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Further Discussion of Bird Strike Design Issues for Engines with Obscured Fans

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Abstract: *A previous conference presentation (Baltimore, 2004) introduced the subject of obscured turbo-fans and discussed it in the context of bird strikes. In such a case, the bird will have significant interaction with the internal structure of the aircraft intake during its passage from intake lip to fan and damage to the bird may well occur causing it to pose a significantly different threat to the integrity of the engine. This paper explores the possible interactions that take place in such an installation prior to the bird reaching the fan face and makes use of engine and bird structural test data to describe the effect of such interactions on the bird structure. The implications of these interactions on the behaviour of the fan during the bird ingestion are then explored; again using test and analytical evidence.*

1. Introduction

The vast majority of aero-engines installed within civil airframes are positioned such that the fan blades are clearly visible from the exterior of the engine and as such there is a direct line of sight during flight for any ingested bird to impact the engine structure. In this case, the bird may be considered to be intact as it enters the engine.

This paper however, is concerned with those engines installed principally within military airframes where there is no direct line of sight for the bird from the exterior of the intake to the fan blades. In this case there is inevitably an interaction of the bird with the intake and the possibility of damage to either the bird or the intake structure.

The aspect of this interaction that this paper is concerned with is the effect of the impact on the structure of the bird, with the ultimate aim of demonstrating the likely impact threat at the entry to the engine.

This work builds on that presented in Reference 1.

2. Background

The problem is presented in pictorial form in Figures 1A and 1B. Clearly, for this design of intake, it is only at very contorted flight attitudes that a bird might reach the engine structure without touching the intake wall. For other, more exotic intake profiles, contact with the intake wall will be inevitable

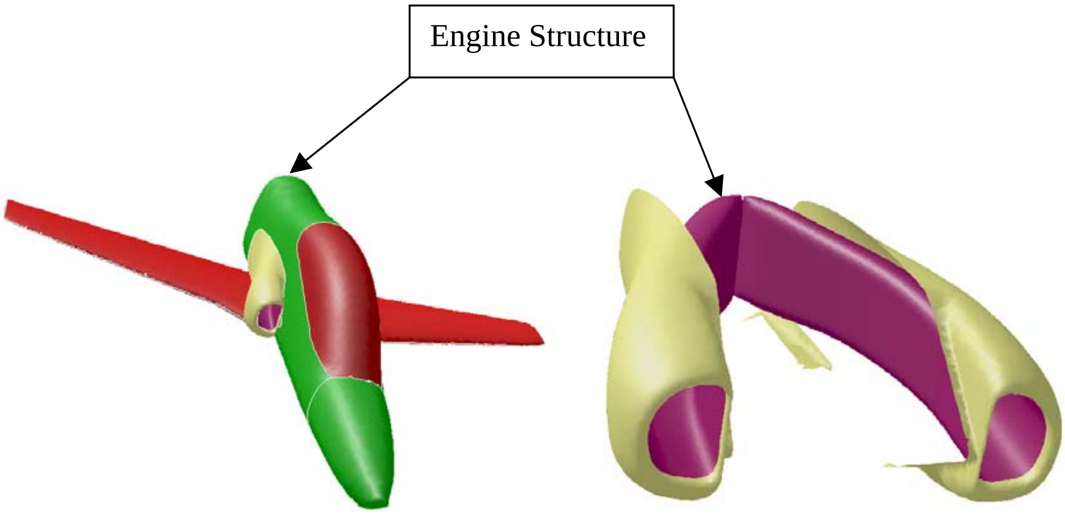

Figure 1A – Generic Single-Engine A/C *Figure 1B – Bifurcated Intake*

For someone involved in the design of engines for such airframes, there are then two obvious questions to be answered prior to commencing a new project:

1; What path will the bird follow down the intake and what will be the severity of the impact(s) that the bird experiences with the intake wall?
2; Following such impact(s) what will the bird state be at the time it begins to interact with the engine structure.

In addition to the complex engineering issues raised by these questions, the process of answering will inevitably add a further level of complexity; i.e. the use of statistics. This is because provided that the bird is smaller in area than the intake aperture, there will be many different ways in which the bird and intake can contact prior to arrival at the engine and therefore there will be a continuum of relevant answers.

3; Impact Spread

The spread of the bird impacts round the internal intake structure is governed by three main parameters:

1; The geometrical position at which the bird enters the intake structure.
2; The trajectory with which the bird enters the intake structure.
3; The intake geometry.

