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DERIVATION OF A DUMMY BIRD FOR ANALYSIS AND TEST OF AIRFRAME STRUCTURES

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Introduction

Certification of aircraft against the birdstrike threat is expensive and time consuming. With the need to reduce design life cycle time and costs with ever more complex structures (materials, geometries and manufacturing methods) yet with no reduction in safety, the possibilities of certification via generic analysis is an attractive proposition.

This paper discusses one approach being considered within British Aerospace (BAe). It relies heavily on research activities that have derived extensive data for bird biometrics and innovative testing that can provide mechanical data for bird failure modes unique to military aircraft.

Generic Certification

Whilst almost all birdstrike clearance is performed via testing using real birds on representative structure, some alternatives methods are now possible. Reference 1 for civil aircraft, states that "compliance may be shown by analysis" but that the analysis must be based on tests performed on "sufficiently representative" structures of "similar" design; as yet there is no equivalent wording for military aircraft. Although open to interpretation, the basis premise is that if you have designed and tested a similar component before, and if you can show an analysis method that gives an acceptable level of accuracy then you can clear a new "generic" component by analysis alone.

Definition of structures within appropriate non-linear finite element (FE) codes is now well understood and developed, however, bird models vary considerably between workers. Differences in density, shape and aspect ratio are easy to see; differences in mechanical properties are not as transparent. Unless data to define analytical birds can be justified against viable sources, it is unlikely that certification of structures by analysis alone will be successful.

Similar thoughts apply when considering substituting real birds for synthetic birds in testing. It is important that data used in defining bird properties has been taken from a justifiable source, not just assumed or fitted to test data. Previous workers (Ref. 2) have stated that “Scientists should aim to make the model fit the bird, not make the bird fit the model”.

What is a Bird ?

As an engineer, it's simple to define an aircraft component, but how do you characterise a bird ? In principle, the same rules apply, how big is it and what material is it made from ? By obtaining data to these variables, it should be possible to define a dummy bird for testing and analytical studies. BAe has been a contributor to two major research programmes; the first is aimed at providing bird biometrics, the second to obtain mechanical properties for birds under representative impact scenarios.

Birds Biometrics

Methods of measuring bird biometrics have been well documented (Refs. 3 to 4). The International Birdstrike Research Group (IBRG) has been developing an extensive database for some years, considering a worldwide list of species most often seen in birdstrike incidents and covering critical ranges of certification test weights. Over 30 species of bird have now been measured and basic trends in the data can be seen (Ref. 5), see Figure 1.

In order to develop dummy birds for either testing or analysis the essential variables are density, diameter, aspect ratio and shape. Obviously there must be simplification ie birds are not homogeneous and are not a simple shape, yet these factors can be considered to have a lower order effect on resultant damage.

Data covering the bulk of the bird, the unfeathered carcass, is simple to gather. A major discussion point, however, concerns what to do with the mass of feathers. Certainly the mass of these should be included in any bird definition but as their density is low compared to the torso, it needs to be smeared somehow. If added to the dummy bird length, the impact event will be longer than actual, if added to the diameter, the width of the impact will increase. To take due allowance of actual bird aspect ratios, the diameter option is considered more appropriate.

Using data from Reference 5, the following example dummy bird has been "created" at the 1kg test point used for UK military aircraft certification tests :-

Example

Mass : 1kg feathered, 0.87kg plucked

Density : using Log(Density plucked)=-0.0726xLog(Mass)+1.171 = 0.9532

Underwing Diameter : using Log(Dia plucked)=Log(Mass)x0.332+0.908 = 80mm

Overwing Diameter = underwing diameter + 11.1% = 88.88mm

Shape : Hemispherically ended cylinder

Cylinder Length : $[870/0.9532 - (4 \times 4.444^3/3)]/(\pi \times 4.444^2)$ = 87.8mm (plucked)

Overall Length : 87.8+44.44+44.44 = 176.68mm (plucked)

Considering the feathers as additional diameter :-
Additional diameter due to feathers = 2.64mm

Total length = 176.68+2.64+2.64 = 181.96mm

Aspect ratio = 181.96/(44.44+2.64) = 1.93

The resultant aspect ratio and shape is very similar to that proposed in the past by USAF WPAFB for testing and analysis (Ref. 6) and hence is considered a good fit.

