Using Full-Field Measurements to Improve Understanding of Water Droplet Erosion of Aeroengine Fan Blades

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Abstract. Water Droplet Erosion (WDE) is increasingly becoming a barrier to future improvements in the efficiency of aeroengines. However, the specific challenges presented by repeated, high-speed, water droplet impingement on the leading-edge of aeroengine fan blades are not fully understood. Full-field measurements have the potential to provide great insight into this highly dynamic event. These measurements will allow for the quantification of the temporal variations in strain and acceleration (leading to stress) in a sample impinged by a water droplet. They allow for the effect of surface form to be evaluated and a more general comparison between the current theoretical treatment of the dynamic loading, and the measured loading through the sample, to occur.

Introduction

The Water Droplet Erosion (WDE) of fan blades, on large civil aeroengines, can lead to a decrease in engine performance and increase the risk of unstable vibrations [1]. This is due to the significant roughening that can occur on the leading-edge of the titanium alloy (Ti-6Al-4V) blades. The need for aeroengine manufacturers to produce fans that are increasingly efficient has changed the WDE of leading-edges from a type of wear that is simply 'tolerated', to one that needs to be actively reduced. Recent advances in surface engineering and coatings could provide the resistance to WDE needed for the next generation of aeroengines. However, it is far from certain what the 'ideal' coating/surface layer would look like; the dynamic loading and its effect on the solid are not fully understood, so materials or coating solutions are difficult to provide.

The mechanisms of WDE are often presented as material and situation specific. However, a general classification of four mechanisms of material removal has been proposed: direct deformation, stress wave propagation, lateral outflow jetting, and hydraulic penetration [2]. In the early stages of WDE, direct deformation and stress wave propagation are active. Once the initially smooth and crack-free leading-edges start to become damaged, lateral outflow jetting and hydraulic penetration also start to occur and the engineering solutions to prevent further erosion are more limited. Thus, increasing understanding of the 'direct deformation' and 'stress wave propagation' mechanisms in the early stages is of primary concern to mitigate their effects.

In order to understand these two mechanisms, it is first necessary to study the two distinct phases of a liquid droplet impingement [3]. These are an initial 'compressible' stage, followed by a secondary 'flow' stage. During the compressible stage, high impact pressures are applied to the surface that are of very short (commonly less than a μs) duration. These pressures can be of the order of GPa for high-speed droplet impingement. They are caused by an initial expansion of the contact periphery between the liquid droplet and the solid surface, so rapid that it exceeds the speed at which displacements can propagate through the liquid. As a result, the droplet behaves compressibly [4] and a region of compressed liquid is formed. This is followed by the flow stage, whose main feature are high-velocity flows of liquid in a radial direction, referred to as lateral outflow jetting. 'Direct deformation' is the material damage resulting from the high pressures applied to the surface of the material during the compressible stage. This damage can take a wide variety of forms. For example, the initial WDE of ductile metals often presents as large numbers of small surface depressions (or 'pitting'). The high rate of loading has been shown to be critical to the mechanism [5]. By contrast, when applied to more brittle materials, the compressive loading of the compressible stage results in damage due to tensile failure. 'Stress wave propagation' describes the stress waves that result within the material from the dynamic pressures of the compressible stage. These stress waves can interact with features within the material and with each other, leading to multiple damage mechanisms.

Various techniques have been used to measure and understand the dynamic loading associated with the initial compressible stage. These have included piezo-electric transducers, schlieren imaging and photon doppler velocimetry [6, 7]. However, researchers continue to rely on basic analytical formulae to characterise the dynamic loading of the compressible stage, in the absence of a more accurate method. Recent advances in ultra-high speed imaging (up to 5MHz), coupled with the Grid Method (www.photodyn.org), provide an opportunity to improve this. By using full-field measurements of the material response to the loading resulting from a high-speed droplet impingement, we hope to improve understanding of the temporal and spatial variations of the pressure applied during a high-speed droplet impingement.

Generating a High-Speed Droplet Impingement

In order to subject a sample to realistic loading, a high-speed droplet impingement is required. Generating this is not trivial and a number of different approaches have been employed by investigators in the past. In this work, a high-speed, curved-fronted, discrete liquid jet (or 'liquid slug') is used to recreate the impingement of a droplet. This technique has been instrumental in developing understanding of WDE and used successfully for over 50 years [4, 7]. The impact of a 9 mm steel ball, accelerated by a gas-gun, is used to produce the liquid slug. To do this, the chamber of a specially-designed nozzle is filled with water, covered with a small piston at rear, which (when impacted) produces a liquid slug from an orifice. Figure 1 shows the experimental set-up.

