Ship System Design Space Exploration Using Templating

Natasha Patterson, Julie S. Chalfant

ABSTRACT

Research and an experimental study were performed to construct a flexible, user-friendly methodology that integrates ship system design into the Navy's early-stage ship design tool suite, called the Rapid Ship Design Environment (RSDE). This project establishes specified Naval ship system architecture and design use cases and examples that demonstrate the implementation of templates, or pre-designed segments of ship systems, to enable automation of ship system design for tradespace exploration. The use cases represent common functions RSDE users seek to perform in the ship design process, including mission system design, propulsion train and electrical system design, and associated full-ship studies for design exploration using templates. This research allows common systems and/or plant configurations to be easily accessible in a familiar format.

To develop this methodology and implement templating in future projects, the methods, steps, and tools used are recorded and analyzed with feedback from various end-state users and technical experts.

1 Background

Navy ship mission systems are increasingly power-intensive and integrated and thus are increasingly dependent on ship system performance, especially the electrical distribution, thermal management, and data control systems [8]. In recognition of this, the U.S. Navy expanded an ongoing partnership with the Electric Ship Research and Development Consortium (ESRDC) to develop Smart Ship Systems Design (S3D), a ship system design software environment fully integrated with the Navy's early-stage ship design toolkit. Augmenting this software with the associated templating process provides a level of automation to system architecture design, thus providing a capability for the design and analysis of ship systems much earlier in the design process than previously possible.

This paper reports the research and experimental studies performed to construct a flexible, user-friendly methodology that integrates S3D and its templating tools into the Navy's Rapid Ship Design Environment (RSDE), thus providing system design in a familiar format. The templates explored include mission systems, propulsion train, and electrical system designs.

The remainder of the paper is organized as follows. Section 2 describes existing design tools. Section 3 is an overview of the templating process. Section 4 details the problem this methodology seeks to resolve. Section 5 explains generic templating implementation proposed for RSDE, and Section 6 applies this generic methodology to specific examples. Section 7 discusses the proposed use of templates for RSDE's design space exploration functionality. Conclusions and recommendations for future work are presented in Sections 8 and 9.

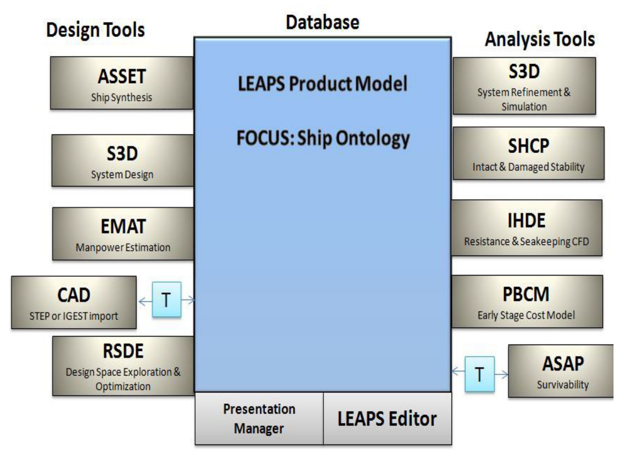

Figure 1. Design Tools, Database, and Analysis Tools Interaction [12] (Reproduced with permission from the American Society of Naval Engineers)

2 Tools and Methods

The design tools and associated databases this research focuses on include the Navy's early-stage ship design and analysis tool, called the Rapid Ship Design Environment (RSDE); the associated data repository, termed the Leading Edge Architecture for Prototyping Systems (LEAPS); the product meta-model describing the storage of surface ship data, known as the Formal Object Classification for Understanding Ships (FOCUS); and a new tool for ship system design and analysis, called Smart Ship System Design (S3D). Figure 1 is a visual representation of the interaction of these databases and tools. The essential design and analysis tools referenced in the figure relevant to this paper are explained in further detail in Sections 2.1-2.**3**.

2.1 Leading Edge Architecture for Prototyping Systems (LEAPS) and Formal Object Classification for Understanding Ships (FOCUS)

The Leading Edge Architecture for Prototyping Systems (LEAPS) is the Navy's data repository for storing all relevant information to a ship design in a single file format. A component stored in the LEAPS database with specifications set in accordance with the FOCUS product meta-model is considered FOCUS-compliant. Many of the Navy's ship design and analysis tools for computer-aided design (CAD), structures, and computational fluid dynamics (CFD) are compatible with LEAPS and FOCUS, as represented in Figure 1.

2.2 Rapid Ship Design Environment (RSDE)

RSDE is sponsored by the Department of Defense High Performance Computing Modernization Program (HPCMP) under the Computational Research and Engineering Acquisition Tools and Environments (CREATE) portfolio. The CREATE-Ships Design projects were developed to create software applications to assess various tradespace options and design decision parameters for Navy ships [11]. RSDE was developed specifically for design space exploration and assessment [12]. It is an overarching tool that automatically runs subtools to explore select property variation impact on a full ship design. These properties include a range of parameters from space, weight, and power affecting hydrodynamic performance, survivability, and cost. RSDE outputs are a demonstrative computational analysis and associated model modifications of the design space, as Figure 2 depicts [12].

