P&P Architectures for Highly Constrained Designs

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Introduction

Highly constrained designs are becoming more frequent in high-end, high-capability naval combatants, due to increased mission uncertainty (including emergent areas of operation), new/developing threat types, and large power and space margins.

This results in increasing complexity in the power and propulsion plant architectures and the layout of machinery spaces.

These additional requirements within a vessel size that meets budgetary constraints can impact power and propulsion choices at concept stage and increases the number of variables to balance, requiring a level of definition of the electrical load and propulsion train elements that have not “historically” been required for concept design.

This paper explores the following areas:

- *The problem space*. Trends in the design of surface combatants, drivers for growth in size and complexity, constraints on engine room size.
- *The solution space*. Propulsion and power generation architectures and emerging alternatives.
- *The design process*. How do the increase in constraints and the ever-expanding pool of solutions affect the design process.
- *Leveraging technological developments.* Can AI help streamline the design process?

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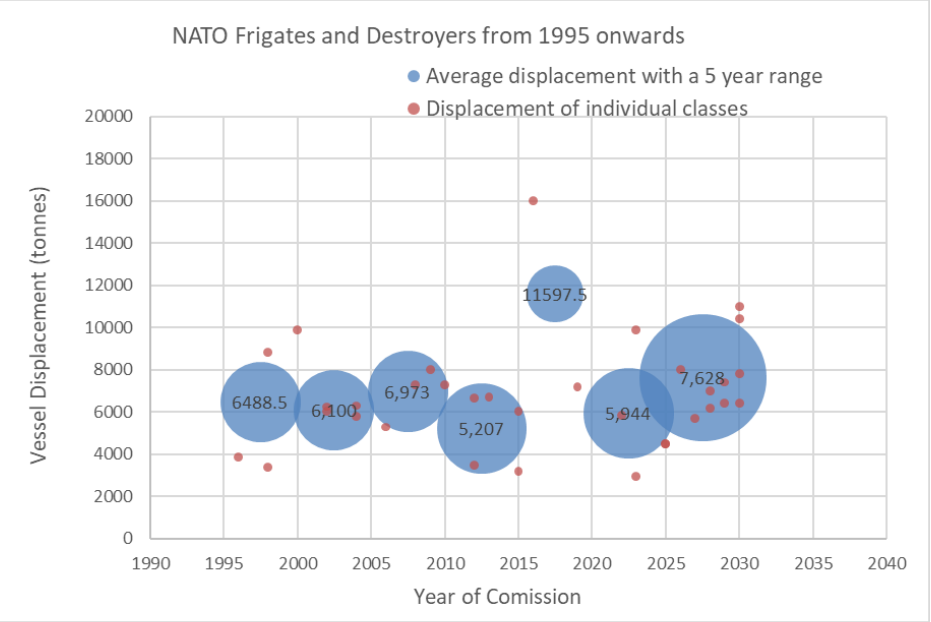
Trends for Surface Combatants

- NATO naval fleets have been shrinking
- Vessels are becoming more flexible/adaptable and capable overall. Enabled by:
  - Modular capabilities
  - Combat system technology
- Ships are larger and more complex than the classes they replace (new generation of 10,000 tonne+ warships emerging)
- Increase in new ship classes for 2025-2030 (10 vs 5 in the most prolific periods since the end of the Cold War).



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Destroyer Trends

- More gradual trend. Steady increase in displacement and power.
- Arleigh Burke. Increase in capability driving power generation requirements.
- European Destroyers 2000-2010. Reserve electrical power in the region of 3-5 MW.
- Power generation requirements increase from 2015.

Arleigh Burke Destroyers

Flight	First Year commissioned	Displacement (fully loaded)	Power generation capacity
I	1991	8400	3 x 2500 kW gensets = 7.5MW
II	1997	8500	3 x 2500 kW gensets = 7.5MW
IIA	2000	9700	3 x 3000 kW gensets = 9MW
III	2023	9900	3 x 4000 kW gensets = 12MW

European Destroyer Data 2000-2010

Class	First Year commissioned	Displacement (fully loaded)	Power generation capacity
Type 45 (UK)	2006	8500	45 MW (2x20 MW AC induction motors) 5 MW reserve at full power.
Horizon class (France)	2007	7770	3.2 MW
F100 (Spain)	2000	6400	4 MW
Orizzonte-class (Italy)	2005	7050	5 MW

