Numerical study of transverse helium injection into plane channel with backward facing step

Natalya N. Fedorova[1,2], Irina A. Fedorchenko[1,2], Svetlana A. Valger[2]
Dennis Daub[3], and Uwe Gaisbauer[3]

[1]*Khristianovich Institute of Theoretical and Applied Mechanics SB RAS, Novosibirsk, Russia*
[2] *Novosibirsk State University of Architecture and Civil Engineering (Sibstrin), Novosibirsk, Russia*
[3]*Institute of Aerodynamics and Gasdynamics, University of Stuttgart, Germany*

Jets introduced transversally into a supersonic flow are commonly used in various engineering applications including fuel supply in a combustion chamber. Study of the problem is extremely challenging for CFD since the flow structure is very complex due to multiple shock waves, large recirculation zones and high flow non-homogeneity.

In the paper, results of the numerical study of helium injection into supersonic flow in plane channel with backward facing step (BFS) are presented. The simulations are performed under the conditions of high-enthalpy flow, which are similar to those of high speed flight. The objectives of the investigation were to study the flow structure for 2D and 3D problems and to find conditions for better air and He mixing.

Numerical investigation was performed by means of RANS-based approach closed by *k-ω/*SST model. The problem was solved with ANSYS Fluent instrumentation. Validation of the model and numerical algorithm is provided in terms of experimental data[1], presenting helium jet injected transversally into supersonic air flow (P_∞=6.8 kPa, M_∞ = 2.61) through 0.27 mm width slot in a flat plate at M_j=1 and static pressure P_j=151 and 287 kP. Grid convergence study as well as comparison to experimental data were performed. Good agreement between the experimental and numerical data has been obtained (Fig. 1).

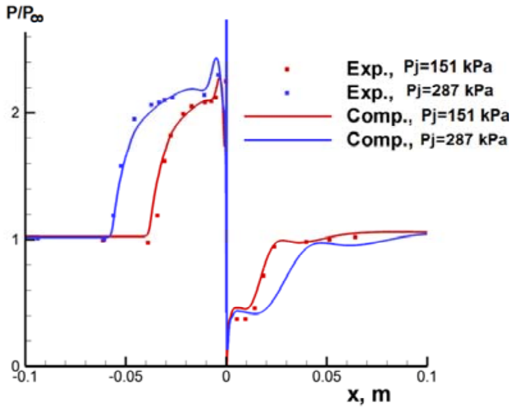

Fig. 1: Experimental and computed static pressure distributions along the plate

Next, the numerical investigation for the helium jet supplied into the primary air flow in the plane channel with BFS was carried out. The problem was solved in 2D and 3D approaches at M_∞=2.8, P_∞=0.11 Mpa and total temperature T_0=2000K. "Cold wall" temperature conditions were applied at the walls. Jet parameters were as follows: P_j=1.72, M_j=1 and total temperature T_0=293 K.

Jet was injected through the slot of 2 mm width (2D) or from the hole of 2 mm diameter (3D) with its center located 25 mm prior the BFS (Fig. 2). For 3D problem, the section of 35 mm width containing only one injection hole was computed.

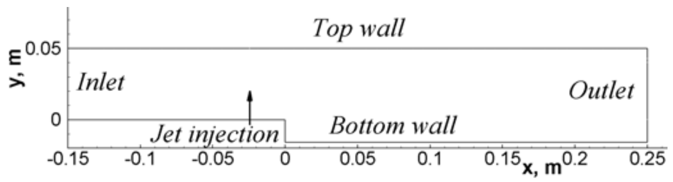

Fig. 2: Channel scheme and 2D calculation domain

For 2D problem, several cases were simulated with the injection angle varying in the range of $\alpha=30\div90^o$. The influence of the injection angle on flow structure is shown in Fig. 3. The flowfield in the channel includes the separation zones S1 and S2, jet shock (JS), reflected shock (RS) and reattachment shock waves (RW, RW1, RW2). It was evidently demonstrated that besides a substantial increase of jet penetration distance, the growth of the jet axis slope results in the change of the flow

[1] E.E. Zukoski and F.W. Spaid: Secondary injection of gases into a supersonic flow. *AIAA J.*, 2(1964), 1689-1696

parameters in the channel and the mixing enhancement. It is necessary to pay attention to the large separation area appearance on the upper surface that can lead to the blockage of the channel. Due to the specific vortex structure, high He mass concentration was observed in the recirculation zone after the BFS.

