Characterisation of Splashing from Jet to Rotating Solid

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ABSTRACT

The interaction between a jet and a solid is of key importance in a multitude of systems and is the key to minimizing and containing any splashing that occurs at the point of impact and any subsequent droplets within the system. The ability of characterizing the results of the impact and look at how operating conditions and geometry affect droplet formation.

A rig has been made that allows for the interaction between the blade profiles and the jet to be observed using high-speed camera imagery that has allowed the characterization of any droplets and splashing that occurs. The rig allows for varying rotational speeds of the blade, and varying flow rates through the nozzle which has allowed for a parametric study to be conducted allowing for a greater understanding of the jet to solid impact and how different operating conditions affect the quantity and distribution of different categories identified as part of the characterization.

1. INTRODUCTION

Lubrication of Aeroengine transmission systems is of key importance to ensure the bearings within the system are cooled and reduce the wear on the bearing due to friction. Depending on the bearing design the oil is either delivered through channels within the under race of the bearing or through the gap between the inner and outer race as shown in Figure 1.

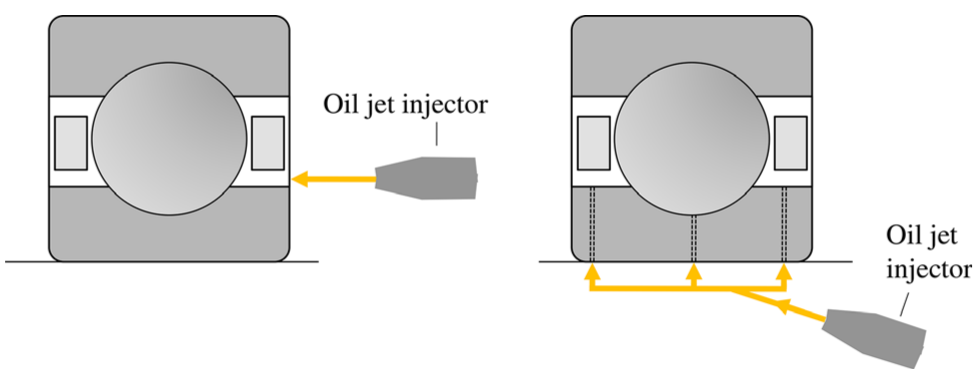

Figure 1 Methods of delivering oil to the bearing through (a) the gap between the inner and outer race and (b) through channels within the under race of the bearing [1]

The current method of delivering the oil to the bearing is using a rotating scoop to change the direction of the oil from radially to axially with respect to the main engine shaft. This can be done with multiple scoop blade which captures oil that is then diverted into the bearing chamber.

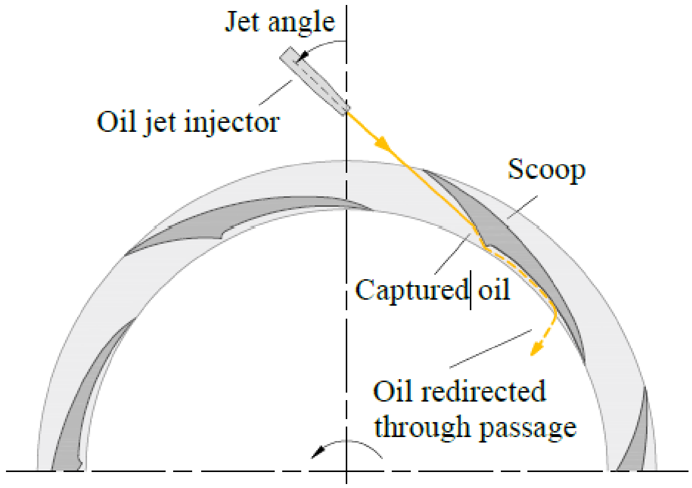

Figure 2 Scoop blade configuration [2]

As the blades rotate, they interact with the jet of oil which results in splashing, this splashing can be seen as a loss of oil that is not delivered to the bearing at that point. When the splashing occurs, it can be categorized into one of the 6 impact types; Deposition, Prompt splash, Corona splash, Receding breakup, Partial rebound and rebound [3]. By categorizing the impact of the jet when there is contact with the blade the relevant parameter to that impact type can be studied to reduce the splashing that occurs.

