The Significance of Fuel Preparation for Low Emissions Aero-Engine Combustion Technnology

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Abstract

The expected annual growth rates of air traffic with about 3% for the next two decades are only sustainable if the environmental footprint of engines for aviation is minimised. Besides the progressing stringency of legislative requirements for noise and NOx emissions, customer requirements and market competition are increasingly focussing on the environmental friendliness of aero-engines. Fuel burn und thus CO2 emissions, as the predominant driver for aero-engine design optimisation over the last years has been accompanied by very stringent NOx and noise requirements. A successful new engine design needs a well-balanced consideration of these three parameters and their associated trade-offs. In contrast to previous practise recent approaches for new engine applications are characterised by more revolutionary changes of existing technologies and engine architectures.

The development of combustors for this next generation of aero-engines is predominantly driven by future NOx requirements. Until today only significant improvements of conventional but highly optimised rich burn combustors avoided excessive NOx formation due to aggravated engine cycle conditions with increased combustor inlet pressures, temperatures and significant lower air-to-fuel-ratios. Beside NOx, particulate matter (PM) is another gas turbine combustion emission, which is relevant for local air quality. Engine manufacturers are therefore faced with the need for a reliable combustor design meeting future certification requirements with sufficient margin. Rich burn combustion approach however has a limited potential to cope with future legislative and customer requirements for emission reduction while facing further demanding cycle conditions for lower fuel burn and CO2 emission levels, therefore a revolutionary step towards lean-burn combustion techniques is inevitable.

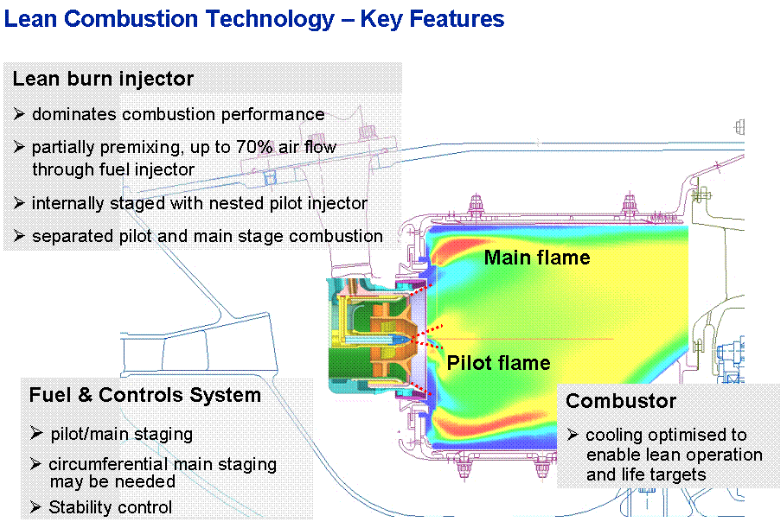

Fig. 1 Rolls-Royce Lean Burn Combustion Technology – Schematic

Lean-burn combustion is identified to offer the highest potential for NOx mitigation contributing to the overall ACARE goal of 80% reduction. Therefore, a significant amount of the air mass flow has to be utilised for fuel preparation and initiation of lean combustion. Lean-burn combustors require fuel staging to obtain full combustor operability and to enable typical aero-engine turn-down ratios while burning lean at high power conditions. The aero- and fluid-dynamic design of the fuel injector is of paramount importance for the combustor performance and a significant portion of the research and development work is focusing on this subject.

Fuel staging is achieved by an internally staged lean-burn fuel injector, which generates a homogeneous fuel-air mixture in the combustor to ensure combustion with reduced peak temperatures at medium to high power operating conditions. The fuel injector configuration features a concentric arrangement of a main fuel stage embedded into large swirling air streams carrying the biggest portion of the combustor air and a nested pilot fuel injector located in the centre.

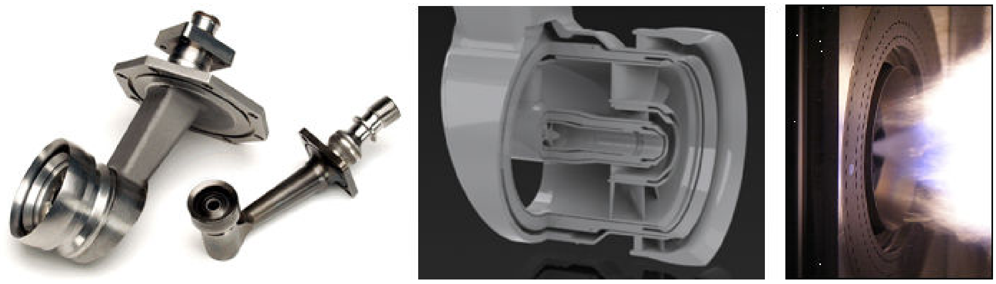

Fig. 2 Rolls-Royce Internally Staged Lean Direct Injection Fuel Spray Nozzle

Lean premixing has to be accomplished in between main fuel injection porting and main flame anchoring location downstream of the fuel injector. The main lean direct injection (LDI) can be arranged with a pre-filming air-blast concept. Within the pre-filmer fuel is distributed over a large surface area resulting in a thin fuel layer exposed to air with high velocity. As a result, the fuel sheet disintegrates into fine droplets being dispersed and evaporated downstream. The fuel rich pilot stage is required for low power operation and stabilisation of the main stage maintaining full combustor turn-down ratios for operability, especially for transient manoeuvres during adverse weather conditions such as hail and rain.

The understanding and steering of the interaction of pilot and main combustion zones is the key technology of lean burn low emissions combustion. Fuel preparation and fuel placement as well as local stoichiometries within the combustor have to be understood and optimised. Both combustion zones have to be sufficiently separated to enable low NOx combustion at reduced flame temperatures at high power conditions, whereas their interaction must be strong enough at low and mid power conditions to avoid emissions and inefficiencies caused by incomplete combustion.

The presentation will illustrate the relevant steps for the development of Rolls-Royce’s low emission combustion system focussing on the significance of fuel preparation and premixing. Initially starting from numerical predictions Rolls-Royce and its partners passed through a substantial experimental development and validation programme on single sector, multi sector, full annular combustion rigs and engine demonstrators along with the development and deployment of advanced optical diagnostic methods of DLR.