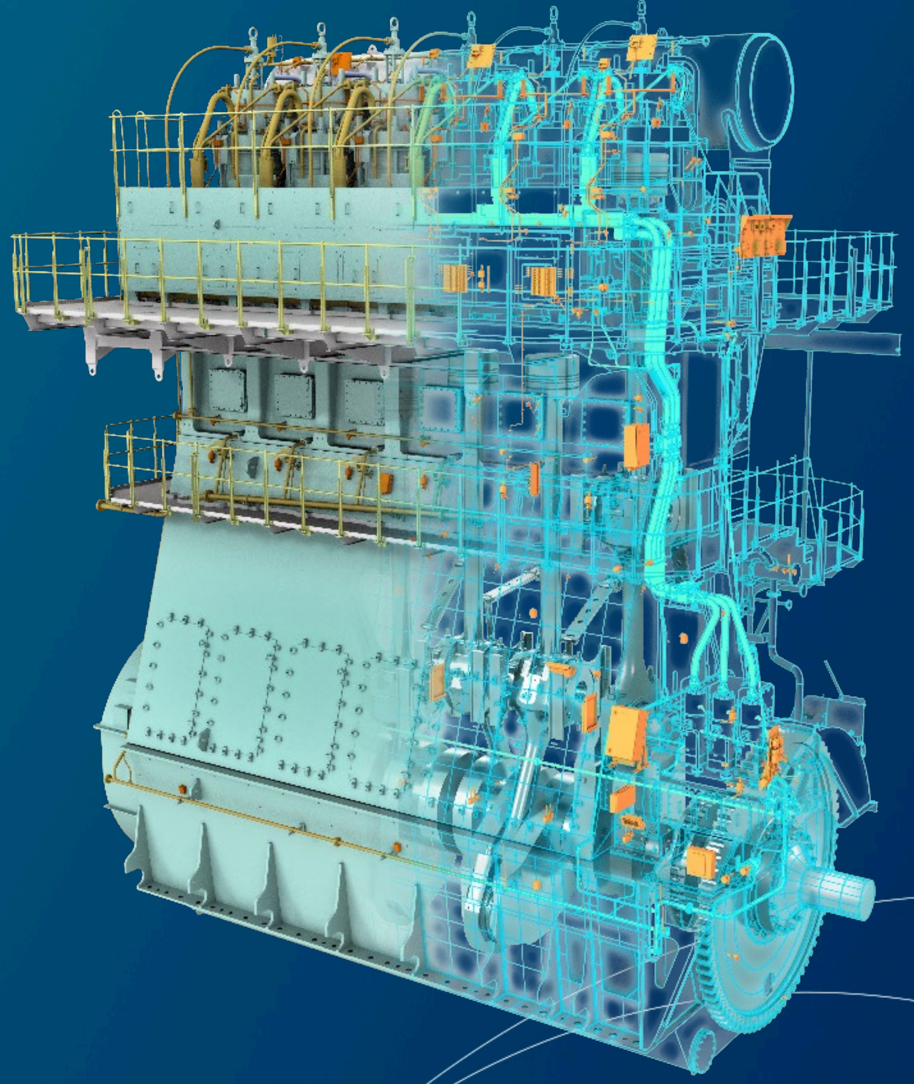
Development and Deployment of a 2-Stroke Marine Engine Digital Twin

within a 0D/1D-Simulation Environment



Markus Kerellaj, MSc. & BSc. Mech. Eng.

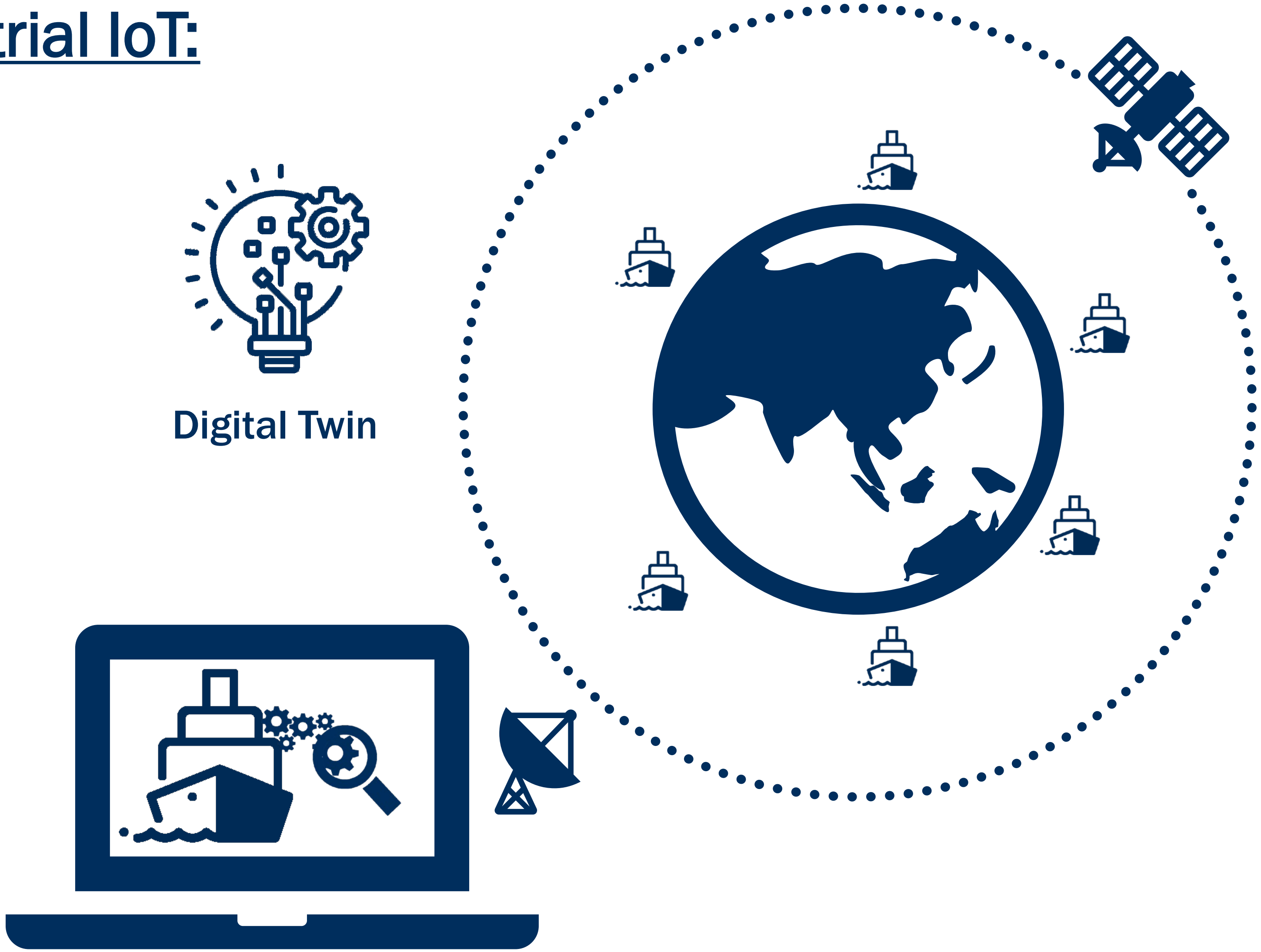
CIMAC CASCADES Graz, Austria 2021

University of Applied Sciences and Arts Northwestern Switzerland
School of Engineering

New possibilities from Industrial IoT:

Ship operation:
- On ship live data collection
- Live data analysis
- Prediction of engine state
- Offline & remote support

Engine development:
- Early concept phase
- Proof of concept
- Full engine simulation
- Final development



Motivation

→ Opening up new opportunities:

- Complex full system simulations (today)
- Control function development/testing
- Model-based controls

