MIT WHOLESHIP CONSTRUCTOR USER'S GUIDE

J. Chalfant

MITSG 13-15

Sea Grant College Program
Massachusetts Institute of Technology
Cambridge, Massachusetts 02139

NOAA Grant No. NA06OAR4170019 Project No. 2008-ESRDC-01-LEV

MIT WholeShip Constructor User's Guide

Julie Chalfant, MIT
October 31, 2013
MITSG 13-15

Introduction

The Electric Ship Research and Development Consortium (ESRDC) is developing the Smart Ship System Design (S3D) environment, which is a collaborative design environment that brings together many engineering disciplines early in the ship design process. While there is impressive capability available within the S3D platform, there is a dividing line between what should be inherent capability and what should be kept external to S3D and provided as enhancement with a smooth interface. For example, there exist a number of very capable programs for naval architecture calculations such as intact and damaged stability, resistance and power estimation, hullform optimization, structural integrity, and more. We take as a sample GRC's Paramarine [2013], an integrated computer aided design and engineering tool available today for commercial ship, warship and submarine design.

We have written code in MATLAB to automatically and rapidly construct a surface warship in Paramarine using information from S3D, and to produce information required in S3D for surface ship design. One of the strengths of Paramarine is also one of the difficulties in using Paramarine; each design begins with a blank slate, and the designer constructs the modeling scenario from scratch, defining all pointers and interrelationships. This code accomplishes the following:

- Sets up a standard format for storing the ship design, using U.S. Navy-specific terminology.
- Using a small set of parameters to define the size of the ship, constructs a ship hull using the "quickhull" capability within Paramarine using a baseline set of hull curves.
- Inserts bulkheads and subdivide the hull into watertight compartments.
- Inserts decks.
- Constructs a deckhouse.
- Inserts weight data categorized by ESWBS.
- Establishes an audit system.
- Analyzes intact and damaged stability.

Further modules allow:

- Estimating resistance and propulsion power.
- Inserting equipment specifically selected and placed using S3D.
- Updating bulkhead and deck placement.

This code is described in more detail below. Familiarity with Paramarine is necessary to use (and understand) this code and user's guide.

Quickstart Directions

This code may be downloaded from the MIT Sea Grant College Program website, seagrant.mit.edu. To run the code:

1. Open Paramarine and leave the file blank.
2. Check the Excel or .csv data files to ensure they represent the ship you would like to build.
3. Check the data file names and default values in the first section of the MATLAB script: A00_WholeShip.m.
4. Run A00_WholeShip.m in MATLAB.
5. In Paramarine, open the file structure for the ship and ensure all was built correctly. Some choices in parameter values in the data files can cause adverse effects in the resulting hullform.
6. Additional modules can be run to calculate power, insert equipment, and move decks or bulkheads if desired: A06_power.m, A07_insert_equipment.m, A111_update_bhd.m and A112_update_decks.m. After running each module, switch to Paramarine to allow Paramarine time to perform necessary calculations before running the next module in MATLAB.

Ship Design Standard Format

Establishing a standard format for arranging the ship design data allows the automated updating of the design with external programs. As such we established a format with sections entitled Ship Data, Reference, Supporting Geometry, Design, Audit and Analysis. These sections are elaborated below:

Ship Data. This placeholder includes ship-specific performance and geometry data, arranged as follows:

- Ship_Data.performance
    - Range – distance in nautical miles to be traveled at endurance speed without refueling
    - Endurance speed – in knots
    - Max speed – maximum sustained speed of the vessel
- Ship_Data.hull
    - Displacement – in metric tons at design draft
    - LBP – length between perpendiculars in meters
    - Beam – at waterline in meters
    - Draft – design draft to keel, in meters
    - D0 – Depth at station zero in meters (located at forward perpendicular)
    - D10 - Depth at station ten in meters (located amidships)
    - D20 – Depth at station twenty in meters (located at aft perpendicular)
    - HOA – Height overall in meters from keel to top of deckhouse
- Ship_Data.hull.hullform_generation_data
    - Cp – prismatic coefficient
    - Cm – midships coefficient
    - Transom_draft – distance from keel to bottom of transom
    - transom_beam – beam at transom at main deck level
    - skeg_width – width of skeg; must be greater than zero
    - bow_angle – angle made with horizontal by bow, in degrees, positive
    - transom_angle – angle made with horizontal by transom, in degrees, positive

