Theoretical Investigation of an Optimized Turbo Compound System applied on a Marine 2-Stroke Diesel Engine

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Contents

- Background and Motivation
- Fuel Consumption Reduction & Waste Heat Recovery Overview
- Simulation model description and validation
- Turbocompounding System Optimization: Results and Main Findings
  - Power Turbine Speed Variation @ 85% Load
  - Turbocharger Turbine Size Variation @ 85% Load
  - SOI advance @ 85% Load
- Conclusions

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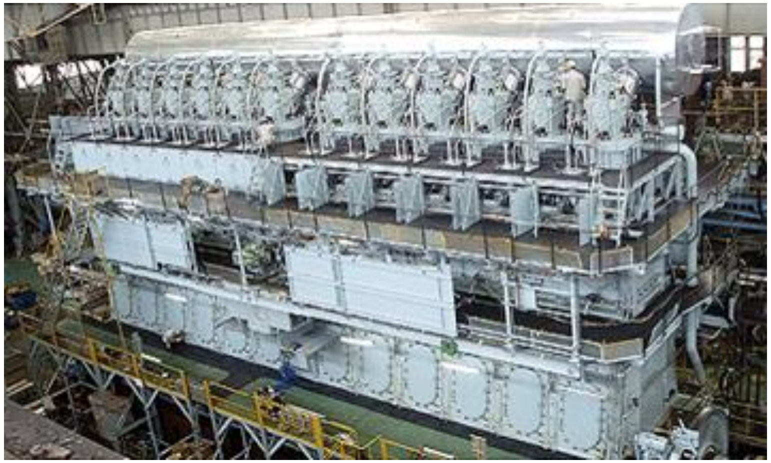
Background and Motivation

- Maritime Transport an important sector of global transport.
- 2-Stroke Diesel Engine is the primary mover & energy consumer (85% of fuel)
  - ✓ Efficient
  - ✓ Reliable
  - ✓ High Power Density
  - ✓ Cost effective (Operation using HFO)



- Further reduction in fuel consumption necessary:
  - ➢ Environmental regulation/ Greenhouse Gas reduction
  - ➢ Rising fuel prices

→ <u>Possible measures for Fuel Consumption reduction?</u>

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Fuel Consumption Reduction& Waste Heat Recovery Overview (1)

Measures to reduce fuel consumption	Examples	Advantages	Disadvantages
Operational	Slow Steaming Optimal routing/ loading Diagnosing/ Reducing energy losses	✓ Simple Implementation ✓ Low cost ✓ Significant benefit	× Impact on delivery time × Impact on engine subsystem due to off design operation × Often require technical modifications
Technical	Engine subsystem/ Combustion optimization Friction reduction Vessel hydrodynamics Alternative fuels **Waste heat recovery**	✓ Applicable in wide engine operating range ✓ Specific NOx and SOx reduction along with CO_2	× Pay back period often unfavorable × Limited application on existing vessels

- High Potential : About 50% of fuel heat rejected in large 2-stroke Diesel Engines
- Exhaust gas : Most significant, high temperature waste heat

? Technical Implementation
? Actual Benefit
? Impact on engine operation

Fuel Consumption Reduction & Waste Heat Recovery Overview (2)

Exhaust Heat Recovery

Vessel Heat Loads		
Exhaust side boilers	✓ Steam ✓ Fuel Pre- Heating	× Engine Back- Pressure

Power Generation		
Rankine Bottoming Cycle: Complete exhaust gas powered Rankine system (including boilers, expander, condensers etc)	✓ Water or organic medium ✓ Large BSFC benefit ✓ Minimal interaction with engine	× Size × Complexity/ Cost × Engine Back- Pressure
Turbo-Compounding: Expand a portion of exhaust gas in a power turbine	✓ Low cost	× Lower BSFC benefit × Limited application on existing vessels

Aim of Current Work

? Max. Theoretical benefit in practical applications
? Methodology to determine optimal power turbine/ Engine settings.
? Application in existing engines
? Impact on engine operation