Offline

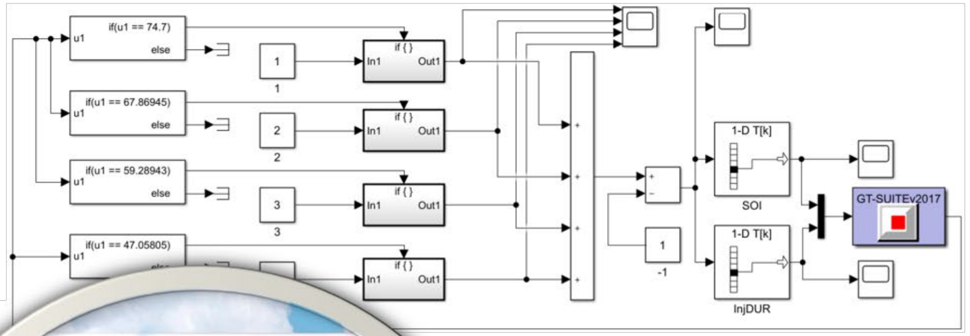
Development

Operation

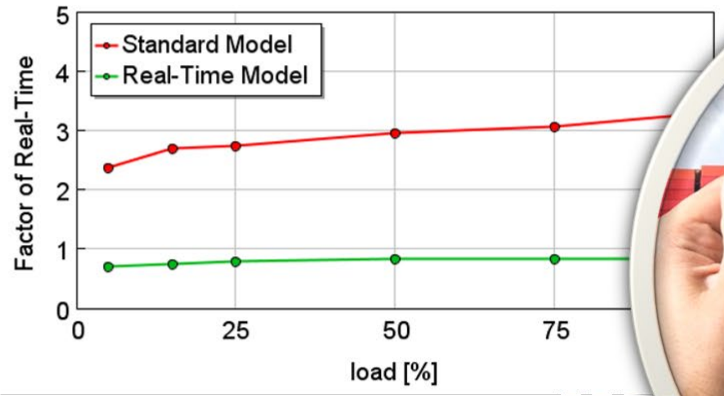
Online

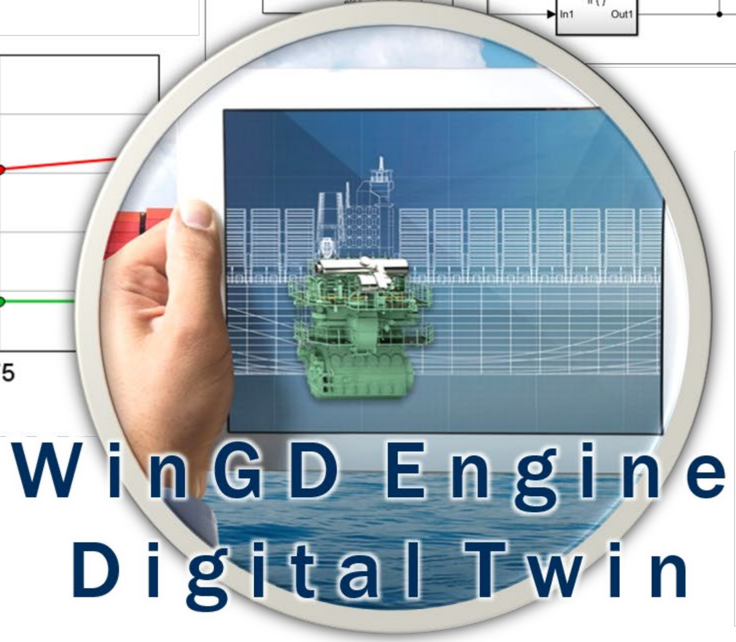
- Engine monitoring & health management
- Predictive maintenance systems

Integrated

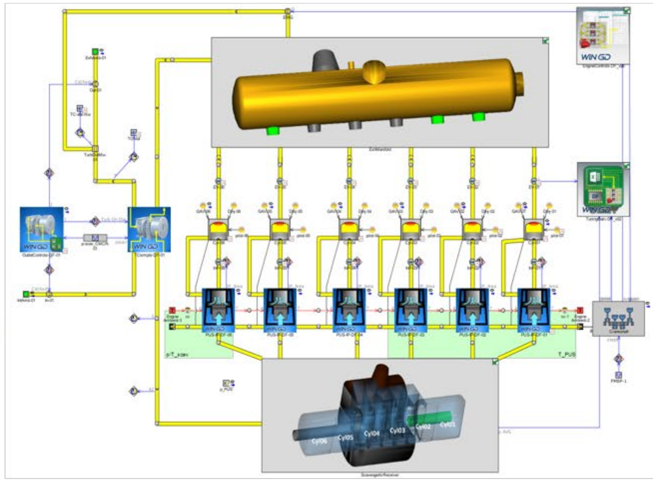


Real-time



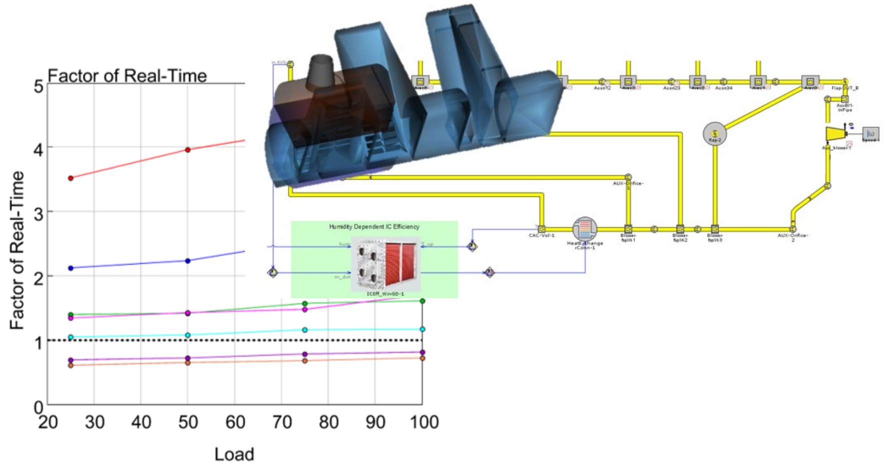


Physical

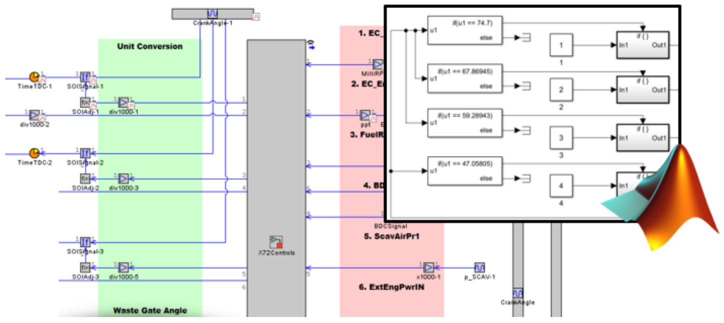


Offline engine performance digital twin development:

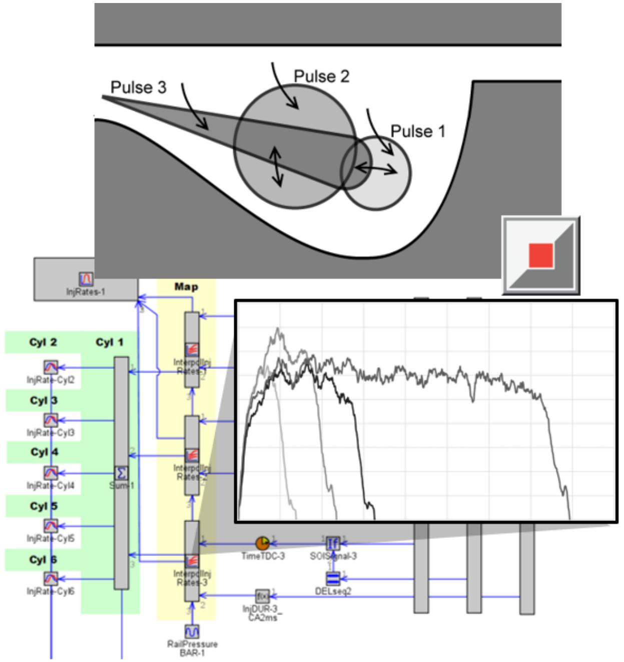
- Replicating engine performance & operation of large 2-stroke marine engines
- Physical 1D-CFD model, high modelling fidelity (air path, predictive combustion)



