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Axial compressor airfoil optimization

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1. Introduction

The KOBRA project is focused on the development of the safety system for the gas-cooled nuclear reactor. The classical approach to the compressor airfoil family definition used for this project is introduced in [2]. The airfoils are assembled from their mean curve and thickness function. Experimental measurements of the airfoil was done by the Institute of Thermomechanics, Czech Academy of Sciences. This paper describes further development and optimization of the airfoils. The representative airfoil chosen for the investigation is representative rotor airfoil at the blade tip with relative inlet flow angle $\alpha_{IN} = 60°$ and inlet Mach number $M_{IN} = 0.8$. Mean line camber angle is $\theta = 12°$.

2. Methods

Further development of the airfoil 3 from [2] is based on the optimization of the airfoil mean line. The original aifoil 3 cascade is shown in Fig. 1. This airfoil has the mean line with the slope change of the first derivative, see Fig. 2 (right), which probably causes separation near to the leading edge in some cases. The new variant of airfoil is based on the constant flow velocity change on the airfoil.

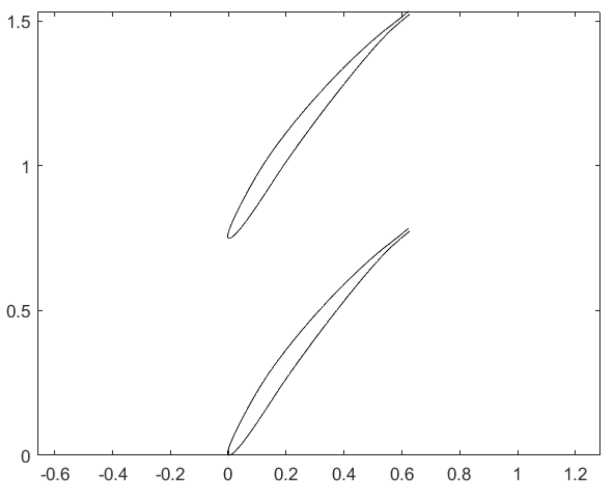

Fig. 1. Original airfoil 3 cascade with 1% leading edge thickness from [2]

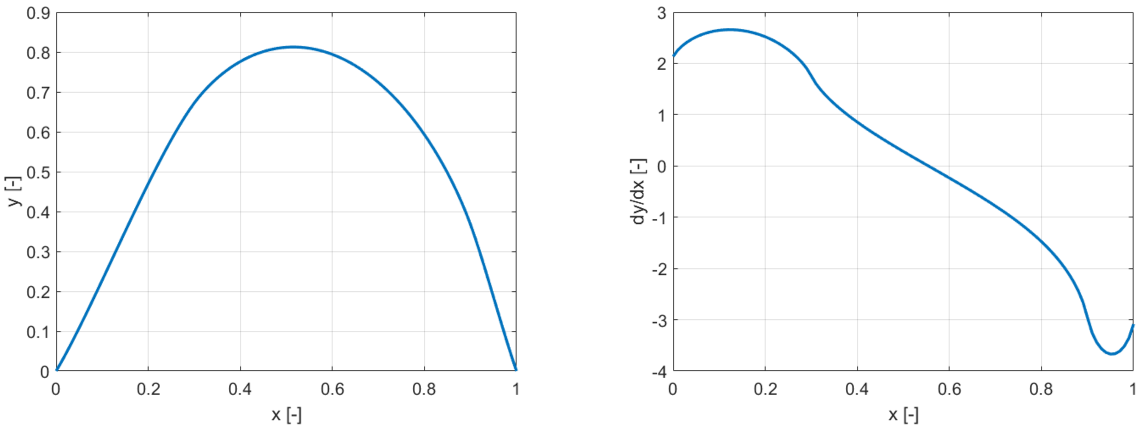

Fig. 2. Aifoil 3 mean line shape (left) and its slope (right)

The compressible flow velocity change for 1D inviscid case can be expressed in the following form (see [1]):

$$\frac{dv}{v}\left(M^2-1\right)=\frac{dA}{A}, \tag{1}$$

where A is the channel cross section area. The channel cross section can be expressed in the following form for the compressor cascade (constant blade length):

$$A=\frac{A_0}{\cos\alpha}, \tag{2}$$

where A_0 is the channel cross section for the axial flow and α is the flow angle measured from the compressor axis. Standard assumption for the compressor aerodynamic design is based on the constant axial velocity, i.e.,

$$v=\frac{v_{ax}}{\cos\alpha}, \tag{3}$$

where v_{ax} is the velocity component in axial direction. This means that the blade length changes so that changes in the density is compensated. Equations (2) and (3) are similar so, with some simplification, the flow acceleration with respect to the airfoil chord can be expressed by $d\alpha/dc$.

The function of $d\alpha/dc(x)$ is used as an input parameter for the airfoil mean line design. Numerical integration of $d\alpha/dc(x)$ with respect to the airfoil chord is used then to obtain desired mean line shape. Mean curve is generated directly in the final position, i.e., no airfoil rotation to the desired angle is used.

2D blade cascades were analysed by the means of the in-house CFD code at the Department of Technical mathematics, FME CTU in Prague. Cascade solidity t/c is from 0.5 to 2.0.

3. Results

The airfoil with constant $d\alpha/dc$ is presented in Fig. 3. The constant value of $d\alpha/dc$ should be favourable from the shock wave point of view so that strong shock waves should be suppressed, which should lead to low cascade losses. Results from the 2D CFD simulation are presented in Fig. 4 (cascade loss coefficient), Fig. 5 (cascade outlet angle) and Fig. 6 (flow turn angle).