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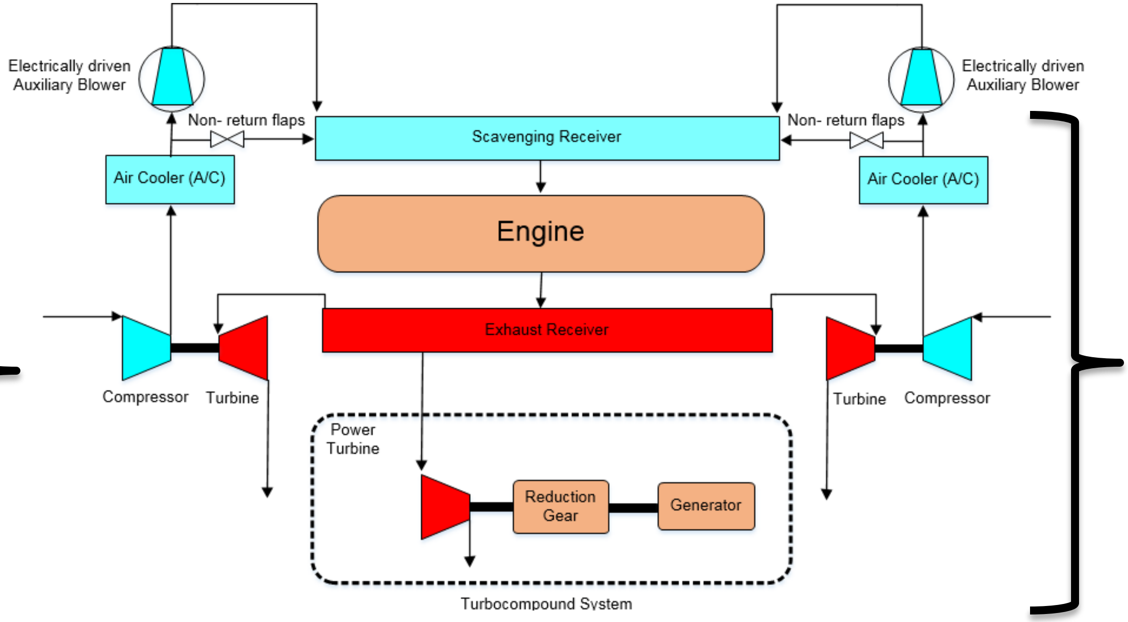
Model description & validation

Description

Simulation Tool	GT- Power
Compressor/ Turbine	Meanline (0-D) models using measured geometry data. Implemented as user subroutines in the code
Combustion	Built- in predictive combustion model (DI- Jet). Calibrated using cylinder pressure data acquired by present research group

Model Inputs

- **Ambient Conditions**
- **Fuelling rate**
- **Start of Injection (SOI)**
- **Temperature after A/C**
- **Engine/ Turbine/ Compressor main geometry data**
- **Power turbine speed**
- **Engine rotational speed**



Model Outputs

T/C performance
- Scavenging & Exhaust receiver pressure
- TC speed
- Turbine inlet & Outlet temperature
- Etc...

Power Turbine Output

Engine Performance
- Cylinder pressure
- Heat Release
- Start of Combustion
- Power Output
- BFSC
- Etc...

Model description & validation

Validation

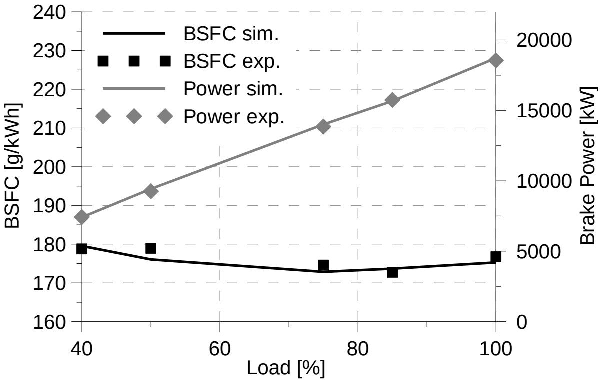
Test Case: 2-Stroke Marine Diesel	
Bore	700 mm
Stroke	2800 mm
Connecting Rod Length	2850 mm
Cylinders/ Turbochargers	6/2

