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[Extended Abstract]

Sensitivity analysis of BLISK airfoil wear

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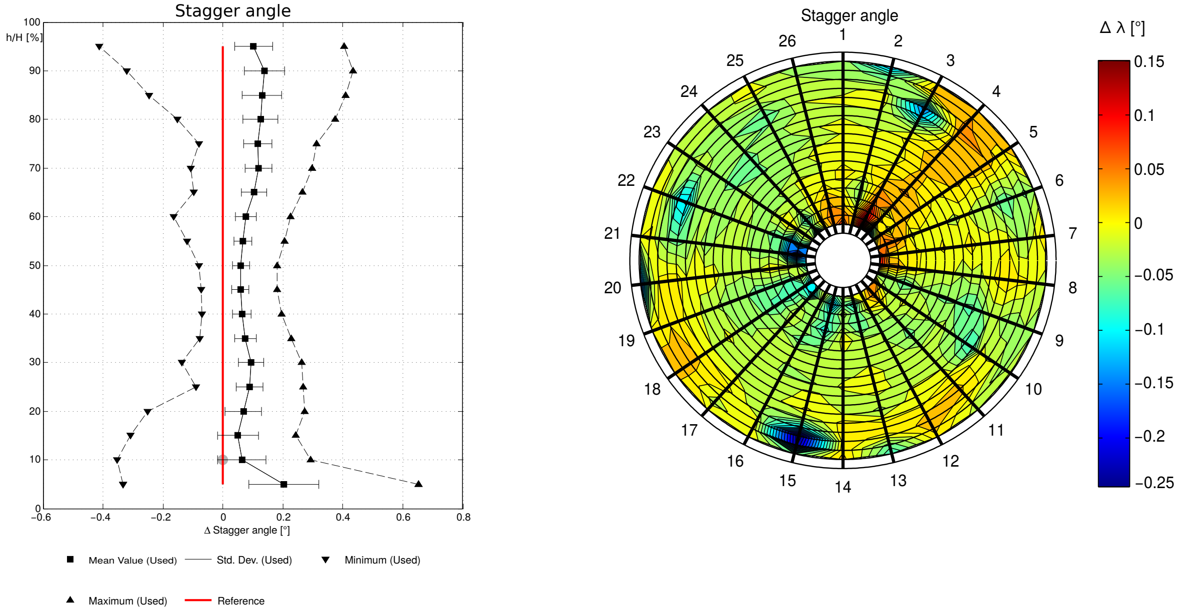
Introduction

In jet engines deterioration occurs during on-wing time which leads to a decreasing performance. Therefore, jet engines are overhauled regularly in order to maintain safety level and high efficiency. Nowadays, the efficiency level has a rising importance and therefore, the maintenance companies has to provide exact performance parameters like EGT (Exhaust Gas Temperature) and SFC (Specific Fuel Consumption). To reach these goals, maintenance companies often use customized maintenance actions for each engine. To improve the repair and overhaul tailored repairs for each blade can be a choice.

Special attention is given to the high pressure compressor because of the comparatively large influence on the overall engine performance. Therefore, a detailed knowledge about the aerodynamic behavior of deteriorated blades is necessary. For BLISK (BLade-Integrated-diSK) the aerodynamic behavior is even more complicated because the blade arrangement cannot be changed or individual blades cannot be replaced. Thus, coupled deteriorated blades have a high significance and a more complex behavior. To ensure an effective maintenance for BLISKs the effects of different coupled misshaped blades are the key factor.

The present study addresses the effects of coupled deteriorated blades on the aerodynamic performance of the first stage BLISK of a high pressure compressor. Therefore, a Design of Experiments (DoE) is done to identify the geometric properties which lead to reduced performance. To give a detailed view three critical operating points (cruise, takeoff and touchdown) are analyzed and compared.

The statistical background of geometrical variances is determined by measuring ten first stage high pressure compressor BLISKs. These are installed in a state of the art bypass-engine which is mainly used in a rear mounted configuration for regional and business aircrafts. All BLISKs has been in operation for about 20,000 cycles. Each of it has 26 blades which sets the statistical data to 260 blades. The geometric properties are gathered with an in-house programmed analyzing tool (cf. Reitz et al. [1]). The geometry is described by 12 geometric properties on 19 blade profiles from 5% to 95% blade height. In figure 1 a) an example of a radial distribution of the geometric parameter stagger angle based on 10 BLISK is shown. The maximum range of deviation is $\Delta\lambda = 1°$. The standard deviation is $\sigma_\lambda = 0.12°$ for tip and $\sigma_\lambda = 0.05°$ for mid span. The spreading of the standard deviation of all 12 geometric properties is base of the design space which is used for the DoE. In figure 1 b) the variation of the stagger angle λ along the blade height is shown. The stagger angle shows a spread of 0.8° at the



(a) Variation of stagger angle for 10 BLISK

(b) Circumferential rotor blade stagger angle distribution λ on BLISK No. 9

Figure 1. Geometric variances of BLISK

tip and 0.3° in mid span. The important aspect to be considered is the inhomogeneous wear on blades placed next to each other on the circumference. It has to be mentioned that no newly manufactured BLISK could be analyzed. Both plots show the variation to a chosen airfoil of the statistical data representing a mean value. But a comparison with Marx et al. [2] shows that the wear distribution is in the same magnitude and therefore representative.

