Final work : Numerical investigation of the influence of geometric uncertainties on transonic compressor flows

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Numerical Investigation of the Influence of Geometric Uncertainties on Transonic Compressor Flows

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Modern aeronautical engine development relies on a good computational prediction of flow quantities within the design process. Besides potential limitations in CFD related to flow modelling, a non-neglectable source of error can be related to geometric differences between the design and the final product, caused by wear and tear and manufacturing uncertainties. These variations do not simply impact the global performance of the machine, but may also give rise to flow phenomena that could change the stability limits of the machine or cause increased wear.

The Institute of Gas Turbines and Aerospace Propulsion at Technical University of Darmstadt conducted experiments in a 1.5-stage transonic axial compressor within the ARIAS project, funded by the Horizon2020 programme. In these measurements, a blade-to-blade variation in flow quantities could be observed at the rotor tip with Particle Image Velocimetry and unsteady pressure measurements. The aim of this work is hence to analyse the influence on the compressor flow of potential geometric uncertainties in the rotor blades by means of a parametrization of the original CAD geometry. By doing so, it becomes possible to set up an automated script that generates blades which differ from the standard in one or more aspects, according to real geometric variations. A feasible reference domain of the 1.5 stage transonic compressor is first created with the CAD model and analysed. Then, the rotor blade is parametrized and compared both in geometry and performance to the reference setup. The parametrized blade is then used as a base to generate sets of modified blades, which are each studied in single-passage simulations in order to compare the consequent flow variations. Finally, a full-annulus simulation is set up where only a single blade is modified in its stagger angle, with the

objective of capturing blade-to-blade flow variations.

The flow seems to be highly sensitive to leading edge curl, with significant sensitivity to trailing edge curl and leading edge thickness, while limited change was recorded with the chosen amount of stagger angle change. When misstaggering a single blade, passage-to-passage variations were found in blade loading, shock positioning, and others, with some rotor outlet quantities displaying weak patterns in the circumferential direction in the tip and hub regions.

Below are presented some figures to sum up the study.

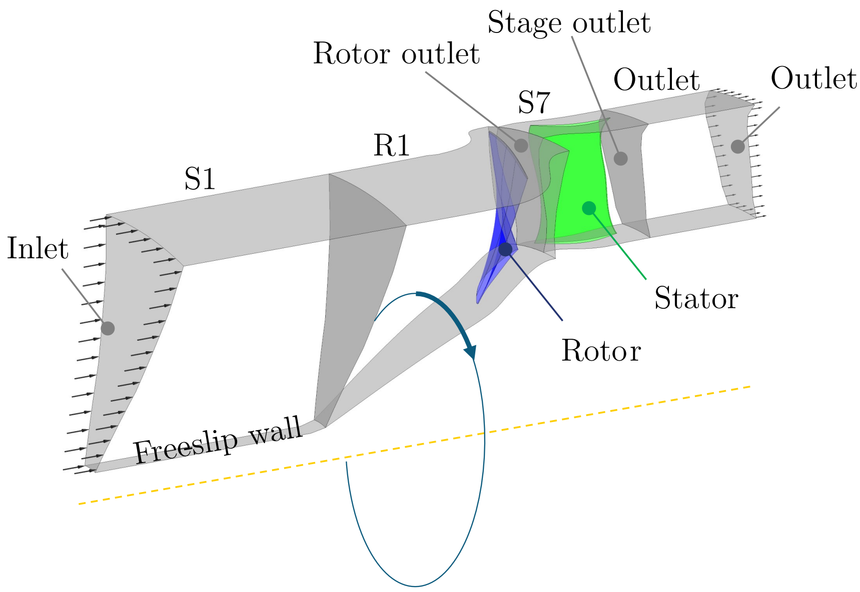
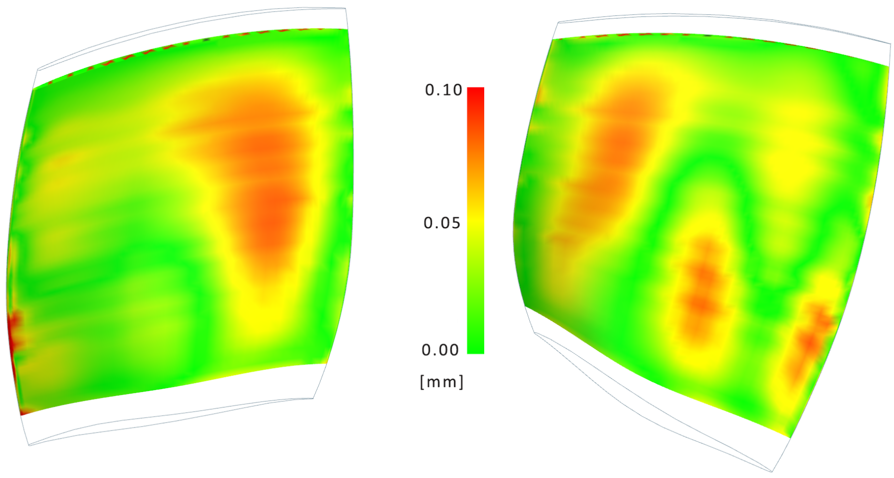


