

Integration of System Templating into the Rapid Ship Design Environment

by

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B.S. in Mathematics, United States Naval Academy (2015)

Submitted to the Department of Mechanical Engineering
in partial fulfillment of the requirements for the degrees of
Master of Science in Naval Architecture Marine Engineering
and

Master of Science in Mechanical Engineering

at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

May 2022

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Abstract

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. In recognition of this, the U.S. Navy has recently worked with the Electric Ship Research and Development Consortium to develop Smart Ship Systems Design (S3D), a ship system design software environment fully integrated with the Navy's early-stage ship design toolkit. In addition, the associated templating process provides a level of automation to system design, thus providing a capability for the design and analysis of ship systems much earlier in the design process than was previously possible.

Research and an experimental study were performed to construct a flexible, user-friendly methodology that integrates S3D and its templating tools into the Navy's Rapid Ship Design Environment (RSDE). This project establishes specified use cases and examples that demonstrate this implementation. The use cases represent common functions that RSDE users seek to implement in the ship design process. The targeted use cases include mission system, propulsion train and electrical system design, and associated full ship studies for design exploration. This research is pivotal to the design process and allows common systems and/or plant configurations to be accessible in a familiar format.

To develop this methodology and implement S3D templating in future projects, the methods, steps, and tools used are recorded and analyzed with feedback from various end-state users and technical experts.

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Acknowledgments

First and foremost, I would like to thank my advisors: Dr. Julie Chalfant and Professor Michael Triantafyllou. Dr. Julie Chalfant, none of this would be possible without your guidance, ingenuity, approachability, and sheer kindness. You are a wealth of knowledge, and it has been a pleasure to work with you. Professor Triantafyllou, thank you for your candid, timely, and helpful feedback. Your flexible leadership style allowed me to curate my path, and I am forever grateful for this opportunity. Thank you both for your unwavering support and challenging me throughout my research.

I sincerely appreciate the technical warrant holders at Naval Surface Warfare Center Carderock, specifically Dr. Norbert Doerry, Dr. Alex Gray, and Dr. Mark Parsons. Your support, consistent feedback, and willingness to help gave me the direction to define this research topic.

I extend a special thanks to the Center for Innovative Ship Design (CISD) students, graduates, and leadership. Thank you, Anthony Madalena and Michael Bosworth, for facilitating a means to garner the stakeholder perspective.

Thank you to all the key players involved in S3D program design, specifically Rich Smart. You helped establish my thorough baseline knowledge and answered every tedious question without judgment. I am incredibly appreciative of your support to complete this body of work.

I am deeply grateful for my cohorts and Professors in the Naval Construction and Engineering (2N) Program. You all have been pivotal in providing valuable friendships, encouragement, support, and professional/academic feedback throughout my time at MIT.

To my parents, thank you for everything. I love you both beyond words.

And last but certainly not least, Kevyn. You are my rock. I am forever indebted to you for your love, encouragement, patience, and support throughout this graduate program. Thank you and I love you.

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Chapter 1

Introduction and Motivation

This work is motivated by the United States Navy’s necessity of tradespace exploration requirements in a simulated environment in the early stages of the design process. Traditionally, the Navy operated under a Point Based Design (PBD) system, which commits a project to a single design strategy early. PBD delineates a problem leading to the brainstorming of various alternatives, subsequent narrowing of alternatives to a single concept, and repeating until the final design is reached [18, p. 5]. As technology advances rapidly and becomes more complex, the PBD tactic is inefficient and rather time-consuming as a sole design technique as Figure 1-1 depicts. One primary downfall of the PBD approach: budget approval and allocation in conjunction with design research and development timelines lead to outdated and technologically obsolete systems onboard Navy vessels.

In the past 15 years, the Navy adopted the Set Based Design (SBD) method, also referred to as concurrent engineering, popularized by the commercial sector. This methodology allows for more flexibility and open aperture for design related decisions without delaying the overall process, allowing for timelier, consistent deliveries [18, p. 2]. SBD more accurately approximates cost and increases the knowledge base by maintaining tradespace analysis for future reference [18, p. 8-11]. Specifically, the Set Based Design logic is highly applicable in the Preliminary Design phase during the Analysis of Alternatives (AoA) section as highlighted in Figure 1-2 [18, p. 1]. The Navy’s use of SBD continues to adhere to typical design procedures that begin with

<u>Task</u>	<u>Point Based Design</u>	<u>Set Based Design</u>
Search: How to find solutions.	Iterate an existing idea by modifying it to achieve objectives and improve performance. Brainstorm new ideas	Define a feasible design space, then constrict it by removing regions where solutions are proven to be inferior
Communication: Which ideas are communicated	Communicate the best idea.	Communicate sets of possibilities that are not Pareto dominated.
Integration: How to integrate the system	Provide teams design budgets and constraints. If a team can't meet budget or constraints, reallocate to other teams	Look for intersections that meet total system requirements.
Selection: How to identify best idea.	Formal schemes for selecting the best alternative. Simulate or make prototypes to confirm that the solution works	Design alternatives in parallel. Eliminate those proven inferior to others. Use low cost tests to prove infeasibility or identify Pareto dominance
Optimization: How to optimize the design	Analyze and test the design. Modify the design to achieve objectives and improve performance.	Design alternatives in parallel. Eliminate those proven inferior to others.
Specification: How to constrain others with respect to your subsystem design?	Maximize constraints in specifications to assure functionality and interface fit.	Use minimum control specifications to allow optimization and mutual adjustment.
Decision Risk Control: How to minimize risk of "going down the wrong path?"	Establish feedback channels. Communicate often. Respond quickly to changes.	Establish feasibility before commitment. Pursue options in parallel. Seek solutions robust to physical, market, and design variations.
Risk control: How to minimize damage from unreliable communications; how to control communications	Establish feedback channels. Communicate often. Respond quickly to changes. Review designs and manage information at transition points.	Stay within sets once committed. Manage uncertainty at process gates.

Figure 1-1: Comparison of Point Based Design and Set Based Design [18, p. 7]
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determining the design space; however, this approach seeks to “optimize a design and establish feasibility before commitment” [18, p. 11].

Generally, modeling is one way to pre-determine management of budget and duration of a project and demonstrate tradeoffs [8, p. 3]. In the past, the Navy placed a large emphasis on modeling from the naval architecture perspective. For several decades, various programs have existed that demonstrate model design via computer-aided design (CAD) and verify structural soundness and stability. These programs are not limited to, but include Rhinoceros 3D, Program of Ship Salvage En-

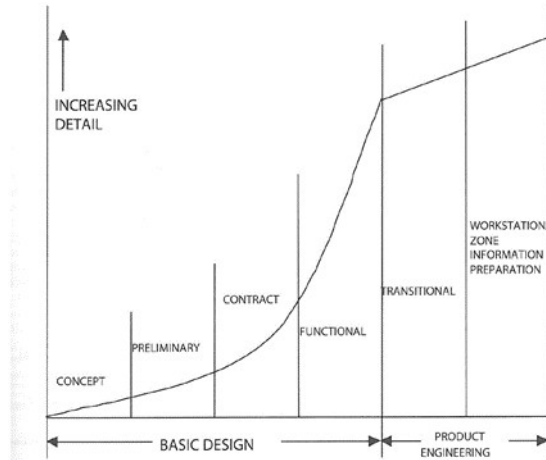


Figure 1-3: Ship Design Phases [14]

Originally presented in Ship Design and Construction Vol. I, 2003. Reprinted with the permission of the Society of Naval Architects and Marine Engineers (SNAME).

The design tools/programs and associated databases this research focuses on are ASSET/RSDE, Leading Edge Architecture for Prototyping Systems (LEAPS), Formal Object Classification for Understanding Ships (FOCUS), and Smart Ship System Design (S3D). The graphic below, Figure 1-4, is a visual representation of the interaction of these databases and tools, which are explored in future sections. Section 1.1 details the architecture of LEAPS and its instrumental role for data storage as well as its interaction with each tool. Section 1.2 specifies the FOCUS utility and the implications of FOCUS compliant components in each design tool. Section 1.3 introduces the capabilities of ASSET/RSDE in the design process. Section 1.4 presents the S3D program as a whole, listing its capabilities, current limitations, and how to manipulate it generally. This section also introduces the “templating” code addition to the S3D program to be expounded upon further in Chapter 2.

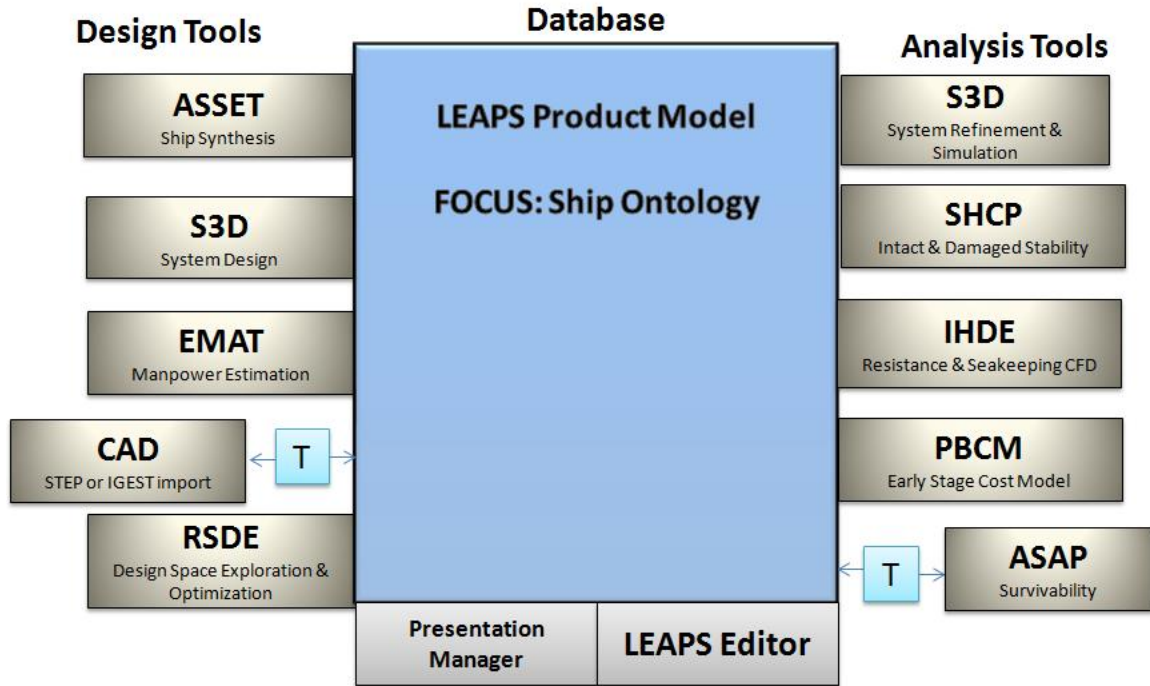


Figure 1-4: Design Tools, Database, and Analysis Tools Interaction Visual [17, p. 6]
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1.1 Leading Edge Architecture for Prototyping Systems (LEAPS)

LEAPS is a data repository for virtual prototyping that acts as the metaphorical “glue” for S3D and ASSET/RSDE. It is maintained by Naval Surface Warfare Center Carderock Division (NSWCCD). Additionally, LEAPS provides a framework for manipulating the data contained in the repository. The primary utilities within that toolkit that this project utilizes are the LEAPS Editor and Database Utilities.

The database is both advantageous and useful because it creates a single file format that maintains all relevant information to a ship. In addition, it is compatible with many of the Navy’s ship design and analysis tools for CAD, structures and computational fluid dynamics (CFD) as shown in Figure 1-4. Therefore, anything stored in this database is translatable and interpretable across various programs and

platforms.

1.2 Formal Object Classification for Understanding Ships (FOCUS)

Set specifications for individual components can be stored in the LEAPS database. If the schema follows certain properties, identifiers, and semantics, then the object is considered to be FOCUS compliant [2].

The stored ship ontology and overall standardization, serving as a product metamodel for ships, are also translatable across various design tools. Compliance with the product metamodel ensures that data created or modified by one design tool is usable by other FOCUS-compliant tools.

For this research, FOCUS-compliance can be applied to the naval architecture-based ship design tools: Rapid Ship Design Environment (RSDE)/Advanced Ship and Submarine Evaluation Tool (ASSET), Smart Ship Systems Design (S3D), and the System Builder software.

1.3 Advanced Ship and Submarine Evaluation Tool (ASSET)/Rapid Ship Design Environment (RSDE)

The naval architect design segment primarily uses ASSET and RSDE. In recent years, these two have been combined such that RSDE, the overarching tool, operates using the model structure created in the ASSET domain. Sections 1.3.1 and 1.3.2 explain in depth the difference between the two tools and the components that comprise each tool.

1.3.1 Advanced Ship and Submarine Evaluation Tool (ASSET)

ASSET is a sub-tool of RSDE created by Naval Surface Warfare Center Carderock primarily used to create three-dimensional ship and submarine models for performance assessment. ASSET assimilates various engineering plant systems (i.e., propulsion, electrical, and auxiliary), hullform, structures, and appendages to demonstrate performance relative to speed, range, efficiency, intact and damaged stability, seakeeping, etc., and subsequently, ship performance based on inputted characteristics.

ASSET Editor is a key subcomponent of the overarching tool that contains many of the wizards and modules required to define ship parameters through modification of existing hullforms and arranging equipment throughout the model [13, p. 19]. Another key aspect of this tool is the Synthesis segment which compiles all the outputs/reports from each sector within ASSET for “feasibility” purposes [13, p. 19].

ASSET and S3D are linked through the LEAPS database illustrated in 1.1.

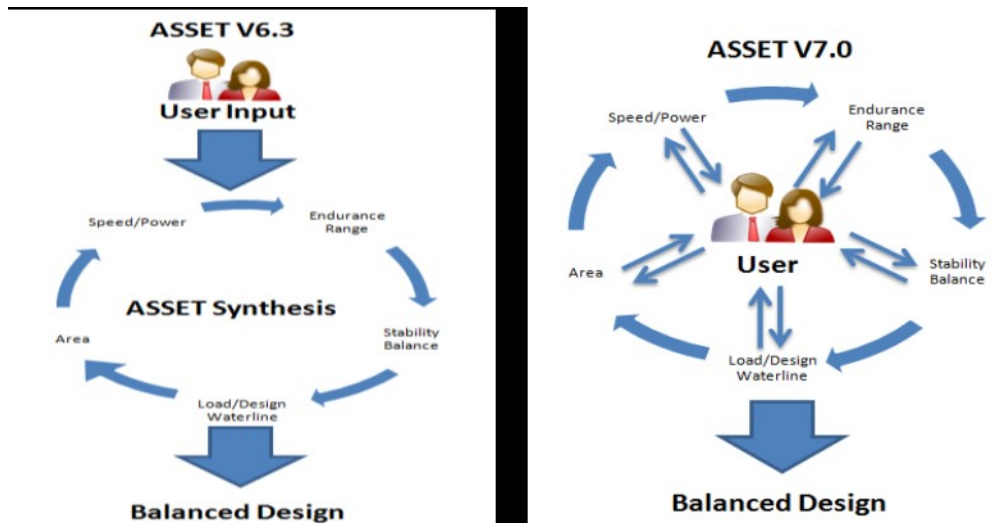


Figure 1-5: ASSET Version Comparison [17, p. 8]

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1.3.2 Rapid Ship Design Environment (RSDE)

RSDE was developed specifically for design space optimization and assessment. As previously explained in 1.3.1, ASSET creates the model itself and the Synthesis utility is applied for feasibility determination [13, p. 19]. The ASSET model becomes the input for RSDE calculations. RSDE outputs are a combination of demonstrative computational analysis and associated model modifications of the design space as Figure 1-6 depicts. As Rigterink et al. write in their discussion of this program, “RSDE facilitates design space exploration (DSE) through the use of Design of Experiments (DoE). DoE is the formal strategy of developing a collection of experiments in which a set of design variables are varied systematically. The purpose of which is to predict, and discover, the relationships between design variables and responses” [17, p. 8]. In the operation of this program, the number of designs to create are requested via Latin hypercube sampling or points [17, p. 8].

RSDE also utilizes the LEAPS database for storage. Similar to the procedure that is described in Section 1.3.1 for ASSET, any ship model modifications are applied using the ASSET tool and/or S3D and the associated templates. Upon completion of ship design modifications, the user can run analyses using relevant tools such as Ship Hull Characteristics Program LEAPS (SHCP-L) for stability analysis and Integrated Hydrodynamic Design Environment (IHDE) for hydrodynamic calculations. The data from these analyses are stored in LEAPS.

1.4 Smart Ship Systems Design (S3D)

The Electric Ship Research and Development Consortium (ESRDC), in conjunction with the Office of Naval Research (ONR) and Naval Surface Warfare Center Carderock Division, developed a software tool for ship design called Smart Ship Systems Design (S3D). This tool demonstrates thermal (air or liquid cooling), electrical, and mechanical domain simulations and analysis and equipment arrangement in a 3-D space [17, p. 4]. The Smart Ship Systems Design program allows the Navy to construct, analyze, and simulate various individual and integrated systems and components at an early

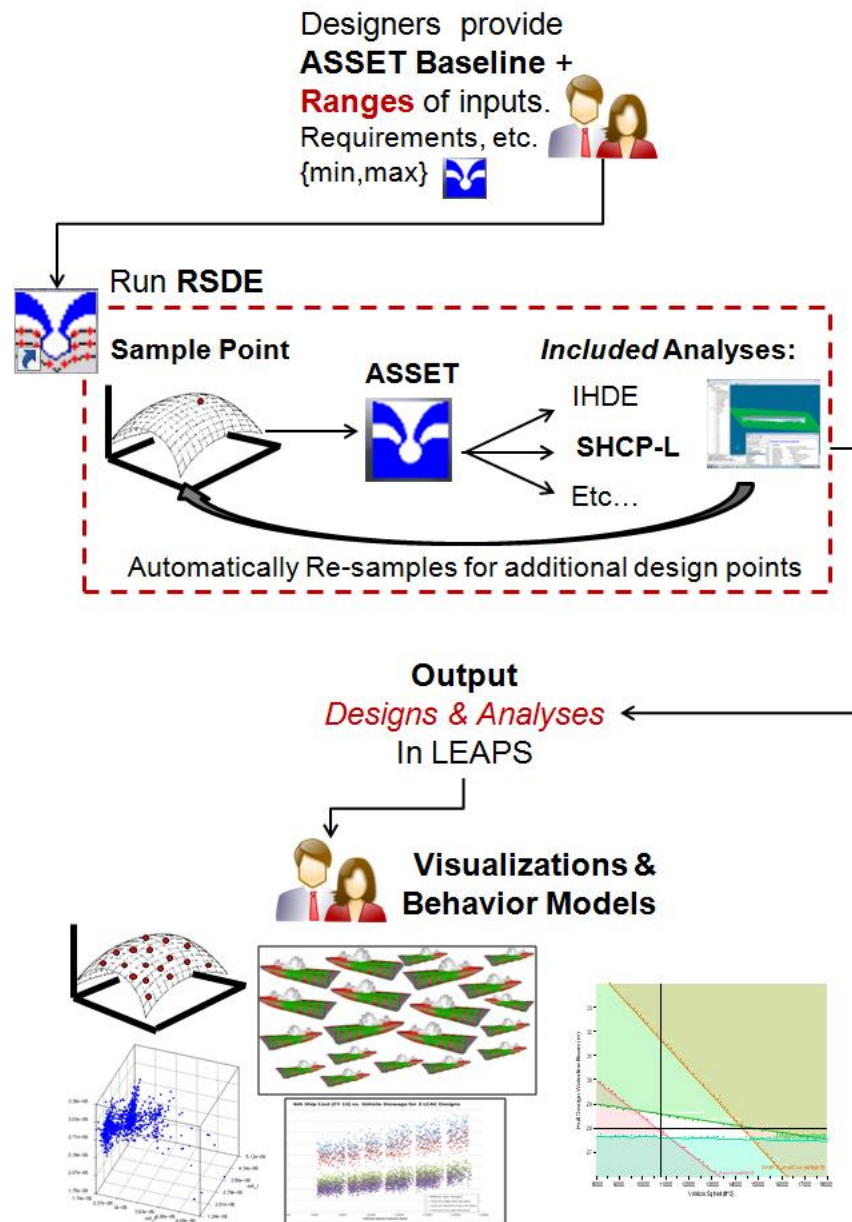


Figure 1-6: RSDE Operation [17, p. 9] (Reproduced with permission from the American Society of Naval Engineers)

design stage utilizing computer aid design (CAD) and other resources. The development of S3D aims to integrate with legacy design tools; the specific one that this research explores is ASSET/RSDE [19, p. 1]. Beyond that, the “vision for S3D has always contained the concept of expanding the capability to include an automated, user-directed process in which multiple systems can be created, adapted to different hullforms, simulated, and analyzed” [16, p. 1].