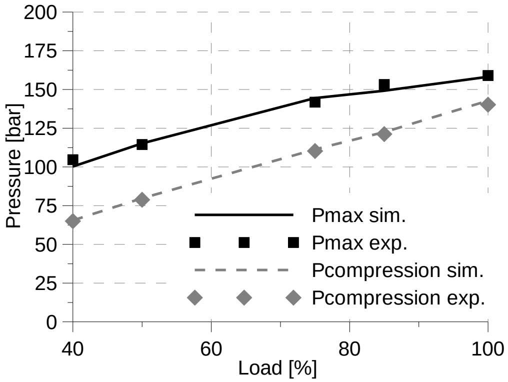
Model Validation

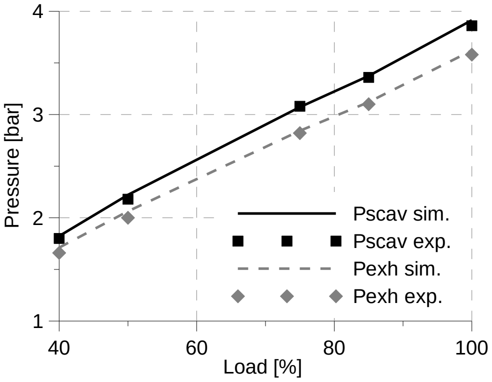
Comparison of models prediction vs exp. Data (official engine shop tests)

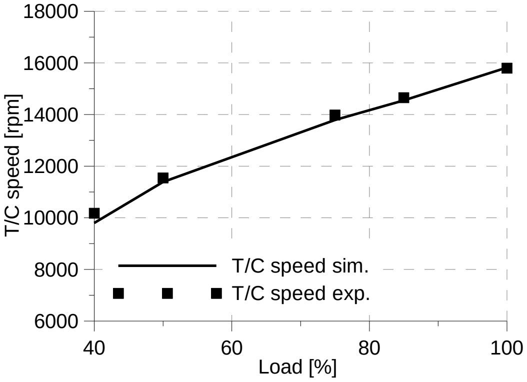
- Good predictions over a wide range of loads
- Engine and T/C performance predicted well

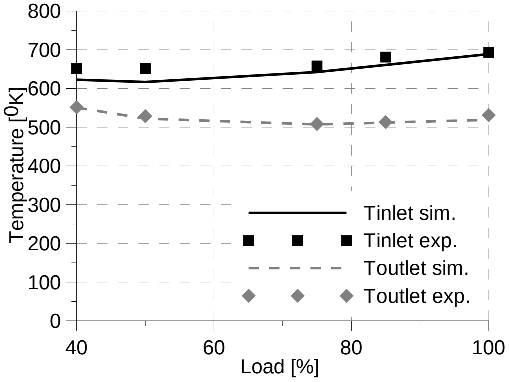
→ Reliability of engine and T/C model











Contents

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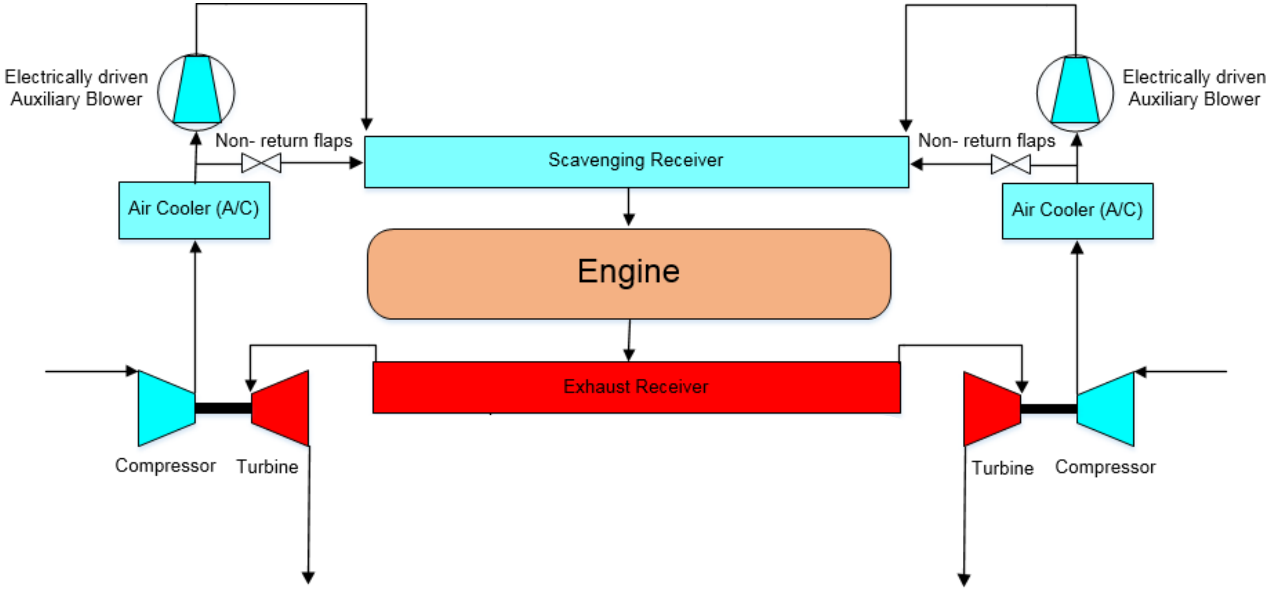
Turbocompounding System Optimization: Results and Main Findings

