FLUID STRUCTURE INTERACTIONS RESEARCH GROUP

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Low Carbon and Hazardous Emissions Shipping

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Motivation and Aim

- "The whole is more than the sum of the parts" – Aristotle
- This study is based on the systemic approach of propulsion system (Systems engineering) instead of the traditional optimisation of single components
- Ultimate objective: Provide an alternative reliable, economical feasible, marine propulsion system to reduce the CO_2, SO_x, NO_x and particle emissions for ships
- Investigate the potential of large scale application of Nuclear propulsion using small portable reactors and the installation of energy storage devices for load leveling and controlled energy flow
- Currently: A lot work has been done in large 2 Stroke engines to reduce SO_x, NO_x using external means, like Exhaust Gas Recirculation, Sea Scrubbing but also by optimizing the operation of engine such as valve timing and combustion
- Domestic shipping and fishing activity bring totals to 1050 million tonnes of CO_2, or 3.3% of global anthropogenic CO_2 emissions
- Despite the undoubted CO_2 efficiency of shipping in terms of grammes of CO_2 emitted per tonne-km, it is recognised within the maritime sector that reductions in these totals must be made. Shipping is responsible for a greater percentage share of NO_x (~37%) and SO_x (~28%) emissions
- Due to the increasing grown of marine transportation, immediate action is required to stop the climate change
- The current state of play is ready for adoption of new technologies including the nuclear propulsion, combined energy cycles, advanced heat recovery systems.
- Combination of such technologies has not been assessed and optimised yet

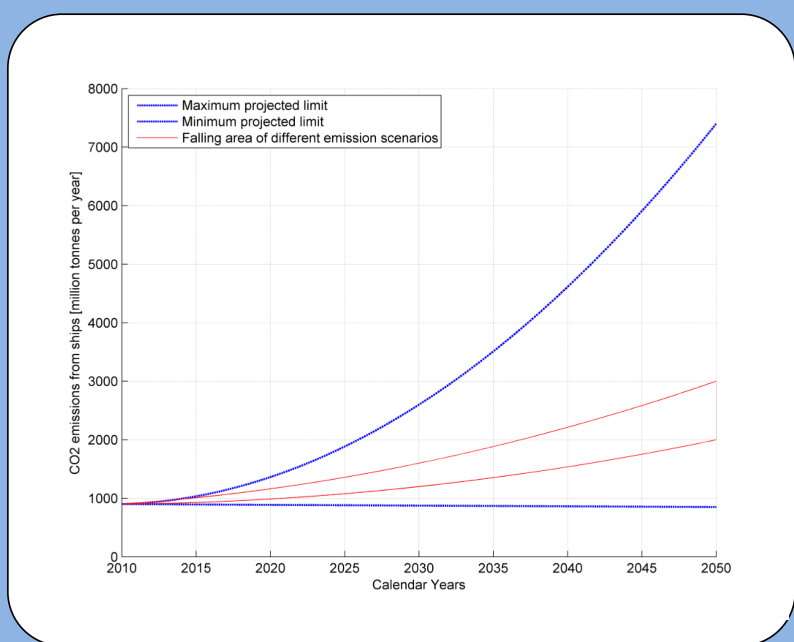

Figure 1: Predicted emissions of the shipping sector according to I.M.O. 2nd Greenhouse emission study

Energy Storage Devices

- Sodium Nickel Chloride and Vanadium Redox Flow batteries were investigated

Figure 2: examined energy storage devices for marine hybrid propulsion, Redox (left), Zebra (right)

- Low Weight
- High and medium energy density respectively
- Low cost compared to Lithium Ion batteries
- Tested in Marine applications / tested in automotive industry
- Energy efficiency that reaches up to 92% in low current conditions / reaches up to 88% efficiency

