A Novel Transient-Pulsating Flow Rig for Engine Air System Research and Development

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TASR
Transient Air System Rig

1. Background

We are witnessing a period of great change in the automotive industry. Road transport in the EU accounts for around 20% of all emissions of CO_2, the main greenhouse gas. The shift to hybrid/electric powertrains in passenger car and light-duty vehicles with ultra-low or zero CO_2 tailpipe emissions continues, but a complete transition will take decades. This is especially so for heavy-duty applications, which are not well-suited to current electrical energy storage technology. In fact, between 1990 and 2010 CO_2 emissions from heavy-duty vehicles actually grew by ~36% [1], due to expanding demand for road freight and stagnant fuel economy. Irrespective of the future powertrain technology mix across sectors, the internal combustion (IC) engine will remain the most numerous prime mover, and the consensus [2] is that we must continue to strive to raise the efficiency of thermal propulsion systems in order to reduce CO_2 emissions across all modes of transport.

2. Motivation

- A key enabling technology for high thermal efficiency is the **multi-stage turbocharged engine air system** (e.g., Fig. 1), which can attain higher boost pressures, provide greater air flow, and faster transient response, enabling thermal efficiency strategies and reduced emissions from IC engines
- These are complex systems, designed using 1D engine simulation tools, followed by physical testing on engine
- However, due to modelling inaccuracies, multiple design and test iterations are required
- Improving the physical accuracy of these models will require representative validation test data
- This motivated the design and commissioning of a new experimental facility: ***TASR***, the *Transient Air System Rig*