2. IMPACT TYPE CHARACTERISATION

When droplets impact a solid 6 different impact types can occur; Deposition, Prompt splash, Corona splash, Receding breakup, Partial rebound and rebound through the work by Rioboo et al [3] the parameters that can determine the type of outcome as the droplet makes contact with the solid surface.

Rioboo et al. [3] examined how the impact velocity and droplet size affected the outcome along with other parameters relating to the solid's surface properties and the fluid properties of the droplet. Rioboo et al. [3] noted that the increase in impact velocity, which can also be considered as an increase in jet velocity in the case of a rotating blade system, promotes more prompt splashing (See Figure 1). The effect that impacts velocity has on the outcome of splashing was also noted by Tropea et al. [4] who when investigating noted that in multiple studies the relationship between a higher impact velocity and the Ohnesorge number resulted in droplets moving from deposition outcome to either incipient splashing or splashing. Rioboo et al. [3] also noted that the increase in impact velocity resulted in a higher probability of receding breakup.

Figure 3 Prompt Splashing Example [5]

Rioboo et al. [3] also noted that droplet size can cause the outcome to change from deposition to corona splash as the droplet increases in size, when the surface roughness of the solid increases a prompt splash can occur before the corona can be formed minimising the quantity of smaller droplets forming.

As noted in Rioboo et al. [1] and Tropea et al. [2], operating conditions such as impact velocity and droplet size can cause different outcomes depending on the system. When translating these factors to the rotating blade system the main factors as noted by Kruisbrink et al. [2] are the jet diameter, the speed ratio between the jet and rotating blade as well as the angle at which the jet is in relation to the blade are key factors in any splashing that can occur. The idea of geometry to also study the effect that the area of impact has on the outcome has not been heavily studied, the work by both Rioboo et al. [3] and Tropea et al. [4] both used contact areas greater than the droplet diameter.

The jet can also be a source of impact outcomes as noted by Yarin [5] and this can contribute to small droplets being formed as toroidal bubbles can form which immediately break up into smaller bubbles. This can also be seen in that if any water from the blade disrupts the flow it can be considered as a head-on collision of two liquid jets which Yarin [5] determines as an example of splashing in the form of a radially expanding liquid sheet.

3. INTERACTION BETWEEN BLADE AND JET

The geometry that is the subject of this study is a double-blade system that has now a collection system to divert the water away from the blade surface as shown in Figure 4. The profile has a straight blade profile which is used in U.S. Patent No. 6,682,222 [6]. This simplified geometry allows for the impact of the jet to be more easily categorised.

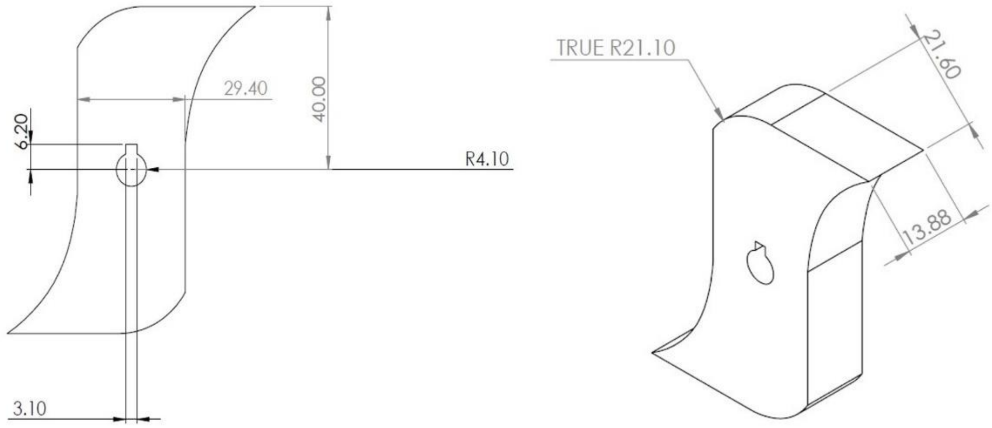

Figure 4 Scoop blade geometry

3.1. Operating Conditions

The interaction of the jet was captured using a Photron MINI UX100 with the frame rate set at 8000fps which allows for the splashing that occurs at the point of interaction to be captured. The blade shown in Figure 4 was run at 3000RPM with a flow rate from the nozzle increasing from 0.2L\min to 0.4L\min.