The RSDE environment contains a synthesis tool that creates three-dimensional ship and submarine models for performance assessment, assimilating various engineering plant components (propulsion, electrical, and auxiliary), hullform, structures, and appendages. These input characteristics are required to demonstrate performance relative to speed, range, efficiency, intact and damaged stability, sea-keeping, etc., and, subsequently, ship performance.

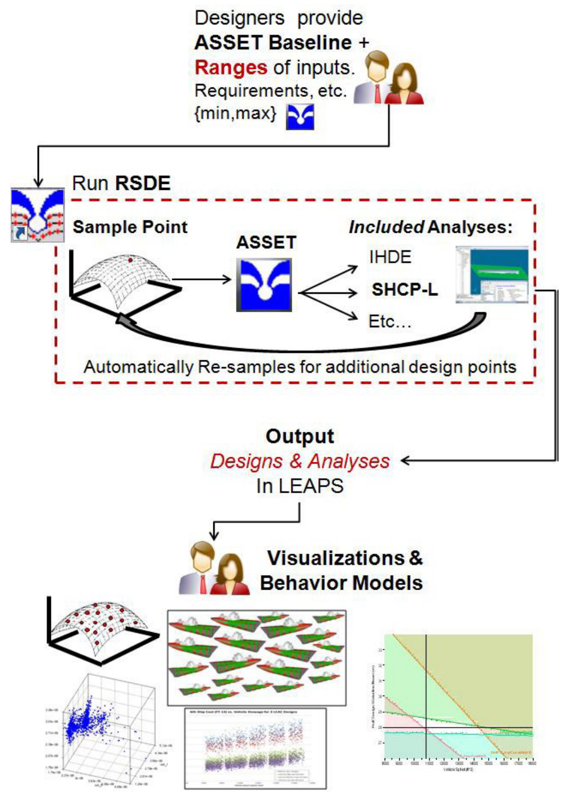

Figure 2. RSDE Operation [12] (Reproduced with permission from the American Society of Naval Engineers)

2.3 Smart Ship Systems Design (S3D)

The Office of Naval Research (ONR) led ESRDC, in conjunction with the Naval Surface Warfare Center Carderock Division (NSWCCD), to develop a software tool for ship system design called Smart Ship Systems Design (S3D) [7]. This tool performs thermal (air or liquid cooling), electrical, and mechanical domain co-simulations, analysis, and logical equipment arrangement in a two-dimensional, one-line diagram format. Further, the assigned components have three-dimensional properties and may have CAD representations available for arrangement using LEAPS-based tools extant in the RSDE environment. S3D is integrated with existing Navy design tools; the specific tool that this research explores is RSDE [12].

3 Templating Background

While S3D provides a leap forward in the capability to model and simulate the structure and performance of ship systems, the current implementation is not conducive to an automated exploration of a design space, as it requires user involvement to drag, drop and connect each component in a design. A new methodology, termed templating, is being explored to bring more automation to the system design process.

Templates are pre-designed systems or segments of systems composed of components and connections. Templating instantiates and combines templates within a virtual prototype to create fully-implemented ship system designs. These templates are designed to be interchangeable, thus facilitating design space exploration in which templates within a ship design are swapped with alternative options. The templating tool is critical in making the integration of S3D into RSDE viable from a usability standpoint.

Templating brings several advantages to the ship design process. The primary advantage is that the tool enables an automated method for incorporating system designs in RSDE. Another benefit is that templates are reusable, thus preserving users' efforts by allowing previous designs to be scaled or integrated with other templates and systems for use in various hullforms. Lastly, templating allows individual system experts to construct an accurate model to integrate with other systems independently and, subsequently, the holistic design. In this way, the naval architect can draw on the knowledge of system-level experts during the ship design process.

From a design standpoint, this tool allows the flexibility to create several systems, testing various design space options in a simulation and analysis environment. These templates are created and stored for use in future projects.

The templating process consists of four main steps, described below.

Template Creation. A template is created by building a system or portion of a system within S3D. Components are selected, parameterized, and connected, and the resulting system is saved as a concept in a LEAPS database. In the future, it may become necessary to store templates as .xml files so that they can be accessed simultaneously by several RSDE threads in a high-performance computing application. The templates are designed to be connected at template nodes, which contain information that ensures proper connection into a full system when the templates are placed into a ship design. See [1] for details describing the nature of these connections.

System Construction. Full systems, based on architectural and design requirements, within a ship design are created by selecting appropriate templates and assigning them to a location (compartment, zone, or hull) within the ship design. The template is deep-copied into the location within the ship design. The deep-copy process retains template formatting to include components, nodes, connections, diagrams, system assignments, properties, and common views. The template components are automatically allocated within the ship upon assignment to a location, and connections to existing templates are automatically made at the appropriate template nodes denoted by blue circles. Template node properties are established during template construction. An example template is shown in Figure 3.

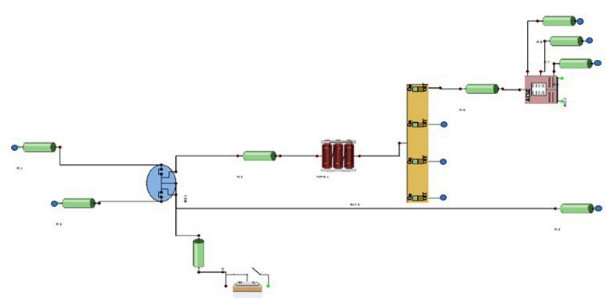

Figure 3. Sample template.