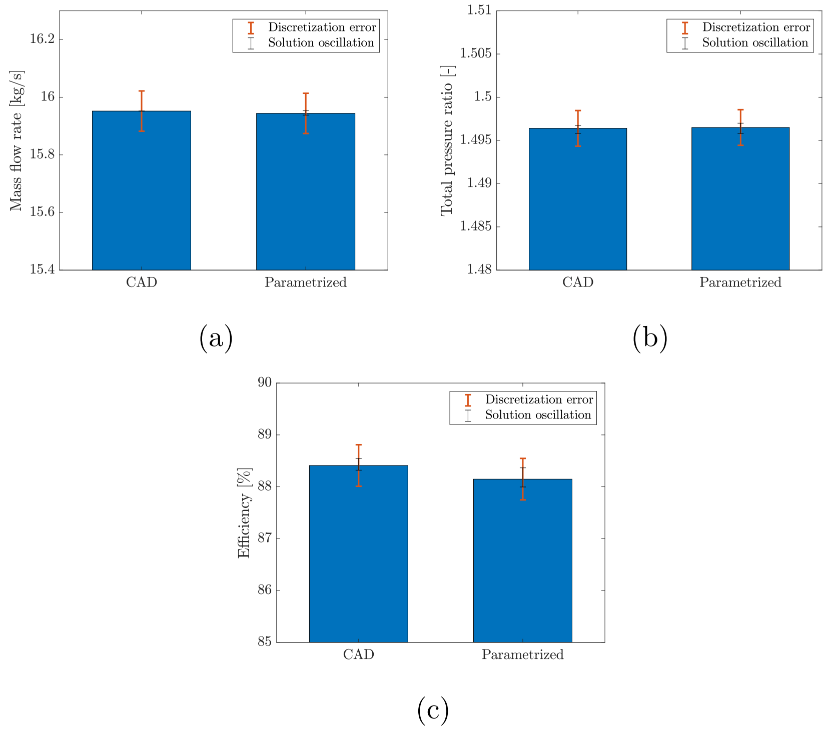
Figure 1: The single-passage domain used in the simulations, and its subdomains.



(a)

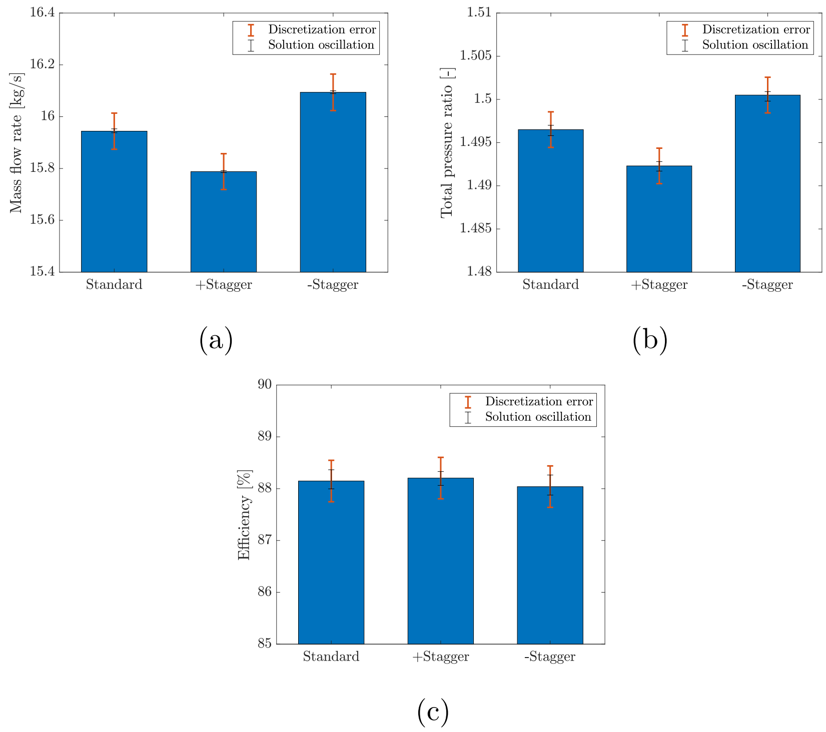
(b)