The understanding of these phenomena is facilitated by the use of Rolls-Royce proprietary software 'Splat'. This allows a particle (in this case a bird) to be tracked through a flow field given set boundary geometry and arbitrary initial conditions such as trajectories and velocities; this includes any 'bounces'.

The data contained within Figures 2A,B,C is output from Splat and shows how for a generic intake the passage of a bird can vary considerably for the example of two initial starting conditions.

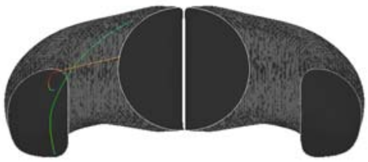

Figure 2A – Front View with Two Typical Trajectories

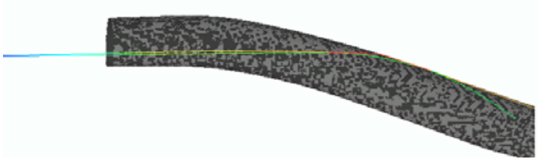

Figure 2B – Top View

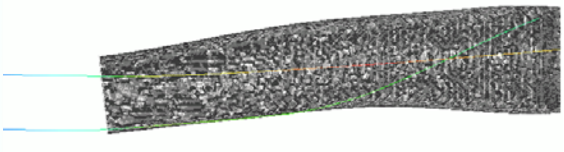

Figure 2C – Side View

The output from this process is that for a given set of input conditions, the velocity and trajectory of the bird at the front of the engine structure can be determined. This includes any acceleration/deceleration due to drag or energy loss that is automatically accounted for.

4; Bird Damage

The state of the bird as it arrives at the engine following its passage through the intake and interaction with the intake walls is not something that is easily determined. Legacy data did exist within Rolls-Royce at the start of recent work however, as is typically the case with legacy data, there was not enough to be statistically significant and what there was had not been recorded in sufficient detail to be useful.

An example of this is shown in Figure 3 that is a still from high-speed film of a 1970's development test as a bird is about to be ingested. In this test, the effect of the intake has arbitrarily been represented by the bird impact on a flat plate (not shown) prior to passing into the engine structure. From the still it is clear that the bird is in the process of breaking up however it is impossible to say anything about fragment size or shape.

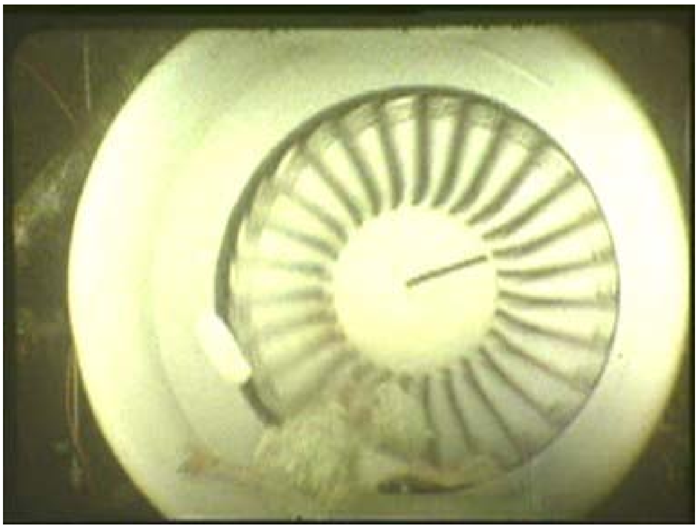

Figure 3 – High Speed Film Still Showing Bird Breaking Up

Clearly one possible way forward would be to consider creating the required data computationally however even with today's computing power and modelling capabilities, the accurate prediction of bird break-up is impossible simply because the detailed physiological models of birds (and the associated material models) do not currently exist.

In order to address this shortfall on bird damage data following impact, a dedicated test programme was initiated with the following requirements:

1; The ability to launch birds of varying masses with a range of velocities.
2; To impact a flat plate of varying stiffness and varying inclination to the bird line of flight.
3; A soft recovery system to enable the resulting bird fragments to be collected and then weighed and measured.

5; Bird Break-Up Test Technique

Using a single stage gas gun, Pheasants were fired at a variety of stiff and flexible flat plates and then soft recovered. The decision to use Pheasants was based on availability and because of the relatively wide mass range that is found in the field.