Mechanical Properties of Splitting Birds

With the shape defined, the second aspect of the problem is that of mechanical properties. Data has existed for some time on the pressure time history of real birds impacting rigid targets (Ref. 7), however, no data has been available to consider the case of impact and resulting splitting of birds against sharp targets. This situation is of considerable importance to engine designers and airframe manufactures, particularly those in the military field where thickness/chord ratios of wing and control surfaces is considerably less than civil aircraft.

In conjunction with Rolls-Royce, Derby and the University of Gent, Belgium, an innovative test facility has been developed. This is capable of direct measurement of the force required to split real and synthetic birds at a range of velocities. By determining the threshold velocity and force to just split these projectiles, a fundamental material related test case is capable of directly validating the FE model for the bird splitting case.

The facility at Gent (Fig. 2) consists of a gas gun capable of firing real or synthetic birds of up to 0.5 kgs mass at a velocity of up to 250 m/s. The target is a rigid metal symmetric splitter mounted on a low friction track. A Moire Fringe grating is imaged through a window in the side of the track and the frequency information is recorded against time. Complex signal processing enables a displacement time history to be determined for the target and from this, velocity and force time histories can also be calulated. The method of force measurement has been developed over many years and has been extensively validated against classical techniques.

Typical projectiles after impact, in this case Gelatine, are shown in Figure 3. In these particular cases, the impact velocity has been insufficient to fully split the projectile, ie it is below the splitting threshold. Typical displacement and force time histories are shown in Figure 4, in this case above the splitting threshold shown by the constant velocity of the projectile at the end of the event. By gathering data for a range of velocities, the splitting threshold can be determined, Figure 5.

The technique has been utilised to determine the splitting threshold for Gelatine and wild ducks of mass 0.45 kg. It could be used for other potential dummy bird materials and against other target shapes to indicate, or otherwise, any differences in the impact response as well as providing a detailed understanding of the process of bird splitting. In this manner, a more representative dummy bird for testing can be developed for these particular component geometries.

Validation of Analytical Bird Models

Whilst the geometric definition of an analytical bird is simple, the mechanical properties have been more difficult to model. Traditional methods of representing birds for FE birdstrike analysis use simple elasto-plastic or equation of state materials models. Whilst these have been shown to be suitable for impact events where the whole of the bird has been involved in the impact and has fluidised, they have been shown to be unsuitable for cases where the bird is split by the structure.

It has been seen, for example, that metallic leading edge targets of a depth less than or similar to the diameter of the bird will undergo pinching of their skins leading to full or partial splitting of impacting birds. This effect, effectively a change in bird failure mode, explains the sudden increase in penetration velocity for reducing target nose radius (Figure 6). As it may be impossible to predict when this pinching will take place, and to make the analytical process flexible, BAe has developed an "intelligent" bird that can sense the target it is impacting and perform accordingly, Figure 7.

Using the data from the bird splitting tests, it is now possible to fully validate the analytical bird model for both gelatine and real birds. At the time of writing this paper, this work was still in progress within BAe. This data will also provide an indication on the acceptability of Gelatine (or other materials once tested) as a dummy bird material for all structural geometries.

Conclusions

Data gathered on bird biometrics and the mechanical behaviour of birds when impacted against sharp targets will enable a finite element bird model to be fully validated against experimental data. This opens the possibility to accurately predict damage to aircraft structures when impacting a range of structural geometries from blunt to sharp targets. Given this data, certification via predictive techniques is now technically feasible. Furthermore, the technique of controlled bird splitting can help derive suitable material(s) for dummy birds that can be used in birdstrike testing.

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Bird biometrics (via the International Birdstrike Research Group)

Collaborators :- British Aerospace, Rolls-Royce, Civil Aviation Authority, Central Science Laboratory, General Electric, United States Department of Agriculture, USAF Wright Patterson Air Force Base.