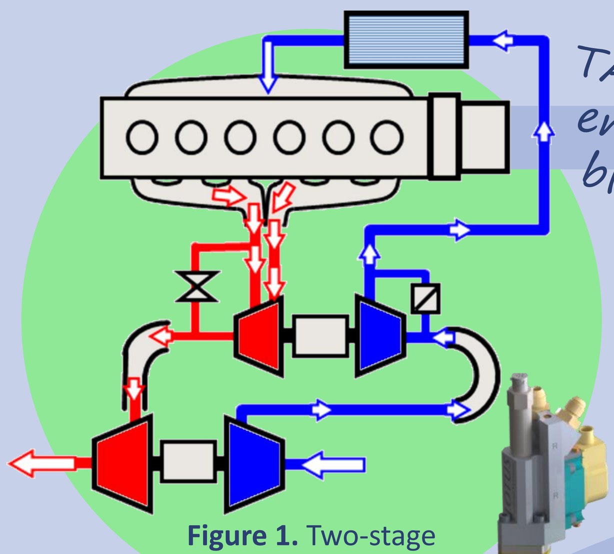


Figure 1. Two-stage air system layout

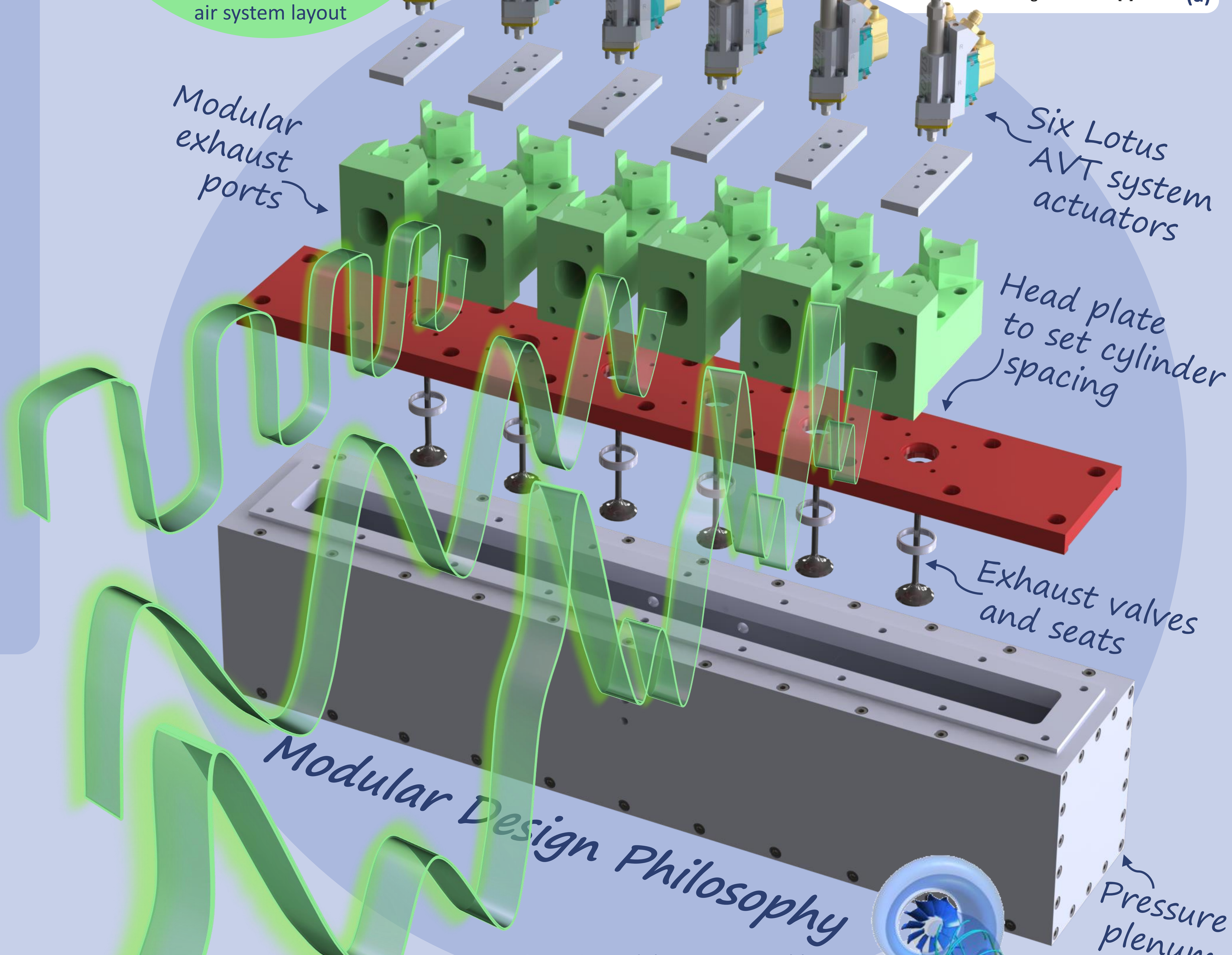


Figure 2. Modular TASR assembly

3. Objectives

- To measure performance of multi-stage engine air systems under engine-realistic conditions, **but without an engine**
- To reproduce the **unsteady gas dynamics** in an IC engine exhaust manifold undergoing a specified transient event
- Thus, to generate **two unsteadiness timescales**:
  - **Transient** – timescale of engine acceleration, in the order of 10^0 Hz
  - **Pulsating** – timescale of exhaust pulses due to opening and closing of valves, order of 10^1–10^2 Hz

