Department of Mechanical Engineering

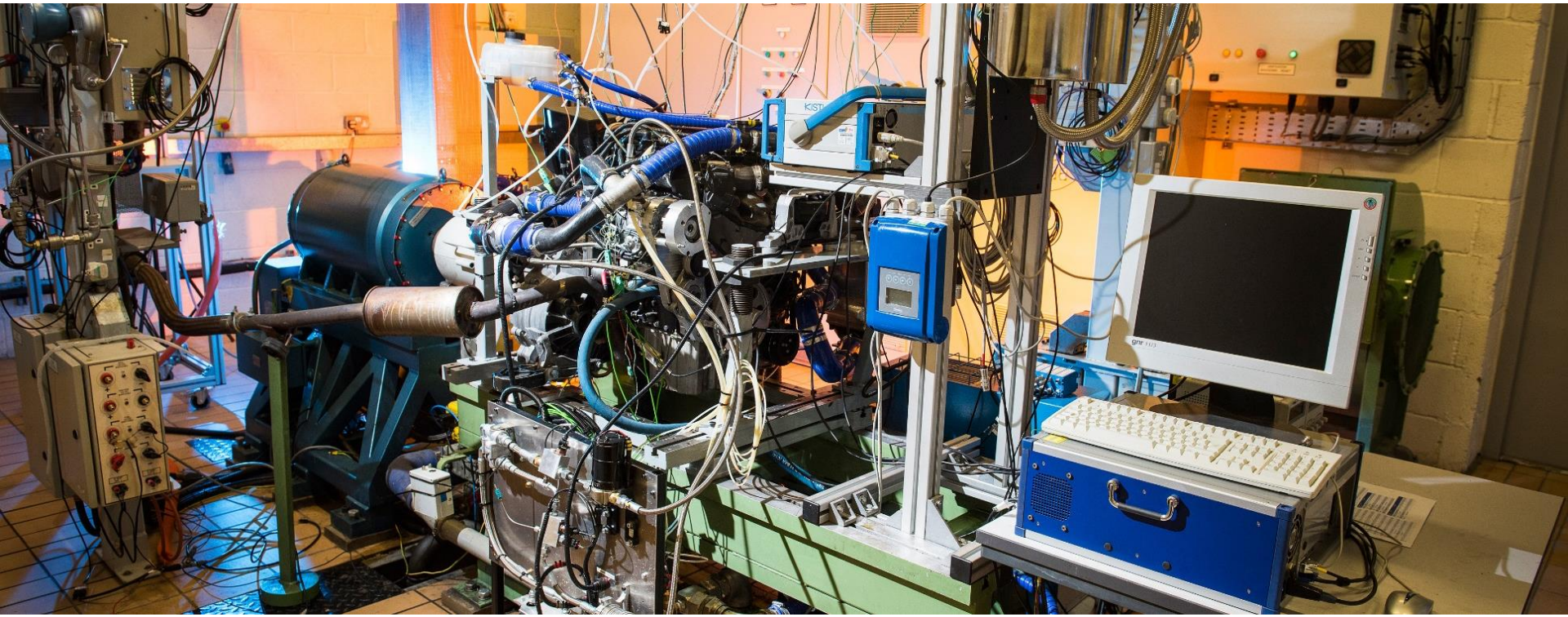
UNIVERSITY OF BATH

Powertrain & Vehicle Research Centre

Airpaths for Future Diesel Powertrains: Opportunities and Challenges

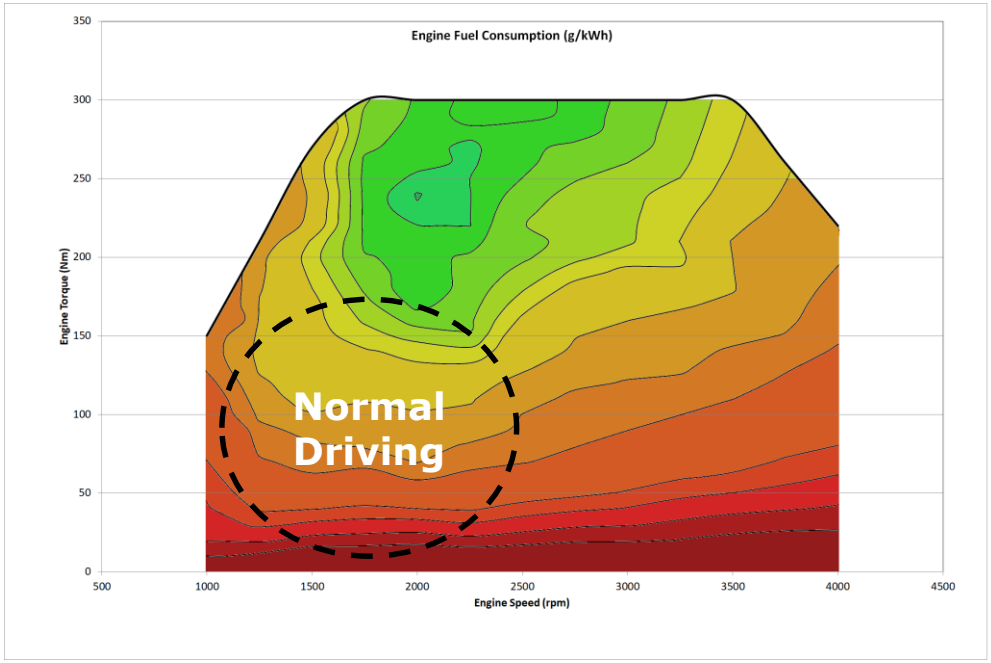
Dr Richard Burke

Senior Lecturer in Mechanical Engineering



Introduction – Why boost an engine?

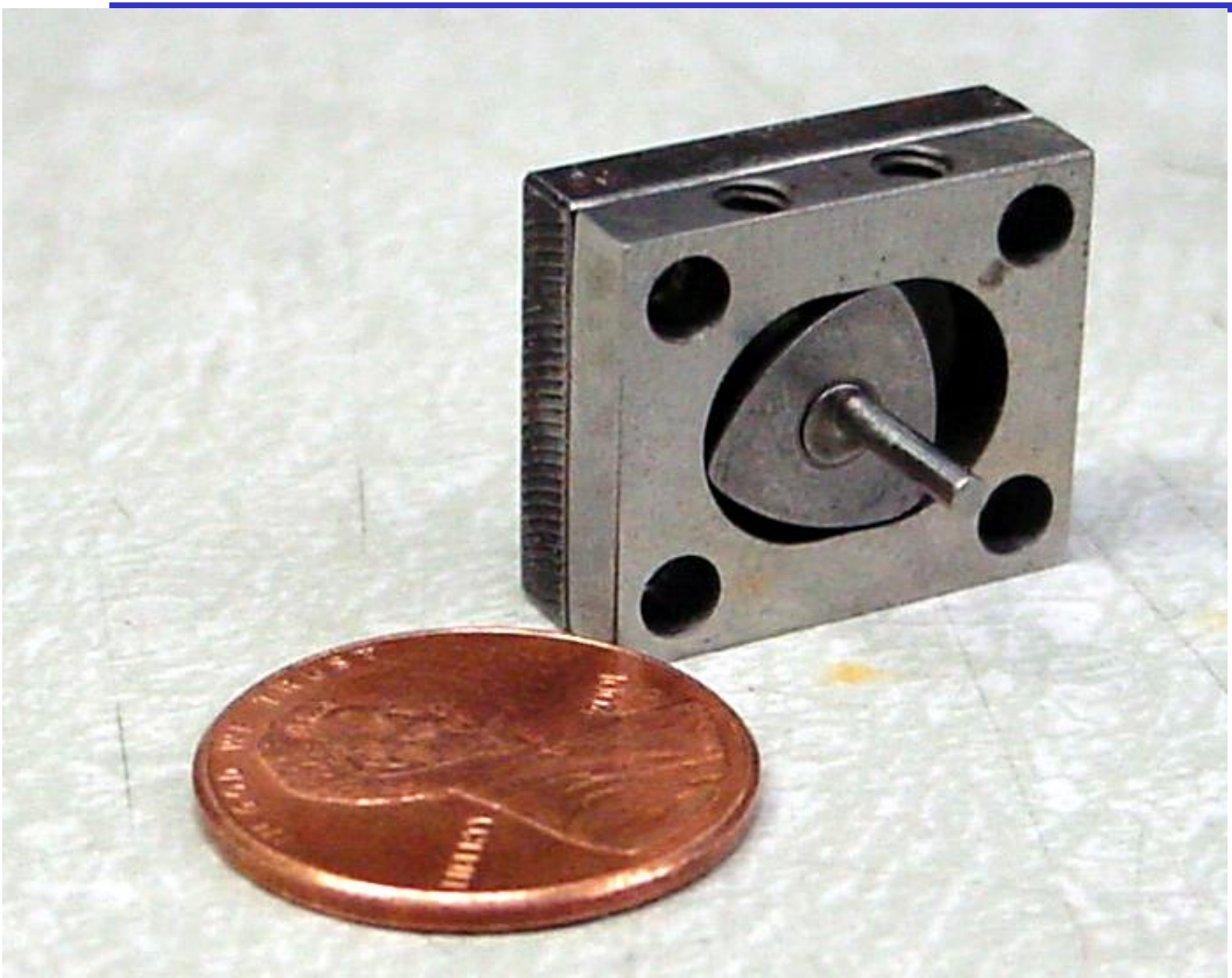
- Engines are efficient at high load



- Drive for reduced Fuel Consumption
  - Shift high efficiency region towards lower torques
  - Smaller engines do this by reducing overall friction

