Key Requirements for Surface Combatant Electrical Power System and Propulsion System Design

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Setting the Scene

"In FY2030, the DON plans to start building an affordable follow-on, multi-mission, mid-sized future surface combatant to replace the Flight IIA DDG 51s that will begin reaching their ESLs [Estimated Service Life] in FY2040."

Report to Congress on the Annual Long-Range Plan for Construction of Naval Vessels for FY2015

Big differences from DDG 51:

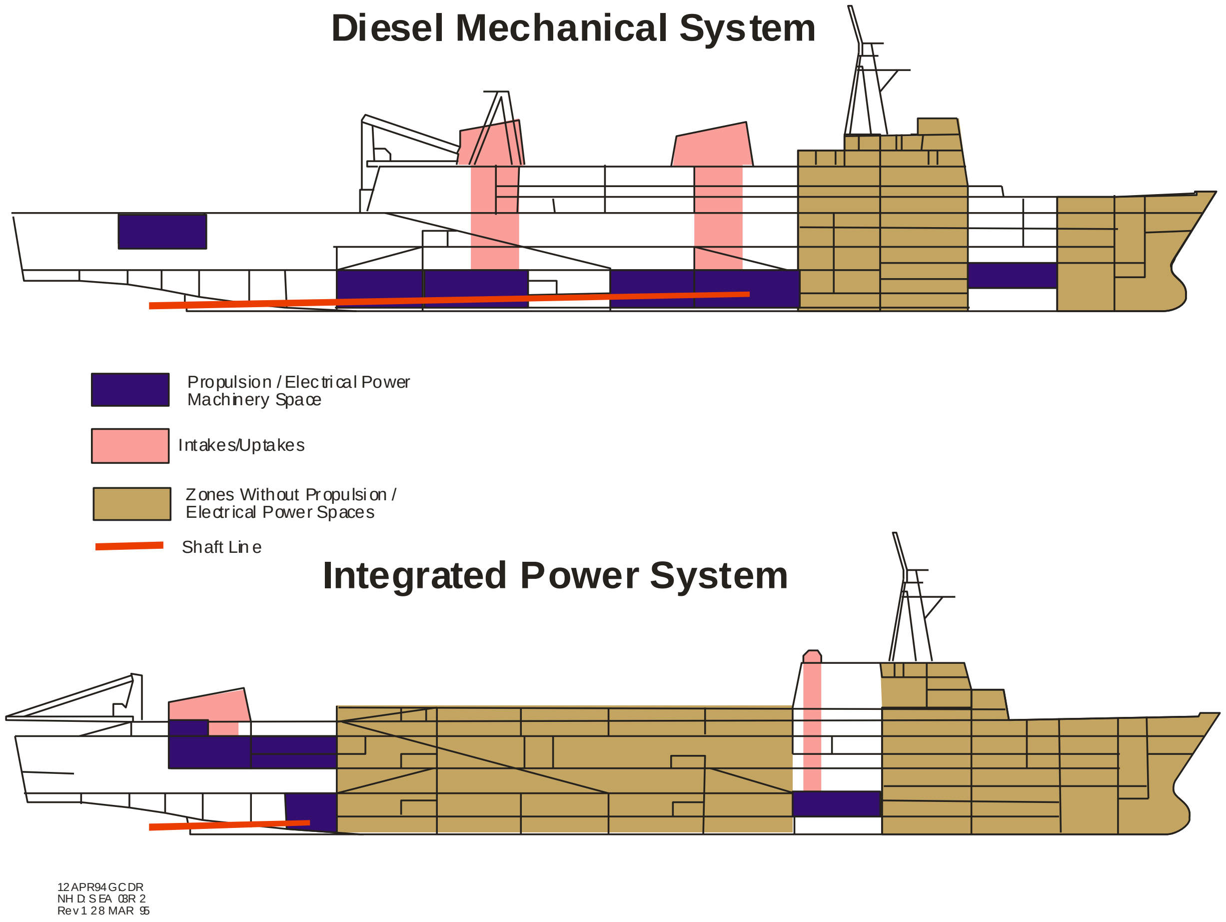
- High-energy weapons and sensors
- Flexibility for affordable capability updates