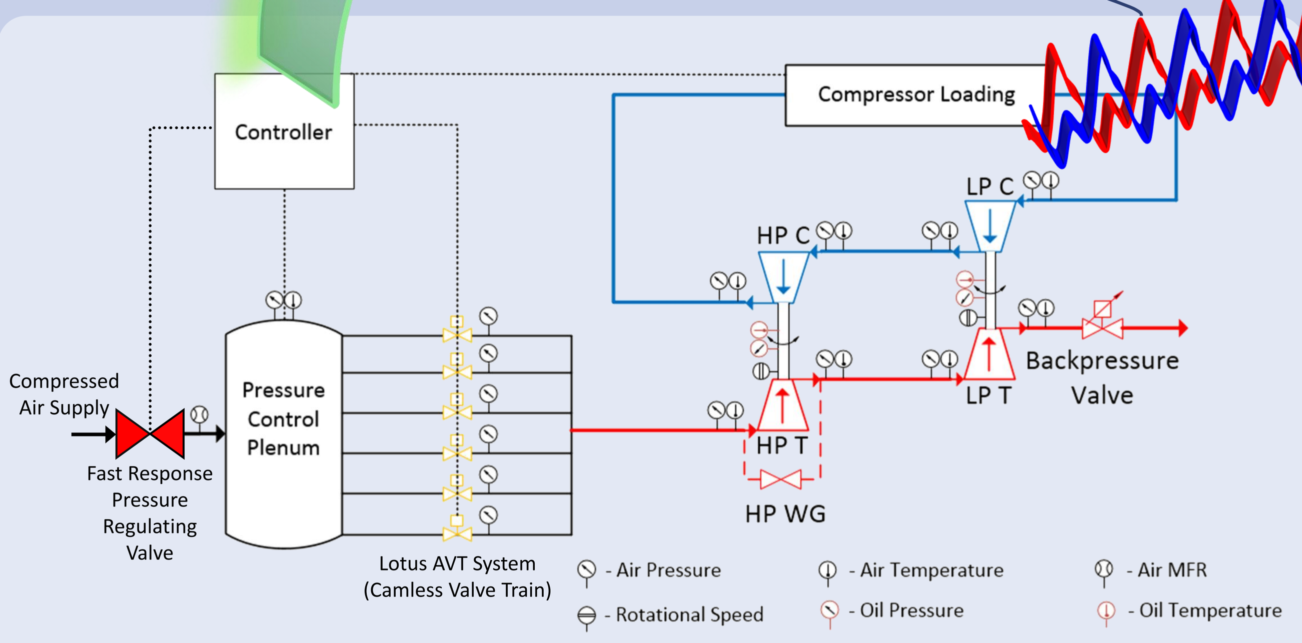


Figure 3. Overall TASR schematic

4. Design

- Transients are created by a fast-acting pressure regulating valve, which imposes ramps in the mean flow entering the pressure plenum (Figs 2 & 3), to imitate vehicle-level events
- Pulses are generated by a Lotus AVT (Active Valve Train) system [3], comprising six electrohydraulic poppet valve actuators, with corresponding mounting plates, exhaust ports, valves and seats, which are installed on top of the pressure plenum (Fig. 2)
- Our modular design philosophy allows different engine cylinder spacing to be accommodated with a minimum of part changes, while the simple plenum design can be adjusted for overall volume, or be adapted to include internal features

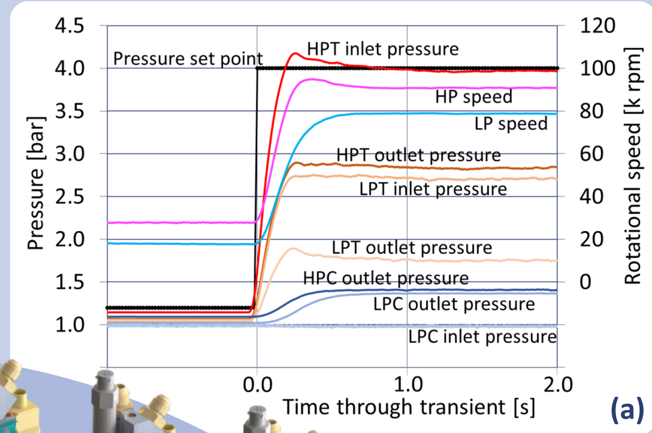
5. Advantages

TASR offers numerous advantages over traditional gas stand or engine testing:

- It isolates the air system from combustion effects and associated confounding factors
- The non-combusting flow permits new manifold and turbocharger concepts to be inexpensively and rapidly 3D-printed in plastic, ready for immediate testing
- Its capabilities (Tab. 1) and modular design, which is not restricted to any particular cylinder configuration, allows a wide range of engine air systems to be evaluated

Table 1. TASR capabilities

Parameter	Capability (up to)
Mass flow rate (corr.)	1 kg/s
Rate of change of MFR	0.5 kg/s^2
Pulsation frequency	400 Hz (6-cyl @ 8000 rpm)
Pulsation shape	Mean pressure & amplitude



