

**ARCHITECTURAL MODEL TO ENABLE POWER
SYSTEM TRADEOFF STUDIES (PPT presentation)**

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Architectural Model to Enable Power System Tradeoff Studies

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Goal

- Overall architectural model for an all-electric ship
- Fully-integrated physics-based simulation of electrical, hydrodynamic, thermal, and structural components of ship operating in seaway.
- An early-stage design tool capable of performing tradeoff studies on concepts such as
 - AC vs. DC distribution
 - frequency and voltage level
 - energy and power management options
 - effect of arrangements and topology



Metrics

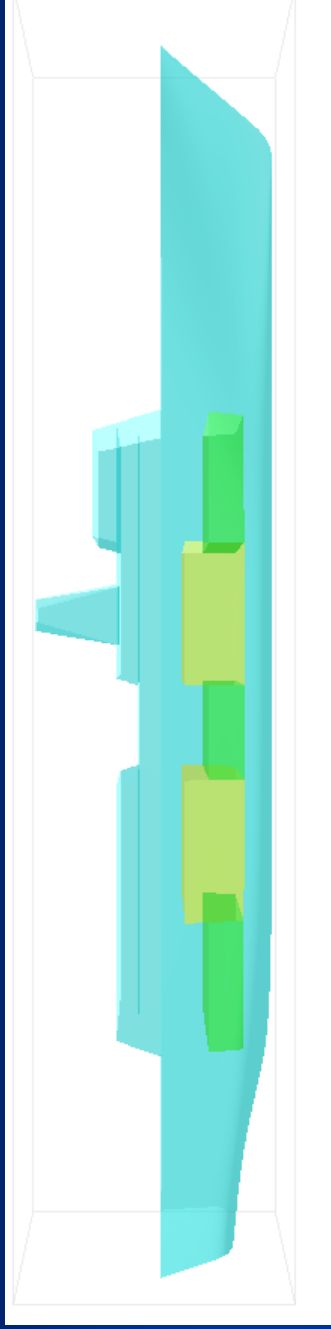
- Weight
- Volume
- Efficiency/Fuel Consumption
- Cost
- Reliability (Quality of Service)
- **Survivability**

hull, mechanical and electrical (HM&E) systems



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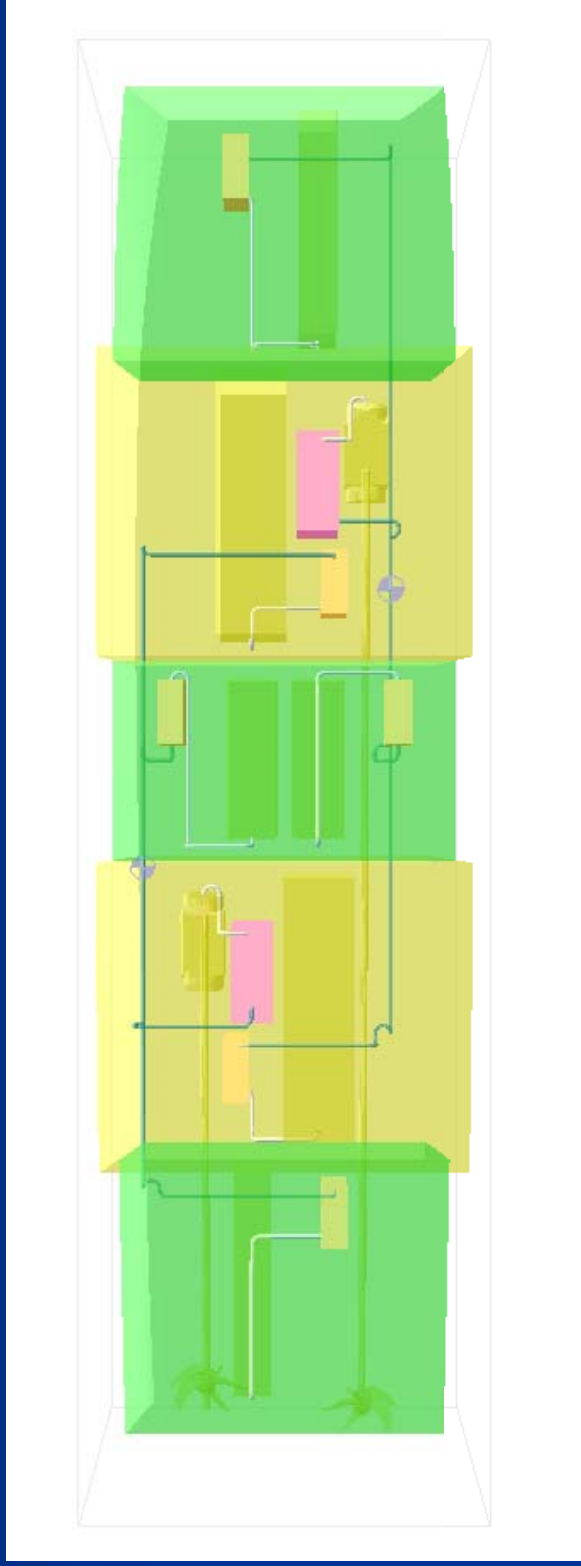
Naval Architecture Model