RT-capable engine simulation model



Coupling with SIMULINK controls model



Predictive Combustion

→ **Real-time, transient capable Digital Twin model development**

Experimental setup

Engine:

- WinGD “6X72”
- 2-stroke in-line, 6 cylinder
- Bore 72cm, stroke 3086mm
- ABB turbocharger
- CMCR speed of 74.7 RPM
- CMCR power output 15080 kW

Instrumentation and data:

- Crank angle-resolved data
- Time averaged measurements
- 4 load points on propeller curve @ 100, 75, 50, 25%

→ Load applied using a water-brake

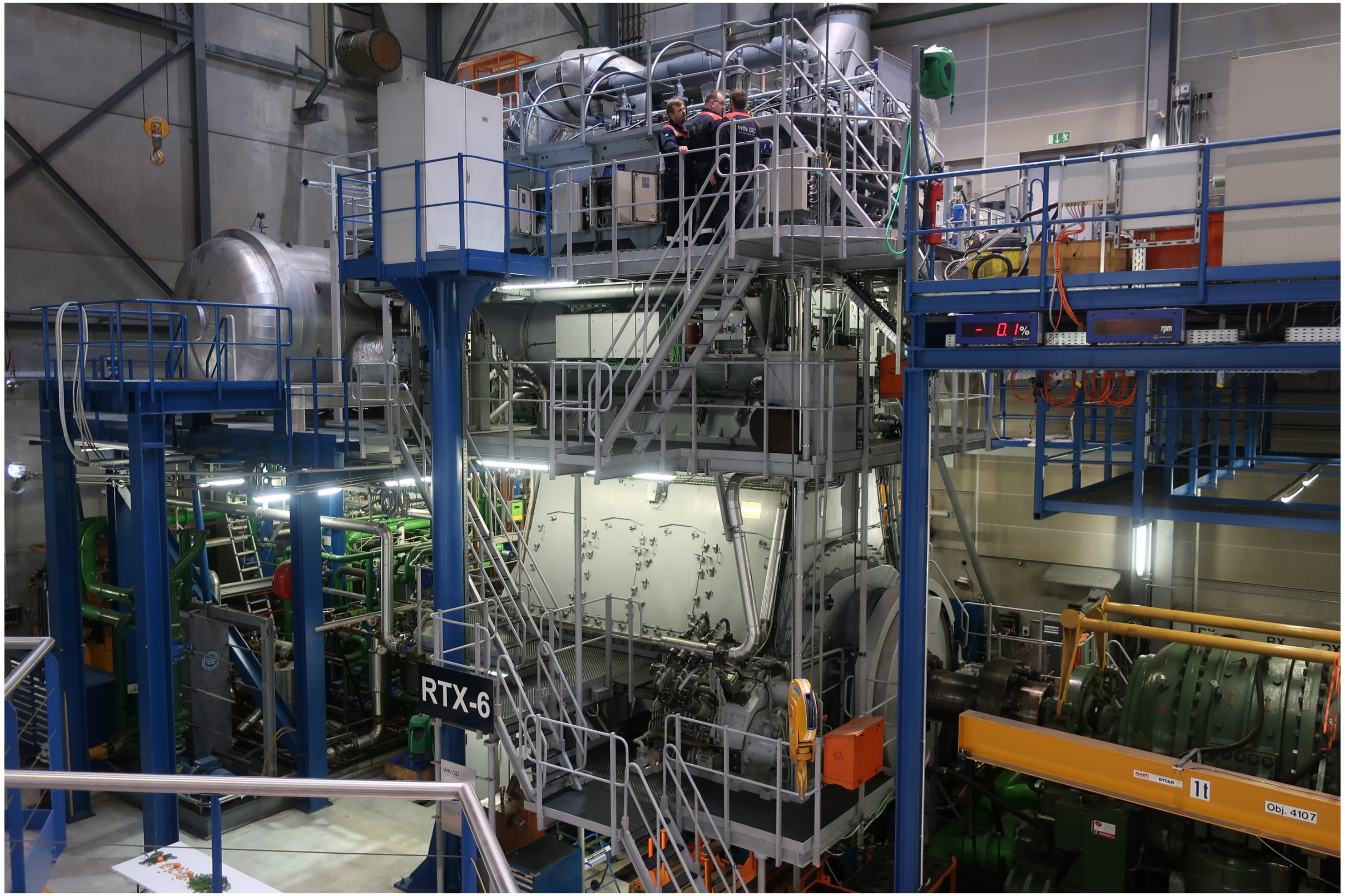


Illustration of an engine test bed; WinGD’s research engine RTX-6

→ Cost for experimental measurements: ~20k€ per day

Detailed GT-POWER engine model:

- Full air path
- Map-based turbocharger
- Fuel injection system
- Charge air cooler system
- EV-control system

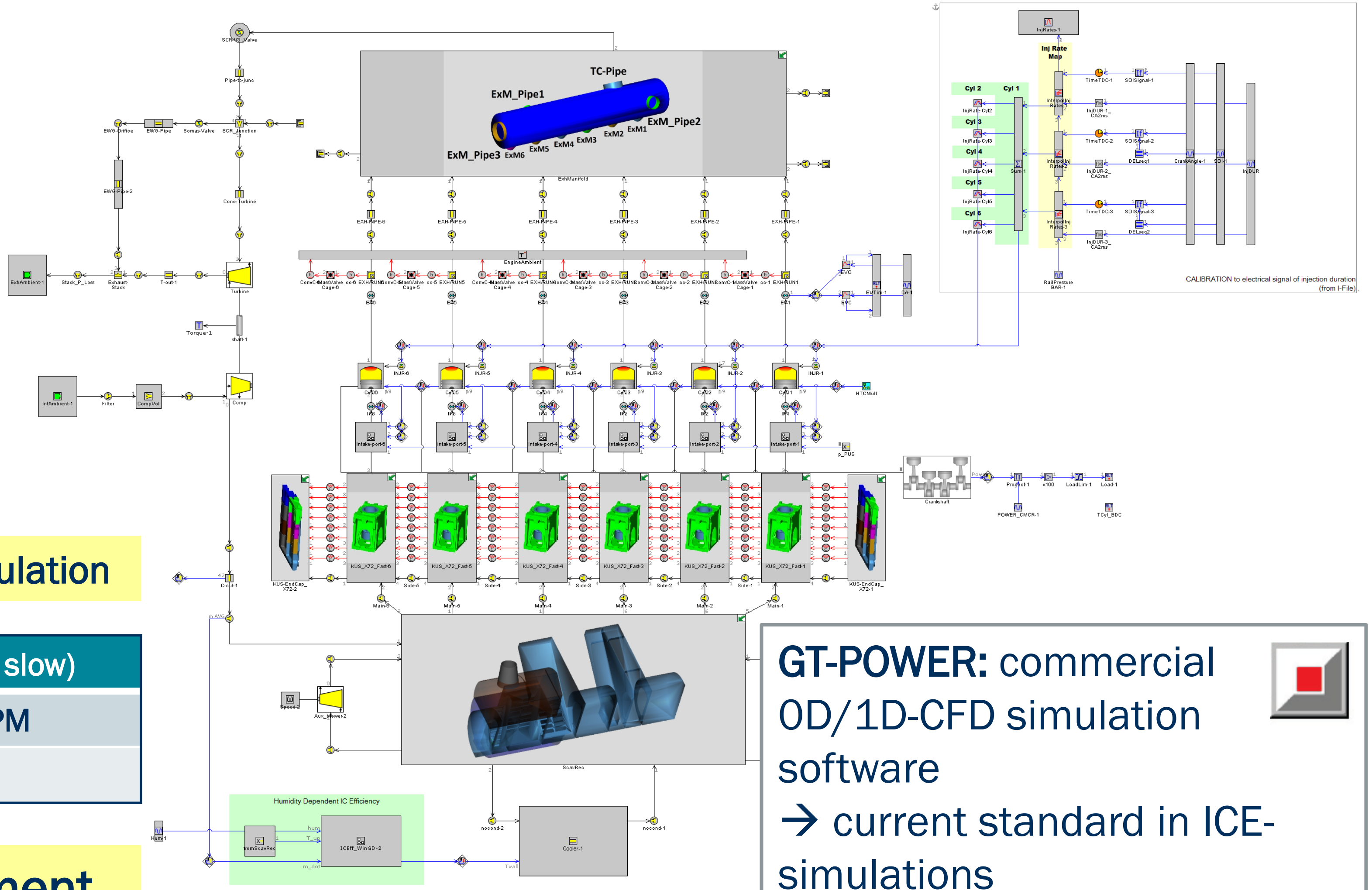
➢ Crank-angle resolved results

➢ Running slower than real-time

→ State of the art engine performance simulation

Automotive	Marine (2-stroke, slow)
~800 - 8000 RPM	~25 – 125 RPM
~100 x RT	~3 - 4 x RT

