Wave drag reduction by means of aerospikes on transonic wings

M. Rein, H. Rosemann, and E. Schülein

Institute of Aerodynamics and Flow Technology, German Aerospace Center
Bunsenstr. 10, 37073 Göttingen, Germany

1 Introduction

Wave drag and shock induced boundary layer separation are important issues of flows around transonic wings. At transonic speeds the supersonic flow regime that is formed locally above wings, is terminated by a shock wave. This happens especially under off-design flight conditions and results in a wave drag. In addition, the shock-boundary layer interaction can cause a separation of the boundary layer and can thus lead to further losses and, eventually, to buffeting. These phenomena limit the maximum economic cruise speed of airplanes. The negative effect of the transonic flow regime can be mitigated by controlling the shock terminating the supersonic region above the wing. In the past many different concepts based, for example, on passive ventilation (perforated plates, slots, grooves), active suction, contour bumps or adaptive walls have been persued [1–3]. Mostly, these control methods are based on a two-dimensional approach, i.e., control devices are applied unifomly along the whole span. More recently, also three-dimensional control devices have been shown to positively affect lift and drag [4–7]. All these approaches have in common that measures for controlling the shock are applied directly at the surface of the wing. However, a control of the shock wave is also possible by placing external devices above the surface of the wing into the supersonic flow regime. The latter concept that is related to the one of aerospikes on blunt bodies, is studied in the present paper. As in the case of flow control measures that are applied directly at the surface of a wing the basic idea of aerospikes is achieving the pressure rise across a system of oblique and normal shocks instead of across a single normal shock thus reducing wave losses. In the present investigation oblique shocks were produced by disturbing the supersonic flow above the wing. In a test series the effectiveness of a variety of different spike-shaped bodies placed above a transonic wing was tested in the DNW-TWG, Göttingen. In addition to pressure measurements a colour schlieren system was set up for providing information about the influence of spikes on the flow field. In the following, first basics of aerospikes on transonic wings are explained. Then, wind tunnel experiments are described and results of measurements are presented and discussed. This is followed by a conclusion.

2 Aerospikes on transonic wings

The drag reduction mechanism of spike-shaped bodies that are placed in the supersonic flow above a transonic wing is based on the generation of wake flows and oblique shock waves interfering with the virtually normal shock terminating the supersonic region (Fig. 1). In this manner instead of an abrupt pressure rise across a single shock the pressure increases more gradually thus limiting losses. Since the spike is located above
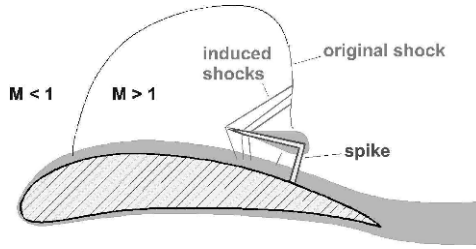
Fig. 1. Mode of action of a spike on a transonic wing

the surface of the wing the boundary layer on the wing is not directly disturbed. In the streamwise direction the exact position of the spike is likely to be of little influence on its efficiency because the properties of the wake are only little dependent on the streamwise location of the spike. The height H at which the spike is arranged above the surface should be chosen so that the shock is especially weakened in its lower part where the shock strength is greatest. Typical dimensions depend on the chord length c and the Mach angle μ. Similarly, in order to weaken the shock over the whole span width several spikes need to be placed next to each other in spanwise direction (Fig. 2).

Bodies of various geometries can be conceived acting as wake and shock inducing spikes. In the following, results are reported that were obtained with a cylindrical body
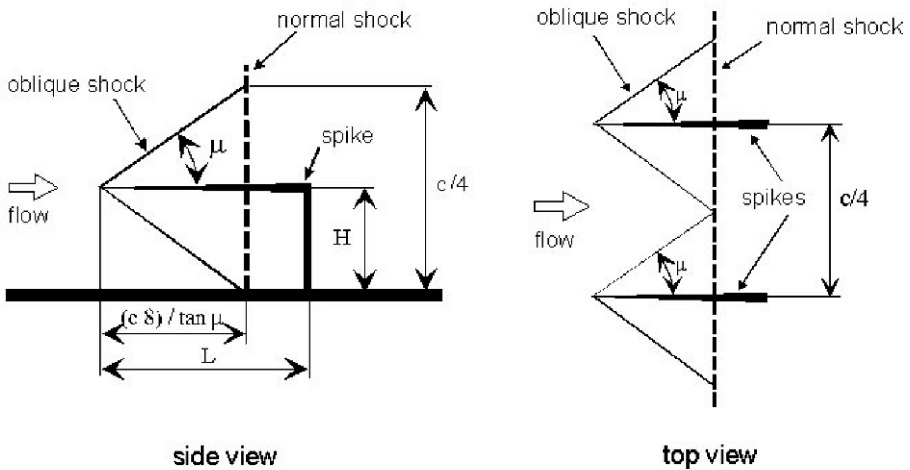

Fig. 2. Region of influence of a spike.

having a needle-like tip (cylindrical spike), a punctured pipe that was open at its leading end (punctured pipe) and a cone (conical spike). The cylindrical spike was chosen to resemble aerospikes as used on the nose of supersonic aircraft. Since the Reynolds number in the wind tunnel tests performed in the present study was much smaller than under real flight conditions a punctured pipe was then used in order to produce a wake like flow by jets that are ejected out of little holes arranged along the cylindrical surface of the pipe. Finally, a well defined displacement of the flow was achieved by means of the conical spike.