- Begin with balanced design of ship envelope, bulkheads, decks
- Zonal arrangement of major equipment
- Zonal distribution of systems
- Tool used: Paramarine
- Very high level model but can monitor usual naval architecture criteria (LCG, VCG, GM, Floodable Length)



Distributed System Model

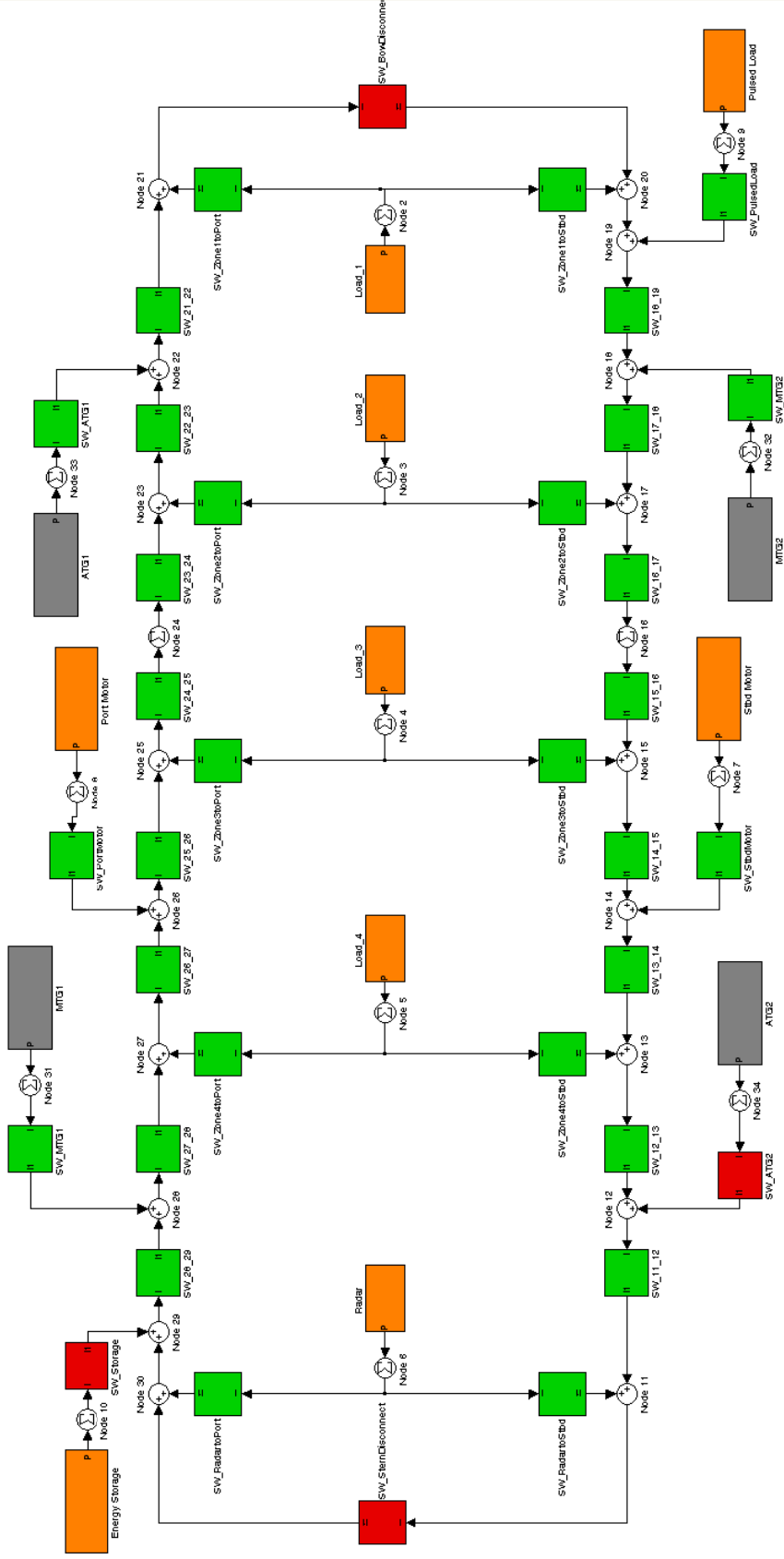


Paramarine



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Distributed System Model



Distributed System Model

Electrical Loads

- Propulsion
- Radar
- Pulsed Weapon
- Load Centers in each zone
- Energy Storage