Creating systems within the S3D program has several defined steps. In general, the first step is ensuring all applicable components are available for manipulation in the S3D graphical user interface (GUI). This GUI can be divided into electrical, mechanical, and thermal domains. The individual components required for system construction are in a library associated with S3D or can be created using the entity designer in S3D. Whether the components are recently developed in the Editor or imported from the database, if they are considered “notional components” then certain component properties can be parametrized with new values [17, p. 5]. For “actual components,” those that mirror specified values of real system components, these values are pre-determined [17, p. 5]. Once all of the system components, whether notional or actual, are placed in the GUI section, the next step is to connect them. These connections are depicted in a one-line diagram in the appropriate domain(s); one component may appear in multiple domains if it can be represented across multiple domains. A technical architecture can describe the compilation of required components for a particular system, the appropriate associated linkages, and connections. The next step is to conduct the analysis and simulation of this connected system. More information regarding system analysis outputs organized by domain can be found in Appendix A. Finally, with the current version of S3D, the last step is to integrate this constructed system into a ship model created within ASSET/RSDE.

While S3D provides a leap forward in the capability to model and simulate the structure and performance of ship systems, the current implementation is labor-intensive. A new methodology, termed “templating,” is being explored to bring more automation to the system design process. In general, templating allows the construction of full ship systems through the reuse of pre-designed portions of systems

modified to meet the specifications of the new ship design. Templating is described in more detail in Chapter 2, Section 2.1.

Chapter 2

Templating Overview

2.1 Templating

Templating is a process that instantiates and combines pre-designed systems or segments of systems within a virtual prototype to create fully-implemented ship system designs. These templates are interchangeable, for removal and replacement, during early design stages. This tool is a key element that allows the integration of S3D into RSDE viable. The procedure is relatively simple once the user runs the S3D version with templating implemented. Each template is initially constructed in S3D, and the creation procedure is exactly like the detailed steps for system development mentioned in 1.4. Within the S3D program, these components can be interconnected to create systems or sub-systems, compiled, and saved within the LEAPS database as a template. The stored templates can be saved with set specifications in a Formal Object Classification for Understanding Ships (FOCUS) compliant manner, used in various tools including naval architecture-based ship design tools like Rapid Ship Design Environment (RSDE)/Advanced Ship and Submarine Evaluation Tool (ASSET). As discussed in 1.4, the final step is to place the system, or interconnected templates, in their appropriate three-dimensional position in the ship model.

Templating brings several advantages to the ship design process. The primary advantage is the tool's efficiency in saving time by providing a better automation method. As mentioned in the previous section, the fully manual process of creating

each of these systems is very time-consuming. Another benefit is that these templates are reusable, scalable, or integrated with other templates/systems for various hull-forms. Lastly, templating allows individual system experts to construct an accurate model to integrate with other systems and subsequently the holistic design. Templating is the key tool employed in this research to connect the developed systems and ASSET/RSDE. The overall goal and most important advantage of templating is to utilize a known pattern and specified technical architecture that can be applied universally.

From a design standpoint, this tool allows the flexibility to create several patterns and systems to demonstrate the various design space options available in a simulation and analysis environment. These templates are created and stored, which can then be used for future projects in ship design. This approach combines concurrent engineering/set-based design, computer-aided design modeling and analysis, and known components with set specifications. This process ultimately helps narrow the design tradespace in preliminary design stages by simplifying the system design process and providing design flexibility to accurately assess cost and design requirements while integrating with the requisite naval architecture stability and structure elements of design.

As expressed, templating is a tool within S3D that introduces a more efficient, automated method to design systems utilizing Set Based Design theory. This chapter describes templating in greater detail. Section 2.2 identifies key terms unique to the creation of a template. Section 2.3 specifies various approaches for template application. Section 2.4 describes the process and characteristics associated with templating. Section 2.5 highlights the steps required to implement templating onto a ship concept.

2.2 Definitions

Several terms are unique to the location, storage, and arrangement of template-related data. The following definitions are discussed in relation to templates. Figure 2-1

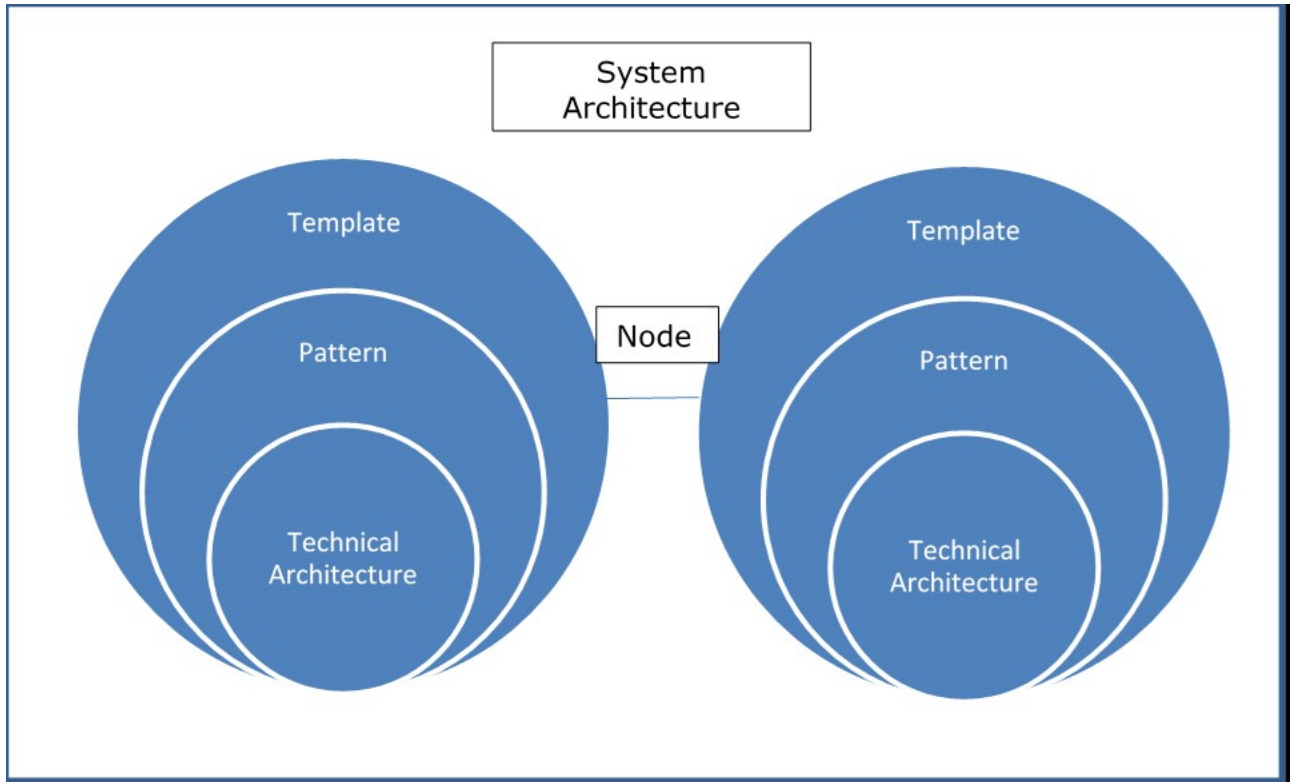


Figure 2-1: System Architecture Depiction

illustrates what defines a system architecture except for spatial requirements.

2.2.1 Patterns

A pattern is the basis of a template. Patterns drive system design by outlining the necessary parameters, components, and subsequent connectivity; this is explained in section 2.1.3 as a technical architecture. Once a pattern is fully connected and stored within the LEAPS database, it becomes a template [3, p. 1]. The naming convention within LEAPS is clarified in Section 2.2.5.

2.2.2 Template

A template combines pre-designed components, systems, or system segments within a virtual prototype.

2.2.3 Technical Architecture

In Section 2.2.1, the term technical architecture is vaguely described as a major component of a pattern. Technical architecture is a blueprint for a particular system, including the topology of the system (i.e., components and their interconnection/arrangement) [3, p. 3]. A technical architecture, which leads to creating a pattern, and its storage in LEAPS are the basis of a template.

2.2.4 System Architecture

A system architecture is the compilation of multiple templates and includes their collective spatial orientation on the ship. The compilation of these templates forms a system. Their associated, combined technical architectures are collectively known as the system architecture.

2.2.5 Concept

Concepts are classified within the LEAPS database and comprise all of the required objects for a system. Concepts contain geometry, systems, components, connections, and properties; they contain all the information for an individual design.

Ship Concept

Ship concepts are LEAPS concepts, as explicated above, that templates (or template concepts which will be spelled out below) are copied into [3, p. 4].

Template Concept

This definition is semantic because templates are stored as concepts in the LEAPS database; therefore, templates and template concepts can be used interchangeably when referring to their storage location [3, p. 4].

2.2.6 Distribution Components

Distribution components are the apparatuses that interconnect system components; typically, this refers to apparatuses that might extend across bulkhead and deck boundaries. Examples of these components include cables, pipes, and shafts [3, p. 4]. These components are scalable in the length direction.

2.3 Current Applications

This section provides an overview of the different approaches which are automated upon completion of templating construction. The process of construction is outlined in more detail in Section 2.4. Utilizing the definitions that are explained in Sections 2.2.1-2.2.5, once the technical architecture and subsequent patterns are determined as preliminary design requirements, a template is formed. Several templates can be formed using the same procedure, and then those templates can be amalgamated to create an overall system. Upon system construction, the template can be copied into the ship database and effectively placed in the ship design, which is explained further in Section 2.5. The current infrastructure allows template manipulation by copying a template to a ship. The “copy template to ship” function subsequently copies all existing components and their relationships to other components (i.e., connections), systems, and common view diagrams. Within the “copy” function, there are three ways to implement these templates: 1) “copy,” 2) “assign,” and 3) “scale.” “Copy” can either establish a bounding box of the geometry (except for distribution components as defined above) or impose the geometry itself. “Assign” places the template in the appropriate ship subdivision of either a compartment, hull, or zone. Finally, “scale” enlarges or reduces the size of the template within the appropriate ship subdivision as mentioned previously in the “assign” function.

Additional operations can be used with templates, including the “copy component” function, which allows single components to be copied, “remove component and associated template”, or a traditional “undo”, and “replace component with template.” The latter two are self-explanatory in name and illuminate their expected operation.

An alternative function is to use the system created by the template to size system components appropriately. One method that has already been explored is the maximum flow algorithm that resolves each component’s capacity requirements. However, this algorithm can only be used on a “fully connected system” and it outputs measurements like “rated power, voltage, temperature, and flow rate” [3, p. 10]. In a quick summary, this procedure calculates all of the permutations of all possible component positions and system alignments. It minimizes the associated output measurement by providing the “shortest path” version of the output [3, p. 5]. Therefore, a minimalized approximation can be made in early design stages surrounding simulated capacity requirements.

Finally, the last application is to determine the physical location of each component and further resolve positional conflict [11]. As this research work describes, subdivision blocks can be uniquely crafted to break individual compartments into rectangular prisms. These blocks can then be stored in the LEAPS database into the overall ship concept and represented in the 3D ship design. A single component can be placed in a specified subdivision block and thus represented in the overall ship concept, creating an automated method for positioning specific components.

2.4 Process of Construction

In general, the steps for creating a template are introduced in Sections 1.4 and 2.1 directly. Constructing a template is the most tedious step; each component must be manually connected to other components within the S3D GUI for the appropriate domain. With the additional tools that are available in the templating tool, as one would expect, the most efficient way to construct a system is to design the simplest/smallest repeatable subsection of a system and implement the appropriate function (as outlined in Section 2.3 above).

2.4.1 Characteristics

Some template characteristics require user input when constructed. These characteristics are briefly expounded upon in the following subsections of Section 2.4.1. All of the characteristics below are directly reflected whenever a template is placed in a ship concept or copied into another template (making use of the various approaches outlined in Section 2.3) [3, p. 5].

Template Instantiation Number

As Section 2.3 describes, the same template can be copied multiple times. An instantiation number is associated with a particular template to identify the number of times it has been copied. This association is denoted as “template name_0000001”, where the instantiation number is “0000001” and “template name” is generically used in this example.

Template Identifier

Using the example from 2.4.1, the “template name” portion of “template name_0000001” is referred to as the template identifier. The user typically chooses this name as a familiar reference describing what the template is comprised of or designed to represent.

Template Dimensions

In Section 2.3, the scaling function is introduced. To properly size the template within the bounds of a compartment, zone, or hull, the associated length, width, and height of that template must be established. As such, the following terms are utilized to reflect the properties mentioned above: overall template length (length), overall template breadth (width), and overall template depth (height).

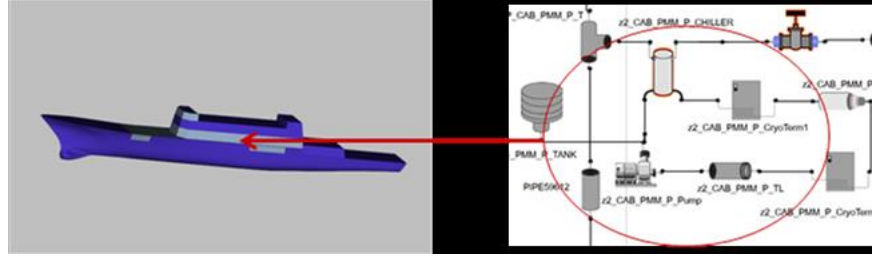


Figure 2-2: Ship and System Representation [3, p. 14]

2.4.2 Template Node

Templates can be joined to other templates via connections called "template nodes." A single template can have multiple nodal connections, and each nodal connection can refer to a different domain (thermal, mechanical, or electrical) [3, p. 2].

Template Node Type Identifier

In Section 2.2.2 the term template node is described. Each node has an associated identifier that specifies the domain (thermal, electrical, or mechanical) it serves. This identifier is referred to as the node type identifier.

Template Node Descriptive Name

The user must designate a name associated with the purpose of a template node. Section 2.4.1 establishes that a template identifier denotes the node with its appropriate domain, but system complexity and the number of nodes associated with a template dictate the necessity for further identification [3, p. 7]. Thus, template node descriptive names meet that need.

Template Node Plug Direction

Each node also has a "plug direction," where the plug refers to the connection between two templates. These plug directions, in conjunction with the descriptive names, help the user determine the "proper connections" and are paired "forward-aft, up-down, port-starboard, inboard-outboard, and intoAggregate-outOfAggregate" [3, p. 8]. Of note, this list of coded pairs can be expanded as required.

2.5 Ship Implementation

Translating a system to a ship requires compiling multiple templates onto a ship design concept. This process is accomplished through inputting data characteristics into the LEAPS repository and utilizing the templating tool functions described in Section 2.3. Within the LEAPS repository, the characteristics mentioned above are defined, namely the template node type, template node descriptive name, and the plug direction (Sections 2.4.2-2.4.2). Defining these characteristics allows the template nodes to be manipulated and appropriately configured and then connected to other templates. In Section 2.2.5, concepts are introduced where Section 2.2.5 defines ship concepts and 2.2.5 defines template concepts. As a reminder, concepts are simply the naming convention denoting the compilation of all ship components or a template stored in LEAPS. Once a template is built, the template concept is stored in the LEAPS database.

The following steps denote how to translate an S3D template into a ship concept using code [3, p. 8-9]:

1. Open both ship and template databases, selecting the appropriate template and ship concepts.
2. Select the location on the ship to place the template.

These locations are broken down into the ship subdivisions mentioned earlier: compartment, zone, or hull. For clarification, a zone is defined as a "geographic region of the ship," typically confined within watertight bulkheads, but can "span multiple watertight divisions" if necessary therefore increasing survivability) [9].

If the user does not select a location, then the default location is the original template specified location.

Chapter 3

Problem Description and Use Cases

Chapter 3 describes specific RSDE use cases that this methodology seeks to satisfy. The coupling of S3D's capabilities with templating methodologies enhances RSDE's ship design relevance without significant program code updates while enhancing tradespace exploration in early-stage design.

Much of ASSET is regression-based, utilizing historical or parametric data as the basis for its calculations and algorithms. This makes it difficult to assess new technologies or design concepts without a significant amount of tedious calculations by the user. The primary goal of implementing templating in RSDE is to automate and enable the assessment of new design concepts and technologies in any domain.

This goal segues several use cases for template application in early-stage ship design; three specific cases are described below.

3.1 Payloads and Adjustments Table Capabilities and Limitations

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. This table accounts for significant electrical and/or cooling loads, weights, and volumes which are neither modeled nor accounted for in other RSDE modules.

One significant drawback of the current model is that the equipment listed in the table is not represented 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.

3.2 Machinery Module Capabilities and Limitations

ASSET 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 arrangements. Once the appropriate inputs are entered, a synthesized report details the number of generators required, total available power for the converged model, and other machinery details. The list below details the reports the Machinery Module currently provides:

1. Transmission Type
2. Shaft Support System
3. Propulsion Engine Configuration
 - Engine Type
 - Main and Secondary Engines
 - Sustained and Endurance Speed
 - Operational Engine Configuration
4. Ship Service or Propulsion Derived Ship Service System Power Ratings
5. Propulsion and Reduction Gear Arrangements
6. Mechanical Propulsion Arrangement Positioning

7. Main Propulsion Engine Specifications and Characteristics
8. Ship Service Engine Specifications and Characteristics
9. Auxiliary Propulsion Module (APM) Specifications and Characteristics

However, the current construction of the module presents several issues. The two primary issues are highlighted here. 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.

