NAVSEA
NAVAL SEA SYSTEMS COMMAND

US Navy Railgun and LASER Weapon System Intro and Power Requirements

14th Directed Energy Test & Evaluation Workshop

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DISTRIBUTION STATEMENT A:
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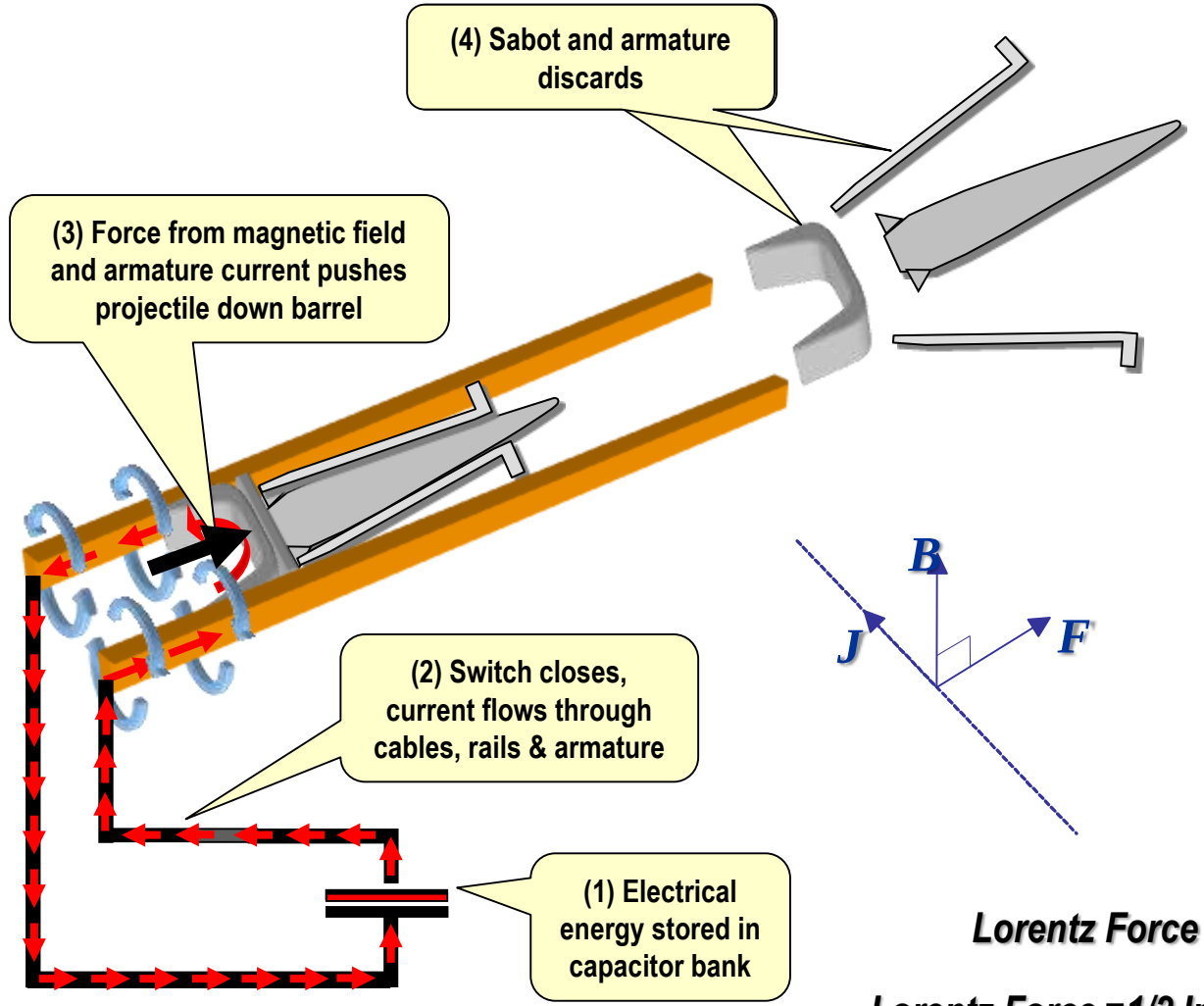
Overview

- Railgun / Solid State Laser Overview
- Power Response: An Analogous Situation
- Energy Storage and Power Response
- Future Needs: Energy Storage
- Conclusions