3 Wind tunnel tests

A 400mm-chord model of the transonic airfoil VC-Opt [8] was mounted in the 1m x 1m adaptive walls test section of the TWG. Onto the top of the VC-Opt model a single spike was placed the tip of the spike being located about in the middle of the chord (Fig. 3). Slender schlieren windows were fitted into the 2D-support right above the airfoil and a colour schlieren system was set up for observing the flow field. Lift and drag were determined by pressure measurements. On the wing the static pressure was obtained via pressure taps that were arranged in a slightly diagonal manner thus avoiding interferences between the taps. The drag was calculated from total pressure data obtained by wake-rake measurements one and a half chord lengths behind the trailing edge. The rake was laterally displaced with respect to the spike because the hold of the spike produces a wake that causes an effect opposing drag reduction by weakening the shock. Tests were performed at a Reynolds number of $Re \approx 5 \cdot 10^6$ and at two Mach numbers, $M = 0.775$ and $M = 0.795$, respectively.

Fig. 3. Transonic wing with conical spike in the DNW-TWG

In Fig. 4 schlieren pictures of the flow around the VC-Opt model without and with spikes are shown for a Mach number of $M = 0.795$ and an angle of attack of $\alpha = 3°$. Due to the slenderness of the schlieren windows the spikes are not always fully visible. A comparison of the pictures of the flow around the clean airfoil and the flow around airfoils with spikes shows only little differences. This is due to the span width $(1m)$ being much greater than the size of the spike (diameter $2 - 12mm$). However, a shock wave

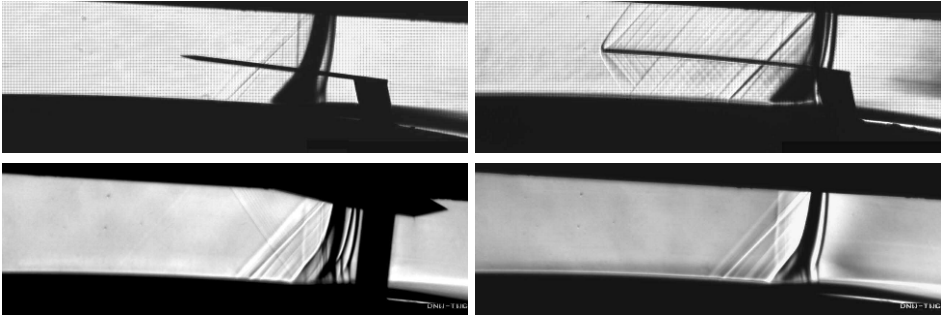**Fig. 4.** Schlieren pictures of spike, punctured pipe, conical spike and clean airfoil. Mach number: $M = 0.795$, angle of attack: $\alpha = 3°$.

and Mach lines originating from the tip and the surface of the spike, respectively, can clearly be seen for the case of the conical spike and the punctured pipe. Lift and drag polars were obtained also for configurations not shown in Fig. 4. Here, those for a clean airfoil and for an airfoil with a cylindrical spike, a punctured pipe and a conical spike are compared to each other (Fig. 5). In the case of the cylindrical spike the displacement of the wake rake was two and a half percent and in all other cases it was ten percent of the chord length. At certain angles of attack there is a gain in lift and the drag is clearly reduced. This effect is most pronounced for the conical spike, i.e., for that body which produces the greatest displacement of the flow.
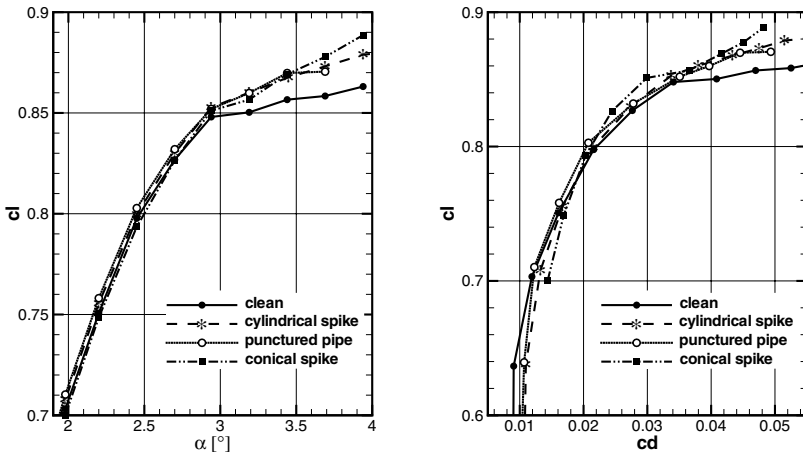

Fig. 5. Effect of different spikes on lift and drag

4 Conclusion

A preliminary study of the effect on the wave drag of aerospikes placed on top of transonic wings has been presented. Since the Reynolds number formed with the diameter of the model of a cylindrical spike is relatively small when compared to real flight conditions the efficiency of the cylindrical spike was less than expected. In order to produce larger disturbances in the supersonic flow field above the wing spikes of other geometries have also been tested. For certain angles of attack, $\alpha > 2.5°$, a gain in lift and a reduction of drag has been observed. Thus, the concept of using aerospikes on transonic wings clearly shows a potential for reducing wave drag. The shape of the spikes needs a further optimization taking into account real flight Reynolds numbers. Furthermore, it is important to obtain more global information on the wave drag by perfoming wake-rake measurements at different lateral positions thus resolving the spanwise distribution of the sectional drag and determining the influence of the hold of the spike. In this several spikes should be arranged next to each other in spanwise direction on top of the wing. In future tests schlieren pictures may not be of primary importance. Then integral values of forces such as lift and drag can be directly obtained by using a wind tunnel balance.

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