Component Sizing. Once all templates are copied into the ship, the system component connections are traced to determine the required capacity of each component. For example, the capacity of an electrical component is the maximum amount of power that can flow through the component, given any possible system alignment. Using graph theory, an equipment sizing algorithm to determine this power requirement is described in [2]. This algorithm is applied to a fully connected system, and the rated power of each component is set to the value determined by the algorithm. Sizing algorithms for each component in response to the maximum power assigned remain to be developed.

Final Arrangement. The final step is to adjust component locations to eliminate overlaps between equipment or with the hull, bulkheads, or decks. This deconfliction is achieved using a force-directed graph drawing method; it eliminates overlaps and adjusts positioning to reduce cable and piping length and position large equipment low in the compartment [7].

4 Problem Description

This paper defines a methodology to implement templating into the Navy's early-stage design process through integration into the RSDE toolset, thus adding ship system design to the tradespace exploration.

Much of RSDE is regression-based, utilizing historical or parametric data as the basis for its calculations and algorithms. This aspect of RSDE makes it difficult to assess new technologies or design concepts without a significant amount of tedious calculations by the user. One goal of incorporating S3D into the RSDE toolset is to replace these regression-based algorithms in RSDE with more flexible, user-friendly methodologies capable of exploring new technologies and arrangements.

There are several use cases for applying templates to early-stage ship design; three specific cases are described below.

Payloads and Adjustments. RSDE currently uses a Payloads and Adjustments (P&A) table that lists the weight, space, power, and cooling impacts of specific mission modules and payloads on the ship. One significant drawback of the current model is that the equipment listed in this table does not generate a geometrical representation in three-dimensional space. Further, the major loads are not available for simulation using S3D. The ultimate goal is to replace this table format with a component-based structure in which each mission load or payload is represented by a single component or a system of components with appropriate properties and a physical, three-dimensional position assigned. Further, both RSDE and S3D will use all the information and properties provided by this component representation.

Machinery Module. RSDE currently creates representations of the ship's propulsion, power, and cooling equipment using a Machinery Module, which requires the user to select options among a set of hard-coded machinery architectures. However, the current construction of the module presents several issues. First, the module follows a prescribed set of codified rules for calculations and component placement, thus inhibiting flexibility and impeding future growth in engineering technology modeling. Second, although the Machinery Module provides a high level of detail and appropriately sizes major propulsion and electrical system components, other components and equipment are either not sized or are represented with a low level of detail based on parametric data.

Design Exploration. The "Design Exploration Tool: Full Ship Study Generator" allows the user to conduct rapid calculations of technical characteristics to create ship studies. The proposed methodology aims to improve the design exploration tool in RSDE for mission equipment, payloads, and machinery. The current design exploration tool is limited to support design exploration for a select few modules. Specifically, the current tool does not allow the user to conduct tradespace analysis for propulsion or electrical machinery components.

Problem Statement. The summarized problem statement for this work is: to develop a process that expands the capabilities of RSDE to model and assess ship systems, payloads, and mission-specific equipment to meet modern technological demands at the system level without hard-coded, historical assumptions.

5 Approach

This approach defines a methodology to simplify the creation of system design and explore tradespace requirements. It includes two generic use cases for templating: system design implementation and design space exploration.

5.1 Templating Process in RSDE

The templates follow the guidelines discussed in Section 3. It is important to note that these templates must be generated and stored in a template library prior to beginning the RSDE design process. It is envisioned that a set of pre-designed templates, generated by a subject matter expert and approved by the appropriate technical warrant holder, are included with the RSDE software, and the capability to create additional templates is provided. In many cases, all information in a ship design exploration needs to meet Navy specifications, requiring the employment of pre-approved templates. However, allowing the creation of additional templates facilitates the exploration of new, different ideas before authorization by the technical warrant holder. For example, the Center for Innovative Ship Design (CISD) uses Navy design tools to explore untested ideas; this innovation should be possible in RSDE.

5.1.1 Generic Templating Implementation

The proposed generic interface methodology for using templates within RSDE is as follows.

1. Choose a template from a library of pre-generated templates (see Figure 4, top) by selecting from a drop-down list of available templates. This drop-down list should be populated by RSDE using the templates available in the template repository. The repository will likely need to be organized into sections or categories for cases when many templates are required.

2. If necessary, update properties for specified components within the template (see Figure 4, middle) using the presently existing S3D interface. This step assumes that S3D has become integral to RSDE, as is currently planned [12].

3. Assign the template to an appropriate ship subdivision, i.e., compartment, zone, or overall hull. Figure 4, bottom, shows a possible interface in which the user could select a single compartment, a zone, or a full hull. This method is designed to be flexible enough to allow a wide range of applications, from a very small single-hull autonomous underwater vessel with no zone delineations and only one or two compartments to a multi-hull ship with different compartmentation in each hull.

This process is repeated as necessary to ensure the entire physical system architecture is represented in the appropriate ship subdivisions.

Overall process flexibility is maintained by the user's ability to select and order template(s) and apply them to a specified location. The same template can be applied multiple times in different locations. Multiple templates can be combined to create a system, or a single template can be used to represent a complete system.

