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Areal parametric characterisation of ex-service compressor blade leading edges

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ABSTRACT

In-service the degradation of compressor blade leading edges can have a disproportional effect on compressor efficiency. The high surface curvature in this region makes quantifying the surface finish of this sensitive and prominent region difficult. An automated technique that characterises the roughness of the leading edge in terms of areal parameters is presented. A set of ex-service blades of differing sizes are used to demonstrate the procedure. Improved characterisation of this blade region will allow engine companies to better understand where in-service deterioration has the greatest effect and inform them as to how they might minimise the effect. The present work shows that the leading edges of compressor blades exhibit a significantly higher characteristic surface roughness than other blade regions, and the spatial distribution of peaks in this characteristic roughness is detailed. In addition it is shown that peak wear and roughness are not uniformly correlated.

1. Introduction

1.1. Leading edge significance

The prominence of the leading edge makes it particularly susceptible to both deposition and erosion. It is also a region where small changes to the roughness and geometry can have a disproportionate effect on compressor efficiency. Due to this susceptibility and by visual inspection it has been generally accepted that the leading edge typically exhibits greater surface roughness due to degradation than other similarly sensitive areas of compressor blades. The sensitivity to roughness was demonstrated by Wilshee [1] he tested compressor blades with roughness imposed onto discrete regions. He found that applying roughness over the leading edge and the first 4% of the chord (for blade nomenclature see Fig. 1) the aerodynamic losses increased by almost half of that seen when the whole blade was roughened. This can be attributed to the fact that the boundary layer around the leading edge is much smaller and the roughness will therefore have a larger effect. The sensitivity to geometry was demonstrated by Goodhand and Miller [2] they tested a compressor blade with different leading edges. They found that premature flow turbulence and associated losses caused by circular leading edges could be offset with a 3:1 elliptical leading edge. This change can be attributed to the more gentle change of the profile geometry of the elliptical edge, and the associated reduction in flow disturbance. In service, similar, or even greater changes to leading geometry may be expected due to either erosion or deposition. This raises the question what are the changes and what effect will they have on the flow?

1.2. Leading edge profile and areal metrology

To date the large majority of investigations into compressor degradation have focussed on military or power generation applications. In civil aero engines the levels of degradation are more modest, and unlikely to be safety critical, but can have a significant effect on fuel burn. The fact that they are not safety critical means that there is little published data of leading edge metrology. The compressor blades investigated have circular leading edges; typically with nominal leading edge radii less than 1 mm and high flank angles (see Fig. 2 (G)). A flank angle of 90° means the surface is parallel to the optical axis and not measurable; measurements become optimal as this angle approaches 0°. In practice imperfections arising during manufacture as well as the deterioration in-service, means that the leading edges are rarely circular in practice and as such, their dimension is typically described as 'half thickness'. This study focuses on the leading edges of the rotor blades from a single engine see Fig. 3; one blade

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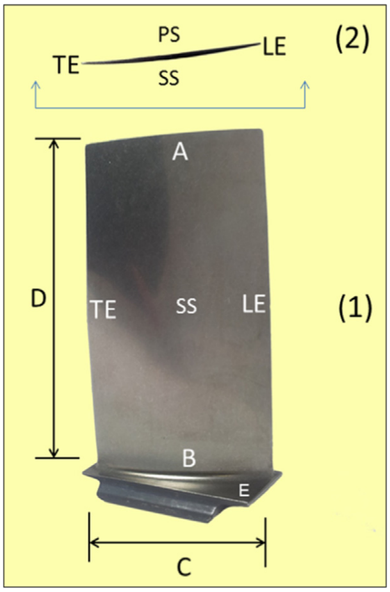

Fig. 1. Generic compressor blade nomenclature; (1)-side view and (2)-tip view(x section) showing; LE-leading edge, A-tip, B-root, C-chord (chordwise direction), TE-trailing edge, D-Span (spanwise direction), SS-suction side (convex), PS-pressure side (concave), E-end wall.