Figure 2: Absolute geometric deviation between CAD and parametrized blade, pressure side (a) and suction side (b).



(a) (b) (c)

Figure 3: The mass flow rate (a), total pressure ratio (b), and isentropic efficiency (c) compared between the CAD blade and the parametrized blade.



(a) (b) (c)

Figure 4: Comparison of mass flow rate (a), total pressure ratio (b), and isentropic efficiency (c) between the standard blade and the blades modified in stagger angle.

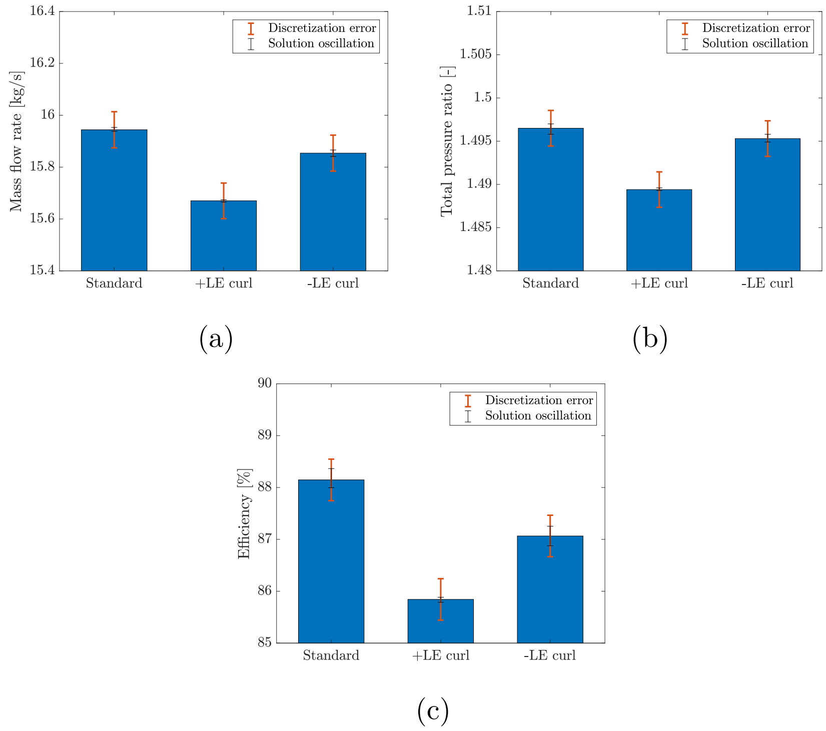


Figure 5: Comparison of mass flow rate (a), total pressure ratio (b), and isentropic efficiency (c) between the standard blade and the blades modified in leading edge curl.