Photo by CAPT Robert Lang, USN (Ret), from site http://www.public.navy.mil/surfor/swmag/Pages/2014-SNA-Photo-Contest-Winners.aspx

Getting the Requirements right is critically important

Power and Propulsion Architectures

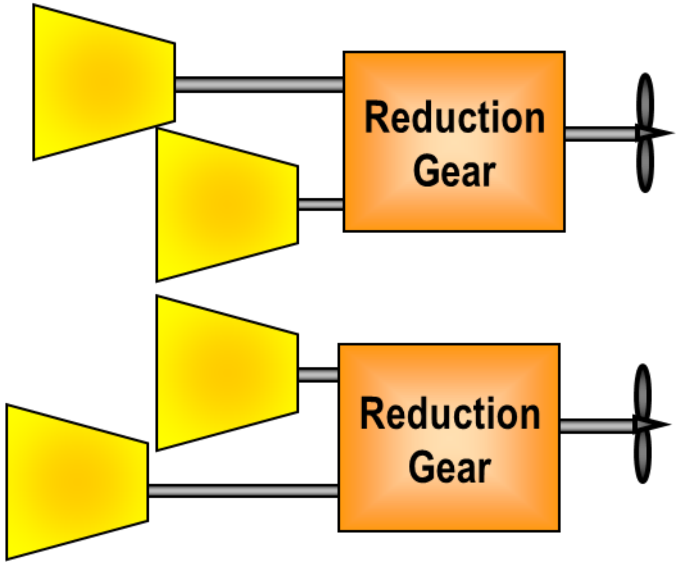
- Mechanical Drive
- Integrated Power (and Energy) Systems (IPS / IPES)
- Hybrid Drive
- Hybrid Drive with Propulsion Derived Ship Service Power (PDSS)

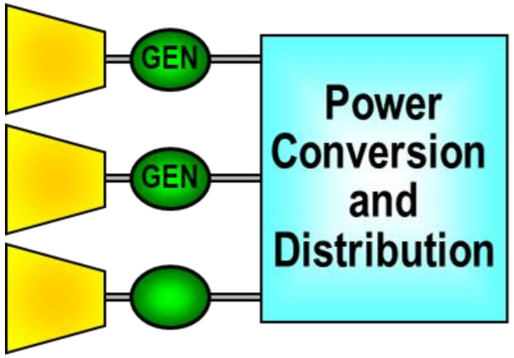


Power and Propulsion Architectures have 1st order impact on ship design

Mechanical Drive

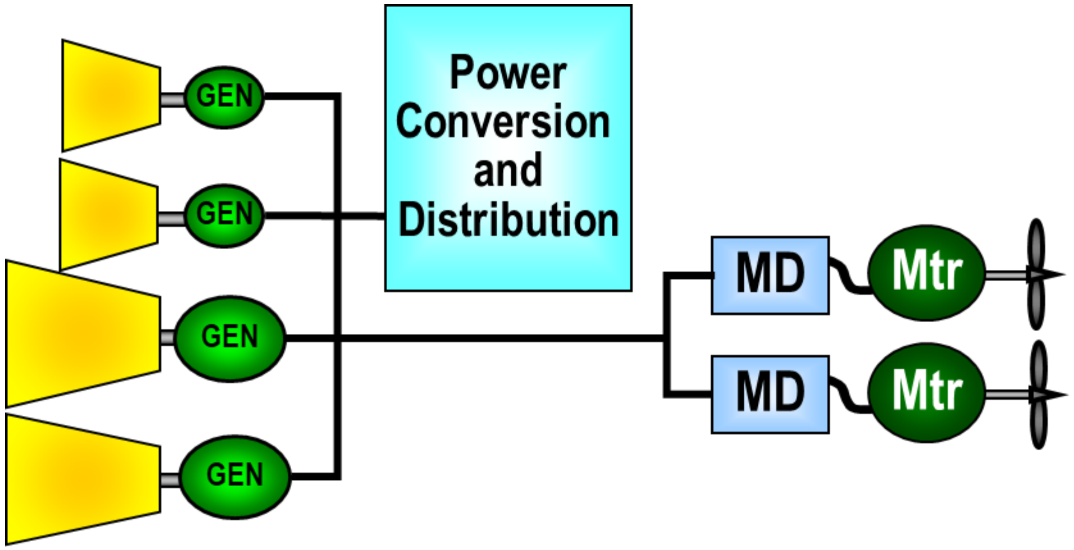
- Propulsion Prime Movers and drive train sized for sustained speed.
  - Achieve Sustained Speed at 80% of rated power in calm water, clean bottom, etc.
  - Should be efficient at endurance conditions
- Ship service sized for maximum margined ship service load with one of the largest rated generators offline
  - For systems with 3 generator sets, an increase in load of 1 kW requires 1.5 kW increase in generation capacity
- Generally at least 3 prime movers online
  - One or more propulsion engines
  - Two or more ship service generators
    - Sufficient energy storage can reduce to one indefinitely or zero for short times