→ **Base for Digital Twin development**



GT-POWER: commercial 0D/1D-CFD simulation software
→ current standard in ICE-simulations

Target: Transient capable Engine Performance Digital Twin

→ Predictive GT-internal "DIPulse" combustion model

Combustion rate prediction:

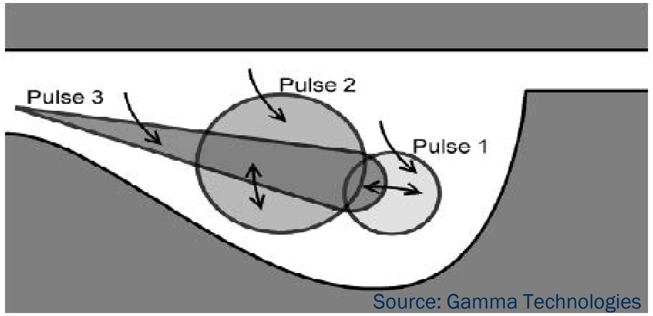
- Single/multi-pulse injection events
- Injection rate map approach
- Measurement-based calibration

→ f (injection profile, injection timing *) → Burn rate

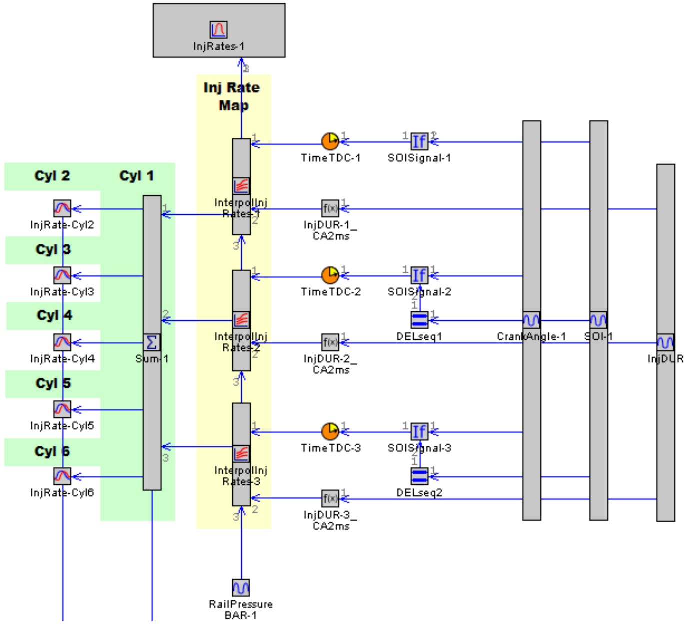
*combustion chamber conditions, nozzle geometry, ...

Maps f(fuel rail pressure & energizing time)

+ other sub-models (e.g. injection system, intake ports, ...)



DIPulse-schematic for predictive combustion



Model map section of the injection system

Model approach – Real-time conversion

→ Build of a (Marine Engine) "Fast Running Model"

Reasons for an FRM:

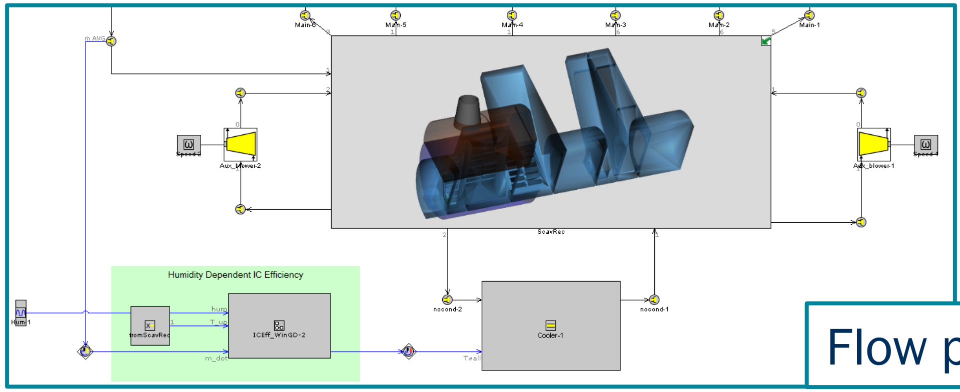
- Maintaining engine topology
- Dynamic model
- Predictive sub-models
- High accuracy

"Speed-up vs. accuracy"

Conversion steps:

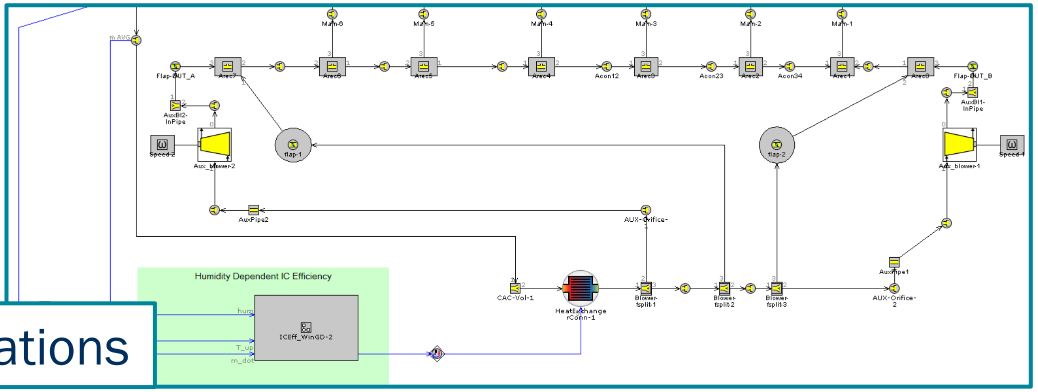
- Flow path simplifications
- Discretization length changes
- Output setting optimization