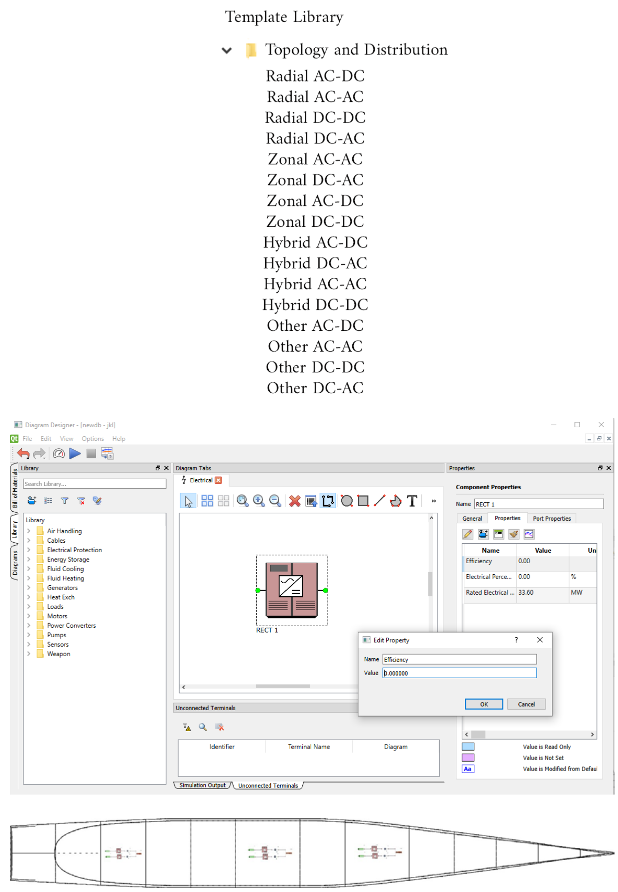

Figure 4: Sample interface for generic implementation of templating in RSDE, showing the Template Library (top), Properties Modification (middle), and Location Assignment (bottom).

6 RSDE Module Replacement

RSDE is comprised of several modules to facilitate ship construction. These modules include but are not limited to hull geometry, hull subdivision, deckhouse geometry, hull structures, appendages, resistance, and machinery.

Each module has a series of inputs that dictate design decisions, calculations for analysis, spatial arrangements, and three-dimensional positioning in ship subdivisions (i.e., compartments, zones, or the hull). The user must complete the minimum required entries for each module; then, the program synchronizes to converge on a single model that reflects those inputs.

This methodology addresses individual module inputs through templating, specifically applying to modules responsible for system design at the component level.

6.1 Ship Design Methodology using Templates

The RSDE process is flexible, so the visitation order to each module can vary. An example consolidated methodology for the application of templating to the P&A and machinery module roles follows:

1) Add major mission loads in component form to the ship design using a templating process.
2) Use the existing RSDE process to complete the following modules: hull geometry, hull subdivision, deckhouse geometry, deckhouse, hull structures, appendage, and resistance.
3) In lieu of the Machinery Module, open S3D as a RSDE module.
4) Choose ship service configuration
   a) Choose power generation template(s) and associated options
   b) Choose architecture/topology and distribution template(s) and associated options
5) Choose propulsion transmission configuration
   a) Choose propulsor type template(s) and associated options
   b) Choose shafting template(s) and associated options
   c) Choose power transmission template(s) and associated options
6) Run automated connection of templates, followed by automated tracing of systems to determine capacities, running of sizing algorithms, and resolution of collisions
7) Run S3D module simulation to generate reports
8) Complete remaining ship construction modules and synchronize model

6.2 Payloads and Adjustments

The P&A table adds the space, weight, power, and cooling impacts of components not modeled in other modules. This table typically includes all mission equipment, such as weapons and sensors, along with adjustments to any incorrect estimates from the built-in algorithms. Specific properties include:

1. Weight
2. Area (footprint)
3. Cooling Load at various operational levels
4. Electrical load at various operational levels
5. Ship Work Breakdown Structure (SWBS) and Ship Space Classification System (SSCS) groupings
6. Location (vertical, longitudinal, transverse)

Replacing the P&A table entries with either individual components or templates containing systems of components still accounts for all the information listed above through properties associated with the components while adding the capability of pulling the P&A table items into the S3D simulation environment.

The P&A replacement continues to represent large loads, which account for the top 20% of all electrical and cooling demands [5]. These loads are organized by Ship Work Breakdown Structure (SWBS) groups.

6.2.1 Example

For example, a rail gun is modeled using templates in two domains (electrical and piping). First, the template “Rail Gun (AC-DC)” is chosen from the picklist as shown on the left-hand side of Figure 5. The rail gun has a mathematical representation in both domains and thus appears in both the electrical domain image shown in the light blue box and the piping domain image shown in the light green box. The electrical support equipment includes a rectifier, a transformer, and the cables connecting them. The liquid distribution equipment includes the piping and a valve connecting this architecture to the cooling water system.

Upon choosing the appropriate template from the dropdown list, the user may open the template in the S3D interface within RSDE and modify properties of any components as necessary. For example, Figure 6 shows a modification of the rail gun properties in the electrical domain.

The template is then assigned to a subdivision in the ship design, in this case a compartment, as represented by Figure 7. This figure depicts the piping domain. Figure 8 shows the rail gun system integrated with the electrical distribution system.