Nuclear Reactor Technology

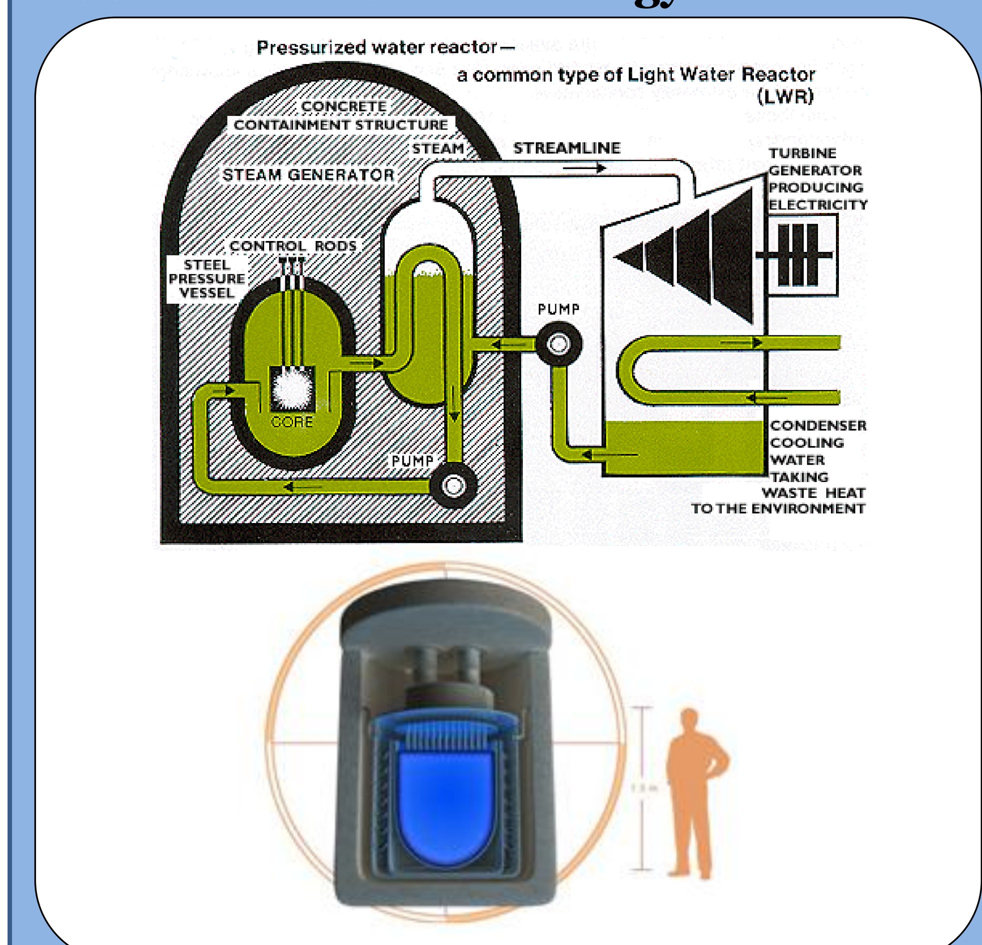

Figure 3: Reactor types: PWR(top), Hyperion (down)

Present technology is based on Pressurised Water Reactor (PWR) design

- *32% efficiency*
- *high pressure*
- *small dimensions,*
- *<20% enrichment*

Novel small Reactor such as Hyperion Power consist of:

- *Compact small dimensions*
- *Absence of pressure vessel*
- *Operation like nuclear battery*
- *Shielded inaccessible container*
- *Low cost compared to PWR*
- *Zero risk of core melt down*

Emission Reduction and Economic Feasibility

Fuel savings depend on storage system, vessel condition and vessel type, can reach:

- up to 111,538 tonnes in NO_x
- 74,460 tonnes in SO_x
- 4,162,655 tonnes in CO_2

Represent a maximum 22.5% reduction in dry bulk sector and 2.8% of world's fleet emissions
The economic feasibility is depended on the capacity and power of storage medium

- Sodium Nickel Chloride Battery is more economical feasible option
- Vanadium redox Flow batteries have high potential and it is promising technology
- Depending on vessel type fuel savings can exceed 1m $ per year
- Cost of construction drops
- Initial investment cost remains high
- Internal Rate of Return varies from 4.3% - 44.7%

