Analysis of jet in cross flow interaction with different investigation techniques

T. Gawehn, P. Gruhn, A. Gülhan *
Institute of Aerodynamics and Flow Technology, Supersonic and Hypersonic Technology Department, German Aerospace Center (DLR), 51147 Cologne, Germany
W. H. Beck, U. Henne, C. Klein, W. E. Sachs
Institute of Aerodynamics and Flow Technology, Department Experimental Methods, German Aerospace Center (DLR), 37073 Göttingen, Germany

The task of an antiballistic missile is a direct hit of the target at very high altitude. At that height, the effectiveness of aerodynamic control surfaces suffers from the low density level. To guarantee maneuverability of the missile in the final flight phase gasdynamic control systems are applied, e.g. using multiple lateral jets.

As known from literature and previous investigations (e.g. Stahl et al. 2010) the lateral expansion of a jet into a supersonic free stream generates a complex structure of shock waves and causes local and downstream interactions. In most of the investigations the jet exits the lateral nozzle with sonic speed and is further accelerated until a Mach disk forms. The plume of the overexpanded jet is enclosed by a barrel shock whereby inclination and penetration depth depend on parameters like free stream velocity, jet pressure ratio and nozzle diameter.

The lateral jet acts as an obstacle to the free stream. Therefore a 3-dimensional bow shock is generated right upstream which leads to a local deceleration of the flow to subsonic speed. The pressure increase causes an upstream flow separation and here the formation of a λ-shock which in turn leads to a decreased pressure rise. Downstream of the jet counter-rotation vortex pairs are generated in the wake.

The actual paper presents results from surface pressure and interference force measurements obtained with a generic missile model. Fig. 1 gives an overview of the flow field around the model by means of schlieren technique. Additionally, the surface pressure distribution obtained from Pressure Sensitive Paint (PSP) measurements is shown. For this test case, the free stream Mach number was Ma=5.3 and the jet pressure ratio $p_{Jet}/p_\infty = 300$. Variation of the jet pressure ratio leads to a change in the shock structure and surface pressure distribution. This results in changed interference forces and moments.

With help of a 4-component strain gauge duct balance and a specially designed wind tunnel model it was possible to investigate the aerodynamic forces and moments decoupled from the side jet itself. After subtraction of the reference test case without side jet one obtains the pure interference forces and moments. Fig. 2 exemplifies the change of the induced normal force by variation of the jet pressure ratio up to $p_{Jet}/p_\infty = 1000$ for different angles of incidence. As indicated, at positive angles the interference force leads to a reduction of the side jet force whereas for negative angles an enhancement takes place.

A proper design of a gasdynamic control system has to take these interactions into account. Up to now it is difficult to predict those interactions numerically. Therefore a database for different Mach numbers and flight altitudes is needed. Additionally, a detailed analysis of the shock structure's dependence on parameters like Mach number, pressure ratio and angle of incidence helps to better understand the complex flow physics.

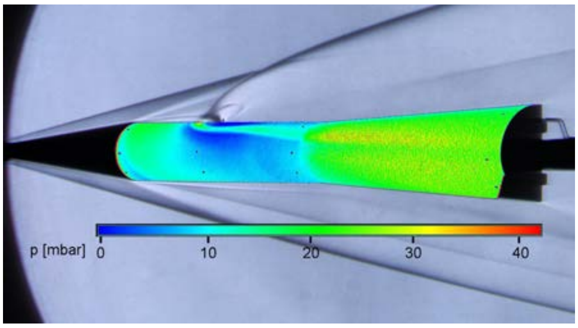

Figure 1. Flow structure and surface pressure distribution of jet in cross flow at pressure ratio $p_{Jet}/p_\infty = 300$, Ma = 5.3, generic image.

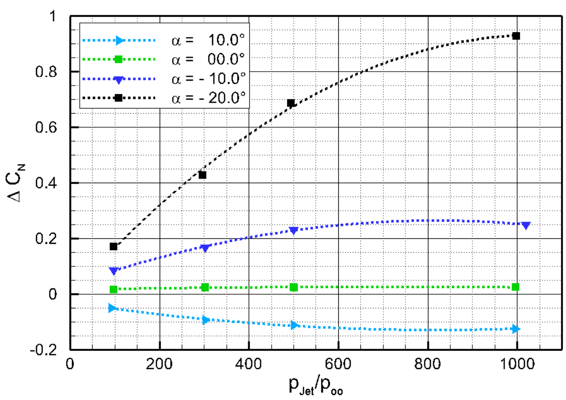

Figure 2. Dependence of induced normal force $\triangle C_N$ on α and p_{Jet}/p_∞ at Ma = 5.3.

References

Stahl B, Siebe F, Gülhan A (2010) Hot Gas Side Jet in a Supersonic Cross-Flow. Journal of Spacecraft and Rockets, Vol. 47, No. 6, ISSN 0022-4650, pp. 957-965.

*Present address: DLR, 51147 Cologne, Germany