World Destroyer Data 2015 Onwards

Class	First Year commissioned	Displacement (fully loaded)	Electrical power generation capacity
Zumwalt	2015	16000	78 MW (2 x 34.6 MW motors) 8.8 MW reserve at full power
Type 055 destroyer China	2020	13000	30 MW
Maya class Japan	2020	10250	12 MW
F126 frigate Germany	In build	10550	15.6 MW

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Drivers for Growth

- **Enhanced user requirements**. Newer ships are expected to do more. More capabilities drive volume and power demands.
  - Modular equipment drives mission bays into the design.
- **Equipment impacts**. Specific pieces of equipment have become size and/or power drivers (VLS, AAW Radars, DEW).
- **Modular construction systems and maintenance by replacement**. More space for installation and larger removal routes.
- **Increased resilience and survivability**.
  - Drives size via duplication and separation.
  - RCS reduction measures negatively impact available internal volume.
- **Improved habitability**: Crew numbers have gone down but accommodation standards have gone up.

Source: Navylookout (The development of a lean crewing solution for the Royal Navy's Type 31 frigate - Navy Lookout)

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Engineering Spaces

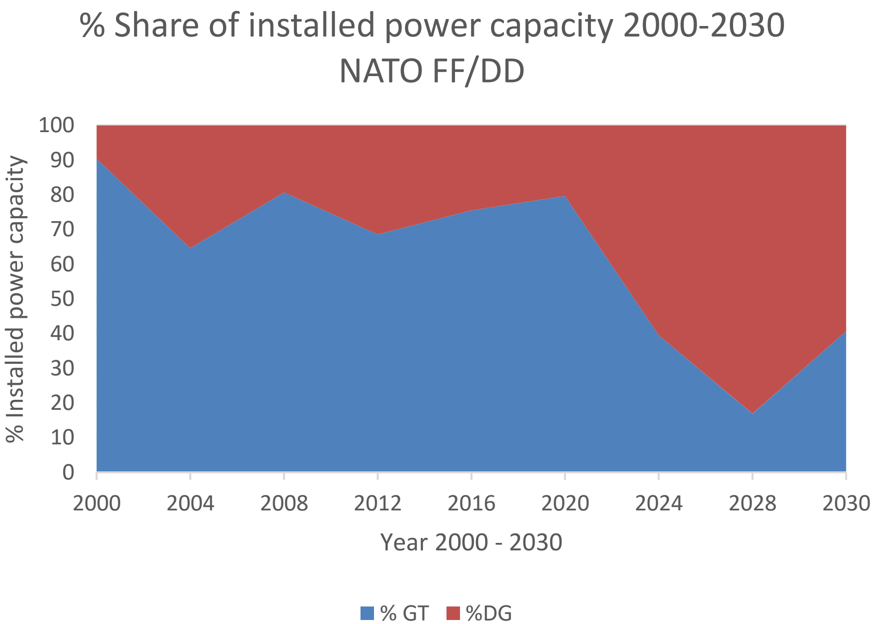
- **Environmental regulations**. Additional equipment for MARPOL compliance as far as reasonably practicable.
- **Fuel efficiency.** Has driven the use of diesel engines rather than gas turbines in recent designs (e.g., Dutch ASWF, German F126).
- **Climate change and attendant changes in areas of operation**.
  - Polar requirements for Arctic Routes
  - In the tropics, increased HVAC and engine cooling.
  - For operation in both areas: more complex intake and engine room ventilation systems.
- **Damage stability rules**. General trend for increased damage lengths, which drive increased internal subdivision aft (DNV rules, other Classification Societies expected to follow suit)

The So What:

- More power to be fitted in shorter spaces.
- Favours mechanical/electrical hybrids, as they are better able to use the width of the engine room.

Prime Movers

- The constraints favour GTs, but as diesels become more power dense, a shift towards diesel-based installed capacity can be observed.
- Full GT arrangements have become less desirable as the "cruising" GTs become less competitive against modern DGs, due to poor low-speed fuel efficiency.
- DGs are cheaper to buy, operate and maintain, so if a diesel meets the requirement, then generally that is what will be used.
- Since the 2000s, GT-only plants are rare outside of the US. Zumwalt and Arleigh Burke still use all GTs.
- Most warships have cruising DGs and GTs for top end sprinting such as the QEC/T45/T26.



