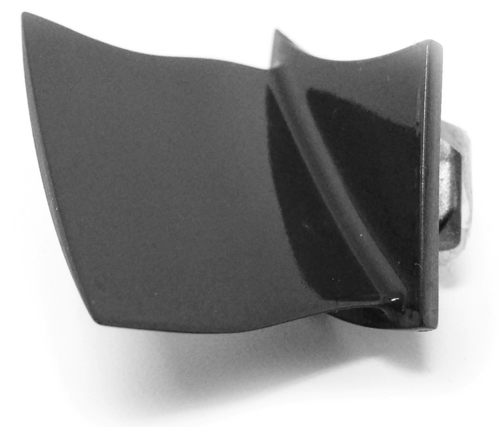
COMPRESSOR BLADE MEASUREMENT USING 3D LINE SCAN PROFILOMETRY



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INTRO

Combining the benefits of high efficiency and large mass flow rate, axial flow compressors are widely used in large gas turbines such as aerospace engines, high speed ship engines, and small scale power stations. They have a sophisticated structure containing rows of aerodynamically-shaped, complex rotor and stationary blades, which makes their designing, manufacturing and repairing extremely expensive. High precision turbine compressor blades are decisive for achieving the best aerodynamic efficiency. Computational fluid dynamics (CFD) models are developed to design the 3D geometry of the compressor blades with all the details. This is followed by forging and machining of the compressor blades, where the precision and dimensional accuracy play a critical role in engine power and efficiency. A fast and precise measurement of the 3D blade geometries is in need to ensure the narrowest tolerances in quality control of manufacturing processes.

Moreover, during the service time of the engines, erosion and corrosion can either create locally dents, pits or cracks, or they can attack uniformly across a wide blade surface and cause mass loss and surface roughening. This may result in decreased power efficiency and potential mechanical failure of the engines. The annual cost on compressor blade maintenance was above 80 billion USD according to a report by USA Department of Defense in 2010[i]. A fast 3D surface analysis is desirable to inspect the blades and provide insight of failure mechanism and severity, allowing selection of the best erosion and corrosion control measures.

MEASUREMENT OBJECTIVE

In this application, we showcase that the Nanovea ST500 High-Speed Profilometer equipped with an optical line sensor finishes a full 3D surface scan of a compressor blade in *20 seconds*.

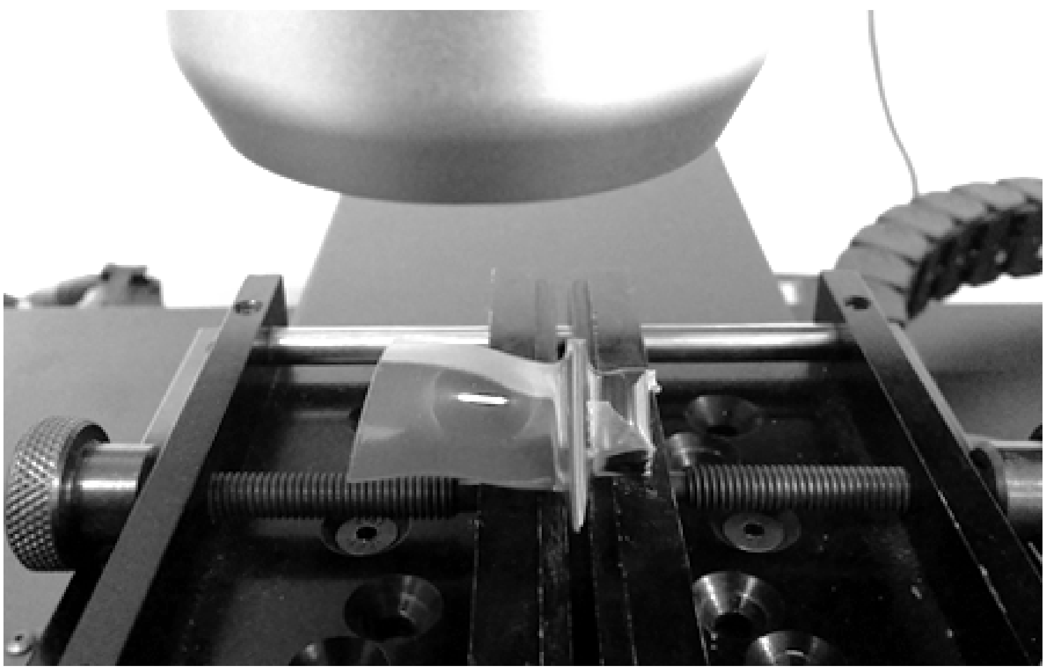


Figure 1: Optical line sensor scanning on the compressor blade.

