Complex ship energy systems modelling, simulation and optimization
Applications experience in various ship types
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Introduction:
Ship Energy systems & Need for Modelling and Simulation
Ship Energy Systems: Features

- Isolated operation: resource constraints.
- Safe, redundant and uninterrupted operation.
- Time varying mission profiles.
- Environmental performance & compliance.
- Need for fuel economy.
- Commercial pressure.
- Complexity increases.

**Objective: Competitive Assets**

*Build and operate better ships in terms of safety, efficiency, costs, and environmental footprint.*
Key driver: Digitalisation in Shipping and Maritime Operations

- Need for integration: vendors, service providers, designers, yards, operators
- Leverage of (big) data
- Systems Engineering: *the sum is more than its parts*
- Holistic approaches
- Improved analytics and quantification.
Ship systems: the way forward

Increased Systems and Operation Complexity

Data & Connectivity + Modelling & Simulation = Quantification

Useful insights implemented in practice
Actionable Knowledge!
Modelling Simulation and Optimisation of Ship Energy Systems

@ DNV GL: COSSMOS
Modelling & simulation of vessels and systems: building Digital Twins & Virtual Engine Rooms
Building virtual integrated ship machinery systems

Library of machinery component models

GUI and modelling platform

Steady-state / dynamic simulations, optimisation...
COSSMOS current service examples

- COSSMOS New Buildings
  Techno-economic comparison of full machinery / propulsion configuration alternatives
  - Engines
  - Auxiliaries
  - Cargo handling systems
  - Waste heat recovery systems solutions
  - Economizers
  - Shaft generators
  - Steam/power turbine systems
  - VOC recovery systems optimal sizing
  - Scrubbers estimation of additional fuel consumption
  - Diesel electric propulsion
  - Hybrid battery propulsion systems.
COSSMOS current service examples

- COSSMOS Fleet in Service
  - Advanced performance monitoring & optimisation
  - Energy audit coupled with advanced thermodynamics.
  - Energy efficiency assessment of power management strategies in Diesel-electric vessels and improvement suggestions.
  - Trouble-shooting and root cause analysis.

- COSSMOS Retrofit & Conversion
  - Techno-economic comparison of solutions and optimisation.
  - Gas carriers reliquefaction plants: techno-economic comparison of vendors options and optimal sizing.
  - Waste heat recovery solutions e.g. economizers, etc.
  - Scrubbers retrofit techno-economic evaluation
  - Battery-hybrid systems.
Applications in New Buildings, Retrofits & Concept Designs
NB machinery configurations for modern LNGCs
What is the best integrated machinery propulsion configuration for the vessel and project we want to build or bid?

i.e. what is the configuration that maximises the expected performance of our investment?

Use COSSMOS to compare in techno-economics alternative machinery / propulsion configurations to support improved decision making

General Ship Applicability
The LNG carrier integrated marine energy system

- Multi-fuel / multi-product energy system
- LNG evaporation: natural Boil-Off Gas variable during voyage (natural BOG)
- Forced LNG vaporisation when natural is not enough (forced BOG)
- Gas combustion of surplus BOG ... or
- Reliquefaction plant onboard
The LNG carrier integrated energy system – decomposed

- Tightly integrated system (feedback loops)
- BOG composition and re-liquefaction affect gas quality to engines
- Time varying operational profile
Adopt novel design approaches

- **Design for trade**
- **Competitive Asset**
- **Efficiency & Economic viability**
- **Integrated Systems Engineering**
Techno-economic comparison of alternative configurations in new buildings and retrofits

Build COSSMOS models, the ship’s Digital Twin to sail virtual

Specific fuel cost (USD/nm)
Overall fuel consumption per mode of operation

Trade route + Operating Profile

Equivalent HFO, tonnes / day
Techno-economic appraisal & Payback time calculations
Reliquefaction systems in LNGC NB

kUSD / year

LNG recovered profit

Payback period

Higher efficiency
But...
More economically attractive
Overall Fuel Consumption and actual Boil-off Rates, entire speed range simulations

Graph 1: Fuel consumption, equiv. HFO [Tons/day] vs. Sailing Speed [kn]