→ Model recalibration



Model map of the initial scavenge air receiver

Flow path simplifications

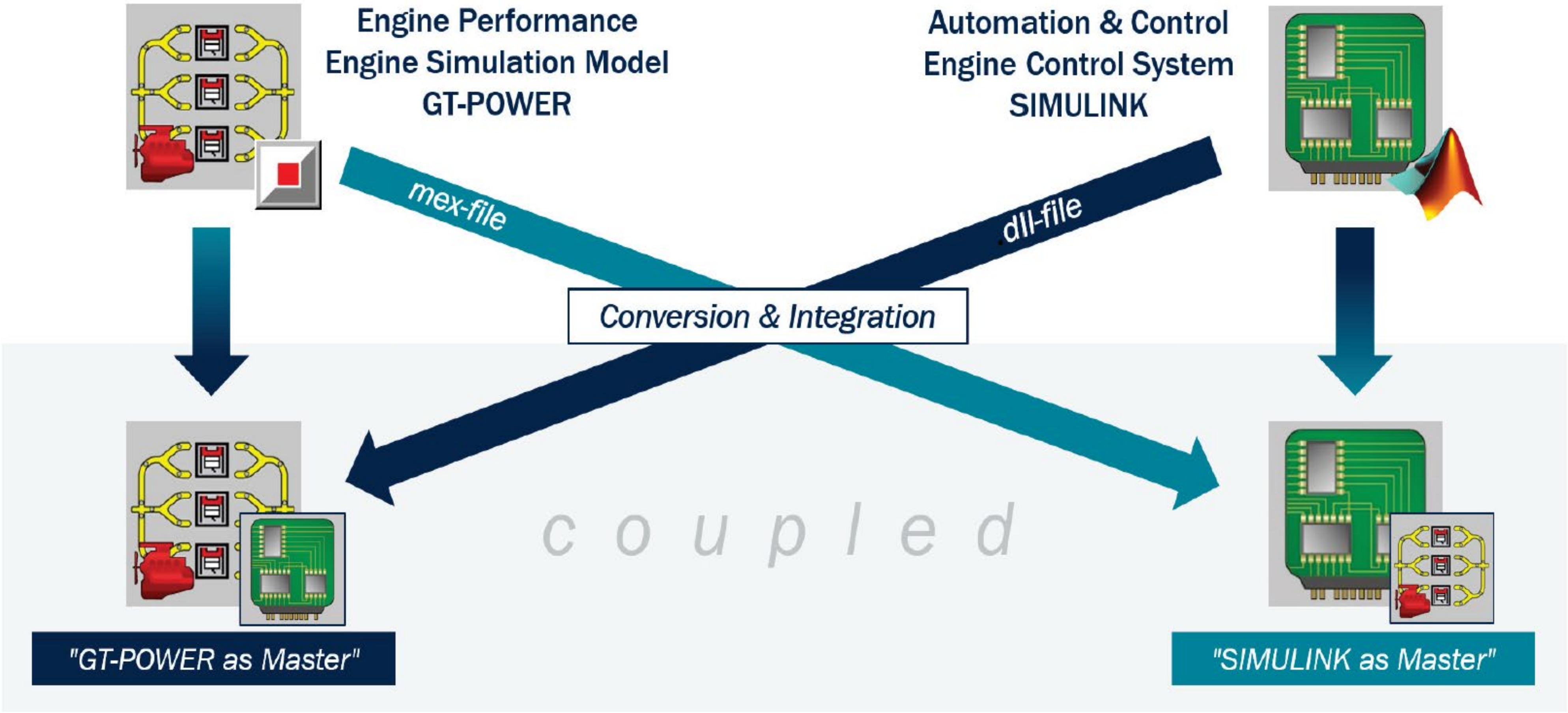


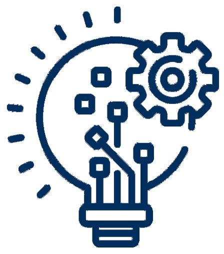
Flow path in the new scavenge air receiver

→ Real-time capable engine performance simulation model

Model approach – Model coupling

→ Different couplings for different developments and applications:





Digital Twin

for offline engine development applications

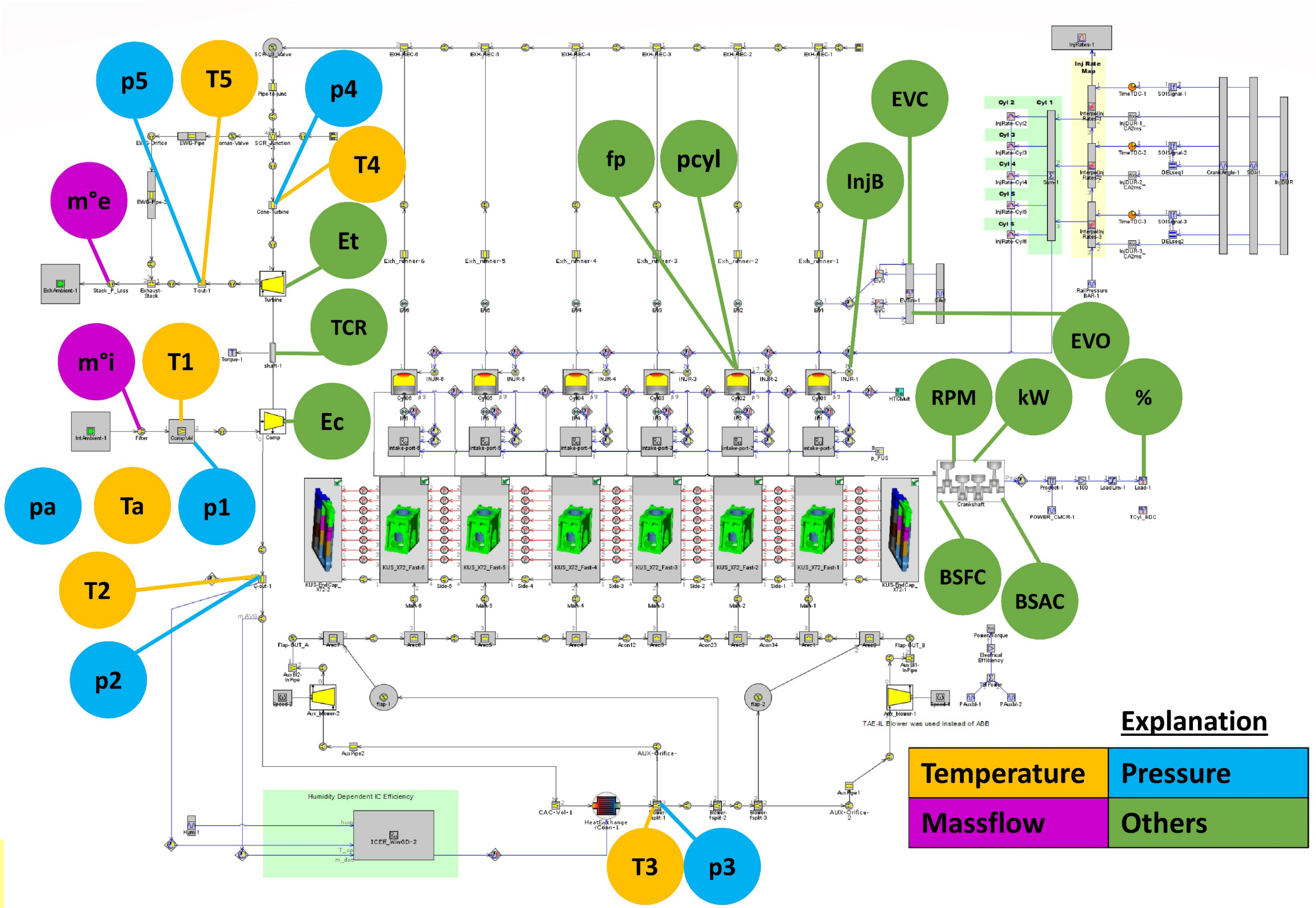
→ Transient, predictive & real-time capable engine performance simulation model

Main validation criteria:

- Air path p, T at 6 locations
- Air mass flow inlet/exhaust
- Turbo-charger speed
- Engine power and speed
- Cylinder pressure as f (°CA)
- EV-Timing
- ECU-commands

→ **Measurement data from a WinGD 6X72**
(4 load points: 100, 75, 50, 25%)

Validation concept applicable for all stages of model-development



Measuring point scheme of the 6X72

Maximum deviations over all measuring points:

- Air path pressures: 4.5%, previously 5.00%
- Air temperatures: 10K, previously 27K
- Air mass flow: 3.7%, previously 5.8%

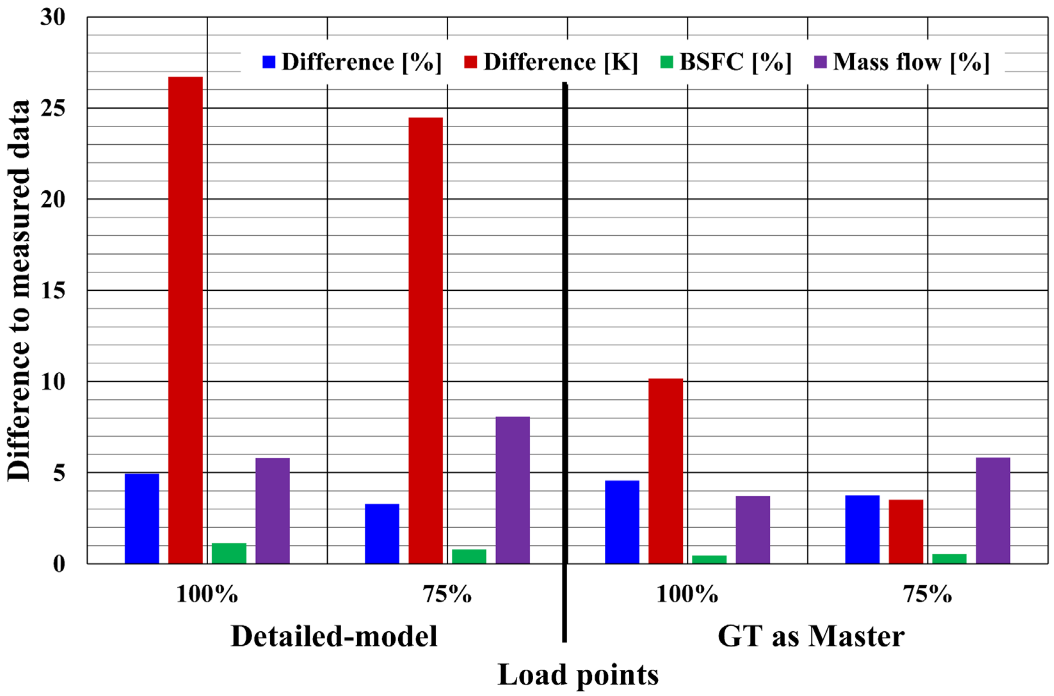
(Coupled "GT as Master" compared to traditional "Detailed-model" @ 100% load)