The ultimate goal is to replace this module with S3D utilizing its capabilities to perform system analysis and detailed design displaying the appropriate properties and a physical, three-dimensional position assigned for both the electrical and mechanical domains.

3.3 Design Exploration Tool

As Section 1.3.2 highlights, RSDE can conduct a design of experiments through its Full Ship Study Generators. The "Design Exploration Tool: Full Ship Study Generator" allows the user to conduct rapid calculations of technical characteristics to create multiple ship studies. The current Design Exploration Tool supports design exploration for a select few modules and ship characteristics. However, this tool does not allow the user to conduct tradespace analysis for propulsion or electrical machinery components, nor is it component-based. For example, RSDE has a Payload and Adjustments Full Ship Study Generator interchanging the Payloads and Adjustments table. Therefore, modifications to this tool are required to mirror the component-based construct.

The ultimate goal is to improve the Design Exploration Tool in RSDE for mission equipment, payloads, and electrical and propulsion systems through the replacement

and creation of three generators. These generators are the Payloads and Adjustments Full Ship Study Generator, Machinery Module Full Ship Study Generator (Electrical), and Machinery Module Full Ship Study Generator (Propulsion). The proposed generators use templates as the baseline for design variation, thus enabling system-level changes to be incorporated in a design space exploration.

Chapter 4

Methodology Development

This chapter highlights domain-based design decisions as a precursor to the full methodology described in Chapter 5.

Exploring these design decisions developed the content requirements and structure for each template. Which subsequently defined the domain functional areas, which determined the follow-on use case methodologies, ensuring the full scope of domain-based design decisions was met.

The remainder of this chapter is organized as follows. Section 4.1 defines the primary domain design decisions for the electrical domain. Section 4.2 breaks the primary electrical design decisions into defined functional areas. Section 4.3 defines the primary domain design decisions for piping systems. Section 4.4 breaks the primary piping design decisions into defined functional areas. Finally, Section 4.5 defines the primary domain design decisions for the mechanical domain. Section 4.6 breaks the primary mechanical design decisions into defined functional areas.

4.1 Electrical Domain Design Decisions

The following design decisions are determined when creating the appropriate, holistic electrical system.

4.1.1 Architecture Type (Topology)

The architecture describes the logical architecture of the electrical system equipment and component orientation in relation to other components. Three primary examples are employed on ships today: Radial, Zonal, and Hybrid.

Radial. A radial architecture is comprised of a generator/energy source connected to switchboards and cabling to power loads and load centers/power panels [12, p. 28].

Zonal. This architecture divides the ship into multiple zones. Each zone can include power generation, power distribution, and energy storage [12, p. 29].

Hybrid. This architecture includes any remaining architectures that do not fit into radial or zonal constraints [12, p. 30].

4.1.2 Distribution System

The power distribution system describes the logical architecture that transfers power throughout an electrical system [12, p. 39-40]. The distribution system is described using two kinds of current: Alternating Current and Direct Current. A distribution system can also be described based on the number of main buses. A bus describes the primary node that distributes voltage, power, and current to the electrical system.

Alternating Current (AC). The flow of electric charge changes direction periodically.

Direct Current (DC). The electric charge flows in a single direction.

Power Distribution Buses. These components are required for distributing voltage, power, and current from the source to the loads. There can be single, dual, or multiple bus distribution systems.

4.1.3 Voltage Level

An electrical system has voltage level requirements for power generation and load usage: power utilization and power generation.

Power Utilization. Power utilization is defined as the power required for the anticipated load.

Power Generation. Power generation is the power created for distribution and use. Power generation "...consists of equipment that converts an energy source (such as fuel) into electrical power for use by loads via one or more power distribution systems" [12, p. 40].

4.2 Electrical Domain Functional Areas

Furthermore, the primary design decisions outlined in Section 4.1 can be broken down into specific functional areas: Power Generation, Power Distribution, Power Conversion, Electrical Power System Supervisory Control, Energy Storage, and Loads [12].

This breakdown of functional areas serves as the basis for the electrical portion of the Machinery Module methodology described in Chapter 5 and demonstrated in Chapter 6.

Power Generation. The power generation functional area directly mirrors the definition described in Section 4.1.3.

Power Distribution. The power distribution functional area directly mirrors the definition described in Section 4.1.2.

Power Conversion. Power conversion converts electrical power type and quality [12, p 41].

Electrical Power Supervisory System Control. The supervisory system control is responsible for "monitor[ing], controll[ing], and protect[ing], and coordinat[ing] an integrated electrical power system" [12, p 41].

Energy Storage. This component stores electrical energy for emergency/later use.

Load. A load is defined as any component that consumes electrical power. For the purpose of this methodology, the "large load" definition is used. A large load is one that constitutes more than 20% of the online power generation capacity [12, p. 43].

4.3 Piping Domain Design Decisions

The sections below describe the design decisions to consider when building a piping system.

4.3.1 Architecture Type (Topology)

The architecture describes the logical architecture of the piping system. Similar to the electrical domain, two primary architecture types are Radial and Zonal.

Radial. A radial architecture is comprised of a single source connected directly to distribution elements (i.e., piping, valves, etc.).

Zonal. This architecture divides the ship into multiple zones. Each zone can include a source and distribution elements of a piping system.

4.3.2 Distribution System

A piping distribution system describes the logical architecture that connects the main header to the loads. The distribution system can be broken down into two types: open and closed.

Open System. An open system is exposed to the surrounding environment. The piping system flows in a single direction.

Closed System. A closed system is not exposed to the surrounding environment. The piping system has both supply and return components.

Cross-Connection Locations. Cross-connection valves are present in the distribution system to segregate or disconnect the piping system, controlling the flow from the source to the load.

4.4 Piping Domain Functional Areas

Furthermore, the primary design decisions outlined in Section 4.3 can be broken down into specific functional areas: Source and Distribution.

This breakdown of functional areas is not explicitly demonstrated in the follow-on methodology. However, the Payload and Adjustment example partially utilizes this structure. The example is demonstrated in Chapter 6.

Source. Similar to electrical power generation, the source is responsible for introducing the medium (air or liquid) to the piping system for distribution and use.

Distribution. The distribution functional area directly mirrors the definition described in Section 4.3.2.

4.5 Mechanical Domain Design Decisions

The following design decisions are considered for development of a mechanical system.

4.5.1 Input.

The input is responsible for delivering the initial motion, energy, or force for mechanical system operation.

4.5.2 Process.

The process describes the components that transmit or convert the input motion, energy, or force and deliver it to the output.

4.5.3 Output.

The output is the end-state motion, energy, or force of a mechanical system.

4.6 Mechanical Domain Functional Areas

Furthermore, the primary design decisions outlined in Section 4.5 can be broken down into specific functional areas: Generation, Energy Storage, Distribution, and Output.

This breakdown of functional areas serves as the framework for the Machinery Module methodology using the propulsion example described in Chapter 5 and demonstrated in Chapter 6.

Generation. The generation functional area directly mirrors the definition described in Section 4.5.1.

Energy Storage. This component stores mechanical energy for emergency/later use.

Distribution. The distribution functional area directly mirrors the definition defined as "process" in Section 4.5.2.

Output. The output functional area directly mirrors the definition described in Section 4.5.3.

Chapter 5

Methodology

This chapter delineates the methodology in detail and addresses how S3D operates as a stand-alone module in lieu of existing modules and tables. Chapter 5 depicts these general methodologies, providing specific guidelines to demonstrate this method.

5.1 Payloads and Adjustments Replacement

This methodology implements Payloads and Adjustments in a component-based form.

5.1.1 Payloads and Adjustments Methodology

Before detailing the methodology steps, the components must be defined. Three main components comprise the P&A table: loads, electrical support equipment, and mechanical support equipment.

The P&A table replacement represents large loads that account for the top 20% of all electrical and cooling demands, spanning a variety of equipment and components. These loads can be organized by Ships Work Breakdown Structure (SWBS) groups and include components such as weapons, sensors, etc., and associated electrical and mechanical support equipment such as electrical cabinets and cooling skids.

5.2 Machinery Module Replacement

This methodology is organized in two subsections. The first subsection represents the electrical system and the second represents the propulsion system.

5.2.1 Electrical System Methodology

Before detailing the methodology steps, the templates and associated components must be defined.

As Chapter 4 describes, the IEEE Standard 45 organizes electrical systems into the following six subsections:

1. Power Generation
2. Power Conversion
3. Power Distribution
4. Energy Storage
5. Electrical Power System Supervisory Control
6. Loads

The electrical methodology reflects the IEEE Standard 45 organization of electrical systems except for loads and power conversion. Loads are covered in the previously mentioned P&A template, and power conversion is included in power generation and distribution templates. The electrical methodology is divided into two separate templates: power generation and distribution.

Power Generation Templates

Power generation templates include power generation source(s) and appropriate support equipment, circuit breaker(s), power conversion equipment, and cabling components.

Architecture/Topology and Power Distribution Templates

Power distribution templates consist of switchboards, load centers, power converters, cabling, and energy storage for the power generation source.

The power conversion components include rectifiers, inverters, transformers, Integrated Power Node Centers (IPNCs), and Power Control Modules (PCMs). In this methodology, the power conversion components convert power from the generation source to the main bus and the main bus to the load.

5.2.2 Propulsion System Methodology

The propulsion system is organized in three different templates:

1. Propulsor
2. Shafting
3. Power Transmission

This organization aligns with the mechanical domain functional areas described in Chapter 4, Section 4.6 describes.

Propulsor

Propulsor templates include propulsors, shafting, and shafting supports and struts.

There are several types of propulsors including fixed propellers, controllable reversible pitch propellers, rotating tractor pods, fixed tractor pods, rotating pusher pods, fixed pusher pods, and waterjets.

The shaft support types include open shafts and struts or stern tubes and skegs.

Shafting

Shafting templates include shafting, bearings, and oil distribution (OD) boxes.

Power Transmission

Power transmission templates include power generation source(s) and appropriate support equipment, reduction gear(s), and shafting.

Similar to the electrical system, some generation sources include Non-Integrated Ship Service Power (Mechanical), Integrated Power Systems (IPS), Power Take-in (PTI)/Hybrid Electric Drive, Power Take-Off (PTO)/Propulsion Derived Ship Service (PDSS), bidirectional hybrid drive, and future developments.

5.3 Consolidated Ship Design Methodology

1. Begin the initial ship design, creating a new hullform or using an existing model.

Payloads and Adjustments

- (a) In lieu of Payloads module, open S3D as a RSDE module.
- (b) Add component-based large loads representing Payloads and Adjustments using the templating process.

Machinery Module

- (a) In lieu of machinery module, open S3D as a RSDE module.
- (b) Choose ship service configuration.

Choose power generation template and associated options.

Choose architecture/topology and distribution template and associated options.

- (c) Choose propulsion transmission configuration.

Choose propulsor template and associated options.

Choose shafting template and associated options.

Choose power transmission type and associated options.

2. Automated connection of templates and, in tandem, trace systems to determine capacities, run sizing algorithms, and resolve collisions.

3. Run S3D module simulation to generate reports.
4. Complete remaining ship construction modules and synthesize model.

5.4 Design Exploration

Once all the ship construction modules are complete and the ship is synthesized, the user can open the Design Study (Full Ship Synthesis Study) module to conduct tradespace analysis.

There are three proposed Full Ship Study generators:

1. Design Exploration: Full Ship Study Generator for Payloads and Adjustments
2. Design Exploration: Full Ship Study Generator for Machinery Module (Electrical)
3. Design Exploration: Full Ship Study Generator for Machinery Module (Propulsion)

Each generator is comprised of three different columns. These columns 1) allow the user to select a template to modify, 2) allow the user to replace a chosen template with a different template in its entirety, and/or 3) replace individual components within a template with a different component or modify individual component properties.

The sections below detail the appropriate steps which utilize methodology-consistent template naming conventions.

5.4.1 Design Exploration: Full Ship Study Generator

Payloads and Adjustments Methodology

1. Open a Full Ship Study generator for Payloads and Adjustments variations.

Choose one or more pre-generated P&A templates and associated options.

Choose a pre-generated replacement or modified template of the aforementioned templates. (If this step is not required, proceed to the final column).

Add, modify, delete components in the original templates chosen or the modified/replacement templates chosen in the second column. (This step is required if the second column was not required).

2. Run full ship study with the appropriate changes.
3. View both feasible and infeasible combinations using the LEAPS data export application tool. The end-state user must filter the appropriate combinations according to design intentions.

5.4.2 Design Exploration: Full Ship Study Generator Machinery Module Methodology (Electrical)

1. Open a Full Ship Study generator for electrical variations.

Choose one or more pre-generated power generation templates and associated options and/or one or more pre-generated architecture/topology and distribution template and associated options.

Choose a pre-generated replacement or modified template of the aforementioned templates. (If this step is not required, proceed to the final column).

Add, modify, delete components in the original templates chosen or the modified/replacement templates chosen in the second column. (This step is required if the second column was not required).

2. Run full ship study with the appropriate changes.
3. View both feasible and infeasible combinations using the LEAPS data export application tool. The end-state user must filter the appropriate combinations according to design intentions.

5.4.3 Design Exploration: Full Ship Study Generator Machinery Module Methodology (Propulsion)

1. Open a Full Ship Study generator for propulsion variations.

Choose one or more pre-generated power transmission templates and associated options, one or more pre-generated shafting template and associated options, and/or one or more pre-generated propulsor template and associated options.

Choose a pre-generated replacement or modified template of the aforementioned templates. (If this step is not required, proceed to the final column).

Add, modify, delete components in the original templates chosen or the modified/replacement templates chosen in the second column. (This step is required if the second column was not required).

2. Run full ship study with the appropriate changes.
3. View both feasible and infeasible combinations using the LEAPS data export application tool. The end-state user must filter the appropriate combinations according to design intentions.

Chapter 6

Use Case Examples

6.1 Payloads and Adjustments

The following use case example mirrors the methodology described in Section 5.1.

In this example, a rail gun is modeled using templates represented in two domains: electrical and piping, as shown in Figure 6-1. The electrical domain includes additional support components: a transformer, a rectifier, and cabling to illustrate power conversion from the main bus to the load. The piping domain includes distribution equipment, namely, a valve and piping connecting the rail gun to the overall cooling system.

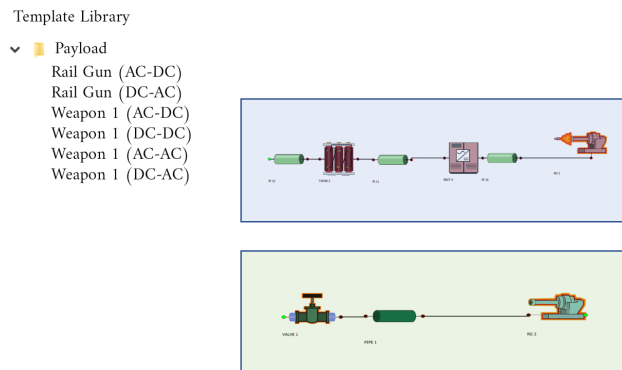


Figure 6-1: This figure demonstrates a rail gun template represented in the electrical and piping domain. The blue box represents the electrical domain and the green box represents the piping domain.

Reiterating the steps covered in Section 5.1, this demonstration assumes the hull-form is selected.

Firstly, the template "Rail Gun (AC-DC)" is chosen from the template library, represented as a drop-down menu in Figure 6-1.

Once the appropriate template is selected, the user has the option to modify the component properties as shown in Figure 6-2.

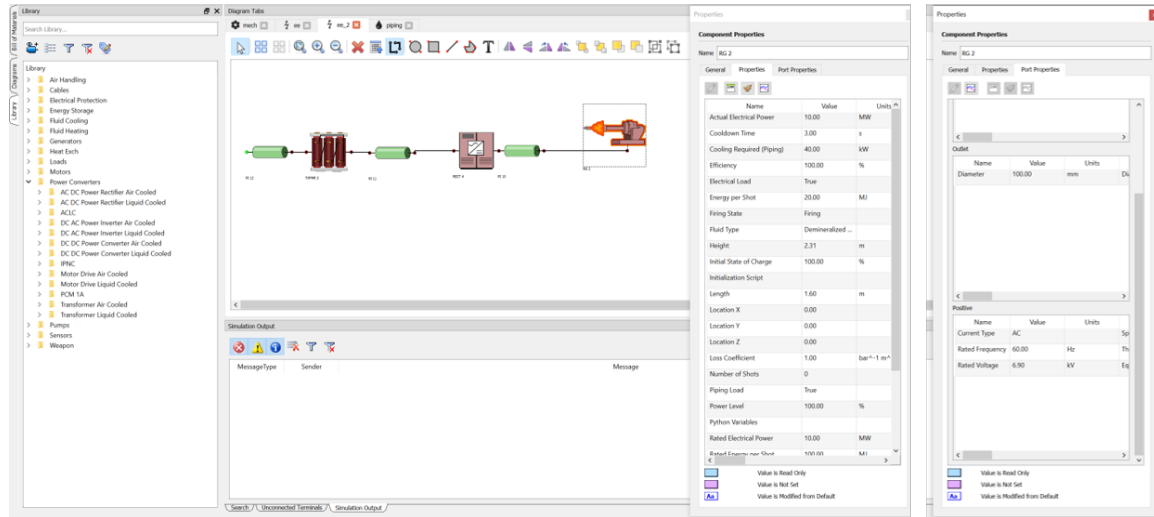


Figure 6-2: Modify the properties associated with the rail gun

Similarly, the user can modify the properties for all the support equipment or interchange components as required in both domains. Figure 6-3 demonstrates this concept for electrical cabling; however, these modifications can be extended to the piping and valve components as well. The figures representing these property modifications can be found in Appendix C.1. The full list of associated properties for each component is outlined in Appendix B.1 and B.2.

Properties associated with the amount of power or fluid 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 loads, but rated power for connecting items such as converters and cables can be set automatically.