Graph 2: Actual Boil-Off Rate [%/day] vs. Sailing Speed [kn]

- Minimum BOG speed
- Forcing starts
Concept Designs
LPG carriers: design and operation
Integrated system approaches

Integrated machinery: propulsion + power generation + cargo handling

Machinery & energy recovery

Cargo ops:
- Loading
- Pressure keeping

Tank pressure development

Overall fuel consumption TPD, HFO eq. LADEN

Loading  Cool down
**LPGreen concept VLGC: Final concept appraisal**

- **Cargo handling:**
  - Design for faster loading
  - Reduced energy demand
  - Reduced reliquefaction plant size
  - Un-manned cargo room concept
  - Adequate redundancy

- **Tank design:**
  - New IGC code / IMO Tier 3 compliant
  - Higher tank design pressure

- **Machinery configurations:**
  - Improved overall efficiency
  - Conventional and LPG as a fuel
  - Energy recovery technologies
  - IMO Tier III compliant

- **Hull and propeller:**
  - Optimised for both calm water and waves
  - Multiple speeds and loading conditions
  - Energy saving devices

- **LPG as fuel:**
  - Technical feasibility
  - SOx CAP compliant
  - Reduction of fuel expenses

- **Overall Efficiency Improvement:** 6–9%

- **LPG as fuel, technically feasible:**
  - Up to 30% Reduction of Fuel Expenses

- **Up to 30% Reduction of Loading time**
NB machinery configurations for a small-scale LNGC, 7.5k m³
Analysis of different machinery options for various operating profiles

- Mechanical-electric #1
- Diesel-electric #1
- Mechanical-electric #2
- Diesel-electric #2
Assessing the fuel consumption of the various configuration alternatives

Fuel consumption per operating mode and configuration

Tons / day

Annual fuel OPEX under different scenarios

Tons / year

3 operating profiles considered:

Fast evaluation of alternatives: total project support <5 days !!!
Reliquefaction plants: NB and Retrofitting of existing LNGCs
Reliquefaction systems assessment

COSSMOS techno-economic studies by DNVGL
determining reliquefaction systems suitability to Owner and market needs

Applications:
- Retrofitting on existing vessels of various technologies
- New buildings according to charterers requirements

Systems under consideration (recent projects):
- Nitrogen-loop, inverse Brayton cycle
- Mixed refrigerants (MR) cycle
- Joule Thomson Valve effect cycle

Leverage ship / operational data to increase value of analysis
Reliquefaction virtual retrofitting based on real operational data

COSSMOS simulation for a year of sailing, historic data

**Blue**: Vessel as is – without reliquefaction

**Red**: Vessel with MR reliquefaction 1.5tn/h

Fuel consumption HFO equiv. [tn/day]
Reliquefaction virtual retrofitting based on real operational data

Based on voyage / noon reports:

- 5700 tons / year, Reliquefied BOG quantity
- 1.35 mil. USD reliquefied BOG value (@ 5 $/mmBTU)
- X% reduction of GCU usage
- Y% reduction of annual fuel consumption
- 3.6 years, simple payback period

Benefits:

- Increased attractiveness of existing vessels
- Lifetime / charter party extensions
- Trade route / cargo flexibility
- Cost-effectiveness / increased competitiveness

Decision to retrofit gotten!
Battery Hybrids NB or Retrofits
Hybrid-electric propulsion assessment case

Viking Lady OSV

Hybrid-electric systems

On-board measurements

Optimal power management

DNV GL © 2015
19 June 2017
Example
Use of modelling and simulation techniques to derive the best power management strategy

Measurements of operational profile

Proposed power management strategies

Modelling of different control strategies

Quantification of fuel savings

Comparison of alternatives

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Comparison of alternatives
DP mode: measured profile

→ Used data from the measurements to set-up simulations

Thrusters power

Scenario
DP-mode (average load)

Avg. power: 0.8 MW

7 May 2012
10:00-11:00

Total power

Exact operational conditions never to be repeated !!!
DP mode: Peak-shaving strategy fuel consumption