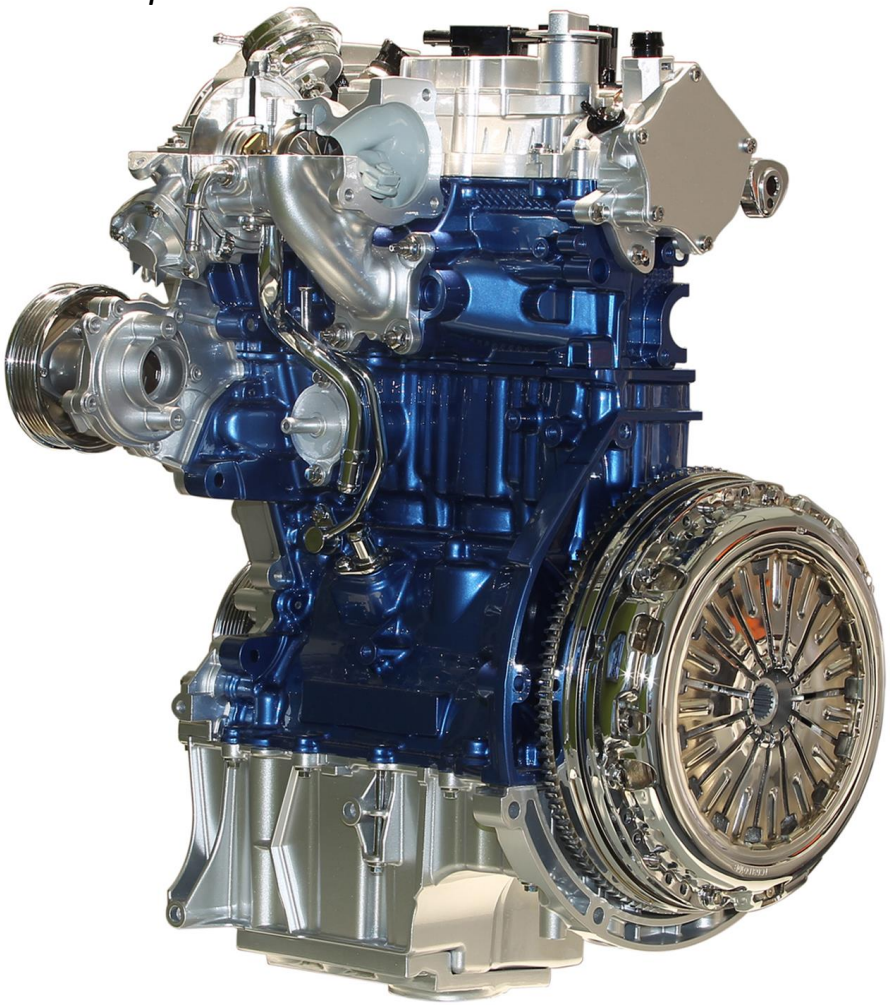
Replace big engines…

With small ones

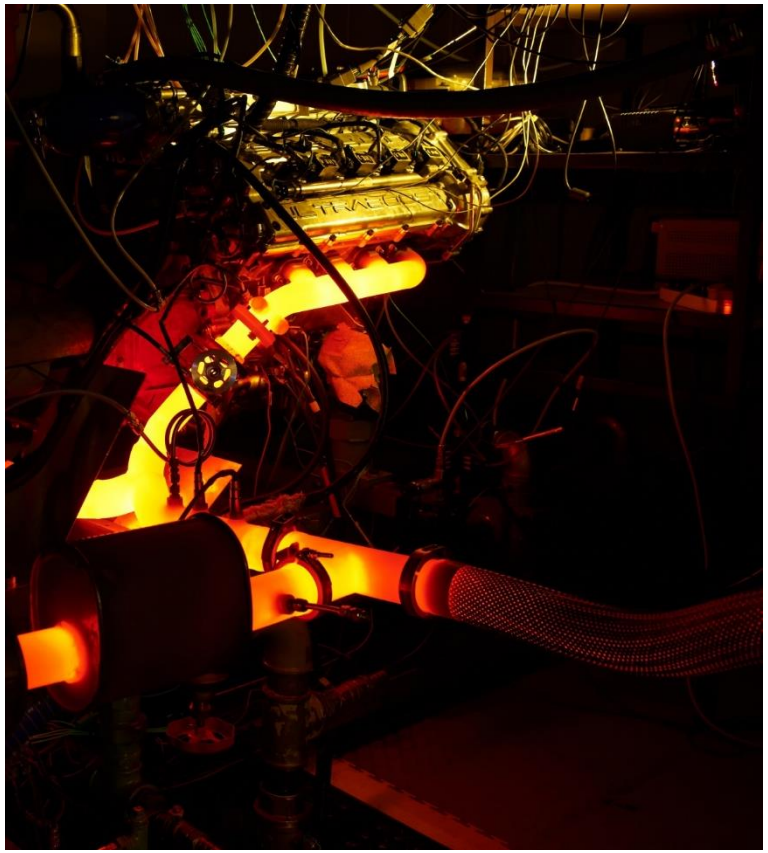


Downsizing Examples

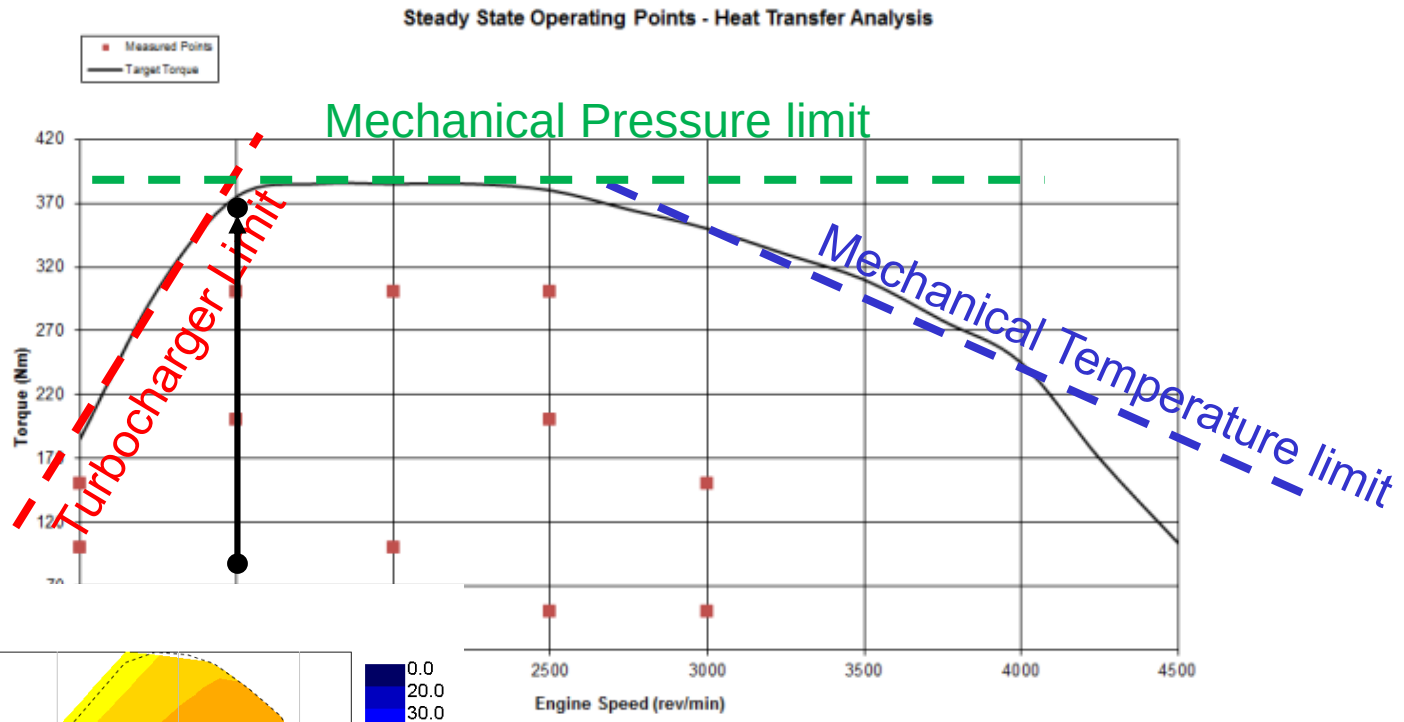
- Ford 1.0L Ecoboost
  - *Replaced 1.6L*

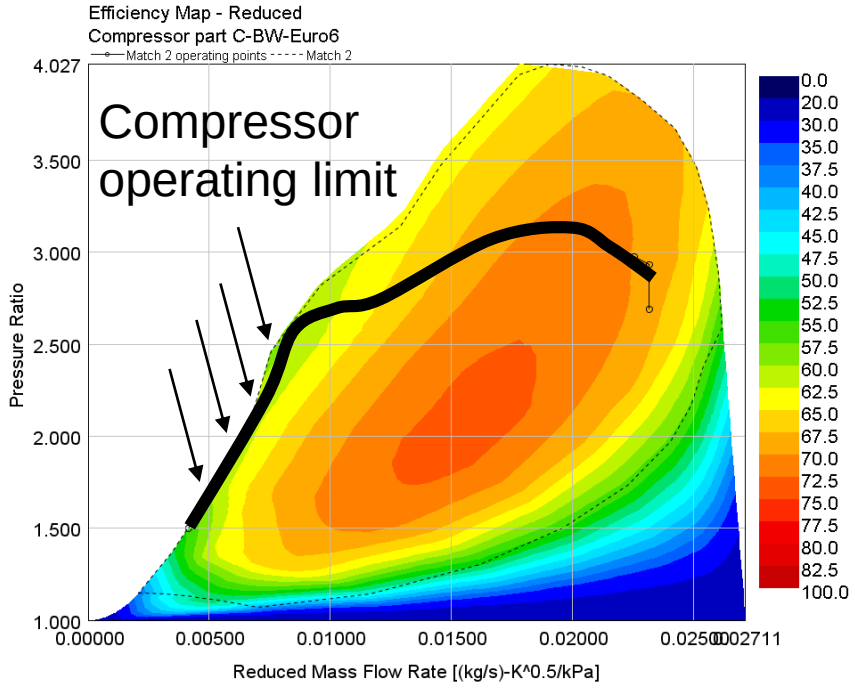


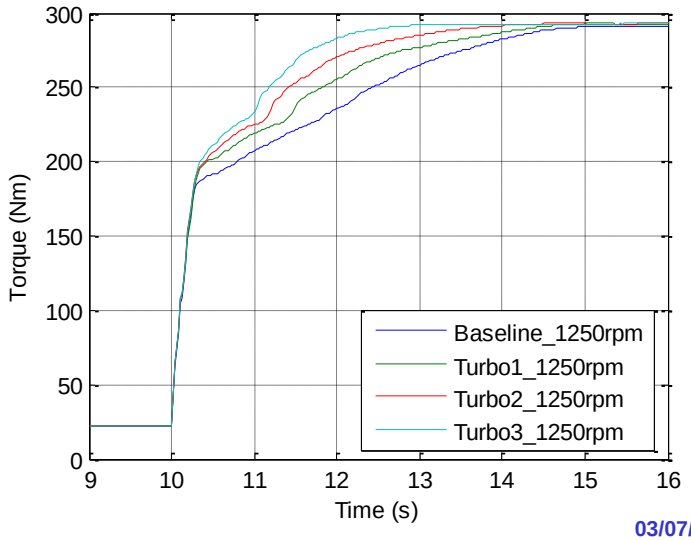
- Ultraboost 2.0L
  - *Replaced 5L V8*



Boosting Challenges







Boosting System Requirements

- Requirements of a future Diesel airpath
  - Emissions
  - Fuel economy
  - Transient response
  - Electrification
  - Thermal management
  - All in real world operating conditions

Contents

- Boosting Technology
- Modelling techniques
- Experimental techniques
- Conclusions

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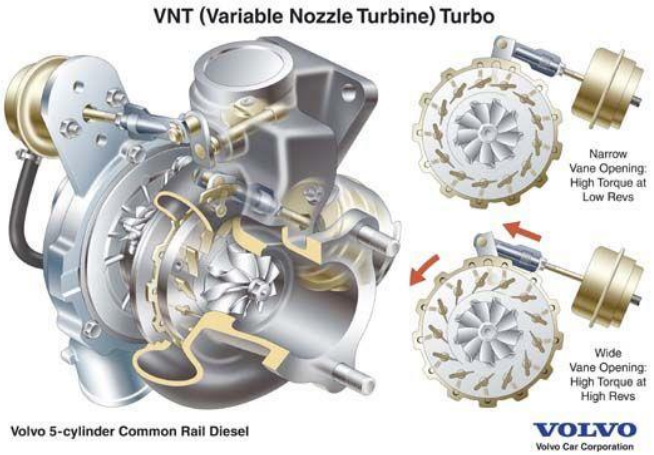
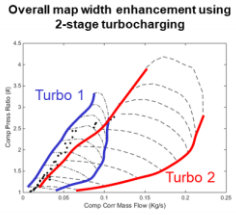
Boosting Technologies

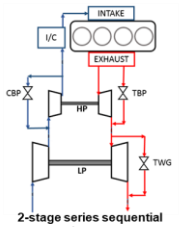
VG Turbine (multiple turbines)

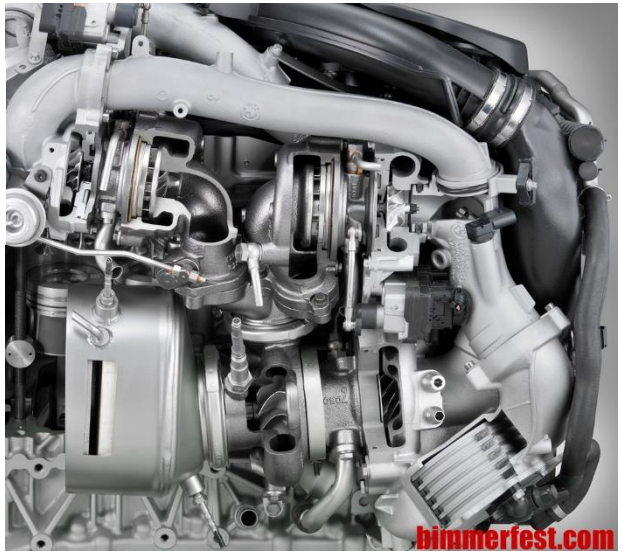


VG Compressor (Multiple compressors)