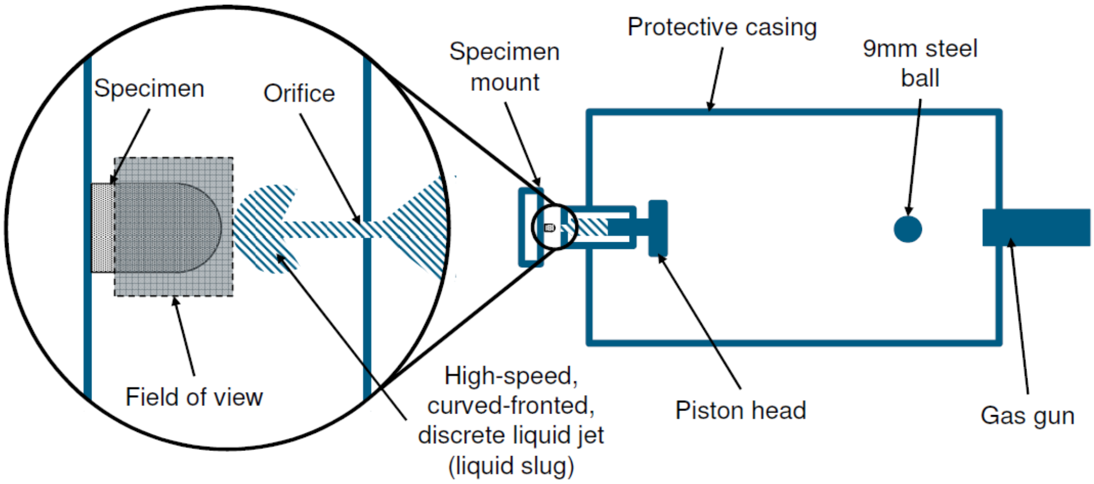

Figure 1: Experimental set-up for producing high-speed droplet impingement on specimen with grid pattern.

The equipment described in Fig. 1 has successfully generated liquid slugs with speeds of the order of hundreds of m/s. Figure 2 shows a sequence of frames from a high-speed recording of the production of a liquid slug.

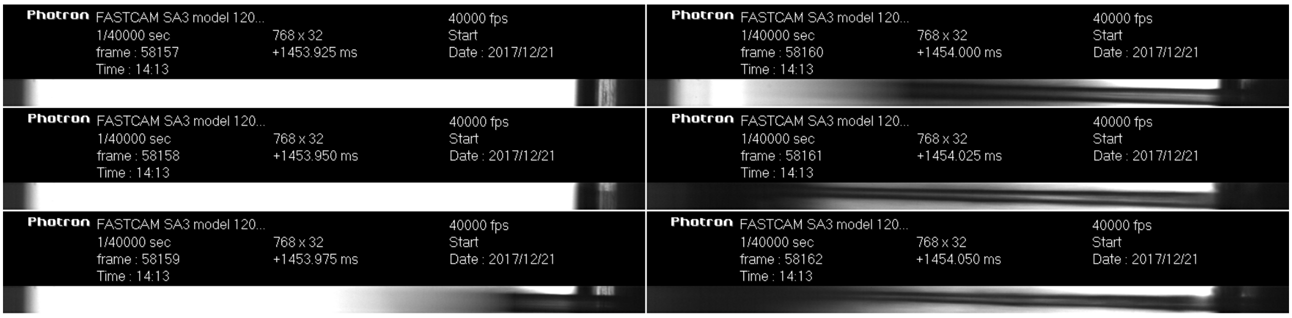

Figure 2: High-speed, curved-fronted, discrete liquid jet produced by experimental equipment

Full-Field Measurements

The Grid Method allows full-field measurement of the temporal variations in displacement, from which strain and acceleration can be calculated. It uses the ultra-high speed (5 MHz) recording of the deformation of a sample, measuring the displacement of the pattern printed on the sample surface. The Grid Method has been selected due to the good compromise it offers between measurement resolution and spatial resolution [8]. It is also possible to use the measurements of acceleration to reconstruct the impact force as a function of time [9]. The presentation will detail the experiment and the data processing, along with results of impacts on different shapes and materials.

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