BIRD STRIKE COMMITTEE EUROPE
BSCE23/WP61
LONDON, 13-17 MAY 1996

BIRD INGESTION AND ROLLS - ROYCE AERO ENGINES

by Ian Martindale
Corporate Specialist - Mechanical Methods
Rolls - Royce plc
PO Box 31
Derby
DE24 8BJ
UK

SUMMARY

This paper is intended to give non-engineers an insight into the problems encountered when designing a civil aero-engine to meet the bird ingestion threat. It gives a brief introduction to the principles of the jet engine and to the components which are most vulnerable to damage, outlines the certification regulations which must be satisfied and describes the design methods and testing involved. It conclude that, while great steps have been made in improving the mechanical integrity of engines to make them capable of ingesting birds of increasingly higher weight, there is a law of diminishing returns in operation which shows that it may be unrealistic to expect further improvements in air safety in this field to be achieved by engineering alone. The problem must be recognised as a common one for engine manufacturers, engine operators and airport managers to combat together.

Key Words: Engines, Propellers/Rotors, Certification Standards, Finite Element Analysis, Mathematical Models, Testing, Bird Impact, Civil Aviation

1. INTRODUCTION – PRINCIPLES OF PROPULSION – HOW IT WORKS

'SUCK, SQUEEZE, BANG, BLOW'

The jet engine is a machine designed to carry out a fairly simple action. The engine takes in air at the front, compresses it, adds energy to it in the form of heat and then allows it to rush out of the rear of the engine at high velocity. The reaction to the air rushing out of the back propels the engine forward. From the engine man's perspective,all you then have to do is to attach an aeroplane to a number of engines and the job is done!

The cycle the air undergoes in passing through the engine is the familiar one of induction, compression, ignition and exhaust that takes place in our own car engines. The less technical description I have heard is 'suck, squeeze, bang, blow'.

However, just as a real aeroplane is a great deal more complicated than a paper dart, the real engine which does all this blowing of hot air is also extremely complex.

Figure 1 shows a sectioned view of a Rolls – Royce Trent 890, an engine which produces up to 90,000lbf (400KN) of thrust. This is a great deal of thrust for a machine of modest weight. If my car engine had the same power to weight ratio as the Trent then it would be developing 2000 horsepower instead of the 120hp it actually delivers and it would reduce my 0 to 60 miles per hour (100kph) acceleration time to half a second.

About 75% of the thrust is provided by the large fan at the front of the engine. It is 2.8 metres (110 inches) in diameter and contains 26 hollow titanium fan blades. The tip of each fan blade is travelling at over 1½ times the speed of sound on take off. The shape of the fan blade is controlled to very small fractions of a millimetre; its aerofoil angles are critical to fractions of a degree; one blade contains enough Kinetic energy to lift a family car 35 metres into the air; but it is less than 1 millimetre thick in some places.

The point of these statistics is to underline the fact that the energy density in an engine like this is very high and the rotating blades and discs are travelling at very high speeds. Maintaining the engine's components in good condition and with the correct geometry to effectively pump 1000kg of air per second is vital to maintaining the engine's thrust and keeping the aircraft flying.

However, when a bird flies into the front of the engine, things can go wrong.

2. BIRD INGESTION

'SUCK, (*THUMP*), SQUEEZE, BANG, BLOW'

The fan produces thrust by pushing a large mass of air rearwards at high velocity. This pumping action produces an air pressure of typically 40KPa (~6 psi) on the surface of the fan blade. A bird is very much more dense than the air and it enters the fan at a relatively slow speed. These two effects mean that it applies very high local pressures to the surface of the aerofoil. These can be as high as 15MPa (~1 tsi) and distortion of the aerofoil and sometimes failure of the blade can be the result.

Figure 2 shows how the fan slices a bird and figure 3 shows how the high pressure has caused the blade to bulge forward. These bulges disrupt the airflow and cause thrust loss and blade vibration. With too much thrust loss , if more than one engine has been hit, the aircraft could have difficulty continuing the flight. Too much vibration might also damage the engine structure or cause blades to fail.