Multi-stage turbocharging







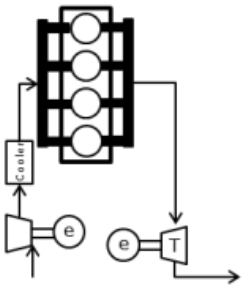
Turbo super and mechanical compounding

Torotrak V-Charge System

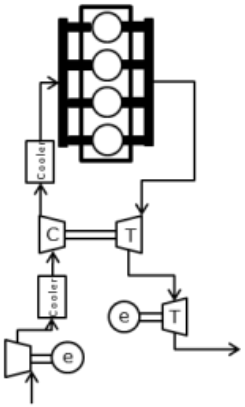
Van Dyne Super Turbo

Boosting Electrification

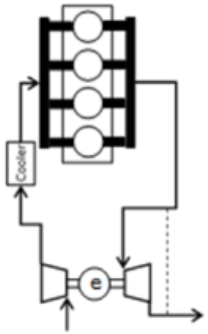
E-Turbo application



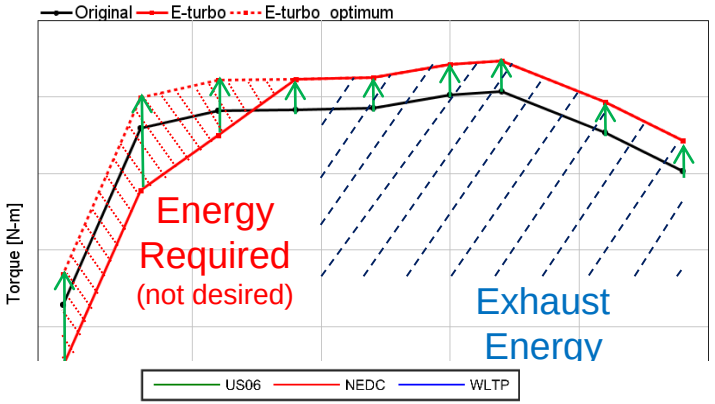
Electric turbine with an electrically or mechanically driven compressor

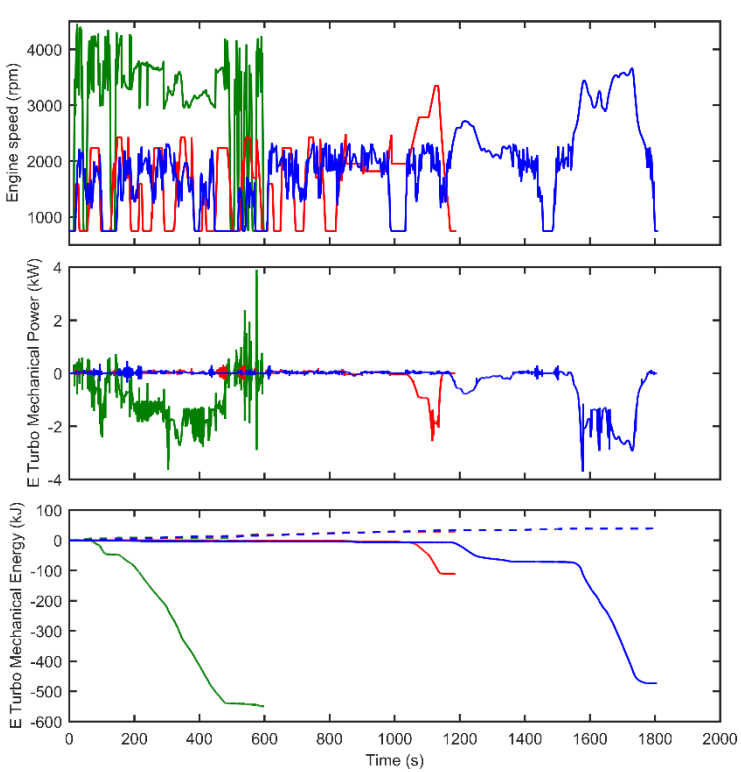


Two-stage system



Electric turbocharger





Dimitriou, P, Burke, R, Zhang, Q, Copeland, C & Stoffels, H 2017, 'Electric Turbocharging for Energy Regeneration and Increased Efficiency at Real Driving Conditions' Applied Sciences, vol 7, no. 4, 350. DOI: 10.3390/app7040350

Boosting Electrification

- System Opportunities
  - Offers a low weight option for deployment of electrical energy
  - Offers the possibility to recuperate exhaust heat
  - Can improve transient response
  - Can lead to fuel economy benefits by relaxing transient requirements of other engine features

- System Challenges
  - Energy flow need to be managed carefully with other systems
  - Benefits are only apparent with review of full system design (not simply a retrofit)
  - System needs to be designed and controlled in an optimal way

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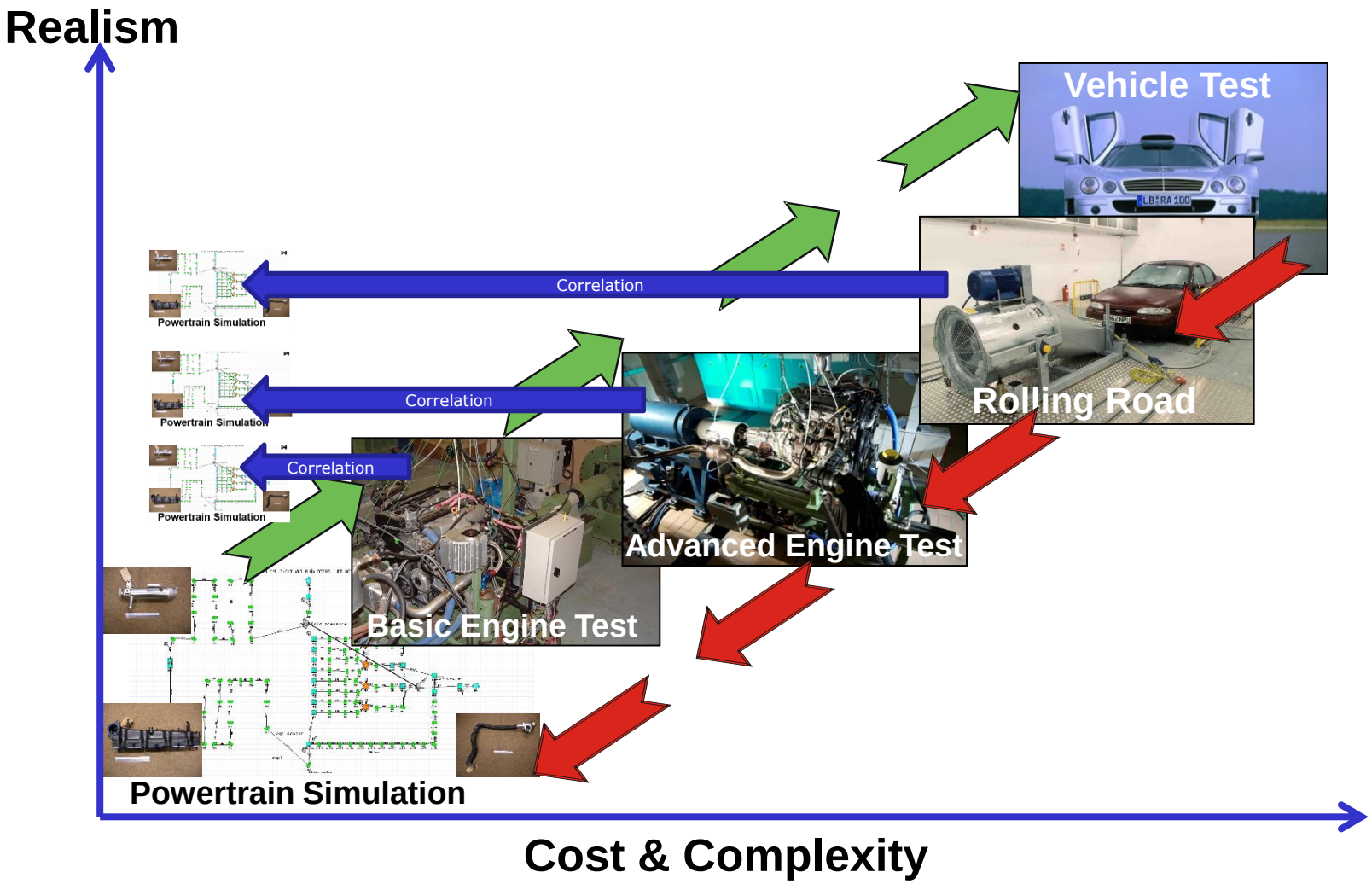
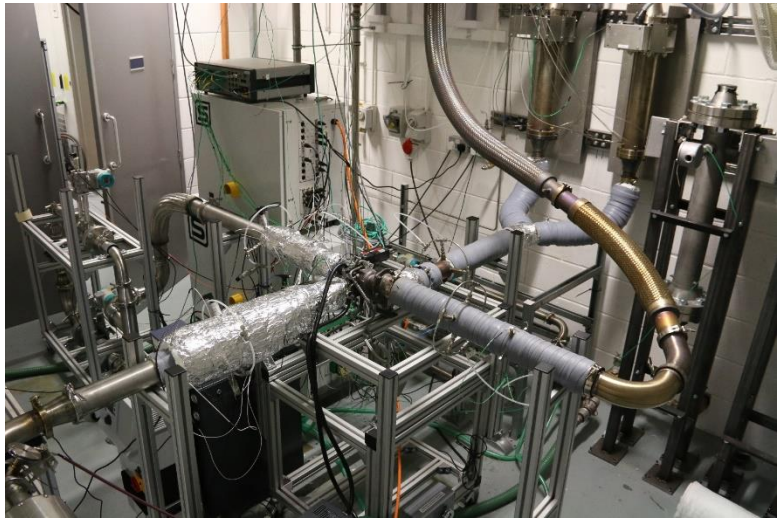
Simple Turbocharging

Powertrain Development



Turbocharger/Engine simulation issues



Gas Stand Characterisation

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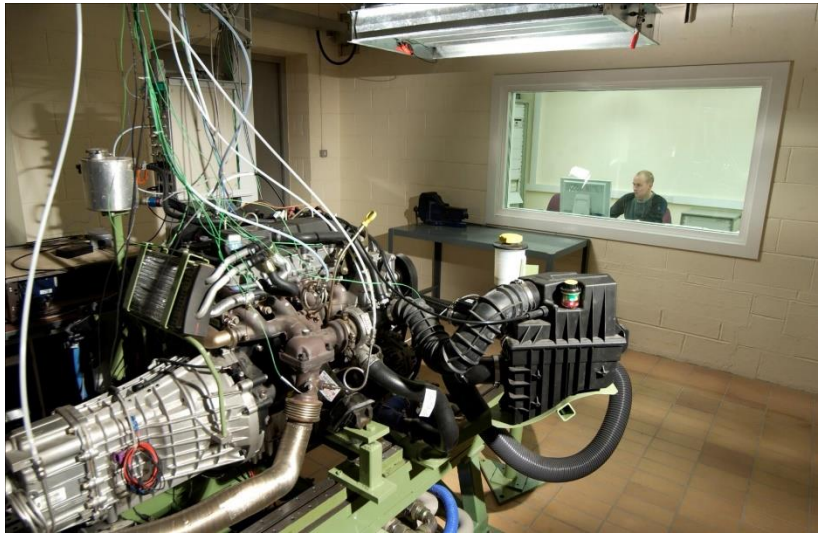
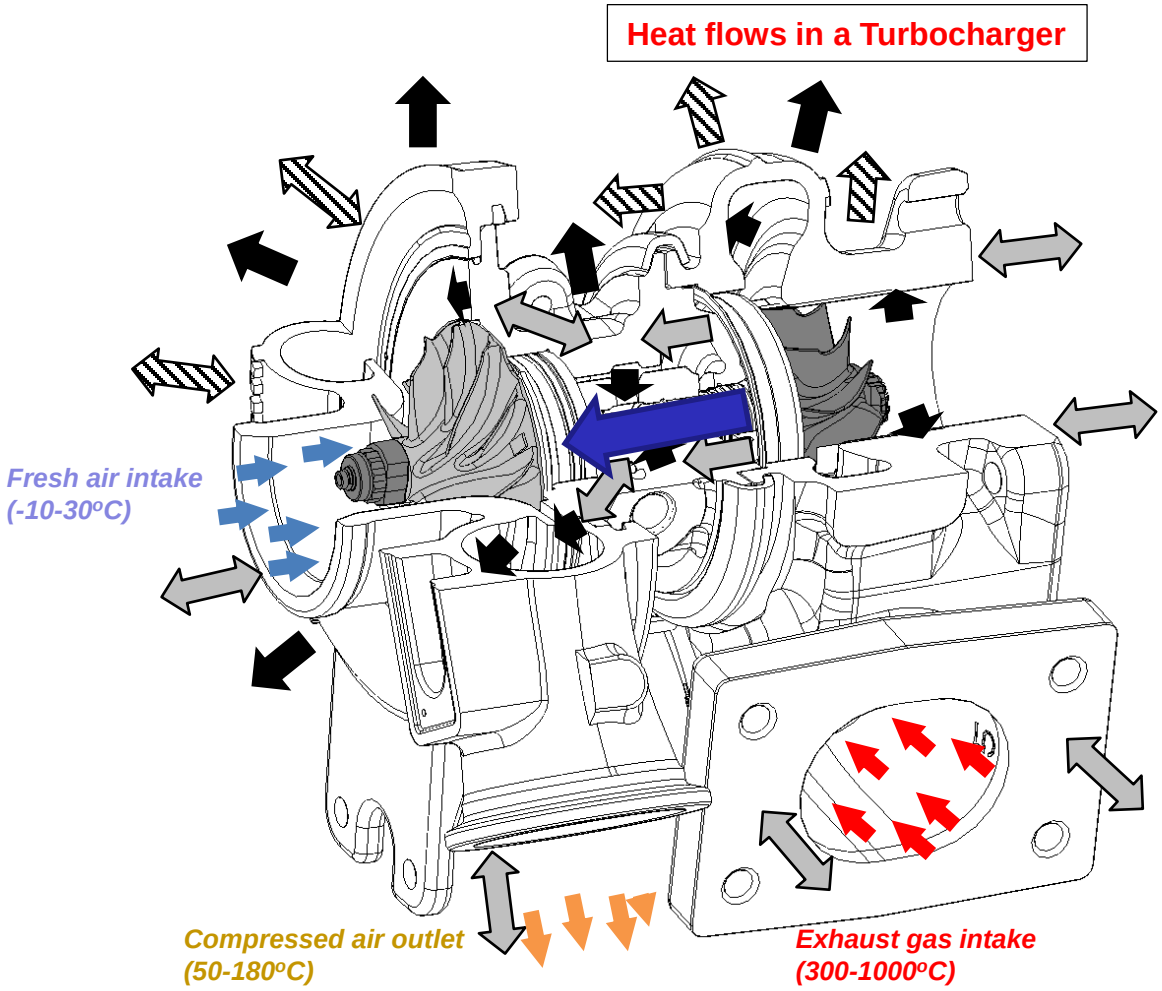