RESULTS AND DISCUSSION

As shown in Figure 1, the optical line sensor generates a bright line, which is composed of 192 light spots that scan the sample surface at the same time. This significantly increases the scan speed and enables a 30 mm × 30 mm 3D scan of a full compressor blade in 20 sec. For a detailed description of the measurement principle refer to the Appendix at the end of this report. The False Color View and 3D View provide users a straightforward tool to directly observe the blade from different angles as shown in Figure 2 and Figure 3, respectively.

The data of the precise 3D surface scan can be imported to professional computational fluid dynamics (CFD) software for complete blade design and analysis in order to achieve the best aerodynamic efficiency. It can also serve as a tool to evaluate the shape and roughness of the blade after manufacturing and compare them with the original design for the purpose of quality control. Figure 4 displays the 2D profiles of the blade as an example.

(a) Front face: **(b) Back face:**

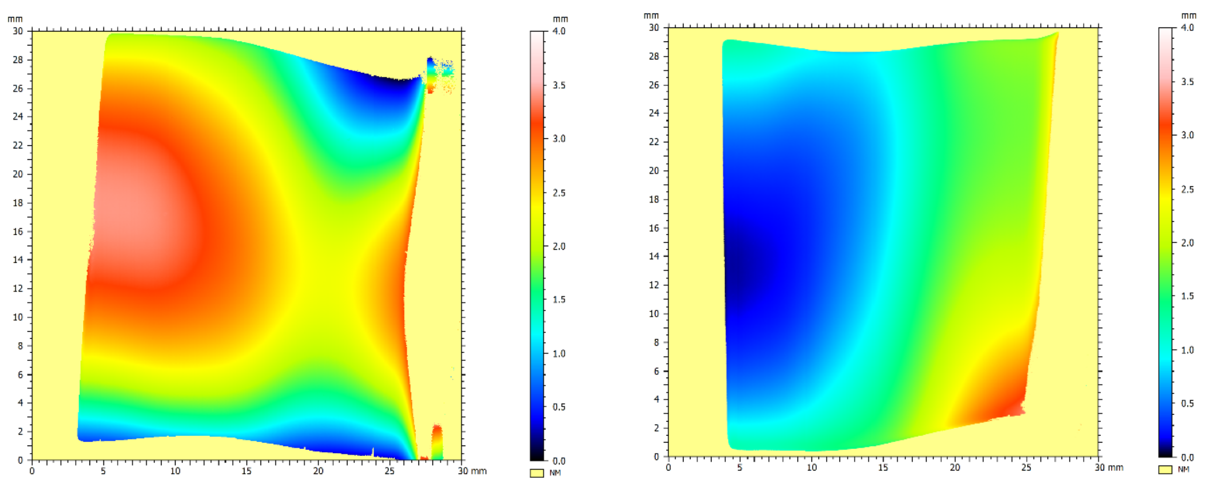
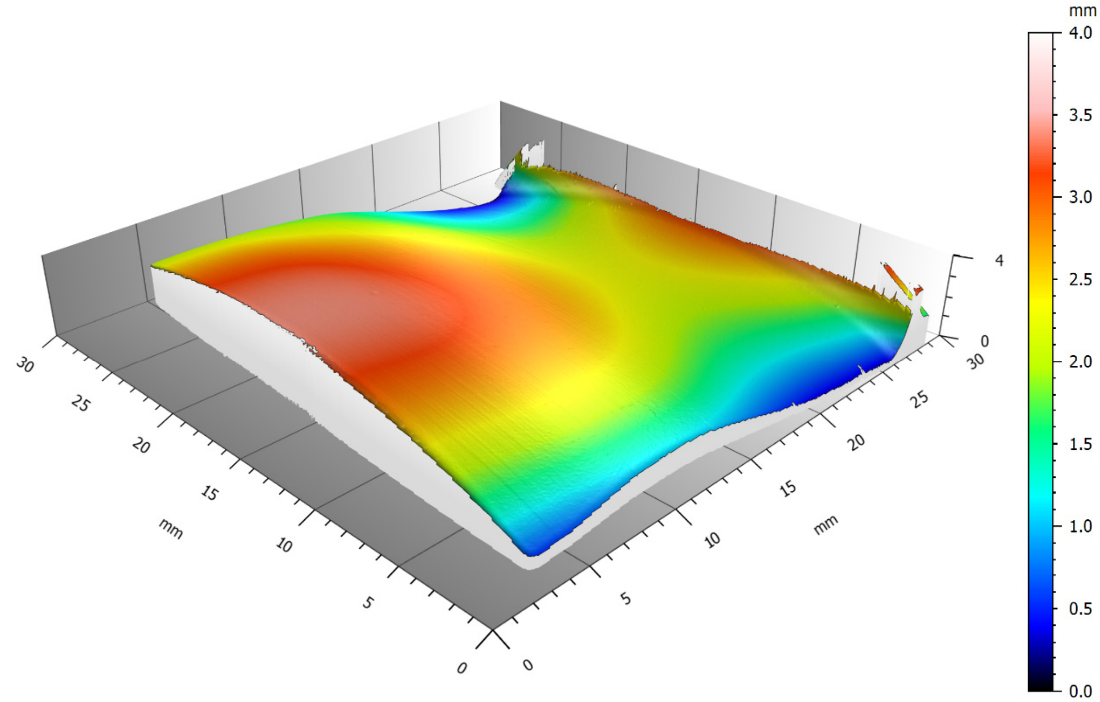