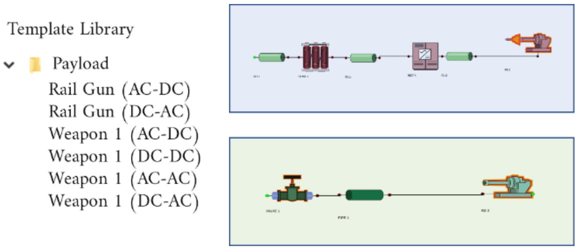

Figure 5: Payload template example showing a rail gun. The light blue box at the top indicates electrical domain equipment, and the light green box at the bottom represents piping domain equipment.

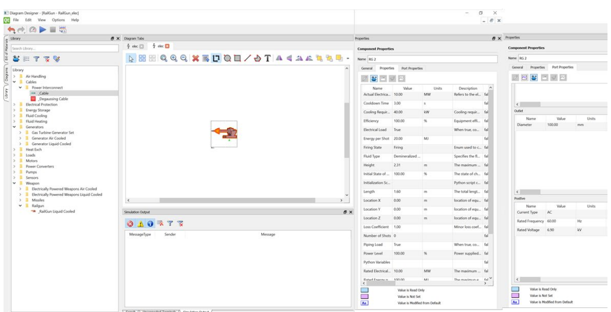

Figure 6. Choose properties

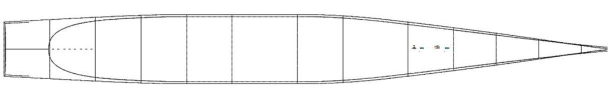

Figure 7. Arrange template

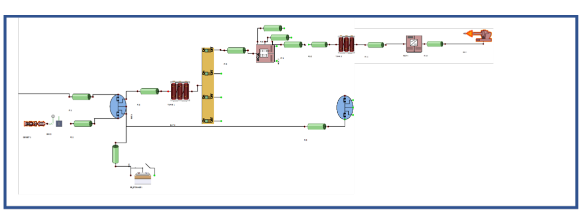

Figure 8: Sample P&A arrangement connected to electrical distribution

6.3 Machinery Module

RSDE's Machinery Module calculates the weight, space, power, and cooling needs of the propulsion and electric plants by leading the user through the selection and placement of major propulsion and electrical generation equipment and the designation of the operating characteristics at various operating conditions.

This functionality can be accomplished using templates and S3D. Two main systems must be designed: propulsion and electrical distribution systems. One example process follows:

1) Choose ship service configuration, including
   a) power generation template(s) and associated options
   b) architecture/topology and distribution template(s) and associated options
2) Choose propulsion transmission configuration, including
   a) propulsor type template(s) and associated options
   b) shafting template(s) and associated options
   c) power transmission template(s) and associated options

The examples below show the process in more detail.

6.3.1 Machinery Module (Electrical) Example

This example shows an electrical power generation and distribution system using gas-turbine generator sets, Medium-Voltage DC (MVDC) distribution buses, and in-zone distribution providing 450 VAC and 60 Hz power. To accomplish this example, two main templates are applied: an electrical power generation template which is applied once in each of the three machinery rooms, and an electrical distribution template which is applied once in each electrical zone.

Power Generation. The power-generation template, shown in Figure 9, includes an LM2500 generator, circuit breaker, rectifier, and cabling to provide bus-voltage power to the distribution system once connected. In addition to this primary electrical generation equipment, three pumps comprise the auxiliary support equipment. These pumps require electrical power, so they are present in the electrical domain template.

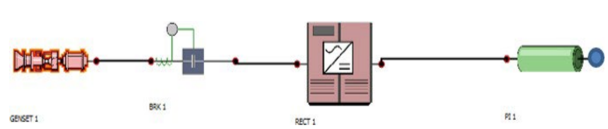

Figure 9: Electrical power generation template

Prior to assigning the template to the ship spaces, the specific equipment can be changed and properties modified if necessary. In this example, changes were made to the template's specific gas-turbine generator set (genset). Figure 10 shows the selection of a new genset that replaces the one in the pre-designed template. Similarly, other equipment in the template can be selected, and other properties changed if the user desires. Note that properties associated with the amount of power flowing through a component are automatically set as part of the system tracing and sizing algorithm that occurs after all systems are logically connected and placed into the ship design. The user sets rated power for sources and loads, but rated power for connecting items such as converters and cables can be set automatically.

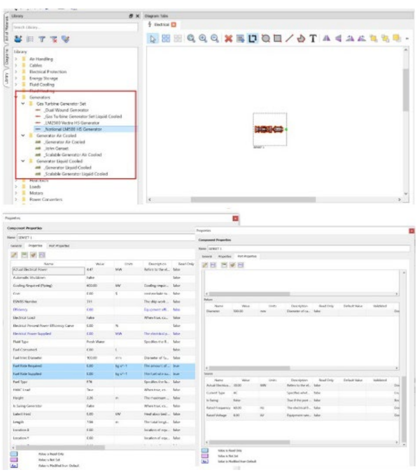

Figure 10: Choose generator set and associated properties

Next, the power generation template is placed in each machinery room, as shown in Figure 11.

