Development of a Novel Transient-Pulsating Flow Rig for Engine Air System Research using GT-SUITE

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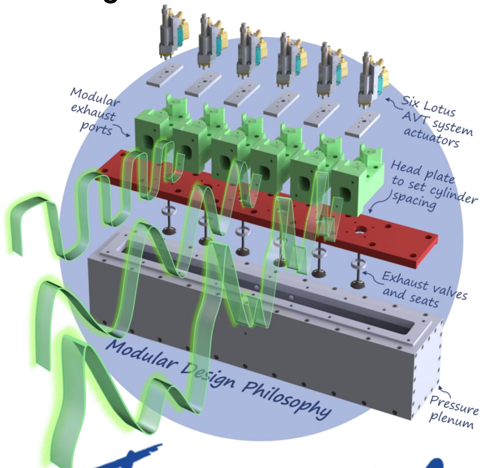

TASR

Transient Air System Rig

http://www.imperial.ac.uk/turbochargers/facilities/tasr/

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1. Introduction: *Background*

- Road transport in the EU accounts for around 20% of all CO_2 emissions
- Transition to hybrid- or full-electric powertrains in pass-car / light-duty vehicles continues…
- …but much more difficult for heavy-duty applications – not as well-suited to electrification
  - CO_2 from heavy-duty vehicles *increased* **36%** between 1990–2010[1]; continues to grow
- While the powertrain mix is changing, the internal combustion engine is currently the most numerous prime mover, and will be around in some form for many decades
- So the consensus[2] is that we must continue striving for thermal efficiency improvements, to reduce CO_2 emissions across all modes of transport

[1] European Commission (2014) Strategy for reducing Heavy-Duty Vehicles' fuel consumption and CO2 emissions. Communication from the Commission to the Council and The European Parliament, COM(2014) 285 final. Last accessed 17-06-2018. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:52014DC0285

[2] Automotive Council and Advanced Propulsion Centre (2017) Product Roadmap 2017: Commercial and Off-highway Vehicle. Last accessed 17-06-2018. Retrieved from https://www.automotivecouncil.co.uk/wp-content/uploads/sites/13/2017/09/CV_OH-Roadmap.jpg

1. Introduction: *Project*

High Performance Engine Air System (EAS) Project

- Objective: *This project will design and develop a highly responsive and efficient Engine Air System that will enable engine downsizing and alternative engine operating strategies with their associated fuel efficiency gains*
- Commissioned as part of the Energy Technologies Institute (ETI)'s Heavy Duty Vehicle Efficiency (HDVE) Programme[3]
- Collaboration between Caterpillar Inc., Imperial College London, Honeywell Transportation Systems
- Demo engine is a 7-litre heavy-duty industrial diesel engine, built in the UK
  - Numerous different applications and duty cycles
  - **Two-stage air system** – two fixed geometry turbos in series

[3] Energy Technologies Institute (2018) Technology Programmes: Transport – HDV. Last accessed 20-06-2018. Retrieved from: http://www.eti.co.uk/programmes/transport-hdv

1. Introduction: *Objectives*

Imperial's primary role: **Air system test rig design and development**

The essential requirement of the Transient Air System Rig is:
*To enable the performance (efficiency and **transient** response) of multi-stage engine air system concepts to be evaluated experimentally*

Transient – meaning at the timescale of engine acceleration (e.g., due to a load change), typically in order of a few seconds

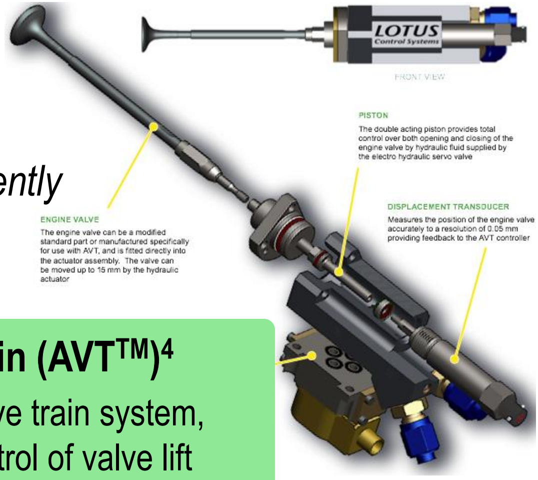
Pulse, pulse flow, pulsating flow – meaning at the timescale of pulses in the exhaust manifold caused by the opening and closing of the valves

