Influence of Liquid Injection at the Nose of a Supersonic Aircraft on the Sonic Boom

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Introduction

The objective of this study is to investigate the influence of the liquid injection at the nose of a supersonic aircraft on the near field and ground pressure signature. An experimental study is performed in a supersonic tunnel at Mach 2 using a generic model aircraft with a double sweep delta wing. The pressure measurements provide the near field signature around the aircraft on a cylinder at a distance 1.2L where L is the length of the model. Then, a numerical code is used to complete experimental data. Finally, non-linear acoustic propagation theory [1] gives the corresponding ground signature. The combination of numerical and experimental approaches enables the study of the influence of injection on ground pressure signatures.

Experimental setup

The experiments are performed in a Mach 2 supersonic wind tunnel with a test section of $150X150\ mm^2$. An L_{mod}=66 mm long model designed by the National Aerospace Laboratory in Japan is placed in the wind tunnel as shown in figure (1) . The aircraft model has an axisymmetrical body with a slender nose whereas the wing plan form is made of two parts: the first part has a subsonic leading edge and the second one is supersonic.

A strioscopic bench allows the obsrevation of the global shock wave pattern and to check that the model is located so that there is no interference between the studied flow and the wall reflected effects. In order to measure with sufficient accuracy the rather small perturbations induced by the model at a distance 1.2L of the main body axis we used the following technique:

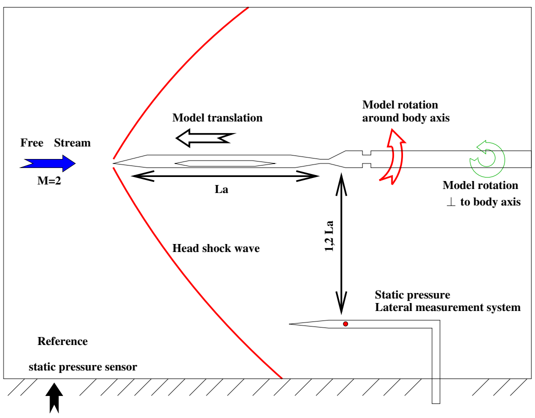

Figure 1: Experimental setup scheme

- Only pressure differences were recorded between a reference static pressure on the tunnel wall in the undisturbed field. A second static pressure sensor is located at 1.2L under the model in the flow and outside the wall boundary layer.

- In order to reduce as far as possible the influence of the unavoidable small defects in the free stream uniformity, the model was moved keeping the static probes fixed.

- The interaction of the static pressure probe with shock or expansion waves was minimized by using two lateral pressure taps on the probe.

Analytical extrapolation procedure

The experimental data are combined with an extrapolation procedure using the non-linear acoustic propagation theory. Here, the diffraction effects between the near field and the far field are neglected. Therefore, no matching is applied between near and far field. A parametrical study using test signals has shown that major effects on the ground signature can be obtained by moving the nose shock away from the head wing shock and by increasing the relaxation behind the nose shock.

The signals obtained at 1.2L away from the aircraft are propagated through a uniform atmosphere without winds. This simplified configuration is chosen to identify clearly the influence of liquid injection. The near field data are transposed to the flight of a 10 m long supersonic aircraft. The aircraft is supposed to have a straight steady flight at an altitude of 20 km - atmospheric conditions fixed to z=20 km values.

Results and discussions

Supersonic aircraft pressure signature pattern

A first set of measurements was achieved without injection in order to validate the measurement system. Pressure is measured every 2.10^{-3} s, the model moves at with a speed of 4.3 mm.s^{-1} and measurements are made for 22 azimuthal angles. These data will be used as reference data to be compared with the injection configuration data. Four important overpressures can be highlighted on the near field undertrack signature - Fig (2). The first one corresponds to the nose shock, which is followed by an important relaxation. Then, the first wing shock wave appears, followed by a stronger overpressure due to the second part of the wing. The last overpressure is due to merging of wing trailing edge shock with a shock wave due to the sting system. A similar pattern is observed for the other azimuthal angles with the influence of the first part of the wing becoming weaker when θ increases. The extrapolated signature procedure is highly