Trials were completed with zero (no plate interaction) impact energy conditions to ensure that the soft recovery system functioned correctly with birds being weighed before firing and after recovery to prove no break-up and no loss of mass.

After each test, all the significant remains of the bird were gathered together. The total mass recovered was measured along with the mass of the five largest fragments. Figure 4 shows a typical bird after recovery.

Figure 4 – Typical Mid-Sized Bird Remnants

6; Bird Break-Up Results

One of the central drivers for the work was to develop understanding of the relationship between size of bird and the size of final fragment for a given set of input conditions. Figure 5 shows a set of remains from a substantially larger bird than that in Figure 4. In Figure 5, it may be observed that the size and therefore mass of the largest fragment is proportionally considerably larger than that in Figure 4.

Figure 5 – Typical Larger Bird Remnants

This observation is what might be expected given experience of performing tests in this manner for engine development. In addition, the existence of thresholds has long been suspected; either side of which the behaviour of the bird is markedly different.

The data contained within Figure 6 is just one example of the thresholds found during this work. This clearly shows that in the case of a series of tests where all parameters are held constant except for impact plate angle, a bird will not begin to break up until the angle reaches a set value i.e. the impact energy reaches the threshold level. After this point, the bird breaks up in what is initially a very rapid manner.

It is also interesting to note that as the angle of the plate becomes more severe and therefore the impact energy seen by the bird rises still further, the gradient of the line becomes much reduced implying that it is becoming much harder to put further damage into the structure of the bird.

It is observed in practice that in the limit, a bird will break up so that it closely resembles a thick soup – commonly termed 'bird slurry' – where the fragment size is very small and there are no recognisable pieces of bird left. This is typically the case when impacting a fan blade where very high energies are achievable.

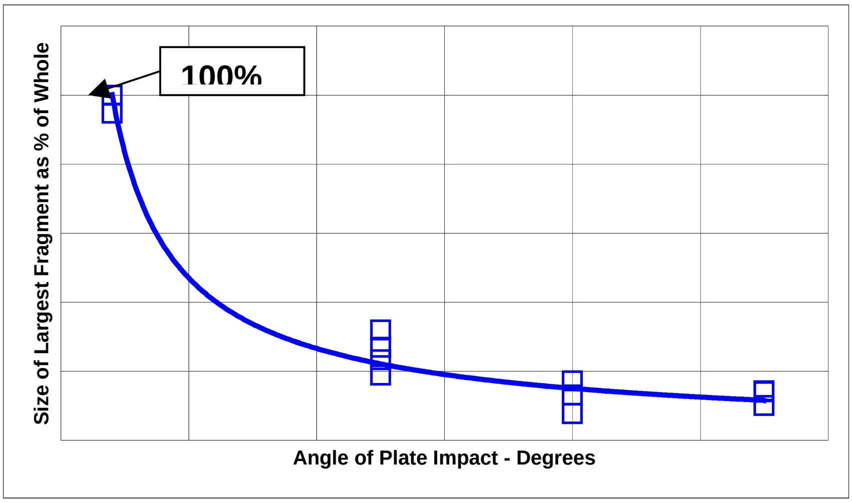

Figure 6 – Variation of Fragment Size with Plate Impact Angle

The data contained within Figure 7 allows some discussion of the effect of the angled plate (rigid or flexible) on the state of the bird when soft recovered. Again, as might be expected, for a given bird size the rigid plate seems to drive a smaller bird fragment as a result of a more severe impact. However, this only appears to be the case at smaller bird sizes and washes out for larger birds.