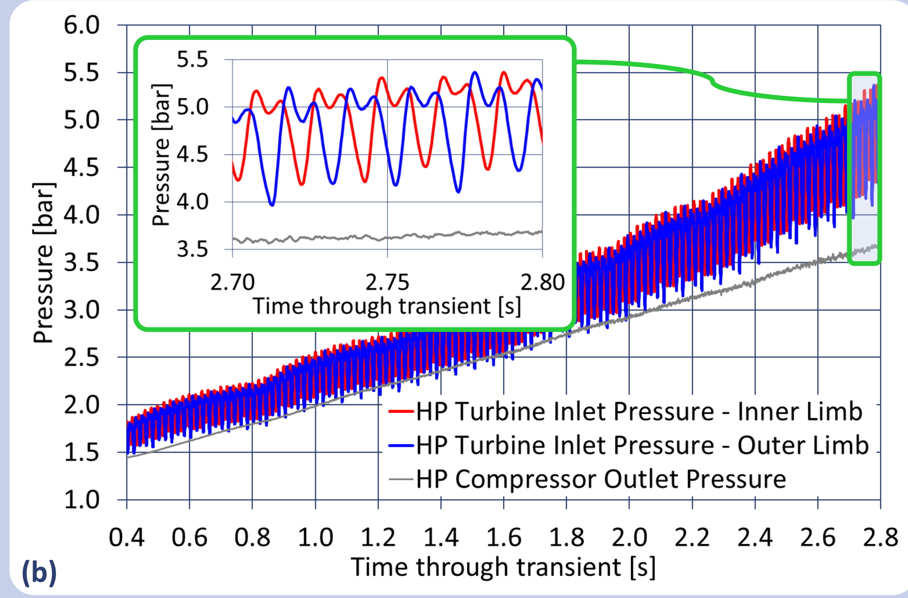


Figure 4. (a) 1–4 bar step response; (b) twin-entry turbine, out-of-phase pulses

6. Results

Figure 4 (a) shows the rapid air system response to a step change in demanded plenum pressure. Figure 4 (b) shows the response of the high pressure stage in a 2-stage air system for a 7-litre industrial diesel engine, highlighting the out-of-phase pressure pulses entering either limb of the twin-entry turbine (inset).

7. Applications

- Multistage air system matching under engine-realistic, transient-pulsating conditions
- Unsteady 1D and 3D CFD (Fig. 5) model validation
- Performance validation and optimization of new air system concepts and components, in steady-state, pulsating and transient-pulsating operation (Fig. 6)
- Valve event optimization; effect of pulse frequency, amplitude and shape on air system performance
- Intake and exhaust system acoustics

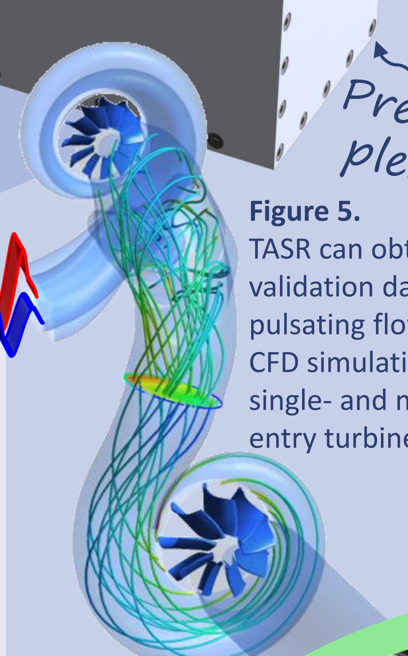


Figure 5. TASR can obtain validation data for pulsating flow 3D CFD simulations of single- and multi-entry turbines

8. Conclusions

- TASR, the new Transient Air System Rig, has been commissioned at Imperial College London
- It simultaneously recreates transient and pulsating gas dynamics entering an engine air system
- Engine air system performance can be measured in engine-realistic conditions, without recourse to expensive and time consuming engine testing!

