Towards a digital twin of a mid-speed marine engine

From detailed 1D engine model to real-time implementation on a target platform

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Agenda

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Introduction

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Introduction

- **Challenge**
  - Proof of concept for digital twin applications for mid-speed marine engines

- **Solution**
  - Fast Running Engine Model together with dedicated solvers to achieve real-time operation

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Materials and Methods

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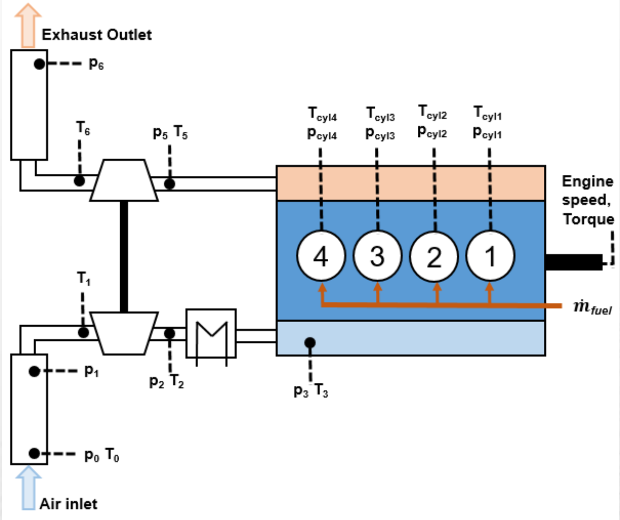
Wärtsilä 4L20 in VEBIC Engine Laboratory (University of Vaasa)

Research object and experimental setup

Cylinder configuration	four, in line
Bore	200 mm
Stroke	280 mm
Swept volume / cylinder	8.8 dm^3
Compression ratio	16:1
Rated Speed	1000 rpm
Brake power	848 kW
Fuel system	Common rail
Injector	Solenoid / nine-hole axisymmetric / 153º umbrella angle
Turbocharger	ABB TPS48E01
Valve system	four valves/cylinder, Miller timing-capable