Source: Jane's Fighting Ships, 2024

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Architectures

IFEP

- Shortest shaft-line and distributed prime movers.
- Additional power available for weapon systems.
- Avoidance of low loading.

Combined Diesel and Electric (CODLAD/CODLAG)

- Resilient and Versatile.
- Good performance throughout the operating range.
- Long shaft line.

Mechanical

- Management of low loading.
- Cheap, well understood and simple.
- Long shaft-line and gearbox.

- United States. Zumwalt – (16000 tonnes). IFEP.
- China's Type 055 – (13000 tonnes) COGAG (Mechanical).
- Japan Maya Class (10250 tonnes) commissioned 2020 - COGLAG/CODLAG.
- German F126 frigate (10550 tonnes) CODLAD.

Each Architecture is a compromise, there is no clear winner.

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Electrical Power Systems

Possible move away from AC Grid – Constant speed generators – 440 V 3 Phase 60Hz.

DC Grid

- No need for synchronisation when switching.
- Space savings from more compact switchboards.

Variable Speed Power Generation.

- Able to match a DG's speed to load resulting in improved efficiency.
- Space and weight savings from reduced tankage.
- DC and AC applications.

Energy Storage Systems

- Energy recovery, increasing fuel economy and range.
- Management of variable loads.
- Enabler for DEW.
- Large weight and space impact.

DC at Sea:

- Established technology in the merchant fleet.
- Offshore support vessel Dina Star shown was one of the first vessels to feature a DC grid and was launched in 2013.
- Selected for the German F126 and Dutch ASW Frigates.
- Chinese aircraft carrier Fujian uses MVDC for the EMALS system.

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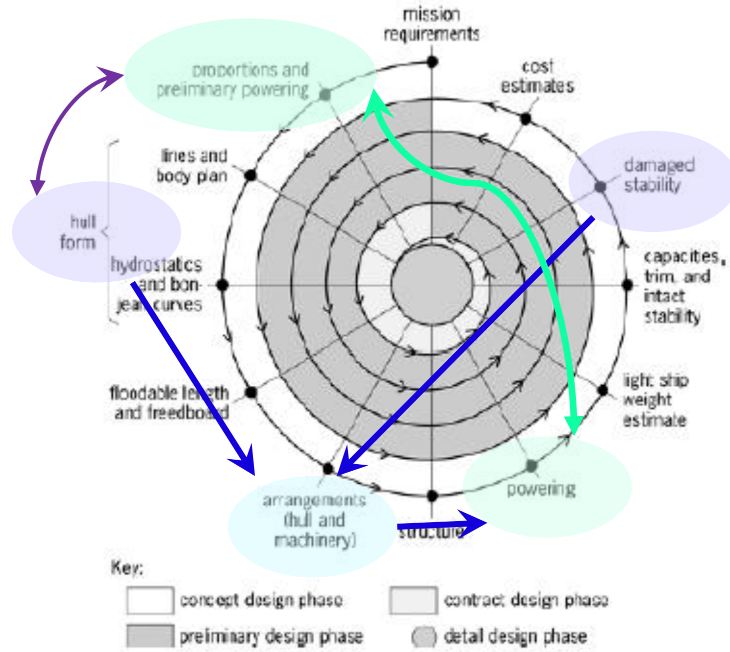
Impacts on Design

- Preliminary Powering is no longer mostly about propulsion.
- The change in balance of propulsion and hotel/mission load, and their impact on the ship means a much more detailed interrogation of electrical loads.
- Powering architecture solution highly intertwined with hull form and the internal subdivision, as driven by the damage stability rules.
- Iteration will close when the power that can be fitted matches the power required for propulsion, platform and mission loads.
- It can require a significant number of iterations to identify a balanced design.



