Spanwise properties of a hypersonic shock wave/boundary layer interaction on a heated surface

Divek Surujhlal[1,*], Alexander Wagner[1], Tobias Ecker[1] and Jan Martinez Schramm[1]
1: Spacecraft Department, Institute for Aerodynamics and Flow Technology, German Aerospace Center (DLR)
* Corresponding author: divek.surujhlal@dlr.de

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ABSTRACT

A shockwave/boundary-layer interaction (SBLI) occurring within the flow over hypersonic flight vehicle aerodynamic surfaces can be crucial for control authority or propulsion system performance. SBLIs occur on external or internal surfaces and cause intense adverse pressure gradients in the boundary layer imposed by the shock. If the shock is strong enough to trigger boundary layer separation, dramatic changes in the entire flow field can result with formation of intense vortices or complex shock patterns (H. Babinsky and J.K. Harvey, 2011).

Modern experimental and numerical works on hypersonic SBLIs have traditionally concentrated on cases with a nearly adiabatic wall, i.e. where the wall temperature T_w is close to the recovery temperature T_r of the incoming boundary layer, see for example the works of (Schülein, 2014), (Law, 1976), (Horstman, 1992), (Sandham, Schülein, Wagner, Willems, & Steelant, 2014). Under hypervelocity conditions of shock tunnels, cooled wall conditions can be obtained in which the wall temperature is much lower than that of the recovery temperature, representative of certain hypersonic flight conditions.

One method to obtain a variation in wall-to-freestream temperature ratio in shock tunnels is to implement conditions with different stagnation temperatures (Holden M. S., 1972), (Holden M. , 1978). This however, results in a variation in freestream conditions for each stagnation temperature such that tests are not fully comparable. Another method regarding variation in the wall-temperature ratio is to artificially heat the model to different wall temperatures resulting in the need for additional model infrastructure. The latter method was carried out for a shock generator and flat plate model (686 mm x 360 mm) implemented at the High Enthalpy Shock Tunnel Göttingen (HEG) at the German Aerospace Center (DLR) (DLR, 2020). An overview of the model is shown in Figure 1a, and an infrared image of the impingement surface, heated to approximately 705 K at the location of the highest temperature, is shown in Figure 1b. The change of the boundary layer development from the heated front section of the model to the unheated rear surface was negligible (Wagner, Schramm, Hannemann, Whitside, & Hickey, 2018) and the unheated surface served the purpose of affording a higher spatial density of transducers.

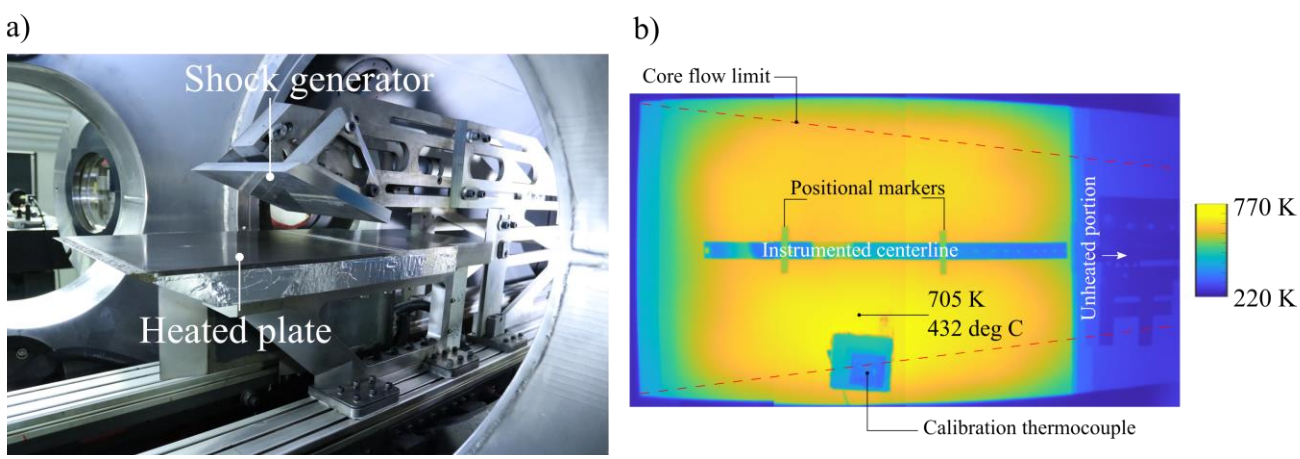

Figure 1: a) Overview of the test model installed in the HEG test section showing the impingement surface (the heated plate), and the shock generator. b) IR image of the top view of the plate impingement surface (no flow) having been electrically heated. The leading edge is located at the left-hand side of the image.