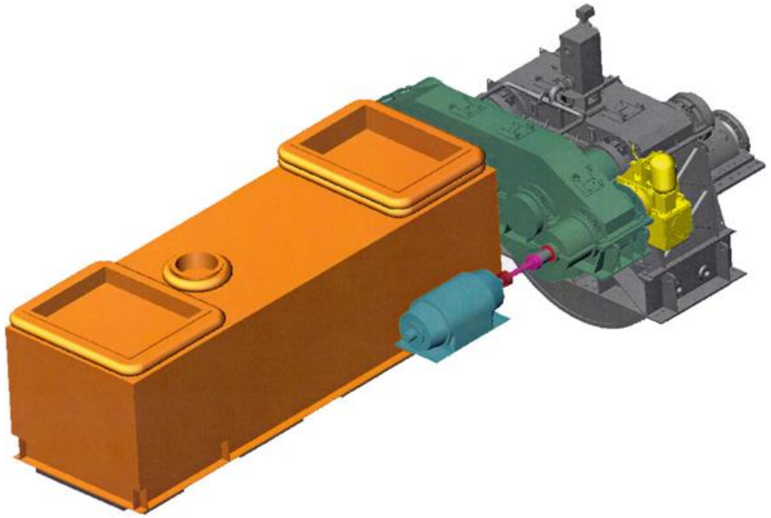
Integrated Power (and Energy) Systems

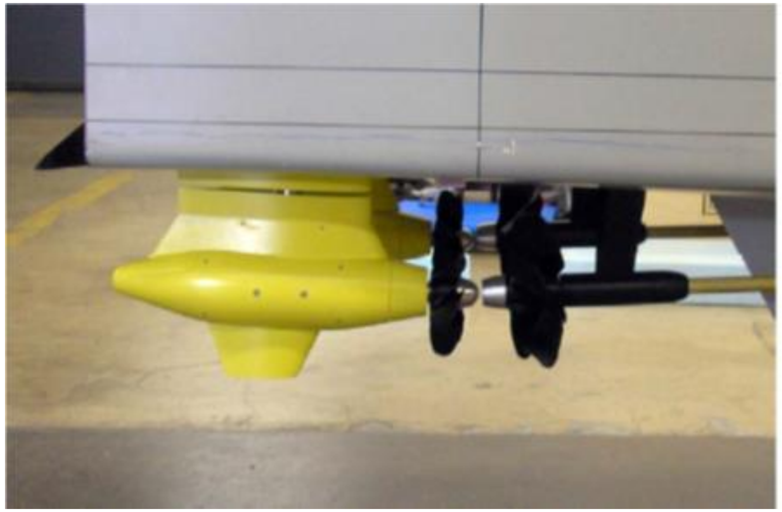
- Propulsion Motors and drive train sized to achieve sustained speed
  - Should be efficient at endurance conditions
- Power Generation sized for maximum propulsion power and maximum ship service power when at maximum propulsion power.
  - Must be able to achieve a lower speed with largest generator offline
  - Usually, an increase in load of 1 kW requires 1 kW increase in generation capacity.
- Generally at least 2 prime movers online
  - Sufficient energy storage can reduce to one indefinitely or zero for short times
- Integrated Power and Energy Systems (IPES)
  - Integrated Power System (IPS)
  - Energy Storage
  - Advanced Controls