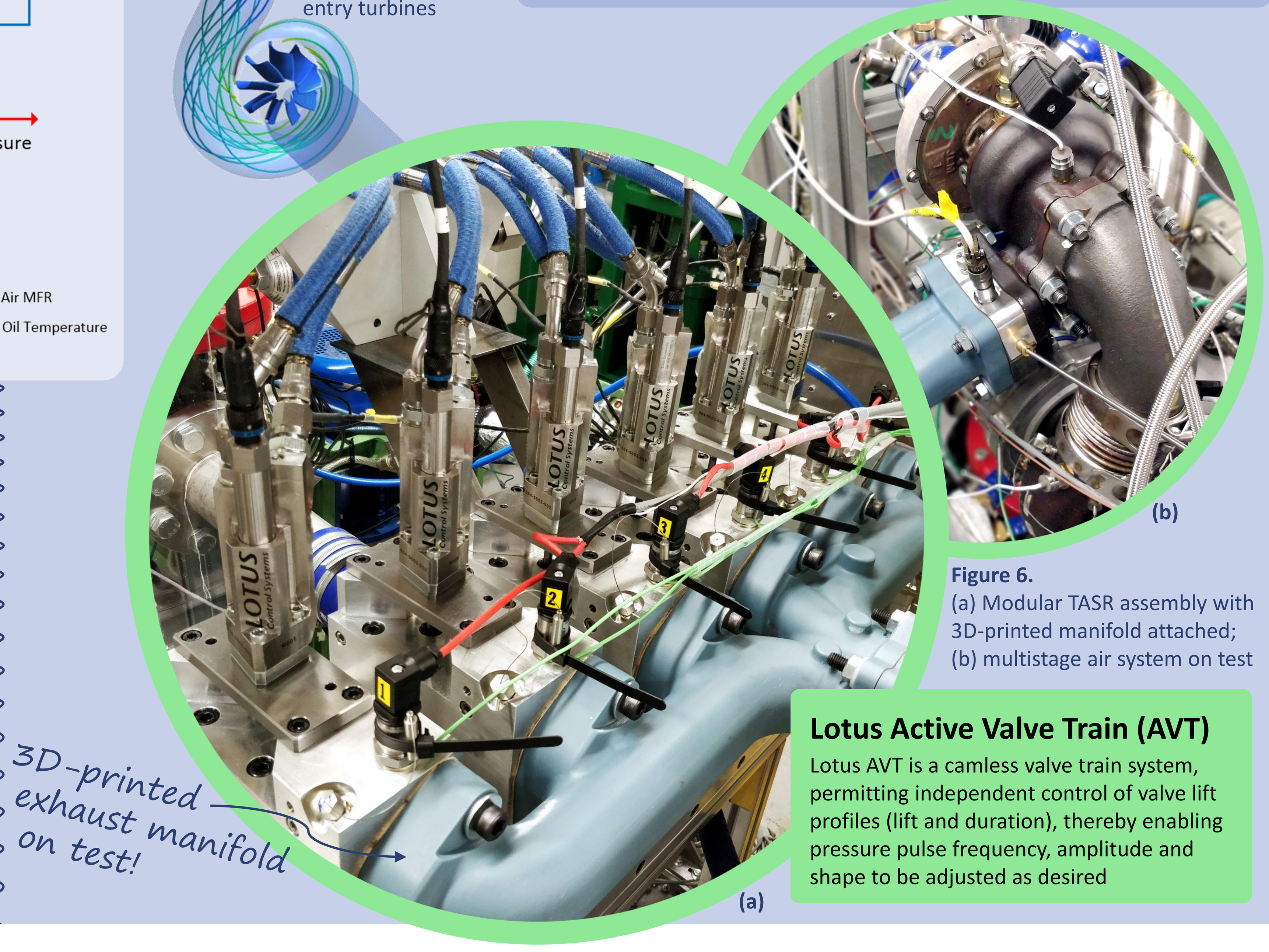


Figure 6. (a) Modular TASR assembly with 3D-printed manifold attached; (b) multistage air system on test

Lotus Active Valve Train (AVT)

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

More info...

Acknowledgements

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energy technologies institute

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