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Hybrid RANS/LES simulation of a supersonic coaxial He/Air jet experiment with variable turbulent Prandtl and Schmidt numbers

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Due to strong complex interactions between plume and atmosphere, space launchers structures are subject to unsteady loads and heat transfer during ascent phase. For example, at high altitude, the large expansion of plumes (due to low external pressure level) can induce a massive flow separation in the boundary layer of the fuselage. The resulting recirculation bubble can mix and reacts with the supersonic hot plume, containing unburnt fuel, and bring very hot gas upwind of the base. These Plume Induced Flow Separations (PIFS) were observed on the Saturn V launcher and are very dependent on the base design. During the development of a new launcher, the prediction of the behaviour of this kind of flow is primordial as it can threaten the integrity of the structure and equipment. Moreover, its highly unsteady character cannot be predicted correctly by RANS simulations. Considering the wide range of spatial and temporal scales involved, unsteady turbulent flows on large geometries cannot be fully resolved with current computational resources. As a result the use of LES or hybrid RANS/LES models is necessary.

In this kind of simulations, cells dimensions are often many orders of magnitude larger than smallest scales. The effects of unresolved scales on resolved ones are modelled through several assumptions. For example, transports by unresolved scales are considered analogous to diffusion processes. In a large part of LES simulations, turbulent diffusion coefficients for energy and species mass fraction are linked to turbulent momentum diffusion coefficient (turbulent eddy viscosity) by constant non-dimensional ratios (turbulent Prandtl and Schmidt numbers). This simple model is generally sufficient as most of the transport is carried by large structures. However, in reactive simulations, unresolved transports of energy and species mass fraction play a key role in the reaction. Constant Prandtl/Schmidt number hypothesis may not be sufficient. Some improved models were recently developed in a RANS context to address this issue and shows some promising results [1]. They use additional equation of transport and dissipation rate of unresolved enthalpy or energy variance and sum of species mass fraction variance. Combined with a k-ε turbulence model, a computation of local turbulent Prandtl/Schmidt number is possible.

In this paper, we propose an extension of such model to hybrid RANS/LES simulations. The unstructured, high order finite-volume CFD solver FLUSEPA, developed by Airbus Defence & Space, is used for unsteady simulations of supersonic coaxial Helium/air jet mixing based on Cutler *et al.* experiment [2]. A recently implemented DDES k-ε turbulence model is utilized. The influence of constant Prandtl/Schmidt number hypothesis is first studied. We compare these results with experimental velocity, Mach, total temperature, velocity fluctuation and species mass fraction data, as well as with the Spalart DDES model computation previously available in FLUSEPA [3]. Results are fair to good, depending on the constant Prandtl/Schmidt numbers chosen. Then, the new variable Prandtl/Schmidt number model is tested. Two meshes are used to study the impact of spatial resolution on the results.

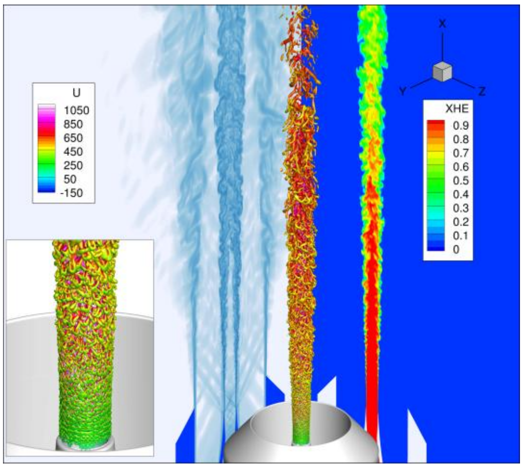

Fig. 1 Preliminary results with translated numerical Schlieren slice (left), isosurface of Q-criterion coloured by x-velocity (center), translated Helium molar fraction slice (right)

References

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