Figure 2: False color view of the two faces of the compressor blade.

(a) Front face:



(b) Back face:

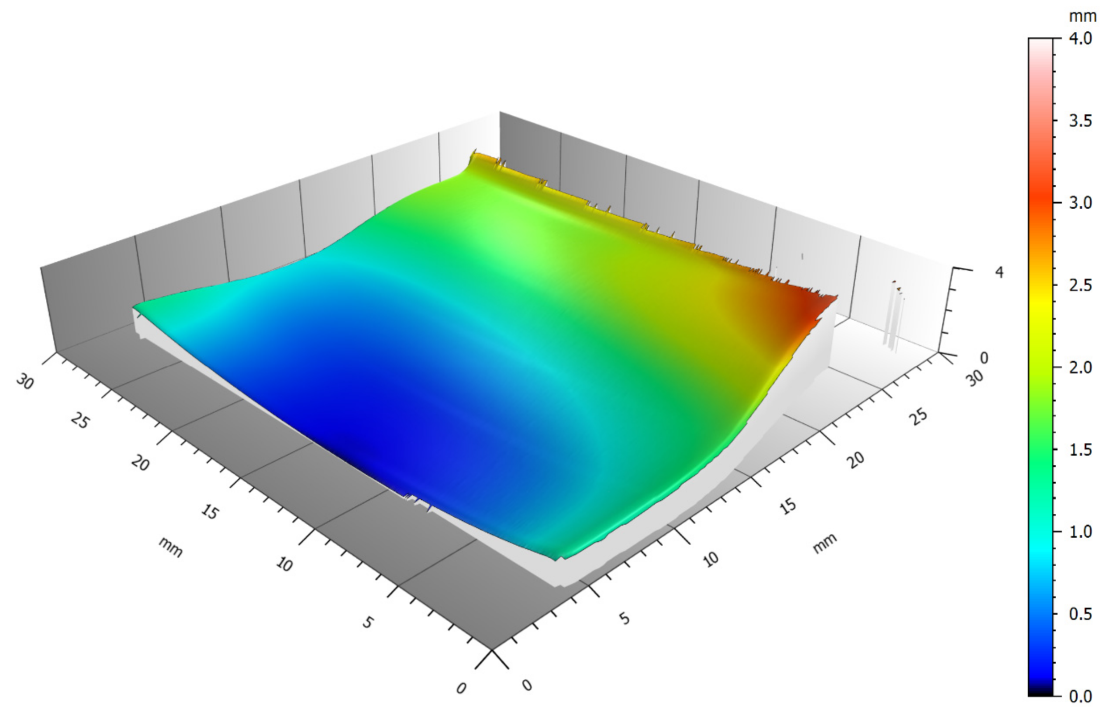
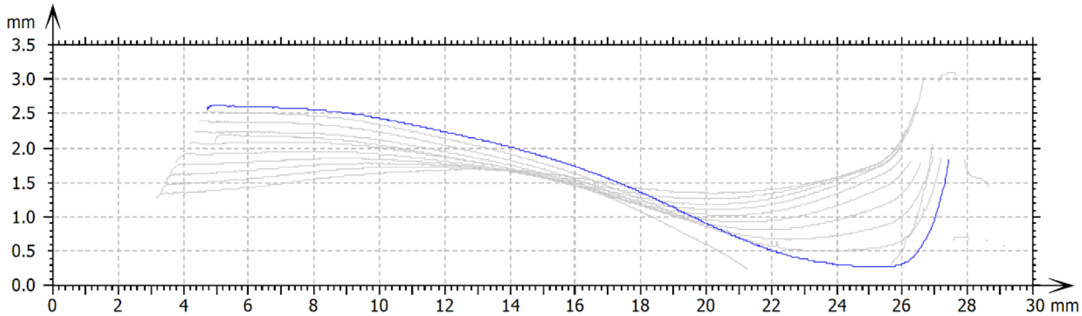