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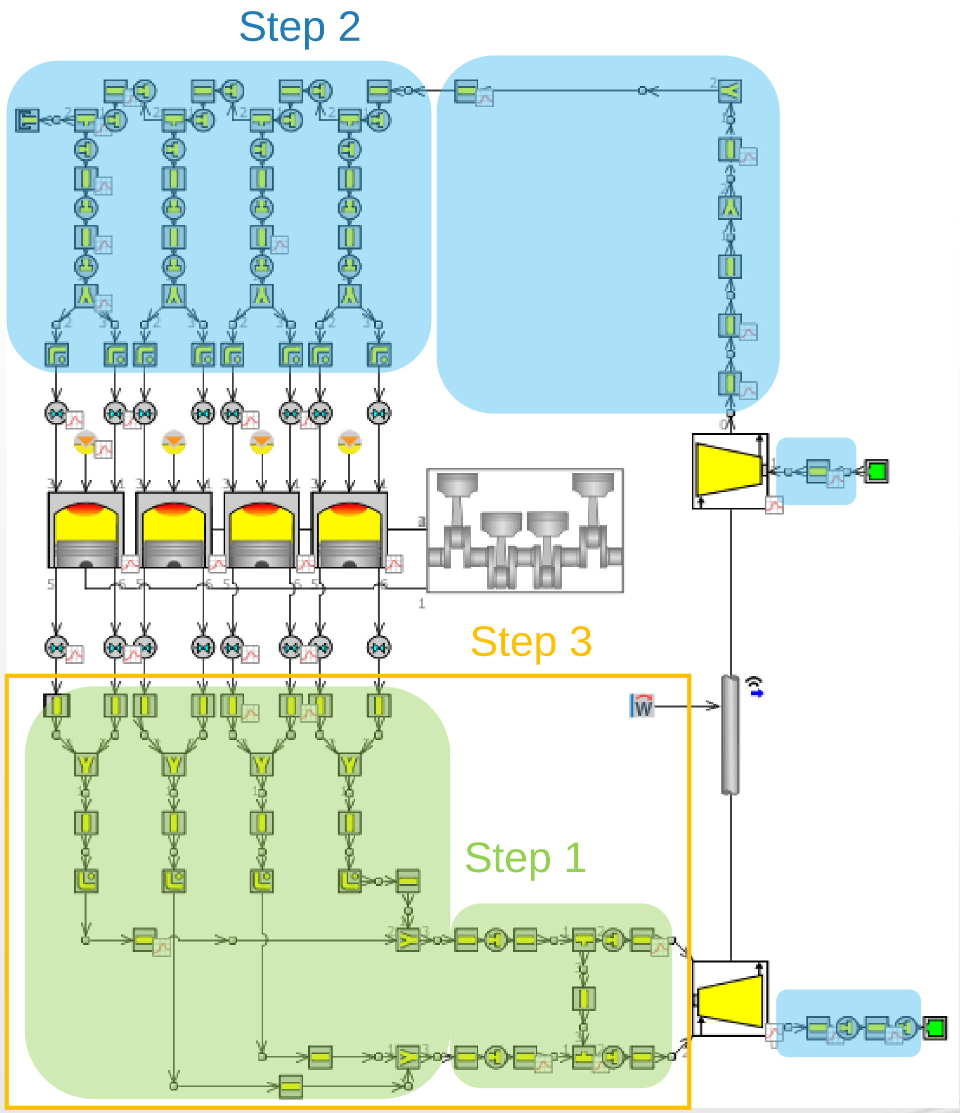
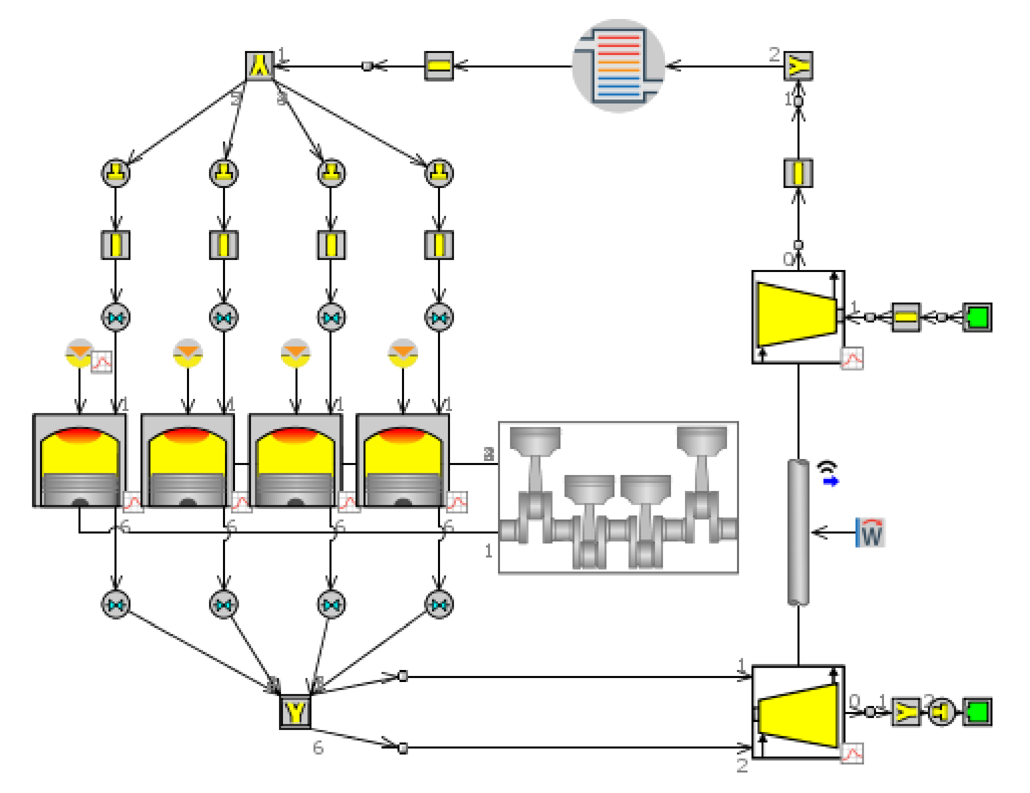


