Testcase 3.7
DNS and LES of transitional flow around a high lift turbine cascade at low Reynolds number

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1 Overview

This testcase concerns the DNS or LES of the transitional and separated flow on the T106C high-lift subsonic turbine cascade. This is a well-known testcase for assessing transition models for Reynolds numbers of 80.000 and beyond. The Reynolds number of 80.000 chosen for this workshop. As the inlet turbulence is very low (turbulence intensity of 0.9%), the flow features laminar separation and a relatively slow natural transition.

Blade pressure distribution and wake total pressure loss profiles have been measured at the von Karman institute (VKI) in the framework of the European research projects UTAT and TATMO. These will be used for assessing the computations.

2 Governing Equations and models

The compressible Navier-Stokes equations should be used, with air as working medium. Thereofore the gas constant $R = 287.1 J/kgK$ and the heat capacity ratio $\gamma = C_p/C_v = 1.4$. Finally the Prandtl number $Pr = \frac{\mu C_p}{\kappa} = 0.71$ is fixed. Here C_p and C_v are the specific heats at constant pressure and volume respectively, μ the dynamic viscosity and κ the heat conductivity. The viscosity μ follows from Sutherlands law

$$\begin{aligned}
\mu &= \mu_0 \cdot \frac{T^{3/2}}{T+T_0} \\
\mu_0 &= 1.45810^{-6} Pas/\sqrt{K} \\
T_0 &= 110,4K
\end{aligned}$$

but can be supposed constant corresponding to the exit conditions

$$\mu = 1.7248\ 10^{-5} Pa.s$$

The testcase should be run with at least a wall-resolvedlarge eddy simulation (LES) approach, up to direct numerical simulations (DNS). Participants are obviously free concerning the choice of models, but are expected to provide details on the model itself as well as the specificities of the implementation in relation to the discretisation method. Participants are allowed to complete the results with wall-modeled LES (WMLES) or other hybrids of LES.

3 Flow Conditions

The low Reynolds number is obtained during the measurements by lowering the pressure in the closed loop tunnel [1]. The conditions are derived in A, and are summarized as:

- inlet total pressure $p_t = 7198.5Pa$;
- inlet total temperature $T_t = 298.15K$;
- pitchwise inlet flow angle $32.7°$ from the axial direction;
- the exit static pressure $p_2 = 5419.3Pa$

4 Geometry and grids

The geometry of the T106C blade is shown in figure 1 and available as a set of ordered points running around the blade; their location is shown in figure 2. Furthermore a basic Gmsh geometry and meshing description is available which constructs an extruded mesh over a spanwise extent of $S = 0.2C$. Also IGS/STEP/PARASOLID of the 2D and 3D geometry can be obtained.

5 Mandatory results

The following results will be used for quantitative assessment

- the time- and spanwise averaged static pressure distribution on the blade as function of the axial distance with respect to the axial chord. This distance is measured between the vertical tangents at the front and aft of the blade;
- the total pressure distribution in the wake, measured at an axial distance of $0.465C_{ax}$ downstream of the vertical tangent of the aft of the blade;
- the mean exit flow angle measured at the same position.

The following results are requested for further qualitative discussion

- the rms and correlations of the velocity fluctuations on the spanwise periodic plane;
- the rms of the pressure fluctuations on the surface;
- the time-averaged skin-friction on the blade;
- the time-averaged vorticity on the spanwise periodic plane;
- the time-averaged total pressure on the spanwise periodic plane;