4. Discussion

A modified method for the axial compressor airfoil design is presented. The method has been developed in the frame of the KOBRA project. The novel design method is based on the assumption of constant flow velocity increase on the airfoil. This should lead to lower losses and

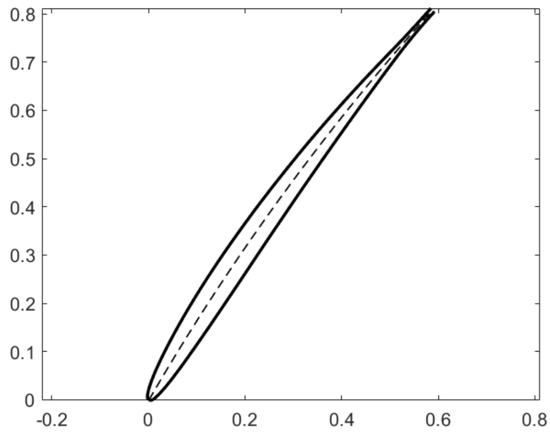

Fig. 3. Airfoil 5 with constant $d\alpha/dc$

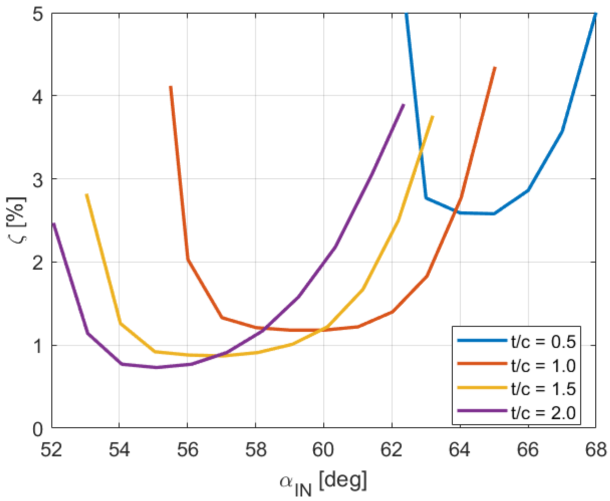

Fig. 4. Airfoil 5 with constant $d\alpha/dc$ – cascade loss coefficient ζ [%]

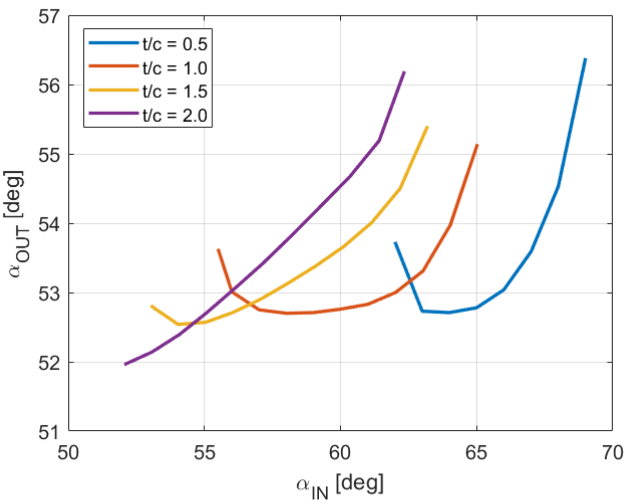

Fig. 5. Airfoil 5 with constant $d\alpha/dc$ – cascade outlet angle α_{OUT} [°]

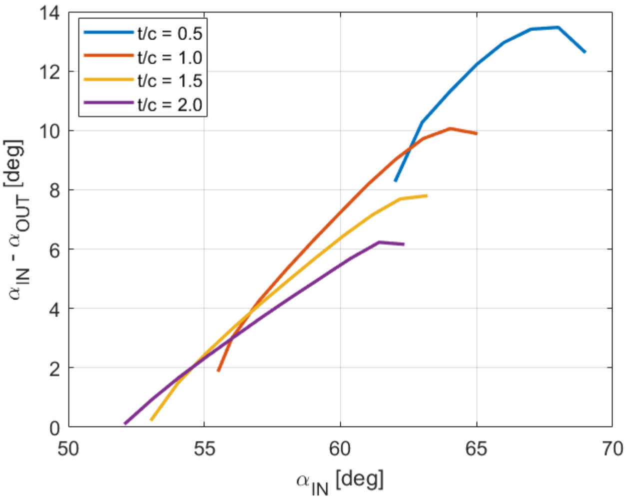

Fig. 6. Airfoil 5 with constant $d\alpha/dc$ – flow turn angle $(\alpha_{IN} - \alpha_{OUT})$ $[^\circ]$

wider operational range due to lower Mach numbers at the airfoil, and thus, less intensive shock waves. The new airfoil is designed for the sample rotor tip with the relative inlet flow angle $\alpha_{IN} = 60^\circ$, inlet Mach number $M_{IN} = 0.8$ and camber angle is $\theta = 12^\circ$. 2D CFD calculations with in-house code are performed for the cascade solidity t/c chosen from 0.5 to 2.0.

Acknowledgements

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References

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[2] Klesa, J., Aerodynamic design of transsonic compressor airfoil family, Proceedings of the 36th conference Computational Mechanics Conference, Srní, Czech Republic, 2021, pp. 115-117.