- Order of 10^1–10^2 Hz
- e.g., 6-cylinder engine running at 1200 rpm corresponds to (6*1200)/(2*60) = 60 Hz

2. Methodology: *Requirements gathering & concept downselection*

Requirements – be able to:

- Test air systems for a wide range of engine sizes and speeds, both heavy- and light-duty
  - Drives requirements for *high flow*, *fast response*, and *high pulse frequency*
- Replicate exhaust pulse shape throughout an engine transient event
  - Drives requirement to be able to *control pulse amplitude* and *frequency*, *transiently*



Concept downselection – various concepts assessed, e.g.,

- Actual engine (fired or motored)
- Pressure plenum + actual engine cylinder head
- Pressure plenum + pulse generator (chopper/rotary valve)
- **Pressure plenum + camless valve train**

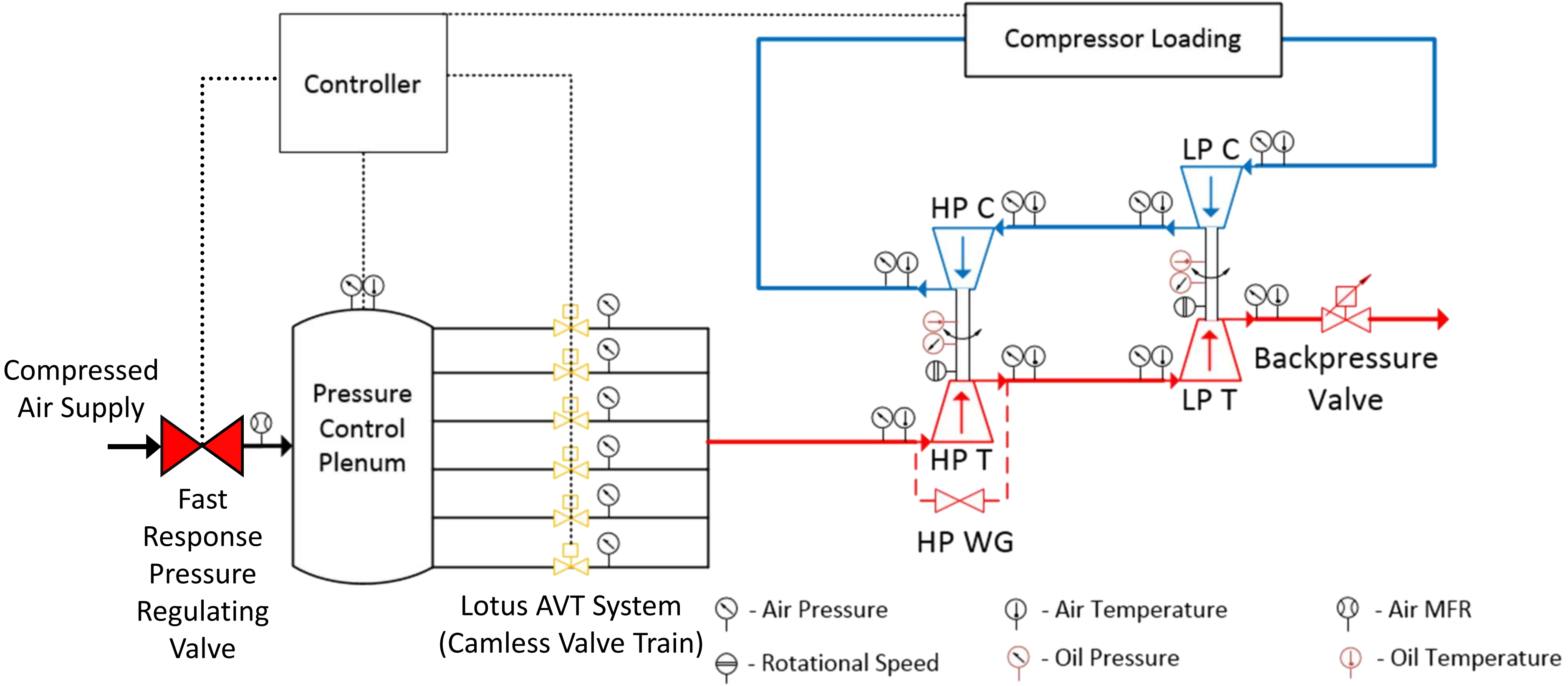
Lotus Active Valve Train (AVT™)[4]