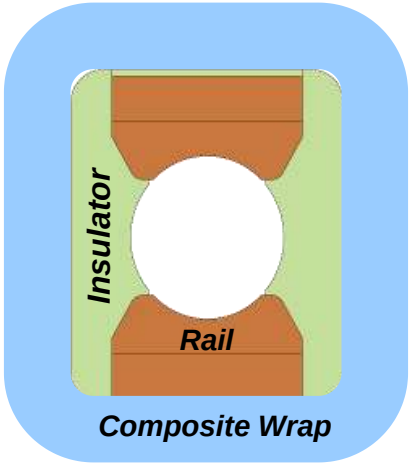
Railgun Intro

How Railgun Works

Operating Principle



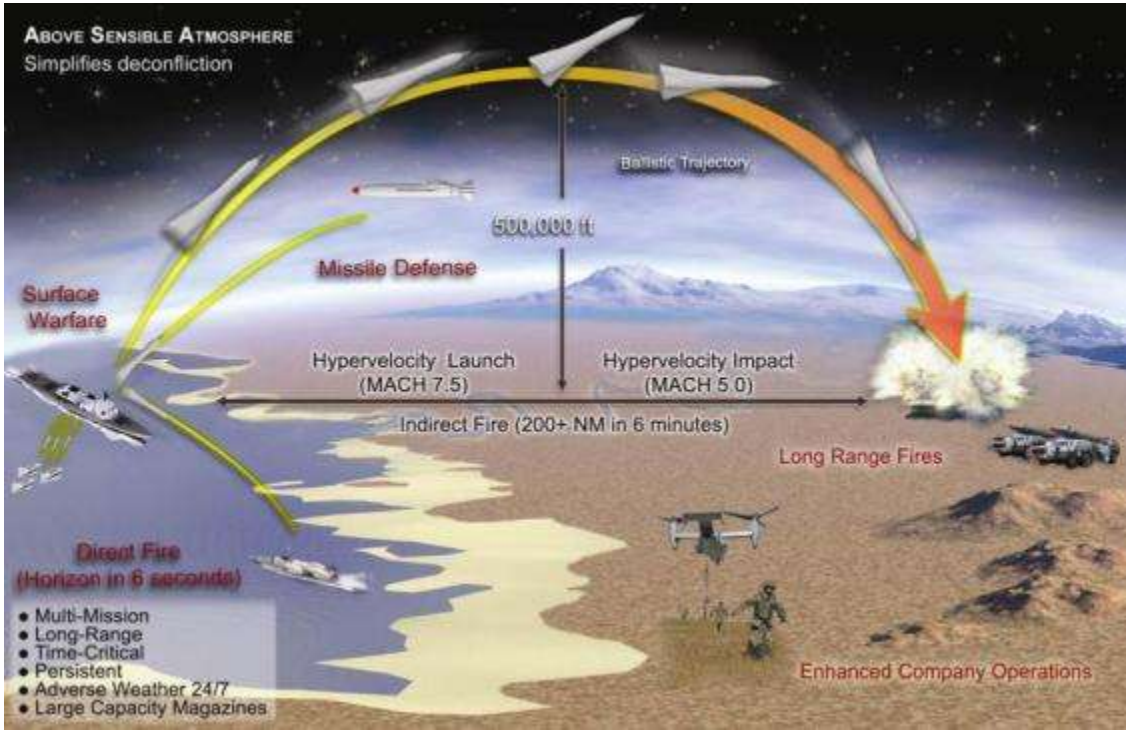
Cross-Section



Lorentz Force = Current (J) X Magnetic Field (B)
or
Lorentz Force =1/2 Inductance Gradient (L') * Current (I)^2

Railgun Operational Impact

- *Wide Area Coverage*
  - Increased speed to target
  - 200+ NM
- *Accelerates operational tempo*
  - Faster attrition of enemy personnel and equipment
  - Operation timeline shifts left
- *Reduces Cost per Kill*
  - Lower Unit Cost
  - Lower handling cost
- *Enhances Safety*
  - No risk of sympathetic detonation
  - Simplified storage, transportation and replenishment
  - Reduced collateral damage
  - No unexploded ordnance on battlefield
- *Reduces Logistics*
  - Eliminates gun powder trail
  - Deep magazines

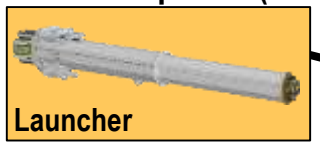


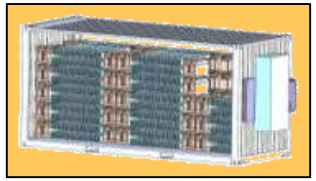
- *Multi-Mission Capability*
  - *Surface Warfare*
  - *Missile Defense*
  - *Long Range Fires*
  - *Direct Fire*
  - *ASuW*

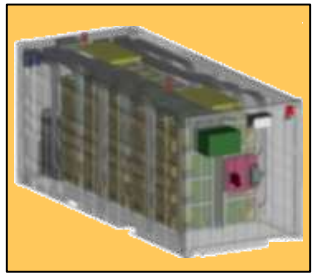
Multi-Mission Capable for Offense and Defense