Distribution System

- Zonal Distribution
- Ring Bus (initially)
- Load Centers modeled as lump parameters
- Switches included for isolation



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Damage Model

- Center and radius
- Anything within radius is destroyed
- Trace systems back to first undamaged isolation point



Overall Architectural Model

- Notional Ship
- Survivability Metric



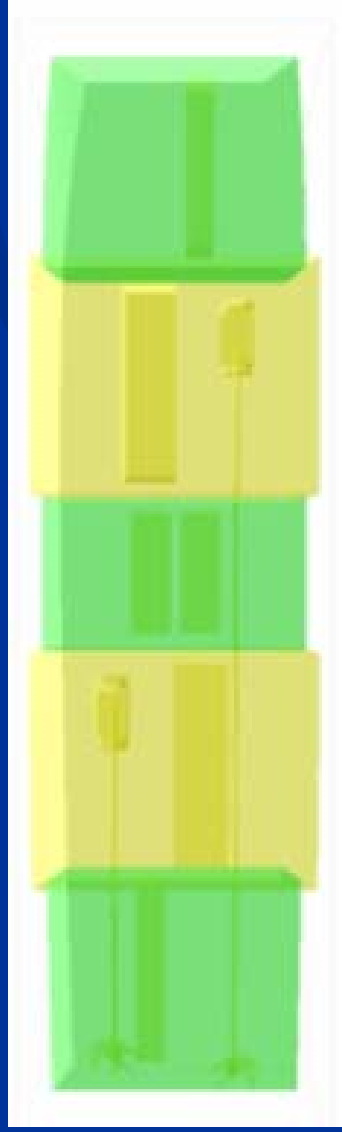
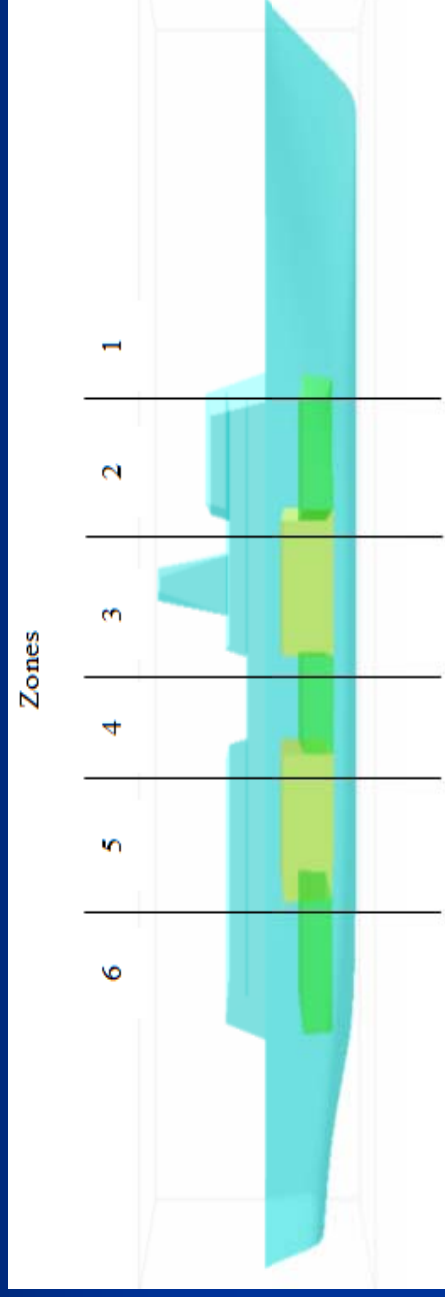
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Paramarine Design

- Began with a balanced low-level Frigate design
- Initial power requirements
 - 80MW Propulsion
 - 37MW Estimated future electric loading
- 6 vertical zones
 - At least 1 PGM per zone (except 1 – ESM?)



Zonal and Machinery Layout



Design Challenges/Possible Solutions

- Gas turbine exhaust, fore and aft
 - Diesels would give more flexibility
 - Moving the bridge location
 - Restricting Helo operations
- PMM placement
 - Poded propulsion



Survivability Metric

- Manageable scope - useful in early stage design
- Prioritizing loads:
 - Survive the damage
 - Continue to operate
 - Perform its mission
- Can be applied to:
 - Electrical Power
 - Chill water
 - Seawater
 - Ventilation
- Changes in fidelity of analysis by altering level of system detail