    - aft_cut_up_dist_fm_AP – distance forward of aft perpendicular where aft hull rise from keel line begins
    - pmb_dist_fwd_of_midships – distance forward of midships where parallel midbody begins
    - pmb_dist_aft_of_midships – distance aft of midships where parallel midbody ends. This number can be negative, and the fwd and aft midbody distances may coincide if there is no parallel midbody section
    - entry_coeff – entry coefficient; default value provided by code
    - run_coeff – run coefficient; default value provided by code
    - skeg_area_coeff – skeg area coefficient; default value provided by code
    - transom_area_coeff – transom area coefficient; default value provided by code
    - bow_area_coeff – bow area coefficient; default value provided by code
    - LCB_fm_midship_as_percent_LBP – longitudinal center of buoyancy from midship as percent of length between perpendicular, positive forward; default value provided by code
    - CSA_iterations – the number of iterations used by Paramarine to generate the hullform; default value provided by code
- Ship_Data.deckhouse
    - beam_offset_for_deckhouse – distance from edge of deck to deckhouse
- Ship_Data.decks
    - Heights – scalar values of heights of decks in meters, including hull decks and platforms and deckhouse decks
    - Planes – geometric planes parallel to the xy axes, corresponding to heights listed above
- Ship_Data.transverse_bulkheads
    - Locations – scalar values of locations of transverse watertight bulkheads in the hull, in meters
    - Planes – geometric planes parallel to the xz axes, corresponding to locations listed above, used for hull subdivision

The **Reference** section includes standard classification and concept data used within Paramarine. The organization is as follows:

- Reference.classification_systems – establishes 1-digit ESWBS groups for classification of weights
- Reference.ship_conditions – establishes lightship, minimum operating and full load conditions for stability and powering analysis
- Reference.densities – sets densities for liquids, including seawater and fresh water
- Reference.service_specs – provides a container for service systems

The **Supporting Geometry** section provides a location to store the background information needed to construct the ship hull and superstructure.

- Supporting_Geometry.hull_generation – control hull, guide curves and data to generate a quickhull

- Supporting_Geometry.deckhouse_generation – points and planes required to generate deckhouse solids. This begins with a single sample block for copy.
- Supporting_Geometry.profile_sheet, plan_sheet, transverse_sheet and margin_sheet – sheets used in stability calculations

The **Design** section holds the actual ship design, including the final hull, deckhouse, and equipment.

- Design.envelope – contains the subdivided hull and deckhouse
- Design.Design – contains all equipment

The **Audit** section provides tallies of weight and commodities and provides a location to put additional checks such as clash detection.

The **Analysis** section provides a location for analysis of the resultant ship design, including stability and powering.

Hull Generation

This section reads the specific ship data stored in an Excel or .csv file, and stores the data in the structure described above, either in Ship_Data.hull or Ship_Data.hull.hullform_generation_data. A sample set of data is included in Table 1. Using this data, the program then enters the appropriate equations and pointers in the hull_data section for use by the quickhull program.

Table 1. Ship Data.

Range_nm	3000
Endurance_Speed_kt	16
Max_Speed_kt	32
Displacement_mt	10000
LBP_m	144.83
Beam_m	17.65
Draft_m	6.74
D0_m	13.35
D10_m	13.35
D20_m	13.35
prismatic_coefficient	0.572
midships_coefficient	0.854
transom_draft_m	1.5
transom_beam_m	14
skeg_width_m	0.25
bow_angle_deg	45
transom_angle_deg	30
aft_cut_up_dist_fm_AP_m	22
pmb_dist_fwd_of_midships_m	0
pmb_dist_aft_of_midships_m	0

entry_coeff	1
run_coeff	0
skeg_area_coeff	0
transom_area_coeff	0
bow_area_coeff	0
LCB_fm_midship_as_percent_LBP	-1.4
CSA_iterations	40
Propeller Diameter	4.88