Hybrid Drive

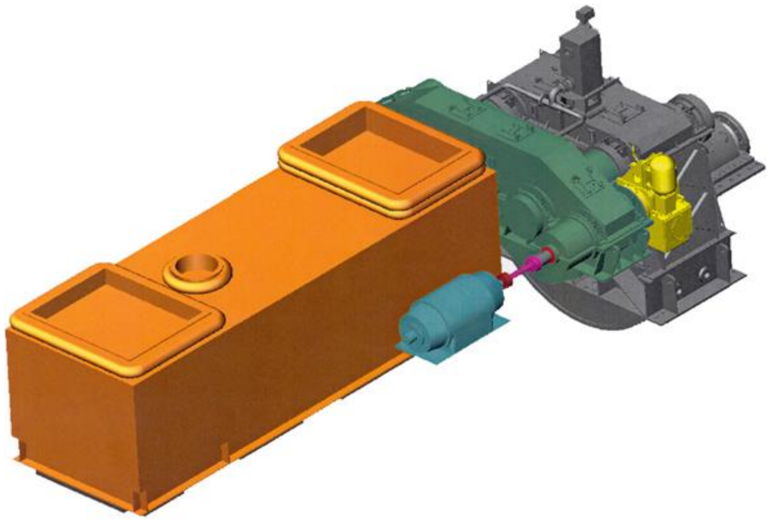
- Mechanical Drive + Auxiliary Propulsion Unit
  - Auxiliary Propulsion unit typically electric motor with VFD
    - Integrated with reduction gear, or
    - Integrated with propulsion shaft
    - Pod augmenting traditional shaft
  - LHD 8 and LHA 6 classes
  - Allows N+1 generator to be used for propulsion
  - Improves fuel economy at low speed
- 'OR' Propulsion
  - Either Motor or Prime mover driving shaft, but not both at the same time.
  - Simplifies motor and motor drive
  - Must be able to meet sustained speed without motor
- 'AND' Propulsion
  - Motor can augment prime mover to achieve sustained speed requirement
  - More complex motor and drive
  - Enables smaller prime mover for propulsion





Hybrid Drive with PDSS

- Variation of Hybrid Drive
- Propulsion Derived Ship Service (PDSS)
  - Motor can act as a generator to enable mechanical drive prime mover to generate electricity
  - Usually uses power electronics to produce distribution voltages and frequencies.
- Can replace ship service generator if power can be generated independent of shaft rpm.
  - Controllable Reversible Propellers are an enabler
- More complex fault detection, localization, and isolation system integration for a.c. systems.



Key Requirements for naval power and propulsion systems

- Flexibility
- Sustained Speed
- Endurance
- “Compromised Mobility” Speed
- Survivability
- Low Observable Mode
- Operating and Support Costs


200203-F-RN211-1061
U.S. Air Force photo by Master Sgt. Ryan Crane


161025-N-UK306-017
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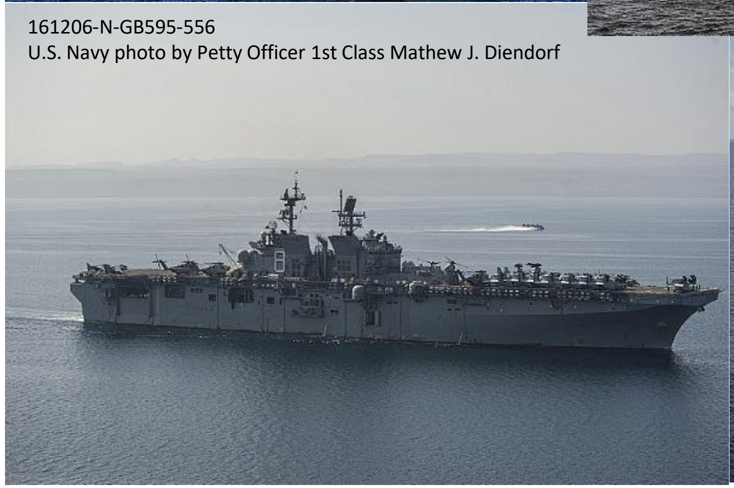
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Flexibility