Electric Load Priority

1. Power Generation
 - PGMs and required auxiliaries
2. Damage Control
 - Fire fighting, dewatering, IC
3. Basic Mobility
 - 4kt propulsion and steering system
4. Self Defense
 - Sufficient sensors and weapons
5. Exterior Communications
 - All excomms
6. Helo and Boat Recovery
 - Lights, RAST, boat davits
7. Increase Speed to 10 knots
8. Basic Offense
 - Min Radar, weapon, ship control sys
9. Full Flight Operations
 - All flight equipment incl. refueling
10. Increased Offense
 - Medium Radar, addl weapons
11. Increase Speed to 20 knots
12. Miscellaneous Mechanical systems
 - Compressors, RO units, etc.
13. Full Offense
 - Full Radar, hi-energy weapon
14. Increase Speed to 25 knots
15. All non-vital loads
 - Laundry, Galley, heat, etc.
16. Increase to Maximum Speed



Proposed Survivability Tiers

A	Ship likely to be lost with the loss of over 25% embarked personnel
B	Ship likely to be lost with the loss 25% or under embarked personnel
C	Does not meet Power Generation and Damage Control - Ship's status is likely to continue to degrade
D	Meets Power Generation and Damage Control- Ship is able to combat existing damage but is vulnerable to further threats.
E	Meets Basic Mobility and Self Defense - Is able to sustain itself against the enemy.
F	Meets Exterior Communications and Helicopter and Boat Recovery - Basic functionality without offense.
G	Meets Increased Speed, Basic Offense - Can perform at least one primary mission
H	Meets Full Flight Operations and Increased Offense - Can perform most or all primary missions
I	Meets Increased Speed, Mechanical Services and Full Offense - As far as a military asset, unaffected
J	Complete functionality - all loads are filled

Survivability Calculation – First Metric

- Highest tier achieved while also meeting lower tier requirements
- To meet the tier requirements the Boolean statement must be satisfied
 - Example to meet Self Defense:
 - SeaRAM OR sensor AND decoy system
 - Example to meet Tier E:
 - Self Defense AND Basic Mobility AND Tier D - implies previous Tiers

Survivability Calculation – Second Metric

- Total load value of all system loads that can be serviced
- Uses surviving Generators and loads along with surviving connectivity to return a weighted score



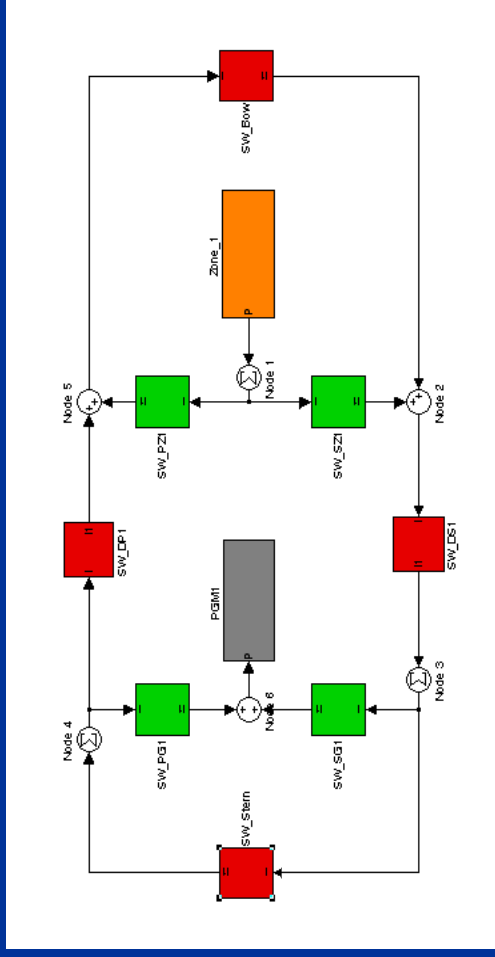
Survivability Metric Calculation

- Calculation process
 - Dijkstra's algorithm
 - linear programming
- Four examples
 - full operation
 - large PGMs isolated
 - zones isolated
 - zone 4 damaged



Dijkstra's Algorithm

- calculates the lowest weight path
- from a single node to each other node
- in a directed, weighted graph

