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PROPOSITION DE STAGE EN COURS D'ETUDES

Référence : **DAADA-2025-29**
(à rappeler dans toute correspondance)

Lieu : Meudon

Département/Dir./Serv. : DAAA / MSAT

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Responsables du stage :
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DESCRIPTION DU STAGE

Thématique(s) : Dynamique des écoulements pariétaux, Ecoulements hypersoniques

Type de stage : ☒ Fin d'études bac+5 ☒ Master 2 ☐ Bac+2 à bac+4 ☐ Autres

Intitulé : Numerical study of the interaction between a hypersonic expansion wave and a turbulent boundary layer

Sujet :

Among the aerospace and defence applications of aerodynamics, the strong demand for atmospheric re-entry and hypersonic vehicles is drawing a growing interest towards the hypersonic flow regime, typically characterised by Mach numbers of the order or greater than 5. From a scientific perspective, this is a challenging domain since the physics at play in the hypersonic regime includes complex phenomena which are absent at lower Mach numbers. This makes the study of turbulent flows especially difficult and the assumption that turbulence is similar to its incompressible counterpart is not valid in the hypersonic regime even if it is rescaled with the mean density variations [1], with specific features such as shocklets. Since most of the turbulence models are derived based on incompressible flow considerations, a very large uncertainty and dispersion of the predictions among the existing models has been observed [2]. Numerical simulations are made even more difficult by the need for dedicated numerical schemes with shock-capturing properties suited for the strong waves encountered at high Mach numbers.

One physical phenomenon present at high Mach numbers occurs when a turbulent boundary layer interacts with an expansion, for instance caused by the cone – slice junction in Figure 1. As illustrated by Figure 2, the interaction results in a significant reduction of the turbulent intensity which may even lead to relaminarisation. A good understanding of this interaction is crucial to assess the aerodynamic performance of a flight vehicle that is strongly influenced by the nature of the boundary layer (laminar, transitional or turbulent) in the downstream region where it may in turn interact with a shock wave (caused by the slice – ramp junction in the example of Figure 1) with a separation length strongly depending on the turbulent activity [3].

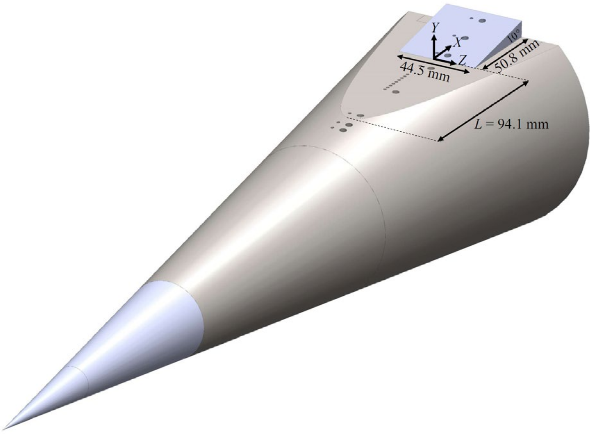

Figure 1: Example cone-slice-ramp geometry for the study of the interaction of wall turbulence with an expansion and a compression, Pandey et al. [3]

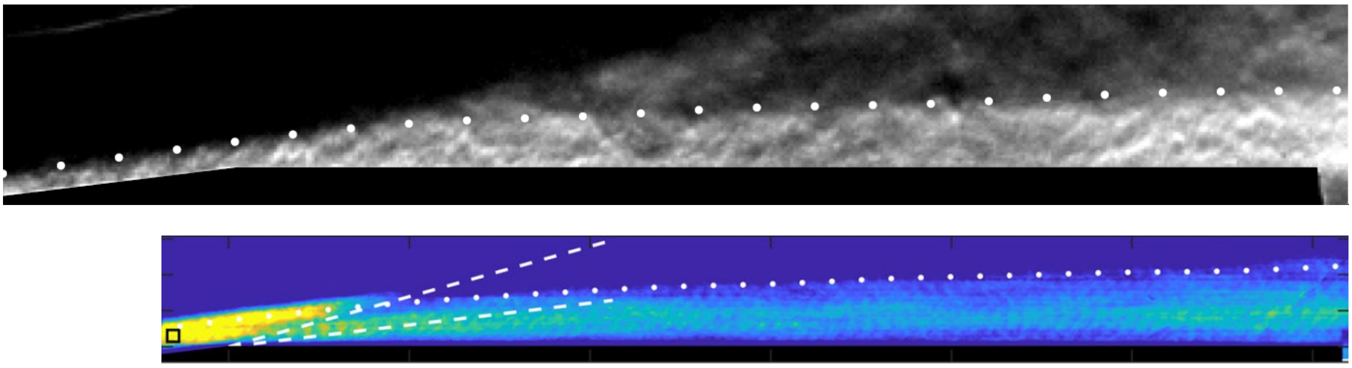

Figure 2: Instantaneous Schlieren and its PSD integrated over a 120–130 kHz band, Pandey et al. [3]