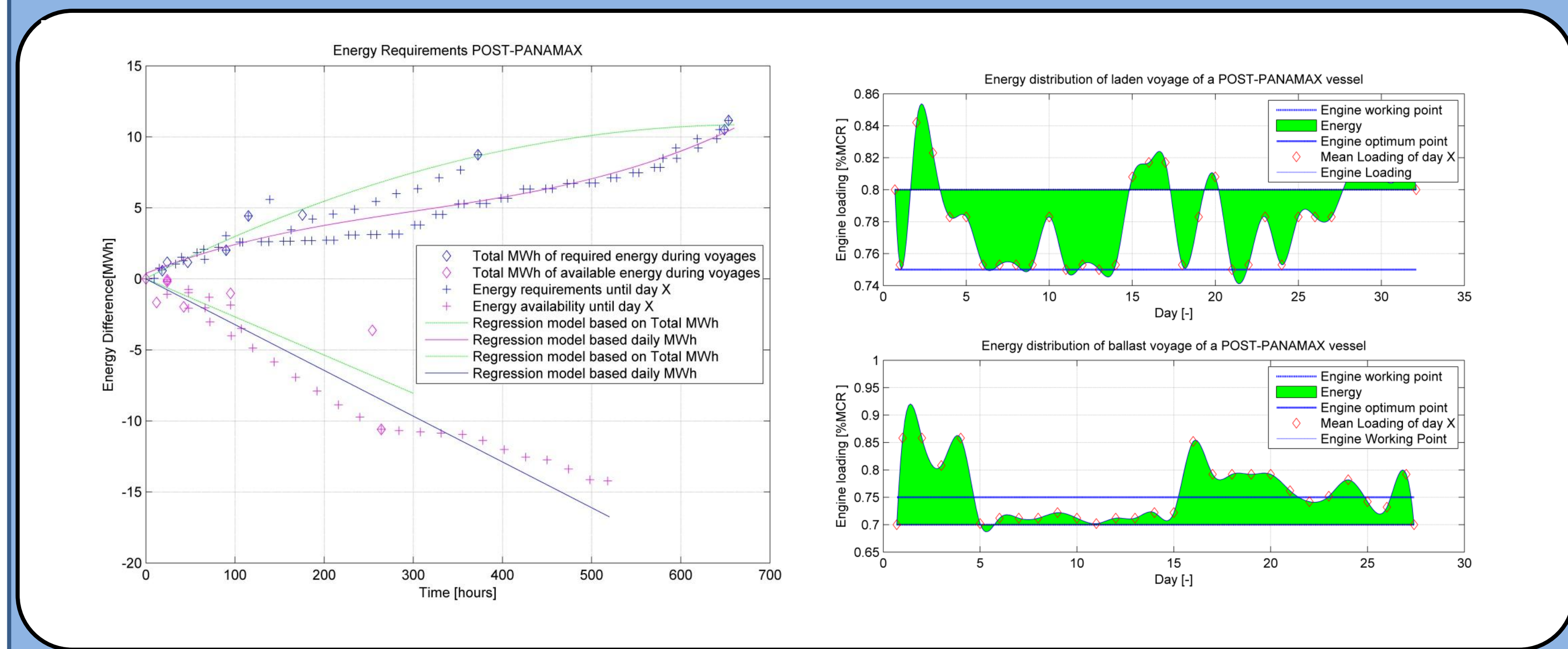

Figure 4: Energy Storage Requirements (left) and Energy fluctuations during Laden and Ballast voyages (right)

Topics already covered in this subject

- Correlation of emission data form empirical formulae and actual operational data
- Investigation of energy requirements in bulk carrier fleets
- Identification of the proper and most efficient type of system to store energy for marine applications
- Complete proposal of the "Hybrid" system for ships
- Technical feasibility, weight and volume approximation and compartmentation
- Nuclear reactor technology comparison and industrial work for potential application in global shipping
- Determination of additional components for nuclear propulsion required to be fitted in Engine Rooms

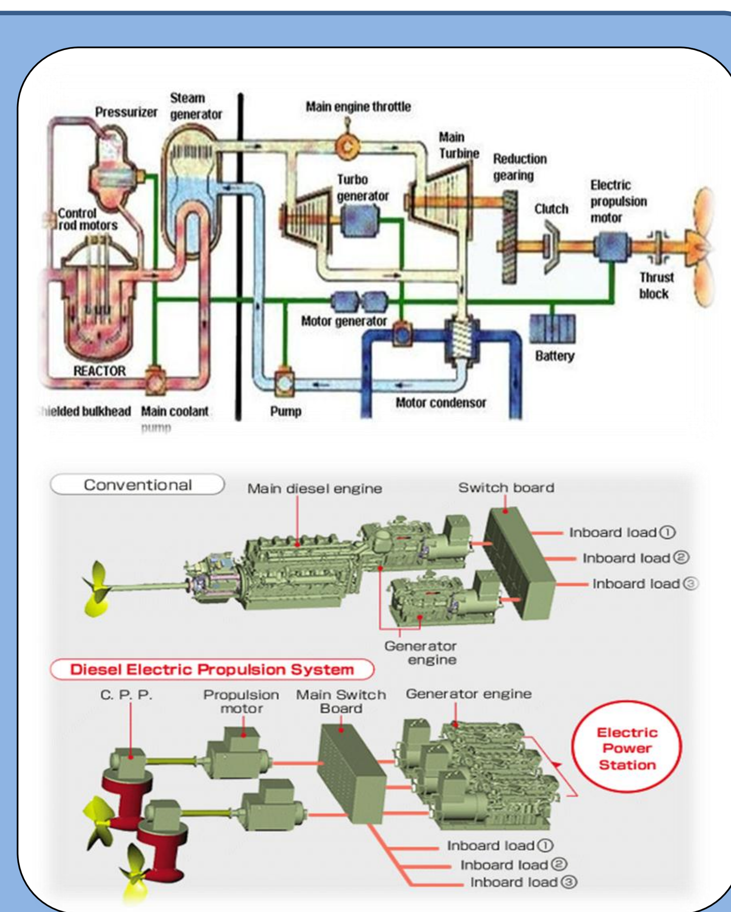

Figure 5: Nuclear (top), conventional (middle, All Electric (down) machinery layouts

Future planned work

- Systems engineering by:
  - Comparison of different propulsion systems such as steam, electrical, conventional Diesel
  - Investigation of extreme scenarios of vessel's life time operation, implementation and simulation of safety and extreme scenarios
  - Module risk and safety assessment of the propulsion system
- Contribute to the Gold based Rules for merchant marine nuclear propulsion

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