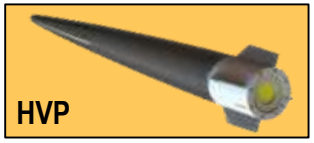
Railgun Development

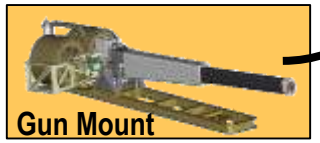
Technology Development (ONR)	Technology Demonstrations (SCO, NAVSEA, ONR)	System Acquisition	System Deployment











JHSV Demo

Maritime Specific Engineering

GPS Targeting

Hardware
Expertise
Software
Program Mgmt
Contracts

Closed-Loop Fire Control

Stressing Missile Threats

Land Defense Demo

MS B

Multi-use Modular Railgun System

US Navy Combatant

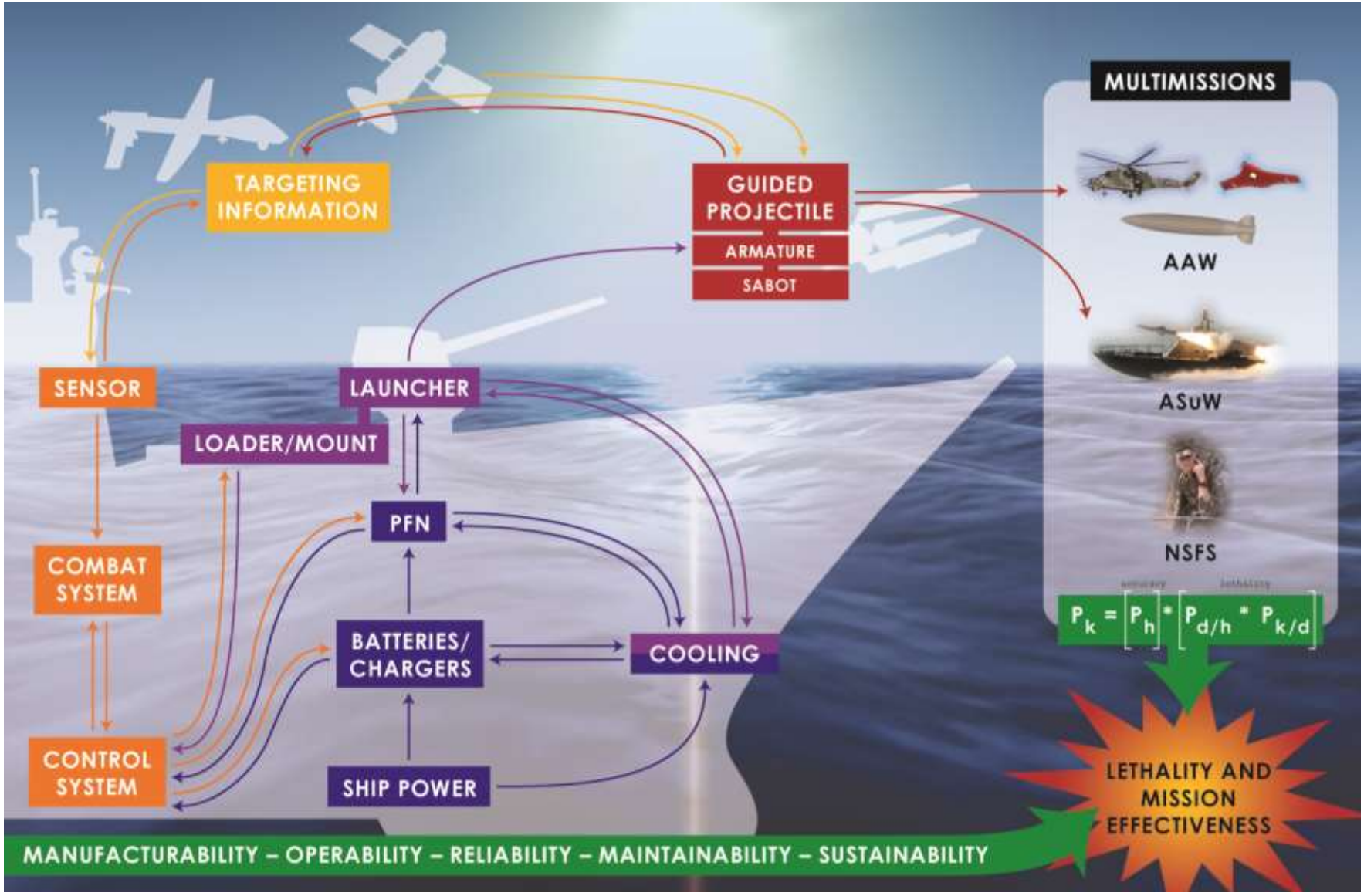
Land Defense

Multiple Deployment Options

Kinetic Energy Conversion

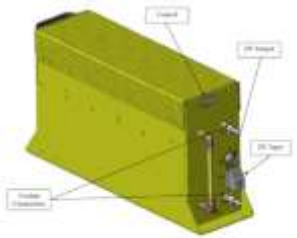
Lethality Demonstration - EMRG

Railgun System Integration



Advanced Power/Energy Systems

High Density Power Electronics

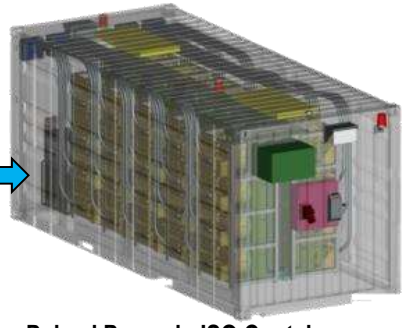


High Voltage Charging Module

- Charging Power Supplies for Advanced Energy Systems
- Converting Ship's Power to High Voltage for Electric Weapons
- Supports Electric Drive, Railguns, Lasers & Radars

Pulsed Forming Network

Actively Cooled Rep-Rate Pulsed Power Module



Pulsed Power in ISO Container for Mobility & Demo Platform Flexibility

- Capacitor based PFN
- Higher Energy Density lowers shipboard volume/footprint
- Rep rate operation & thermal management

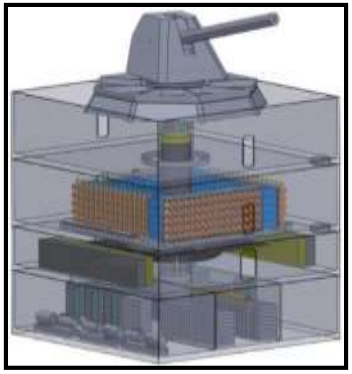
Battery Energy Storage

Lithium Ion Battery Packet

Battery Energy Storage in ISO Container for Mobility & Demo Platform Flexibility

- Energy Storage to buffer Prime Generators
- Ready Reserve Energy for response to "quick" threats
- Requires close Ship Safety Design, Test & Monitoring

System / Ship Integration



- Dynamic power sharing across platform
- Designing with Space and Weight Constraints
- Assessing Thermal and EM Field management

NAVSEA
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National Partners