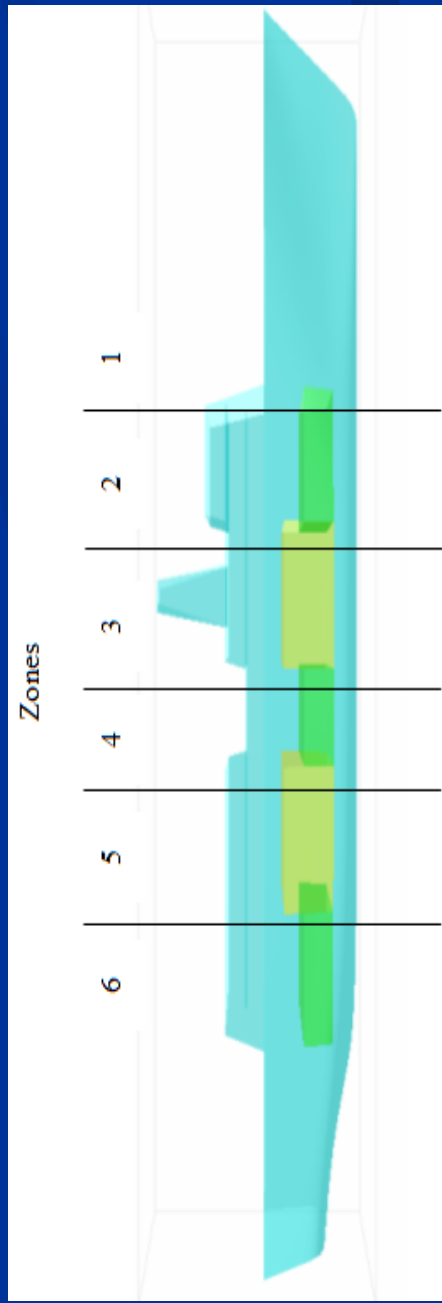
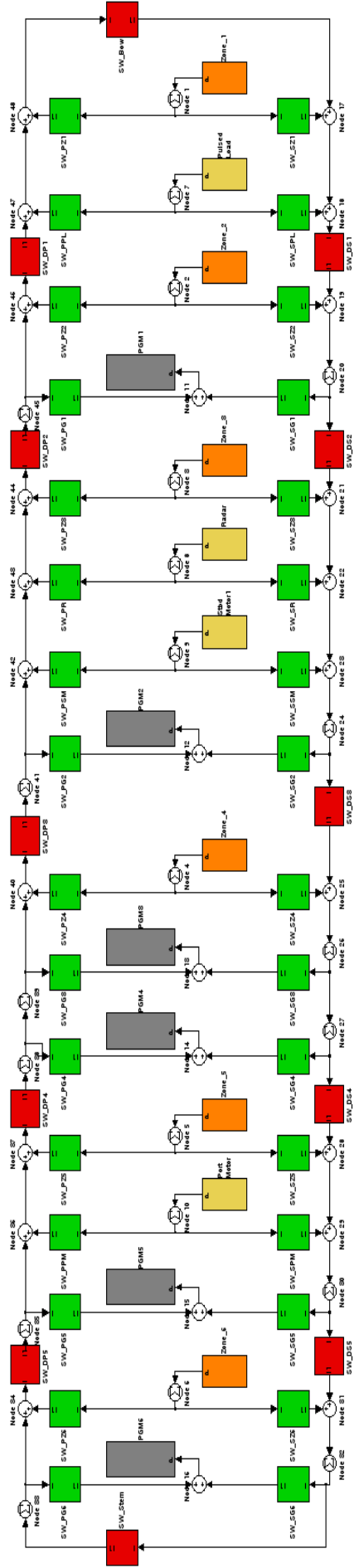


Linear Programming

- find the maximum of $f^* x$
- where f_i is the weight/priority of filling load x_i
- subject to linear constraints such that
 - total power supplied by a generator \leq the capacity of the generator,
 - the total power supplied to a load \leq the size of the load,
 - a generator only supplies power to a load for which connectivity exists between the generator and the load.