Fast Running Engine Model (FRM)

- Target: real-time capable engine model with minimal trade-off to model accuracy
- The process was divided into three main steps
  - Step1: Exhaust manifold (accuracy)
  - Step 2: All other sub-volumes, i.e. exhaust pipes, intake manifold, compressor outlet pipes and intake pipes (accuracy)
  - Step 3: Exhaust manifold (speed)

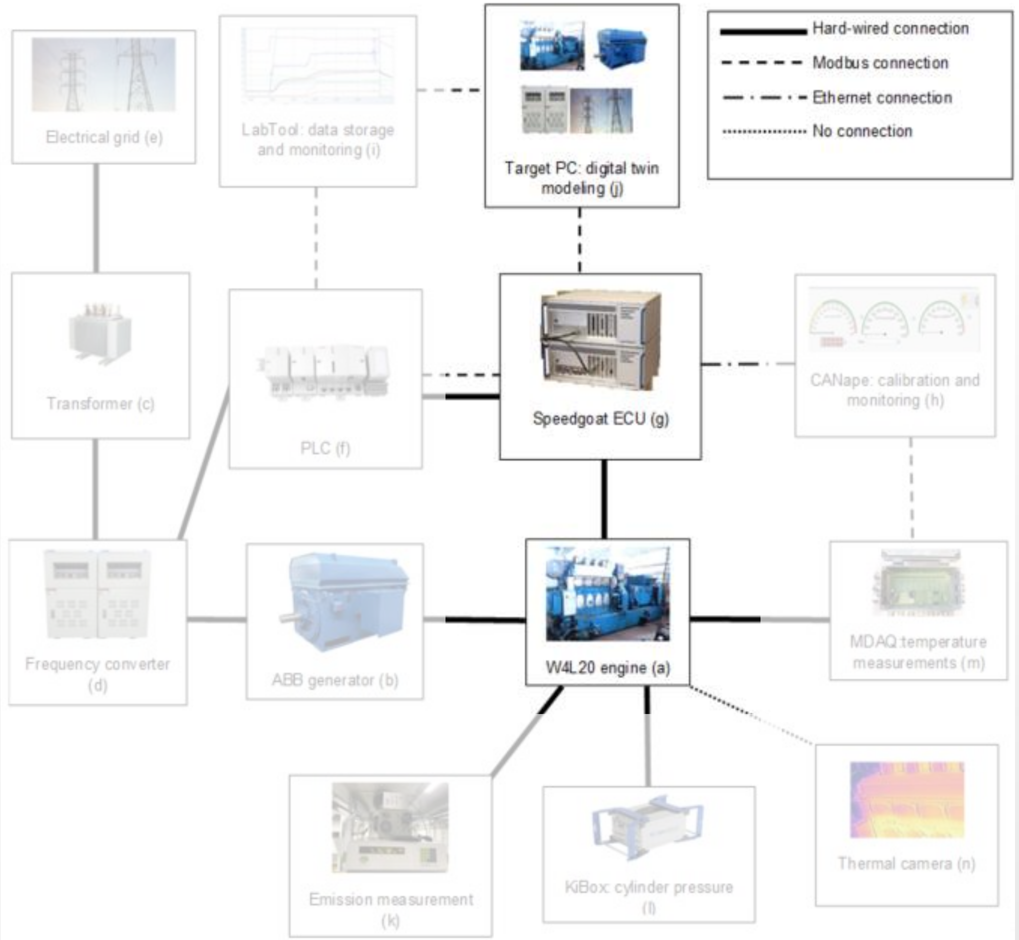
Fast Running Engine Model (FRM)



