Adaptation of PIV for application in cryogenic pressurized wind tunnel facilities at high Reynolds numbers

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Keywords: Cryo-PIV, ETW, high Reynolds numbers

Aerodynamic optimizations of new generation aircraft require tests at flight Mach and Reynolds numbers (M = 0.15 – 0.9, R = 10 – 80 × 10⁹). On scaled wind tunnel models, this is presently possible only in the European Transonic Wind tunnel (ETW) in Cologne or the National Transonic Facility (NTF) at NASA Langly. Both facilities adopt the same concept of using a test gas of moderately compressed pure nitrogen at cryogenic temperatures. To enable detailed flow field investigations on aircraft models at realistic flight conditions, a Cryo-PIV system is developed for an application in the ETW. Many difficulties have so far hindered PIV application under conditions that prevail in such specific wind tunnels, where gas temperatures down to T₀ = 110 K and pressures of up to p₀ = 450 kPa can be reached; such difficulties are mainly:

1. Tracer generation in cryogenic flows

For applications of PIV at transonic speeds, flow tracers in order of 1 μm are required to ensure that the particles follow the flow sufficiently. The classical seeding techniques using oil droplets can not be used in the ETW, since the droplets accumulate on the bottom of the wind tunnel circuit, such that after a warm-up the seeding substance can penetrate into the isolation shell leading to a permanent damage of the isolation material. So, methods are investigated to generate suitable ice particles at cryogenic temperatures, which sublimate completely when the gas is warmed up without leaving residua.

2. Optical arrangement

Applications of PIV in large wind tunnels require laser light of high pulse energy for illumination of the flow field. The PIV laser was placed outside the wind tunnel and the laser beam enters the wind tunnel plenum through a small window (Fig. 1). Special optical modules were designed for a placement of cameras and light sheet optics into the window openings of the test section. Because of the cryogenic environment, these modules are enclosed by temperature controlled housings. To compensate for laser light beam deflections due to optical and mechanical effects when changing the temperature or pressure, a system consisting of a beam monitor and mirrors was employed which allow for an automatic repositioning and redirection of the laser beam with respect to the light sheet optics. Since after a cool-down, the plenum is not accessible for several hours, the whole PIV system can be operated under computer control from the wind tunnel control room.

3. Demonstration tests in ETW

The applicability of the developed Cryo-PIV system has been successfully demonstrated in the ETW during two test campaigns on a full scale and a half-wing model of a transport aircraft by using Mach numbers between 0.2 and 0.8 at temperatures from 220 K to 120 K and total pressures between 125 kPa and 400 kPa.

Further developments will focus on a further reduction of optical effects such as the formation of Schlieren, which occur especially at high pressure levels. To overcome the problem of the inhomogeneous ice particle size distributions in the flow, an alternative seeding substance will be investigated to test its applicability to the ETW.

![Fig. 1 Employed Cryo-PIV setup at ETW](image1)

![Fig. 2 Stereo-PIV result from ETW showing the wing tip vortex for M = 0.6, T₀ = 160 K, p₀ = 125 kPa](image2)