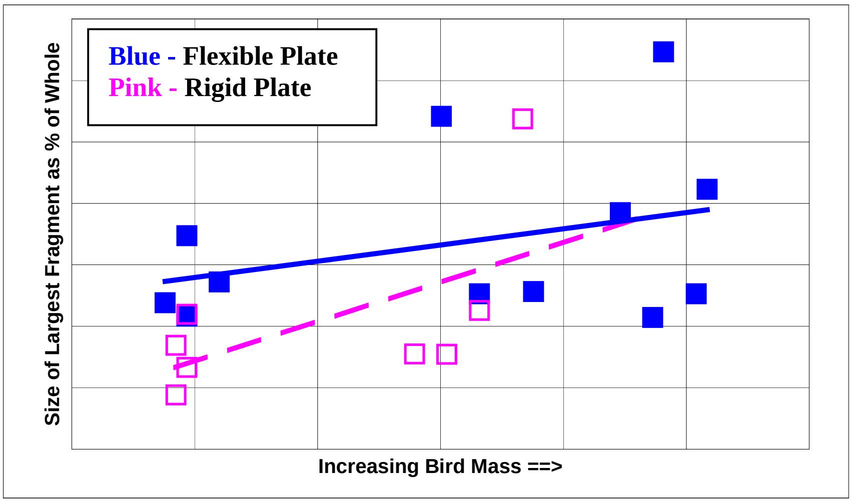

Figure 7 – Variation of Fragment Size with Bird Mass

7; Statistics

Given the data discussed in this paper, it is possible to see how, once a set of initial conditions have been determined, the condition of a bird at the point of ingestion into the engine can be predicted. This is all very well, but does not address the real issue of what effective threat the bird poses to the engine hardware since the engine will ingest birds at a range of masses, forward speeds, power settings and intake locations.

The only effective way to deal with this data is to use a statistical method such as Monte-Carlo analysis. This would allow the theoretical threat posed by a typical bird distribution to be filtered down to the effective threat. This would then provide some alleviation to the prevalent design criteria and allow a proactive and efficient design solution to be generated rather than a reactive one.

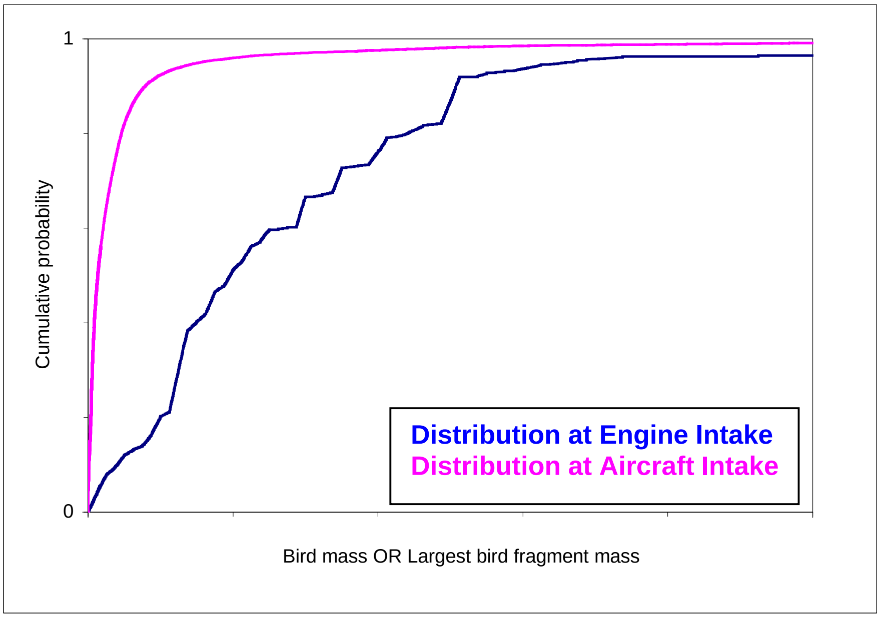

Figure 8 – Relative Distributions of Bird Mass at Intake and Engine Throats

Figure 8 contains a comparison of two bird mass distributions that have been generated after performing a Monte-Carlo analysis for generic intake geometry. The blue line represents the distribution of bird mass at the entrance to the intake whilst the pink line represents the distribution of bird mass at the entrance to the engine; i.e. after filtering by the intake geometry.

The impact of this filtering effect may be estimated by assuming a bird mass at the entrance to the intake and then reading across to the cumulative probability axis. This value is an estimator of the amount of risk that is satisfied by the engine being able to satisfactorily ingest this size of bird. If this same risk level is now read via the pink line down to the bird mass axis, it can be concluded that the size of fragment that actually has to be designed for is significantly smaller and therefore the presence of the intake represents a significant alleviation.

8; Conclusions

The work presented here shows how through testing, an understanding of the variation in bird break-up has been developed. This has direct significance for the design of aero-engines where an interaction of the bird with the aircraft structure is very likely before the bird is ingested.

Of the physical effects investigated thus far, the presence of thresholds in bird break-up behaviour has been mapped and the significance of intake wall stiffness has been described.

It is intended that this work will continue in a limited fashion in order to further investigate features discovered in this preliminary phase.

9; References

1; Proceedings of the Bird Strike Committee USA/Canada – 2004; presentation entitled – ‘Bird Strike Design Issues for Engines with Obscured Fans’