cos(2m-2)\theta + \cos 2m\theta] \end{aligned}$$

$$\begin{aligned}
&= \frac{L s_{\max}}{2} \sum_1^M A_{sm} \left[\frac{1}{2m-2} \sin(2m-2)\theta + \frac{1}{2m} \sin 2m\theta \right]_0^{\pi/2} \\
&= \frac{L s_{\max}}{2} \sum_1^M A_{sm} \left[\frac{\sin(m-1)\pi}{2(m-1)} + \frac{\sin m\pi}{2m} \right].
\end{aligned}$$

These integrals are identically zero except for $m=1$ where the first term contributes $\pi/2$,

$$A_W = \frac{L s_{\max}}{2} \frac{\pi}{2} A_{S1}.$$

The waterplane coefficient is defined as

$$C_{WP} = \frac{A_W}{L s_{\max}}.$$

Therefore

$$A_{S1} = \frac{4C_{WP}}{\pi}.$$

This derivation shows how the waterplane coefficient is related to the Chebychev coefficient, A_{S1} . Similarly we can prove,

$$A_{B1} = \frac{4C_P}{\pi}$$

where C_P is the body prismatic coefficient.

In the SWATHO program the maximum number of terms of the Chebychev series is three. The Chebychev coefficients are determined by the following formulas for the strut:

$$A_{S1} = \frac{4C_{WP}}{\pi},$$

$$A_{S2} = A_{S1}(1 - 16 C_{IW}),$$

$$A_{S3} = 1 - A_{S1} - A_{S2},$$

$$B_{S1} = 4C_{LCF} \cdot A_{S1},$$

$$B_{S2} = 0,$$

$$B_{S3} = 0,$$

and the body coefficients are determined as follows:

$$A_{B1} = \frac{4}{\pi} C_P,$$

$$A_{B2} = 1 - A_{B1},$$

$$A_{B3} = 0,$$

$$B_{B1} = 4C_{LCF} \cdot A_{B1},$$

$$B_{B2} = 0,$$

$$B_{B3} = 0,$$

where

C_{WP} = Waterplane area coefficient

$C_{WP} = A_W / (L_S \cdot T_S)$, where A_W is waterplane area of one strut.

C_{LCF} = Waterplane moment coefficient

$C_{LCF} = M_{X_S} / (A_W \cdot L_S)^*$

C_{IW} = Waterplane inertia coefficient

$C_{IW} = I_{W_X} / (A_W \cdot L_S)^2 *$

C_P = Body prismatic coefficient

$C_P = \nabla_B / (A_X \cdot L_B)$ where ∇_B is displaced volume of one body.

C_{LCB} = Body moment coefficient

$M_{XB} / (\nabla_B \cdot L_B)^*$

* All moments and the moment of inertia are taken about the mid-length of the respective strut or body.

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