Figure 3: 3D view of the two faces of the compressor blade.

(a) Front face:



(b) Back face:

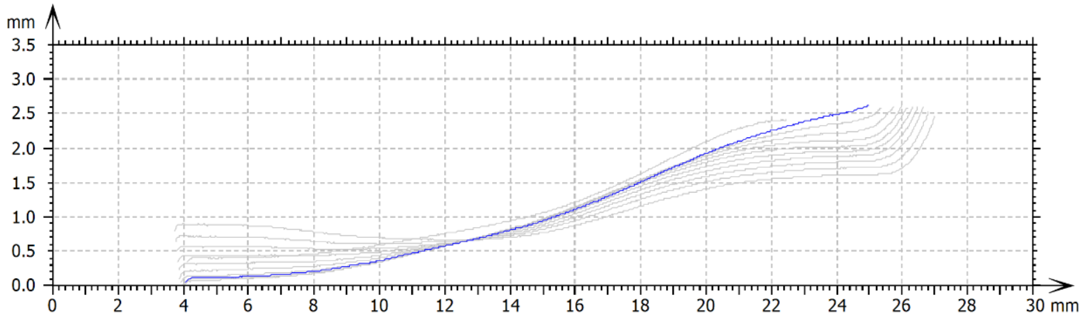


Figure 4: 2D profiles of the blade at different location.

Moreover, the 20-second 3D scan makes it possible to assess the surface conditions of large batches of blade samples after service and quickly detect possible failures such as dents, pitting and cracks for timely repair. Figure 5 displays several typical compressor blade damage. Such blade damage may lead to mechanical failure of the engines and even catastrophic aircraft accidents. Therefore, close inspection and monitoring of the blades is critical to ensure safe flight operation.