Lotus AVT is a camless valve train system, permitting independent control of valve lift profiles, enabling pressure pulse frequency, amplitude and shape to be adjusted as desired

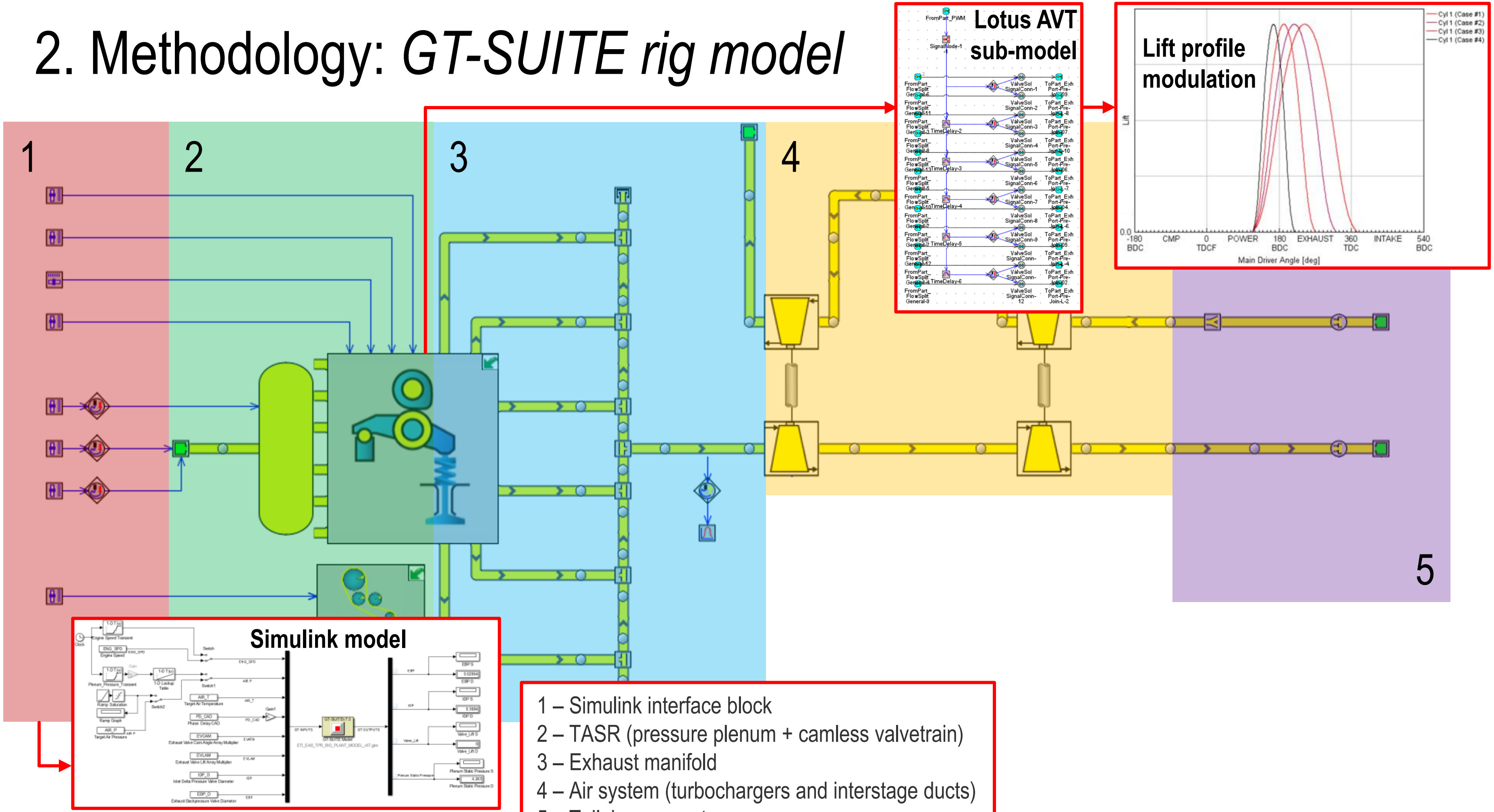
- Only the "**pressure plenum + camless valvetrain**" concept provides the flexibility to cover different engine sizes and speeds, with capability to transiently control pulse amplitude and frequency