Bulkhead Insertion and Hull Subdivision

The program next reads the locations of the bulkheads from an Excel or .csv file, and enters those locations in the Ship_Data.transverse_bulkheads.locations section. The bulkhead planes are already linked. The WholeShip program then subdivides the hull solid at each watertight bulkhead and renames the sections for the appropriate stations. A sample bulkhead listing is shown in Table 2; the bulkhead locations may be listed in any order, and the bulkhead numbering (e.g. Bulkhead 01) is not retained. It is merely helpful when constructing the input file.

Table 2. Sample Bulkhead Listing

Bulkhead 01	7.2
Bulkhead 02	16.8
Bulkhead 03	26.3
Bulkhead 04	35.9
Bulkhead 05	46.7
Bulkhead 06	60.86
Bulkhead 07	69.53999
Bulkhead 08	84.12
Bulkhead 09	101.4
Bulkhead 10	111.725
Bulkhead 11	123.1
Bulkhead 12	132
Bulkhead 12	138

Deck Insertion

The next step is insertion of decks. The heights are listed in an Excel or .csv file; an example is shown in Table 3. This file should include deck heights for all decks and platforms in the hull and superstructure, including the deck at the top of the superstructure. The numbering of the decks in the Excel/.csv file does not matter, and the decks may be listed in any order.

Table 3. Sample Deck Locations

Deck 1	1.2
Deck 2	4.1

Deck 3	7.6
Deck 4	11
Deck 5	13.35
Deck 6	15.7
Deck 7	18.7
Deck 8	21.7

Deckhouse Construction

Once decks are inserted, the deckhouse may be constructed. The data used is stored in an Excel or .csv file. A sample is included in Table 4.

Each deckhouse block runs from a lower deck to an upper deck and the forward and aft edges of the block correspond to watertight bulkheads in the hull so the deckhouse is properly supported with hull structure. The forward, aft, port and starboard sides of each block may be angled with respect to vertical. In addition, the deckhouse may be offset from the beam by a distance specified in the deckhouse data file; this value is constant over the length of the ship.

A hull may be constructed with a raised deck. This is accomplished in our method by constructing the entire hull at the height of the raised deck, then cutting away the portion aft of the raised deck; the location of this cut is designated by a "cut bhd", which is the watertight transverse bulkhead at the forward edge of the cut, and a "cut deck" which is the hull deck at the bottom of the cut. These are designated by number (in our example, the twelfth bulkhead counting aft from the bow and the fourth deck counting up from the keel).

Table 4. Deckhouse Data

	Compartment 1	Compartment 2	Compartment 3
fwd bhd	4	4	8
aft bhd	7	5	10
lower deck	5	7	5
upper deck	7	8	7
fwd angle	10	10	10
aft angle	-10	-10	-10
port angle	10	10	10
stbd angle	-10	-10	-10
beam offset (m)	1.5		
cut bhd	12		
cut deck	4		

The WholeShip program inserts solid blocks for each deckhouse section, makes the hull cut if needed, and updates the profile, plan and transverse sheets with the new ship structure.

Unallocated Weight Data

Weight data is provided in an Excel or .csv file; an example is shown in Table 5. Weight data is categorized by expanded ship work breakdown structure (ESWBS) number and includes weight and longitudinal and vertical centers of gravity (lcg and vcg). Categorizing by ESWBS provides the opportunity to subtract specific equipment weights from the appropriate group as the equipment is placed. While provision is made to accomplish this, work remains to calculate the overall weight estimates and to categorize equipment in the S3D database.