In an extreme case, the bulge might crack and part of the blade might be released. Ultimately, we must cater for the very remote eventuality that a bird removes a whole blade by providing a containment system which will catch the entire released aerofoil.

To ensure that the industry knows what standards to apply in the design of engines, for instance, in terms of bird weight, phase of flight etc.,there are regulations which, using the experience of the years, set us minimum standards of integrity which must be demonstrated during engine certification.

3. CIVIL ENGINE INGESTION REGULATIONS.

The bird ingestion regulations for civil aero engines have gradually become more severe over the years as the manufacturer's and the regulator's perception of the threat has changed. It started with a CAA large bird (4lb) regulation in 1956, a small (4oz) flocking bird requirement (FAA–1960, CAA–1964), moving on to a 1½lb medium bird flocking requirement in the early 70's (CAA–1970, FAA–1974), usually driven by significant in–service events.

In 1975 a ONA DC10 crashed at JFK Airport, NY When Great Black–Backed Gulls were ingested into the number two engine. This triggered a series of events which led to the loss of the aircraft but, thankfully, no passengers or crew. As a direct result of this event, a great deal of work has been done which has lead to the proposed revised regulation summarised on figure 4. In practice, the new, large, high thrust engines (RR Trent, PW4084, GE90) have already been designed to this level of integrity before the new regulation has entered the rule book.

How do we make sure that a new engine can meet the requirements?

4. DESIGNING FOR BIRD IMPACT

There are many parts of the engine which can be struck by birds, ranging from the obvious, like the fan, intake and spinner, to the not so obvious, like the Electronic Engine Control box and the combustion chamber. It is the fan which poses the biggest design challenge, being crucial to the engine's performance in terms of efficiency and weight, so, to gain an appreciation of the magnitude of the task, it is worth looking at how we design and test the fan blade.

The large size of the fan on an engine like the Trent means that it has to be designed to be as weight efficient as possible. Rolls – Royce first put a hollow fan into service in the early 1980's. The latest Trent fan is a development of this technology in which a hollow external aerofoil shape formed by titanium sheets stabilised by an integral core structure. The main parameters which govern the shape of the blade – diameter, hub:tip ratio, number of blades, aerofoil thickness etc is set by aerodynamic requirements. The stressing and mechanical aspects, after an initial preliminary phase, are finalised by Finite Element (FE) Modelling.

Not only are the steady stresses due to blade rotation and the alternating stresses due to blade vibration calculated using FE methods, but the damage due to bird impact is also calculated using an FE program called Dyna3D. Figure 5 shows a Dyna3d model of a blade and bird impact. The typical leading edge dent can be seen forming due to the impact of the bird slice. This method can be used to look for signs of material failure at the leading edge, in the blade panels or at the root fixing. It also gives a prediction of the depth of the leading edge dent which determines the thrust loss suffered by the engine. Further running can be carried out to assess the affect of subsequent vibration on the damaged structure.

However, as all computer modellers know, real life has a habit of catching up with you and it is not until the acual components are tested that you can relax knowing the sums are right.

5. BIRD IMPACT TESTING

As a first step a new blade undergoes what RR calls a 'single–arm' test in which a single blade is impacted by a dummy bird in a spinning rig . The bird is dropped into the fan and is timed to impact the blade such that the correct slice mass is cut from the 'bird'. The incidence angle and velocity are also carefully controlled to give the same impact loading, hence damage, as occurs in an engine.

A fully bladed fan may then be tested in the rig if desired. A real, dead, bird is used to ensure realism.

The certification test also uses real birds which are fired into the running engine from a multi–barrel air gun. The test is monitored using high speed film and video which enables the accuracy of the bird targetting and entry speeds to be confirmed and many engine performance parameters such as pressures, shaft speeds, temperatures, accelerometer and strain gauge output etc. are recorded during the impact of the birds and also during the 20 minute run–on period. The Trent 800 has recently undergone such a test, losing only 3% of maximum take off thrust.

6. CONCLUSIONS

The threat imposed by birds has been perceived differently at different times. The realisation that more stringent requirements were needed to reduce the accident/incident rate for large, twin engined airliners to an acceptable level resulted in the 2½lb medium bird ingestion regulation.