[4] Group Lotus plc. (unknown date) Active Valve Train. Last accessed 20-06-2018. Retrieved from: http://www.lotuscars.com/engineering/active-valve-train

2. Methodology: *Proposed rig layout*



2. Methodology: *GT-SUITE rig model*



1 – Simulink interface block
2 – TASR (pressure plenum + camless valvetrain)
3 – Exhaust manifold
4 – Air system (turbochargers and interstage ducts)
5 – Tailpipe geometry

2. Methodology: *Scale factor*

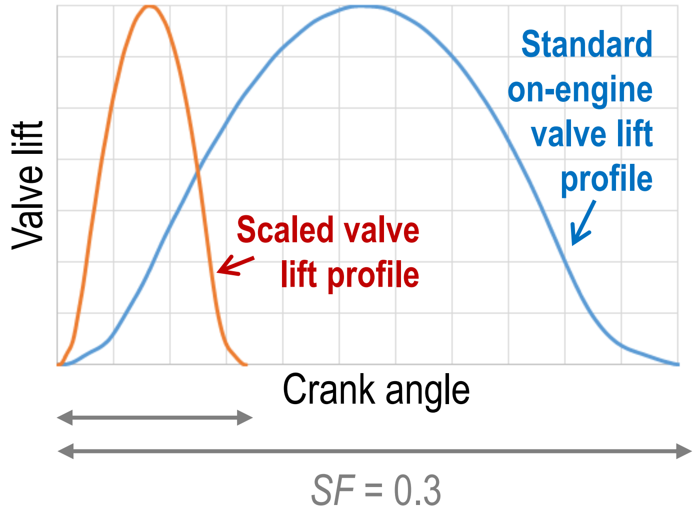
Key question

- *Would proposed rig concept be able to recreate exhaust pressure pulses of the correct amplitude?*
  - …given that the max plenum pressure would be much lower than in an engine cylinder head at EVO
  - …how closely could the pulse shape be matched?