- Classic design spiral (Evans, 1956)

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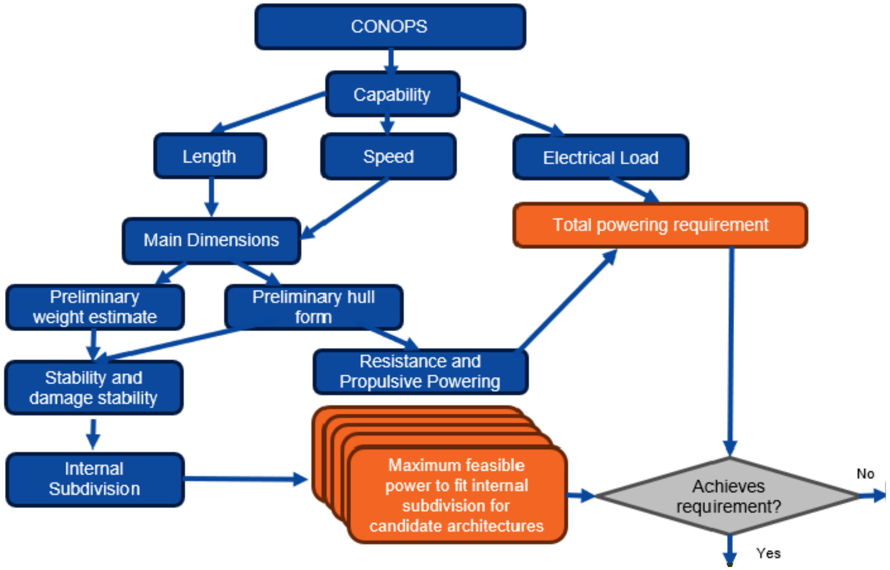
Impacts on Design

- Capability requirements drive length , speed and electrical load.
  - First pass estimate of length from combat capabilities, noting impacts of the propulsion arrangement on the upper deck, e.g. constraints on funnel location, and placement of exhaust aftertreatment.
  - N.B. Length and number of the engine rooms can potentially drive the length of the ship, over and above capability requirements.
- Length and speed drive other main dimensions and preliminary hull form, and total power requirement.
- **Damage stability rules constrain internal subdivision and limit the power that can be fitted.**



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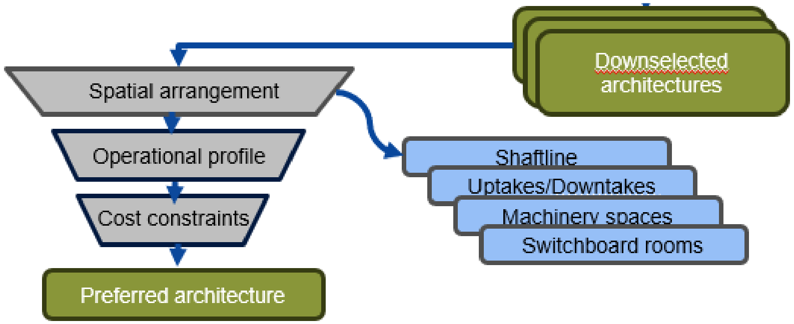
Impacts on Design

- **Assessment and downselection of propulsion architectures.**
  - Does the power that can be fitted match the required power?
- Space and arrangement checks
  - *Shaftline* and auxiliary shaftline equipment.
  - *Uptakes and downtakes*. Feasibility of exhaust and intake routing, including SCRs.
  - Overall machinery footprint.
  - Confirmation of allocation of switchboard spaces, including any applicable height constraints.
- Operational profile and cost



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How can AI be leveraged

- Candidate areas:
  - Data extraction from existing information.
  - Checking feasibility of large numbers of variants.
- Challenges:
  - Naval ship design is data-poor for generative AI.
  - Not that many ships exist.
  - Less than 40 new frigate and destroyer classes in NATO in the last 30 years.
  - The data is not accessible. IP constraints.
- In conclusion:
  - There is room for an assistive use of AI.
  - Ongoing relationships and enduring partnering with OEMs are key.

Conclusions

- *The problem space*. Ships are getting bigger, more complex and more power hungry.
- *The solution space*. Expanding, with a range of new technologies on offer, particularly in electrical power systems.
- *The design process*. Is becoming more complex, with more iterations and more equipment to take into account earlier in the process.
- *AI can help.* But cannot overcome the lack of large volumes of data.
- Use of Combat USVs and distributed capabilities could change this trend. (Not expecting manned ships to disappear, and conclusions will remain valid for those, but there will be fewer of them).

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