Once all template modifications are complete, the template is assigned to the ap-

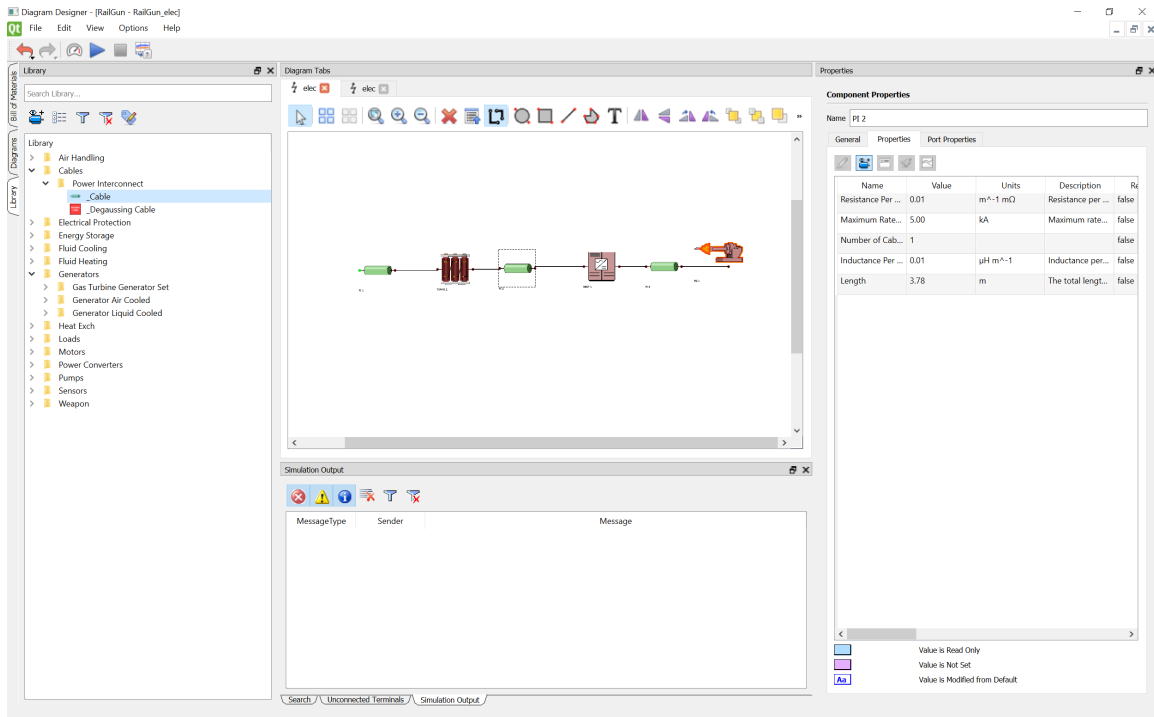


Figure 6-3: Choose cabling properties

proprate ship subdivision (i.e., compartment, zone, or hull). Figure 6-4 illustrates this concept for the piping domain. In this instance, the ship is divided into compartments. Whereas Figure 6-5 shows the ship divided into electrical zones.

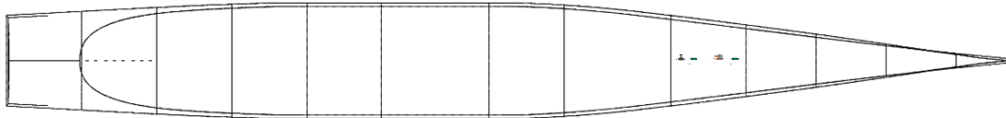


Figure 6-4: Arrange rail gun in the piping domain. The ship is divided in compartments. While the gun is topside, its electrical components are primarily in the space below on the main deck.

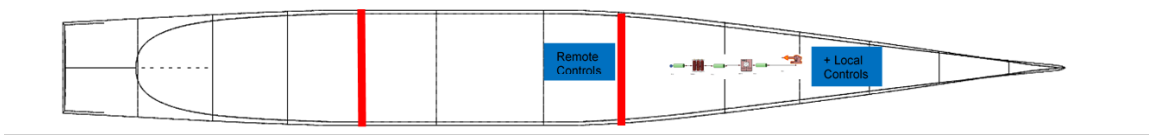


Figure 6-5: Arrange rail gun in the electrical domain. The ship is divided into three electrical zones separated by the vertical red lines. The placeholders in blue boxes represent remote and local control consoles, components that are not yet created in S3D.

6.1.1 Implementation

This methodology is implemented by exploiting the template node properties outlined in Section 2.4.2. Namely, the template node type identifier (diagram listing), the template node descriptive name, and the template node plug direction (orientation relative to other template nodes). As a reminder, template nodes are reflected in the LEAPS database with a blue circle in place of a normal node. See Figure 6-6 for a reference.

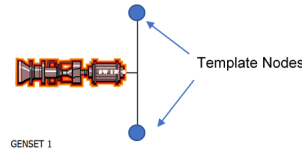


Figure 6-6: Template Node Visual Aid

Template Node Naming Convention

The following method is used to maintain a consistent LEAPS naming convention for each template node property and ensure the necessary logical architecture is met.

The node type identifier is represented by "diagramList," the template node descriptive name is represented by "plugName," and the template node plug direction is represented by "plugDirection." An additional template node property established in LEAPS named "isPlug" allows template connections and is always set to the string "TRUE".

Table 6.1 demonstrates the naming convention for the template nodes connecting the Rail Gun in the electrical and piping domains. The rows list the values for a particular template node property, and the columns show the template node properties relative to the specified template node location.

Table 6.1: Rail Gun template node properties

"LC" stands for load center. "In/Out" denotes template node pairing within a zone/bus, and "Fwd/Aft" denotes template node pairing across a zone/bus.

	Load Node	Piping Supply Load	Piping Return Load
isPlug	TRUE	TRUE	TRUE
plugName	LC	Distribution_Supply	Distribution_Return
plugDirection	In	In	Out
diagramList	Electrical	Piping	Piping

Consistent with the methodology, the template nodes integrate the load with the electrical system as reflected in Figure 6-7.

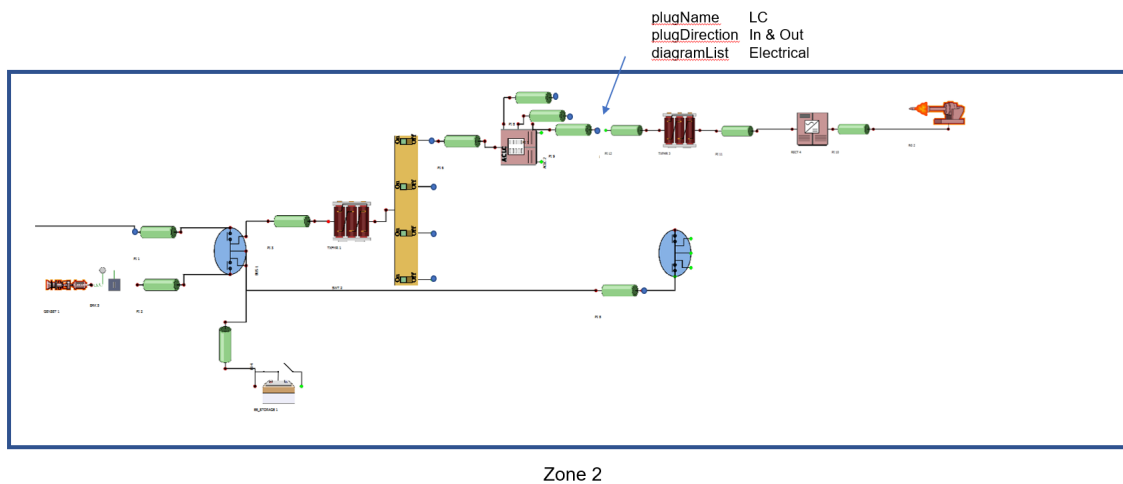


Figure 6-7: Template Node Characteristics Graphic (Electrical)

6.2 Machinery Module

6.2.1 Machinery Module Replacement - Electrical

The following use case example mirrors the methodologies described in Section 5.2.

The electrical system is divided into two main templates: power generation and power distribution. This example uses two different gas-turbine generator sets, Medium-Voltage DC (MVDC) distribution buses, and in-zone distribution providing 450 VAC and 60 Hz power.

Power Generation

The power generation template includes the generator set, circuit breaker, cabling, and pumps. These pumps are disconnected from the electrical architecture in this template, but represent the auxiliary support systems required for generator operation. There is a pump to transfer fuel oil, a pump to transfer lubrication oil, and a pump to transfer the cooling medium which connect to the electrical system in the power distribution template.

Reiterating the steps covered in Section 5.3, this demonstration assumes S3D is open in lieu of the Machinery Module.

Firstly, the template "Mechanical (AC)" is chosen from the template library, represented as a drop-down menu in Figure 6-8.

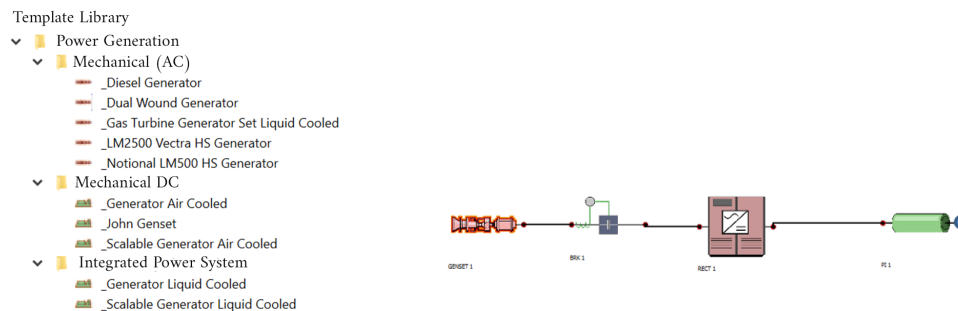


Figure 6-8: Choose power generation template. This template features an LM2500 generator.

Similar to the example in Section 6.1, specific components can be changed, and the associated properties can be modified. This example exchanges the LM2500 generator with a LM500 generator set. Figure 6-9 demonstrates the generator swap. The upper figure shows the selection of a new generator set, highlighting similar S3D components that can be used instead. The bottom figure demonstrates the generator properties that can be modified.

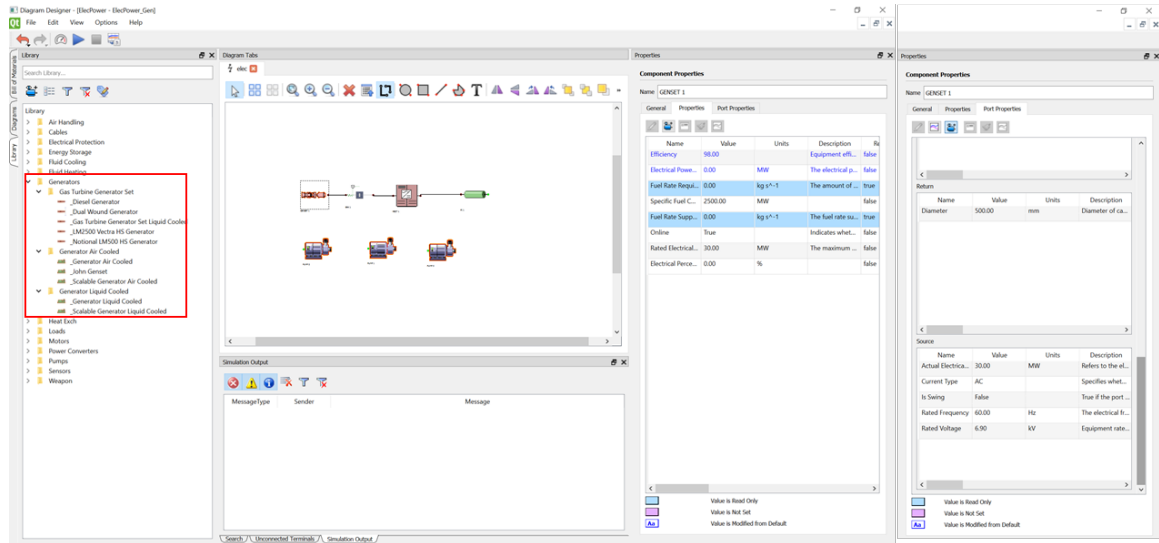


Figure 6-9: Replace LM2500 Vectra HS generator set with a LM500 HS generator. Modify properties as necessary.

The user can replace the component or modify the existing component's properties for the distribution components in the power generation template. Figure 6-10 demonstrates this concept for the rectifier; however, these modifications can be extended to the pumps, cabling, and circuit breaker as well. The figures representing these property modifications can be found in Appendix C.2. The full list of associated properties for each component is outlined in Appendix B.1.

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.

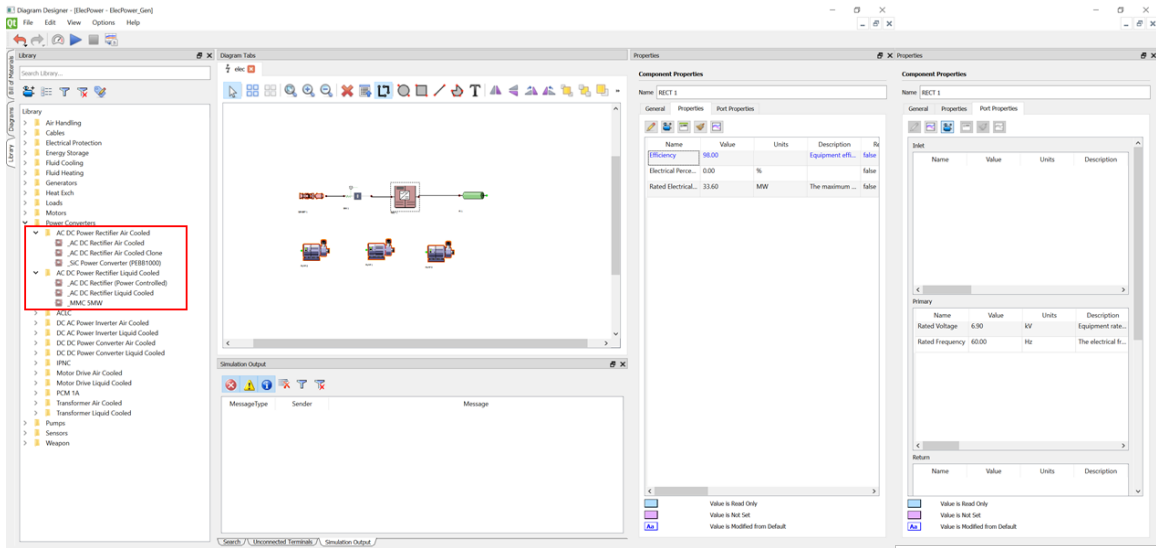


Figure 6-10: Choose rectifier type and properties

Once all template modifications are complete, the template is assigned to the appropriate ship subdivision (i.e., compartment, zone, or hull). Figure 6-11 illustrates this concept for the piping domain. In this instance, the ship is divided into compartments. The power generation template is placed in three separate machinery rooms.

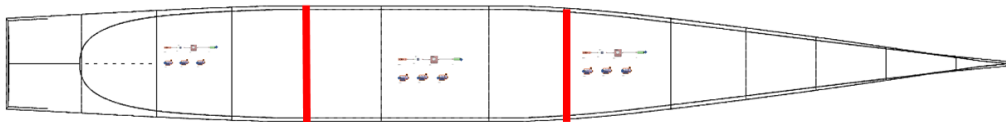


Figure 6-11: Arrange power generation template

Power Distribution

The power distribution template stores energy in a backup energy source (a battery), converts the generated 450 VAC utilizing switchgear, cabling, and a transformer, and distributes the MVDC power through a switchboard and an AC load center.

The first step is choosing the "Zonal AC-DC" template from the template library, represented as a drop-down menu in Figure 6-12.

- Template Library
- ▼ Topology and Distribution
 - Radial AC-DC
 - Radial AC-AC
 - Radial DC-DC
 - Radial DC-AC
 - Zonal AC-AC
 - Zonal DC-AC
 - Zonal AC-DC
 - Zonal DC-DC
 - Hybrid AC-DC
 - Hybrid DC-AC
 - Hybrid AC-AC
 - Hybrid DC-DC
 - Other AC-DC
 - Other AC-AC
 - Other DC-DC
 - Other DC-AC

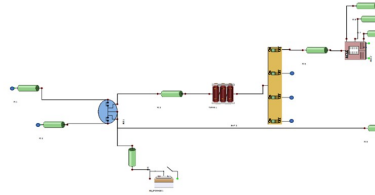


Figure 6-12: Choose the power distribution and topology

The user can replace the component or modify the existing component's properties for the distribution components in the power distribution template. Figure 6-13 demonstrates this concept for the energy storage component; however, these modifications can be extended to the power conversion components and switchgear as well. The figures representing these property modifications can be found in Appendix C.3. The full list of associated properties for each component is outlined in Appendix B.1.

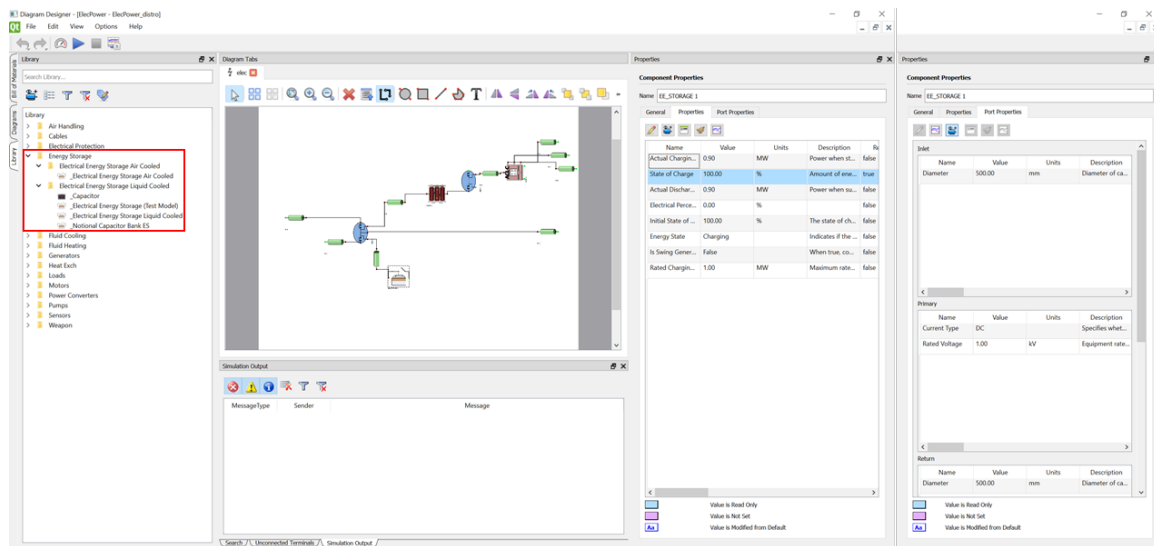


Figure 6-13: Energy storage type and properties

Once all template modifications are complete, the template is assigned to the appropriate ship subdivision (i.e., compartment, zone, or hull). Figure C-3 illustrates

this concept for the piping domain. In this instance, the ship is divided into compartments. The power generation template is placed in three separate machinery rooms.

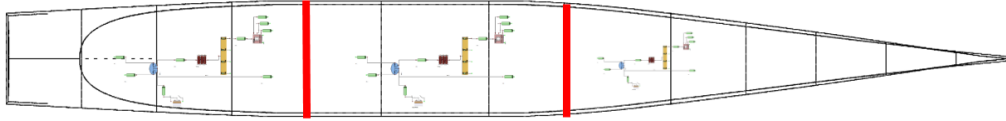


Figure 6-14: Arrange power distribution templates

Template Node Naming Convention

Consistent with the methodology presented in Section 6.1.1, template nodes connect the two templates that comprise the electrical system.

Table 6.2 demonstrates the naming convention for the power generation and distribution template nodes. The rows list the values for a particular template node property, and the columns show the template node properties relative to the specified template node location.

Table 6.2: This table demonstrates the naming convention for all of the nodes used to represent the electrical system.