Key: Industry University SBIR/STTR DoD DOE NASA

WESTERN		
WA	Precision Machine Works	
CA	NWL Meggitt L3 Lawrence Livermore National Lab	General Atomics Naval Post Grad School Technovative Applications General Dynamics NAWC
NV	K2	
NM	Micro Craft Sandia National Lab	KTECH White Sands Missile Range
AZ	MER	Raytheon
TX	University of Texas	

CENTRAL		
MN	BAE Systems	
IA	Rockwell Collins	
MO	Boeing University of Missouri	
OH	IAP Research	
MS	General Atomics	
AL	MSIC/Redstone Arsenal	Parsons

EASTERN		
VT	Arrow Tech General Dynamics	UTC Aerospace
MA	Draper Labs Raytheon	TDK DTI Mayflower
CT	UTC	Simulation LLC
NY	ARDEC Benet Labs	
MD	CAES JHU/APL ARL Northrop Grumman	US Naval Academy NSWC CD NSWC IHD
NJ	ARDEC Picatinny Arsenal	TDK
PA	Northrop Grumman Penn State University	NSWCCD PHIL
DC	CSC Gryphon Kratos Defense	Naval Research Lab SPA NAVSEA
VA	ATK Kratos Defense Lockheed Martin Hart Technologies Booz Allen Hamilton BAE Systems	NSWC Dahlgren Strategic Insight Virginia Tech NASA Wallops MDA Raytheon
NC	ABB	Corvid
GA	Georgia Tech Research Institute	
FL	General Dynamics Elgin AFB	NWL

Laser Intro

Why High Energy Laser Weapons?

Meet the Challenges facing the Navy

- Defeat Anti-access strategies that utilize asymmetric threats
  - Potential adversaries threatening to restrict Navy freedom to operate
  - *Logistics & cost of using $3M weapons against $50k threat*
  - *Directed Energy puts us on the right side of the "cost curve"*
- Expand magazine depth
  - Only limited by fuel onboard
  - Reduce at-sea weapons resupply
- Enhance ROE capabilities
  - *Enable Real-Time Combat ID & Intent determination*
  - Decrease battlespace
  - Speed, range, accuracy, maritime environment

High Energy Laser address existing Mission Requirements/Gaps.