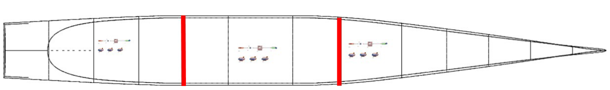

Figure 11: Assign the power generation template to each machinery room.

Power Distribution. The electrical power distribution template, shown in Figure 12, includes cabling and switchgear for main bus distribution and cabling, converters, switchgear, and energy storage for in-zone distribution.

Prior to placing the template into the ship design, equipment selections and property modifications can be accomplished for any of the components in the template.

The power distribution template is assigned to each zone, as shown in Figure 13. Figure 14 depicts one zone after all zones have been populated; note the connections to the bus nodes (blue ovals) in the zones forward and aft of the example zone.

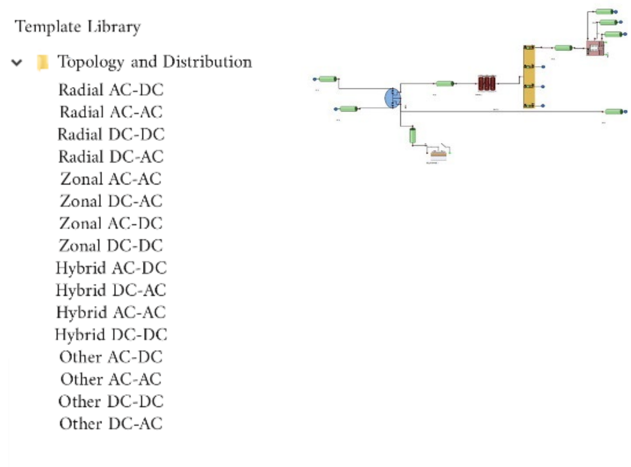

Figure 12: Choose electrical topology and distribution

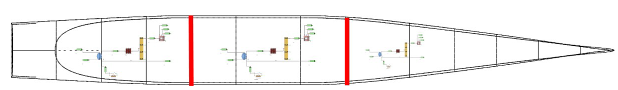

Figure 13: Arrange power distribution templates

6.3.2 Machinery Module (Mechanical) Example

This example shows a direct mechanical-drive propulsion train, including power transmission using gas-turbine engines and a dual-shaft configuration. Three main templates are employed: a propulsor template for each shaft, a shafting template for each shaft, and a power transmission template applied to each engine room.

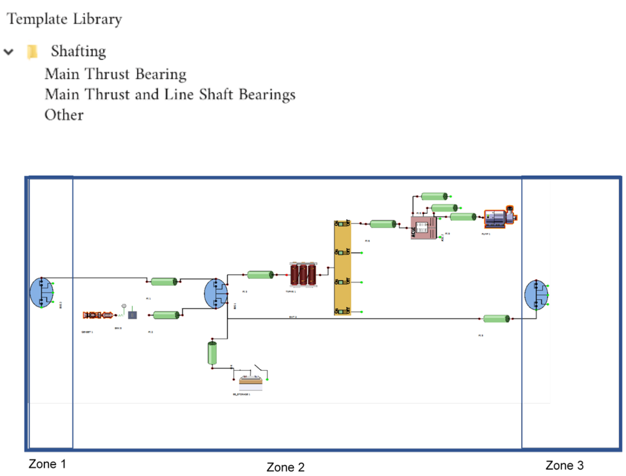

Figure 14. Full electrical methodology

The propulsor template, shown in Figure 15, includes a propeller and shafting to transfer torque to rotate the propeller. The propulsion train is designed based on the propulsor, so this design decision must be chosen first.

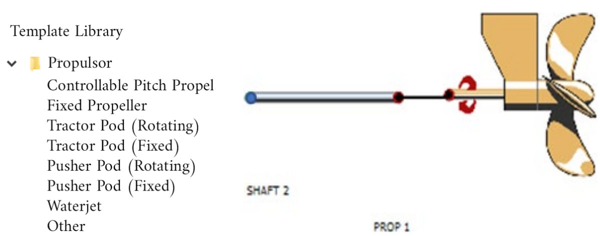

Figure 15. Propulsor template.

For this specific template, space arrangements are not required. However, propulsor properties can be modified if necessary. Figure 16 shows the properties that can be modified for propulsors in S3D. The shaft component can also be selected, and properties changed, if the user desires. As in the electrical distribution methodology, the user sets the rated mechanical power and speed for sources and propulsors, but rated mechanical power for shafts is set automatically.

The shafting template, shown in Figure 17, includes shafting to be sized and distributed throughout the propulsion spaces and bearings to support shaft axial thrust both horizontally and vertically. This template is applied according to the number of shafts in the propulsion train configuration.

Prior to placing the shafting template into the ship design, equipment selections and property modifications can be accomplished for any of the components in the template.

The shafting template is assigned to each main engine room, as shown in Figure 18.

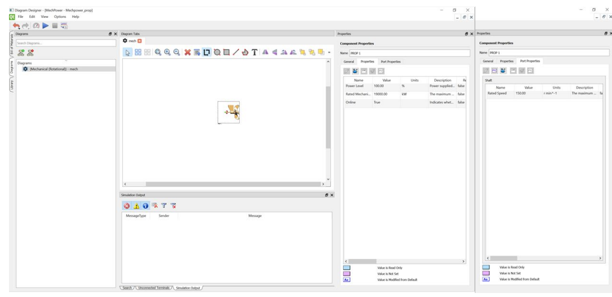

Figure 16. Choose propulsor properties

Figure 17. Shafting template.