→ Feasibility confirmed

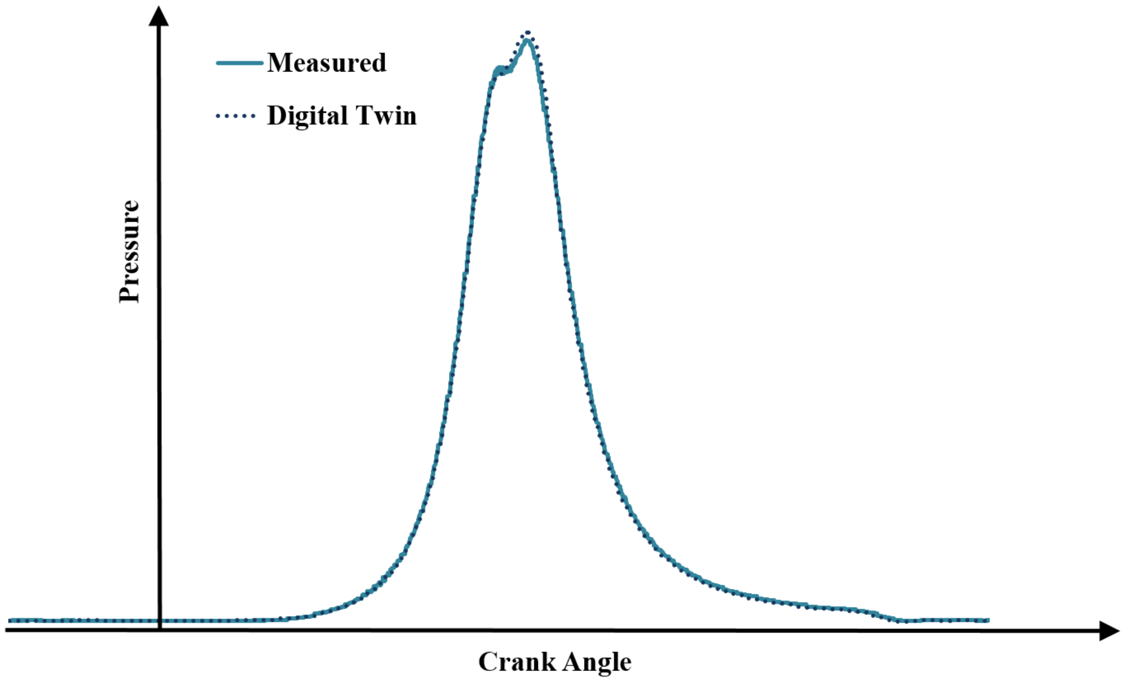
→ Procedure defined

→ Clear refinement of the simulation

→ Real-time capability

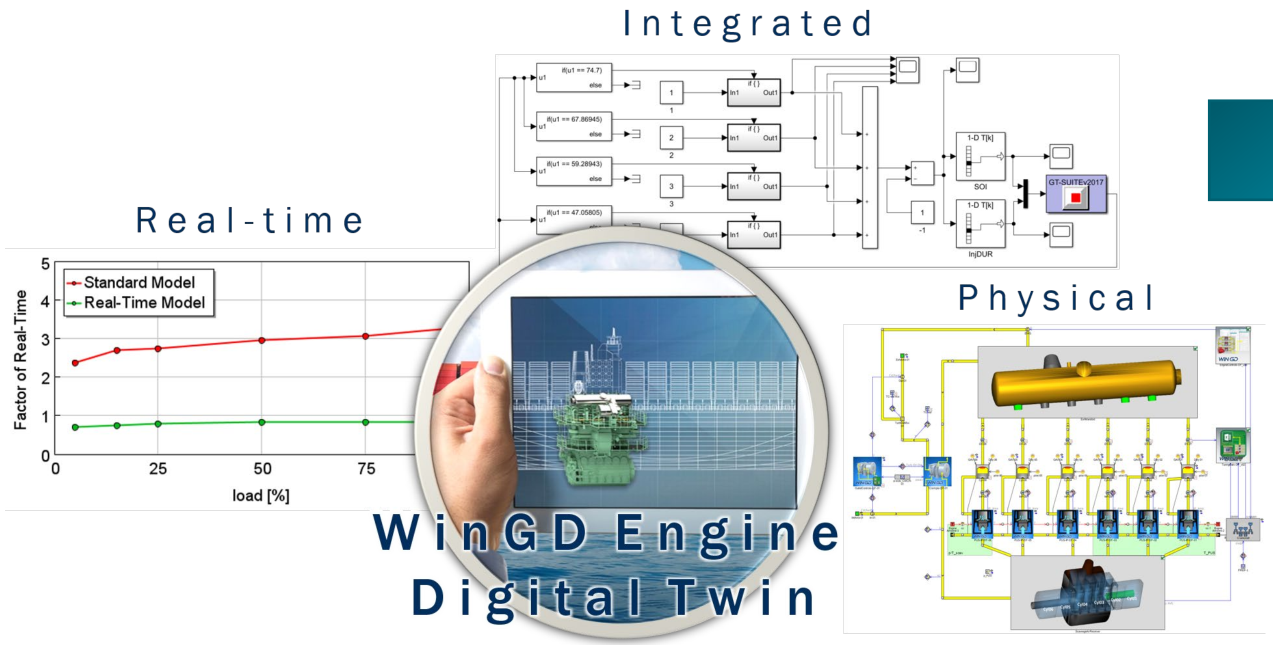


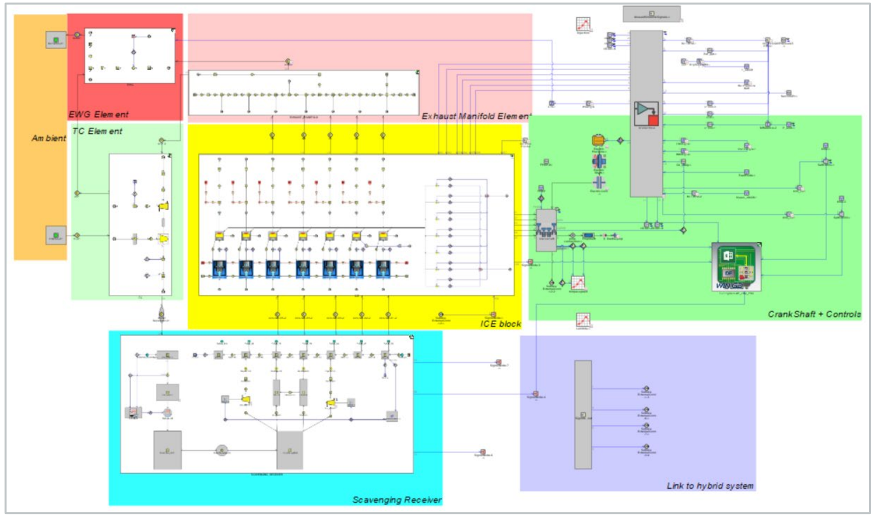
Model comparison and validation



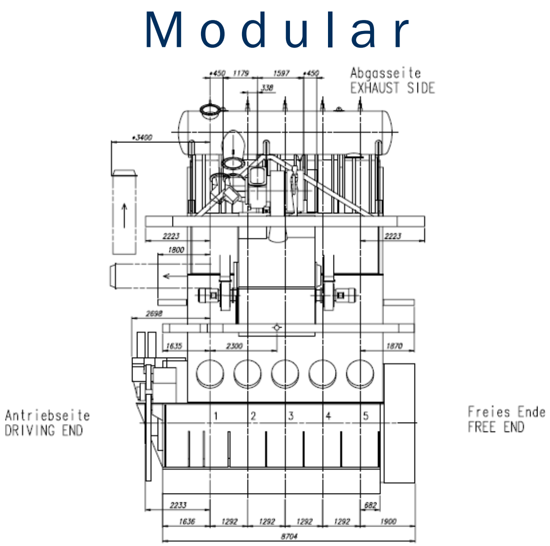
In-cylinder pressure curve at 100% load

Modularization for an automated DT generation





Automated GT-POWER DT-engine performance model



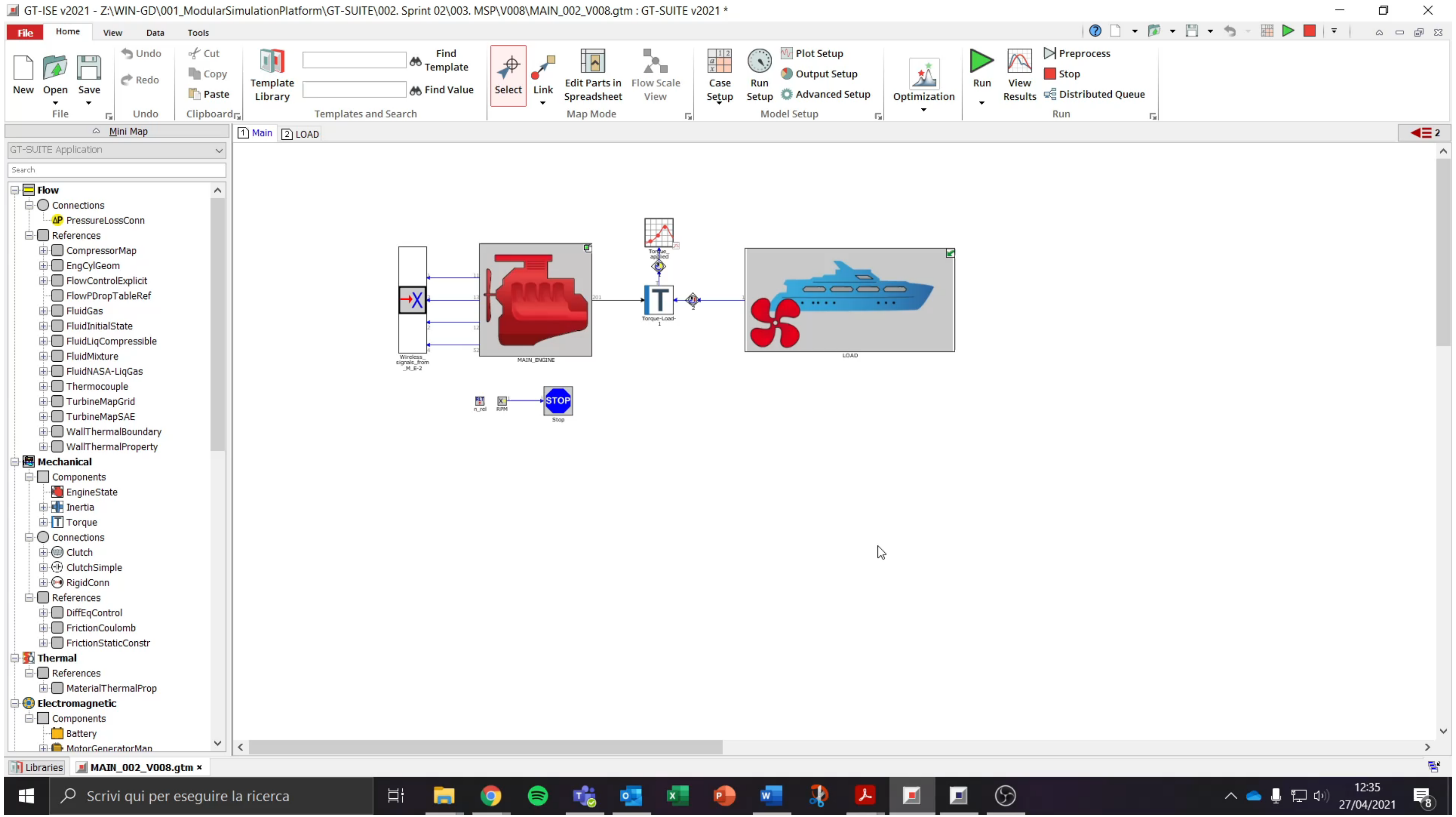
WinGD Marine engine side view