4. EXPERIMENTAL TEST RIG

Figure 5 shows the experimental rig that was created for this study and takes advantage of additive manufacturing to crease the blades as well as the support system for the nozzle while allowing for the angle with respect to the blade face to be altered in further work.
To measure the rotational speed of the blade a handheld tachometer was used with reflective tape on the blade. This method of measuring the rotational speed of the blade had a large percentage error as the movement of the laser resulted in a difference in reading so the target speed was achieved if the value on the tachometer was ±300rpm or 10%.

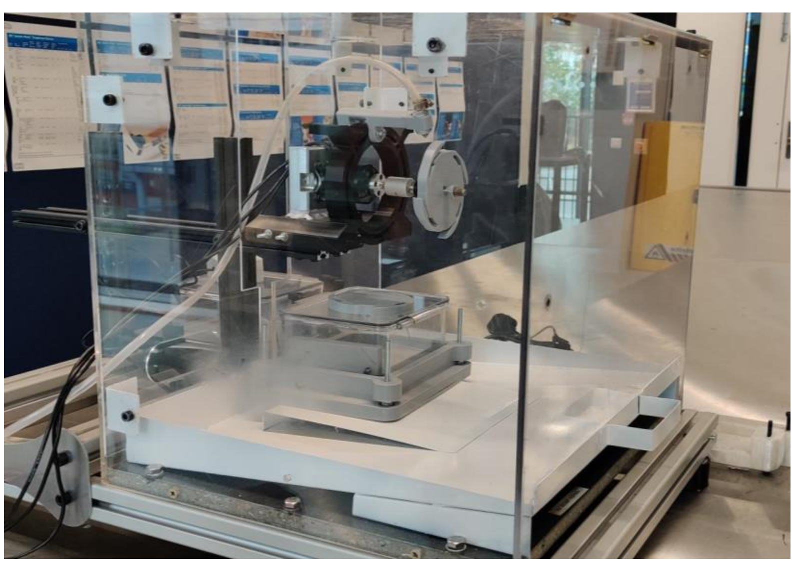

Figure 5 Experimental Test Rig

5. RESULTS AND DISCUSSION

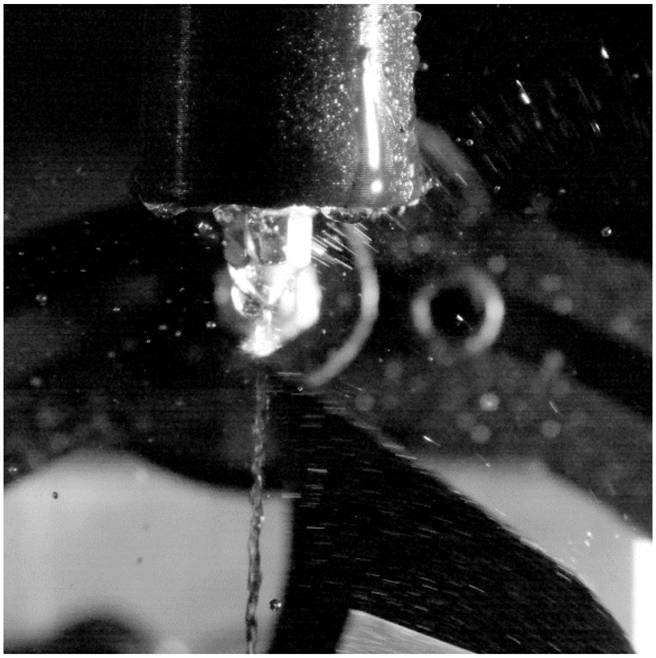

Figure 6 Initial impact with the jet with a flow rate of 0.22L\min

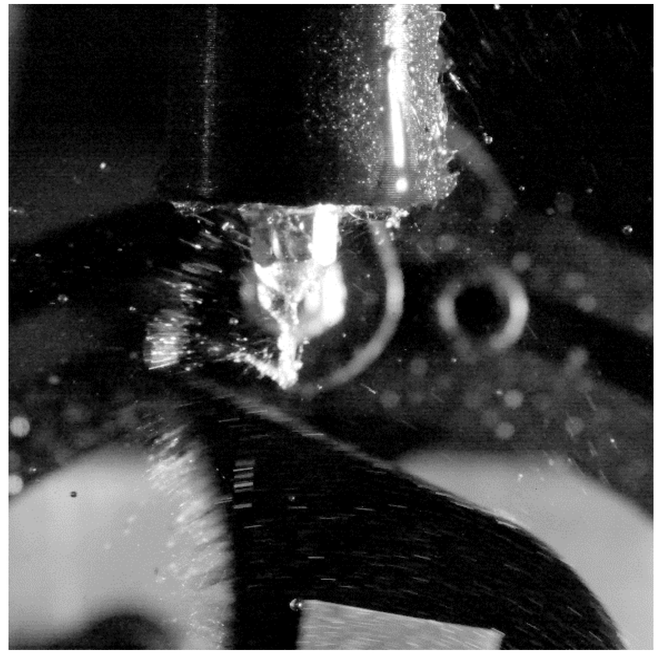

Figure 7 Jet disrupted due to initial impact with a flow rate of 0.22L\min

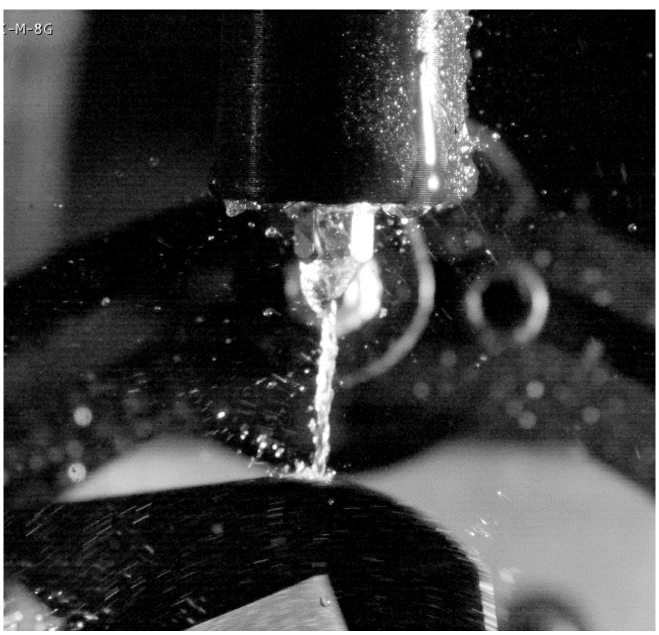

Figure 8 Corona Splashing on the upper blade surface with a flow rate of 0.22L\min