Ring Bus with ZEDS

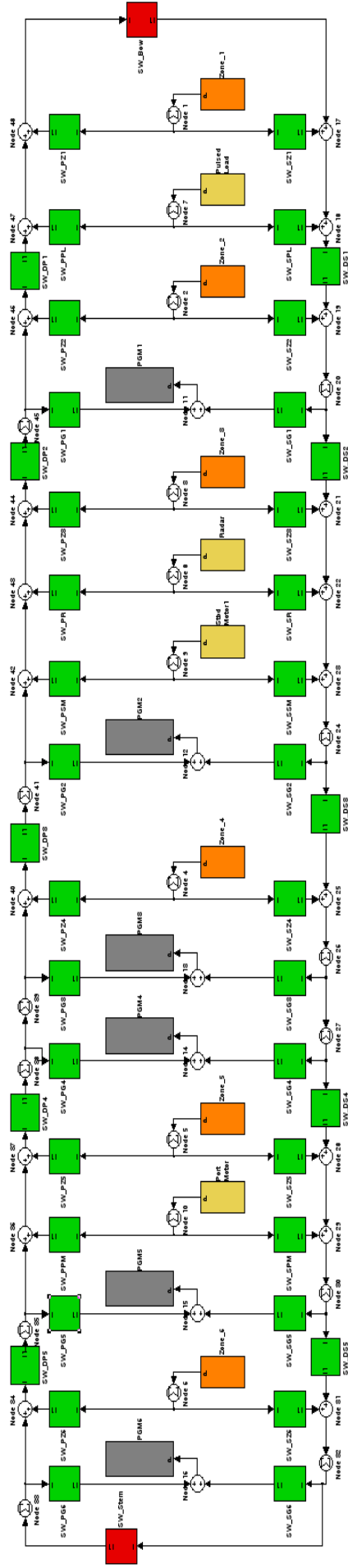


- Zonal Load
- Centers
- Propulsion
- Radar
- Pulsed Weapon

Loads

Priority		Weight	1	2	3	4	5	6	PULSE	RADAR	STBD PMM	PORT PMM
1	POWER GENE	17	3	107	140	130	140	128	-	-	-	-
2	DC	16	84	92	92	82	104	180	-	-	-	-
3	BASIC MOBILITY	15	-	-	5	-	-	100	-	-	700	-
4	SELF DEFENSE	14	100	40	3	8	-	95	-	-	-	-
5	EXCOMM	13	-	22	63	-	-	-	-	-	-	-
6	HELO/BOAT	12	-	-	-	-	-	5	-	-	-	-
7	10 KTS	11	-	-	-	-	-	-	-	-	3,500	-
8	BASIC OFFENSE	10	167	194	127	58	27	74	-	410	-	-
9	FULL FLIGHT OPS	9	-	-	-	-	-	7	-	-	-	-
10	INCR OFFENSE	8	115	-	1,000	101	-	-	-	3,600	-	-
11	20 KTS	7	-	-	-	-	5	-	-	-	4,950	8,450
12	MISC MECH	6	6	30	6	6	12	12	-	-	-	-
13	FULL OFFENSE	5	-	-	-	-	100	100	20,000	5,625	-	-
14	25 KTS	4	-	-	-	-	-	-	-	-	7,700	7,700
15	NON-VITAL	3	55	144	105	74	101	134	-	-	-	-
16	MAX SPEED	2	-	-	-	-	-	-	-	-	23,500	23,500

Full Operation



■ Survivability Tier J: Complete functionality - all loads are filled

■ Survivability Score = 100%

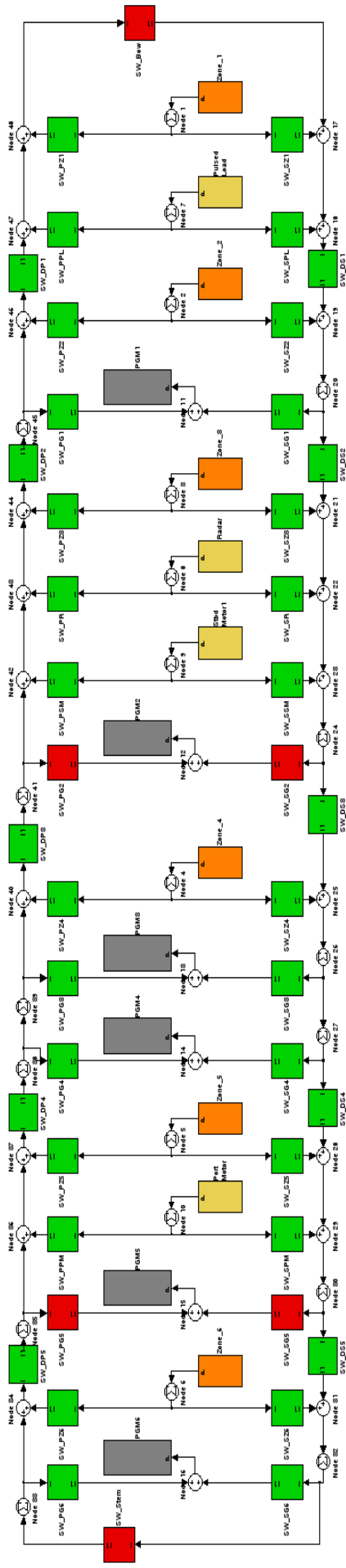


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Full Operation

	1	2	3	4	5	6	PULSE	RADAR	STBD	PORT
									PMM	PMM
POWER GENE	100	100	100	100	100	100	--	--	--	--
DC	100	100	100	100	100	100	--	--	--	--
BASIC MOBILITY	--	--	100	--	--	100	--	--	100	100
SELF DEFENSE	100	100	100	100	--	100	--	--	--	--
EXCOMM	--	100	100	--	--	--	--	--	--	--
HELLO/BOAT	--	--	--	--	--	100	--	--	--	--
10 KTS	--	--	--	--	--	--	--	--	100	--
BASIC OFFENSE	100	100	100	100	100	100	--	100	--	--
FULL FLIGHT OPS	--	--	--	--	--	100	--	--	--	--
INCR OFFENCE	100	--	100	100	--	--	--	100	--	--
20 KTS	--	--	--	--	100	--	--	--	100	100
MISC MECH	100	100	100	100	100	100	--	--	--	--
FULL OFFENSE	--	--	--	--	100	100	100	100	--	--
25 KTS	--	--	--	--	--	--	--	--	100	100
NON-VITAL	100	100	100	100	100	100	--	--	--	--
MAX SPEED	--	--	--	--	--	--	--	--	100	100