Table 5. Sample Weight Data

eswbs	weight	lcg	vcg
100	3132	80.2	7.89
200	1515	82.25	5.05
300	1380	76.51	4.5
400	166	78.62	19.34
500	1251	88.25	8.51
600	592	78.49	10.72
700	309	60	11.96
F00	1660	78.36	5.57

Audit

The audit section provides a tally of weights added, both through the unallocated weight described above and as equipment or tankage is added later in the program. The WholeShip program automatically inserts a weight tally; it is possible to audit other information as well, such as space or commodity usage, and to add such features as collision detection.

Stability Analysis

We add intact and damaged stability checks. Provision is made to accomplish damaged stability checks either as a percent length damaged or as a number of adjacent compartments damaged; the user selects the criteria to be used by setting the appropriate flag in the initial section of the WholeShip MATLAB script. The program automatically designates flooded compartments and runs a series of damage cases throughout the length of the ship.

Update Bulkhead and Deck Locations

Stand alone MATLAB scripts are provided to change bulkhead and deck locations while leaving the rest of the ship unchanged; pointers remain properly assigned so cascading calculations are retained. The code is provided in A111_update_bhd.m and A112_update_decks.m. The decks and bulkheads are provided in a data file; the user should verify the name of the file in the first section of the MATLAB script before running.

Powering Estimates

Code is provided, in A06_power.m, to include resistance and powering estimates. Under the Analysis section, this provides methodology to estimate resistance using Holtrop and Mennen [1982], Fung [1991], Taylor Standard Series [1954], and Series 64 [Yeh, 1965]. Please recognize that these estimates are valid in different ranges of hullforms and speeds, so not all estimates will be applicable to all possible ship designs, and there will be cases in which none are applicable.

These powering estimates provide a speed versus power curve for the vessel. The user must designate relative rotative efficiency, thrust deduction factor and Taylor wake fraction, and indicate whether a bow bulb is present. The program provides default values for appendage resistance as a percentage of bare hull resistance; this may be changed by the user as well. All these values are located at the beginning of the MATLAB script.

Inserting Equipment Designed in S3D

Any equipment inserted within S3D can be exported to a .csv file. The MATLAB script A07_insert_equipment.m can then be used to import that equipment into Paramarine. A sample list of the data required to be exported from S3D is presented in Table 6. To save space, we have not displayed the ID, which is a 32 digit hexadecimal unique identifier used by the S3D database.

Table 6. Sample Equipment List from S3D

Name	ID	Height (m)	Length (m)	Location X (m)	Location Y (m)	Location Z (m)	Weight (kg)	Width (m)
Chiller	###	2.5	5.99	30.85	-2.05	4.47	26667	2.5
Tank	###	1.48	1.12	78.65	2.19	3.73	0	0.71
GenSet	###	2.8	12.3	54.25	3.15	5.88	54750	2.4
NonVitalLoad	###	1	1	13.97	4.02	11.52	10	1
PropMotor	###	4	6	106.43	-4	1.71	0	4
Weapon	###	2	2.78	133.92	4.81	7.67	2500	1

The WholeShip code constructs a bounding box representation of each piece of equipment at the proper location within the ship design structure in Paramarine and includes the weight.

Acknowledgements

This work is supported by the Office of Naval Research N00014-08-1-0080, ESRDC Consortium, and MIT Sea Grant College Program under NOAA Grant Number NA06OAR4170019, MIT SG Project Number 2008-ESRDC-01-LEV.

License

References

Fung, Siu C., " Resistance and Powering for Transom Stern Hullforms During Early Stage Ship Design", Society of Naval Architects and Marine Engineers, Transactions, Vol 99, pp 29-84, 1991.

Gertler, M., "A Reanalysis of the Original Test Data for the Taylor Standard Series", United States Government Printing Office, Washington, D.C., 1954.

GRC Paramarine. http://www.grc.qinetiq.com/products/paramarine/Pages/default.aspx Accessed October 28, 2013.

Holtrop, J. and Mennen, G.G.J., "An Approximate Power Prediction Method", International Shipbuilding Progress, Vol. 29, No. 335, July 1982.

Yeh, H. Y. H., "Series 64 Resistance Experiments on High Speed Displacement Forms", Marine Technology, July 1965.