Scale factor approach

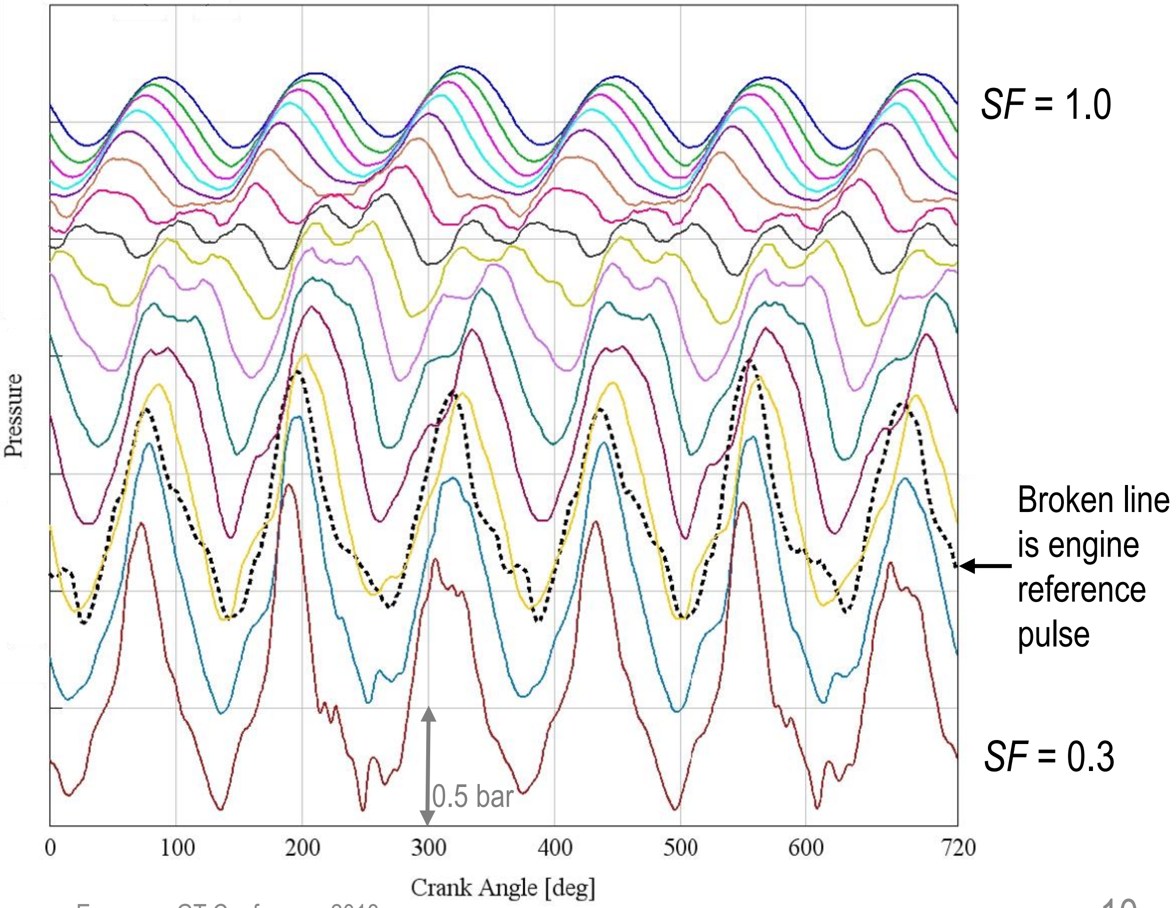
- Use Simulink controls to compress lift duration

  → define a simple *Scale Factor (SF)* referenced to the real engine lift profile duration
- Use GT-SUITE rig model to simulate effect of different *SF* values on HP turbine inlet pressure
  - Only duration was scaled; no changes to profile shape