Methods

In order to analyze the sensitivities of deterioration for different operating conditions, a DoE for the 85%-blade height of a front stage BLISK-airfoil is done. Therefore, in-house programmed tools are used to built the design space, the design geometries and to evaluate the results in a meta-model (cf. Reitz et al. [3]).

To train the meta-model a design space of 700 different coupled geometric variances is used. The design space factors are equally distributed by a Latin-Hypercube-Sampling-algorithm (cf. Lophaven et al. [4]). The geometric parameters are modified in a range of $\pm 1.5\sigma$, whereas the standard deviation of the wear characteristics is exemplary shown in Fig. 1 a). Also, correlations within the geometric parameters are used to reduce the number of parameters and to avoid mistakes in the meta-model (cf. Reitz et al. [5]). The created design space is used to built coupled artificially deteriorated airfoils of the 85% profile section of a first stage rotor. These built airfoils are simulated with the numerical CFD-solver TRACE of DLR Cologne. To reduce the computational effort, Q3D-simulations of coupled blade profiles are carried out. To ensure that the simulations are in line with the different boundary conditions of a 3D-simulation, the boundary conditions as well as the computational domain has to be adapted. Therefore, the non-dimensional surface pressure distribution of all three operating conditions for a 3D-simulation (cf. Fig. 2) are matched by Q3D-simulations to ensure the correct flow

behavior. To apply this, the AVDR distribution of the 3D 85% blade height is taken into account by specifying the Q3D stream tube height [6].
The meta-model evaluates the design space with the Kriging-Method developed by Lophaven et al. [4] for all three operating conditions. This procedure generates Pareto Charts to identify aerodynamic sensitivities of coupled wear parameters. The aerodynamic performance is evaluated by the flow turning $\Delta\beta$, the non-dimensional pressure rise Δp and the loss coefficient ζ.

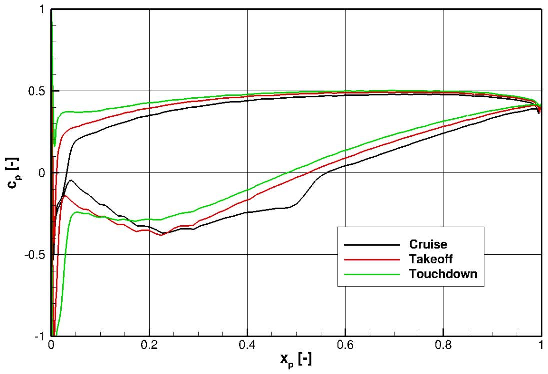


Figure 2. Non-dimensional surface pressure distribution c_p for three operating points on 85% blade height

References

[1] Gerald Reitz and Jens Friedrichs. Procedure for analyzing, manipulating and meshing of compressor blades to simulate their flow. In *International Gas Turbine Conference, Tokjo, Japan, 2015*, 2015.

[2] Jonas Marx, Jörn Städing, Gerald Reitz, and Jens Friedrichs. Investigation and analysis of deterioration in high pressure compressors. In *DLRK Conference, Stuttgart, Germany*, 2013.

[3] Gerald Reitz, Stephan Schlange, and Jens Friedrichs. Design of experiments and numerical simulation of deteriorated high pressure compressor airfoils. In *ASME Turbo Expo 2014: Turbine Technical Conference and Exposition*, 2016.

[4] Soren Lophaven, Hans Bruun Nielsen, and Jacob Sondergaard. Dace a matlab kriging toolbox; version 2; informatics and mathematical modelling. *Technical University of Denmark, Technical Report No. IMM-TR-2002-12*, 2002.

[5] Gerald Reitz, Kevin Dwinger, Stephan. Schlange, Jens. Friedrichs, and Friedhelm. Kappei. Analysis of jet engine compressor deterioration and capturing correlations between geometric parameters. In *ISROMAC 2016*, 2016.

[6] Udo Stark and Heinz Hoheisel. The combined effect of axial velocity density ratio and aspect ratio on compressor cascade performance. In *ASME 1980 International Gas Turbine Conference and Products Show*, pages V01BT02A044–V01BT02A044. American Society of Mechanical Engineers, 1980.