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Aerodynamic and Thermal Loads at High-Speed Flows

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ABSTRACT

LAPCAT and ATLLAS are two EC funded projects to explore long-term aspects related to high-speed aeronautics. Within both projects, a total of 19 partners are involved including 6 industries, 7 research institutions and 6 universities. The main topics of both studies are related to technical feasibility studies and technology development related to high-speed flows within a range from Mach 3 to 8. The following items are the major objectives of these studies:

- overall design for high-speed transports with proper development and validation of engine-airframe integration tools and methodology
- high-speed airbreathing cycle analysis: precooled turbo-ramjet up to dual mode ramjets
- off- and on-design behaviour of engine and airframe
- dedicated experiments to evaluate the design in various operation points
- development and characterisation of lightweight, temperature resistant materials
- cooling techniques and their interaction with the aero-thermal loads for both the airframe and propulsion components.

Applications :

Major impediments to high-speed transport development are environmental impact (take-off/landing noise, sonic boom and ozone depletion), light-weight high-temperature materials, aerodynamic and propulsion efficiency. These points are all critically dependent on the vehicle configuration. Indeed, propulsion and aerodynamic design must be efficiently integrated combined with lightweight high temperature resistant materials necessary in order to realize a globally performant vehicle.
The overall design for high-speed transports is revisited to increase the lift/drag ratio and volumetric efficiency through the ‘compression lift’ and ‘waverider’ principles, taking into account sonic boom reduction.

Designs with high aerodynamic efficiency tend to demand higher performance materials for example by involving thin flat shapes that are inherently inefficient structures resulting in high material stresses and so on. Further, at these high speeds, classical turbo-jet engines need to be replaced by advanced air-breathing engines which are intrinsically combined cycles. Therefore, there is a strong need to identify critical technologies for both the external airframe and the propulsion units such as lightweight airframe components, lightweight engine components, novel cooling techniques for airframe and engine, modeling and validation of numerical simulation tools for combustion physics, dedicated combustion and aerodynamic experiments, aerodynamic and material interaction modeling and verification; computational fluid dynamic tools for advanced turbulence & transition models among others.

Results:

The system requirements necessary to define realistically the research constraints and directions as well as to assess the results are derived from five specific vehicle concepts, which are also integral part of the studies, i.e.

- a 200-seat SST concept designed to meet an operational requirement of Mach 3 flight over a 5500nm range;
- a Mach 4.5 design hydrocarbon fueled vehicle based around a variable cycle including turbofan technology;
- a Mach 5 pre-cooled turbo-ramjet driven passenger vehicle with antipodal range;
- a turbo-ram-jet Mach 6 aircraft and finally
- a cruise flight Mach number 8.0 vehicle using a hydrogen-fuelled dual-mode scramjet with antipodal range.

The hardest part in the vehicle design is the definition of the propulsion unit and its integration into the vehicle without compromising its aerodynamics performance. Two major directions at conceptual and technological level are considered: ram-compression and active compression. Key objectives are here the definition and evaluation of different propulsion cycles and concepts for high-speed flight in terms of turbine-based and rocket-based combined cycles.
Dedicated experiments on supercritical combustion as well as supersonic combustion are performed to explore their behaviour and constraints. Simultaneously, detailed modeling of these extreme combustion experiments are validated along with a definition of their limitations. Further on hardware development explored the life-cycle limits of pre-cooler components whereas contra-rotating turbine experiments proved the concept to reduce weight and increase compactness.

In parallel, materials, cooling techniques and their interaction with the aero-thermal loads for both the airframe and propulsion components are addressed focusing on sharp leading edges, intakes and skin materials coping with different aero-thermal loads and on combustion chamber liners. After material characterization and shape definition at specific aero-thermal loadings, dedicated on-ground experiments will be conducted. Ceramic Matrix Composites (CMC), Ultra High Temperature Composites (UHTC) and heat resistant metals will be tested to evaluate their thermal and oxidizer resistance. In parallel novel cooling techniques based on transpiration, films, regeneration and electro-aerodynamics principles will be investigated. Further, combined aero-thermal experiments will test various materials specimens with a realistic shape at extreme aero-thermal conditions for elevated flight Mach numbers. Dedicated combustion experiments on CMC combustion chambers will allow the reduction of combustion liner cooling resulting into NOx-reduction and overall thermal efficiency increase.

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