→ Transition from model development to product development

Large Marine Engine development: Each engine specifically developed for customer

Application developments

“Modular Simulation Platform” (MSP) for an automated DT generation



Fully automated model generation

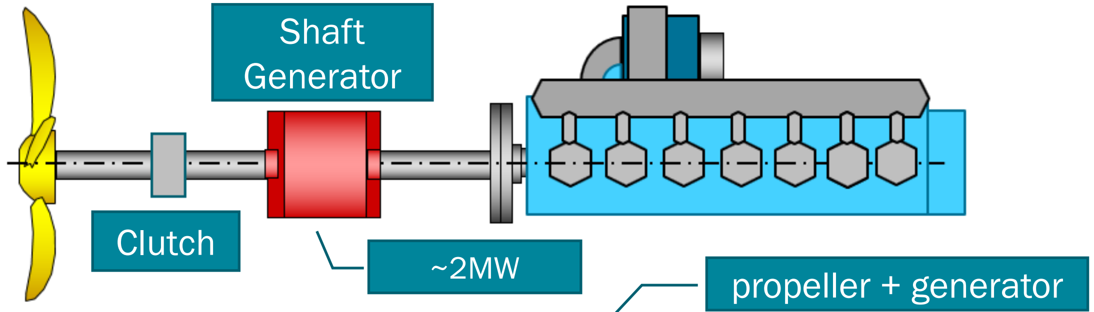
Modular, scalable engine parts library

New “Digital Twin” challenges: “DT” series production & quality assurance

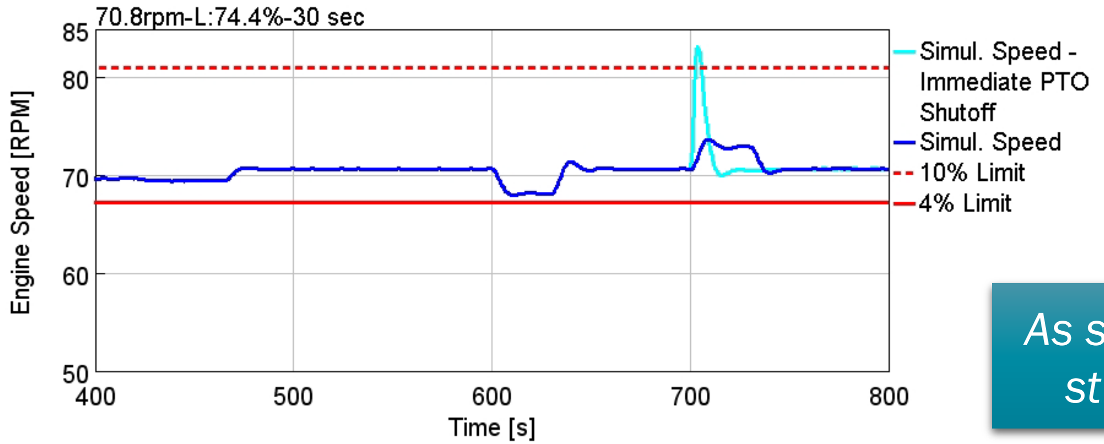
Crank-angle resolved simulation results !