Bird splitting properties

Collaborators :- British Aerospace, Rolls-Royce, University of Gent.

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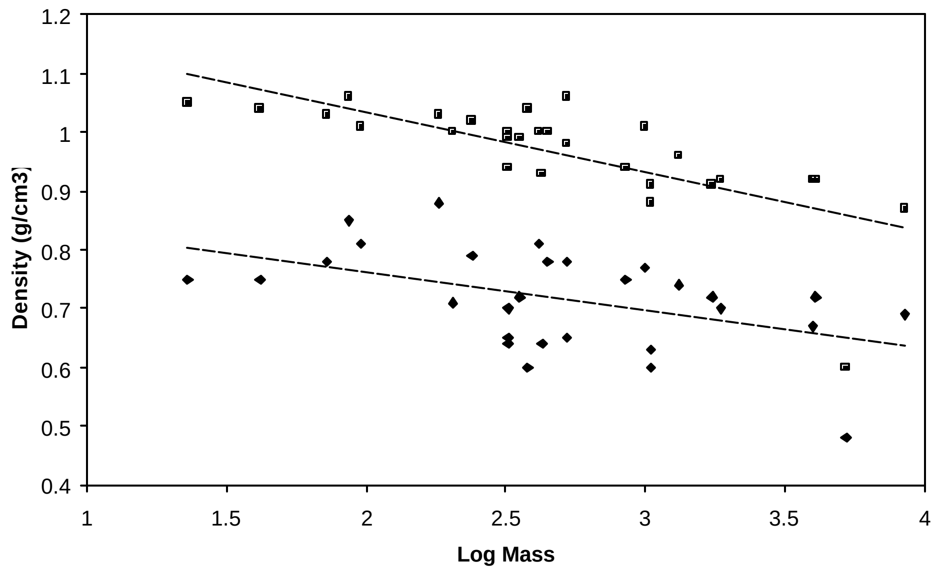
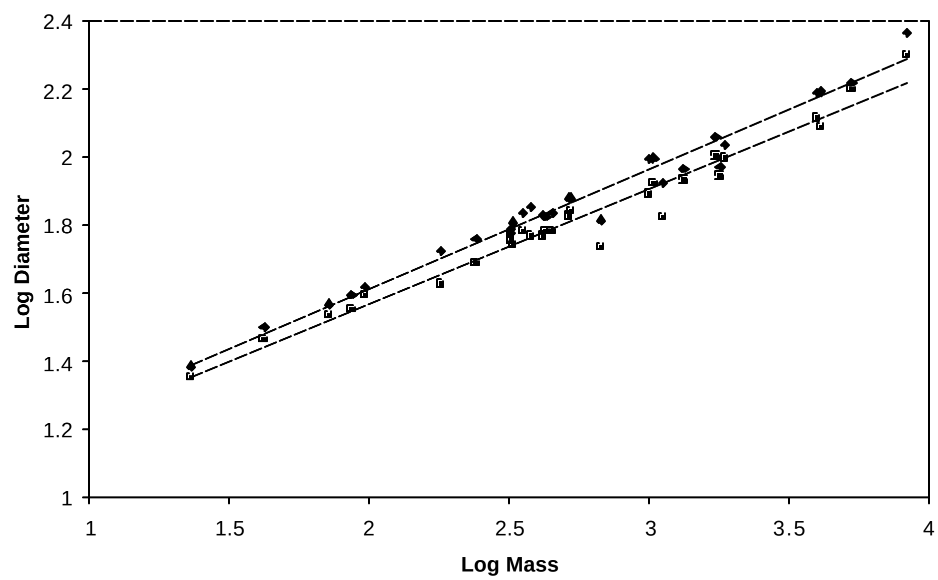
2. "Integration of Biological and Engineering Technologies : X3D Analysis of Six Bird Species Impacting Aircraft Transparencies" - Hamershock, Olson & Bouchard, no reference
3. “Towards standardised birdstrike resistance testing: the work of the international birdstrike research group”- Allan, Proceedings of the 23rd. Birdstrike Committee Europe London 1996
4. “Determination of Body Density for Twelve Bird Species” - Seamans, Hamershock, and Bernhardt, Ibis 137 424-428 1993
5. “International Birdstrike Research Group Progress Report February 1998” Central Science Laboratory, no reference
6. "Validation of a Bird Substitute for Development and Qualification of Aircraft Transparencies" - Antonios & Challita, AFWAL-TR-80-3089, July 1980.
7. “Bird Impact Loading” - Wilbeck & Barber, no reference