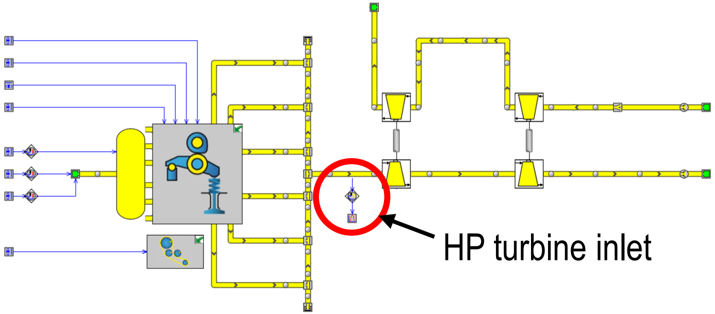
3. Results: *HP turbine inlet pressure*

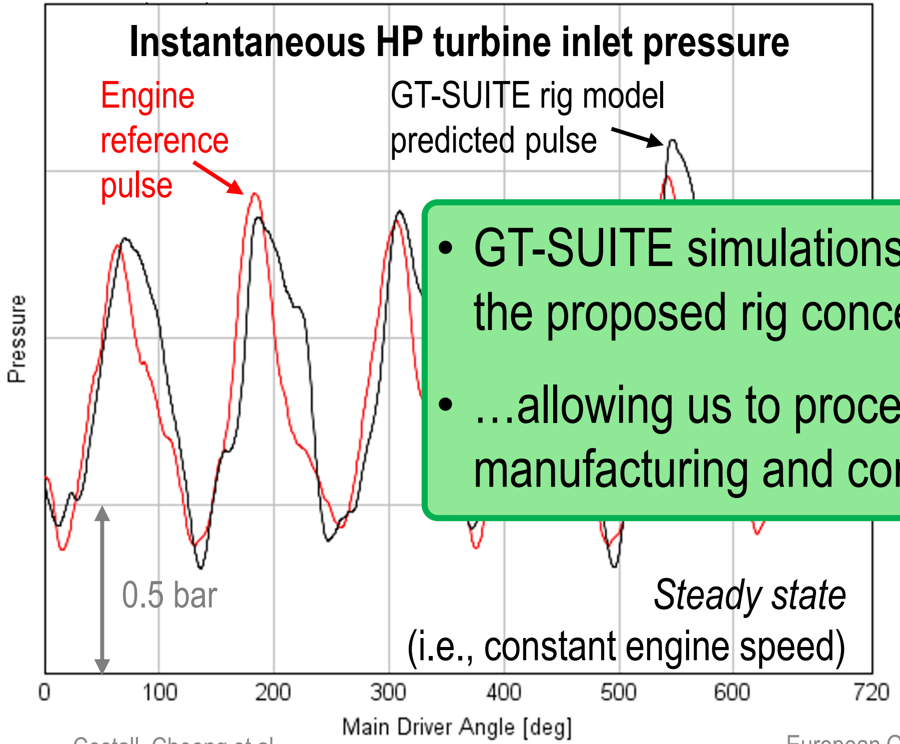
- Plot shows sweep of instantaneous HP turbine inlet pressure as a function of *SF*, in equal intervals of 0.05
- *SF* modulation strongly affects mean pressure and amplitude, as well as the resultant pulse shape
- As *SF* decreases:
  - Mean pressure *decreases*
  - Pulse amplitude *increases*
- In this example, best match is around *SF* ~0.4

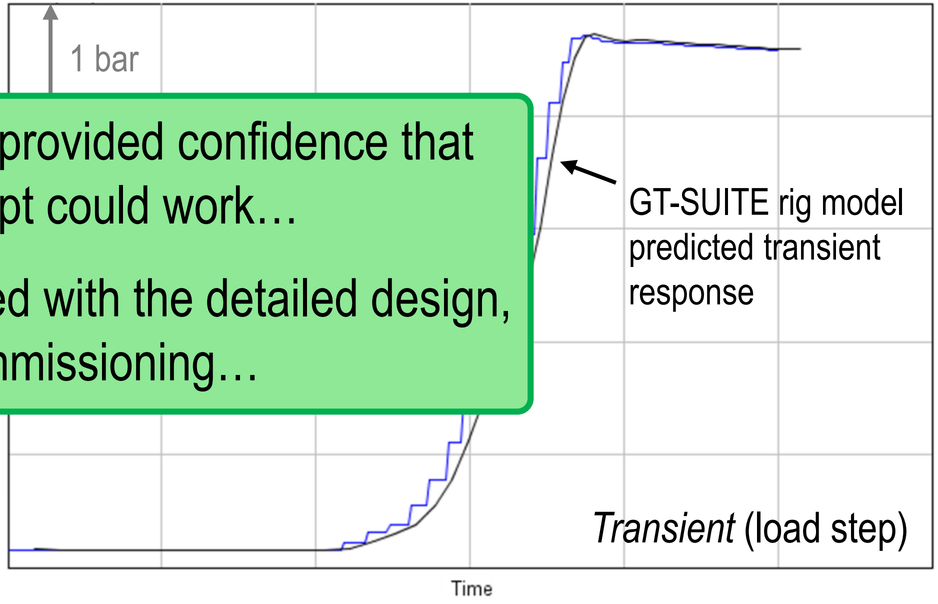


3. Results: *HP turbine inlet pressure*

- Scale factor modulation achieved the following results, in steady-state and transient operation





