HYFAR-ARA 2023 Transition Symposium

Preferred Topic: Topic 4: Experimental methods for laminar/turbulent transition analysis in the hypersonic regime
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Type: Oral

Fundamental breakdown of second modes in the High Enthalpy Shock Tunnel Göttingen

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Boundary layer transition in a hypersonic flow with a zero-pressure gradient takes on particular properties. Trapped acoustic modes [1], hereafter referred to as second modes, can coexist with first modes. Furthermore, the presence of a highly-cooled wall imparts a high growth rate to the second modes [2] and they dominate first mode growth within the boundary layer [3]. An important aspect in this field is the nature of breakdown of the second modes after they reach saturation within the boundary layer. This process results in the initiation of turbulence. The breakdown region is associated with overshoots in surface heat flux [4]. A physical understanding of the breakdown process is required under conditions of highly-cooled walls. This works aims to contribute to this.

Such conditions of highly-cooled walls are realizable in the High Enthalpy Shock Tunnel Göttingen (HEG) [5] and wall-to-stagnation temperature ratios on the order of ~0.1 are achievable.

The test model consisted of a 1.1 m long 7-degree half-angle cone. The nosetip was exchangeable and in this work, 2 cases of different nose radii (R_n) will be presented. The entropy swallowing length [6] was calculated due to the use of blunt nosetips on the cone. Reservoir and freestream parameters are given in table 1.

Table 1: Reservoir and freestream data for the 2 cases examined in this work.

Case	1	2
$R_n[mm]$	2.5	5.0
$P_0[MPa]$	12.22 ± 0.61	12.22 ± 0.61
$T_0[K]$	2738 ± 8	2712 ± 8
M_∞	7.4	7.4
$T_\infty[K]$	273	270
$u_\infty[m/s]$	2736	2364
$X_s[mm]$	321	813

Instrumentation on the cone consisted of 25 coaxial fast-response thermocouples located along the 0-degree meridian. Additionally, fast-response temperature-sensitive paint (TSP) was applied to examine surface heat flux in the transitional and breakdown regions. Piezoelectric pressure transducers (PCBs from Piezoelectronics) were used for pressure perturbation analysis in the frequency domain.

An overview of the surface heat flux for cases 1 and 2 as measured with the thermocouples is shown in figure 1.

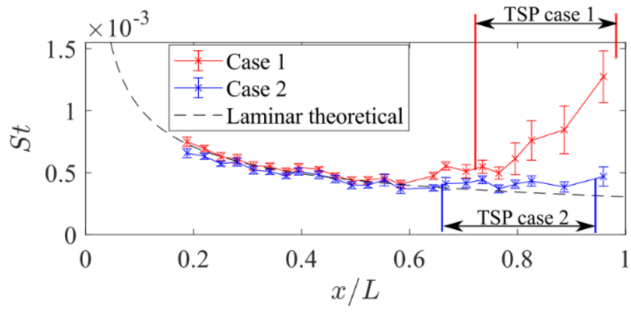

Figure 1: Streamwise Stanton number along the 0-degree meridian.

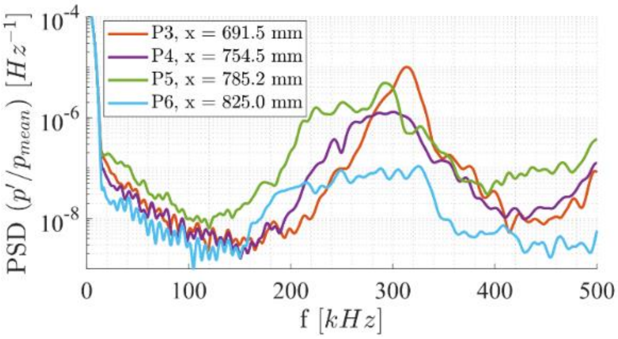

Figure 2: PSD curves from pressure signals obtained within the breakdown region.

For case 1, the boundary layer was observed to undergo transition indicated by the rise in heat flux above the local laminar value. Fast-response PCB transducers were located in this region. The power spectral densities (PSDs) of these time signals, calculated with the Welch method, are shown in figure 2.

The narrow peak in the PSD curve for the PCB located at x = 691.5 mm is indicative of the Mack mode frequency at these freestream conditions. At locations further downstream, the peaks in the PSD start to broaden, indicative of nonlinear breakdown of the second modes. In order to further investigate this, examination was made of the TSP data obtained in this region, as shown in figure 3.

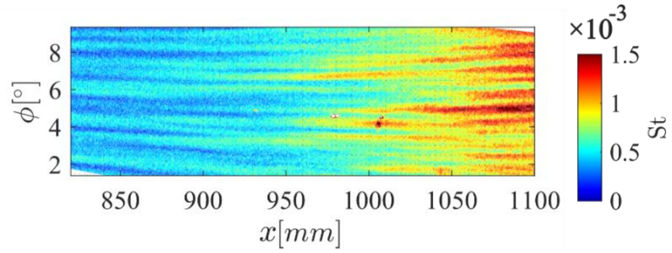

Figure 3: Mean TSP image showing Stanton number within the breakdown region. Meridians are denoted by φ.

The streamwise evolution of streak structures is clearly observable. The azimuthal spacing of these streaks is indicative of breakdown mechanisms as elaborated by Hader and Fasel [7]. These experiments form the basis of an ongoing coupled study with direct numerical simulation (DNS) efforts.

References

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