Instantaneous fuel consumption

Cumulative fuel consumption
### Viking Lady operational modes energy cost

<table>
<thead>
<tr>
<th>Operational mode</th>
<th>Baseline</th>
<th>Optimal</th>
<th>Difference</th>
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<tbody>
<tr>
<td>DP Low</td>
<td>11.84</td>
<td>8.73</td>
<td>-26.26%</td>
</tr>
<tr>
<td>DP High</td>
<td>10.21</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Transit 12kn</td>
<td>7.99</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Transit 9kn*</td>
<td>10.64</td>
<td>7.99</td>
<td>-25%</td>
</tr>
<tr>
<td>Transit 6kn</td>
<td>8.89</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Harbour</td>
<td>11.89</td>
<td>8.99</td>
<td>-24.40%</td>
</tr>
<tr>
<td>Stand-by</td>
<td>11.23</td>
<td>8.79</td>
<td>-21.74%</td>
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Applications in Ships in Operation
Optimum Power management Strategies
DFDE LNGCs in operation

- Is there potential for efficiency gains through power management optimisation for DFDE LNGCs in operation.

- How can we assess performance using COSSMOS?

- Study:
  - Testing of proposed PMS via simulations on historical operational data of a given ship in operation
  - On board implementation from ship-owner in collaboration with DNV GL.

DFDE integrated machinery system,
Z LNG carrier
Operational data measurements from DFDE LNGC in operation

Engine #4 in operation

Engine #3 in operation

Engine #2 in operation

Engine #1 in operation

Vessel speed
Simulation-based power management assessment in Diesel electric vessels

Load (-)  As recorded from onboard operation

Hours from start of month

Load (-)  As selected by COSSMOS optimal Power Management

Hours from start of month

Estimated equivalent fuel savings (tons-LNG/day)
Integrated system energy flow mapping
DATA (design and operational) + computer MODELS

COSSMOS

- DIESEL ENGINES
- AZIPODS
- BOW THRUSTERS
- LT Cooling network
- HT Cooling network
- AC Chillers
- Electricity consumers
- Steam consumers
- BOILERS

Operating Profile

Trading patterns analysis

Accurate mapping of Energy flow, Efficiency and Losses

Improved decision making
Ambition: Model-based data driven asset management (near) Real time support

COSSMOS model simulates the conversion of energy across the vessel’s power train and compares with on board data

Build / adapt / expand COSSMOS models

Availability of an extended set of sensor signals
Performance assessment and improvement of tanker cargo operations
Boiler / Steam turbine-driven pumping station onboard
Compare operational with simulated performance

Data acquisition

Data processing

Ship-specific COSSMOS model

Assessment
Understanding
Best practices
Efficiency gains

Simulations, analysis and optimisation
Crude oil tankers cargo operations

Complex systems, ship & terminal operations, crew functioning, inefficiencies.

How to assess energy efficiency of the operations quantitatively & improve them in practice.

Charterers focus!!!
COSSMOS performance assessment & improvement
Fleet in service

Crew training and best practices adoption

Crew change

Crew change
Using COSSMOS for cargo / BOG systems assessment, improvement and troubleshooting
Model-based troubleshooting of a BOG/LNG re-liquefaction system

- Problem: poor performance and low re-liquefaction quantities (observed during whole voyage(s))
- Complex process many potential causes
- Complex control & scheduling strategies.

- Start for a design basis model
- Assign “Health indexes” to all major components.
- Vary Health indexes to match observed performance.
- Search for large health index variations.
Health index of “Cold box” heat exchanger

- Excessive fouling due to oil contamination of surfaces after ~2-3 hrs of operation
- Purging, Inerting, Gas-freeing and Warming-up clean the oil deposits when open for inspection!
- Modelling was the strongest indicator!
Summarizing
Model-based Approaches for Ships

- Advanced model-based methods that manage complexity in practice: **DNV GL COSSMOS**

- Robust decision making: Asset competitiveness

- Improve attractiveness of maritime assets
  - New bids and tenders: optimum configurations
  - Operations optimisation
  - New trades / charter extension
  - Retrofitting
  - Trouble-shouting

- Quantification and allocation of investments

- **Practical today’s problems → Answered via Modelling, Simulation & Optimisation**
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