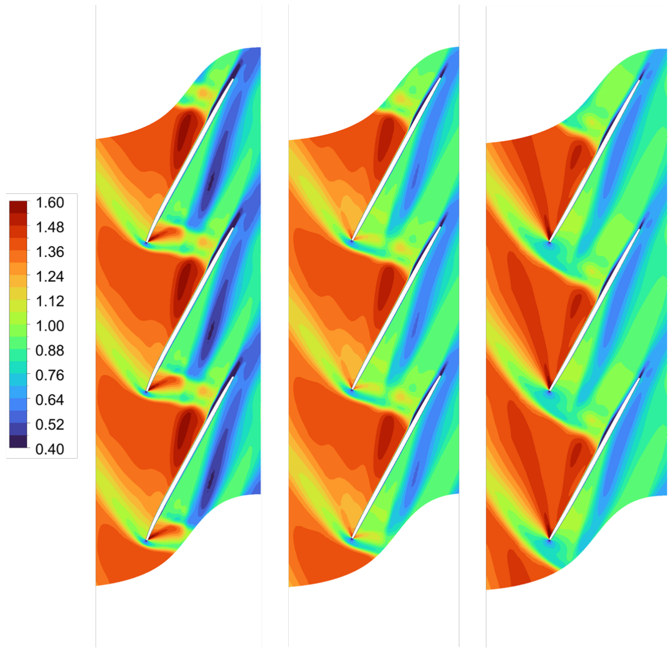


Figure 6: Blade-to-blade plot of the Mach number at 95% of the span of the increased LE curl (left), standard (centre), and decreased LE curl (right) blades.

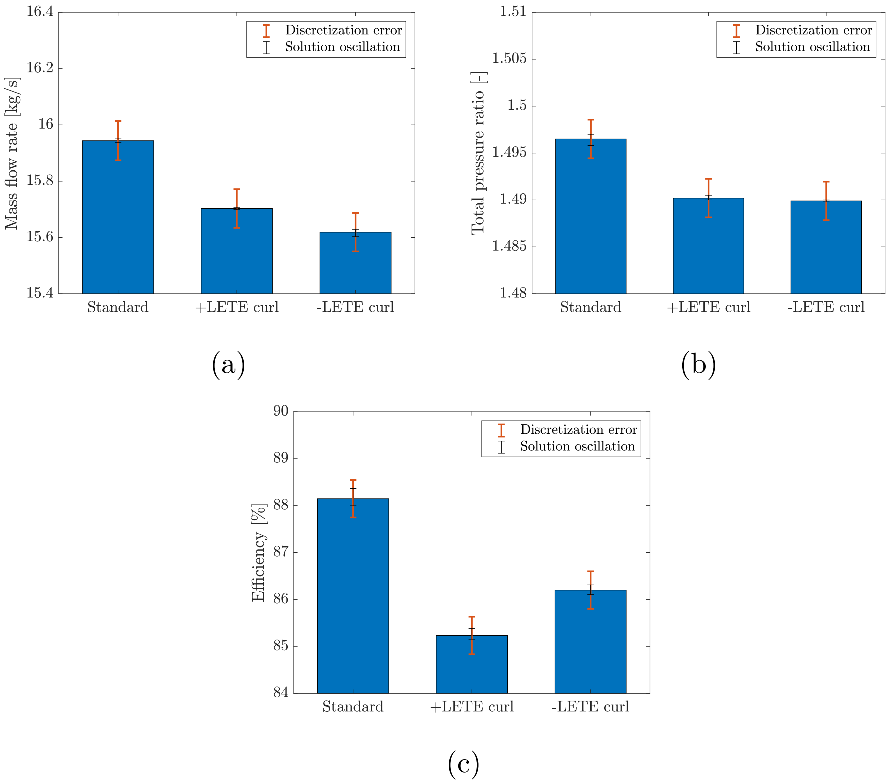


Figure 7: Comparison of mass flow rate (a), total pressure ratio (b), and isentropic efficiency (c) between the standard blade and the blades modified in leading and trailing edge curl.