- Mechanical Drive
  - Requires the most amount of installed ship service generation capacity
  - Requires most amount of energy storage to buffer pulsed sensors and weapons.
- IPS / IPES
  - Best capability to integrate high power and pulsed sensors and weapons
- Hybrid Drive
  - Intermediate capability
- Hybrid Drive with PDSS
  - Intermediate capability, slightly better than without PDSS

120621-N-PO203-129 U.S. Navy photo by John F. Williams

Sustained Speed

- Mechanical Drive
  - Unless using combining gears, need even number of prime movers
  - Limited selection of prime movers
- IPS / IPES
  - Motors tailored to required power
  - Can use any number of prime movers
  - Unless using pods or contra-rotation, efficiency at sustained speed typically less than for Mechanical Drive.
- Hybrid Drive
  - OR configuration has same impact as Mechanical Drive
  - AND configuration reduces required rating of propulsion prime movers
- Hybrid Drive with PDSS
  - If used to replace generator set, prime mover rating must be greater than for mechanical drive
  - Improves fuel efficiency by providing a minimum load to the prime mover.

Sustained Speed is intended to be the speed a ship can achieve in real world conditions by specifying the power at ideal conditions

Endurance

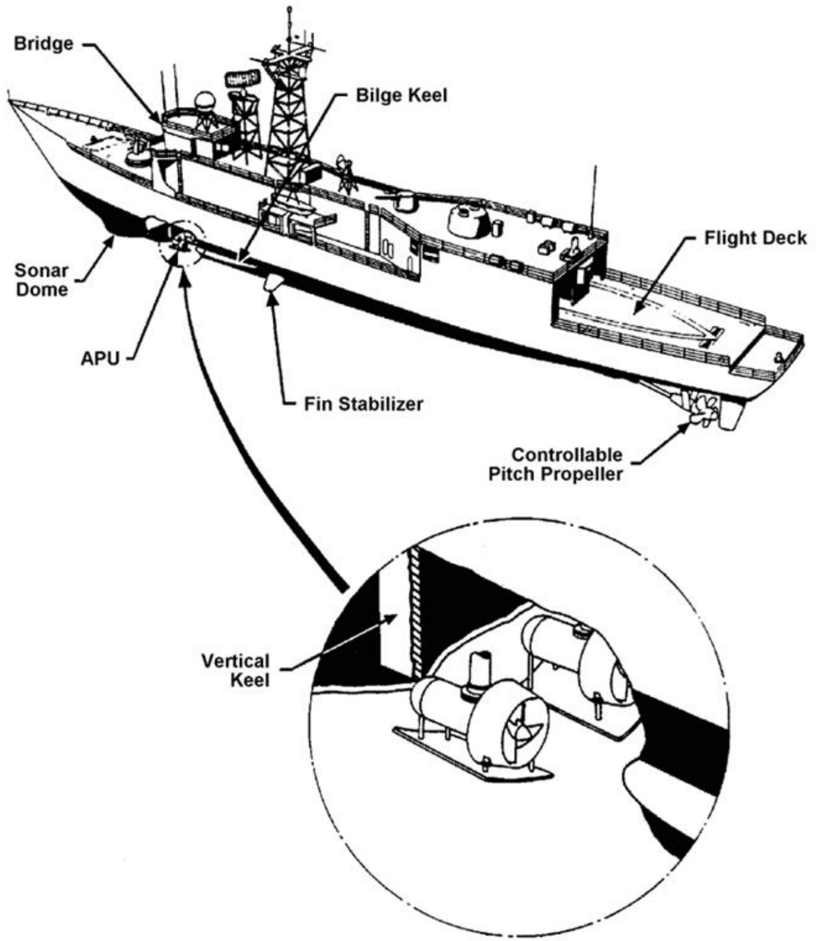
- Mechanical Drive
  - Typically best for “Surge To Theater”
  - Good for “Economic Transit”
  - Typically worst for “Operational Presence”
- IPS / IPES
  - Typically best for “Operational Presence”
  - Good for “Economic Transit”
  - Typically worst for “Surge to Theater”
- Hybrid Drive
  - Good for “Operational Presence”
  - if of sufficient capability good for “Economical Transit”
- Hybrid Drive with PDSS
  - Typically somewhat better than Hybrid Drive
  - Can reduce fuel consumption to improve fuel usage