On-engine operation

Disconnect due to:

- Pulsating flows
- Heat transfer
- Inlet/outlet pipe geometry
- Working fluid

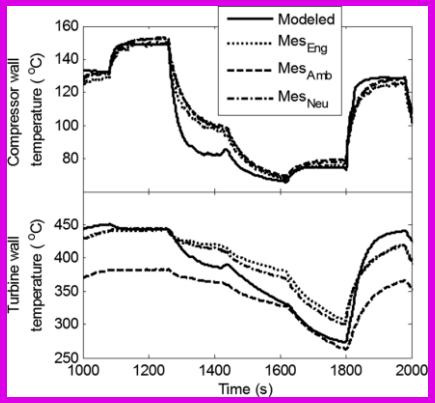
Turbocharger Heat Transfer

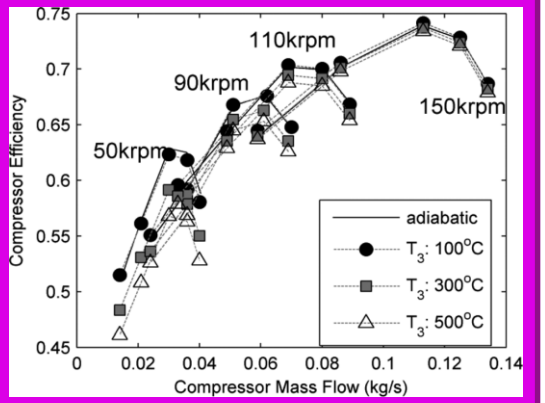


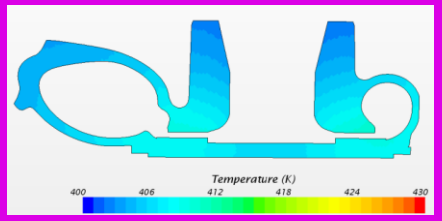
Burke, RD 2014, 'Analysis and modeling of the transient thermal behavior of automotive turbochargers' Journal of Engineering for Gas Turbines and Power: Transactions of the ASME, vol 136, no. 10, GTP-14-1108. DOI: 10.1115/1.4027290

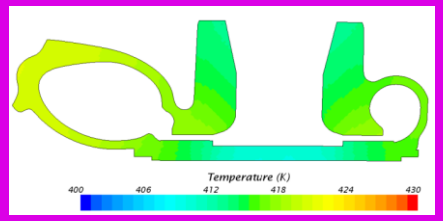
Turbocharger Heat Transfer

Understand the problem by experiments and 3D simulation

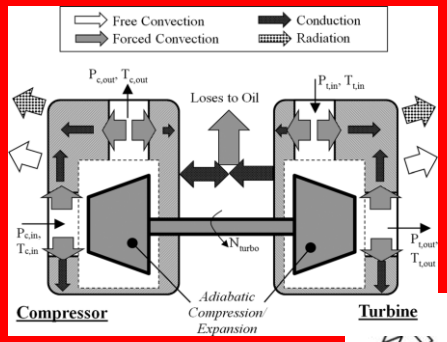


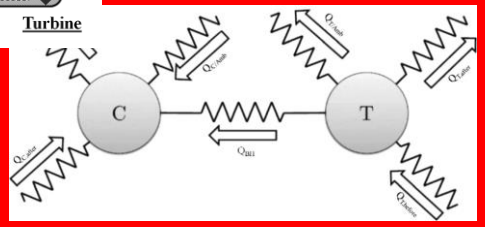




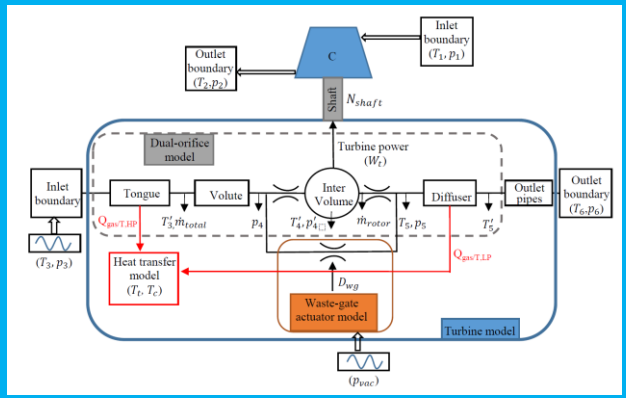


Create simplified model structure





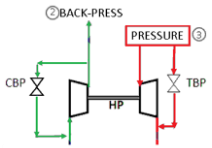
Integrate with other models



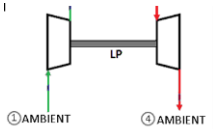
2-stage System Mapping

Conventional Approach

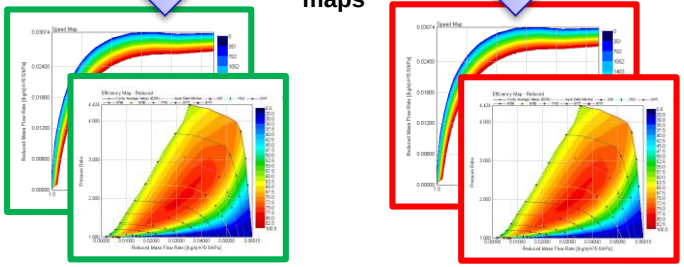
1. Map HP Stage on Gas Stand



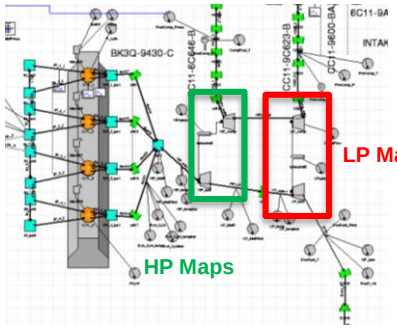
2. Map LP Stage on Gas Stand



3. Produce 2 sets of maps



4. Maps combined into system in 1D environment

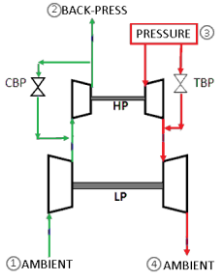


No knowledge of inter-stage phenomenon and resulting losses

Proposed Approach

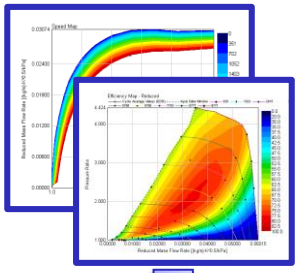
$$N_{eq} = \frac{N_{LP}^2}{N_{HP}}$$

1. Define a monotonically increasing speed metric for full system

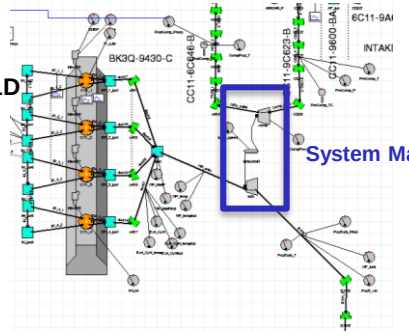


2. Map The 2-stage system as a whole on gas stand

3. Produce a single set of system maps



4. Use system maps in 1D environment

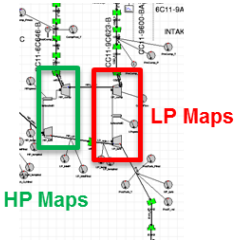


Inter-stage phenomenon and resulting losses are inherently captured in the system map

Avola, C., Copeland, C., Burke, R. and Brace, C., 2017. Effect of inter-stage phenomena on the performance prediction of two-stage turbocharging systems. Energy, DOI: https://doi.org/10.1016/j.energy.2017.06.067

2-stage system mapping

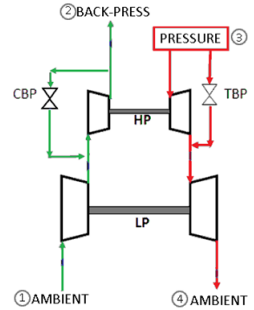
Compressor Maps



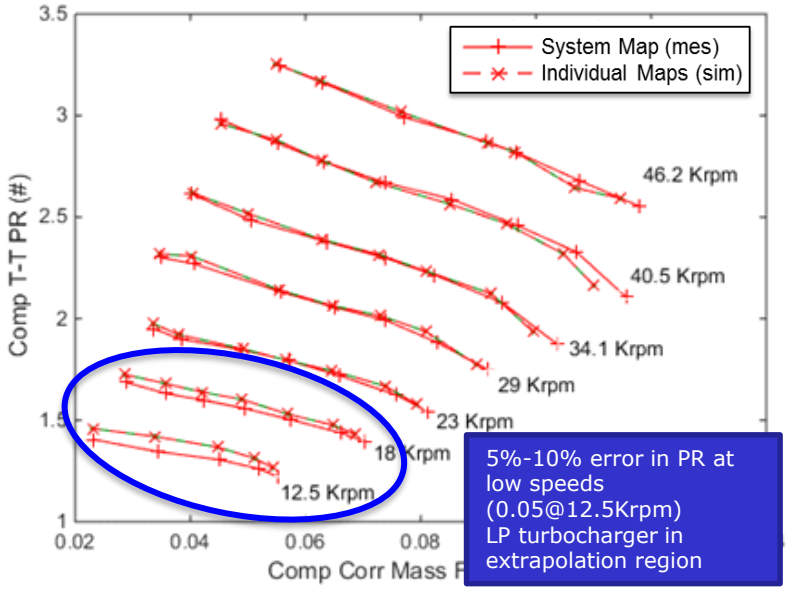
Ricardo Wave simulation of combination of individual maps

Vs.