In addition, bird populations are not static and there is a growing perception that there is an increasing risk of suffering multiple engine failures due to striking flocks of large birds - the growingCanada Goose population is usually quoted as an example of this.

However, it is worth stopping to think about how effective further engine 'bird proofing' measures would be.

Figure 6 shows the bird weight distribution recorded during the FAA Large, High Bypass Ratio engine study of 1990. It shows how the pay off for a move from 1½lb to 2½lb in the medium bird regulation is a respectable reduction in the proportion of the bird population not covered by the regulation. The law of diminishing returns is also clearly in operation. A further increase in the medium bird weight to say, 4lb would represent, in engineering terms, a hugely difficult task, having significant economic and environmental penalties because of the extra engine weight and extra fuel burned, but would have a relatively small improvement in the resultant safety of the aircraft, covering only about 5% more of the bird population than the 2½lb rule.

This leads to the thought that it may not be practical to expect our aspirations for further improvements in birdstrike safety to be satisfied by engineering alone.

The best way forward must be based on the realisation that there is a partnership between manufacturers, regulators, airport operators, pilots and bird control experts to ensure that :

- adequate measures are taken to prevent birds (especially those larger than the certification weights) gathering at all airports to reduce the frequency of encounters

- the best thinking on airport environmental control is applied

- bird scaring teams are constantly on watch, providing warnings when there is a hazard

- all concerned in the industry are educated about the problem

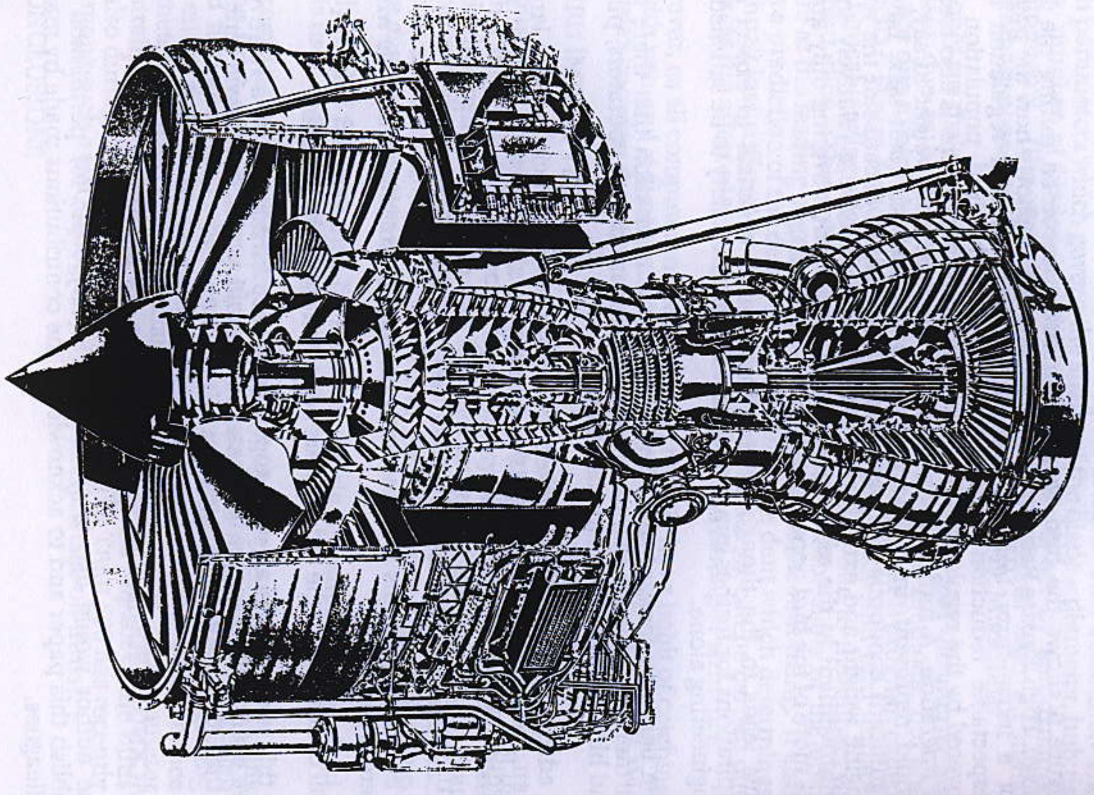
In this way, we can all work together to keep bird ingestion a relatively rare event and to ensure that hazardous, multi engine events will remain in the Exremely Remote category.