"LC" stands for load center and "SWBD" stands for switchboard.

	Power Generation Output Cabling	Pump(s)	Power Distribution Input Cabling (In-Zone)	Power Distribution Input Cabling (Inter-Zone)	Power Distribution Output Cabling	SWBD Nodes	LC Nodes
isPlug	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
plugName	Generation_Bus	LC	Generation_Bus	Distribution_Bus	Distribution_Bus	SWBD_Nodes	LC
plugDirection	Out	In	In	Fwd	Aft	Out	Out
diagramList	Electrical	Electrical	Electrical	Electrical	Electrical	Electrical	Electrical

The full system connection is demonstrated in Figure 6-15. This figure depicts the three zone electrical system connecting the in-zone power generation and distribution templates, cross-zone power distribution connections, and template node naming conventions.

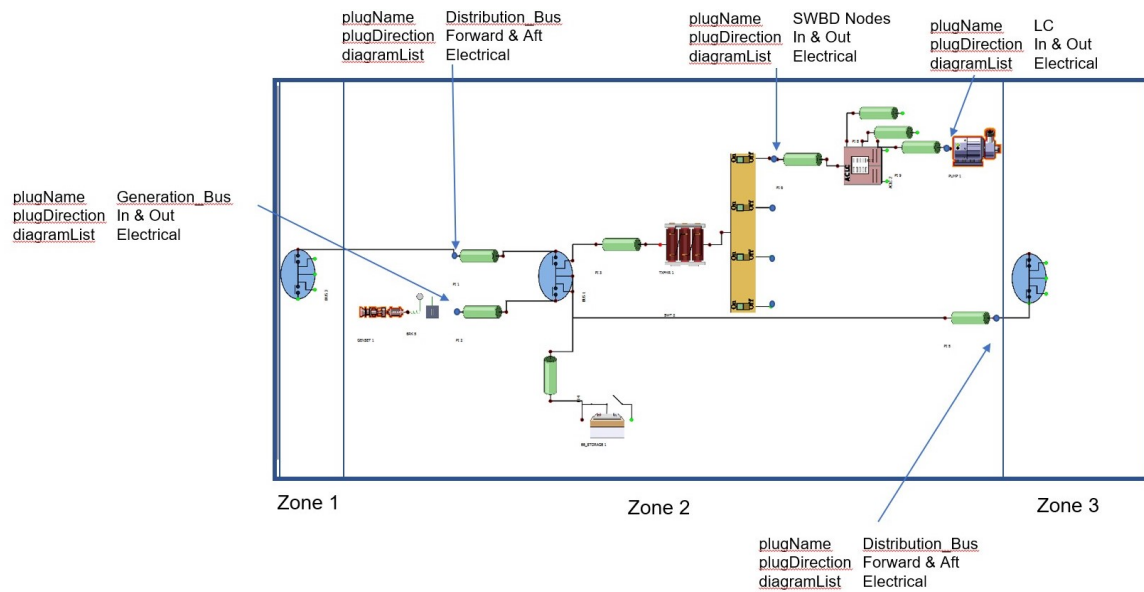


Figure 6-15: Electrical system with template node characteristics

6.2.2 Machinery Module Replacement - Mechanical

The following use case example mirrors the methodologies described in Section 5.2

The propulsion system is divided into three main templates for each shaft: a propulsor template, a shafting template, and a power transmission template. This example depicts a dual shaft, mechanical-drive propulsion train using gas-turbine engines.

Propulsor

The propulsor template example includes a propeller and shafting to deliver torque to rotate the propeller.

Reiterating the steps covered in Section 5.3, S3D is open in lieu of the Machinery Module.

The propulsion train is designed based on the propellers, so this design decision is determined first. The template "Controllable Pitch Propeller" is chosen from the template library, represented as a drop-down menu in Figure 6-16.

Similar to the previous examples, the propulsor can be changed and the associ-

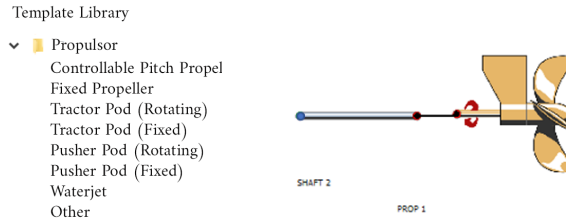


Figure 6-16: Choose propulsor template

ated properties can be modified. Figure 6-17 demonstrates the associated propeller properties that can be modified. The user manually sets the rated mechanical power and speed for the propulsors and rated mechanical power for shafts are automatically set.

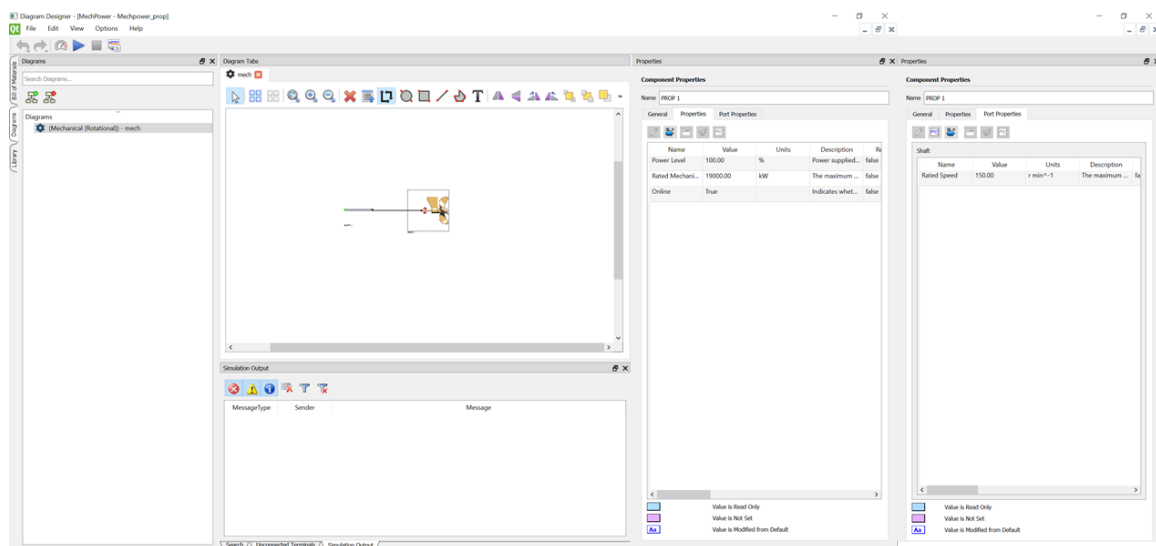


Figure 6-17: Choose propulsor properties

For this specific template, space arrangements are not required.

Shafting

The shafting template includes additional shafting for distribution throughout the machinery spaces and a bearing to support shaft axial thrust both horizontally and vertically.

The first step is choosing the "Shaft + Main Thrust Bearing" template from the template library, represented as a drop-down menu in Figure 6-18.

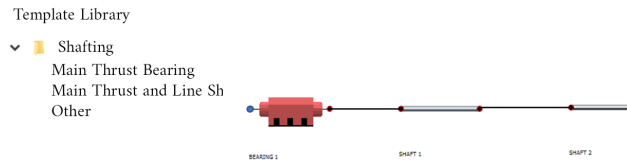


Figure 6-18: Choose shafting template

Shafting properties are set in 6-19. The figure representing bearing property modifications can be found in Appendix C.5. The full list of associated properties for each component is outlined in Appendix B.3.

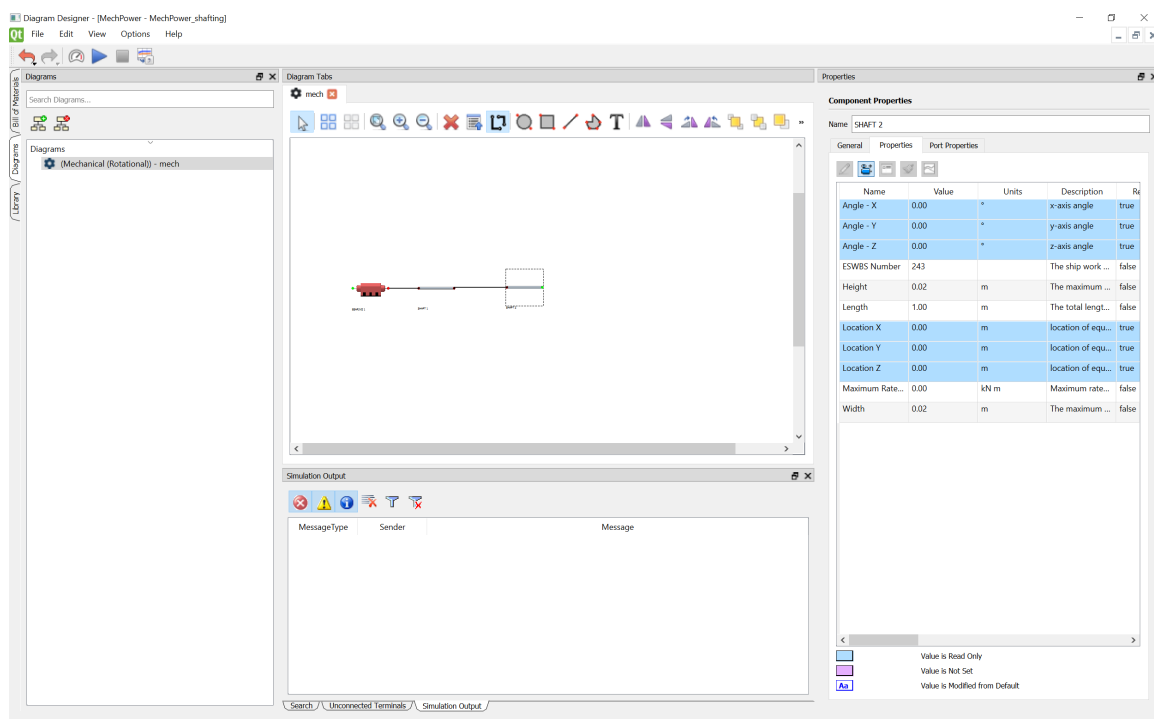


Figure 6-19: Choose shafting properties

Finally, the shafting template is arranged in each main engine room according to the propulsor template(s) as shown in Figure 6-20.

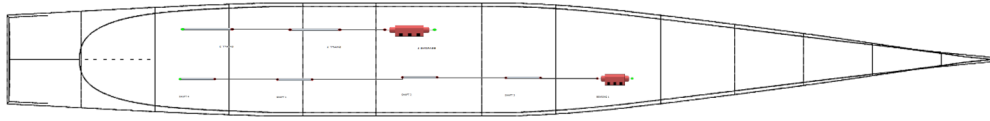


Figure 6-20: Arrange shafting template

Power Transmission

The power transmission example template includes shafting for distribution throughout the machinery spaces, reduction gear to reduce the speed transmitted by the engine(s) and increase torque, a gas-turbine engine for power generation, and three auxiliary pumps representing fuel oil, lubrication oil, and cooling medium distribution. This template is represented in two domains: electrical and mechanical.

The first step is choosing the "Mechanical" template from the template library, represented as a drop-down menu in Figure 6-21.

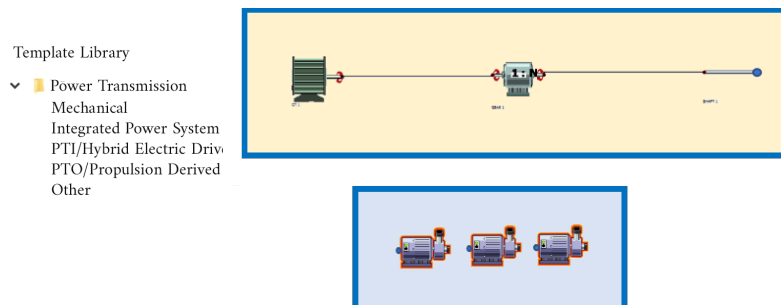


Figure 6-21: Choose power transmission template. This figure demonstrates power transmission template in the electrical and mechanical domain. The blue box represents the electrical domain and the yellow box represents the piping domain.

Similarly, the propulsion engines can be changed and the associated properties can be modified. The figure representing engine property modifications can be found in Appendix C.6 and the full list of associated properties for each component is outlined in Appendix B.3.

Figure 6-22 shows the reduction gear component options and properties that can be modified. The reduction gear component is not automatically sized, unlike other connecting gear, thus requiring user input.

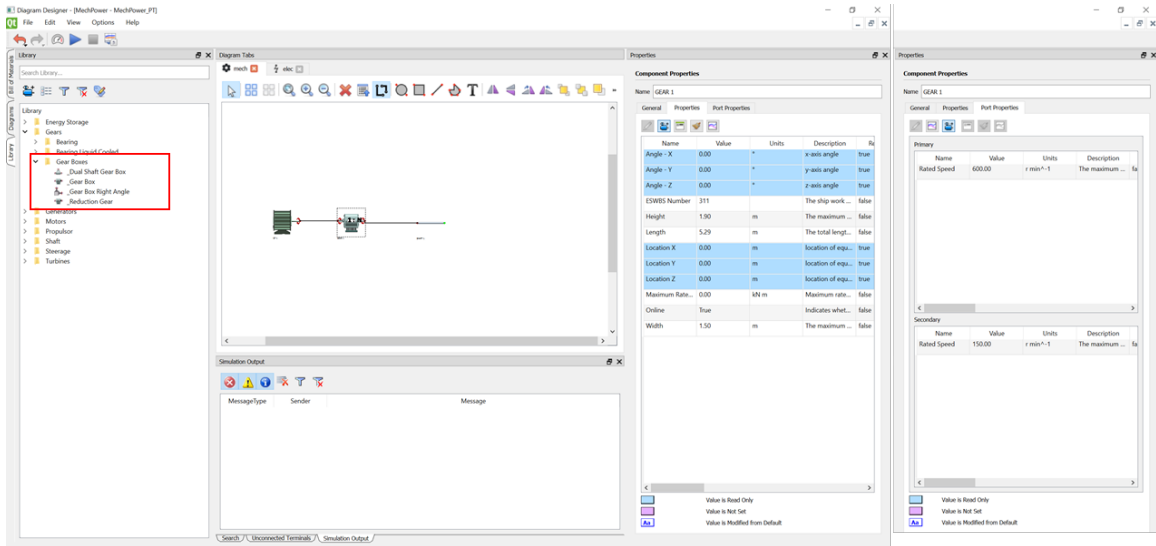


Figure 6-22: Choose reduction gear type and properties

Lastly, Figure 6-23 shows the power transmission template arrangement in each main engine room.

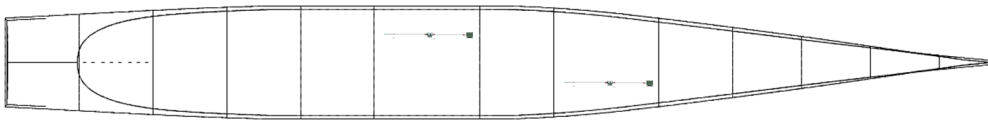


Figure 6-23: Arrange power transmission template

Template Node Naming Convention

Consistent with the methodology presented in Section 6.1.1., template nodes connect the two templates that comprise the electrical system.

Table 6.3 demonstrates the naming convention for the propulsor, shafting, and power transmission template nodes. The rows list the values for a particular template node property, and the columns show the template node properties relative to the specified template node location.

The full system connection is demonstrated in Figure 6-24. This figure depicts the starboard shaft propulsion train spanning three machinery spaces and the sea.

Table 6.3: This table demonstrates the naming convention for all of the nodes used to represent the propulsion system

	Connection of Power Transmission and Shafting Templates	Connection of Shafting and Propulsor Templates
isPlug	TRUE	TRUE
plugName	Power_Transmission	Shafting
plugDirection	Fwd/Aft	Fwd/Aft
diagramList	Mechanical	Mechanical

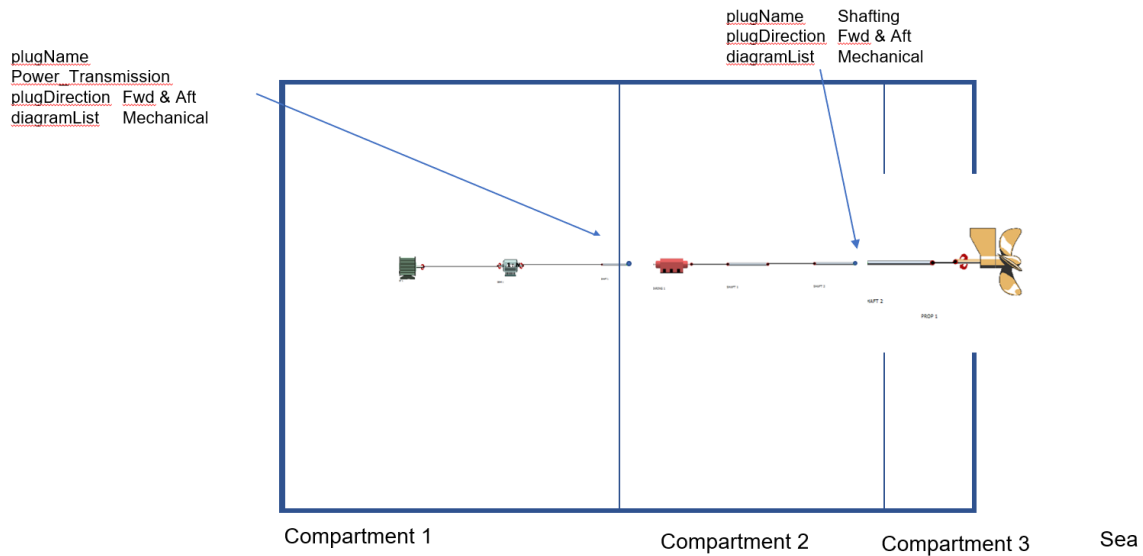


Figure 6-24: Single shaft propulsion example with template node characteristics

6.3 Integrated Propulsion System Example

As described before, this construct allows for more flexibility in system design.

Figure 6-25 below shows a representation of an Integrated Power System (IPS) in both the mechanical and electrical domains. This example uses a dual shaft, Combined Diesel, Electric, and Gas (CODLAG) propulsion system distributing 450 VAC and 60 Hz power. This configuration uses two gas-turbine generator sets, two diesel generators, two frequency converters referred to as a motor drives, two motors, shafting, and two propellers. The electrical domain is represented in light blue and the mechanical domain in represented in yellow.

