Flow Investigations in a Stalling Nacelle Inlet

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At high angles of attack, the flow in engine nacelles may separate similar to the flow on airfoils. In the case of a stalling airfoil this leads to a strong decrease of the lift and may thus cause serious problems. In the case of a separating nacelle the decreasing lift is not a problem. However, vortices are generated in the shear layer, which separates the recirculation area from the outer flow and a loss of total pressure occurs. This leads to heavy loads on the compressor blades which may cause material failure. Under real flight conditions, the flow separation in a nacelle may be caused by a gust due to the induced angel of attack.

In order to understand the basic flow physics and to characterize the dynamics of the flow in a nacelle, an experiment was performed at the Institute of Fluid Mechanics and Aerodynamics. The results are used by project partners to validate and to increase the performance of numerical methods, see Probst et al. (2013).

Methods and results

A flow-through nacelle was mounted 1.74 m downstream of a gust generator in a wind tunnel, see Fig. 1. The gust generator is a pitching airfoil, which allows for the production of well defined vortices and thus reproducible gusts. The vortex generator is moving from \( \alpha_s = -11^\circ \) to \( \alpha_s = 11^\circ \) within 60 ms, pauses at \( \alpha_s = 11^\circ \) for approximately 195 ms, moves back to \( \alpha_s = -11^\circ \) within 79 ms, and pauses again for approximately 168 ms. Therefore, one cycle lasts approximately 500 ms.

Fig. 1 Experimental setup

In this paper, Stereoscopic Particle Image Velocimetry and static pressure measurements are presented. All experiments were performed at a Reynolds number of \( Re = 1.25 \times 10^6 \). The Reynolds number is based on the chord length of the nacelle, which is \( c = 526 \) mm. The experiments were conducted at the atmospheric wind-tunnel Munich. This facility is an Eiffel-type wind-tunnel with a closed test section and a maximum velocity of \( U = 40 \) m/s. The dimensions of the test section are \( 1.85 \times 1.85 \times 20 \) m. The measurements were carried out to investigate the effect of a gust on the attached as well as on the separated flow on the bottom lip of the inlet. If the vortex generator moves from \( \alpha_s = -11^\circ \) to \( \alpha_s = 11^\circ \), a counter clockwise rotating vortex will develop. Therefore, the model's angle of attack is initially increased. This increase is considered critical and thus the corresponding results are presented in this paper.

Figure 2 shows the absolute normalized in-plane velocity which is given as

\[
|U_{x1}|/U_\infty = \sqrt{\left(U_x/U_\infty\right)^2 + \left(U_y/U_\infty\right)^2}
\]

where \( w \) is the velocity component in the z-direction and \( u \) is the velocity component along the roll-axis of the model. The origin of the Cartesian coordinate system is the bottom leading edge of the nacelle, see Fig. 2. The black shape depicts the contour of the inlet. For this experiment, the light sheet was inserted in the mid-section. Figures 2 and 3 show the flow in the nacelle at an angle of attack of \( \alpha = 19^\circ \).

Figure 2 shows the vector field at a time \( t = 28 \) ms after the initial movement of the vortex generator. The time is counted from the moment the vortex generator passes \( \alpha_s = -10^\circ \). In a phase locked recording process, the results were averaged over 1000 single fields. It becomes apparent in Fig. 2 that the maximum in-plane velocity is located close to the leading edge (bright region). Figure 3 displays the flow field at a later time, \( t = 54 \) ms, after the initial movement of the vortex generator. It can not only be seen that the bright region of higher velocity increases, but also the low speed area close to the wall is enlarged by the gust (see dark region in Fig. 3). Therefore, it can be stated that the gust can have a particular effect on the airplane which is flying with an attached intake at \( \alpha_s = 19^\circ \). Static pressure measurements and mean flow fields, as well as statistical data of the stereoscopic PIV results, will be presented and discussed at the conference talk.

Fig. 2 Vector field of the absolute in-plane velocity after \( t = 28 \) ms of the initial movement of the vortex generator at \( \alpha_s = 19^\circ \)

Fig. 3 Vector field at \( t = 54 \) ms at \( \alpha_s = 19^\circ \)