Large PGMs Isolated



- Survivability Tier I: Meets Increased Speed, Mechanical Services and Full Offense - As far as a military asset, unaffected
- Survivability Score = 92%

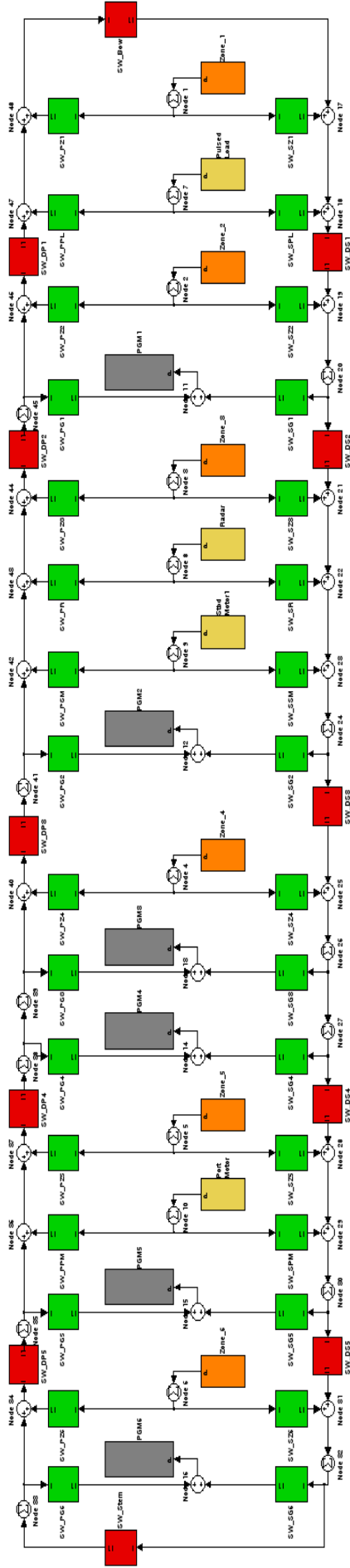


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Large PGMs Isolated

	1	2	3	4	5	6	PULSE	RADAR	STBD	PORT
									PMM	PMM
POWER GENE	100	100	100	100	100	100	--	--	--	--
DC	100	100	100	100	100	100	--	--	--	--
BASIC MOBILITY	--	--	100	--	--	100	--	--	100	100
SELF DEFENSE	100	100	100	100	--	100	--	--	--	--
EXCOMM	--	100	100	--	--	--	--	--	--	--
HELLO/BOAT	--	--	--	--	--	100	--	--	--	--
10 KTS	--	--	--	--	--	--	--	--	100	--
BASIC OFFENSE	100	100	100	100	100	100	--	100	--	--
FULL FLIGHT OPS	--	--	--	--	--	100	--	--	--	--
INCR OFFENCE	100	--	100	100	--	--	--	100	--	--
20 KTS	--	--	--	--	100	--	--	--	100	100
MISC MECH	100	100	100	100	100	100	--	--	--	--
FULL OFFENSE	--	--	--	--	75	75	93	72	--	--
25 KTS	--	--	--	--	--	--	--	--	0	0
NON-VITAL	0	0	0	0	0	0	--	--	--	--
MAX SPEED	--	--	--	--	--	--	--	--	0	0

Zones Isolated

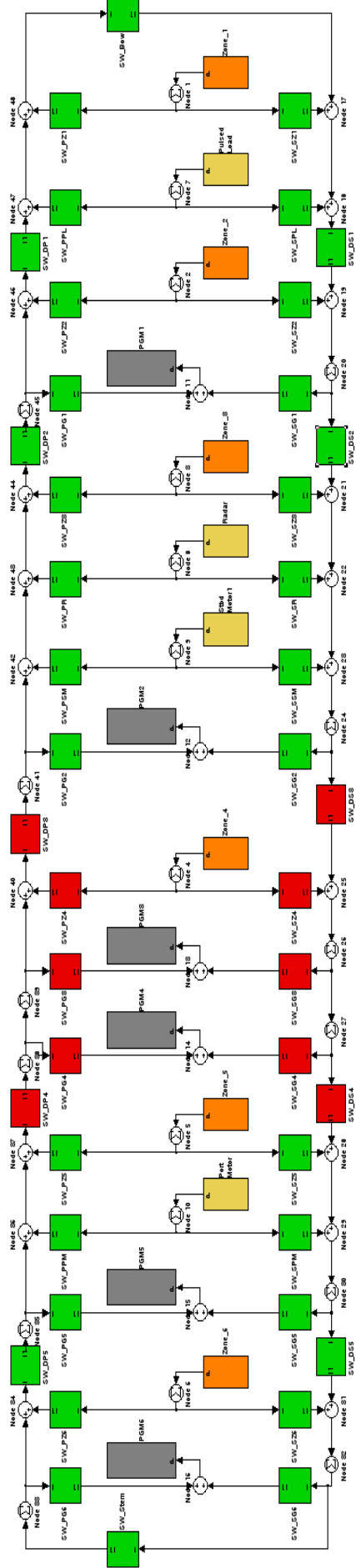


- Survivability Tier H: Meets Full Flight Operations and Increased Offense - Can perform most or all primary missions
- Survivability Score = 73%