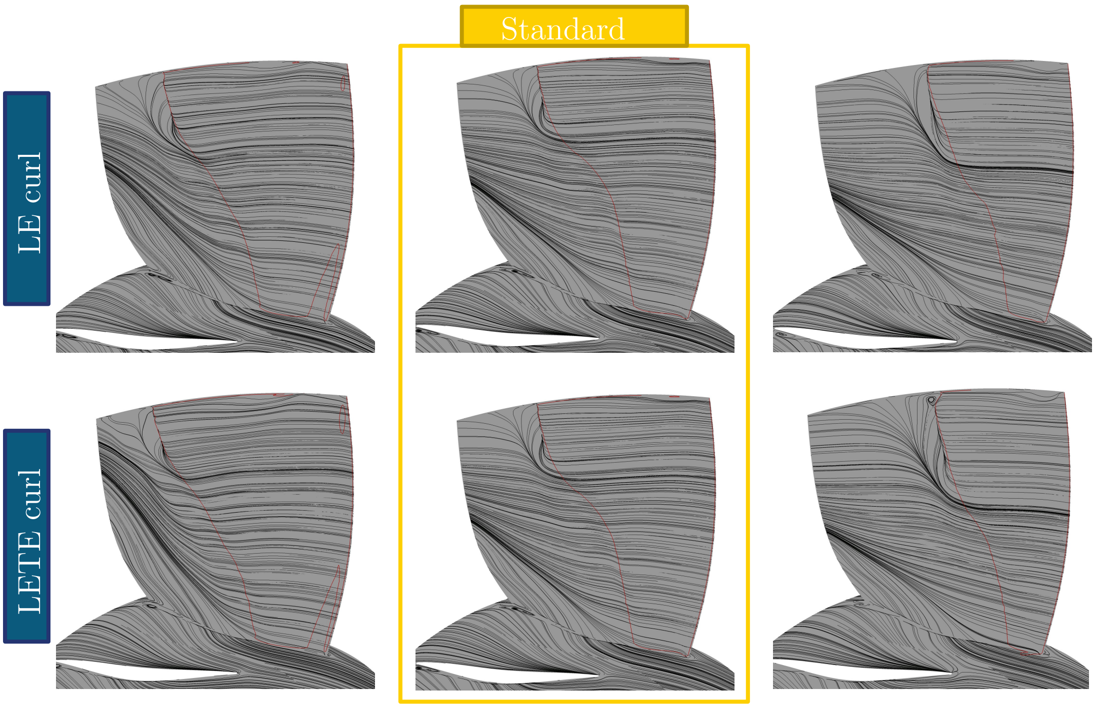
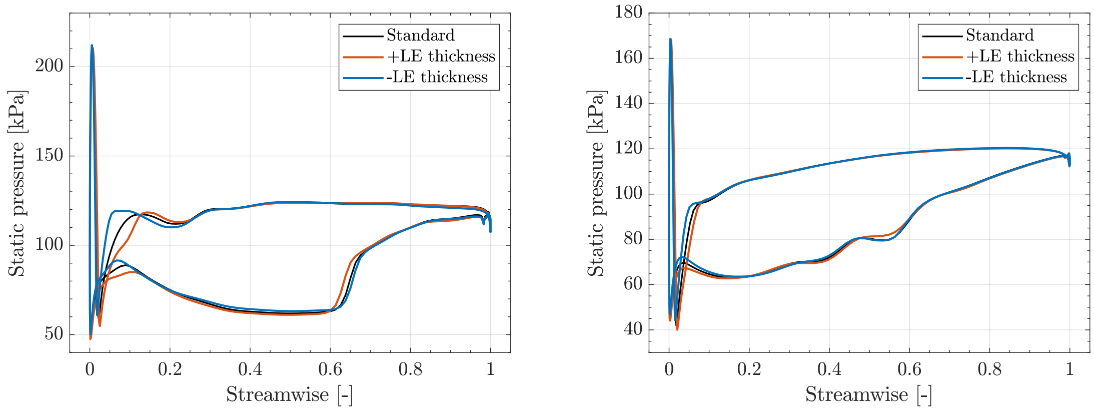


Figure 8: Comparison of the blade streamlines: the top row is for the blade set no.2 while the bottom row for blade set no.3. On the left the positive change, at the centre the standard case, on the right the negative change.



(a) (b)

Figure 9: Blade loading at 95% (a) and 50% span height (b) compared between the standard blade and the blades modified in leading edge thickness.