Endurance Metrics (DPC 200-1)
- Surge to theater distance
- Economical transit distance
- Operational presence time

Endurance Requirements determine size of Fuel Tanks

'Compromised Mobility' Speed

- If below about 14 knots
  - Forward Retractable Pod may be feasible
  - Reduced need for main propulsion separation
- If above about 14 knots
  - Main propulsion must be longitudinally separated and shafts protected
- Mechanical Drive
  - 50% power (~80% of maximum speed)
- IPS / IPES
  - Greater machinery arrangement flexibility
- Hybrid Drive & Hybrid Drive with PDSS
  - Impact about the same as for Mechanical Drive



The degree to which mobility (propulsion) is allowed to degrade following exposure to a threat (either weapons effect or accident)

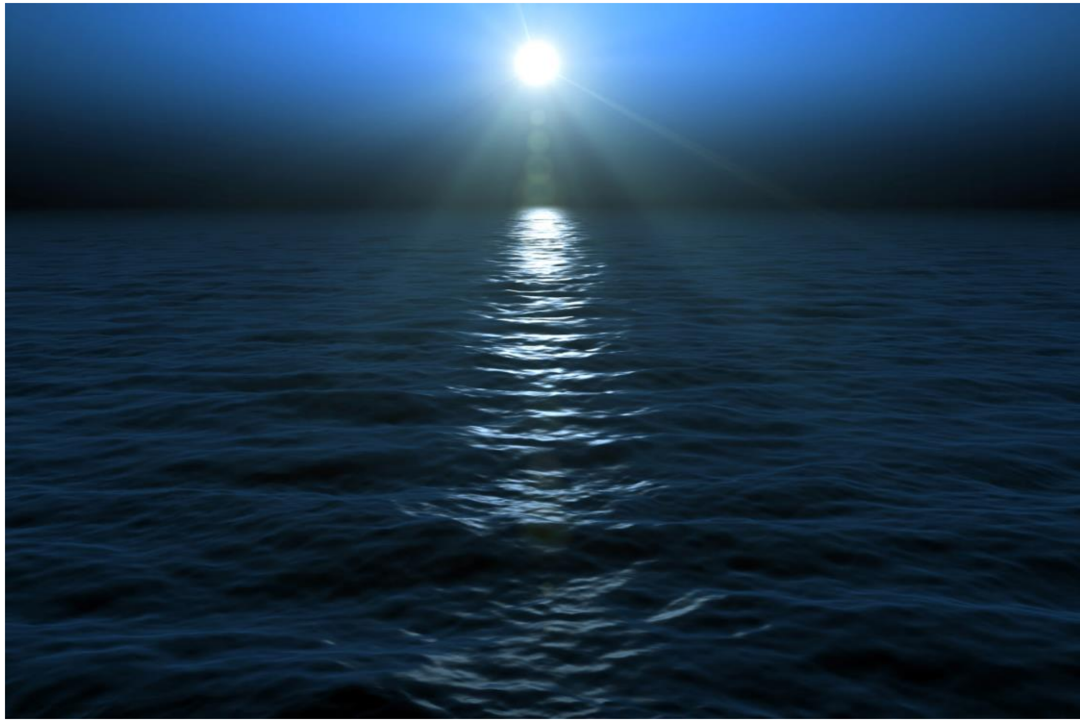
Survivability

- Mechanical Drive
  - Electrical Power Generation Plant can power all Mission Critical Equipment with at least 1 generator out of service.
- IPS / IPES
  - Best ability to have sufficient power to Mission Critical Equipment
- Hybrid Drive
  - About the same as for Mechanical Drive
  - Use of pods may improve survivability
- Hybrid Drive with PDSS
  - PDSS may improve post-damage power generation capability