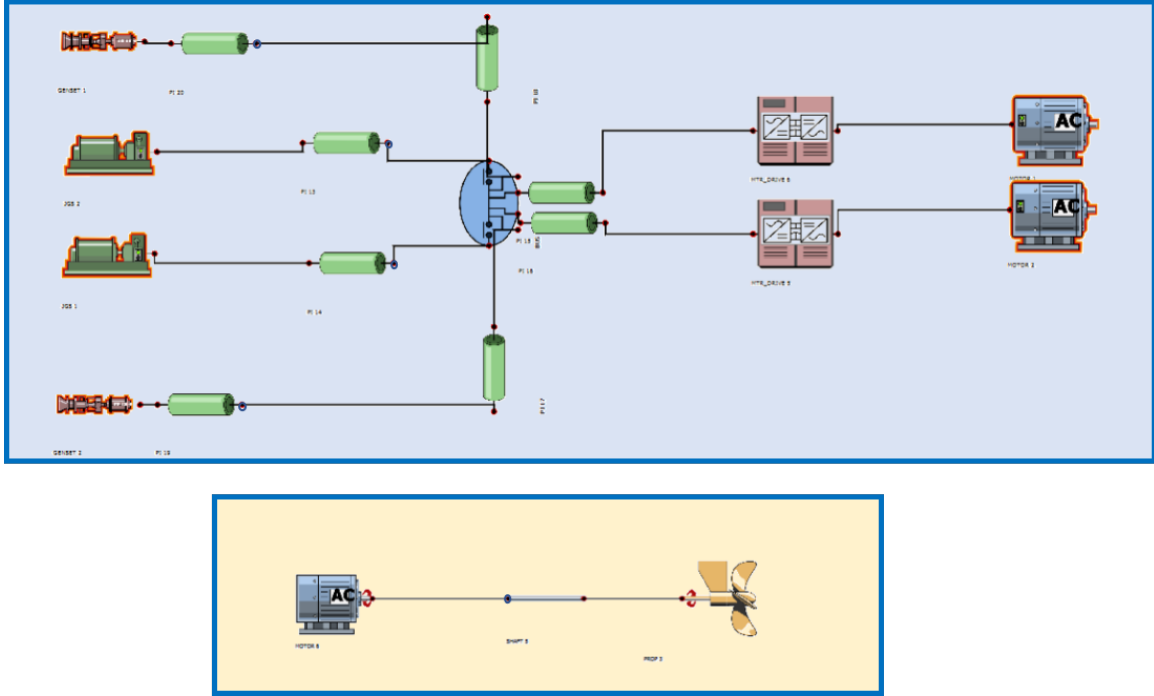


Figure 6-25: Combined Diesel, Electric, and Gas (CODLAG) propulsion system

6.4 Full Ship Study: Design Exploration Generator

RSDE currently uses generators as a way to explore the design space. Utilizing this construct, the represented use cases below take the templates used in the previous use cases to explore various tradespace options.

Section 5.4 details the process in full. As a reminder, each generator is comprised of three different columns. These columns 1) allow the user to select a template to modify, 2) allow the user to replace a chosen template with a different template in its entirety, and/or 3) replace individual components within a template with a different component or modify individual component properties.

The use cases below, shown in Figures 6-26, 6-27, and 6-28, demonstrate the template naming convention used in earlier sections of this chapter and show the functionality of each generator. Figure 6-26 represents the Payloads and Adjustments replacement generator, Figure 6-27 depicts the Machinery Module (Electrical) generator, and Figure 6-28 is the Machinery Module (Propulsion) generator.

Choose template to modify (Can select all or one)	Choose Replacement/Modified Template	Add, modify, delete components in modified replacement template or original template
-Payload_1	-Payload_2 -Payload_3 -Payload_4 -Etc	-Payload_1 • Component 1 • Component 2 • Component 3 • Etc.
OPTION 1	OPTION 2	OPTION 3

Component 55

Figure 6-26: Full Ship Generator for Payloads and Adjustments
This figure depicts the modification of the Payload_1 template, replacing it with the Payload_2 template, and replacing Component 3 with Component 55.

Choose template to modify (Can select all or one)	Choose Replacement/Modified Template	Add, modify, delete components in modified replacement template or original template
-Power generation -Architecture/Topology and Power Distribution	-Power Generation_1 -Power Generation_2 -Power Generation_3 -Etc	-Power Generation_1 • Component 1 • Component 2 • Component 3 • Etc.
OPTION 1	OPTION 2	OPTION 3

Component 55

Figure 6-27: Full Ship Generator for Machinery Module (Electrical)
This figure depicts the modification of the Power Generation template, replacing it with the Power Generation_1 template, and replacing Component 3 with Component 55.

Choose template to modify (Can select all or one)	Choose Replacement/Modified Template	Add, modify, delete components in modified replacement template or original template	
-Power transmission -Shafting -Propulsor Type	-Power Transmission_1 -Power Transmission_2 -Power Transmission_3 -Etc	-Power Transmission_1 • Component 1 • Component 2 • Component 3 • Etc.	Component 55
OPTION 1	OPTION 2	OPTION 3	

Figure 6-28: Full Ship Generator for Machinery Module (Propulsion)

This figure depicts the modification of the Power Transmission template, replacing it with the Power Transmission_1 template, and replacing Component 3 with Component 55.

Chapter 7

Conclusions and Future Work/Integration

7.1 Summary

This thesis presents a methodology for incorporating templates into the Navy’s Rapid Ship Design Environment, specifically addressing the pertinent use cases. The methodology presented in this thesis 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. 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.

7.2 Conclusions

Overall, this methodology meets the requirements to provide flexibility with greater detail for the following use cases: (1) replacing the Payload and Adjustments Table with a component-based module, (2) replacing the Machinery Module with S3D, (3) revamping the Payload and Adjustments Full Ship Study Generator (template-based), and (4) implementing an electrical and propulsion variation Full Ship Study Generator (template-based).

The sections below detail how this methodology met the demands of each stakeholder and technical warrant holder, organized by the tools and methods employed.

7.2.1 RSDE/ASSET

This study developed solutions to several recognized shortcomings of RSDE and ASSET.

One of the main issues of the current version of RSDE is the over-reliance on outdated, parametric data. The RSDE program is regression-based, utilizing historical/parametric data as the basis for its calculations and algorithms. In this program, modern systems technology is hard to replicate from a design perspective without a significant amount of tedious calculations for the user.

This methodology solves this primary issue using a user-friendly interface, S3D, which provides the user with a streamlined process to create templates representative of modern technologies that are not hard-coded into RSDE.

The Payloads and Adjustments table integrates provided weight, volume, cooling, and electrical load data into the corresponding overall ship's characteristics and loading. However, there is no physical representation of each component's location and whether it feasibly fits in three-dimensional space. A user can attempt to model the requisite three-dimensional space accounted for by these added payloads through "Large Object Spaces." However, this approach does not provide sufficient detail and spatial arrangement deconfliction.

This methodology seeks to create a component-based Payload and Adjustments module to ultimately satisfy the spatial arrangement deconfliction for large loads encompassing the top 20% electrical and cooling requirements.

Another stumbling block is RSDE's lack of a design space exploration tool for machinery. The Machinery Module baseline, determined after completing the wizard, cannot be modified without changing initial inputs. Therefore, the user cannot explore design space beyond the initial machinery wizard designation without rework. This methodology facilitates design space exploration by using Full Ship Study Generators for scripting subsystem modifications through templating. The user can view

the combinations in the data export application (a LEAPS-driven tool).

The Machinery Module, in its current state, outputs an analysis/report with a copious amount of data. However, the user must verify the power requirement compared to the available power manually.

Using S3D, the user can quickly verify failed requirements through the built-in program feedback.

7.2.2 S3D

S3D's analysis tool can generate all of the reports that the current Machinery Module can except:

1. Operating and Configuration Conditions
2. Machinery Margins
3. Air Conditioning and associated load

There is more to follow pertaining to the scope of future work for these particular report requirements in Section 7.3.

7.2.3 Templating

In general, creating templates is tedious and time-consuming. This methodology ensures a library for "standard" configurations are built for the user. Additionally, each template the user modifies can be saved and stored in the library for use in future design projects.

7.3 Future Work

Overall, there is still a lot of work and integration required to ensure this methodology is useful.

The sections below detail some of the necessary work by various entities to facilitate this methodology and meet the use case demands in full.

7.3.1 S3D

It is imperative that the appropriate functionalities are transitioned from the web-based version of S3D. Specifically, the "replace component" feature, which allows selection of a new component to replace an existing design component. This is required to implement this methodology.

Sizing Algorithms

For the proposed methodology, there is a major assumption that sizing algorithms are developed to determine component dimensions and weight in response to the maximum flow algorithms [6]. However, this functionality does not exist yet. Further, the maximum flow algorithm is currently only developed for electrical systems; this functionality must be extended to the other domains.

Configuration Calculations

It is important to develop an operational configuration requirements methodology for future growth. It is possible to model operational configurations in S3D for performance determination; however, it is not easily achievable in an automated manner.

Modeling 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 [10].

7.3.2 Templating

Template Positioning Algorithms

Exploiting the current RSDE "assembly" calculations orients each template in the appropriate ship subdivision in two-dimensional space (i.e., longitudinally and transversely). However, it does not address the three-dimensional spatial concerns. Additional methods can be implemented to augment, improve, or eventually replace the current algorithms.

Three Dimensional Arrangements. 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 [16]. Incorporating this algorithm augments current RSDE positioning calculations ensuring that positional algorithms are implemented for support equipment relative to the fixed major equipment, imposing separation between templates in the same ship subdivision, and adding maintenance area/clearance requirements to ensure proper separation between components within the same template.

Automation As system technology expands, more templates are required to meet the demand. Suppose the user desires an exact or similar template that does not exist in the pre-generated library. In that case, the user must understand the basic requirements for creating a template delineated in Chapter 2.4 and apply the principles outlined in Chapter 6. As mentioned in Section 7.2.3, when new templates are created, they can be stored and saved for future design projects.

In future iterations of S3D, the template creation process will be streamlined through automation in the S3D GUI. Specifically, this feature will reduce tedium by programming the template node designation process, including establishing properties, to align with this methodology. In addition, automation will also significantly reduce the potential for error when designating template nodes (e.g., template node property syntax).

7.3.3 LEAPS/FOCUS

As mentioned before, there is a significant amount of work to ensure S3D's full integration into LEAPS, all necessary components are created, and all components are FOCUS-compliant.

Additional Component Creation

Additional components must be made to represent current weapons systems and sensors, including remote and local control systems (i.e., Combat Information Center consoles, etc.).

For the propulsion portion of the Machinery Module replacement, the following components must be created:

1. Propulsor Type:

Tractor pod rotating

Tractor pod fixed

Pusher pod rotating

Pusher pod fixed

Waterjet

For all of these line items, components with more than one input must also be included. This applies to propellers as well.

2. Shafting

Shaft, Line Shaft Bearing (LSB), and struts

Shaft, Main Thrust Bearing (MTB), and struts

Shaft, Stern tube seal, and struts

Additional properties for existing components must also be included:

1. Propulsor Type:

Max Revolutions Per Minute (RPM)

Propulsor type

Dimensions (diameter)

Propeller Series Indicator

Location

Number of Blades

Expanded Area Ratio (EAR)

Pitch Ratio

2. Reduction Gear

Reduction Ratio

Gear Orientation

Gear Shape

Additional components must also be made to represent electrical and cooling loads that are not considered a "large load" (i.e., accounting for the top 20% of cooling and electrical loading). Components coined as "proxy loads" could represent these items.

Appendix A

S3D Analysis

This Appendix introduces the outputs from the system level designer.

A.1 S3D Analysis: Solver Outputs

Depending on the operating domain, there are various outputs that S3D can provide. Once a system is constructed, there are component dependent outputs. It is important to detail these outputs to describe the data exported for use.

Not every individual component within the specified domain yields all of these outputs when the system analysis is complete. Sections A.1.1-A.1.3 lists applicable outputs.

A.1.1 Electrical Domain Outputs

The electrical analysis list of outputs includes power level, power efficiency, real power, imaginary/reactive power, voltage, current, and phase angle.

Power Level. Power level is defined as the electrical power supplied or consumed as a percentage of rated power. It denotes the simulated operating level of a component in comparison to the highest amount of equipment power capacity.

Power Efficiency. Power efficiency highlights cost-savings demonstrating the ratio of supplied power to output power. The ideal goal is to save costs on fuel/energy sources.

Real Power. Real power shows the power consumed by an individual component due to resistive load. Imaginary (reactive power) calculates the electrical energy stored in the system that returns to the source. Real power and imaginary (reactive power) demonstrates the system's apparent power (total requirement the source must be able to withstand).

Voltage. The voltage is an indication of system operation. If the voltage is too low, the system has low power and is constrained in its operations. If the voltage is too high, this could lead to overheating and premature equipment failure. The voltage drop across a circuit is also an indication of losses/dissipation and is vital to observe when analyzing a load circuit diagram.

Current. Analyzing current is an important metric for appropriately sizing power distribution and support equipment (electrical wiring, transformers, circuit breakers, etc.)

Phase Angle. The phase angle is demonstrative of system efficiency. Whether analyzing voltage to voltage phase angles or voltage to current phase angles, the level of synchronization indicates power output.

A.1.2 Piping Domain Outputs

The piping domain system analysis provides calculations for temperature, pressure, direction, mass flow, fluid velocity, and required cooling. The piping analysis outputs listed are essential for valve and piping sizing and material requirements.

Temperature. A measure of hotness or coldness relative to a pre-defined scale (Celsius or Fahrenheit).

Pressure. Pressure is a measurement of the fluid's force per unit area.

Direction. This metric describes the fluid flow direction.

Mass Flow. Mass flow is the rate at which mass is transferred.

Fluid Velocity. The rate at which fluid travels with respect to time.

Required Cooling. The heat dissipation required to maintain equipment operation.

A.1.3 Mechanical Domain Outputs

In the mechanical domain the system analysis provides speed, power level, torque, and angular velocity.

Speed. Speed is defined as rotor speed in rotations per minute (rpm).

Power Level. Power level is defined as the mechanical power supplied or consumed as a percentage of rated mechanical power. It denotes the simulated operating level of a component in comparison to the highest amount of equipment mechanical power capacity.

Torque. Torque is rotational force of mechanical components.

Angular Velocity. Angular velocity measures the rate of angle change for a rotational object. Thus, determining the angular speed over a period of time.

Appendix B

Tables

B.1 Electrical Components and Properties

Table B.1: Electrical Components and Properties

Component	Property	Port Property
Cables	Bending Radius	
	Electrical Load (T/F)	
	Max rated current	
	Inductance/unit length	
	# of cables in bundle	
	Outer diameter/cable	
	Power interconnect type	
	Rated continuous current/cable	
	Resistance/length	
	Weight/length	

Component	Property	Port Property
Cables	Length	
	Width	
	Height	
	Location	
	Automatically compute parameters	
Circuit Breaker	Electrical Load	Current Type
	Length	Rated voltage
	Width	Rated frequency
	Height	
	Location	
	Rated continuous current	
	Switch state	
DC Disconnect	Electrical Load	Current Type
	Length	Rated voltage
	Width	
	Height	
	Location	
	Rated continuous current	
	Switch state (closed/open)	
Junction Box	Electrical Load	Current Type
	Length	Rated voltage
	Width	Rated frequency
	Height	Rated current
	Location	
Bus Node	Electrical Load	Rated continuous current
	Length	Resistance

Component	Property	Port Property
Bus Node	Weight	Switch states (closed/open)
	Height	Current type
	Location	Rated voltage
	Max rated current	Rated frequency
	Electrical Load	Current type
SPDT	Length	Rated voltage
	Width	Rated frequency
	Height	
	Location	
	Max rated current	
Switch	Switch position	
	Electrical Load	Current type
	Length	Rated voltage
	Width	Rated frequency
	Height	
SWBD	Location	
	Max rated current	
	Switch state	
	Electrical Load	Current type
	Length	Rated voltage
Energy storage	Width	Rated frequency
	Height	Switch state
	Location	
	Max rated current	
	Actual charging electrical power	Diameter
	Actual discharging electrical power	Current type
	Air/liquid cooling type	Rated voltage
	Air/liquid flow rate	

Component	Property	Port Property
Energy storage	Duct length	
	Efficiency	
	Electrical load	
	Energy state	
	HVAC load	
	Initial state of change	
	Swing generator	
	Latent heat	
	Length	
	Width	
	Height	
	Location	
	Rated charging electrical power	
	Rated storage capacity	
	Sensible heat	
	Rated discharging electrical power	
Capacitor	Actual charging electrical power	Diameter
	Actual discharging electrical power	Current type
	Cooling required	Rated voltage
	Efficiency	
	Electrical load	
	Energy state	
	Initial state of change	
	Swing generator	
	Loss Coefficient	
	Length	
	Width	
	Height	

Component	Property	Port Property
Capacitor	Location	
	Pipe length	
	Piping load	
	Rated charging electrical power	
	Rated discharging electrical power	
	Rated storage capacity	
	Rupture pressure	
Dual Wound Generator	Cooling required	Diameter
	Efficiency	Fluid type
	Electrical load	Actual electrical power
	Electrical power supplied	Current type
	Fuel consumed	Swing
	Fuel type	Rated frequency
	HVAC Load	Rated voltage
	Latent Heat	
	Loss Coefficient	
	Max power inlet airflow	
	Mech Power supplied	
	Swing generator	
	Length	
	Width	
	Height	
	Location	
	Piping load	
	Rated electrical load	
	Online	
	Sensible heat	
Generator (air/liquid cooled)	Actual mechanical power	Diameter

Component	Property	Port Property
Generator (air/liquid cooled)	Cooling type	Rated speed
	Airflow rate	Actual electrical power
	Duct length/cooling required	Current type
	Efficiency	Swing
	Electrical load	Rated frequency
	HVAC Load/Piping load	Rated voltage
	Latent Heat	
	Mech load (T/F)	
	Mech Power required	
	Mech Power supplied	
	Swing generator	
	Length	
	Width	
	Height	
	Location	
	Rated mechanical power	
	Rated electrical power	
	Online	
	Sensible heat	
GenSet	Cooling required	Diameter
	Efficiency	Fluid type
	Electrical load	Actual electrical power
	Electrical power supplied	Current type
	Fuel consumed	Swing
	Fuel rate required	Rated frequency
	Fuel rate supplied	Rated voltage
	Fuel Type	
	HVAC Load	

Component	Property	Port Property
GenSet	Max power inlet airflow	
	Mech Power supplied	
	Swing generator	
	Length	
	Width	
	Height	
	Location	
	Piping load	
	Rated electrical power	
	Online	
	Sensible heat	
	Weight	
	Loss Coefficient	
	Cooling required	Diameter
	Efficiency	Rated speed
Motor	Electrical load	Current type
	Electrical Power supplied	Rated frequency
	Fluid type	Rated voltage
	Mechanical swing	
	Length	
	Width	
	Height	
	Location	
	Loss Coefficient	
	Online	
	Piping load	
	Power level	
	Rated electrical power	

Component	Property	Port Property
Motor	Rated mechanical power	
	Rupture pressure	
Transformer	Cooling type	Diameter
	Cooling flow rate	Current type
	Duct length/cooling required	Rated frequency
	Efficiency	Rated voltage
	Electrical load	
	HVAC load/Piping load	
	Latent Heat	
	Length	
	Width	
	Height	
	Weight	
	Location	
	Rated Electrical Power	
	Sensible Heat	
PCM	Cooling required	Switch state
	Efficiency	Current type
	Electrical power required	Rated frequency
	Fluid type	Rated voltage
	Internal Bus voltage	Diameter
	Length	Fluid type
	Width	
	Height	
	Location	
	Loss coefficient	
	Rated electrical power	
	Cooling type (fluid, air)	Diameter
Inverter		