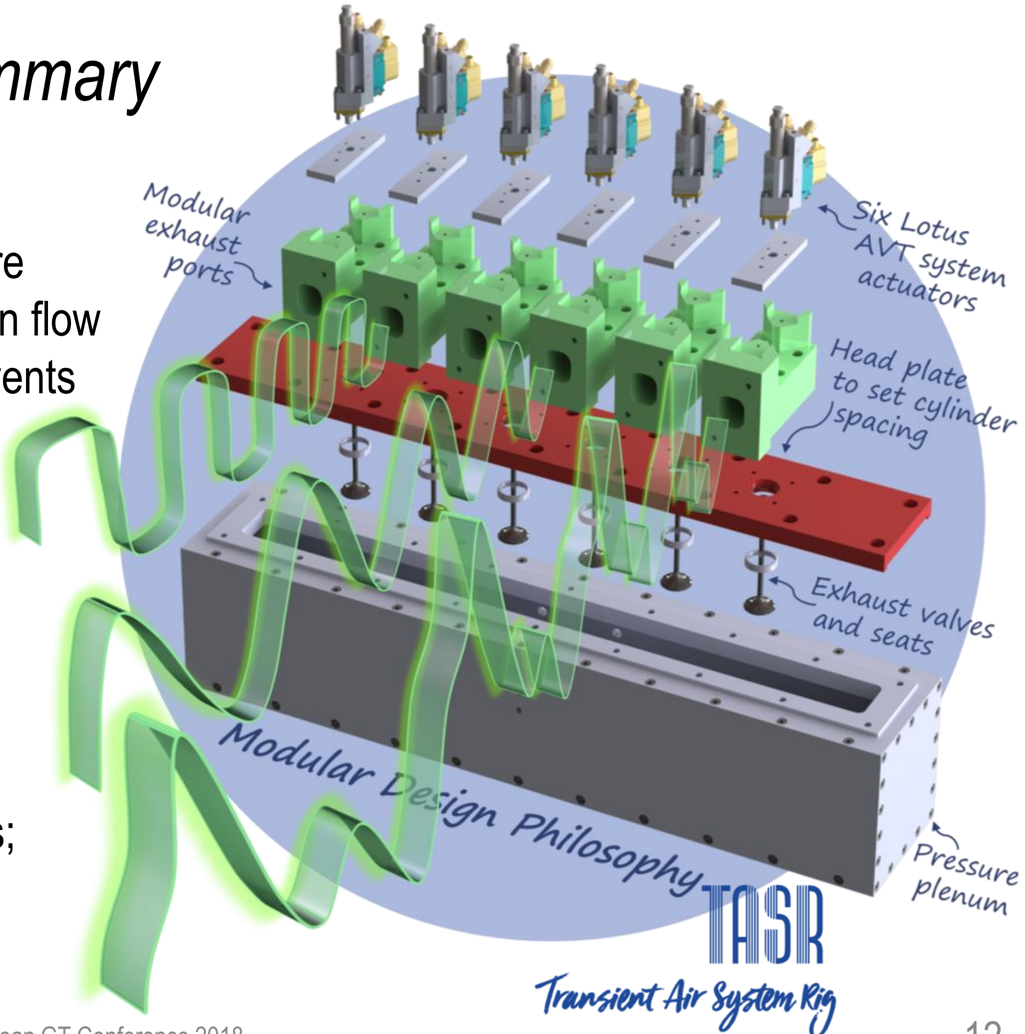


- GT-SUITE simulations provided confidence that the proposed rig concept could work…
- …allowing us to proceed with the detailed design, manufacturing and commissioning…