U.S. Navy Photo

Low Observable Mode

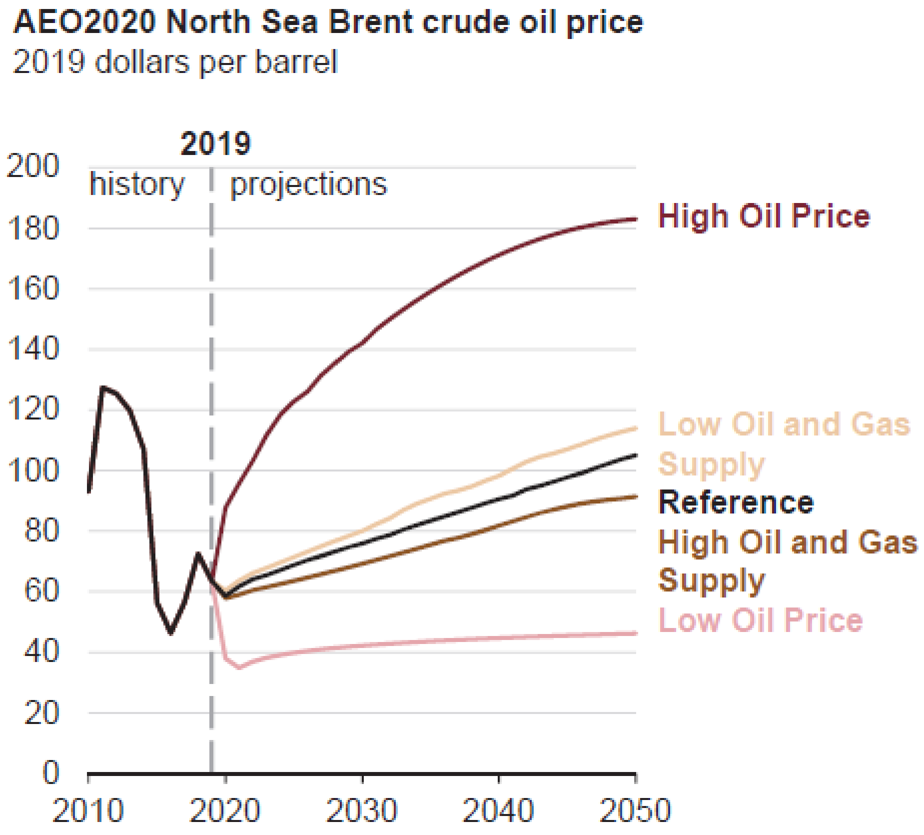
- Mechanical Drive
  - Not many opportunities to minimize IR or acoustic signatures
- IPS / IPES
  - Likely has a lower IR signature than Mechanical Drive
  - Acoustic signature can be better
  - Option to run on Energy Storage alone
- Hybrid Drive
  - Likely better than Mechanical Drive
- Hybrid Drive with PDSS
  - Likely better than Hybrid Drive without PDSS



https://www.publicdomainpictures.net/en/view-image.php?image=33238&picture=ocean

Operating and Support Costs

- Mechanical Drive
  - Usually operates with more prime movers online that are lightly loaded
- IPS / IPES
  - Fewer prime movers online that operate more optimally loaded
- Hybrid Drive
  - Better than Mechanical Drive
- Hybrid Drive with PDSS
  - Better than Hybrid Drive without PDSS



https://www.eia.gov/outlooks/aeo/

Prime Mover maintenance tied to operating hours

Technical Maturity

101210-N-0000X-001, U. S. Navy Photo

- Development and Integration Engineering required for all power and propulsion systems.
- Common Risks
  - Design and implementation of control systems.
  - Maintaining power quality on the power bus in the presence of modern loads
  - Supporting pulsed loads
  - Integrating energy storage
  - Survivability of twin shafts
  - Controlling common mode currents due to proliferation of power electronics

- Specific Risks
  - Pods
  - Contra-rotation
  - PDSS – Integration with fault DLI
  - IPES with MVDC
    - Fault DLI
    - Switchgear and Cabling
    - Equipment Specifications
    - Bus stability via controls

Recommended Studies

- Survivability of twin shafts when subjected to damage from modern torpedoes.
- Value of operating without any prime movers online for limited periods of time.
- Modifications to commercial pods needed to meet naval surface ship requirements.
- Viability of using forward propulsors for low speed operations where signatures are important.