Component	Property	Port Property
Inverter	Cooling flow rate	Current type
	Duct length/cooling required	Rated frequency
	Efficiency	Rated voltage
	Electrical load	
	HVAC load/piping load	
	Latent Heat	
	Length	
	Weight	
	Height	
	Location	
	Rated Electrical Power	
	Sensible Heat	
	Rupture pressure (if liquid)	
	Loss Coefficient (liquid)	
	Cooling type (fluid, air)	Diameter
Motor Drive	Cooling flow rate	Current type
	Duct length (air)	Rated frequency
	Efficiency	Rated voltage
	Electrical load	
	HVAC load/piping load	
	Latent Heat	
	Length	
	Width	
	Height	
	Location	
	Rated Electrical Power	
	Sensible Heat	
	Rupture pressure (if liquid)	

Component	Property	Port Property
Motor Drive	Loss Coefficient (liquid)	
	Cooling required (liquid)	
Rectifier	Cooling type (fluid, air)	Diameter
	Cooling flow rate	Current type
	Duct length (air)	Rated frequency
	Efficiency	Rated voltage
	Electrical load	
	HVAC load/piping load	
	Latent Heat	
	Length	
	Width	
	Height	
Rectifier	Location	
	Rated Electrical Power	
	Sensible Heat	
	Rupture pressure (if liquid)	
	Loss Coefficient (liquid)	
ACLC	Cooling required (liquid)	
	Efficiency	Diameter
	Fluid type	Current type
	Length	Rated frequency
	Width	Rated voltage
	Height	Fluid type
	Location	Switch state
	Loss coefficient	
	Rated electrical power	
	Cooling required	Diameter
IPNC	Efficiency	Current type

Component	Property	Port Property
IPNC	Fluid type	Rated frequency
	Length	Rated voltage
	Width	Fluid type
	Height	Switch state
	Location	
	Loss coefficient	
	Rated electrical power	
Pumps	Flow rate level (if variable)	Diameter
	Efficiency	Current type
	Fluid type	Rated frequency
	Length	Rated voltage
Pumps	Width	
	Height	
	Location	
	Loss coefficient	
	Rated electrical power	
	Electrical load	
	Actual electrical power	
	Liquid Mass Flow rate	
	Online	

B.2 Piping Components and Properties

Table B.2: Piping Components and Properties

Component	Property	Port Property
Inlet/Outlet Pipes	Fluid Type	
	Liquid Temperature	
Distribution Pipes	Dimensions (Diameter, Length)	Diameter
	Number of Bends	
	Rupture Pressure	
Pipes with Valves	Valve Level	
Energy storage	N/A	
Capacitor	N/A	
Dual Wound Generator	Cooling Required	
	Fuel Rate Required	
Generator (air/liquid cooled)	Cooling Required	
	Fuel Rate Required	
GenSet	Cooling Required	
	Fuel Rate Required	
Motor	Cooling Required	
Transformer	N/A	
PCM	N/A	
Inverter	N/A	
Rectifier	N/A	
ACLC	N/A	
IPNC	N/A	
Pumps	Liquid Mass Flow Rate	
Load	N/A	
Valve	Valve Level	Diameter
Heat Exchanger	Heat Transfer Area	Diameter

Component	Property	Port Property
Heat Exchanger	Heat Transfer Coefficient	
Chiller	Rated Cooling Capacity	Diameter
	Temperature	
	Heat transfer area	
	Dimensions (pipe length)	
	Coefficient of Performance	
	Heat Transfer Coefficient	
Heating Coil	Heat Transfer Area	
	Heat Transfer Coefficient	
Expansion Tank	Nominal Pressure	
Tank	Nominal Pressure	
	Tank Capacity	
	Dimensions (L, W, H)	

B.3 Mechanical Components and Properties

Table B.3: Mechanical Components and Properties

Component	Property	Port Property
Bearing	Dimensions (L,W,H)	Rated Speed
	Maximum Rated Torque	
	Rated Mechanical Power	
	Cooling Required	
	Fluid Type	
Gear Box	Dimensions (L,W,H)	Rated Speed
	Maximum Rated Torque	
	Weight	
Motor	Electrical Percent Power Efficiency Curve	Rated frequency
	Dimensions (L,W,H)	Rated voltage
	Cooling Required/Air Flow Rate	Rated speed
	Fluid Type/Air Cooling Type	
	Efficiency	
	Duct Length	
	Latent Heat	
	Power Level	
Propulsor	Dimensions (L,W,H)	Rated Speed
	Rated Mechanical Power	
	Power Level	
Turbine	Air cooling type/Fluid type	Rated Speed
	Fuel rate required	
	Efficiency	
	Fuel type	
	Dimensions (L,W,H)	
	Max power inlet airflow	

Component	Property	Port Property
Turbine	Rated mechanical power	
	Specific fuel consumption	
	Weight	
Shaft	Dimensions (L,W, H)	Rated Speed
	Maximum Rated Torque	
Energy storage	Current type	
	Rated voltage	
	Charging/Discharge electrical power	
	Dimensions (L, W, H)	
	Weight	