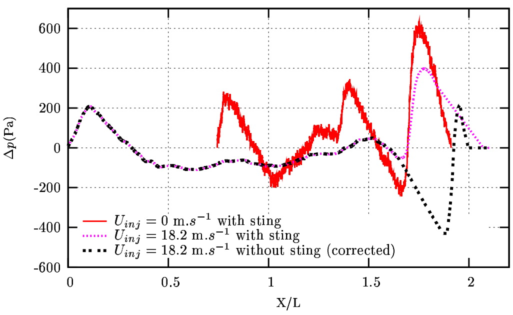

Figure 2: Experimental pressure under-track near field signature with and without injection -pressure signature with injection and numerical correction

dependent on the pattern of the whole near field signal. As explained, the flow downstream of the wing leading edge shock is perturbed by interaction with the sting. To take into account this phenomenon, the signal is corrected by using numerical simulation of the flow field - Fig (2). A numerical code based on Parabolized Navier Stokes equations is used to compute the flow around the model without injection and extract the pressure signature at 1,2L. Both experimental and numerical near field signatures are nearly superimposed until the relaxation behind the second wing shock occurs. For this reason, the whole numerical data is used for the extrapolation without injection.

Influence of injection on ground pressure signature

The injection of liquid is tested for five velocities. When the fluid is injected the head shock gets stronger and moves away from the wing shock. It corresponds to the edge of the injected jet which penetration length increases with the injection velocity U_{inj} - Table 1. A

$U_{inj} m.s^{-1}$	10.5	13.38	15.35	17.16	18.23
L_{inj}/L_a	0.21	0.30	0.45	0.51	0.65

Table 1: Injection penetration non-dimensionned length evolution with respect to injection velocity

relaxation appears between the head shock and the pressure rise corresponding to the nose - Fig (3). As it has been said previously, both effects have an influence on the ground signature. On the other hand side, the wing leading edge overpressures are weakened by the injection. To enable accurate extrapolation, numerical data obtained in the case without injection are used to simulate the last relaxation and shock. This procedure can be justified by the fact that the injection has little influence on the last part of the signal. These modifications of the near field pressure signature pattern have consequences on the far field ones. As it is shown figure (4), the various near field

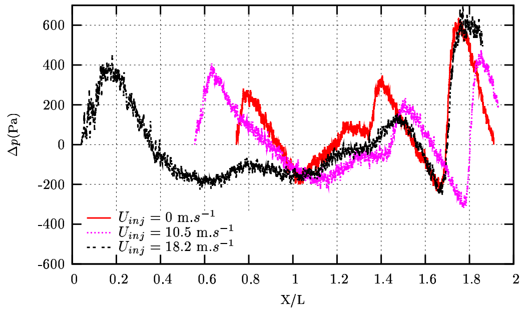

Figure 3: Experimental pressure under-track near field signatures with and without injection

shocks of the reference case have merged at ground level. This is not true when liquid is injected: the shock corresponding to the leading edge has not merged with the head shock. It gets even nearer to the trailing edge shock wave. The most interesting configuration is the smaller injection velocity $U_{inj} = 10.5$ m.s^{-1}. The head shock is weakened and the leading edge shock is also weaker than the maximum velocity configuration.

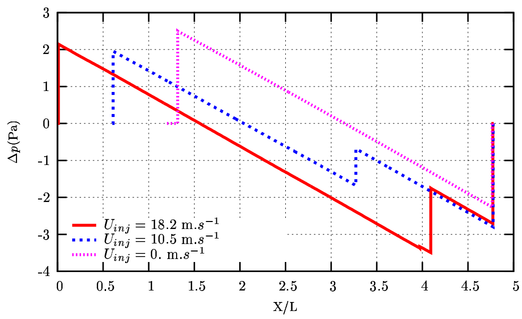

Figure 4: Extrapolated ground pressure signatures for experimental corrected under-track signatures

Conclusion

Injecting fluid at the nose of a supersonic aircraft could definitely be a mean to reduce sonic boom annoyance related to the front shock by acting on shock focusing. It should be kept in mind that the propagation medium has probably an influence almost as important as the injection. Therefore a propagation through a stratified standard atmosphere with various perturbation phenomena such as wind or turbulence should be considered. Eventhough the injection system may hardly be applied to real aircrafts, the study has led to better understanding of the shock focusing phenomena.

References

[1] Sonic Boom Propagation in a Stratified Atmosphere with Computer Program, Wallace C.Hayes, Rudolph C.Haefeli, and H.E.Kulsrud,NASA CR-1299, 1969

[2] Sonic Boom Simulation Facilities, Ira R. Schwarts, NASA, AGARD Conference Proceedings No.42