Power Turbine Speed Variation @ 85% Load

Variation of Power turbine (PT) speed

- Power turbine (PT) added to engine model.
- Investigation conducted for various power turbine sizes from 0.03-0.16 .
- Power Turbine Size= mass flow through PT/(mass flux/es through T/C turbine/s)
- For practical applications : Variation of reduction gear ratio, generator speed

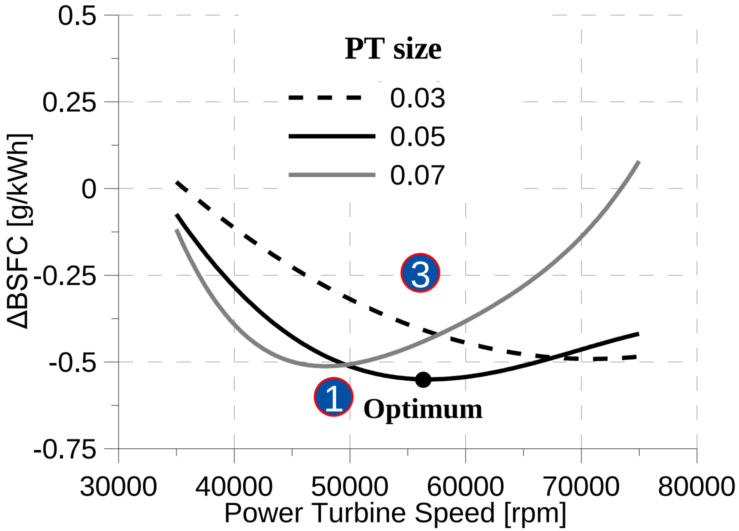


Turbocompounding System Optimization: Results and Main Findings

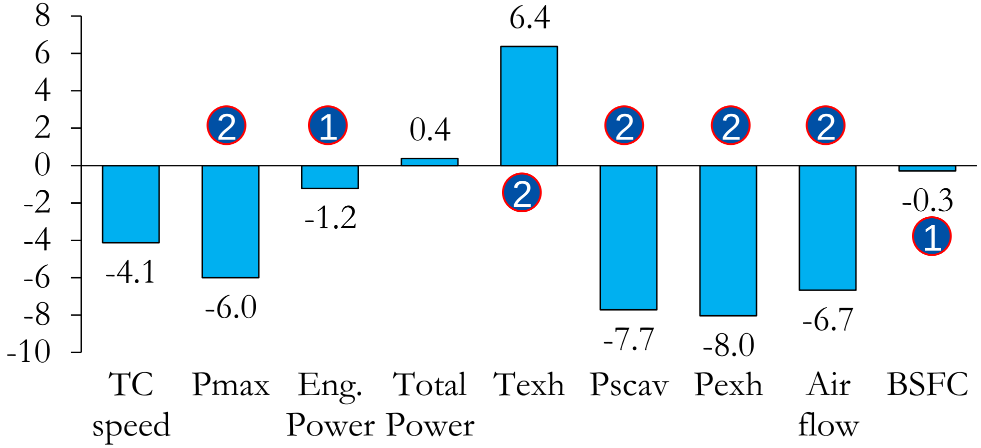
Power Turbine Speed Variation @ 85% Load

Evaluate:

- Brake Specific Fuel consumption benefit (ΔBSFC): BSFC of turbocompound System –BSFC of reference engine
- Constant fuelling rate
- Define optimum
- Impact on engine operation at the defined optimum



Performance compared to reference at optimum [% Variation]



Conclusions:

① Small benefit due to engine performance degradation

② Reduction in Pscav, Pmax , Pexh and Air flow. Increase in Texh

③ Optimal PT speed reduces with increasing PT size

→ Engine tuning to recover engine performance and maximize benefit???