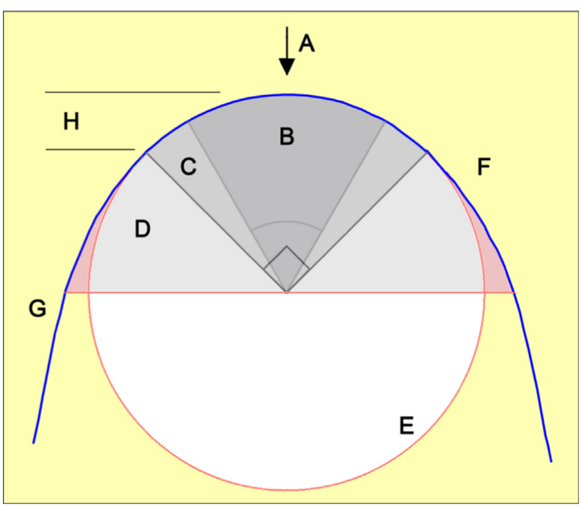

Fig. 2. Leading edge region cross-section schematic; (A) instrument optical axis (zero angle of attack) (B) central 60° frontal field of leading edge, (C) central 90° frontal field of leading edge, (D) nominal frontal field of whole leading edge, (E) circle fitted to nominal leading edge circular profile, (F) approximate blend point of leading edge into blade suction or pressure side (see Fig. 1), (G) leading edge flank, (H) approximate depth of measurement field.

from each row of the Intermediate Pressure Compressor (IPC) and one from each row of the High Pressure Compressors (HPC). Considering blades from all stages provides the opportunity to investigate different leading edge sizes as well as those with different levels of degradation.

Surface metrology in the form of a single line or 'profile' of surface point heights (and associated parameters) often acquired by a contact stylus instrument is widely understood and employed [3]. Areal surface metrology is an increasingly dominant development of this metrology field where a sample surface 'area' is assessed in preference to a simple profile. Areal analysis offers much improved statistical significance, giving better repeatability of results along with greater functional significance. New areal parameters sets have been developed expanding the surface characterisation tool kit to include surface volume and feature based analysis [4–6]. Non-contact optical metrology instruments are commonly employed for areal surface characterisation. Areal surface parameters are computed from the distribution of captured surface point heights with respect to the mean plane of this point height data set; hence to exclude the height influence of any residual form (geometry) of the sample surface this form must first be removed. The characterisation of degraded leading edges involves significant technical challenges in both instrumentation and data processing, amongst these are; significant residual form see Fig. 2 (H), a wide range of surface; roughness amplitude, texture, colour and reflectivity both specular and diffuse. Fig. 4 depicts a form removed false colour height map of a data set acquired from a ex-service compressor blade leading edge in an initial investigation employing a coherence scanning instrument (CCI)[7,8]. Areal surface parameters were computed from this data set, thus giving proof of concept, though this instrument was far from optimal for the task. 'Focus variation' surface metrology instruments [9] such as the Alicona G4 Infinite Focus Microscope [8,10] are one of the few instrument groups capable in practice of the metrology task detailed here. Specifically the Alicona is able to measure both high flank angles and roughness amplitudes.

1.3. Degradation

Particulates both domestic and foreign (from inside and outside an engine) can have a detrimental effect on compressor efficiency by way of deposition or erosion of gas flow surfaces. Salt spray [11], oil, organic material and sand [12], and rotor path material *(anecdotal)* [13] are some of the many particulate sources an aero engine may encounter during service.

1.4. Fouling and erosion

Compressor rotor degradation by adherence of particulates (fouling) has been extensively investigated, and recently reviewed [14].

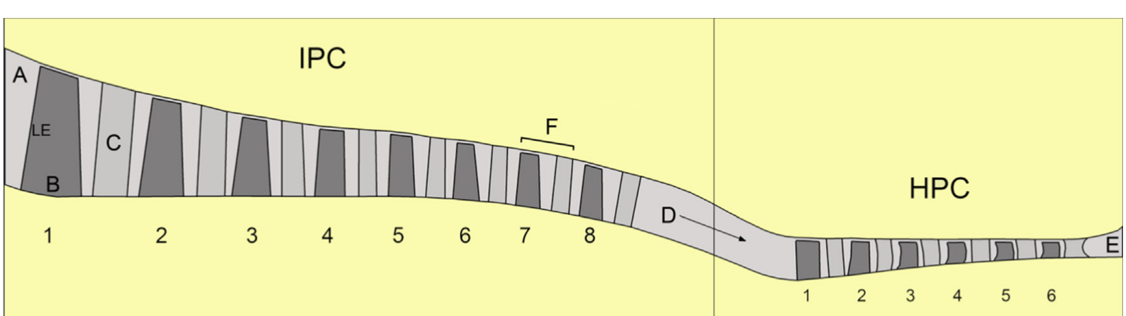

Fig. 3. Compressor jet core schematic; High pressure compressor HPC and intermediate compressor IPC (A) Inlet, (B) rotor blade root, (C) stator blade (vane), (D) compressor core flow, (E) combustion chamber, (F) single compressor stage, (LE) leading edge. Inset numbers indicate blade number.