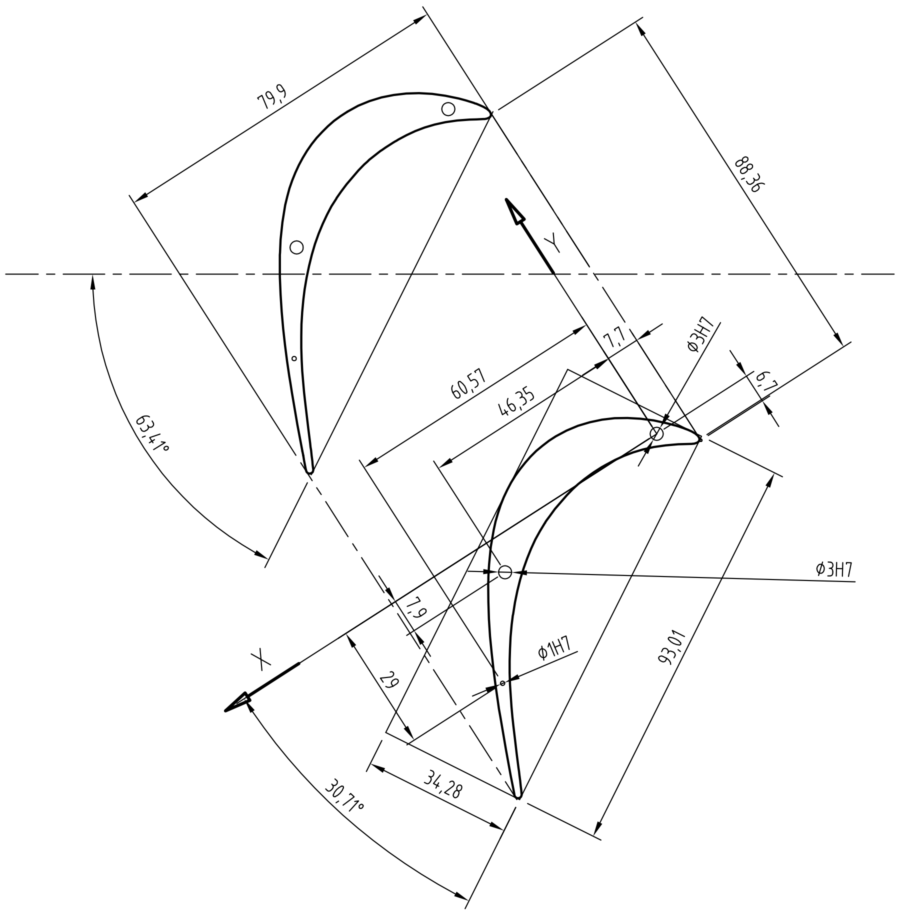


Figure 1: Geometrical description of the blade section (Courtesy VKI)