Laser Weapon System AN/SEQ-3 (XN-1) Timeline

Proof of Concept → Maritime → Maritime Dynamic → US Combatant

Testbed → Prototype → Deployment

2009

- 5/5 UAV engagements
- Commercial welding laser proof of concept

2010

- 4/4 UAV engagements
- ISR dazzle & destroy
- Small boat negation

2011

- Dynamic Tracking at sea
- Combat ID

2012

- Operate from USS DEWEY fantail
- 3/3 UAV engagements
- Long-range Combat ID

2014

- Deploy aboard USS PONCE
- Upgraded lasers, sensors
- CONOPS, Tactics

Successful Prototyping – From the Lab to the Fleet

Solid State Laser – Quick Reaction Capability
AN/SEQ-3(XN-1) Laser Weapon System (LaWS)

Laser Weapon System
Integrated with CIWS and Commercial Radars

Deployed October 2014: USS PONCE

- **Risk reduction for future program of record**
- **Test feasibility of Laser Weapons in a harsh operational environment**

Long Range LOS/Optical
Air Target ID, Defeat & BDA

COUNTER UAV
COUNTER ISR

COUNTER SMALL BOAT

Close & Medium Range
High Resolution Optical
ID, Defeat & BDA

Lethality Demonstration – LaWS

Energy Storage & Power Response

Power Response: An Analogous Situation…

Images from Rego Apps; Closed Road, Professional Drivers

Instant vs. Sustained Power…

At first the Tesla pulls out handily…

But the Lamborghini pulls ahead…

Instantaneous, on demand power;
No transient issues

Sustained high power capability;
Shift and Engine Power Buildup until moving

In the end, we desire both to enable highly functioning, highly transient, continuous operations.

Images from Rego Apps; Closed Road, Professional Drivers

Instant and Sustained Power

PORSCHE 918

887 HP/944 lb-ft Torque

- 4.6L V8-608 HP
- 2 Electric Motors -279 HP

6.8 kWH Lithium Ion Battery

0-60: 2.4 Sec; Top Speed:210 MPH

24 MPG - Highway

Challenge

- How do we get a cross of the Lamborghini and the Tesla??
- For DEWs:
  - Instant response of the battery
  - Wide powerband of a gas turbine or diesel
  - Energy density and content of the fuel tank
- Storage is finite; fuel can provide a much greater duration of operation
- Integrated storage (i.e. batteries) enables optimal use of the prime movers

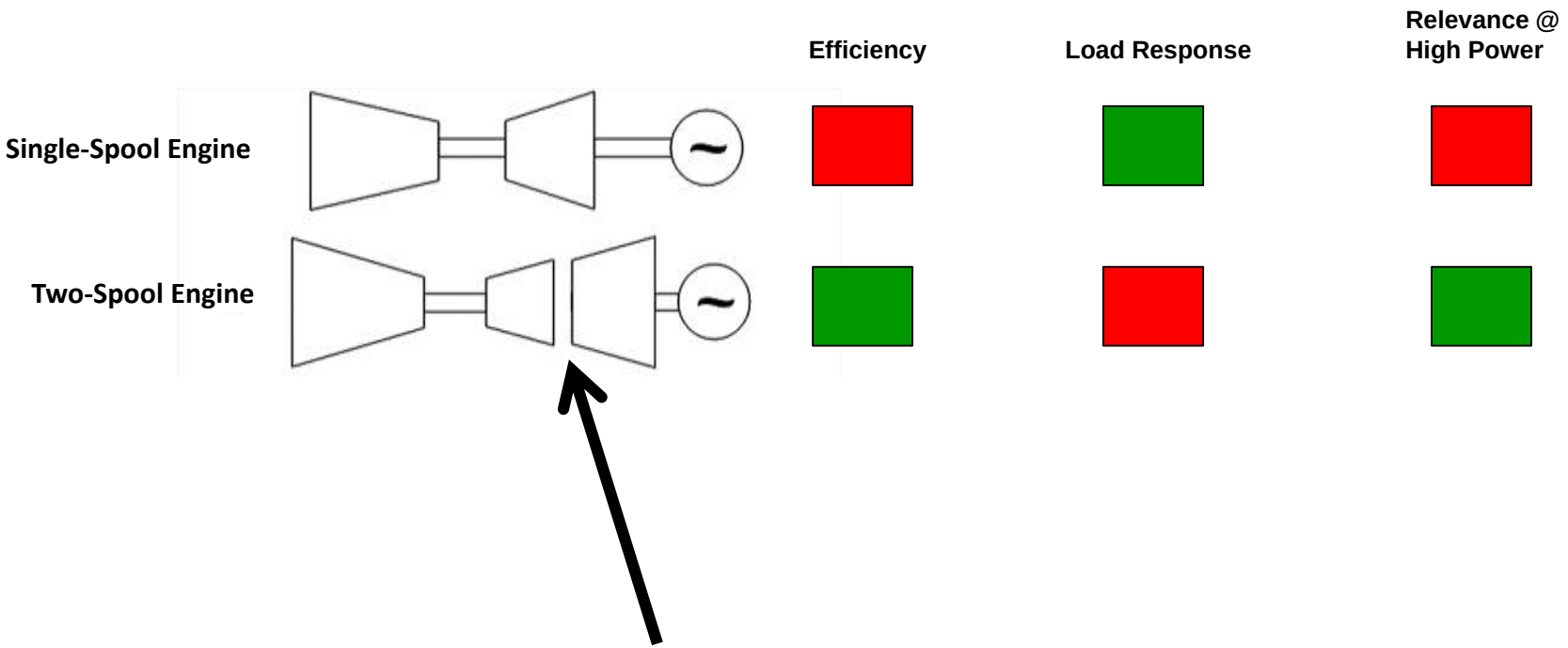
Why Batteries: Don't Ships Have Lots of Power?