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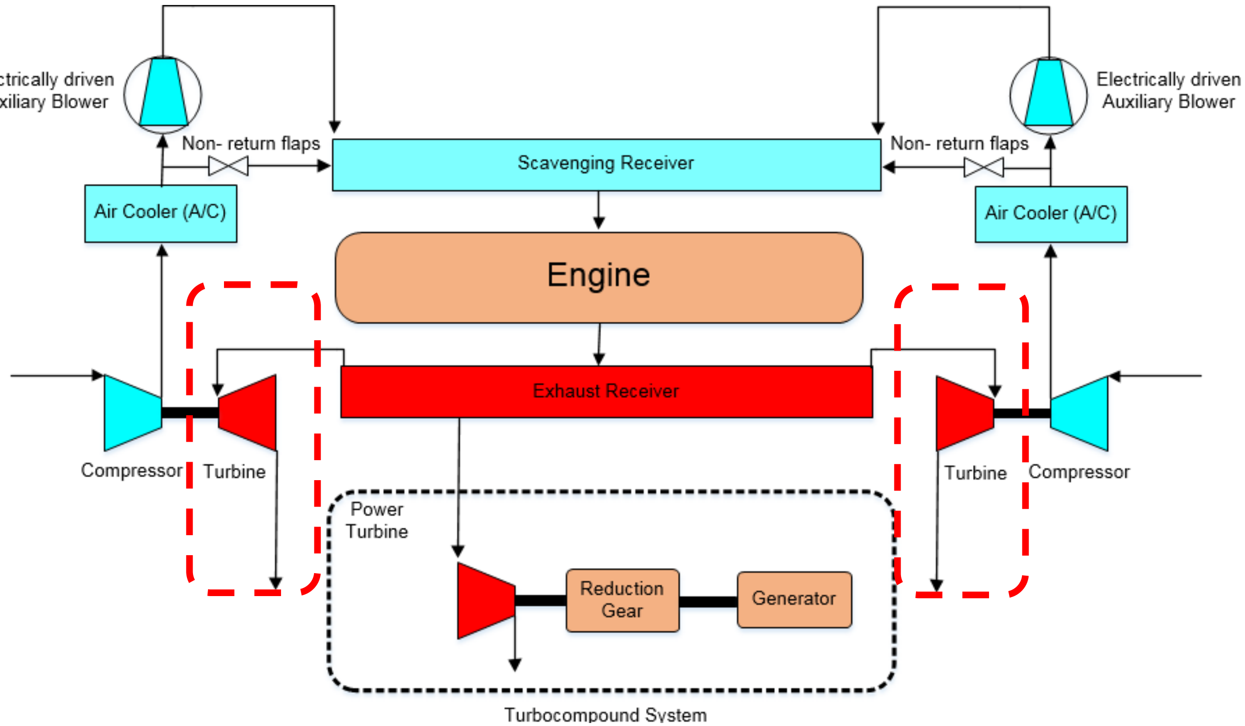
Turbocompounding System Optimization: Results and Main Findings

T/C Turbine size variation @ 85% Load

Variation of Turbocharger Turbine (T/C) Size

- Reduction of T/C turbine flow area Increases scavenging pressure and exhaust receiver pressure
- Power turbine speed for every size at the optimal value, determined from previous step
- In practical applications : Matching a smaller turbine, use of a nozzle ring of reduced flow area.