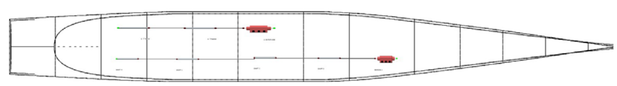

Figure 18. Arrange shafting template.

Lastly, the propulsion power template, shown in Figure 19, includes shafting to be sized and distributed throughout the propulsion spaces, reduction gear to reduce the speed transmitted by the engine(s) and increase torque, the propulsion set for power generation, and three auxiliary pumps as required. This template is also applied according to the number of shafts in the propulsion train configuration. The power transmission template has a mathematical representation in both the mechanical and electrical domains. The mechanical domain is shown in the yellow box, and the electrical domain is shown in the light blue box.

Prior to placing the propulsion power template into the ship design, equipment selections and property modifications can be accomplished for any of the components in the template. The reduction gear component is unique because, unlike other connecting gear, it is not automatically sized and does require user input.

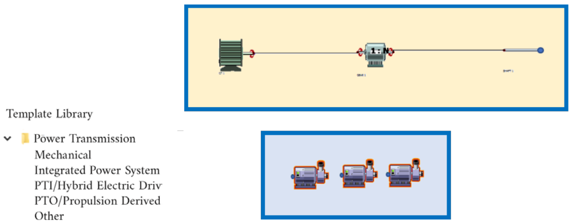

Figure 19: Propulsion power template. The yellow box at the top indicates the mechanical domain equipment and the light blue box at the bottom represents the electrical domain.

The final arrangement of the propulsion power template is placed in each main engine room, as depicted in Figure 20. Figure 21 depicts a compilation of all three templates for a single shaft.

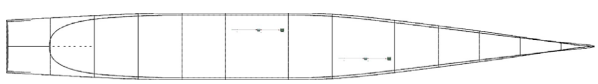

Figure 20. Arrange power transmission template.

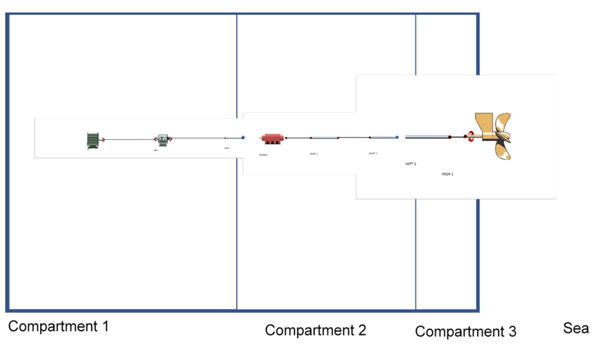

Figure 21. Single shaft example.

7 Design Exploration Generator

The RSDE software currently includes "The Design Exploration Tool: Full Ship Study Generator," which allows the user to create multiple ship studies by changing designated technical parameters. The proposed process uses templates as the baseline for design variation, thus enabling system-level changes to be incorporated in a design space exploration.

To use the Study Generator as currently implemented, a baseline ship is created in RSDE. Each module's minimum required entries/inputs are met, and the model is converged to a single ship concept. Then, the user selects specific properties of the baseline ship for modification, either with specific new values or by sweeping a range of values. The Study Generator automatically creates and analyzes multiple new ship concepts within a given study, using combinations of the new properties selected for modification; this can result in hundreds or thousands of unique ship designs. Results can be viewed using the LEAPS Data Export Application tool and explored using statistical software.

Adding templating to the Study Generator methodology enables the following expansion of capabilities:

- Replace a chosen template with a different template in its entirety.
- Replace a component within a template with a different component.
- Modify a component property, providing a new value or range of values.

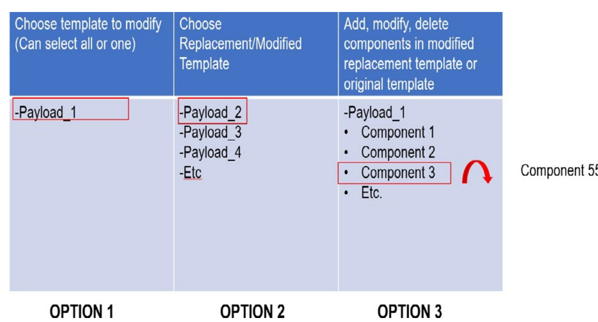

Figure 22: Proposed Full Ship Generator interface. In this example, the user has chosen to replace the "Payload 1" template with the "Payload 2" template, and within the Payload 2 template, has replaced Component 3 with Component 55.

A possible interface for implementing templating in the Study Generator is shown in Figure 22. In the first (left-hand) column, the user selects the appropriate template to be modified or replaced from a list of templates currently used in the ship concept. The second (center) column allows the user to choose a pre-generated replacement template or modify the template used in the ship concept. The third (right-hand) column allows the user to add, modify, or delete components in the original template (chosen in the first column) or a modified/replacement template (chosen in the second column). Columns 2 or 3 can be bypassed if they are not required.