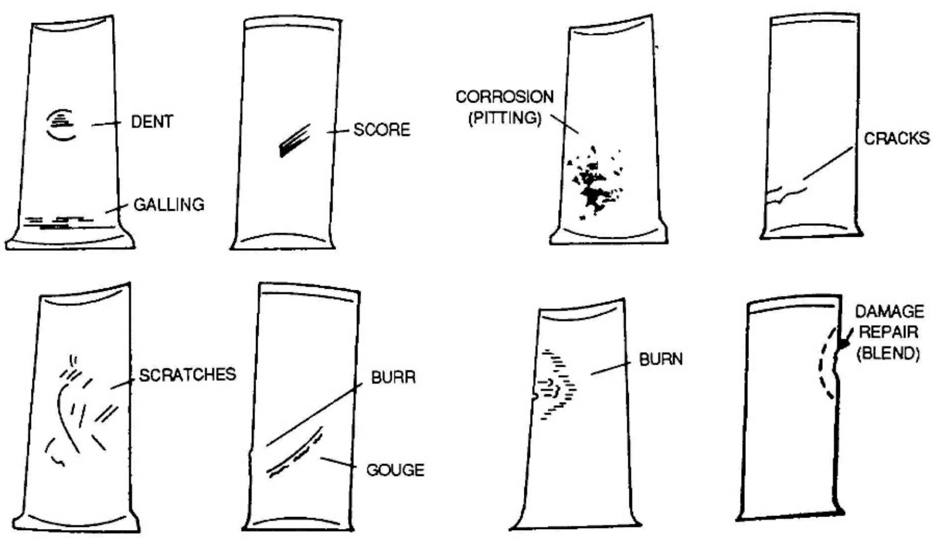


Figure 5: Typical compressor blade damage[ii].

CONCLUSION

In this application, we have shown the Nanovea 3D Non-Contact Profilometer, equipped with an optical line sensor, complete a full 3D profilometry scan of a compressor blade in *20 seconds*. The axial chromatism technique allows measuring the sample surface without touching, making it possible and simple to precisely scan samples with a complex shape such as the compressor blade. The analysis software provides measurements such as roughness, shape analysis, as well as pits and cracks distribution, depth and size, enabling users to obtain more insight in the failure mechanism.

The data shown here represents only a portion of the calculations available in the analysis software. Nanovea Profilometers measure virtually any surface in fields including Semiconductor, Microelectronics, Solar, Fiber Optics, Automotive, Aerospace, Metallurgy, Machining, Coatings, Pharmaceutical, Biomedical, Environmental and many others.

Learn more about the Nanovea Profilometer or Lab Services

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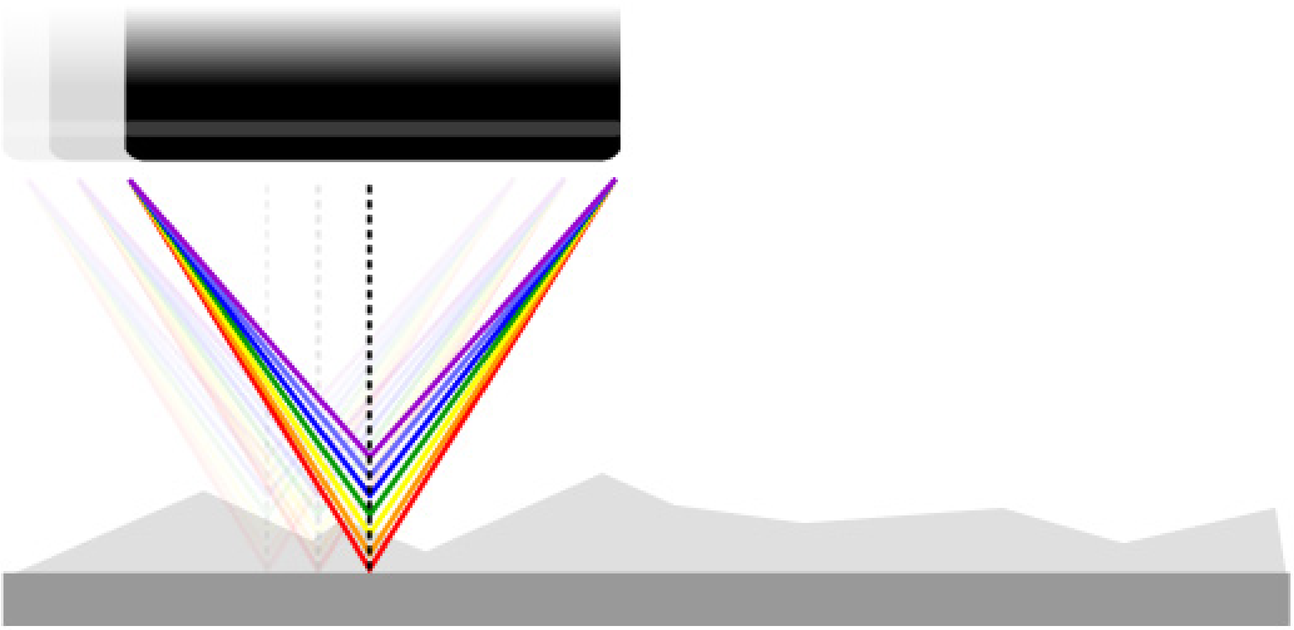
[i] http://www.asetsdefense.org/documents/Workshops/ASETS2012/2/Kilchenstein%20-%20For%20Web.pdf
[ii] http://aviationmiscmanuals.tpub.com/TM-1-1500-204-23-1/css/TM-1-1500-204-23-1_121.htm