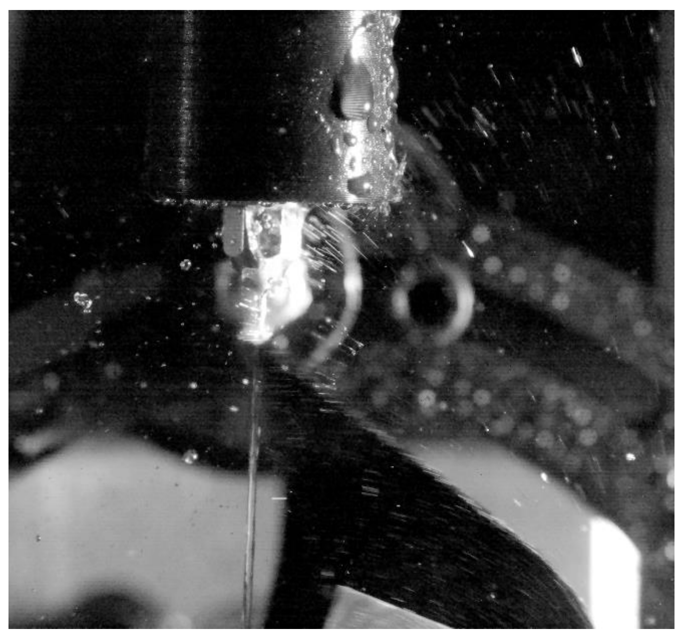

Figure 9 Initial impact with the jet with a flow rate of 0.3L\min

Figure 10 Jet disrupted after initial impact with a jet flow rate of 0.3L\min

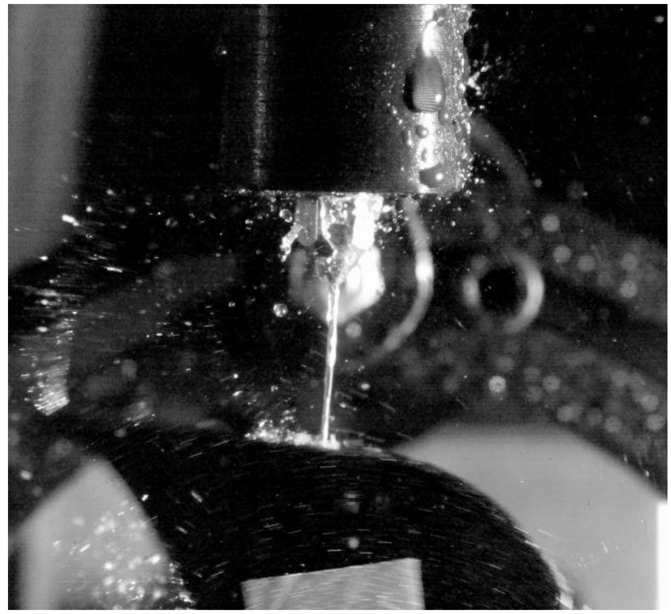

Figure 11 Secondary impact on the blade with a jet flow rate of 0.3L\min

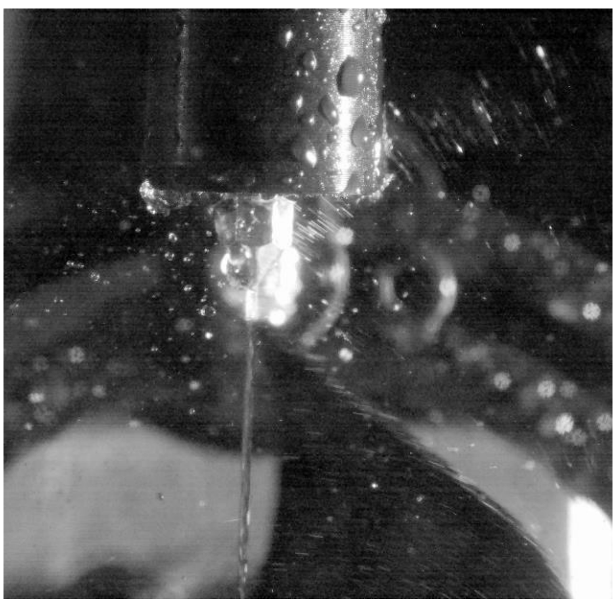

Figure 12 Initial impact with a jet flow rate of 0.4L\min

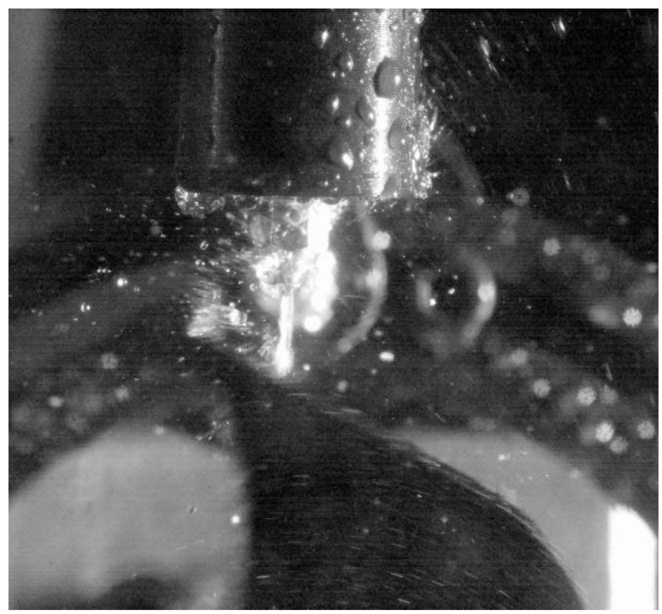

Figure 13 Disrupted jet with a flow rate of 0.4L\min

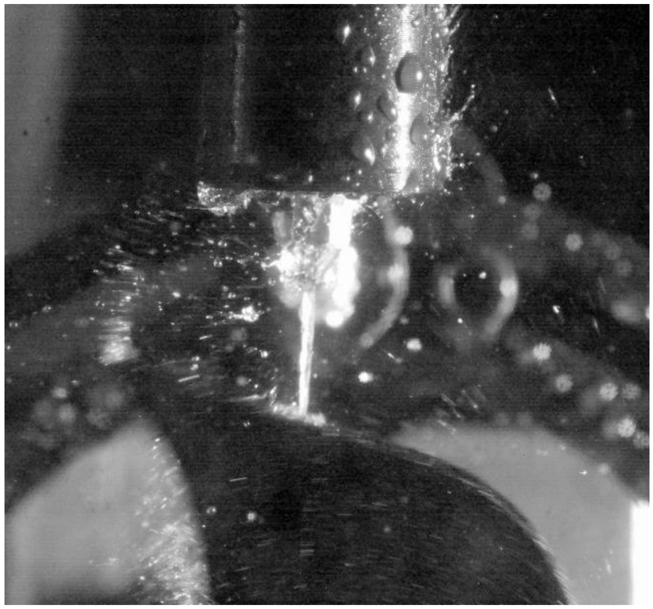

Figure 14 Secondary impact on the blade with a jet flow rate of 0.4L\min

Figures 6, 7, and 8 show the impact sequence when the blade is spinning at 3000RPM with a jet flow rate of 0.22L\min. The initial contact with the blade and the jet causes water droplets to be disbursed and the jet flow to be disrupted with large and small droplets being produced from the impact. As the jet has been disrupted there is a period of no interaction between the blade and the jet as shown in Figure 7. This break along with the geometry of the blade increases the distance between the jet and the blade when the secondary contact occurs as shown in Figure 8. This increase in distance contributes to an increase in stream velocity which intern leads to a higher Weber number which leads to a higher Ohnesorge number through the work demonstrated by Yarin [5] this increase in velocity makes prompt and corona splash more prevalent which can be seen in Figure 8.

As the jet flow rate increases to 0.3L\min the point of secondary interaction happens further towards to leading edge of the blade as shown in Figure 11. This increase in flow rate has caused a greater quantity of larger diameter droplets at the point of initial interaction as shown in Figure 10 which is just after the initial impact as shown in Figure 9. These larger droplets when they interact with other surfaces outside of the frame will be more susceptible to prompt splash as shown in the work by Yarin [5].