Zones Isolated

	1	2	3	4	5	6	PULSE	RADAR	STBD	PORT
									PMM	PMM
POWER GENE	0	100	100	100	100	100	--	--	--	--
DC	0	100	100	100	100	100	--	--	--	--
BASIC MOBILITY	--	--	100	--	--	100	--	--	100	100
SELF DEFENSE	0	100	100	100	--	100	--	--	--	--
EXCOMM	--	100	100	--	--	--	--	--	--	--
HELO/BOAT	--	--	--	--	--	100	--	--	--	--
10 KTS	--	--	--	--	--	--	--	--	100	--
BASIC OFFENSE	0	100	100	100	100	100	--	100	--	--
FULL FLIGHT OPS	--	--	--	--	--	100	--	--	--	--
INCR OFFENSE	0	--	100	100	--	--	--	100	--	--
20 KTS	--	--	--	--	100	--	--	--	100	100
MISC MECH	0	100	100	100	100	100	--	--	--	--
FULL OFFENSE	--	--	--	--	100	100	0	100	--	--
25 KTS	--	--	--	--	--	--	--	--	100	100
NON-VITAL	0	100	100	100	100	100	--	--	--	--
MAX SPEED	--	--	--	--	--	--	--	--	35	81

Zone 4 Damaged



- Survivability Tier I: Meets Increased Speed, Mechanical Services and Full Offense - As far as a military asset, unaffected
- Survivability Score = 94%

Zone 4 Damaged

	1	2	3	4	5	6	PULSE	RADAR	STBD	PORT
									PMM	PMM
POWER GENE	100	100	100	0	100	100	--	--	--	--
DC	100	100	100	0	100	100	--	--	--	--
BASIC MOBILITY	--	--	100	--	--	100	--	--	100	100
SELF DEFENSE	100	100	100	0	--	100	--	--	--	--
EXCOMM	--	100	100	--	--	--	--	--	--	--
HELO/BOAT	--	--	--	--	--	100	--	--	--	--
10 KTS	--	--	--	--	--	--	--	--	100	--
BASIC OFFENSE	100	100	100	0	100	100	--	100	--	--
FULL FLIGHT OPS	--	--	--	--	--	100	--	--	--	--
INCR OFFENSE	100	--	100	0	--	--	--	100	--	--
20 KTS	--	--	--	--	100	--	--	--	100	100
MISC MECH	100	100	100	0	100	100	--	--	--	--
FULL OFFENSE	--	--	--	--	100	100	100	100	--	--
25 KTS	--	--	--	--	--	--	--	--	100	100
NON-VITAL	100	100	100	0	100	100	--	--	--	--
MAX SPEED	--	--	--	--	--	--	--	--	28	100

Summary

- Overall Architectural Model
 - Notional Ship
 - Distribution System
 - Damage Model
 - Metrics
- **Two-fold Survivability Metric**
 - Survivability Tiers
 - Survivability Score



Backup Slide



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Proposed Survivability Tiers

A	Ship likely to be lost with the loss of over 25% embarked personnel
B	Ship likely to be lost with the loss 25% or under embarked personnel
C	Does not meet Power Generation and Damage Control - Ship's status is likely to continue to degrade
D	Meets Power Generation and Damage Control- Ship is able to combat existing damage but is vulnerable to further threats. Minimum requirements: one operational generator with associated auxiliaries, two firepumps.
E	Meets Basic Mobility and Self Defense - Is able to sustain itself against the enemy. Minimum requirements: achieve 4 knots with steering, one self-defense system (either a CIWS/SeaRAM or a sensor and associated missile decoy system).
F	Meets Exterior Communications and Helicopter and Boat Recovery - Basic functionality without offense. Minimum requirements: one operational mode of exterior communications, close-in radar, able to recover helicopter and boat.
G	Meets Increased Speed and Basic Offense - Can perform at least one primary mission Minimum requirements: operate at 10 knots, perform one primary mission.
H	Meets Full Flight Operations and Increased Offense - Can perform most or all primary missions Minimum requirements: flight operations, two primary missions
I	Meets Increased Speed, Mechanical Services and Full Offense - As far as a military asset, unaffected Minimum requirements: power to all loads at this level and below
J	Complete functionality - all loads are fulfilled Minimum requirements: fulfill all loads, including non-vital loads