The proposed internship will focus on the CCF12 academic cone – cylinder – flare geometry (as shown in Figure 3) at a high Reynolds number and hypersonic Mach number, featuring the interaction between a turbulent boundary layer and the hypersonic expansion wave generated by the cone – cylinder junction. This geometry is used for a scientific research program in collaboration with CEA. The work will focus on the physical analysis of the interaction but may also be open to other physical phenomena such as the downstream shock wave – boundary layer interaction, the interaction with the entropy layer generated by a blunt nose and also the effects of a cool wall. A first step will consist of post-processing the data available from ONERA wind-tunnel experiments in the relevant flow conditions. Beside the physical analysis, the main objective will be to assess state of the art RANS models (including Reynolds Stress Transport Models) on this flow problem, examine the turbulence modelling assumptions made for each model and determine the resulting limitations. The output of the internship will consist of recommendations for the improvement of RANS models and for future scale-resolving simulations of the problem, either Direct Numerical Simulations or hybrid RANS/LES techniques such as Zonal Detached Eddy Simulation (ZDES) developed at ONERA [5,6], which are considered for a PhD thesis following the internship.

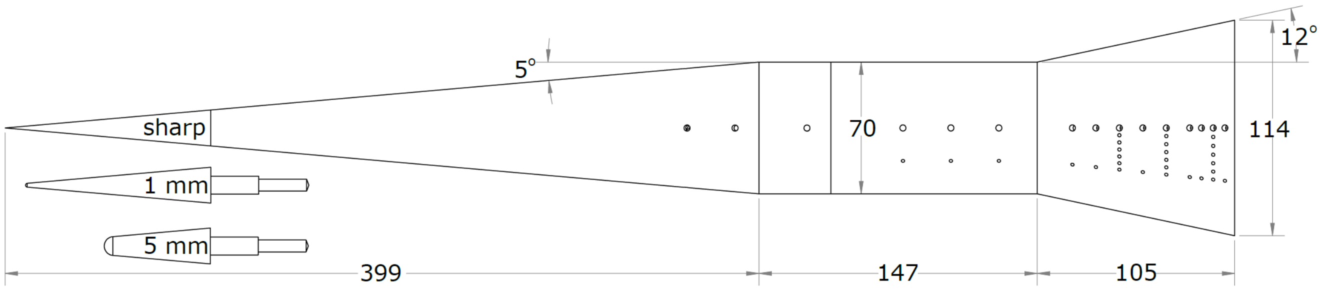

Figure 3: CCF12 geometry [4]

[1] A. Favre, La Turbulence en mécanique des fluides: bases théoriques et expérimentales, méthodes statistiques, Gauthier-Villars, 1976
[2] B. J. Morreale, J. Shine, R. D. Bowersox, N. Bitter, R. Wagnild, Hypersonic Multi-Fidelity Turbulence Modeling on a Mach 5 Blunt Ogive with Cool Walls, AIAA SCITECH 2023 Forum
[3] A. Pandey, K. M. Casper, S. J. Beresh, Relaminarization effects in hypersonic flow on a three-dimensional expansion–compression geometry, Journal of Fluid Mechanics, 2024
[4] E. K. Benitez, M. P. Borg, S. Esquieu, C. Caillaud, M. Lugrin, Z. A. McDaniel, J. S. Jewell, A. Scholten, P. Paredes, F. Li, M. M. Choudhari, Separation and Transition on a Cone-Cylinder-Flare: Experimental Campaigns, AIAA SCITECH 2024 Forum
[5] Deck, S., Recent improvements in the Zonal Detached Eddy Simulation (ZDES) formulation, Theoretical and Computational Fluid Dynamics, 2012, 26, 523-550
[6] Deck, S. & Renard, N., Towards an enhanced protection of attached boundary layers in hybrid RANS/LES methods, Journal of Computational Physics, 2020, 400, 108970

Est-il possible d'envisager un travail en binôme ? Non

Méthodes à mettre en œuvre :

☒ Recherche théorique	☒ Travail de synthèse
☒ Recherche appliquée	☒ Travail de documentation
☐ Recherche expérimentale	☒ Participation à une réalisation

Possibilité de prolongation en thèse : Oui		
Durée du stage :	Minimum : 4 mois	Maximum : 5 mois (6 sur dérogation)
Période souhaitée : démarrage possible à partir de février 2025		

PROFIL DU STAGIAIRE

Connaissances et niveau requis : Mécanique des Fluides et CFD. Programmation : Fortran, Python et Matlab appréciés, éventuellement autres langages de programmation (Shell, C++…). Aérodynamique compressible appréciée.	Ecoles ou établissements souhaités : Ecole d'ingénieurs ou Master 2 ou Ecole d'ingénieurs + Master 2 (souhaité)