7. ACKNOWLEDGEMENTS

The author would like to thank Rolls - Royce plc for permission to publish this paper and to acknowledge the contributions made by many colleagues.

ROLLS ROYCE AEROSPACE GROUP

TRENT 890



BSCE 23

fig 1

ROLLS ROYCE AEROSPACE GROUP

BIRD SLICING BY FAN BLADES

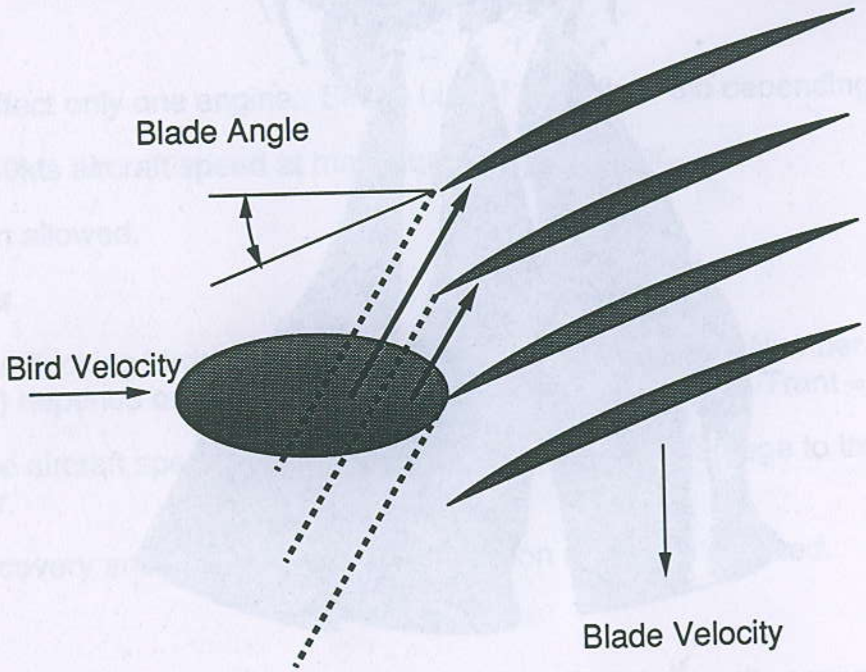


fig 2

ROLLS ROYCE AEROSPACE GROUP

IN SERVICE BIRD INGESTION DAMAGE

BSCE 23

fig 3

ROLLS ROYCE
AEROSPACE GROUP

PROPOSED BIRD INGESTION REGULATIONS

Large birds

Assumed to affect only one engine. Single bird of 4lb, 6lb or 8lb depending on size of engine.

Ingested at 200kts aircraft speed at maximum take off power.

Safe shutdown allowed.

Medium birds

Assumed to be flocking birds so can be ingested by two engines. Number of birds and weight (0.7lb to 2.5lb) depends on size of engine   e.g. BR710 = 4 x 1½lb, Trent = 4 x 2½lbs.

Ingested at the aircraft speed which would produce the most damage to the fan at maximum take off power.

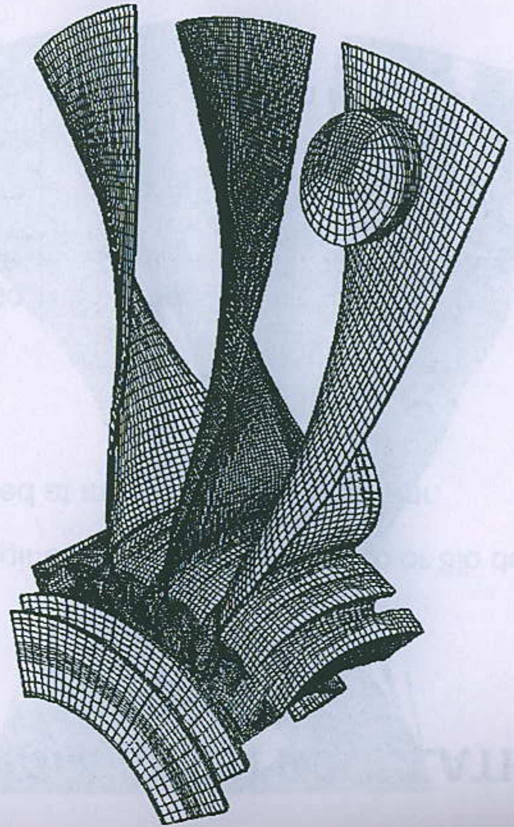
75% thrust recovery and a 20 minute post–ingestion run–on is required.