Figure 1 Bird Biometric Data



◆	Feathered density	—	Regression of feathered density data
■	Plucked density	----	Regression of plucked density data

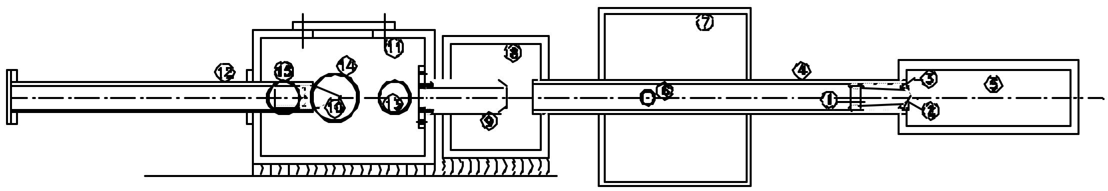
Mass versus Density



◆	Log feathered diameter	—	Regression of feathered diameter data
■	Log plucked diameter	----	Regression of plucked diameter data

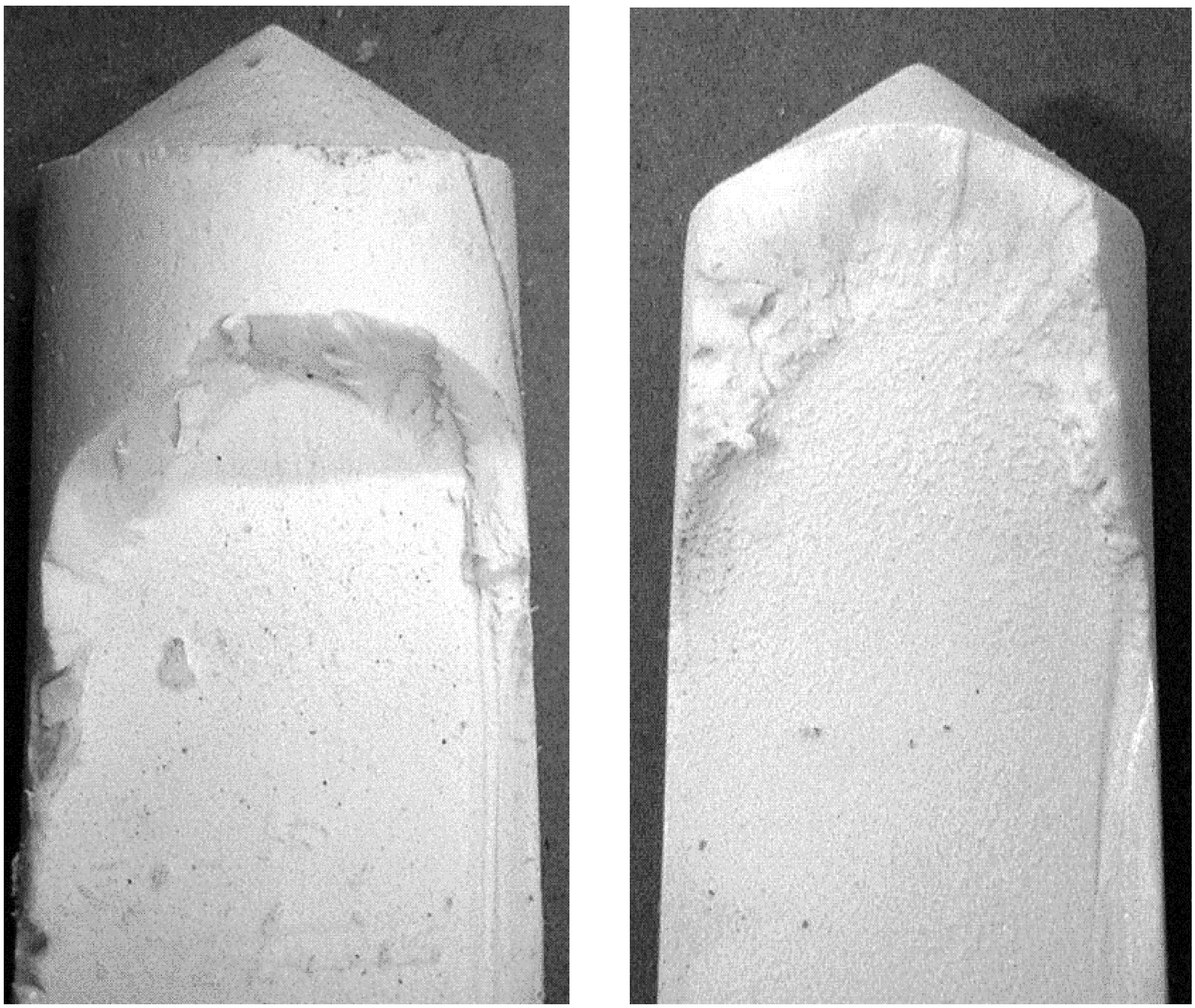
Mass versus Overwing Diameter

Figure 2 University of Gent Test Facility



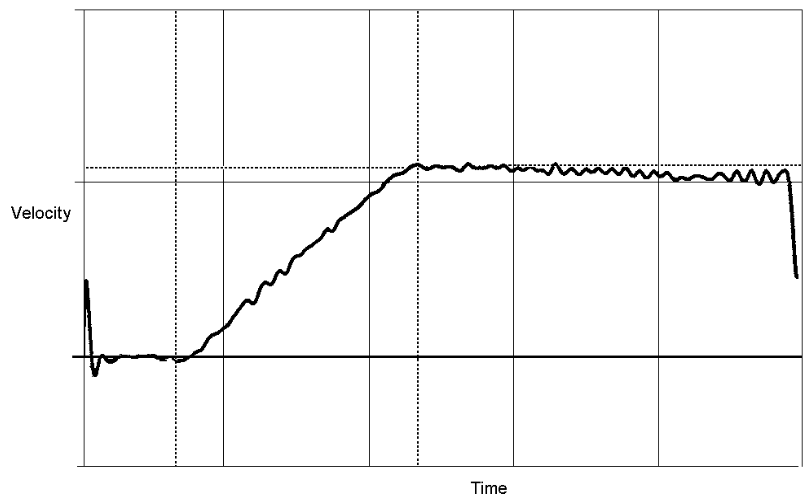
1 Impactor	2 Sabot	3 End Cap Clamp	4 Barrel
5 Gas Reservoir	6 Vent	7 Expansion Chamber	8 Sabot Debris Chamber
9 Sabot Splitter	10 Target	11 Target Chamber	12 Braking Tube
13-15 Imaging/Recording Ports			