080816-N-6031Q-001, U.S. Navy photo by Mass Communication Specialist 3rd Class David R. Quillen

Factors that favor IPS/IPES over Mechanical Drive

- Minimizing operating and support costs is important
- The maximum margined ship service power load with SLA is large (> ~10 MW) and/or includes large pulse loads
- Maximizing on-station time is important
- The ship has an operational profile similar to today's surface combatants
- One wants the option to trade ship speed for supporting future high power loads
- One wants to preserve the option to install multiple high power loads
- Controlling the IR signature and/or acoustic signature is important

160421-N-YE579-005, U.S. Navy

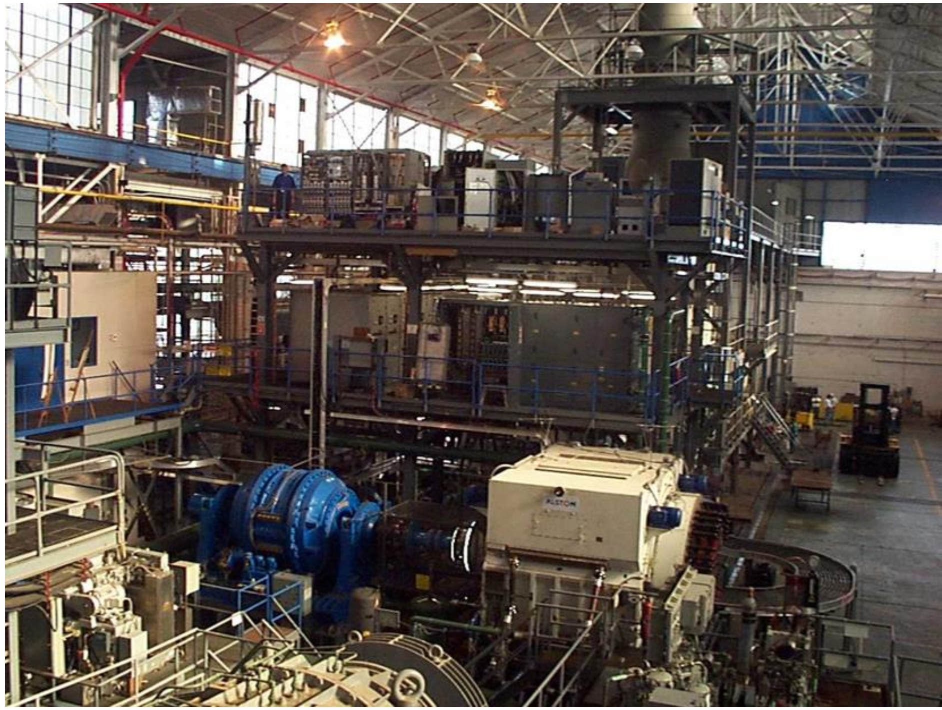
Factors that favor Mechanical Drive / Hybrid Drive over IPS/IPES

- The maximum margined ship service power load with SLA is small (< ~ 8 MW) and does not include large pulse loads
- The ship has an operational profile that emphasizes high speed operation
- One doesn't expect to install multiple newer higher power sensors and electric weapons over the ship's service life. Growth will be limited to the specified SLA
- IR and acoustic signatures are of lesser importance

200128-N-AT530-1919, U.S. Navy photo by Mass Communication Specialist 2nd Class Chris Roys

Concluding thoughts

- Independent of the final choice of power and propulsion architecture, the following will likely be part of the solution:
  - Advanced Controls
  - Power Electronics
  - Energy Storage
- Successful integration of future power and propulsion systems require
  - Robust Digital Engineering environment
  - Power Hardware in the Loop and Control Hardware in the Loop simulation
  - Integrated test facility



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