QUANTIFICATION OF PERFORMANCE UNCERTAINTY DUE TO GEOMETRIC VARIABILITY FOR FULL ANNULUS COMPRESSOR

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Manufactured blades are inevitably different from their intended designs, which leads to a deviation of the performance from the intended value. The performance deviation consists of both a shift (usually negative) of the mean and a scattering around it, eventually leading to an overall reduction of the component performance and even unusable manufactured blades. Therefore, quantitative analysis of aerodynamic performance uncertainty (UQ) is of great significance for robust design or appropriately controlled manufacturing tolerance which could reduce the mean performance deterioration and the scattering.

The impact of the geometric deviation on the compressor performance has been studied extensively for one passage [1]. However, all past research has excluded the effect of full annulus. It is unclear to what extent such simplification would affect the UQ results. Therefore, in this work, geometric variability UQ is performed for a full annulus compressor cascade.

In this work, a nonlinear Monte Carlo (MC) model based on an adjoint method (MC-adj-nonlinear) is employed to perform UQ at the design point and a near stall point. MC-adj-nonlinear can capture a certain nonlinear effect in an efficient manner. Firstly, the one-passage UQ using MC-adj-nonlinear is conducted, which verifies the practicability of MC-adj-nonlinear using the MC results based on an unstructured computational fluid dynamics solver (MC-CFD). Then the aerodynamic performance UQ is performed at the design point and the near stall point for a full-annulus transonic compressor cascade, subject to prescribed geometric variability with industrial relevance. Next, we approximate the annulus UQ by the one-passage simulation, and compare the results with the full annulus results. Finally, conclusions are drawn by comparing the results of the one passage UQ with those of the full-annulus case.

The airfoil of the test case is defined with the coordinates of 398 points, which are more densely populated around the leading and trailing edges, as shown in Figure 1. Total pressure and temperature of 158885.9 Pa and 330.633 K are specified at the inlet and a back pressure of 166420.3 Pa is specified at the outlet. Then 2899 blades are generated which have the geometric deviation variance of σ0 and mean of E0. It is worth noting that E0 and σ0 are derived from measurement data of blades manufactured with the state-of-the-art manufacturing technology. The nominal blade and the average of the perturbed blades are shown in Figure 2.

Figure 3 shows the PDF of mass flow rate, pressure ratio and efficiency at the design point using MC-CFD and MC-adj-nonlinear for one passage UQ, and figure 4 shows those at the near stall point. As we can see from figure 3, the results obtained by the newly-proposed nonlinear model are in excellent agreement with that of the MC-CFD. For the near stall point, the scattering of the performance is bigger than those at the design point. Also, we found that for the annulus case, it seems that the scattering of the performance is smaller than the one passage case, especially the variance. This may be because that the effect of geometric deviation of each blade on aerodynamic performance cancels each other. This shows that we estimate the impact of the manufacturing deviation negatively using a domain of one-passage.

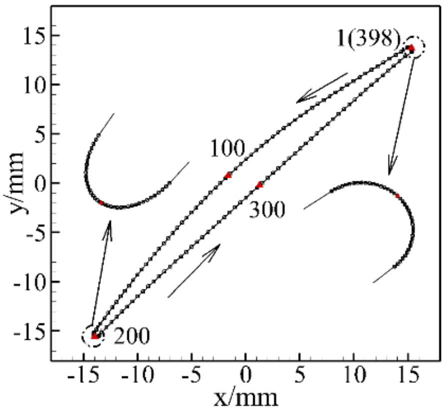

Fig. 1 – Blade profile and control points distribution

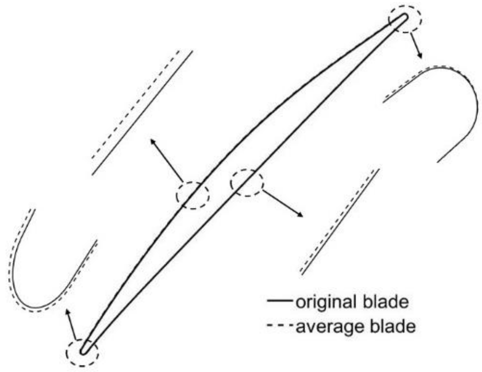

Fig. 2 – Original designed blade and average blade

Detailed analysis of all these results about the design point and the near stall point based on one passage or full annulus UQ will be presented in the full paper.