Feature	1D-Detail	FRM
Minimum discretization length intake	50 mm	200 mm
Minimum discretization length exhaust	50 mm	300 mm
Number of flow components	181	47
Solver	explicit, forward Runge-Kutta method	explicit, forward Runge-Kutta method / explicit Euler real-time (in the RT license)
Maximum simulation time step *	0.00017 s	0.12 s
Average simulation time **	77 s per steady state case	19 s per steady-state case (4 s with a real-time license)

* user-imposed limit
** on single CPU (Intel i7-8750H 2.20 GHz) with 16 GB RAM

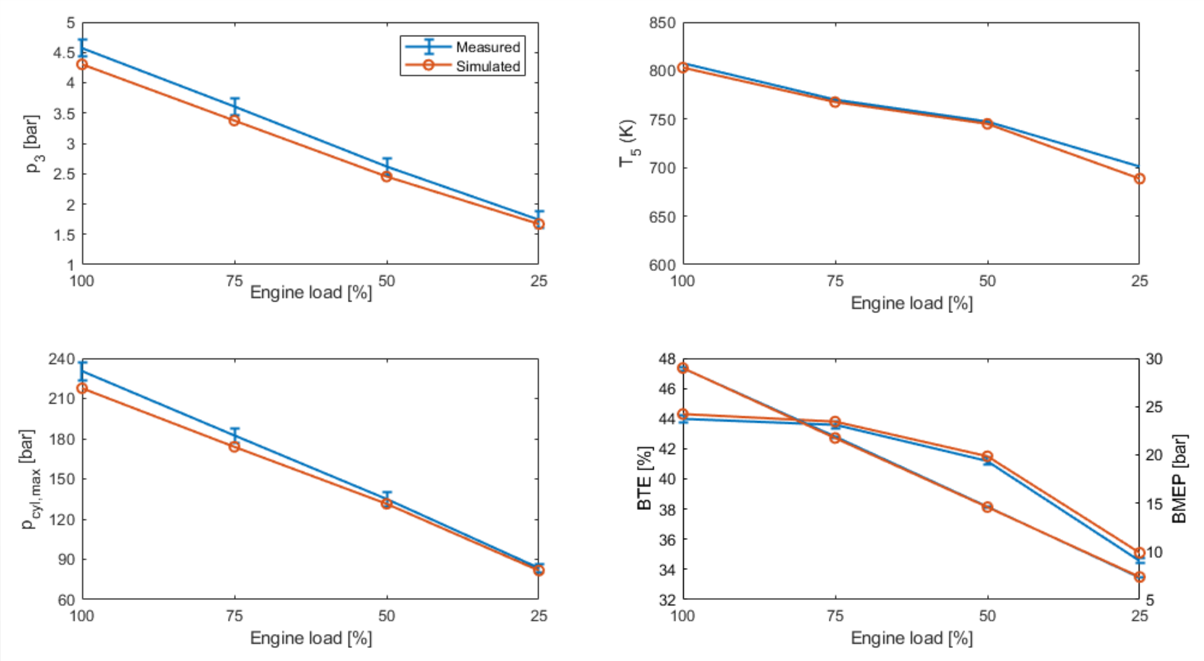
Real-time implementation



- Target platform for real-time simulations
  - Dell Optiplex 760 PC (2008 model year)
    - Simulink Real-Time and a Modbus card
- Main changes for real-time operation
  - Speed optimized solver (GT-Suite-RT license)
  - Representation in Simulink via s-function and C code

