INTRODUCTION. The complexity of Very High Bypass Ratio (VHBR) lean burn combustion systems requires careful fuel control and optimised staging to minimise non-volatile Particulate Matter (nvPM) emissions. Fuel flow variation across injectors will impact the temperature distribution through the turbine and thus influences rates of nvPM formation and consumption. Through Clean Sky 2, Rolls-Royce are developing technologies required for VHBR engines. CIDAR (Combustion species Imaging Diagnostics for Aero-engine Research) supports this initiative. Extractive sampling systems are the current standard method for measuring exhaust gas and fine particle emissions from various types of aircraft engines under actual operating conditions. Emerging non-intrusive approaches to gas and particulate measurement offer alternatives to extractive methods, with some significant advantages (no impact on engine performance and no hardware installed in engine exhaust, bypass or entrained flows).

CIDAR PROJECT. CIDAR will develop and demonstrate exhaust measurement technologies required to deliver robust VHBR engine performance prediction, using approaches described in [1]. The novel technologies developed in CIDAR, will make it easier to increase the number of tests that can be implemented in-situ without affecting the performance of the engine and make it possible to characterise the combustion process in both the stationary and transient regimes, allowing the detection of anomalous phenomena in both states. Therefore, VHBR engines will be subjected to continuous monitoring of their combustion process under different operating and environmental conditions (health monitoring).

TECHNOLOGY. The CIDAR programme includes demonstration of cross-sectional imaging of nvPM in exhaust plumes during a full engine test at INTRA’s jet engine test facility. The measurement system will meet TRL6 (technology demonstrated in relevant industrial environment). Laser induced incandescence (LII) based on orthogonal imaging of a light sheet is a well-established tool for the quantification of soot concentrations and distributions in small flames. However, this configuration is not scalable to large engine exhaust measurements. Scanned beam LII with light collection in the backward direction has been demonstrated in jet exhaust [2, 3]. CIDAR will use in-plane near-orthogonal collection of incandescence from a scanned excitation beam (Figure 1). Cross-sectional images of nvPM concentration will then be produced by autopropjection tomography.

LAVISION CAMERA SYSTEM. The cameras, which are controlled remotely, are mounted on walls of the test cell walls 7m above floor level, on the engine’s horizontal centerline. The detection channel implements wide-field detection using two LaVision E-lite 2M cameras with 1826 pixels in the vertical plane, i.e. along the laser beam path. The cameras are fitted with 90-105 mm focal length lenses which provide a 1.5-1.7 m FOV at 7 m from the imaging plane which translates to around 1 mm per pixel in the vertical image plane. The cameras are synchronously triggered by a LaVision PTU-X synchronisation unit, which provides a 5V TTL-trigger to each camera. Data from the cameras are transferred to a host PC located in an adjacent control room over Ethernet, via a Netgear ProSAFE Gigabit 24 port switch. Control of the synchronisation unit is also via ethernet with USB-RJ45 converters used on both the synchronisation unit and host PC.

Figure 1. LII system layout at INTRA test cell

- Heat soot along a straight line path using a near-IR laser
- Measure incandescence using cameras to quantify nvPM
- Use sequential laser shots to accumulate images
- Scan perpendicular to flow axis

EXCITATION LASER. The laser system (including the associated power supplies, telescope and scanning head), synchronisation unit, and Ethernet switch are located on the gantry above the engine exhaust plume. The laser output is directed via a focusing telescope and scanning head mirror across the engine exhaust plume through an opening in the gantry. Previous experiments on aero-engines have shown that the laser fluence in the plume should fall in the range 0.2 to 1.2 J cm⁻² [4, 5], the upper limit representing the vaporisation threshold. Optical scattering will act to reduce the beam’s fluence as it propagates across the plume. The laser beam will be terminated in a floor-level beam dump over the full scan width. The design of this beam dump must include a means to prevent accumulation of unburned fuel, which would otherwise constitute a fire hazard.

Aims
- Pulse energy and beam parameters must support simultaneous measurement of an entire beam path (fluence: ±1 J/cm²)
- COTS reliability (TRL6)
- Standardise across INTRA (testbed) and Strathclyde (calibration lab) systems

LITRON TRLi 850
- 850 mJ / pulse @ 10 Hz repetition rate
- 6 ns Nd:YAG – conventional LII source
- Resonator chosen for stable (+ top hat) beam profile vs distance
- ±0.6% RMS pulse repeatability

Scanning System Development. Implementation of autopropjection-based nvPM imaging in a test cell requires synchronuous operation of a high energy pulsed laser excitation source, a system for the dynamic scanning of the excitation beam and a camera system for LII signal acquisition. The laser, scanner and camera systems are positioned within the test cell but entirely outside of the flow. This technology can provide non-intrusive nvPM/soot imaging (<10 cm spatial resolution across a 1.6 m diameter flow at 1 Hz and or 10 Hz) if signal levels are adequate. However, the very low nvPM levels of modern engines may require additional signal averaging to achieve good measurement precision under typical operating conditions, resulting in a lower final frame rate.

REFERENCES