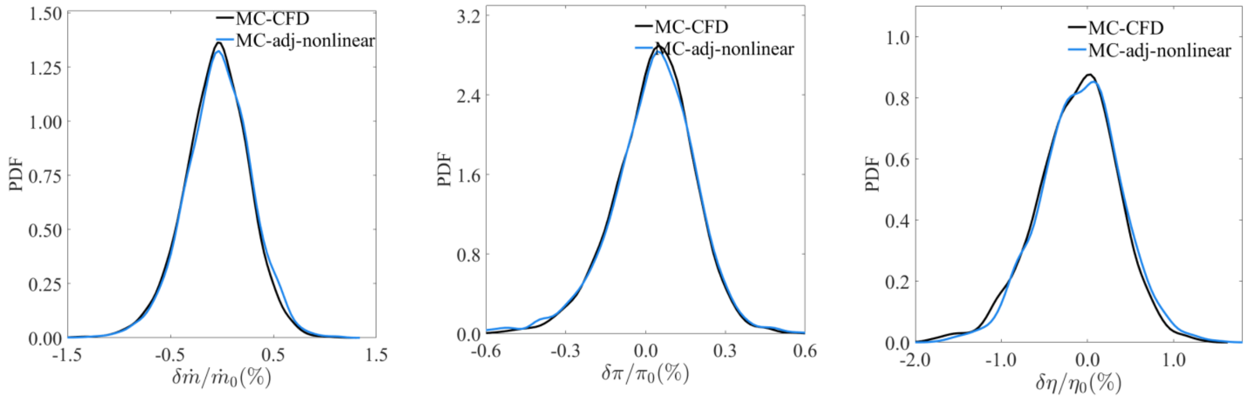

Fig. 3 –The PDF of aerodynamic performanceat the design point using MC-CFD and MC-adj-nonlinear using a domain of one-passage

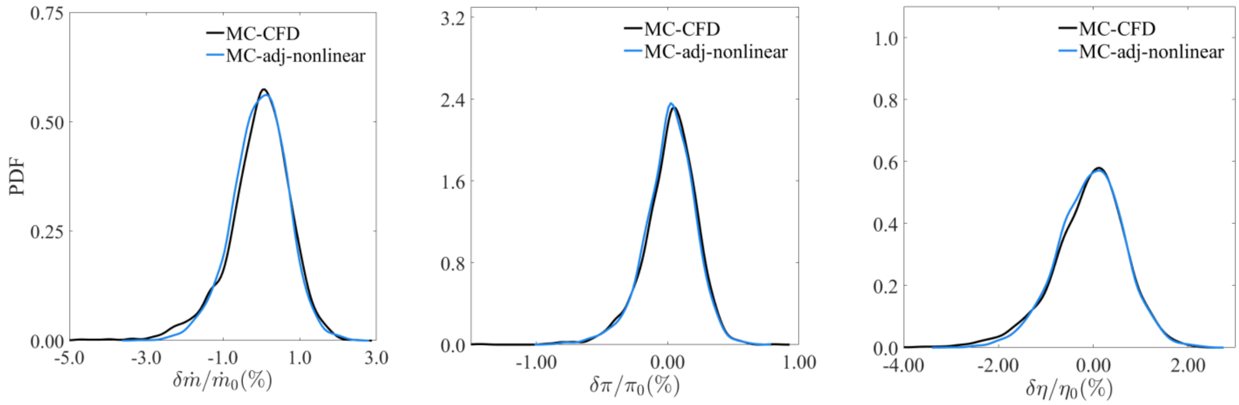

Fig. 4 –The PDF of aerodynamic performanceat the near stall point using MC-CFD and MC-adj-nonlinear using a domain of one-passage

References

1. Garzon V. E., Darmofal D.L. Impact of geometric variability on axial compressor performance // Journal of Turbomachinery. 2003. No. 125(4). Pp. 1199-1213.

2. Luo J.Q., Liu F. Statistical evaluation of performance impact of manufacturing variability by an adjoint method //Aerospace Science and Technology. 2018. No. 77. Pp. 471-484.