# NUMERICAL FLOW VISUALISATION OF SIDE JET/CROSS FLOW INTERACTION

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**KEYWORDS**:
**Main subjects**: side jet/cross flow interaction visualization
**Fluid:** high-speed flow, atmospheric high-altitude conditions
**Visualization method(s):** numerical simulation techniques
**Other keywords:** side jet, bow wave, recirculation zone

**ABSTRACT**: The “lateral side jet technology” is commonly used for flight control of satellites and re-entry vehicles. Nowadays, it is applied to maneuver high-speed missiles flying in earth atmosphere. The flow field in the vicinity of such a lateral jet blown out into a supersonic cross-flow, see Fig. 1, is extremely complex and up to now it has been very difficult to accurately predict the aerodynamic interaction phenomena, especially the total forces resulting from jet thrust. Experimental and numerical investigations have been performed in the past by many researchers, e.g. [1], who mainly have been interested in integrating the surface pressure to quantify the efficacy of the reaction control jet which is characterized using the force amplification factor K. Moreover, the present study is focussed on the analysis of the aerodynamic interaction processes running off in the side jet/cross flow interference region, as shown circled in Fig. 1 by streamline visualization on a generic missile body.

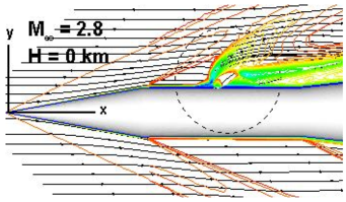

Fig. 1 Side jet/cross flow interaction

The region of observation is numerically simulated using the TAU-Code obtainable from the German Aerospace Center for solving the conservation equations of mass, of momentum by Reynolds-averaged Navier-Stokes equations and of energy. The Mach numbers investigated are M = 2.8 / 6 / 11.5 / 17.5 at atmospheric altitudes of H = 0 / 39 / 49 / 60 km. An example for the numerical calculations at M = 2.8 and 0° angle of attack is shown in Fig. 2 by means of the surface pressure coefficient $\Delta c_p = c_{p,jet\ on} - c_{p,jet\ off}$, visualized as pseudo colour image. By integration of $\Delta c_p$ the factor K is obtainable. The jets pressure ratio is given by the pressure $p_{0j}$, the jets stagnation pressure and $p_\infty$ in the free stream. As well Mach number distributions are visualized in Fig. 3 up to M = 17.5 including real gas effects at high temperatures. They obviously show at 0° attack angle that the jet interference strongly depends on the cross flow Mach number. Detailed discussions will highlight the aerodynamic mechanisms present in the interaction zone. The simulations predict and visualize complex details of the side jet/cross flow interaction. They show how the side jet influences the cross flow like an obstacle producing a bow shock in front, an upstream facing over pressured recirculation and in the wake downstream an under pressured zone with horseshoe vortex separation.

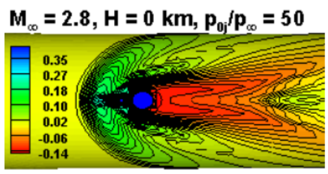

Fig. 2 $\Delta c_p$ distribution

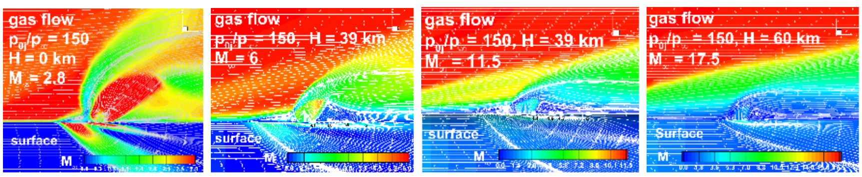

Fig. 3 Visualization of the aerodynamic interaction of a lateral jet with a supersonic cross flow

**References**

1. P. Gnemmi, R. Adeli, J. Longo. *Computational Comparisons of the Interaction of a Lateral Jet on a Supersonic Generic Missile*, AIAA Atmospheric Flight Mechanics Conference and Exhibit, 2008-18-08-2008-21-08, Honolulu, Hawaii, AIAA 2008-6883