An identified area lacking in terms of experimental analysis concerns the spanwise distribution of surface pressure and surface heat flux within the SWBLI region. To obtain these measurements, pressure transducers were placed not only at the centerline of the impingement surface, but also along the outboard regions. Being part of a larger body of results, the current work will discuss the cases pertaining to a shock generator angle of $\phi = 18°$. The wall-to-freestream temperature ratios were varied stepwise and 3 ratios were used for the current work i.e., $T_w/T_\infty \approx [1.14, 2.40, 2.70]$.

Figures 2 a and b show an overview of the surface pressure at the centerline and along a streamwise line located off-centre at a spanwise coordinate of $y = 47\ mm$. These data are plotted for the three different wall-to-freestream temperature ratios. For these figures, the abscissa is based on distance from the theoretical impingement streamwise coordinate x_{imp} and normalized with the wall-normal height of the interaction region, h, which was measurable from the focused schlieren images for all cases focused at the centerline of the impingement plate.

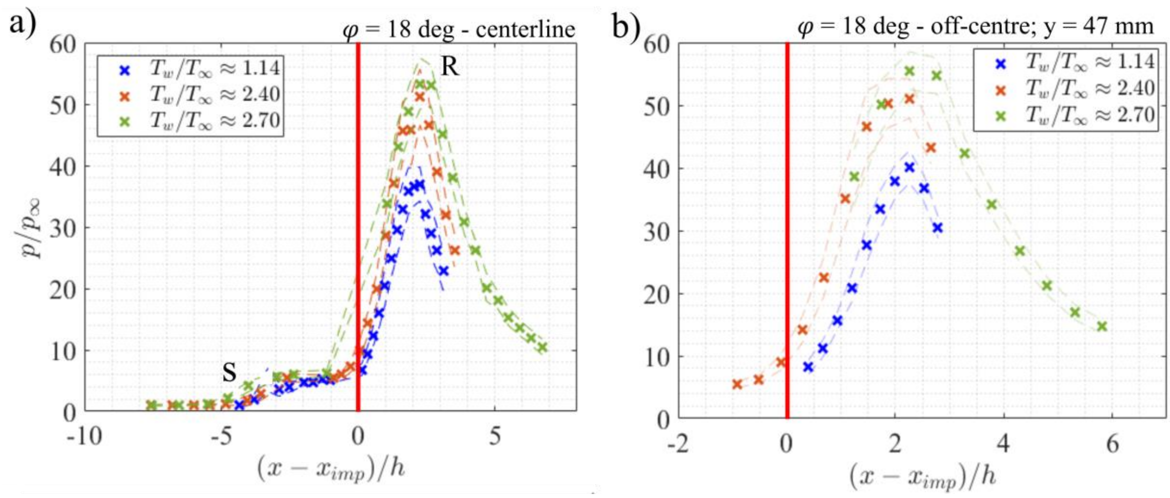

Figure 2: Mean centerline (a) and mean off-centre surface pressure (b) for cases with $\phi = 18°$. All data are anchored to the maximum surface pressures. Dashed lines near the symbols show single standard deviation limits.

Normalized distances from separation onset (indicated as "S" in Figure 2a) to maximum mean surface pressure (indicated as "R" in Figure 2a) vary slightly with wall-to-freestream temperature ratio variation. Larger wall temperatures induced separation onset further upstream. Furthermore, the relaxation region downstream of the maximum mean surface pressure was found to have the same slope independent of surface temperature. This was also observed for the pressure transducers along the spanwise station at $y = 47\ mm$. The increase of wall temperature was found to increase the maximum mean surface pressure, also for the spanwise region.

The current work seeks to explore surface pressure and surface heat flux distribution along the centreline and spanwise portions of the SBLI region. It is aimed to address a gap in the field, dealing with spanwise measurements carried out under hypersonic shock tunnel conditions for different wall-to-freestream temperature ratios.

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