MEASUREMENT PRINCIPLE:

The Chromatic Confocal technique uses a white light source, where light passes through an objective lens with a high degree of chromatic aberration. The refractive index of the objective lens will vary in relation to the wavelength of the light. In effect, each separate wavelength of the incident white light will re-focus at a different distance from the lens (different height). When the measured sample is within the range of possible heights, a single monochromatic point will be focalized to form the image. Due to the confocal configuration of the system, only the focused wavelength will pass through the spatial filter with high efficiency, thus causing all other wavelengths to be out of focus. The spectral analysis is done using a diffraction grating. This technique deviates each wavelength at a different position, intercepting a line of CCD, which in turn indicates the position of the maximum intensity and allows direct correspondence to the Z height position.



Unlike the errors caused by probe contact or the manipulative Interferometry technique, Chromatic Confocal technology measures height directly from the detection of the wavelength that hits the surface of the sample in focus. It is a direct measurement with no mathematical software manipulation. This provides unmatched accuracy on the surface measured because a data point is either measured accurately without software interpretation or not at all. The software completes the unmeasured point but the user is fully aware of it and can have confidence that there are no hidden artifacts created by software guessing.

Nanovea optical pens have zero influence from sample reflectivity or absorption. Variations require no sample preparation and have advanced ability to measure high surface angles. Capable of large Z measurement ranges. Measure any material: transparent or opaque, specular or diffusive, polished or rough. Measurement includes: Profile Dimension, Roughness Finish Texture, Shape Form Topography, Flatness Warpage Planarity, Volume Area, Step-Height Depth Thickness and many others.

DEFINITION OF HEIGHT PARAMETERS

	Height Parameter	Definition
Sa	Arithmetical Mean Height	Mean surface roughness. $Sa = \frac{1}{A}\iint_A \lvert z(x,y)\rvert dxdy$
Sq	Root Mean Square Height	Standard deviation of the height distribution, or RMS surface roughness. $Sq = \sqrt{\frac{1}{A}\iint_A z^2(x,y)dxdy}$ Computes the standard deviation for the amplitudes of the surface (RMS).
Sp	Maximum Peak Height	Height between the highest peak and the mean plane.
Sv	Maximum Pit Height	Depth between the mean plane and the deepest valley.
Sz	Maximum Height	Height between the highest peak and the deepest valley.
Ssk	Skewness	Skewness of the height distribution. $Ssk = \frac{1}{Sq^3}\left[\frac{1}{A}\iint_A z^3(x,y)dxdy\right]$ Skewness qualifies the symmetry of the height distribution. A negative Ssk indicates that the surface is composed of mainly one plateau and deep and fine valleys. In this case, the distribution is sloping to the top. A positive Ssk indicates a surface with a lot of peaks on a plane. Therefore, the distribution is sloping to the bottom. Due to the large exponent used, this parameter is very sensitive to the sampling and noise of the measurement.
Sku	Kurtosis	Kurtosis of the height distribution. $Sku = \frac{1}{Sq^4}\left[\frac{1}{A}\iint_A z^4(x,y)dxdy\right]$ Kurtosis qualifies the flatness of the height distribution. Due to the large exponent used, this parameter is very sensitive to the sampling and noise of the measurement.
Spar	Projected Area	Projected surface area.
Sdar	Developed Area	Developed surface area.