3. Results: *TASR design summary*

***TASR*, the Transient Air System Rig**

- Transients created by a fast-acting pressure regulating valve → imposes ramps in mean flow entering plenum, to imitate vehicle-level events
- Pulses generated by Lotus AVT (Active Valve Train) system (6 electrohydraulic poppet valve actuators) + corresponding mounting plates, exhaust ports, valves and seats, installed on top of plenum
- Modular design philosophy allows different cylinder spacing with minimal part changes; simple plenum design can be adjusted for volume, or internal features added

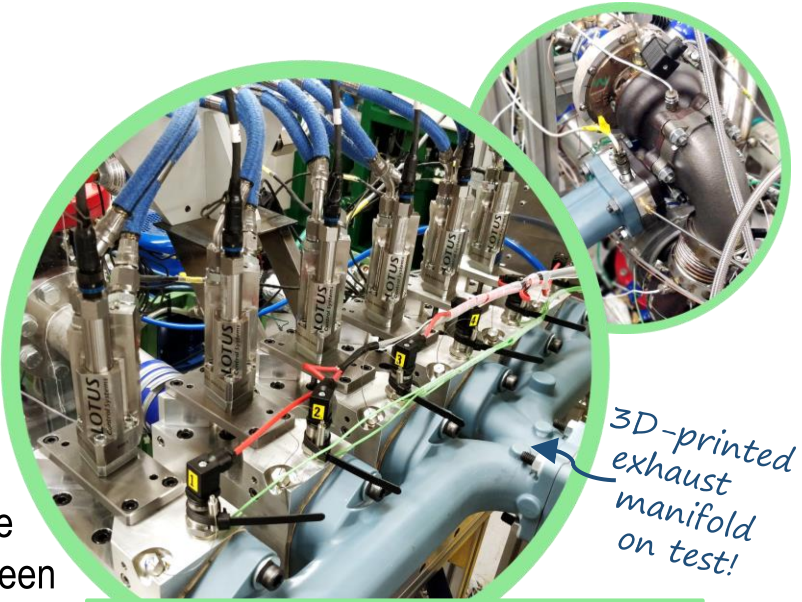


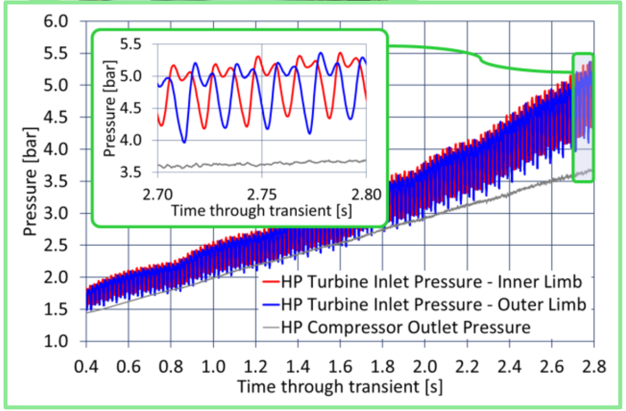
4. Conclusions

Conclusions

- GT-SUITE was used early on in development of TASR
  - Proof-of-concept rig model provided confidence that required air system inlet BCs can be recreated experimentally
- Simulated effect of *Scale Factor* on valve lift duration
  - *SF* allows desired pressure pulse amplitude (and shape) to be recreated, but using plenum pressures lower than would be seen in a real engine at EVO
- TASR has since been successfully built and commissioned
  - Recreates both *transient* and *pulsating* gas dynamics entering the engine air system
  - Air system performance can be measured in engine-realistic conditions, without recourse to expensive and time consuming engine testing!

TASR
Transient Air System Rig





Twin-entry turbine, transient out-of-phase pulses

Acknowledgements

The TASR was built as part of the High Performance Engine Air System project, which is a collaboration between Imperial, Caterpillar Inc., and Honeywell Transportation Systems. It was commissioned as part of the Energy Technologies Institute (ETI)'s Heavy Duty Vehicle Efficiency Programme.

energy technologies institute

Thanks for your attention!