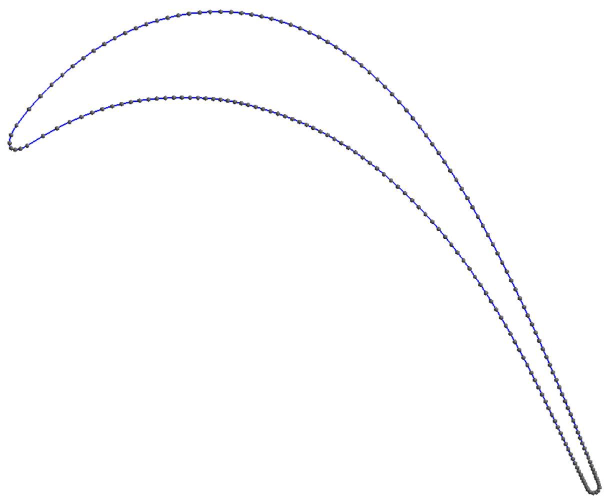


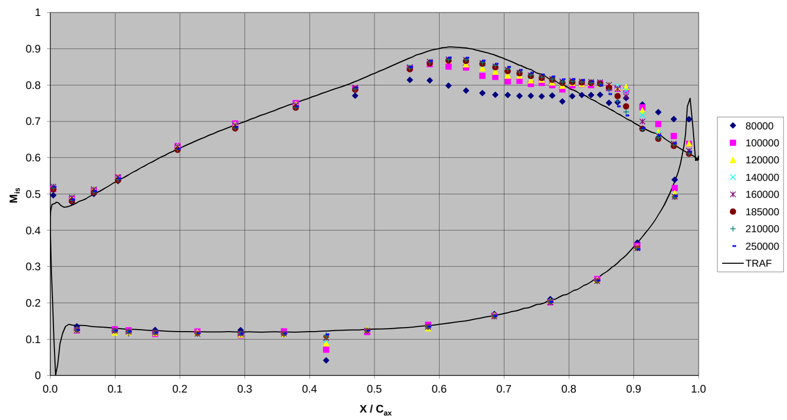
Figure 2: Point distribution

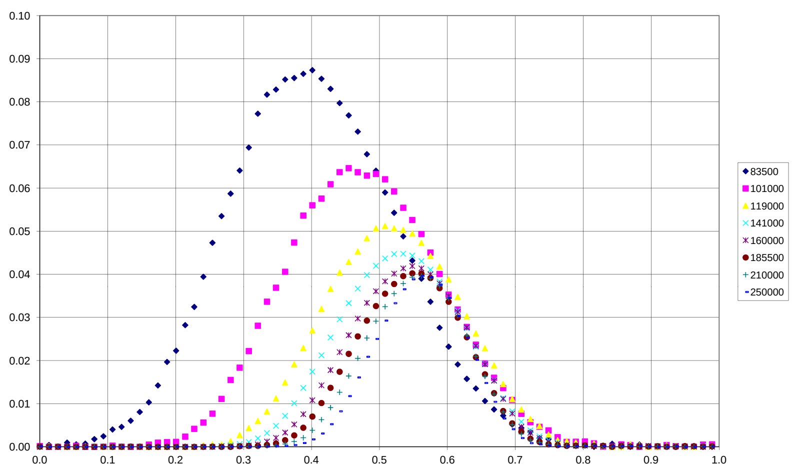
- a snapshot of the vorticity ω_x, ω_y and ω_z components on the spanwise periodic plane;
- a snapshot of the skin friction on the blade at the same time.

6 Reference data

The reference data include static pressure distributions on the blade surface, as well as total pressure distribution in the wake, and have been measured at the von Karman Institute. The results have been partially published in [1].

Isentropic Mach number distribution along the blade for several Reynolds numbers at $M_{2,is}$ = 0.65





References

[1] Jan Michálek, Michelangelo Monaldi,Tony Arts, *Aerodynamic Performance of a Very High Lift Low Pressure Turbine Airfoil (T106C) at Low Reynolds and High Mach Number With Effect of Free Stream Turbulence Intensity*, ASME Journal of Turbomachinery, volume 134, november 2012

A Derivation of the physical conditions

The working gas is air, hence $R = 287.1\ J/kgK$ and $\gamma = 1.4$. The total inlet temperature is fixed at $T_t = 298.15K$, whilst the the isentropic exit Mach number is fixed as $M_{2s} = 0.65$. Consequently, we find

- exit static temperature

$$T_{2s} = \frac{T_t}{1 + \frac{\gamma-1}{2} M_{2s}^2} = 274.92K$$

- exit dynamic viscosity as given by Sutherlands law

$$\mu_{2s} = 1.458 \times 10^{-6} \frac{T_{2s}^{3/2}}{T_{2s} + 110.4} = 1.7248 \times 10^{-5}\ Pa.s$$

- exit velocity $v_{2s} = M_{2s}\sqrt{\gamma R T_{2s}} = 216.07\ m/s$
- outlet isentropic density from the Reynolds number $Re_{2s} = 80.000$ and the chord $C = 0.09301$

$$\rho_{2s} = \frac{Re_{2s}\mu_{2s}}{v_{2s} C} = 0.0687\ kg/m^3$$

- inlet total pressure follows from the outlet pressure p_{2s} and the exit Mach number M_{2s}

$$p_{2s} = \rho_{2s} R T_{2s} = 5419.3Pa$$
$$p_t = p_{2s} \cdot \left(1 + \frac{\gamma - 1}{2} M_{2s}^2\right)^{\frac{\gamma}{\gamma-1}} = 7198.5Pa$$