Small birds

Typically 16 x 4oz birds are to be ingested. This conditon is usually covered by reference to the medium bird test.

ROLLS ROYCE AEROSPACE GROUP

BIRD INGESTION COMPUTER MODEL

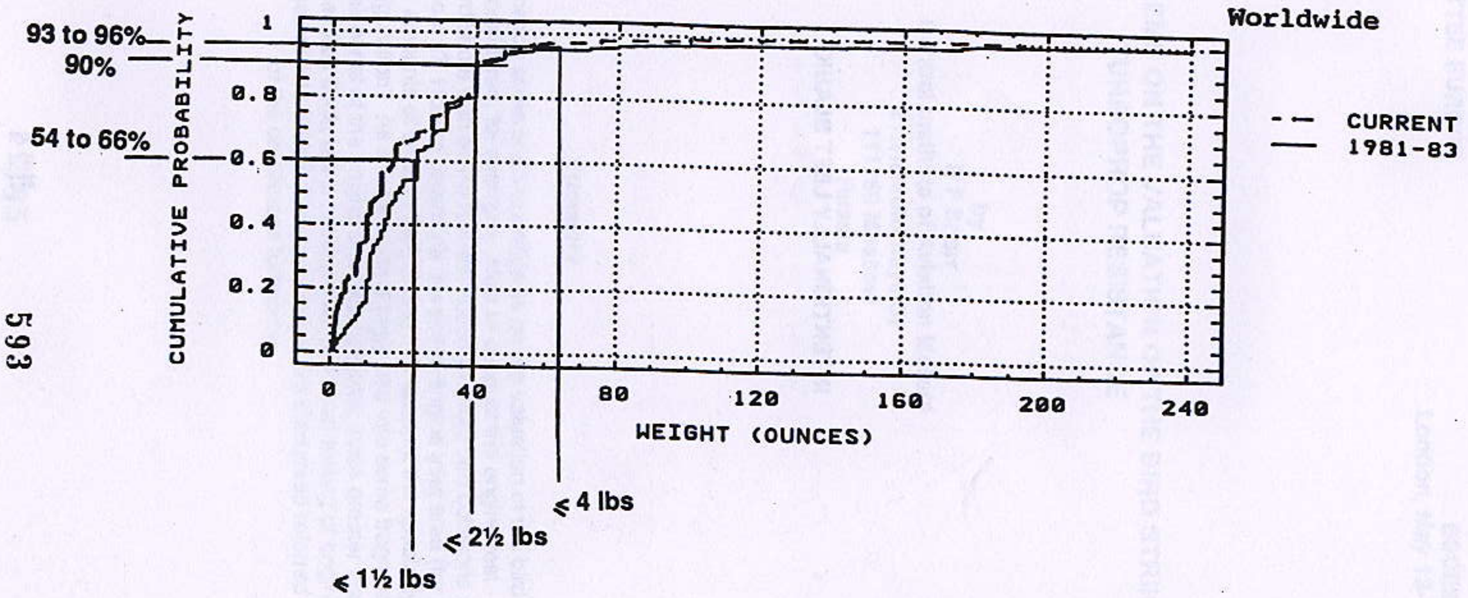


BSCE 23

fig 5

OBSERVED BIRD WEIGHT DISTRIBUTION

ROLLS ROYCE
AEROSPACE GROUP



SOURCE: DOT/FAA/CT-93/14 BIRD INGESTION INTO LARGE TURBOFAN ENGINES