Measured Full system performance



Mass Flow

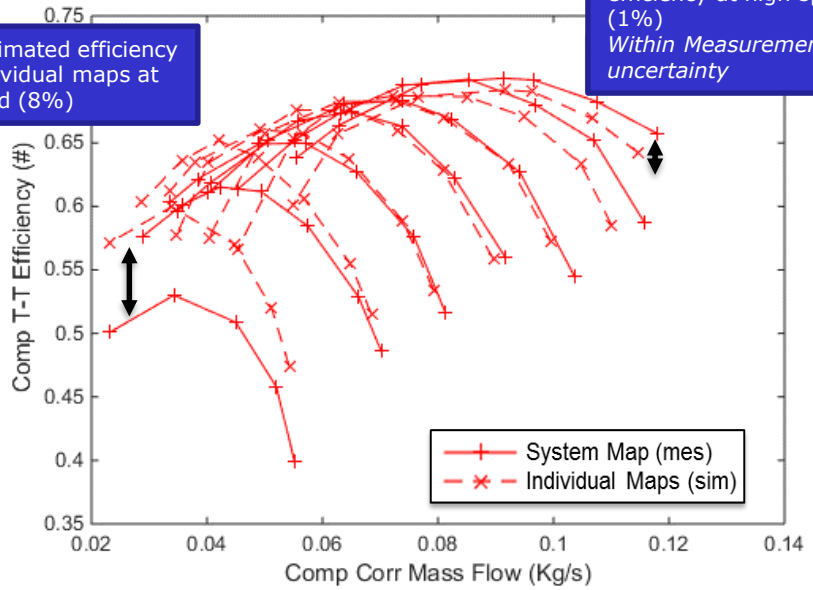


5%-10% error in PR at low speeds (0.05@12.5Krpm)
LP turbocharger in extrapolation region

Efficiency

Over-estimated efficiency from individual maps at low speed (8%)

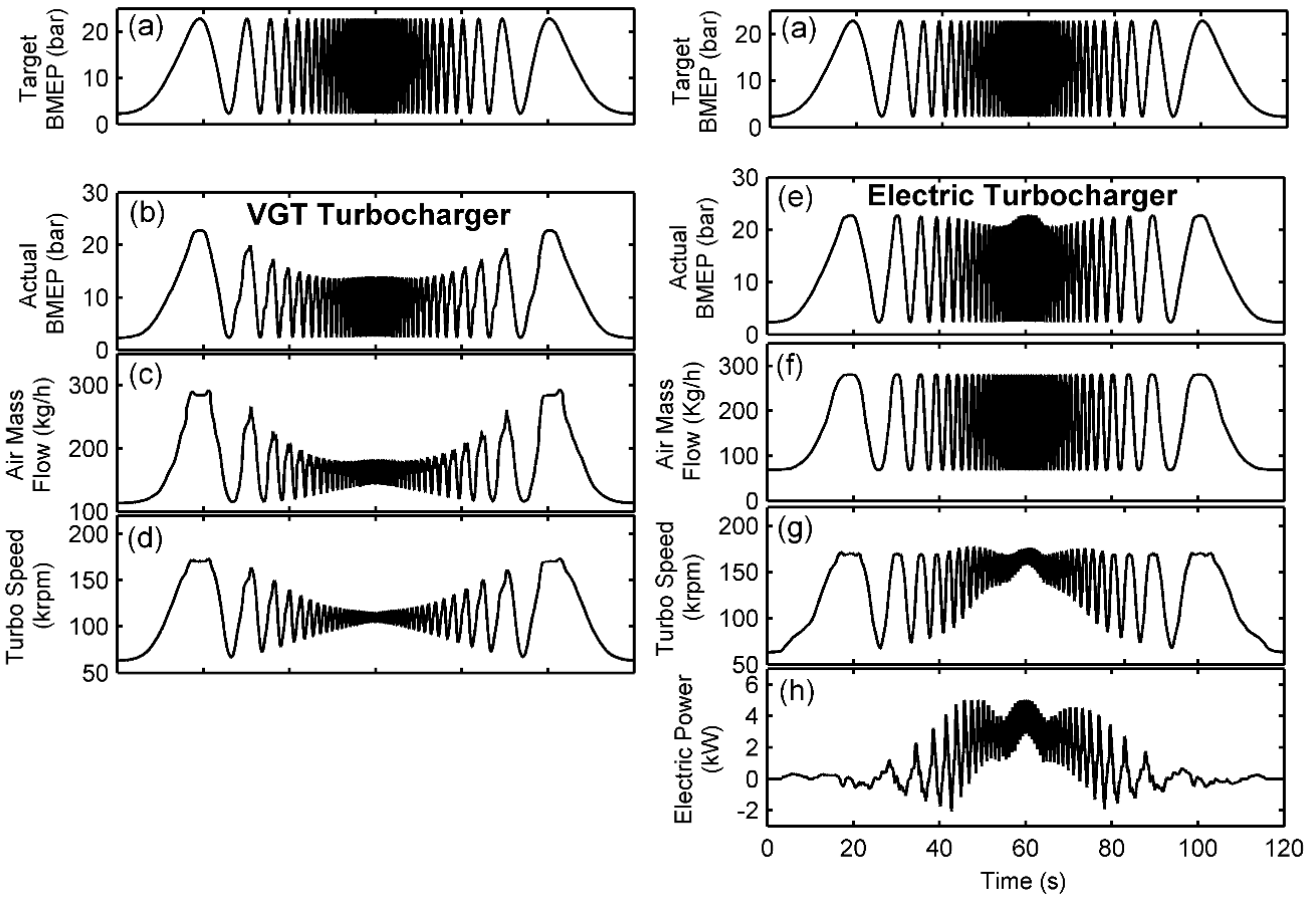
Small underestimate of efficiency at high speeds (1%)
Within Measurement uncertainty

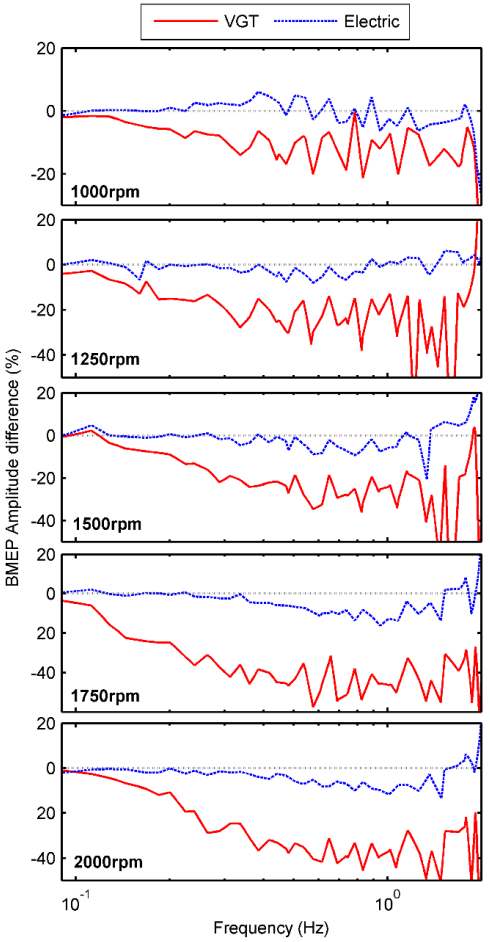


**All speeds are equivalent speeds*

Simulation over-estimates pressure ratio at low speed ➔ Extrapolation on the LP map
Efficiency is also over-estimated at low speed and under-estimated at high speeds

Electric boosting - Transient evaluation

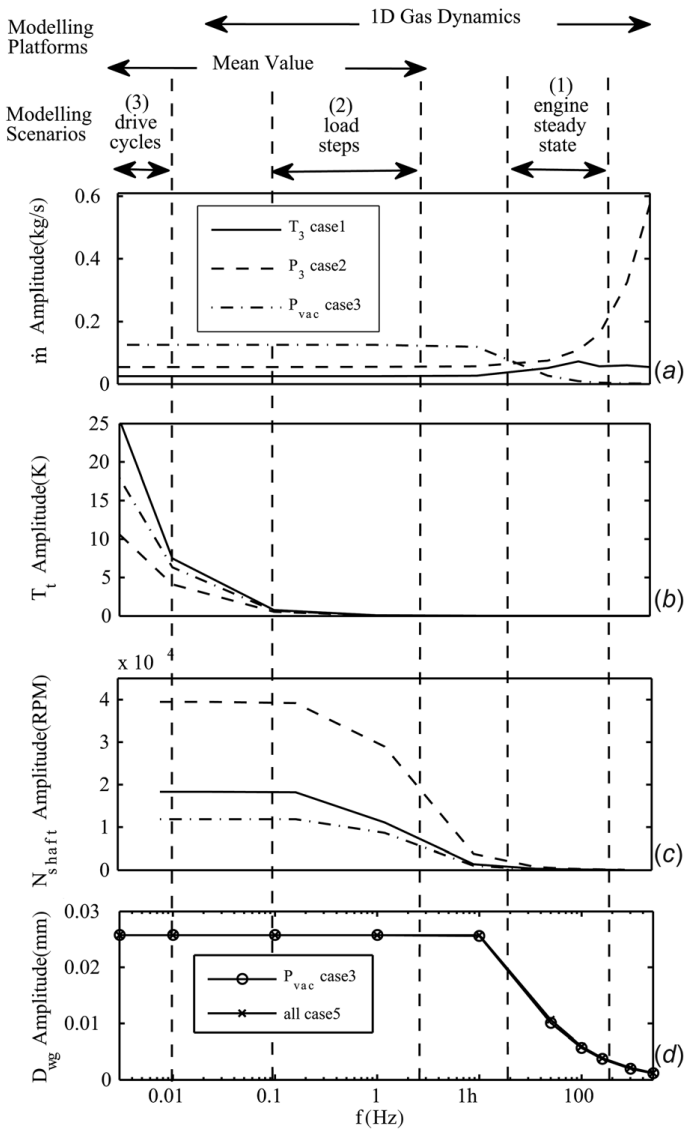




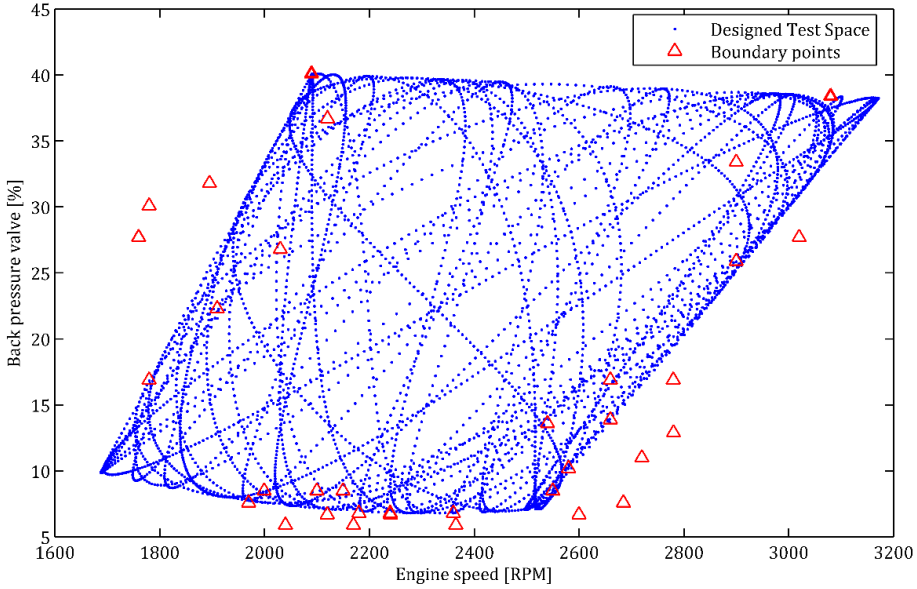
Burke, RD 2016, 'A numerical study of the benefits of electrically assisted boosting systems' Journal of Engineering for Gas Turbines and Power: Transactions of the ASME, vol 138, no. 9, 092808. DOI: 10.1115/1.4032764