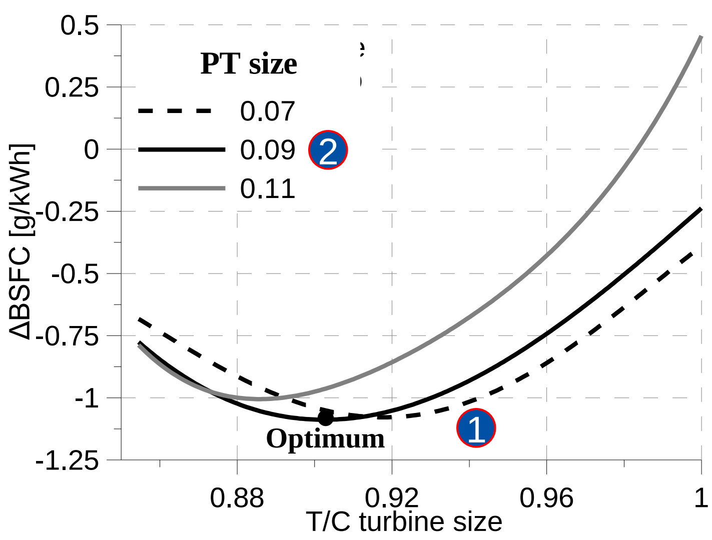


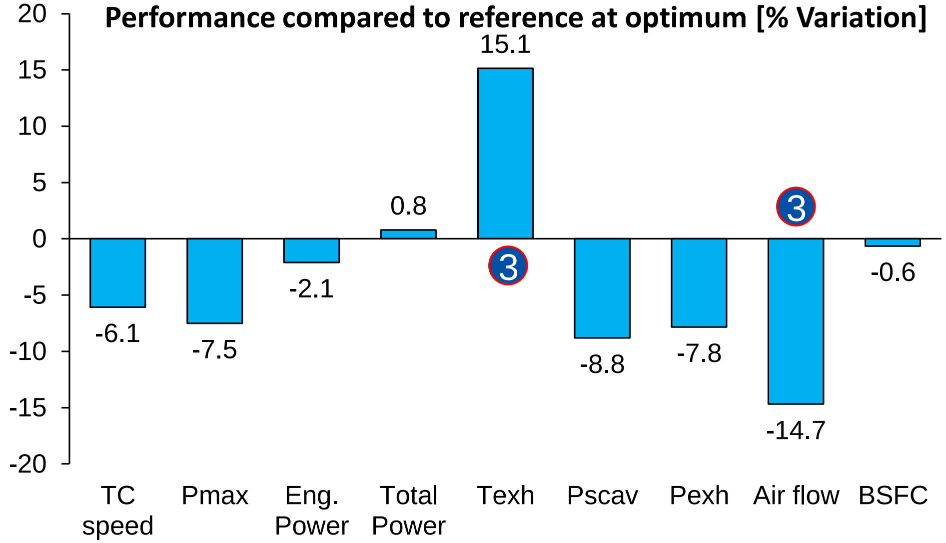
Turbocompounding System Optimization: Results and Main Findings

T/C Turbine size variation @ 85% Load

Evaluate:

- For every PT size is determined the optimal T/C turbine size
- Impact on engine operation at the defined optimum





Conclusions:

① Increased benefit compared to only optimizing PT speed (≈ x 2)

② Optimal performance at larger PT size (0.09)

③ Significant reduction in air flow and increase in Texh

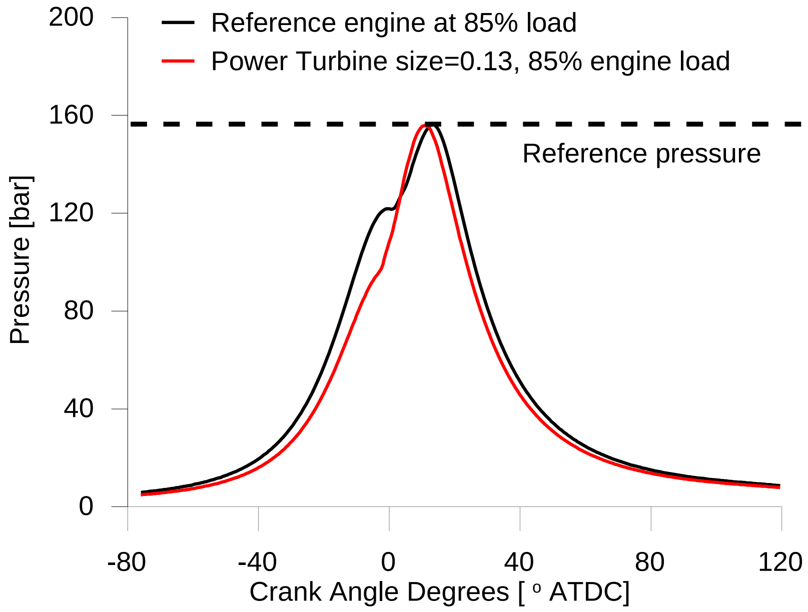
Contents

Turbocompounding System Optimization: Results and Main Findings

SOI advance @ 85% Load

Start of Injection (SOI) advance

- For every power turbine size: Power turbine speed and optimal T/C turbine size at optimal values determined in previous steps
- Earlier injection/ Combustion to reach firing pressure of reference engine (without Turbocompounding)
- For practical applications : Increase of VIT system rack.