Appendix C

Figures

C.1 Payloads and Adjustments Template Additional Figures

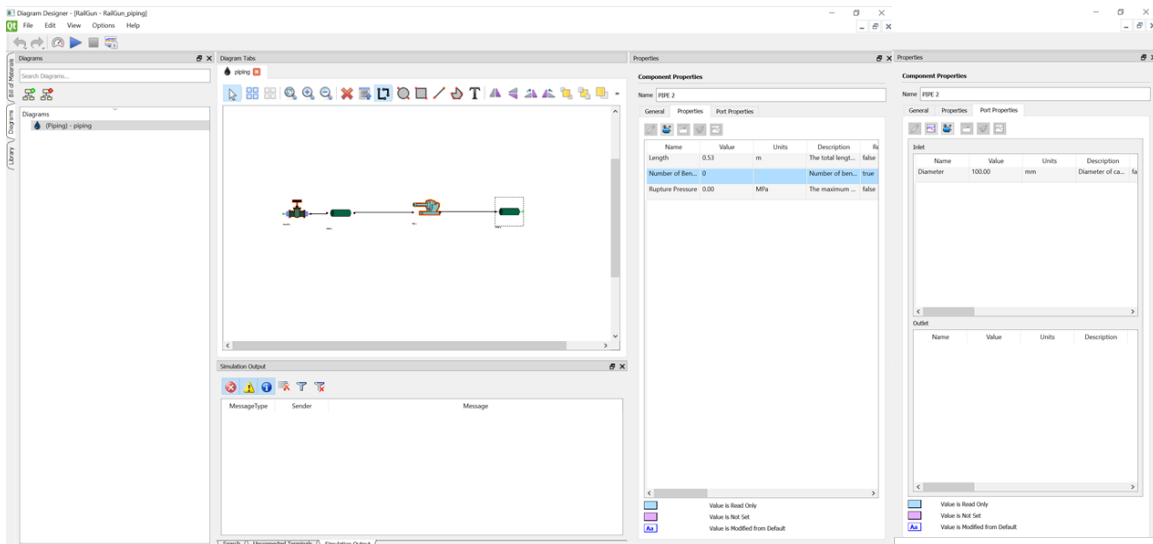


Figure C-1: Choose piping properties

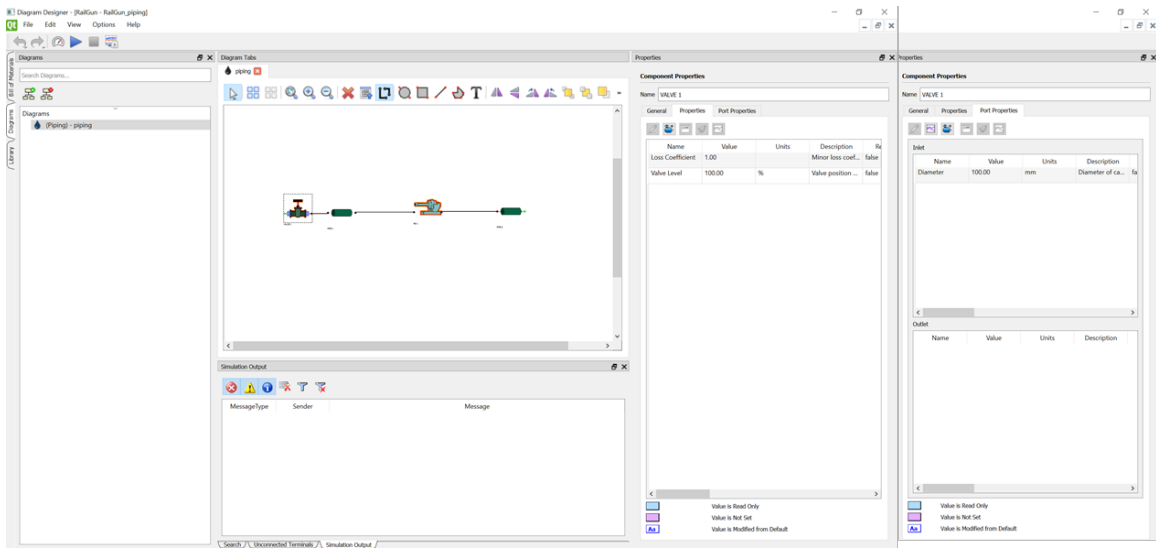


Figure C-2: Choose valve properties

C.2 Power Generation Template Additional Figures

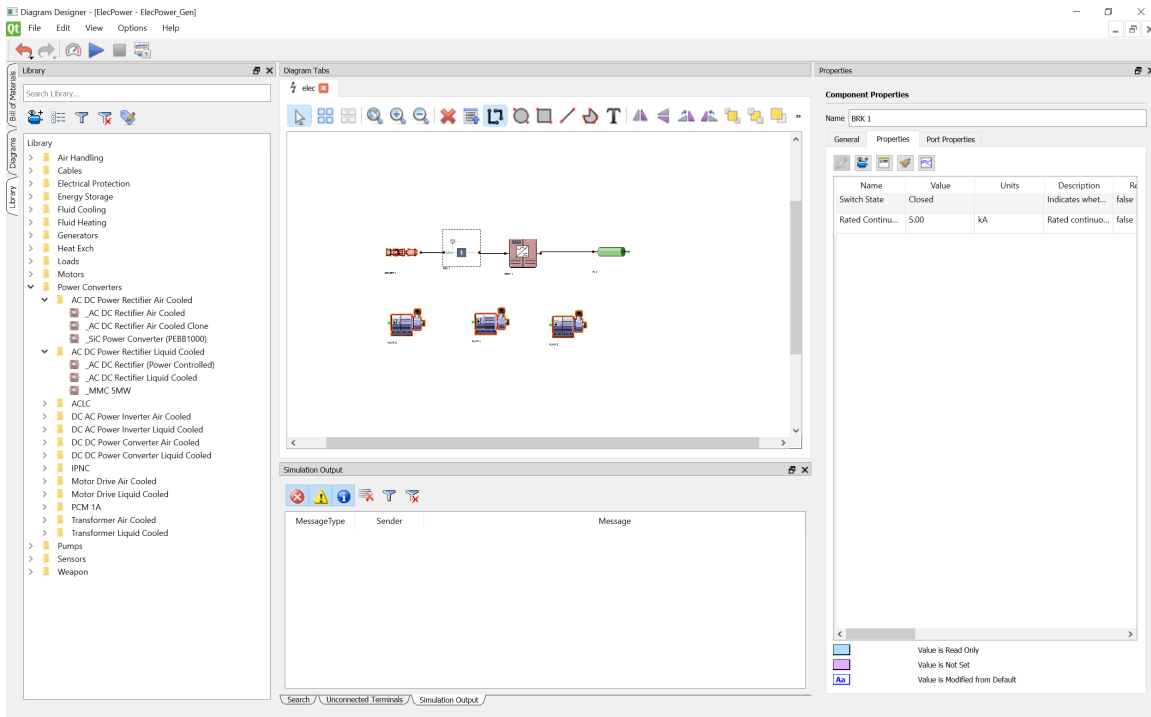


Figure C-3: Choose circuit breaker properties

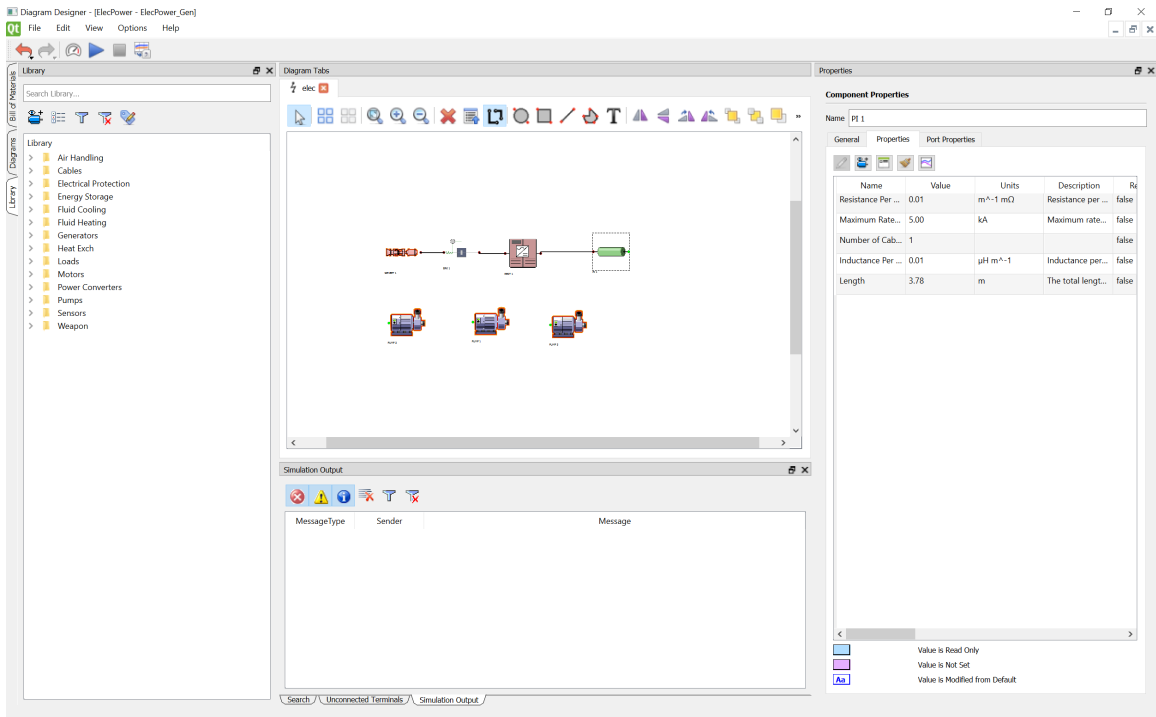


Figure C-4: Choose cabling properties

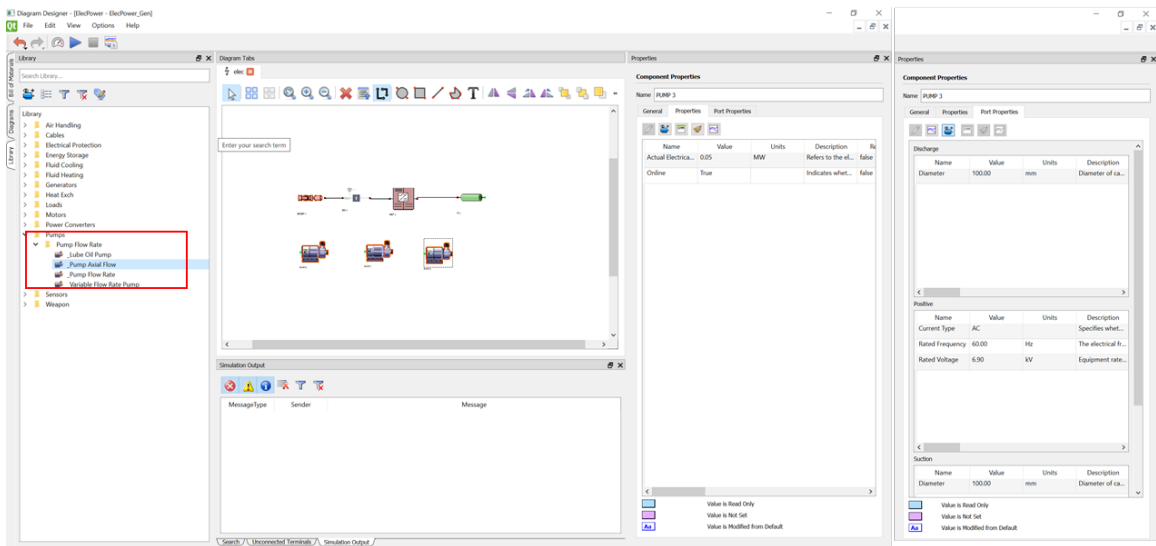


Figure C-5: Choose pump properties

C.3 Power Distribution Template Additional Figures

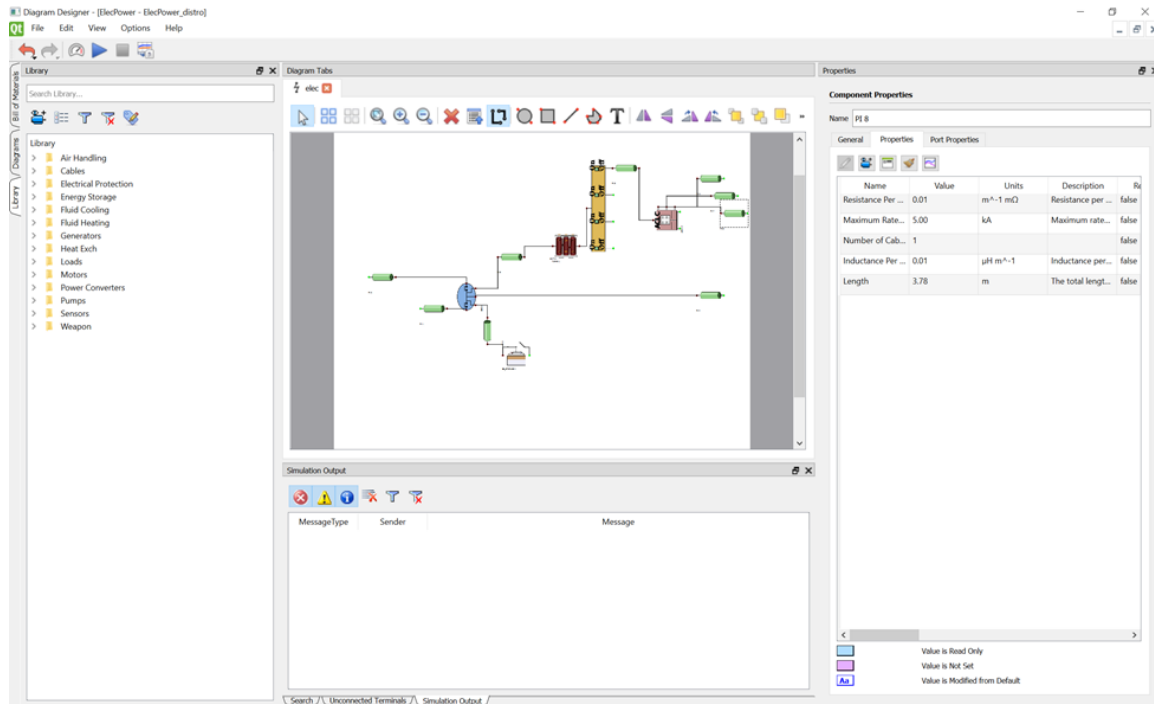


Figure C-6: Choose cabling properties

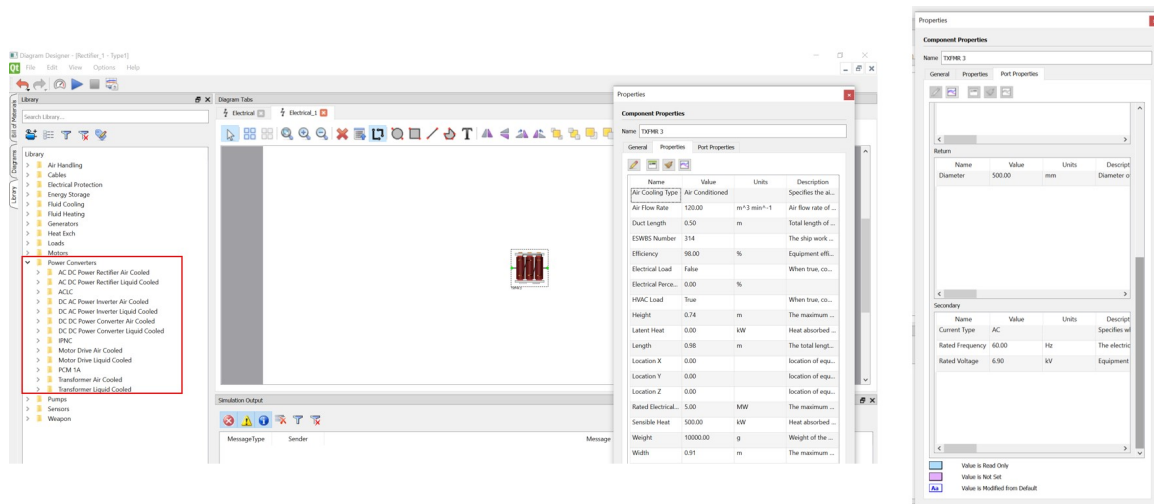


Figure C-7: Choose transformer and associated properties

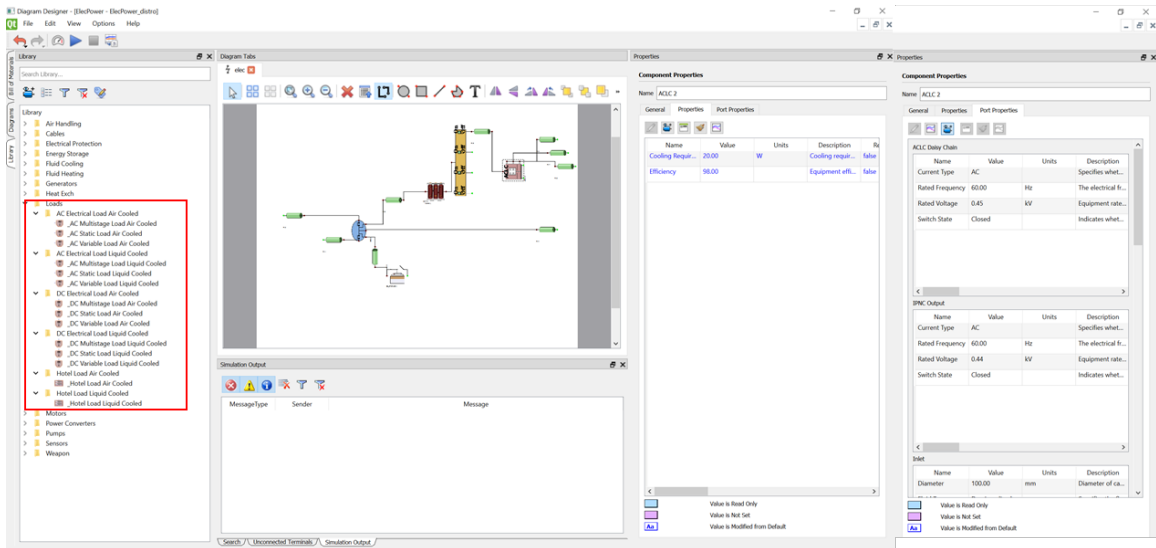


Figure C-8: Choose load center properties

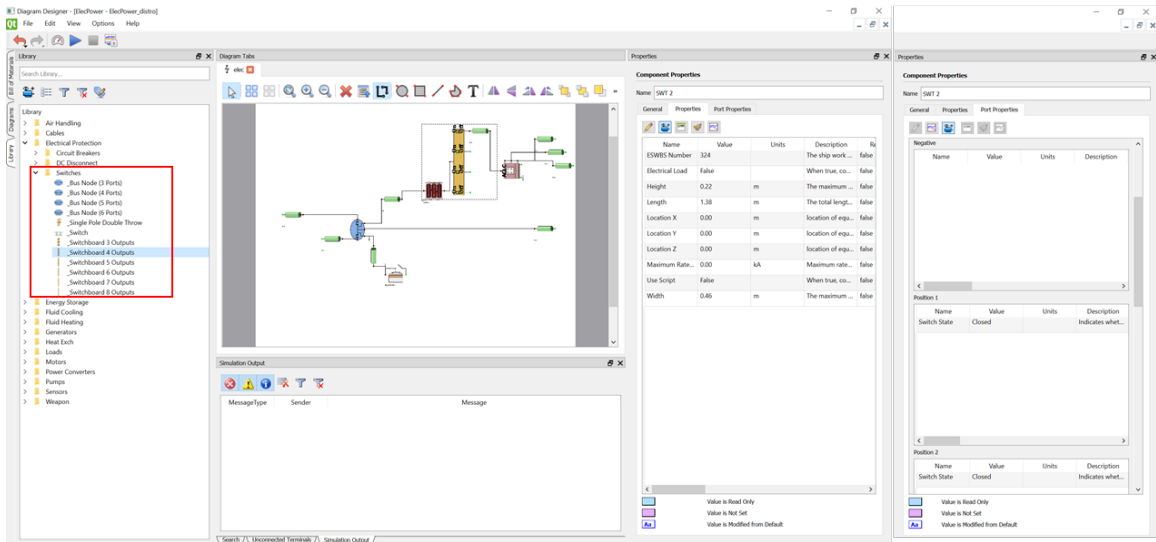


Figure C-9: Choose switchboard properties

C.4 Propulsor Template Additional Figures

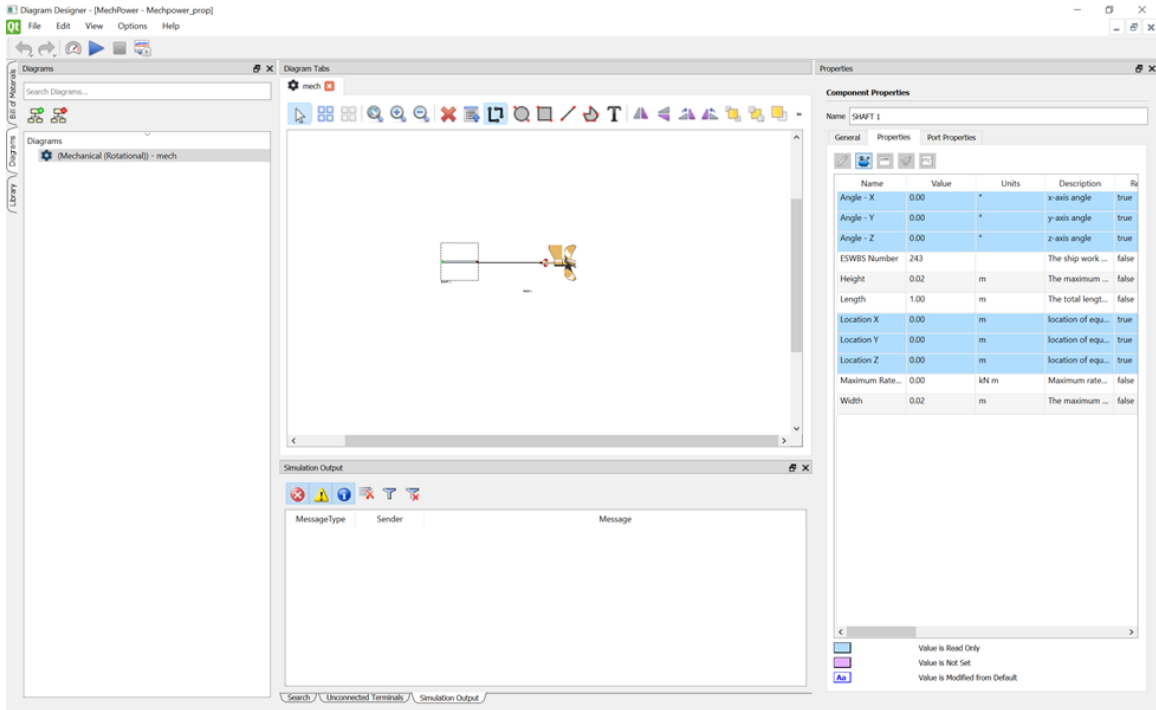


Figure C-10: Choose shafting properties

C.5 Shafting Template Additional Figures

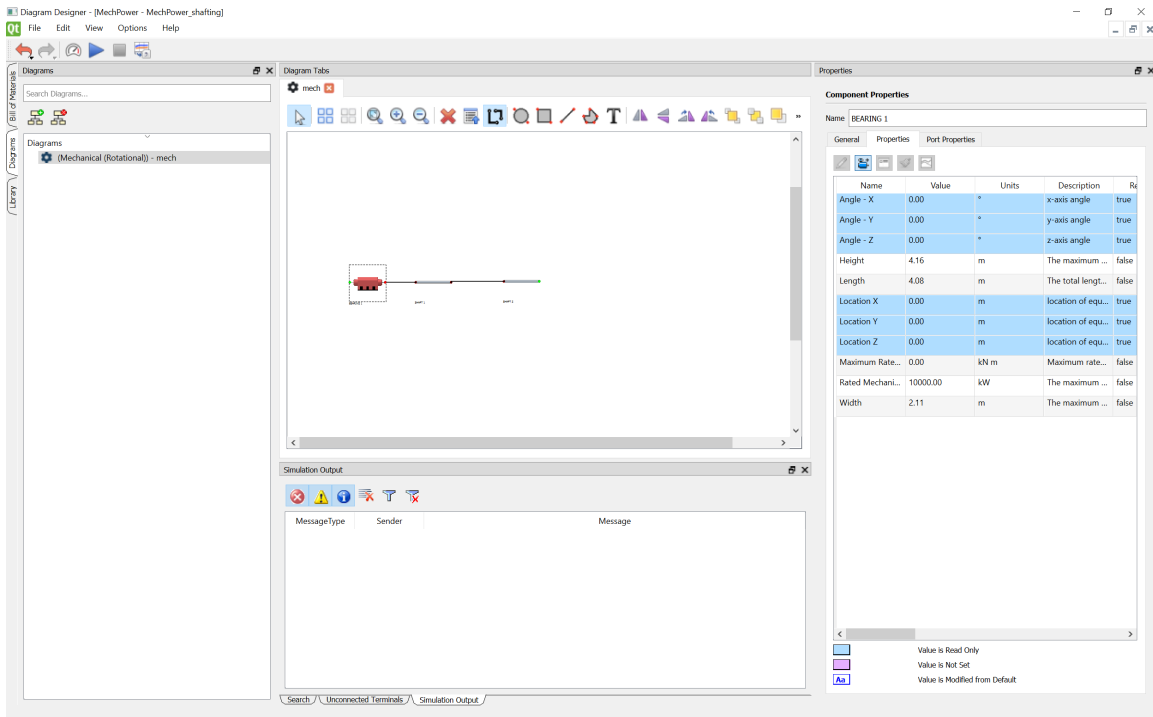


Figure C-11: Choose bearing properties

C.6 Power Transmission Template Additional Figures

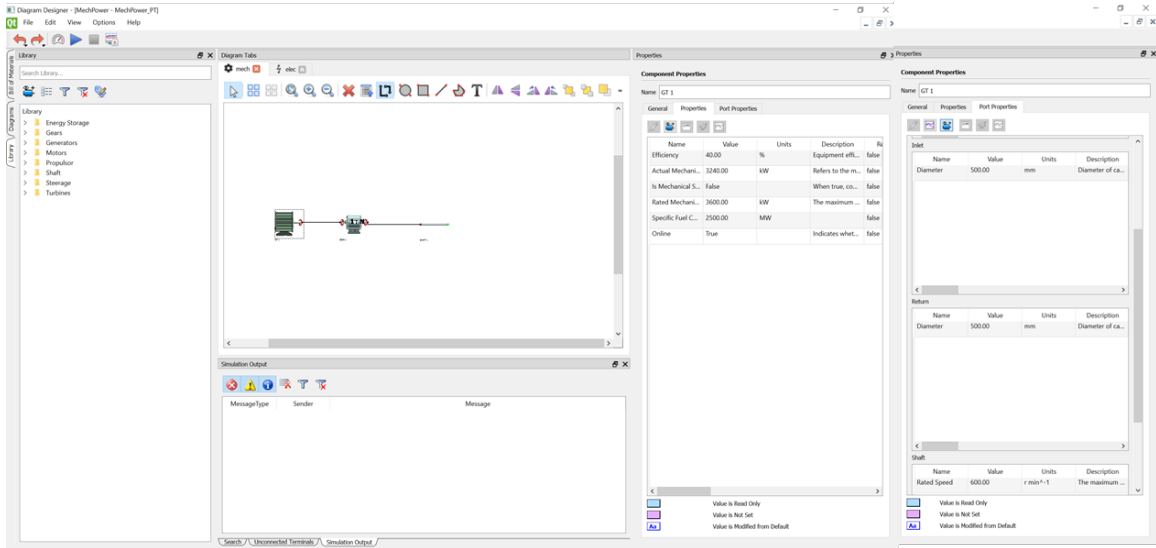


Figure C-12: Choose propulsion set properties

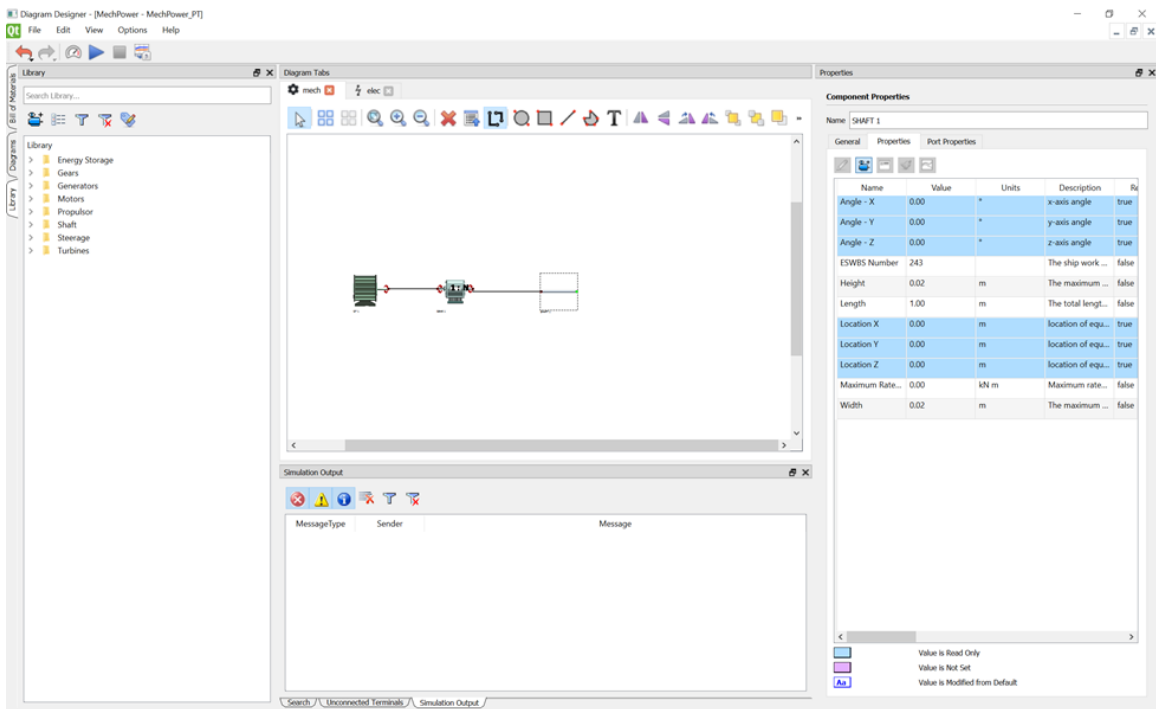


Figure C-13: Choose shafting properties

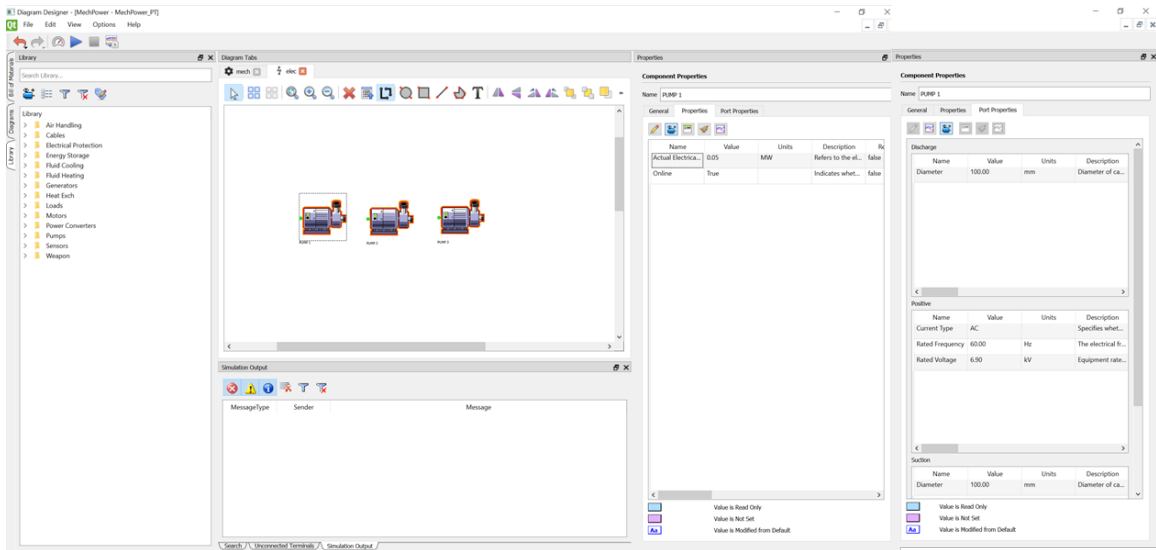


Figure C-14: Choose pump and associated properties

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