Dynamic Turbocharger Maps

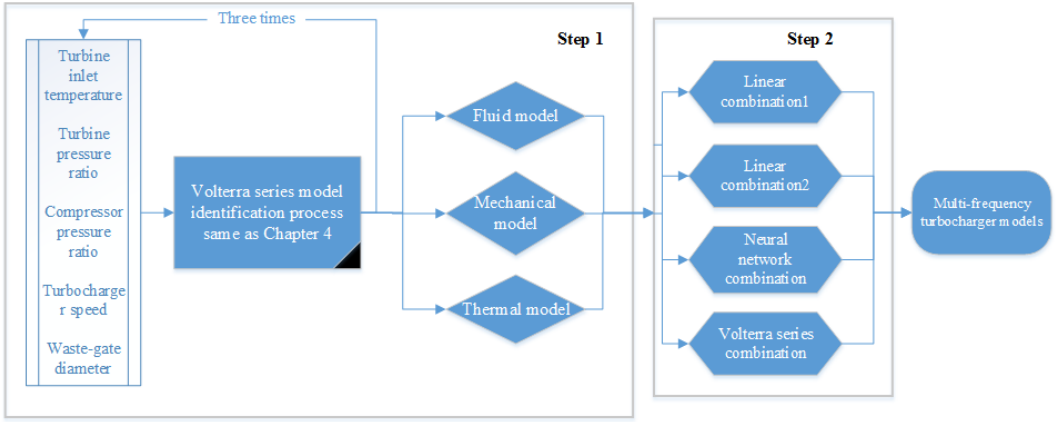
Identify frequency of interest



Transient characterisation experiment



Dynamic Regression model at appropriate frequency range



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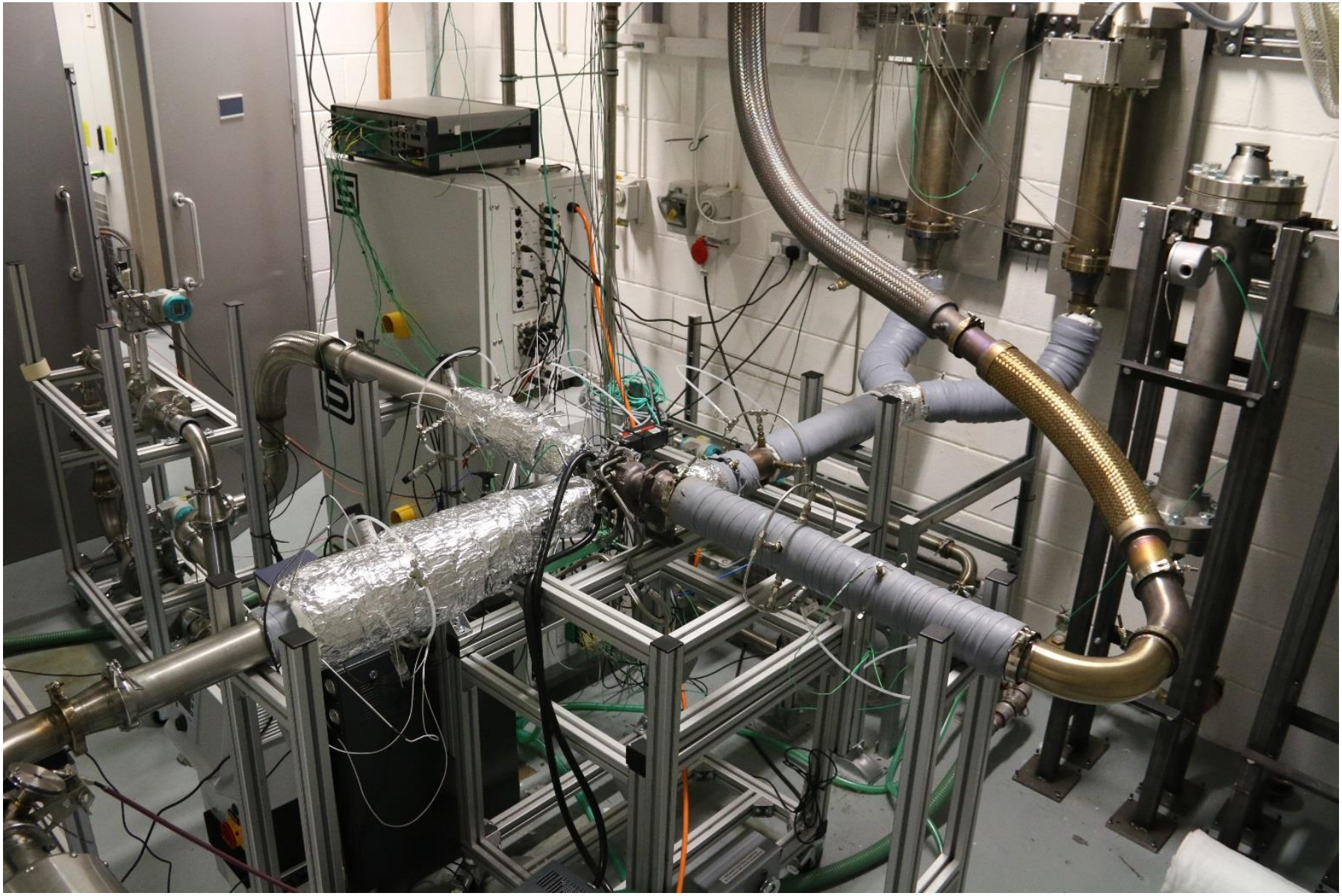
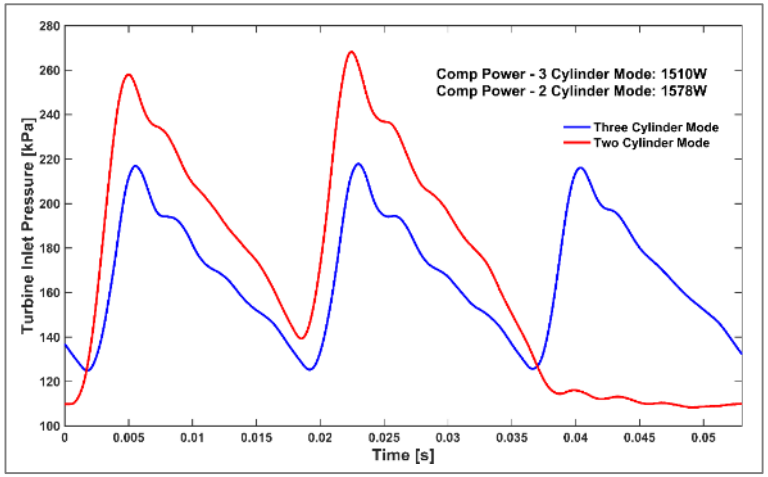
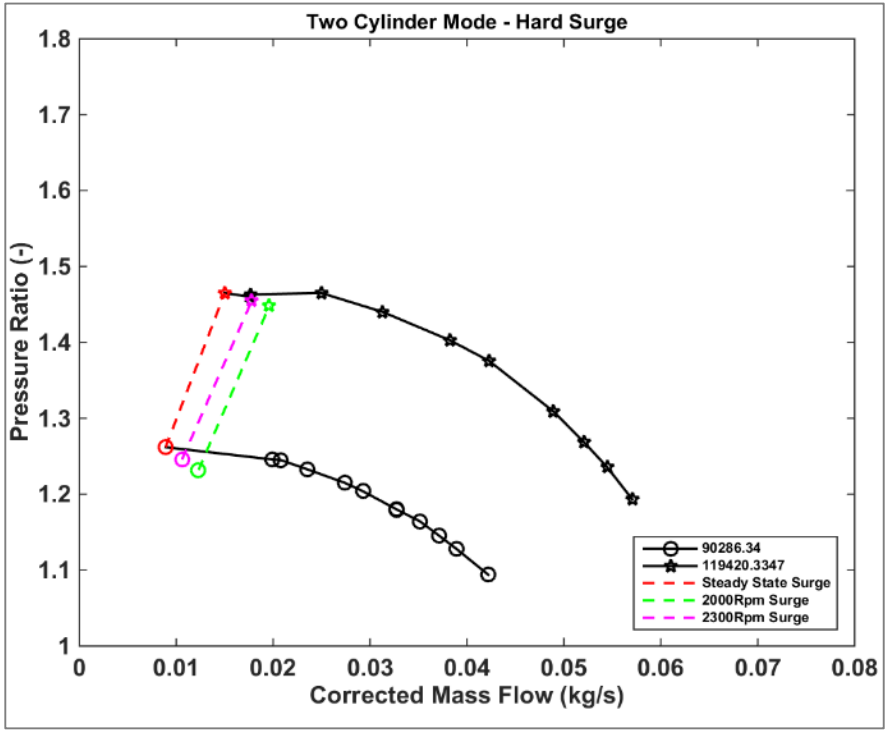
Steady flow Gas Stand