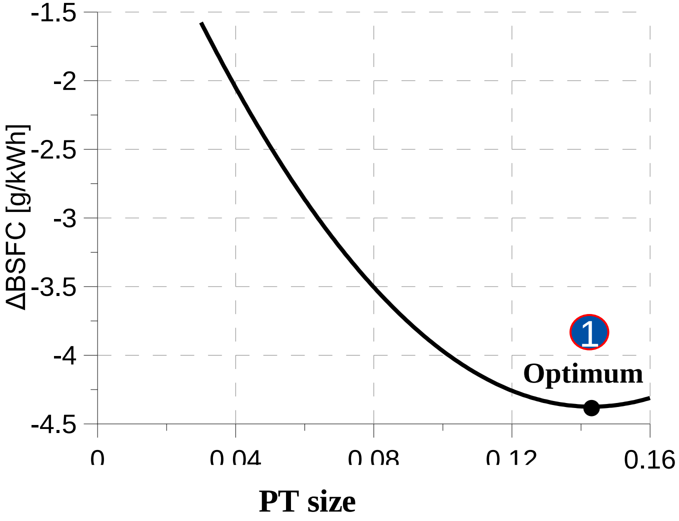


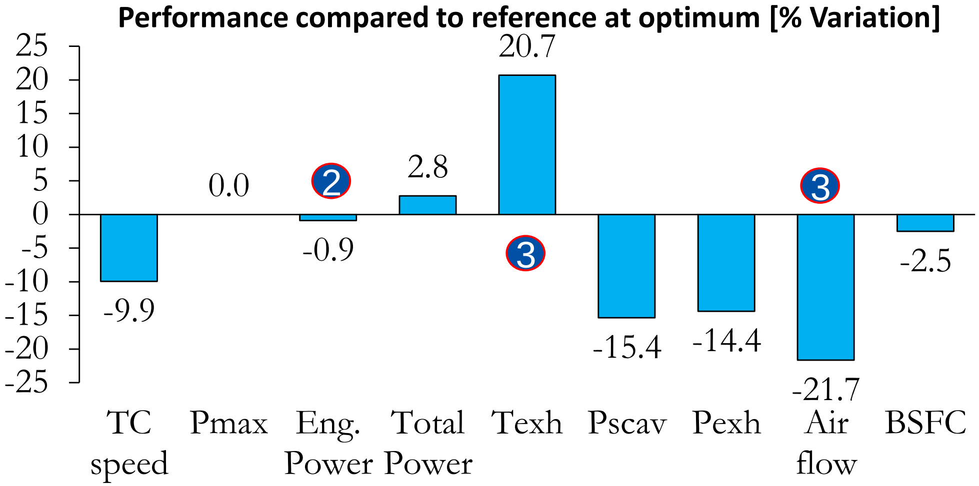
Turbocompounding System Optimization: Results and Main Findings

SOI advance @ 85% Load

Evaluate:

- Define optimal PT size for max ΔBSFC
- Impact on engine operation at the defined optimum




Performance compared to reference at optimum [% Variation]

Conclusions:

① ≈ 4.4 g/kWh benefit in BSFC

② Degradation in engine power very small due to Pmax= Pmax, reference

③ Very significant reduction in air flow and corresponding increase in Texh→ Exhaust temperature and sooting combustion may limit benefit in practical applications!!

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Conclusions

Impact of Turbocompounding on Marine 2-Stroke engine operation:

- **Reduction of engine power output, scavenging, exhaust, peak firing pressure and T/C speed. Power turbine output must compensate for engine power reduction.**
- **Reduction in air flow and increase in exhaust temperature . Manufacturer limitations must be respected in practical applications.**

Measures to maximize the benefit of turbocompounding:

- **Optimize power turbine speed. Optimal power turbine speed reduces with increasing turbine size.**
- **Reduce T/C turbine effective flow area to compensate the reduction in scavenging pressure and increase PT expansion ratio.**
- **Advance SOI to reach the max permissible pressure levels (pressure of reference engine at the same load).**

Benefit of a turbocompound engine optimized using the aforementioned methodology ≈ 4.4 g/kWh (2.5%) ΔBSFC at 85% load.

Theoretical Investigation of an Optimized Turbo Compound System applied on a Marine 2-Stroke Diesel Engine

Thank you for your attention!

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