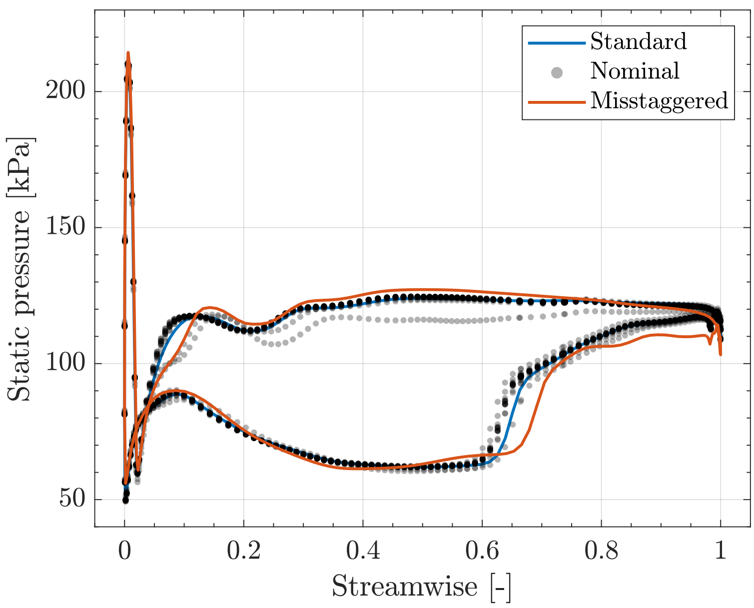
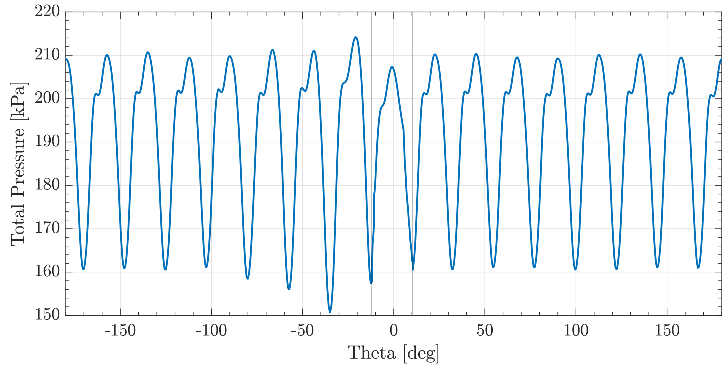
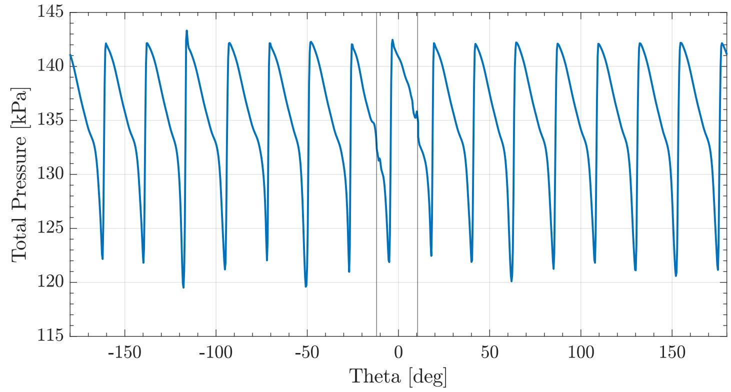


Figure 10: The blade loading profiles on the rotor blades at 95% of the span height vs normalised axial chord for the full annulus.



(a)



(b)

Figure 11: Circumferential profile at rotor exit at 95% (a) and 2% (b) of the span height of the total pressure in the relative frame of reference.

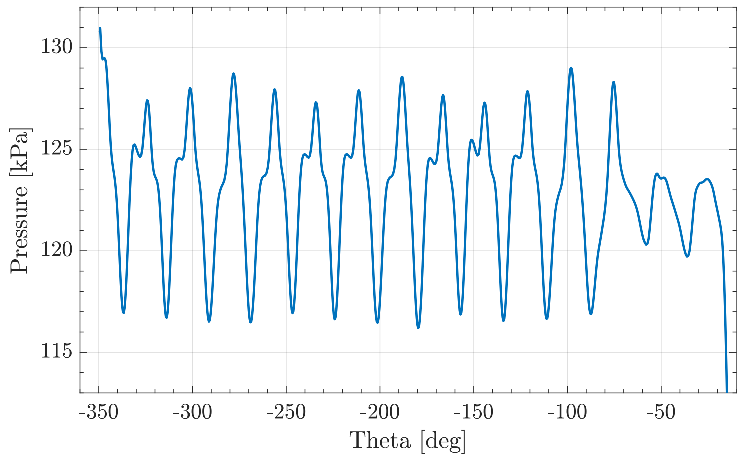


Figure 12: Circumferential profile at rotor exit at 98% of the span height of the pressure only for the nominal blades.