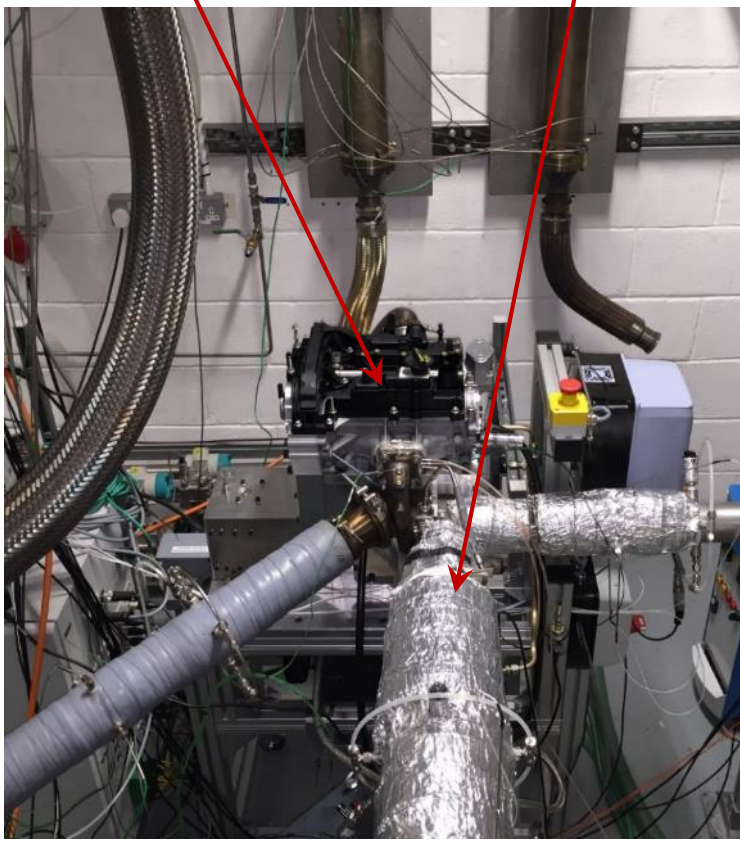
Effect of Pulsations





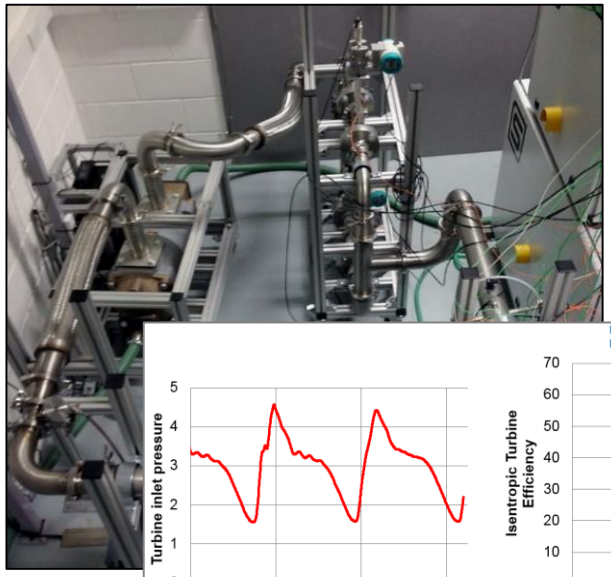
Pulsation flow at the turbine inlet

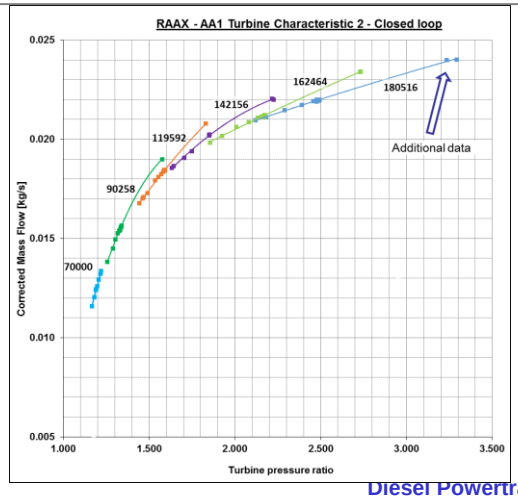
Back pressure valve at compressor outl



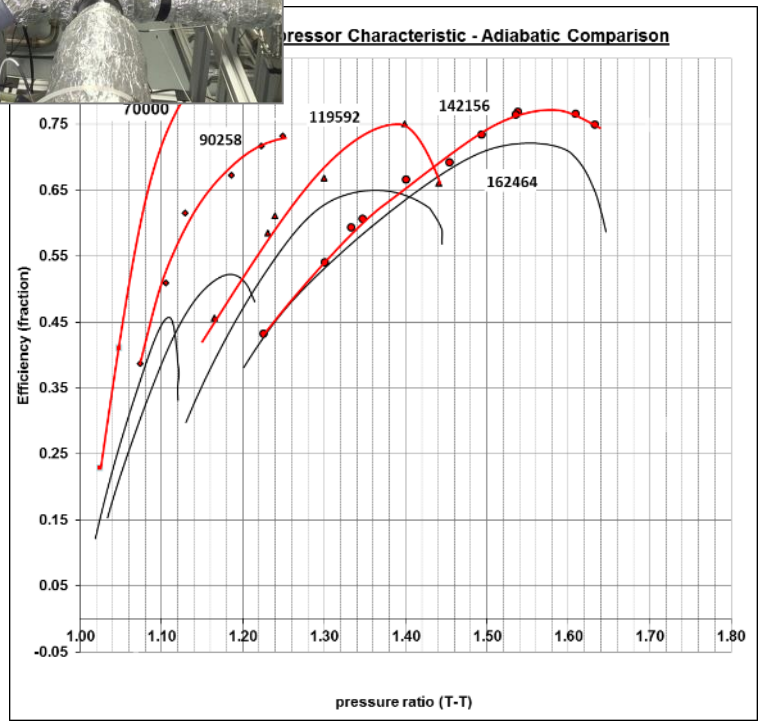
Advanced Mapping techniques

Closed loop compressor





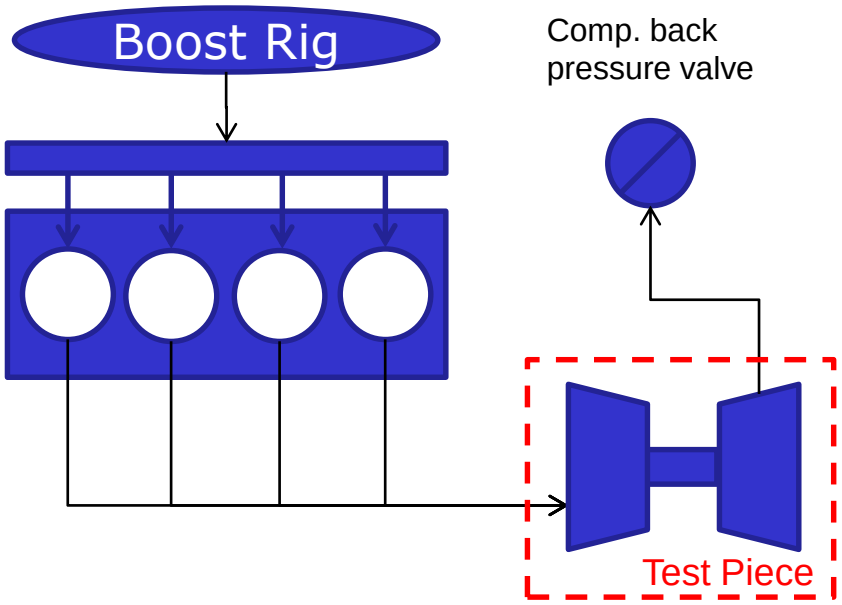
Adiabatic Mapping



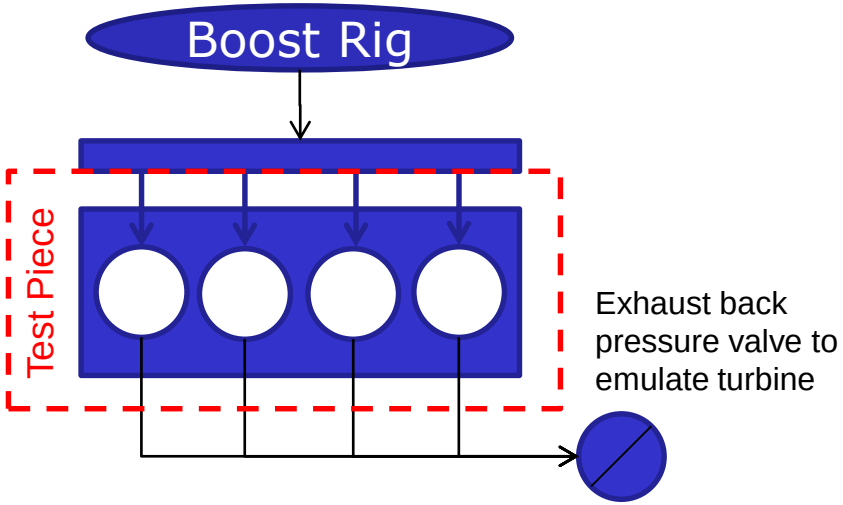
X-i-L testing methods – Engine/Airpath

- Turbomachinery without engine
  - Gas Stand, Engine Gas Stand
- Engine without bootsing hardware
  - Boost emulation rig

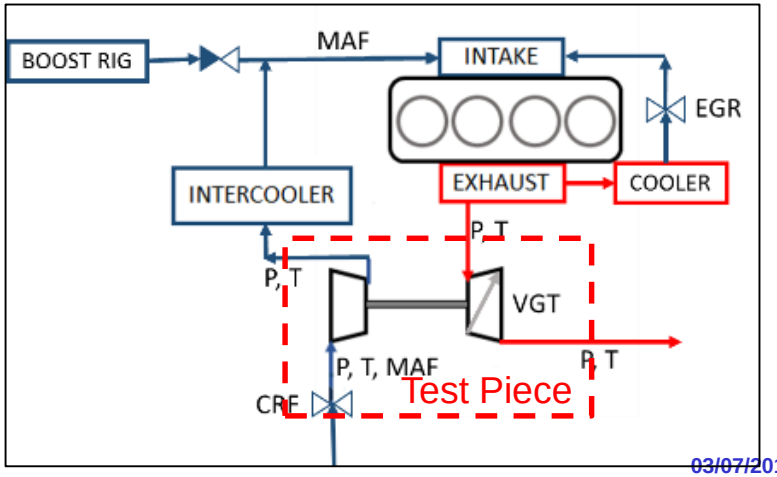
Engine Based Gas Stand A



Boosting system emulation

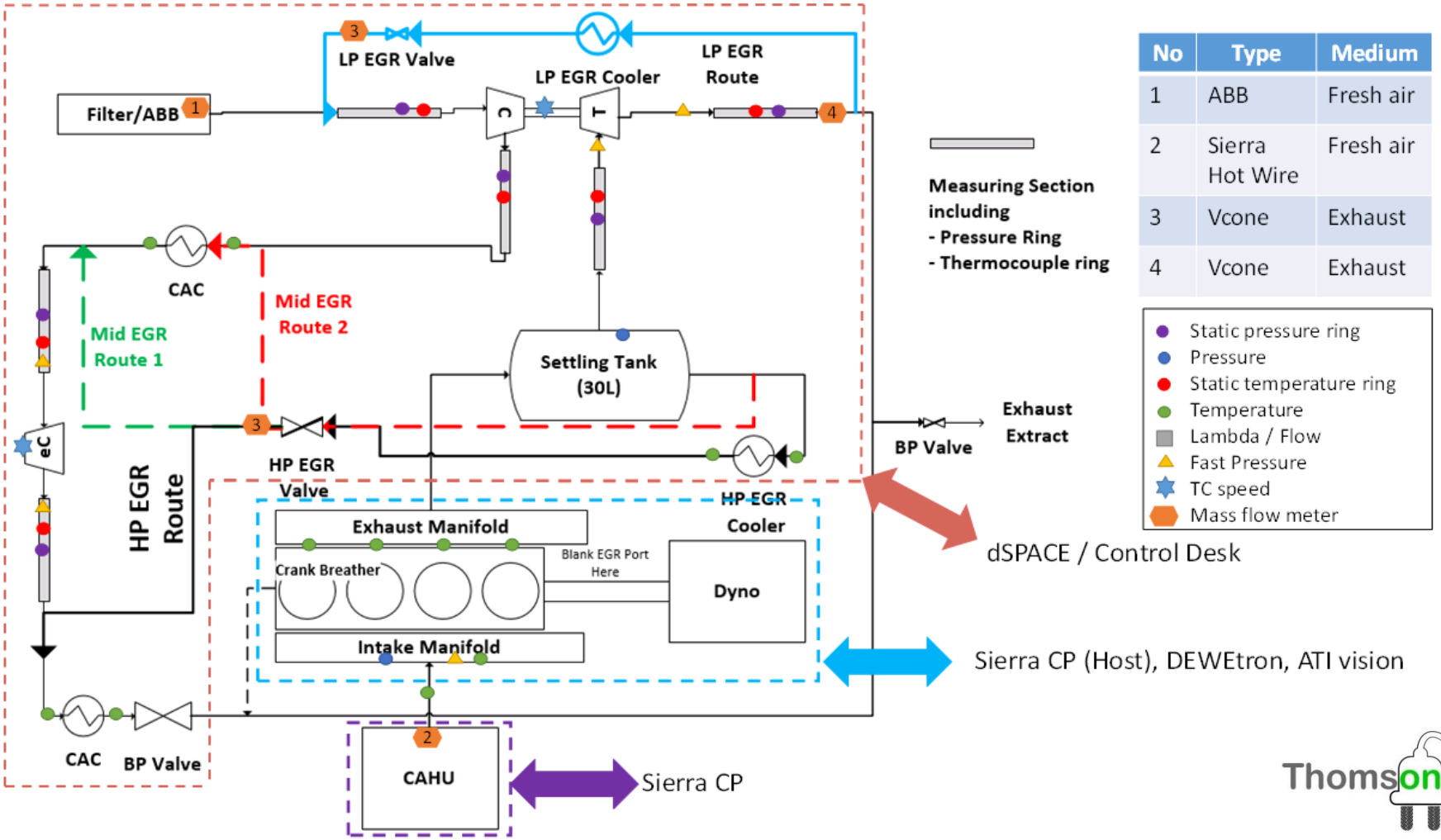


Engine Based Gas Stand B



X-i-L testing methods – Airpath

- System based Test rig replicating air path layout



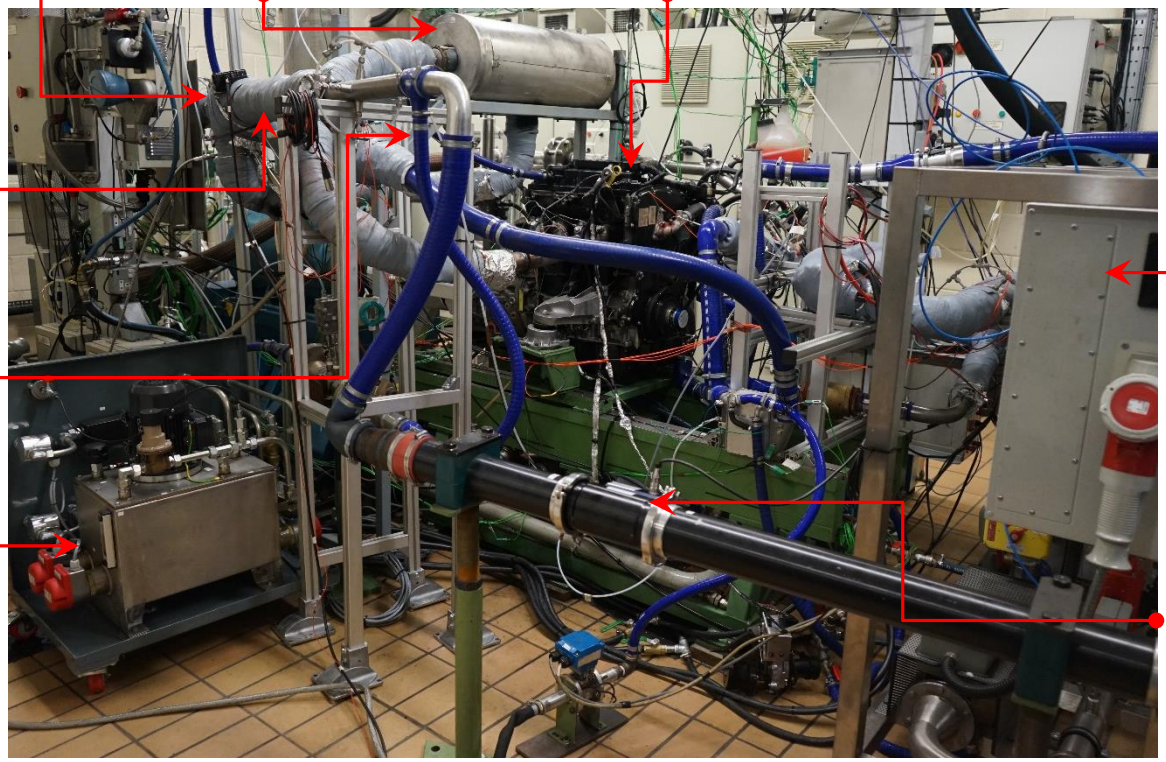
No	Type	Medium
1	ABB	Fresh air
2	Sierra Hot Wire	Fresh air
3	Vcone	Exhaust
4	Vcone	Exhaust