DDG-51: ~9MW installed electric power

DDG-1000: ~78MW installed electric power

Not everything can be used/accessed by the ship – especially one load at a time!!

Gas Turbine Transient Response



Aerodynamic couple in two-spool GTG makes transient concerns greater; however available large GTGs all use this architecture

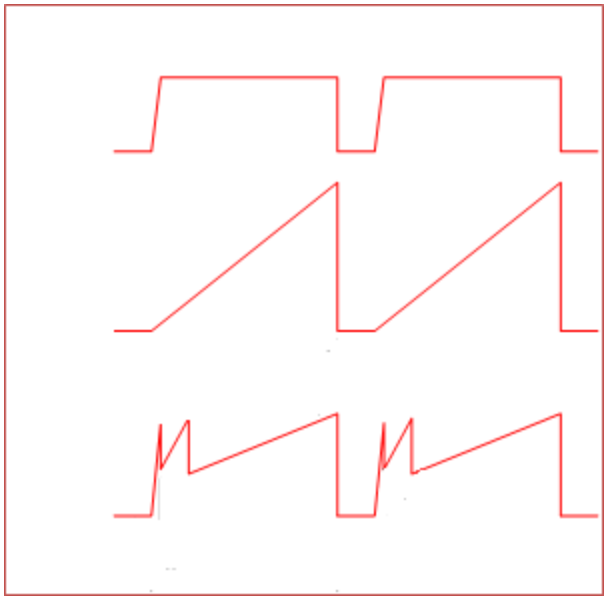
Transients?

DEW Power Profile Options

Constant Power

Constant Current

Stepped Constant Current



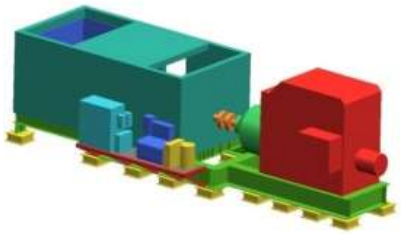
Operations can turn into hundreds of accept and drop load scenarios for even short engagements

- DEW load profiles are highly transient
- Rapid pick up and drop of load
- Creates substantial variation in GTG Loading, and subsequent thermal and electrical quality issues
- Some loads can be much noisier/faster varying dynamics!