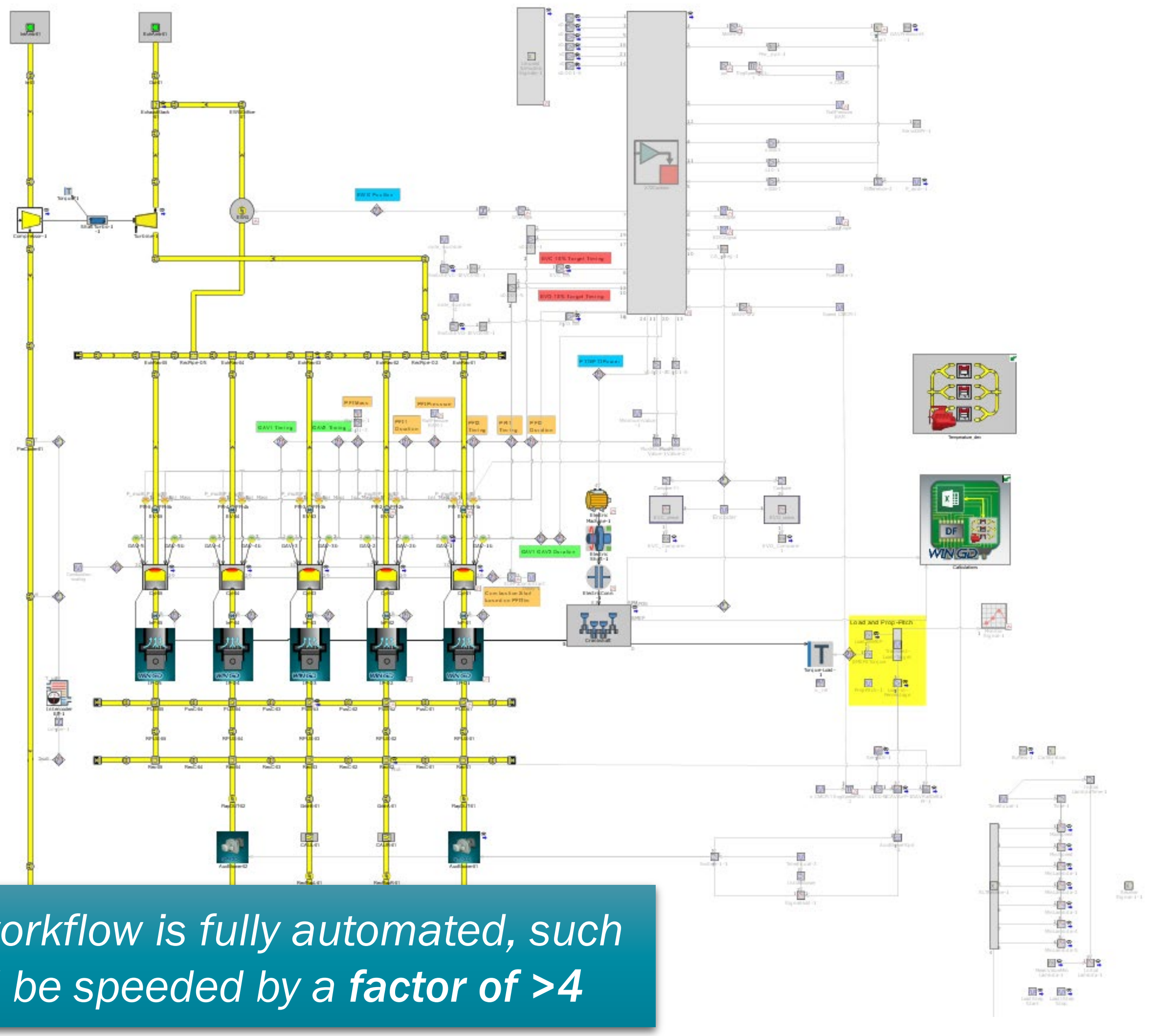
Engine load acceptance study

- 5X72DF, 11MW, 74 rpm
- PTO/PTI application incl. clutch (harbor mode)



PTO (dis)engagement in "sea mode":





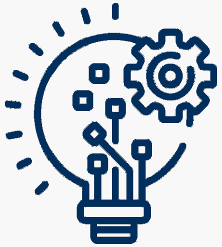
*As soon as workflow is fully automated, such studies will be speeded by a **factor of >4***

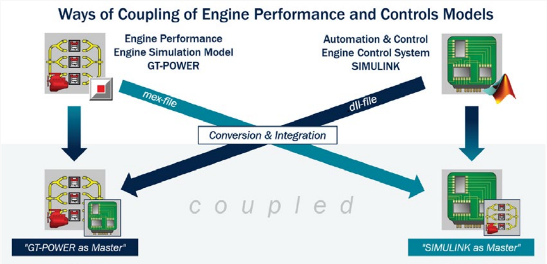
  M.Kerellaj

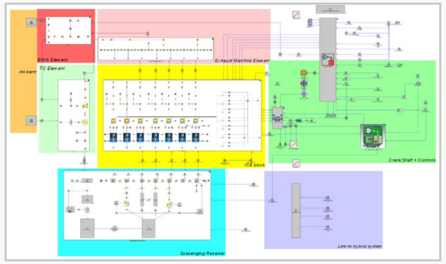
Conclusions & outlook

Conclusion

→ Offline Engine Performance Digital Twin concept could be proven







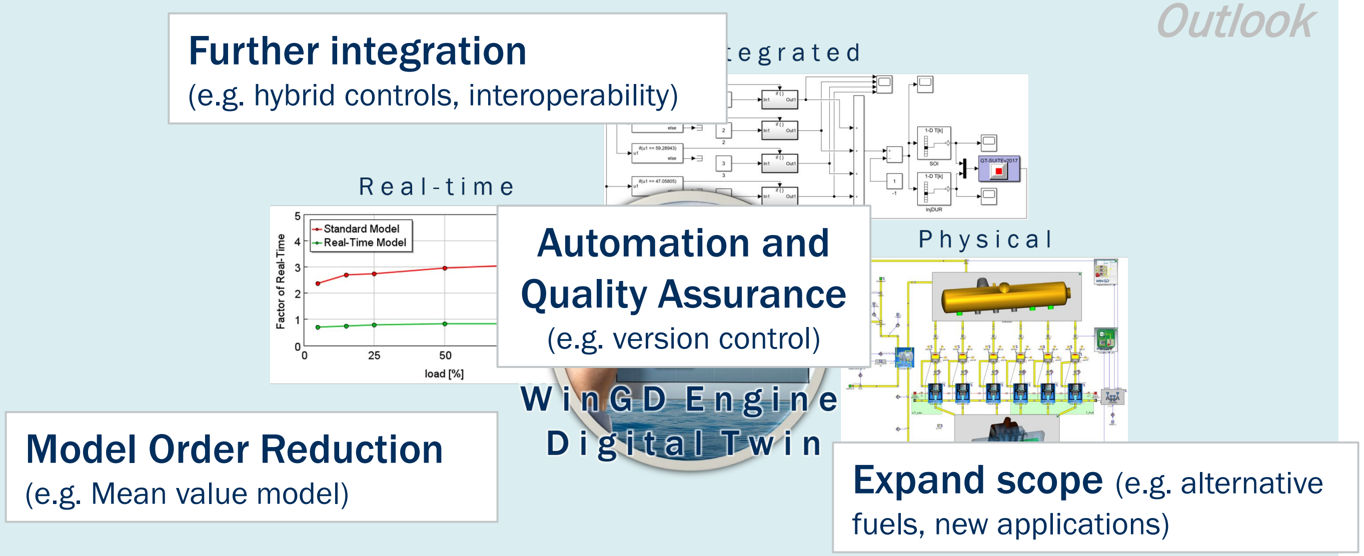
→ Digital Twin as "central element" in engine development & operation

Digital Twin

"One model, one workflow"

Outlook

- Today
  - Maintenance
- Tomorrow
  - Voyage optimization?
  - Virtual certification?
  - Retrofit solutions?
- Requirements
  - Interoperability
  - Platforms
  - Standards



Reference to paper: *"Towards the Development of an Engine Performance Digital Twin", Moses 2021*