Using S3D to Analyze Ship System Alternatives for a 100 MW 10,000 ton Surface Combatant

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Summary

The Electric Ship Research and Development Consortium (ESRDC) conducted an extensive design exercise using the Smart Ship Systems Design (S3D) tool with the goal of exercising and improving the functionality of the S3D design environment currently under development by the ESRDC. To this end, a baseline ship and several variants were designed with a 10,000 ton displacement and a 100 MW integrated power system to explore the effects of new technologies and to determine the capability of S3D in elucidating differences between design variants. Key features and performance effects of each design and an analysis of S3D capabilities are presented.

Motivation

The Smart Ship System Design (S3D) tool is under development to enable concurrent, multi-disciplinary collaboration and introduce simulation capability in early-stage ship design [1]. This work examines the S3D design environment's capabilities in a realistic design exercise. Through the exercising of S3D and the evaluation of competing designs, the team identified capabilities that have been incorporated into S3D as well as a list of desired features.

Results

The team designed a baseline ship and four variants using the S3D environment. A snapshot of the baseline ship design in the Naval Architecture view of the tool is shown in Figure 1. Each electric-drive ship model contains 99 MW of installed power to run the propulsion motors, mission loads and hotel loads. Mission loads include an electromagnetic railgun, laser weapon system, active denial system, vertical launch missile system, dual-band radar, sonar, integrated topside electronic countermeasures and communications, and ship-wide control system.

The ship variants are described below:

- The baseline ship uses a ring bus electrical power distribution system with conventional silicon power electronics at 10 kV dc differential voltage. Liquid-cooled loads are cooled with a chilled water system using parallel supply and return headers in a loop system.
- The high-speed power generation variant replaced the conventional gas turbine generator sets (GTGs) with high-speed versions of the same power level [3]. Since dc power is agnostic to generation frequency, a dc distribution system facilitates inclusion of high-speed GTGs with no gearbox required for synchronizing. Generator size and weight scale with torque, so the high-speed GTGs are significantly lighter and smaller. The only change in this variant was a one-for-one swap of the GTGs.
- The advanced material variant replaced all power electronics with notional converter designs using an advanced semiconductor material, simulating the inclusion of a Silicon-Carbide or Gallium-Nitride-like power electronics technology [4]. This change allowed not only smaller and lighter conversion equipment, but also had cascading benefits of allowing 20 kV distribution voltage and correspondingly lighter cabling. A second benefit is that the power electronics can operate at a higher temperature and thus can be cooled by fresh water instead of chilled water, allowing the replacement of two chiller units with heat exchangers.

- The alternate topology variant provided a different arrangement of the support equipment, in which bus nodes replaced switchboards, in-zone conversion was provided by a single converter, and redundancy for vital loads was provided by cross-connecting the ac load centers in adjacent zones. This design is inspired by the distribution system proposed in [5] with some minor differences necessitated by the models currently available in S3D.
- The mechanical-electric hybrid variant used mechanical drive propulsion supplemented by motor-generators on the main reduction gears, thus allowing more efficient low-speed operations while maintaining maximum speed capability. The capacitor banks supporting the railgun were replaced with pulsed alternators and bi-directional motor-generators [6].

Each design was created within the S3D tool and simulated both in static arrangements and through the mission analyzer tool. Preliminary results are shown in Table 1 and Table 2. A general description of the S3D tool, a discussion of the ship variants and simulation results, and comments on the results and the capabilities of S3D for use in ship design will be provided in the complete paper.

References

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Figures and Tables

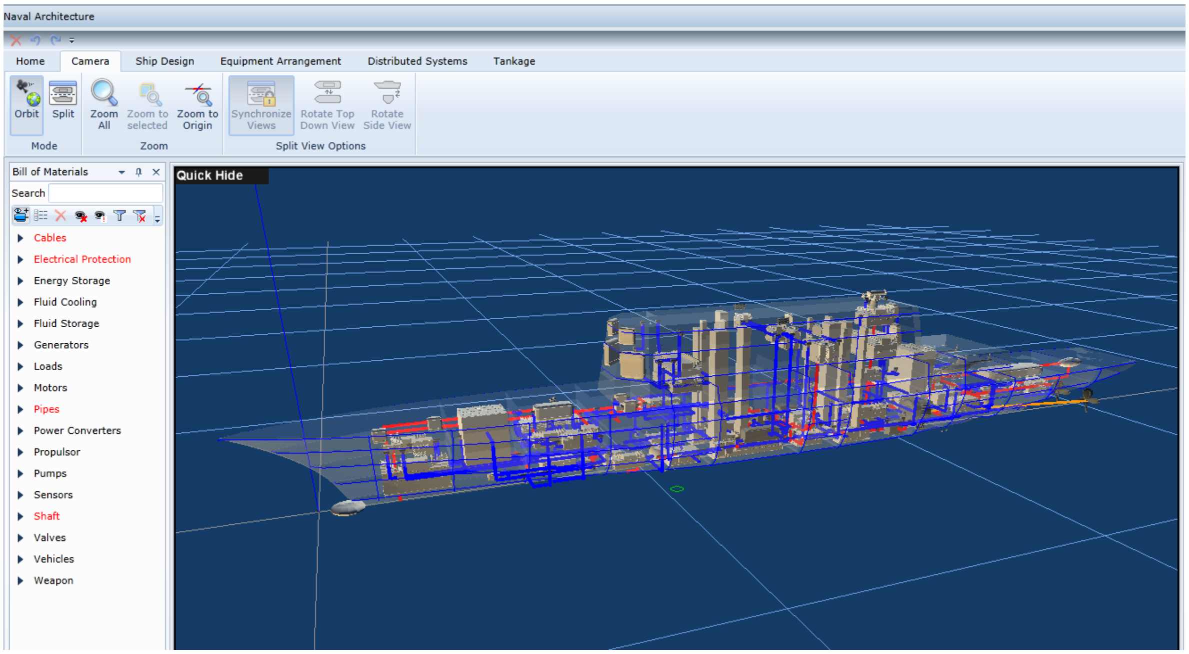

Figure 1 Snapshot from S3D Naval Architecture Tool

Table 1 Weights for each variant: baseline, high-speed generator, advanced materials, and alternate topology. Total weight by category and the change in weight from baseline are shown.

	Total Weight by Category (mton)				Change from Baseline (mton)		
Function	Baseline	HSG	Adv. Matl.	Alt. Topol.	HSG	Adv. Matl.	Alt. Topol.
propulsion	24.7	24.7	21.0	24.7	-	3.7	-
power generation and conversion	510.4	302.7	489.8	473.9	207.7	20.6	36.6
cabling	71.4	68.8	51.9	109.2	-	19.5	(37.8)
switchgear	24.6	24.6	24.6	14.9	-	-	9.8
chiller equipment	245.5	245.5	168.7	245.5	-	76.9	-
piping	76.8	76.8	56.4	74.3	-	20.5	2.5
TOTAL					207.7	141.2	11.0

Table 2. Results

	Baseline	High-Speed Generator	Advanced Materials	Alternate Topology
Number of Components	873	873	867	802
Weight (mton)	1,745	1,538	1,607	1,737
Volume (m^3)	5,583	5,207	5,281	5,337
Range (nm)	49.8	624.3	394.0	94.5
Fuel Consumption (ML)	(under review)			