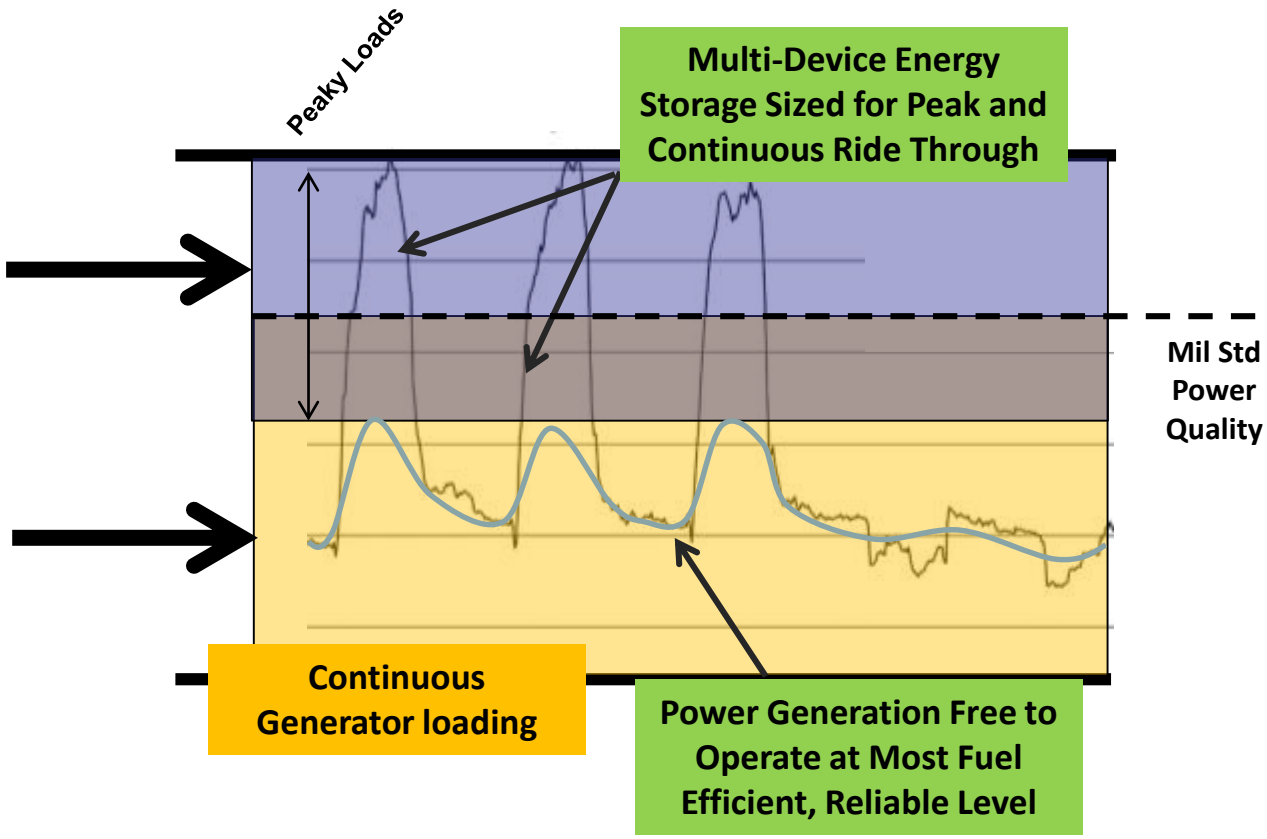
Future Operational Mode

Adv. Energy Storage

+



Generator



Optimize storage buffering prime movers to enable continuous DEW operations with minimal effect on engine mechanicals and power quality…

Li-ion Baggage…

787 APU Battery (NTSB.gov)

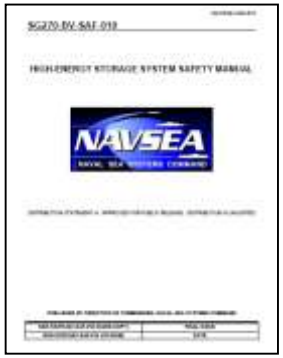
EV Fires (NFPA.org)

Consumer Electronics (wired.com)

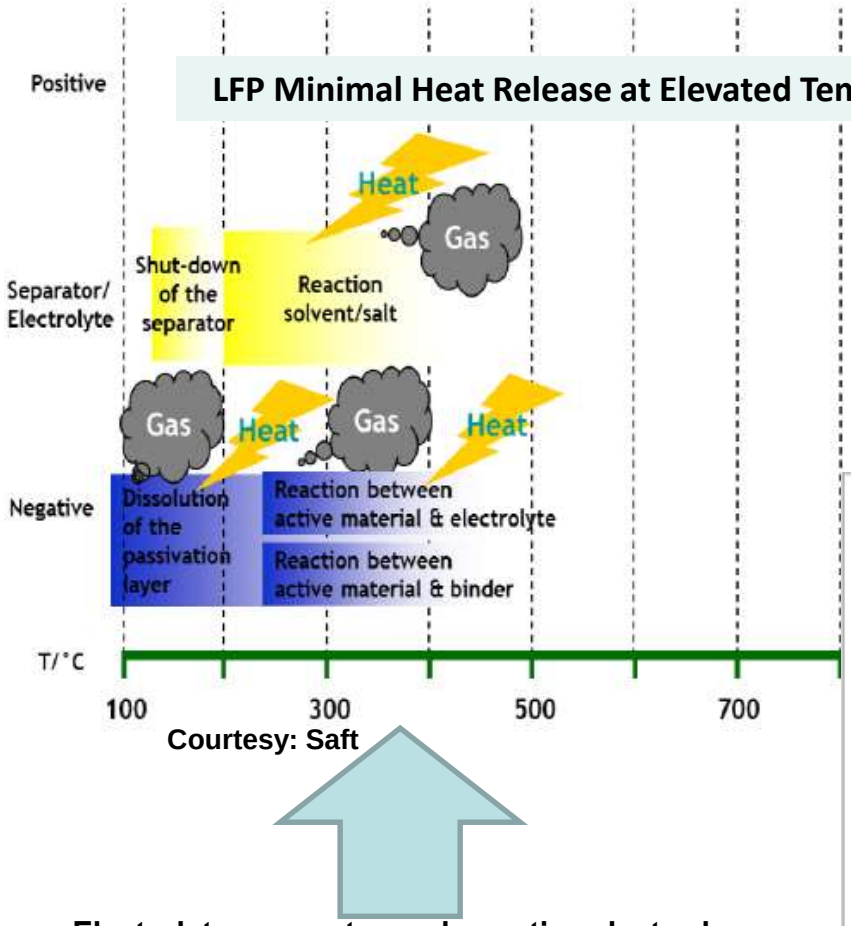
Li-ion Cargo (NTSB.gov)

