AR2 - Transonic Turbulent flow in a 3D channel with a swept bump

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General description

The objective of the present test case is to analyze the field resulting from a 3D shock wave / boundary layer interaction occurring in a 3D channel with a swept bump. In this case, the interactions taking place with the boundary layers of the four walls can lead to the formation of several separations which are at the origin of vortical structures cause of intense secondary flows.

Experiments executed at Onera by the Délery team provide a thorough description of the flow field and detailed experimental data [1]. Reference computations with RANS 2 equation turbulence models have also previously been performed [2].

The target quantities of interest are the static pressure distribution on the walls, the turbulent kinetic energy profiles and the mean stream-wise velocity profiles in longitudinal planes.

Governing equations

The governing system of equations is the 3D Reynolds-averaged Navier-Stokes system with a constant ratio of specific heats of 1.4 and a constant Prandtl number of 0.72. Dynamic viscosity is prescribed with the Sutherland law. The choice of turbulence model is left up to the participants; proposed suggestions are :

- Spalart Allmaras model
- Wilcox k-omega model
- k-omega SST model.

EARSM is an additional option.

Geometry

The geometrical definition of the channel is shown in Fig. 1. It consists of a converging-diverging section with three flat faces and the fourth face (lower wall) bearing a swept bump. The section is 120 mm wide and 100 mm high in the inlet plane. The upstream part of the bump is flat and inclined at 7° with respect to the horizontal. This first portion is followed by a contour of variable slope, beginning with a circular convex part with a radius of 180 mm.

The two circular arcs are defined so as to ensure slope continuity at the points where they interconnect as well as at the points where they come to contact with the rectilinear upstream and downstream parts. The 3D effect is achieved by sweeping the bump crest line from the upstream flow direction.

The maximum height of the bump is 20 mm and its length is equal to 355 mm. The generation is cylindrical downstream of the crest line (see [1] for a more complete definition of the channel geometry).

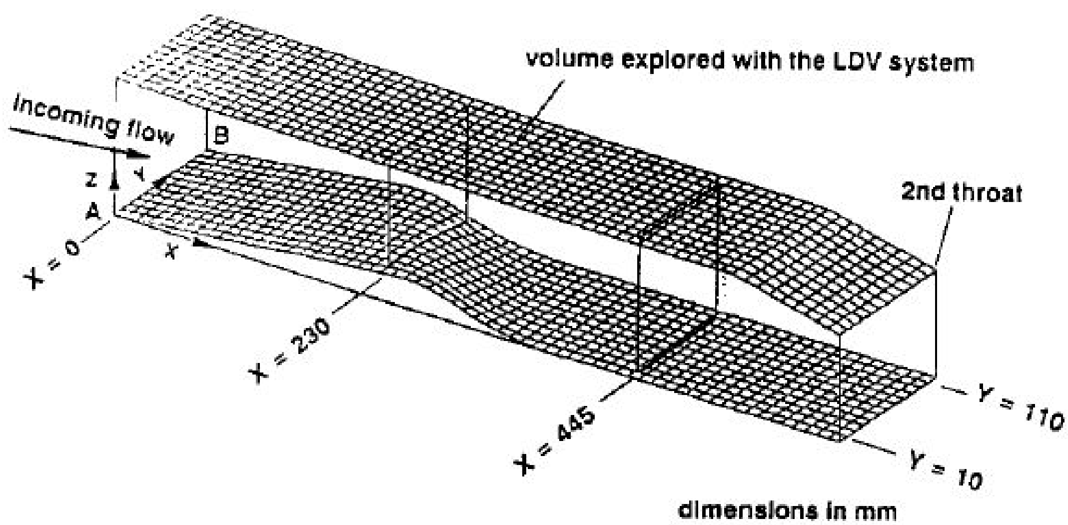

Figure 1: Geometrical definition of the three-dimensional channel (from [1])

Flow conditions and boundary conditions

The subsonic inflow conditions are prescribed with a stagnation pressure of 92,000 Pa, a stagnation temperature of 300K and the flow velocity direction aligned with the x-axis. The Reynolds number computed with the inlet stagnation state (density, sound speed, temperature) and using the throat height (80 mm) as the reference length is Re = 1.69×10^6 . Under these conditions the boundary layers are fully turbulent well upstream of the interactions.

In the subsonic outlet the static pressure is prescribed and adjusted to obtain the experimental location of the leading of the oblique shock. This adjustment can depend on the turbulence model used. The ratio between outlet static pressure and inlet stagnation pressure is about 0.65. Adiabatic no-slip conditions are applied on the four walls.

Meshes

The geometry of the computational domain, including the inlet and outlet limits, will be provided by Onera and available on the web site. Participants may use their own series of grids, but straight and high order hexahedra meshes will be provided by Onera on request.

Expected results

Defining the following quantities:

- Pressure distribution on the 4 walls : Pdist
- Mean stream-wise velocity profiles in several stations of longitudinal planes : Vprof
- Turbulent kinetic energy profiles in several stations of longitudinal planes : Kprof
- RMS profiles : RMSprof

the following is expected:

1. Describe the numerical scheme together with the technique(s) used for DoF's analysis
2. Perform a convergence study of Pdist, Vprof with at least one of the following techniques:
    - uniform h refinement or local h refinement with error estimator
    - uniform p refinement or local p refinement with error estimator
    - uniform hp refinement or local hp refinement with error estimator
3. Optionally, if the turbulence model allows, perform a convergence study of Kprof and RMSprof with at least one of the techniques mentioned above.
4. Submit the set of data to the workshop contact in the format defined on the website

Experimental data

Experimental data will be available in order to verify the consistency of the simulations with physics but not as reference for converged solutions in terms of DoF's (modelling of turbulence models will necessarily introduce a difference).

These data are :

- Pressure distribution on the 4 walls : Pdist
- Turbulent kinetic energy profiles in several stations of longitudinal planes : Kprof
- Mean stream-wise velocity profiles in several stations of longitudinal planes : Vprof

- RMS of the velocity fluctuations : Reynolds stress components.

References

[1] Délery J., and Marvin J.G., “Shock wave/ boundary layer interaction”, AGARDograph No 280, June 1986.

[2] Cahen J., Couaillier V., Délery J., and Pot T.., “Validation of code using turbulence model applied to three-dimensional transonic channel”, AIAA Journal, Vol. 33, No 4, P. 671-679 1995.