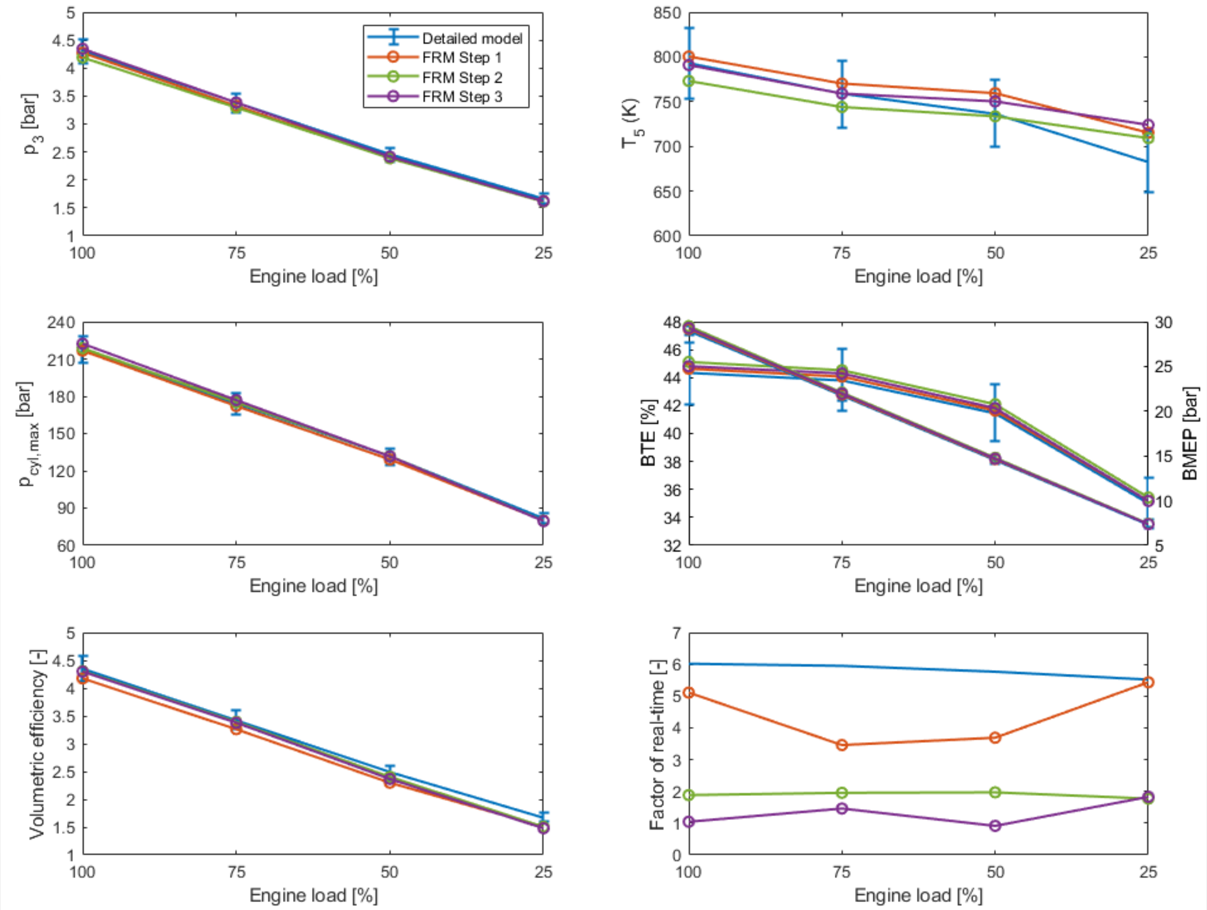
Results

The 1D engine model validation



- Validation against experimental values
- Intake manifold pressure (p_3)
  - Below measurements and target tolerances
- Averaged maximum cylinder pressure ($p_{cyl,\ max}$)
  - Below measurements and target tolerances, result of inaccuracies in p_3
- Exhaust temperature at turbine inlet (T_5)
  - Match measurements with acceptable accuracy (measurement inaccuracies)
- BMEP and BTE
  - Match the measurement sufficiently

Validation of the FRM



- Validation against 1D model values
  - Target tolerances ±5 % (for BMEP 0.5 bar).
- Results were mostly inside the target tolerances
- Largest uncertainty in exhaust temperature at turbine inlet (T_5)
- Significant reduction in simulation time was achieved with minimal impact on model accuracy

Towards real-time implementation

- Compared to standalone FRM:
  - Calculation time is reduced from 19 to 4 seconds*
  - No substantial change in model accuracy

