CONTROL OF INTERNAL SUPERSONIC FLOW SEPARATION

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Summary: Separation of turbulent boundary layer in internal supersonic flow along a convex cylindrical contour is controlled by V-letter shape obstacles and swirling jets injected through the wall. Considerable delay of the boundary layer separation and accompanied shock wave have been observed.

The present experiment was aimed to investigate the capability of the boundary layer excitation to delay separation in a supersonic internal flow (Laval nozzle). Because in this case the separation is accompanied by a shock wave, the shock should displace downstream when the upstream boundary layer is excited.

The 2D half-Laval nozzle with a cylindrical contour (Fig.1a) was used . Such a contour was chosen to have a separated flow for any pressure difference through the nozzle. Obstacles and swirling jets were used to excite the boundary layer at the nozzle surface of its divergent section. In the former case a row of oblique half-cylinders paired in form of V-letters (Fig. 1b) were stuck to the nozzle wall. It was noted in the preceding experiment with a V-type obstacle generator located on a flat plate that at the tip of V-obstacle (directed downstream) two stable streamwise vortices occur that rotate in directions opposite one to another. In the latter case the jets from orifices (Fig. 1c) in the nozzle wall were injected into the boundary layer. They were strongly swirled to induce the vortex break down phenomenon. In this effect the air of the jets spread around orifices and disturbed only the flow region close to the nozzle wall.

Figure 2 shows the normalized (by the supply pressure) distributions along the nozzle surface (versus angular coordinate φ - Fig. 1a) and Fig 3 the schlieren photographs of the nozzle flow for unexcited and excited (by V-generators) boundary layer. One can observe that in both the subsonic and the supersonic flow the V-generator induces distinct pressure hill. In the latter case it is accompanied by a shock wave followed by an expansion wave. The waves which are very close to one another are visible in photograph in Fig. 3d as a preceding light strip (at the left upper corner) originating beyond the field of observation. In the supersonic flow the V-generator, causes distinct delay of the flow separation and thereby the shifting downstream the accompanying shock wave. Figures 4 and 5 show the results obtained in case of boundary layer excited by swirling jets. One can note that the swirling jets generator, like the V-generator, disturbs boundary layer sufficiently strong to delay distinctly the supersonic flow separation. Delay of separation occurs due to the secondary flow which appears in the primary one composed of stationary vortices induced by swirling jets, superimposed on uniform (in span direction) flow. In schlieren photograph two distinct strips are visible. The preceding strip visualise disturbance caused by orifices (used to generate swirling jets) in the Laval nozzle wall and the following one the shock wave accompanying separation. The former is weak and does not show any trace in the pressure distributions. (The orifices were located on sides of the symmetry plane – see Fig.2c).
It seems that the swirling jets type generator, in contrast to obstacle one, does not enhance the drag of the wall. Moreover, the delay of separation can be controlled, in some range, by control of the strength of the injected jets.

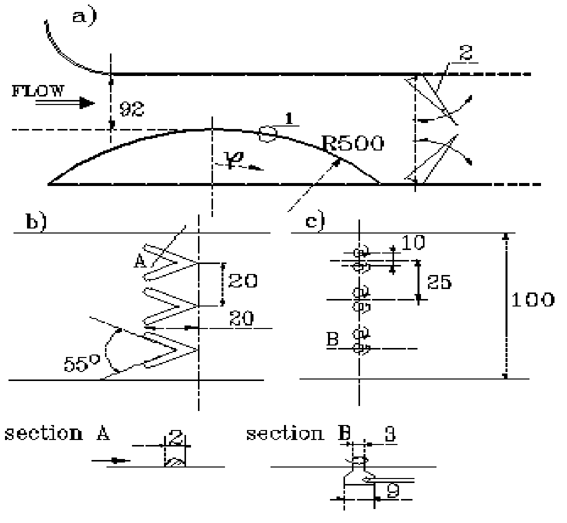

Fig. 1. Test section of wind tunnel (a), obstacle generator (b) and swirling jet generator (c), 1 – generator location, 2 – adjusting valve.

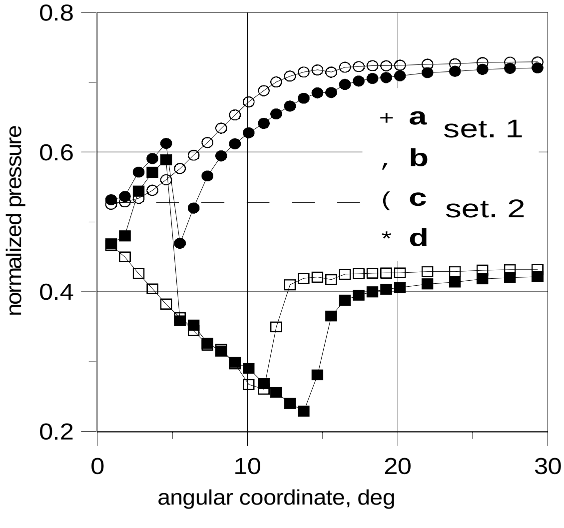

Fig.2. Pressure distributions along nozzle surface for two settings of adjusting valve, without (empty points) and with (filled points) V - generator

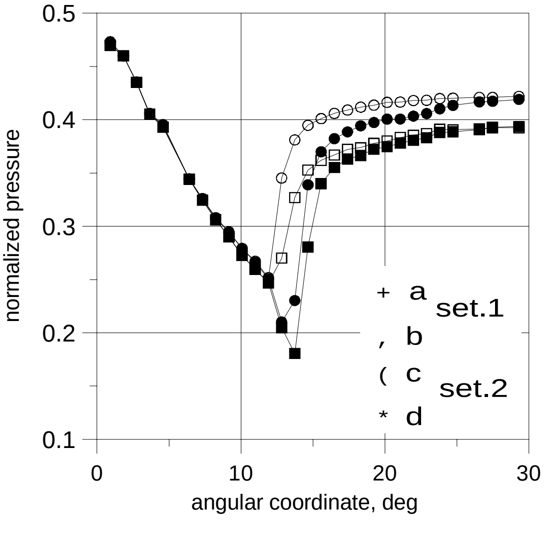

Fig.4. Pressure distributions along nozzle surface for two settings of adjusting valve, without (empty points) and with (filled poets) swirling jet generator

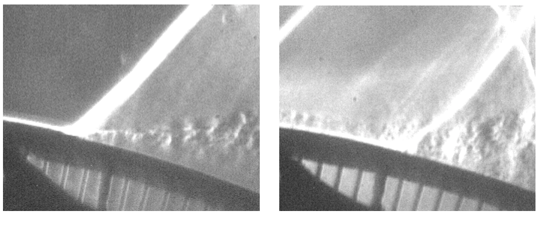

Fig.3. Schlieren photograph of the flow at the nozzle surface corresponding to pressure distributions in Fig. 2

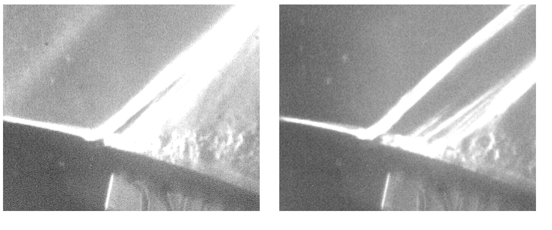

Fig.5. Schlieren photograph of the flow at the nozzle surface corresponding to pressure distributions in Fig. 4