Safety is Paramount

- Chemistry Selection
- Engineering design and controls
- Abusive testing and mitigations
- Unique NAVSEA 9310, MIL-882 and SG-270 analyses and safety packages



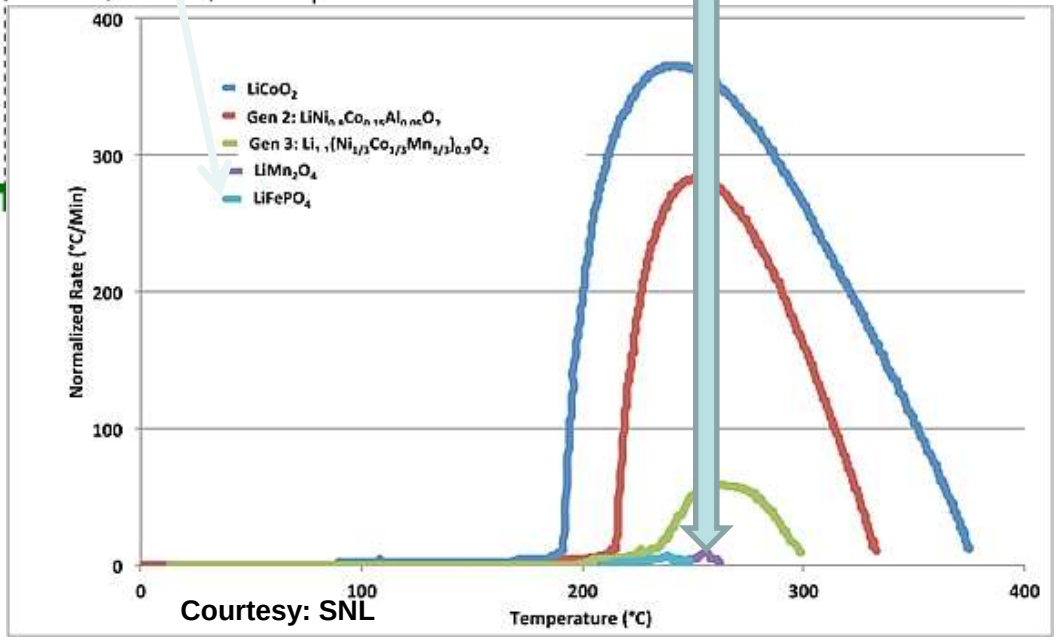
LFP Safety: Heat Release Under Abuse/Failure



Courtesy: Saft

Electrolyte, separator and negative electrode are still thermal contributors

Minimal positive electrode contribution



Courtesy: SNL

Developmental Areas of Interest

BATTERIES/ CHARGERS

- High density components with superior performance: Large format, low impedance, high power batteries
- Higher voltage, safe cathodes to enable LTO and higher energy density variants of LFP
- Non-flammable, high power electrolytes
- High slew rate, high bandwidth, compact power conversion with minimal thermal management
- Allocation of available power and power system components to support multiple loads at the same time
- Rapid-charge energy storage capability
- High-rate operations across wider SOC

Conclusions

- Energy storage is an enabler for DEWs and for lower-consumption, high efficiency operations
- Even the best prime movers need augmentation of instant power capability of stored energy (e.g. batteries)
- Future platforms will be designed to accommodate substantial installed storage to compliment high power generation
- DoD Does not drive the market – Electronics and Advanced Transportation Batteries will
- Partnerships between DoD and DoE/DoT and industry groups can better foster markets and commonality that will ensure widespread adoption

QUESTIONS?