Flow Control for Oblique Shock Wave Reflections

Background

Shock wave / boundary layer interactions can be encountered on transonic wings, on the turbine blades of jet engines, in the inlet of supersonic jets and in many more situations. Because of their importance, they have been investigated for over decades now, but still the underlying processes are not fully understood and controlling these interactions remains difficult. However, new advances in experimental (Particle Image Velocimetry / Infrared Thermography) and numerical techniques (Large Eddy Simulations), make it possible to resolve more details than ever before and provide us with very detailed information of the interaction process.

My focus

My focus is on the oblique shock wave reflections occurring in supersonic jet intakes. The shock poses a strong adverse gradient and can cause the boundary layer to separate. A separated boundary layer not only increases the drag of the engine, but also reduces its performance and can in a worst case scenario cause the engine to unstart.

Flow control strategies are therefore being developed to reduce the amount of separation by stabilizing the incoming boundary layer. Within my project two cases can be distinguished:

• Laminar / transitional boundary layer: To reduce the drag contribution of jet intakes it is beneficial to keep the boundary layer laminar for as long as possible. Laminar boundary layers are, however, also prone to separation and are not suitable for passing through shock waves. The question is therefore where and how to trip the laminar boundary layer into a turbulent state.

• Turbulent boundary layer: Turbulent boundary layers can also separate when the shock wave is strong enough or when the flow has to pass through a series of shocks. Micro-ramp vortex generators offer a promising flow control device within this context. They create two streamwise vortices that transport high-momentum fluid towards the wall, creating a fuller and more stable velocity profile.

Mounting a micro-ramp (MR) upstream of the interaction:

• The micro-ramp is most effective along its centre line, at 50% span the flow behaves virtually as if there is no ramp
• On average there is no separation taking place along the centre line. Instantaneously there still is, however a factor of 4 less than without a ramp
• Maximum turbulence intensity levels along the centre line are reduced by 10-15%

Publications


Planning – Turbulent interaction

• Investigate the effects of Mach and Reynolds number on the micro-ramp’s effectiveness
• Tomographic PIV measurements of the separation bubble, with and without micro-ramp

Planning – Laminar / transitional interaction

• Investigate the scaling of the separation bubble with distance to the natural transition location, shock strength and Reynolds number
• Investigate the effects of boundary layer tripping on the size of the shock-induced separation bubble