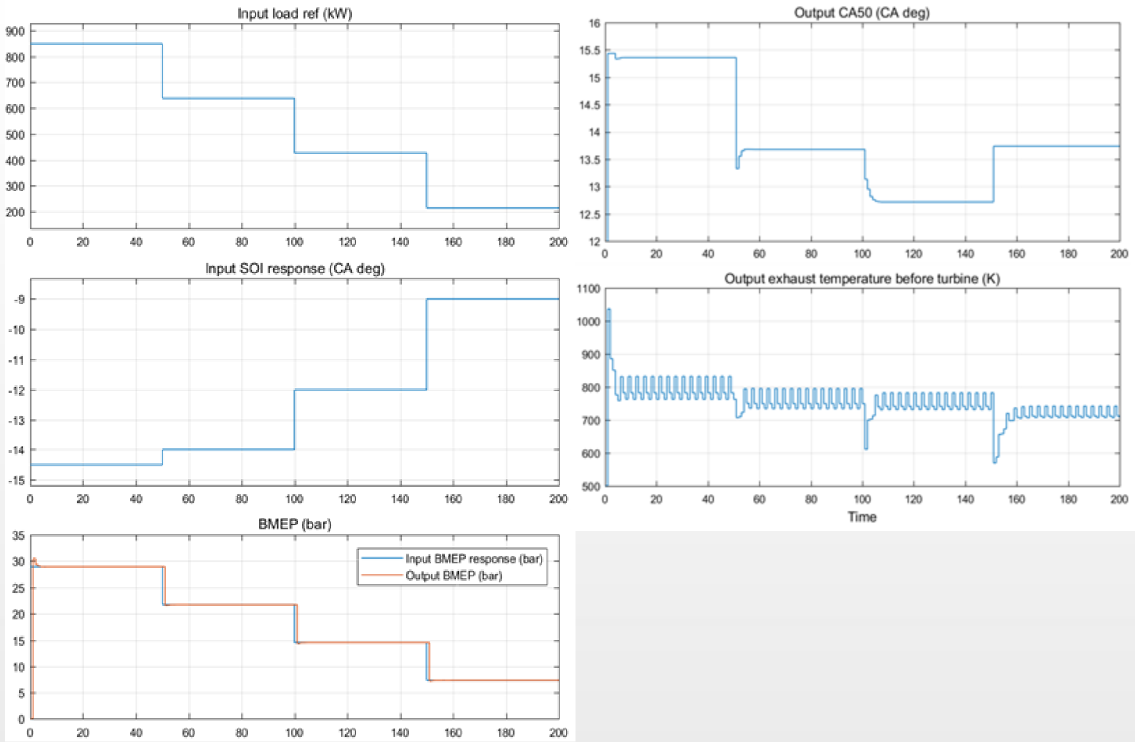
Achieved factor of real-time is 0.35

Over 70% reduction in calculation time

Results inside the target tolerances of ±5 %

*approximate values per steady-state-case

Towards real-time implementation



- The real-time capable FRM was embedded in Simulink and tested on the target platform
- Target platform had lower CPU performance compared to the PC used for prior simulations
  - 1 second step size was forced to be used in Simulink Real-Time

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Conclusions

- Identification and calibration of the detailed 1D engine model, (181 flow components) allows model accuracy within cyclic variations of the real engine. Excellence in this respect enables building an accurate real-time FRM surrogate.
- The FRM reduces the level of complexity (47 flow components), while maintaining a good level of predictivity.
- The FRM reaches fastest simulation with minimum error with discretization length of 100 % and 150 % of cylinder bore for intake and exhaust components respectively.
- Applying explicit solver optimized for speed (GT-Suite-RT license) reduces the FRM´s real-time factor to 0.35.
- The accuracy loss of the FRM compared to the detailed engine model is minor, (comfortably within the 5 % tolerance levels). Largest deviations appear at low-load conditions.
- The CPU speed of the available RT machine was not efficient enough, introducing errors in high-frequency signals. The mean value control outputs were still calculated correctly.

Thank You!

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