The Study Generator can then be run with the appropriate changes selected. Both the feasible and in-feasible template combinations can be viewed using the data export capability. The end-state user can filter the appropriate combinations according to design intentions.

The new methodology implements the usage of three different generators, revamping the existing P&A Generator and introducing two new generators for the Machinery Module:

1. P&A Generator
2. Machinery Module (Electrical) Generator
3. Machinery Module (Mechanical) Generator

8 Future Work

Overall, there is pending work and integration required to ensure that this methodology is appropriately integrated using model-based methods for system engineering and is useful to support design maturation and testing. The sections below detail the necessary work to improve this methodology and meet the demands of each use case in full.

8.1 Report Generation

S3D's analysis tool and the processes augmented by this methodology can generate all of the data to create reports that the current Machinery Module can except:

1) Operating and configuration conditions, and

2) Air conditioning and associated load by operating condition. Processes to calculate the data required for these two reports must be accomplished as future work.

8.2 Navy Design Tools

S3D is currently a stand-alone program that uses the LEAPS data repository. To implement the envisioned changes, S3D should be fully integrated into RSDE, so its functionality is available within the RSDE environment.

S3D is designed to be fully integrated with Navy design tools and programs. Therefore, all components must be fully compliant with the FOCUS meta-model. In some cases, this requires expansion of the properties available in FOCUS. FOCUS-compliance for all components is ongoing work by NSWCCD.

As LEAPS 6.0 undergoes development, some pending changes enhance this methodology, ensuring proper three-dimensional arrangements and sufficient weight calculations by SWBS group. One advance scheduled in LEAPS 6.0 is the addition of component-owned placement points. A placement point includes a three-dimensional location and orientation. Attaching a placement point to a component allows the user to orient components adjacent to other LEAPS objects without prior knowledge of that object's center of gravity, assisting component orientation in three-dimensional space [14].

8.3 S3D

Another important step is to ensure that the appropriate required functionalities are transitioned from an older version of S3D. Specifically, the "replace component" feature, which allows the selection of a new component to replace an existing component in a design, is required to implement this methodology.

For the proposed methodology, it is assumed that sizing algorithms are developed to appropriately determine components' dimensions and weight in response to the maximum flow algorithms [3]. Further, the maximum flow algorithm is currently only developed for electrical systems; similar algorithms are required for other domains.

Although it is possible to model operational configurations in S3D to determine performance in various operational conditions, it is not easily achievable in an automated manner, thus making it infeasible for inclusion in a RSDE study. It is important to develop a methodology to meet operational configuration requirements for future growth.

Being able to model these operational configuration requirements in conjunction with using High-Performance Computing for operational parameter-related sweeping developed by researchers at Mississippi State University (MSU) can expand the tradespace exploration even further [4].

8.4 Template Positioning Algorithms

RSDE defines an assembly as a full system, i.e., the full propulsion train or the electrical system generators. RSDE assembly calculations can be used to position a full assembly in two-dimensional space i.e., longitudinally and transversely. However, RSDE assembly calculations do not address three-dimensional spatial concerns and cannot adjust equipment within the assembly for optimum placement in response to other modifications made to the ship during design space exploration. Additional methods can be implemented to augment, improve, and/or eventually replace the current calculations.

A directed graph algorithm was developed to arrange components in three-dimensional space within a ship subdivision (zone, compartment, etc.), arrange components relative to fixed components, and resolve overlaps among components, including respecting maintenance area and clearance requirements [7]. This functionality would expand the component positioning functionality currently available in RSDE.

8.5 Additional Component Creation

Additional FOCUS-compliant components must be created to represent current weapons systems and sensors, including remote and local control systems (i.e., Combat Information Center consoles, etc.). Expanded options for propulsors, shafting, and reduction gears are also needed to meet the current functionality available in the RSDE Machinery Module. Further, additional properties for existing propulsor and reduction gear components are required. A full list of additional components and properties is provided in [10].

Additional components must also be created to represent electrical and cooling loads that are not considered a "large load", i.e., the mission loads in the P&A table that account for the top 20% of cooling and electrical loading. These components could be modeled using proxy components that represent many loads in a single component.

9 Conclusions

This paper presents a methodology for incorporating templates into the Navy's Rapid Ship Design Environment, specifically addressing the following use cases:

1. Replacing the Payload and Adjustments Table
2. Replacing the Machinery Module
3. Revamping the Full Ship Study Generator to accommodate templating

The methodology meets the vast majority of the demands requested by each stakeholder and technical warrant holder. A few remaining items are identified as future work.

The templating tool is a key advance, making the detailed system design and analysis capabilities of S3D accessible in a broad design space exploration accomplished through RSDE. The methodology presented in this paper demonstrates a clear path to incorporating the flexibility and detail needed to design new ship systems and paradigms while maintaining the current ease of use in the familiar RSDE tool.

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LT Natasha Patterson, USN, is a recent graduate of the Massachusetts Institute of Technology, with a Master's degree in Mechanical Engineering and Naval Architecture. She will be returning to the Fleet as a Surface Warfare Officer, Department Head.

Dr. Julie Chalfant, Ph.D., is a research scientist at MIT Sea Grant. Her current areas of research include ship design and integration, including early-stage ship design tools and power and cooling systems. As a former active duty officer in the U.S. Navy, she also has significant experience in operating and maintaining Navy ships.