As shown in Figure 11 the secondary impact is further forward, this has reduced the distance between the blade and the jet nozzle after the stream has been reformed leading to a reduction in impact velocity leading to more of a receding breakup occurring on the blade. The angle of the surface at the point of interaction is also at a slight angle deflecting the jet along the blade's surface.

This reduction in the distance between the jet nozzle and the surface of the blade is more prevalent when the jet flow rate is 0.4L\min as shown in Figure 13 where the secondary interaction as shown in Figure 14 is in the leading 50% of the blade upper surface. As with the secondary interaction when the flow rate was 0.3L\min the blade surface is at an angle reducing the impact from the jet and reducing the splashing to create a deposition impact between the blade and the jet.

The type of impact that occurs when the jet and blade interact can be affected by the flow rate of the jet nozzle as it determines the point of secondary impact on the blade if the rotational velocity of the blade is constant. If the situation requires a set jet velocity the rotational velocity of the blade can therefore be changed to alter the position of the secondary interaction.

It is also noted that due to the geometry of the blade, the secondary interaction can happen when the blade is at an angle with respect to the jet stream. This can also contribute to a reduction of corona splashing this is demonstrated in Figure 8 where there is large amounts of corona splashing but as soon as the impact is at an angle the amount of corona splash reduces as shown in Figures 11 and 14.

The ability of characterising the splashing that occurs from jet to rotating solid has allowed for parameters from the jet and the blades speed to be understood better and can influence system alterations to reduce splashing such as increase in flow rate or geometric adjustments to create an angle between the jet and solid at the point of secondary impact.

6. REFERENCES

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