Analysis of jet engine compressor deterioration and capturing correlations between geometric parameters

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Long Abstract

Introduction

During on-wing time of a jet engine the engine performance constantly reduces due to deterioration effects. Deterioration leads to decreasing component efficiencies, which increases Exhaust Gas Temperature (EGT) and Specific Fuel Consumption (SFC). The engine typically has to be overhauled when a specified limit of EGT is reached. This does not imply to restore the engine to the new condition, which would mean to replace every component with a new one or repair the parts to new condition. Rather the executing MRO (MRO: Maintenance, Repair and Overhaul) company and its customer, which is considering the most efficient use of its financial maintenance reserves agree by contract to restore the engine performance to a sufficient margin. The contract contains the engine performance requirements for the individual operation and on-wing time. Hence specific deterioration mechanisms are accouted for which have to be attended during maintenance.

To conduct such customized maintenance within strict cost limits, the MRO installs a mix of used, repaired and new parts to restore the engine performance to the desired margin. The used parts are inspected to determine their serviceability and repair demands. However, especially the standard inspection of aerodynamic parts gives typically little clue to the condition of the part regarding its performance in the engine. To evaluate the performance a much more detailed inspection of the parts would be required, due to the diversity in deterioration patterns and the resulting amount of parameters to describe them.

Research on the deterioration of the High Pressure Compressor (HPC) has been conducted, since the HPC performance is critical to overall engine performance. The HPC performance depends on the condition of its compressor blades. These are subjected to a variety of deterioration effects. Their geometric diversion to a new part is equally versatile but should be governed by their position in the compressor regarding the stage and the operation of the aircraft. Therefore, not every parameter required to describe the entity of deterioration patterns is needed to determine the performance of a certain stages compressor blades. Still to reach a conclusion about a blades performance a multitude of parameter has to be measured. To reduce the amount of measurements required, correlations between certain parameters have been researched.

The research is based on the measurements of Marx et al. [1], who analyzed the geometries of 1200 HPC-blades of two jet engines of the same type with similar on-wing time. To improve the data basis, further blades have been measured and analyzed by the authors. Additionally, 300 stator vanes have been digitized to compare them with the rotor results. The airfoils have been digitized by a structured light 3-D scanner. The data is analyzed with an in-house programmed software to determine the geometric properties. The determined geometric variances are examined for correlations among themselves.

1. Methods

A correlation between two or more parameter is a functional relationship based on empirical evidence, rather than a physical theorem. To discribe magnitude of the functional relationship a correlation coefficient is used. For this research the correlation coefficient of Bravais and Pearson [2] [3] has been chosen. The coefficient is calculated by the covarianz of the coupled parameters s_{xy} and the covarianz of the single parameters s_x and s_y.

$$r = \frac{s_{xy}}{s_x \cdot s_y} = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 \sum_{i=1}^{n}(y_i - \bar{y})^2}} \tag{1}$$

Because of the normalization of the coefficient, its values can be only between -1 and $+1$. Values between -0.3 and $+0.3$ show no correlations between the chosen parameters. Nevertheless, preliminary considerations should be done, to avoid spurious correlations [4]. These are correlations which occur if in a chosen general sample two parameters are examined which are independent of one anonther but yield a correlation due to a common third parameter.

Figure 1 and 2 show examples of scatterplots between leading edge asymmetry and its stretching for a front and rear stage. The asymmetry is defined as the ratio from distance of pressure and suction side to a vertical line through the leading edge. Thus, a shifting leading edge point towards suction side results in an increasing asymmetry and vice versa. The stretching is defined as the ratio from thickness and length of the leading edge. On the one hand, the stretching will decrease by a blunting leading edge or increase, if erosion leads to thinner airfoils by material abrasion at the suction- and pressure side.

As can be seen, in front stage the majority of parameter pairs show higher stretchings and decreasing asymmetries compared to new blades. So, a comparatively large amount of abrasion is located at blade suction side. Additionally, the regression line is plotted through the parameter pairs. Its gradient is negative: decreasing stretchings go ahead with decreasing asymmetry values. The belonging correlation coefficient is -0.43.

At rear stage the gradient of regression line and, therefore, the correlation coefficient is negative, too. Nevertheless, the parameter pairs show a different behavior: the majority of parameter pairs show lower stretchings and increasing asymmetry values. So, erosion is located at pressure side and the leading edge point shifts towards pressure side.

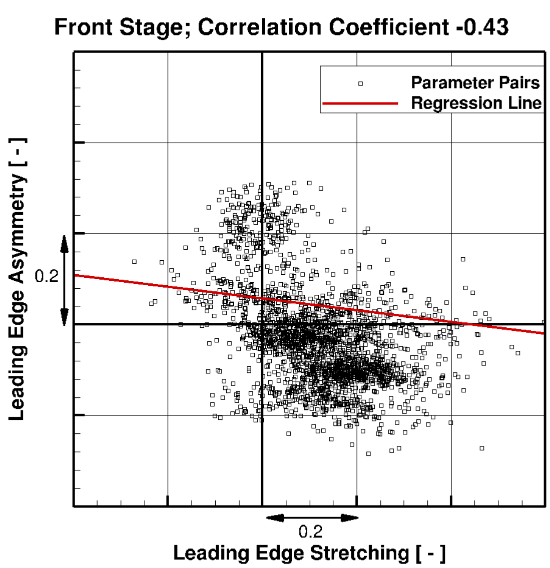

Figure 1. Correlations at front stage

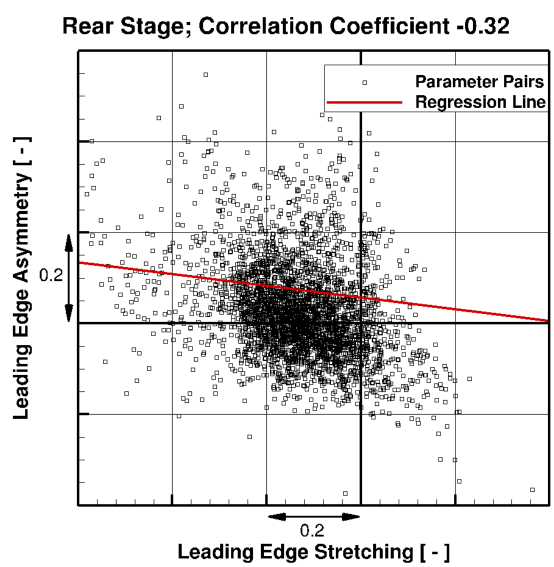

Figure 2. Correlations at rear stage

A possible explanation for this result can be found in the aerodynamic behavior of the compressor, especially during Take-Off (TO). Because of the comparatively large outside temperature during TO, compared to cruise-condition, the HPC is operating at a lower aerodynamic rotational speed, even though the mechanical rotational speed is high. Consequently, the front stages were throttled and the rear stages are working discharged. This results in a changing flow field for the regarded stages: front stages see a positive and rear stages a negative incidence angle. If erosiv particles are following the air flow, they will striking the airfoil at pressure side in front stages and suction side in rear stages.

Further correlations will be shown and explained in the full draft paper. Additionally, correlations of stator vanes will be exhibited and compared to the blades. So, the technical understanding of HPC deterioration will be strengthened and possible effects on the jet engine could be predicted much better.

References

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