Development of advanced hypersonic models for transition to turbulence
Uncertainty Quantification of numerical transition prediction

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Simulations of aerospace applications are challenging problems involving many complex physical phenomena; for instance, predicting the response of thermal protection materials to extreme reentry conditions involve flow transition from laminar to turbulent and aero-thermochemistry. Reliable predictions of such complex systems require sophisticated mathematical models to represent the physics and phenomena such as transition. A systematic and comprehensive validation, including the quantification of uncertainties inherent in such models, is required. Conventionally, engineers resort to safety factors to account for uncertainty parameters and to determine the quantities of interest, such as the heat shield thickness. These factors allow to avoid space mission failure and ensure safety of the astronauts and payload, but this is at the expense of reduced mass of embarked payload. Uncertainty Quantification (UQ) is a systematic approach to establish 'error bars' on quantities of interest, such as the heat-flux, yielding to the design of the heat shield with more confidence. This approach aims at developing rigorous methods to characterize the impact of 'limited knowledge' on the quantities of interest. We propose to develop a UQ methodology to study transition from laminar to turbulent in hypersonic flows.

The project general goal is to propose a new approach in transition prediction. In order to achieve this goal, it will be necessary to also improve our understanding of transition mechanisms in hypersonic flows. A variety of tools will be used to model turbulence (DNS, RANS, e^N, PSE) and coupled with UQ in order to yield a reduced model suitable for engineering applications. All uncertainties and errors will be taken into account in order to define the design margins for space vehicles. The uncertainties will comprise the free stream conditions (Mach number, pressure, temperature, turbulence intensity), surface parameters (roughness element height), transition model parameters and wall chemistry models, in order to investigate a wide range of cases including natural and bypass transition.

The novelty of the approach consists in using UQ in numerical transition prediction. Simulations will be carried out with a case-dependent random parameter which, for instance, will mimic the uncertainty of the disturbance spectrum. The probabilistic distributions as well as the range of variations of the variables will be based on experimental data. Once these parameters will be selected, numerical simulations will be performed and a quantity of interest will be computed to evaluate the effects of the parameters. This quantity can be the stream wise location of increase in skin friction or in heat transfer, which may be regarded as representative of the transition location. Several independent simulations will be performed in order to use, for example, a Monte-Carlo sampling to build the response approximately, as an interpolant of a response surface (the collocation points), using a Lagrange polynomial. Several research codes developed at the VKI will be used in the proposed research. In Figure 1 the transition onset abscissa on a hypersonic flat plate is compared for the experimental and numerical data. The probabilistic prediction is obtained by computing the probability of having an amplification ratio (N-factor) with the Linear Stability Theory greater than 3.8 set for conventional wind tunnel (M=6, 20 inch hypersonic wind tunnel in NASA Langley Research Center).

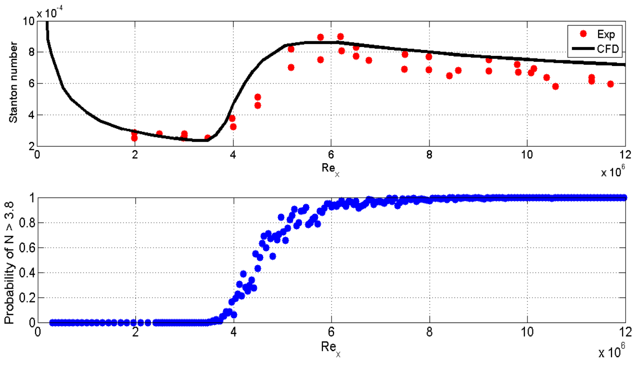

Figure 1 : Transition onset comparison : experimental Stanton number (top) – computed probability (bottom)