Thomson

http://www.thomson-project.eu/

X-i-L testing methods – Airpath

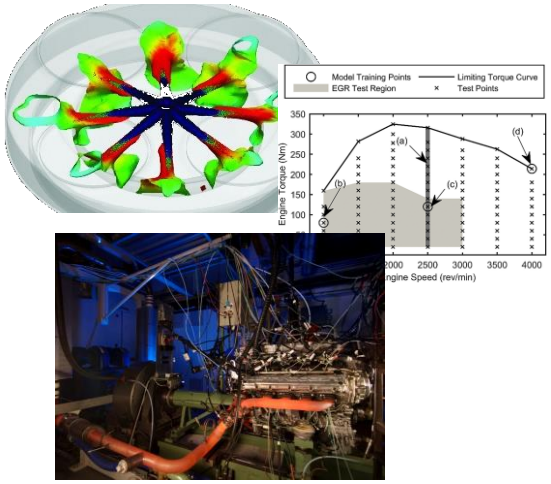
- Built around a 2.2L PUMA Diesel Engine and a Boost rig
- Component level test– Turbocharger turbine & compressor & E-Booster
- Rig successfully commissioned in last week of November

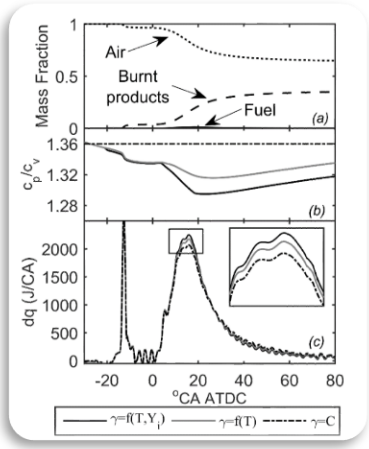


Contents

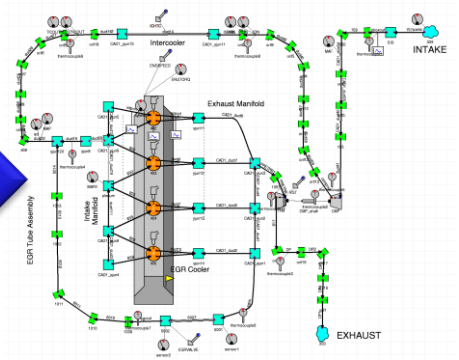
- Boosting Technology
- Modelling techniques
- Experimental techniques
- Conclusions

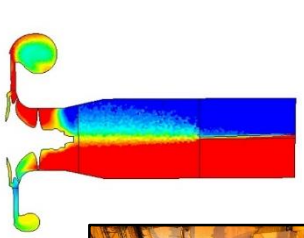
Future Vision: Model Creation

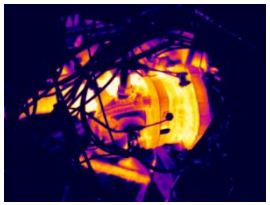


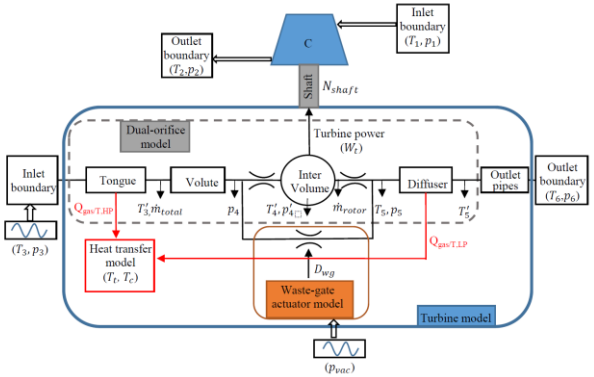


High Order models and HiL testing → Parameterized low order models → HW/Control optimization in system simulation

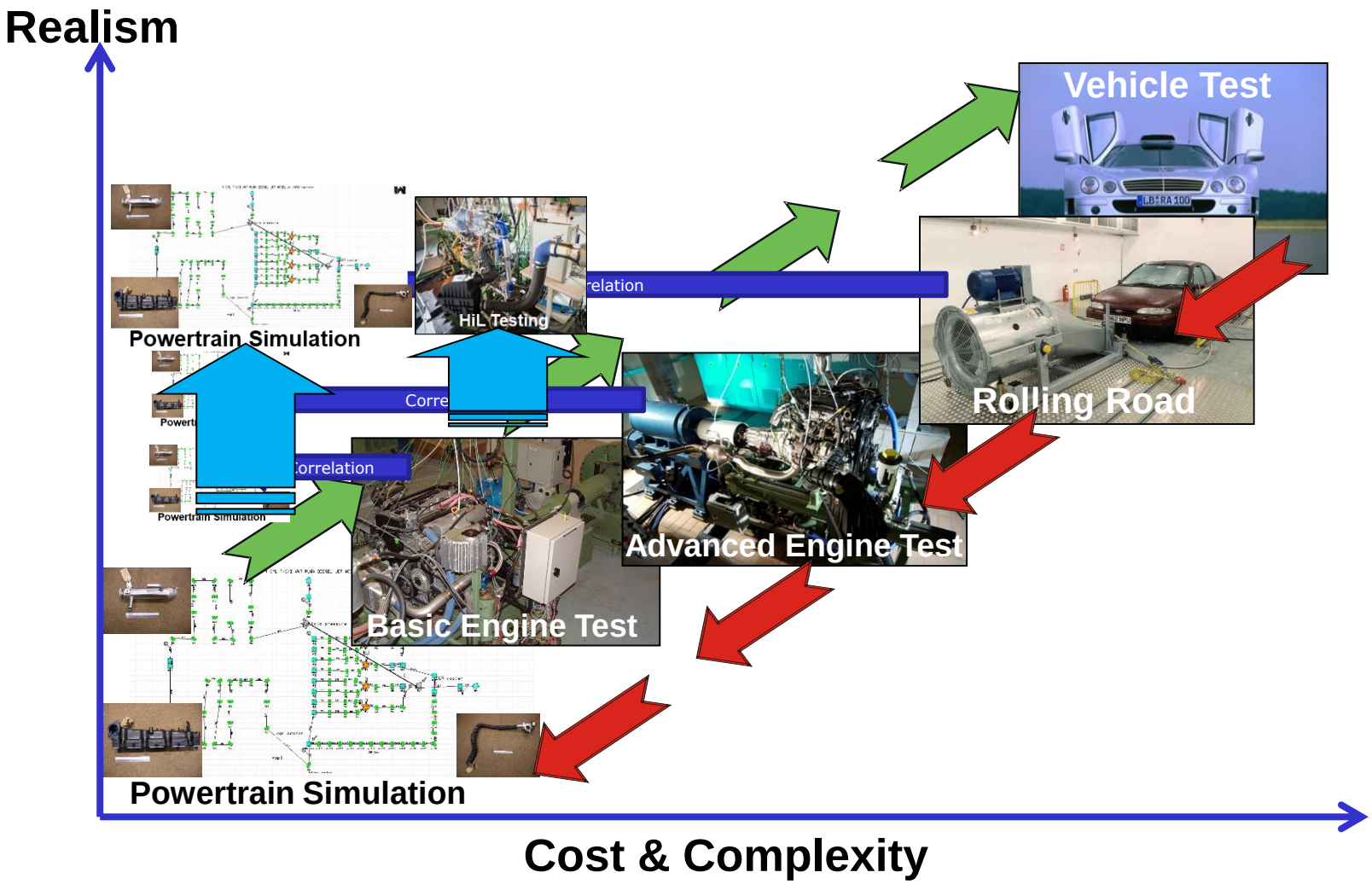






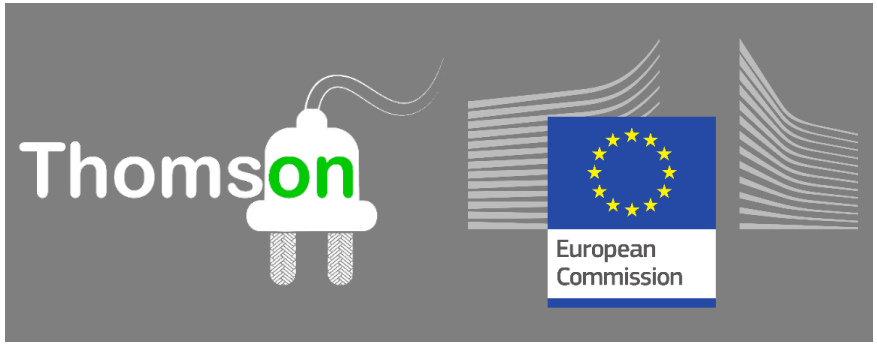


Powertrain Development

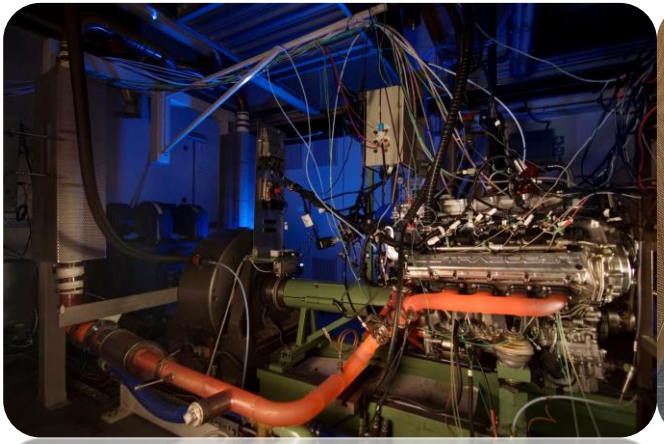


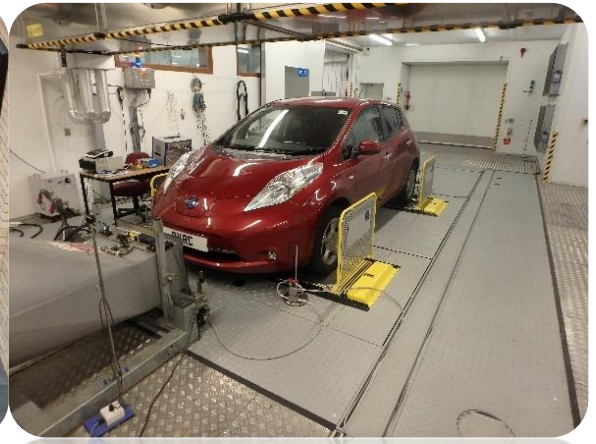
Acknowledgements

Some of this work was conducted with funding from the THOMSON (Mild Hybrid cost effective solutions for a fast Market penetratiON) project which has received funding from the European Union's Horizon 2020 Programme for research, technological development and demonstration under Agreement no. 724037



Any Questions?





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Thanks to my colleagues Calo Avola, Qiyou Deng, Pavlos Dimitriou, Nic Zhang, Sam Akehurst

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