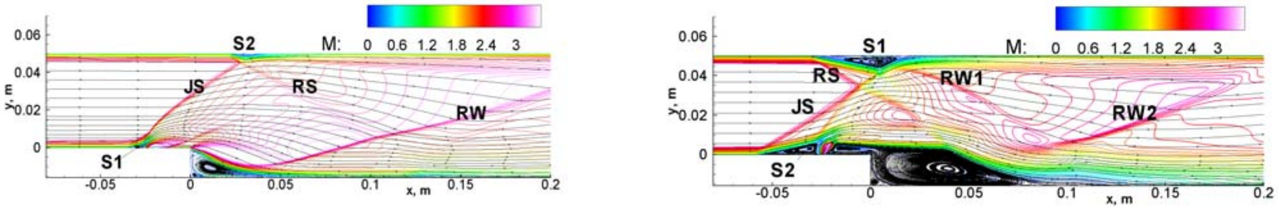

Fig. 3: Mach contours and streamlines at different helium injection angles: left: α=30◦ and right α =60◦

In order to improve the mixing of helium and air, oscilating sine-like static pressure conditions with frequences of about 3.3 and 6.6 kHz were applied at the jet injection position. Jet static pressure amplitude P_j was varying by 25 % of the mean value. Steady-state solution was used as initial condition. The computations showed that mixing characteristics of the flow were improved comparing to the steady case.

As the next step, 3D computations with normal injection were carried out under the flow conditions similar to the 2D case. Mach number fields in *z* cross-sections shown in Fig. 4 exhibit significant flow non-homogeneity. Analysis of the *x* shear stresses at the bottom wall (Fig. 5) has shown that negative values corresponding to the boundary layer separation are observed in two small regions before and after the jet and also in the base region after the BFS. The shape of the reattachment line in the base region is not straight, and the size of the separation at the central line is smaller. In contrast to the 2D case, no helium appears in the recirculation zone after the BFS since the jet goes above the recirculation domain.

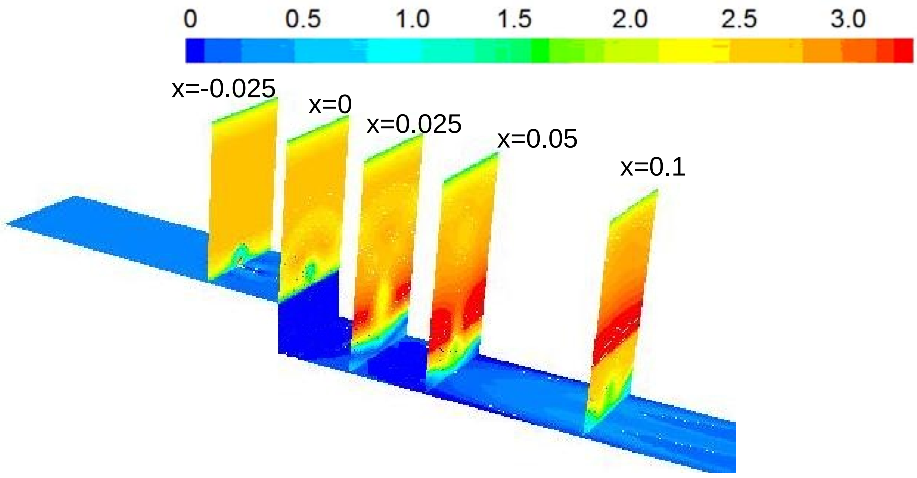

Fig. 4: Computed Mach number fields at several *z*-sections

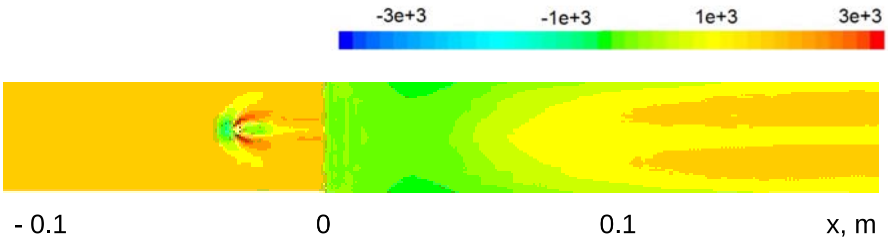

Fig. 5: Shear stresses at the bottom wall of the model

Further work will include the implementation of pulsating jet pressure conditions to 3D problem.

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