Figure 3 **Partially Split Gelatine Projectiles**

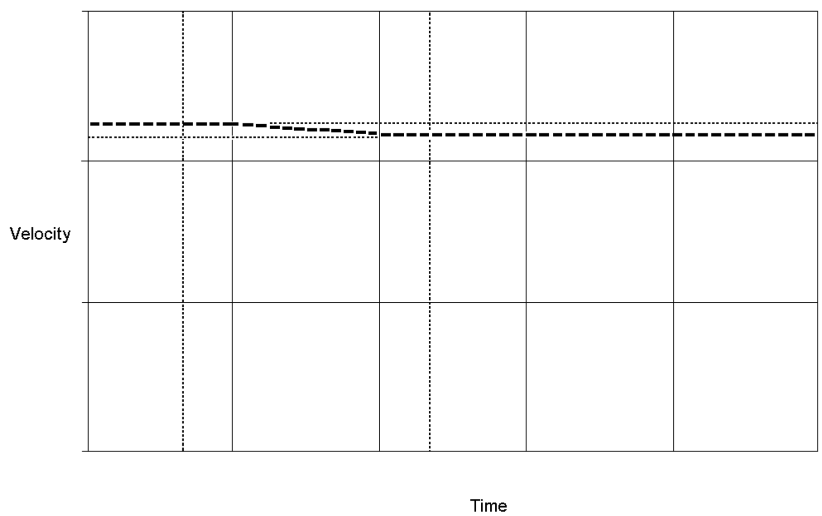


Increasing Impact Velocity >

Figure 4 Time Histories for Gelatine



Target Velocity versus Time



Projectile Velocity versus Time

Force versus Time

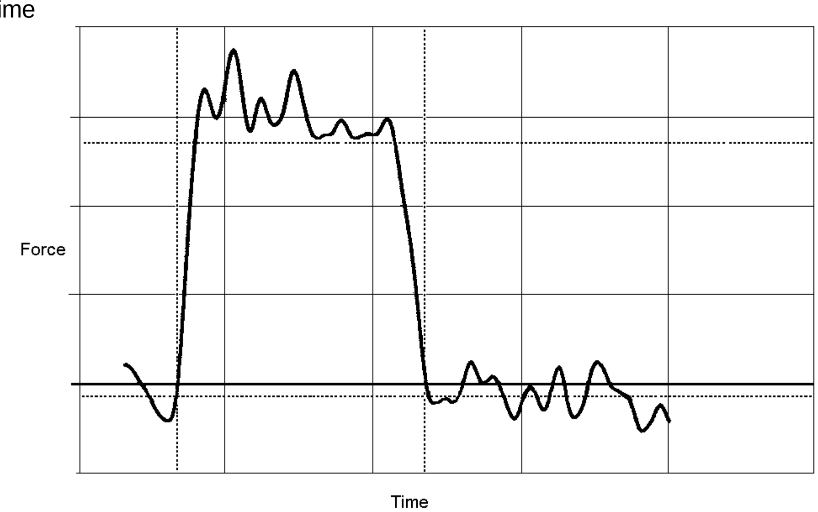


Figure 5 Derivation of Threshold Velocity and Force

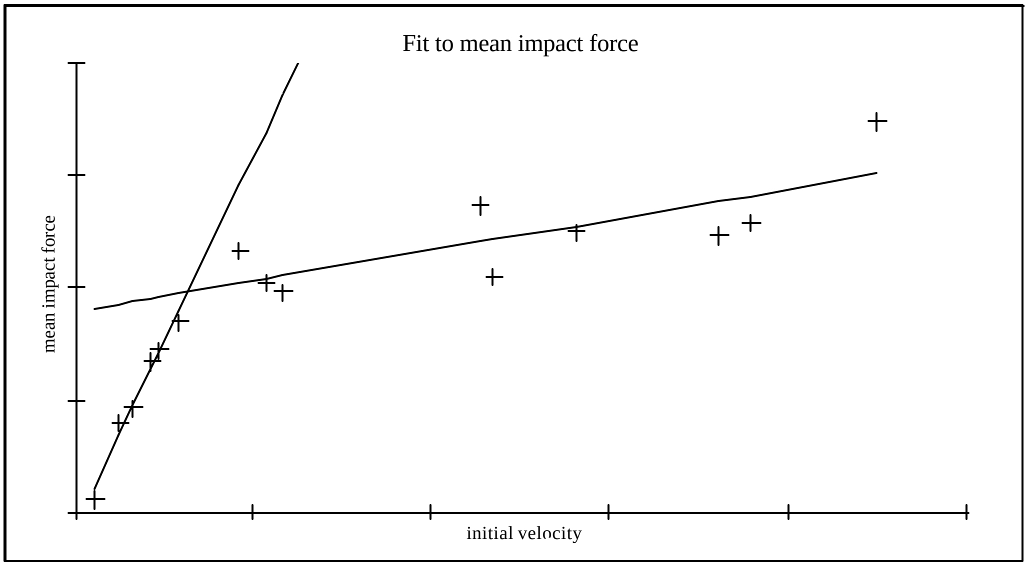


Figure 6 Effect of Leading Edge Nose Radius on Penetration Velocity

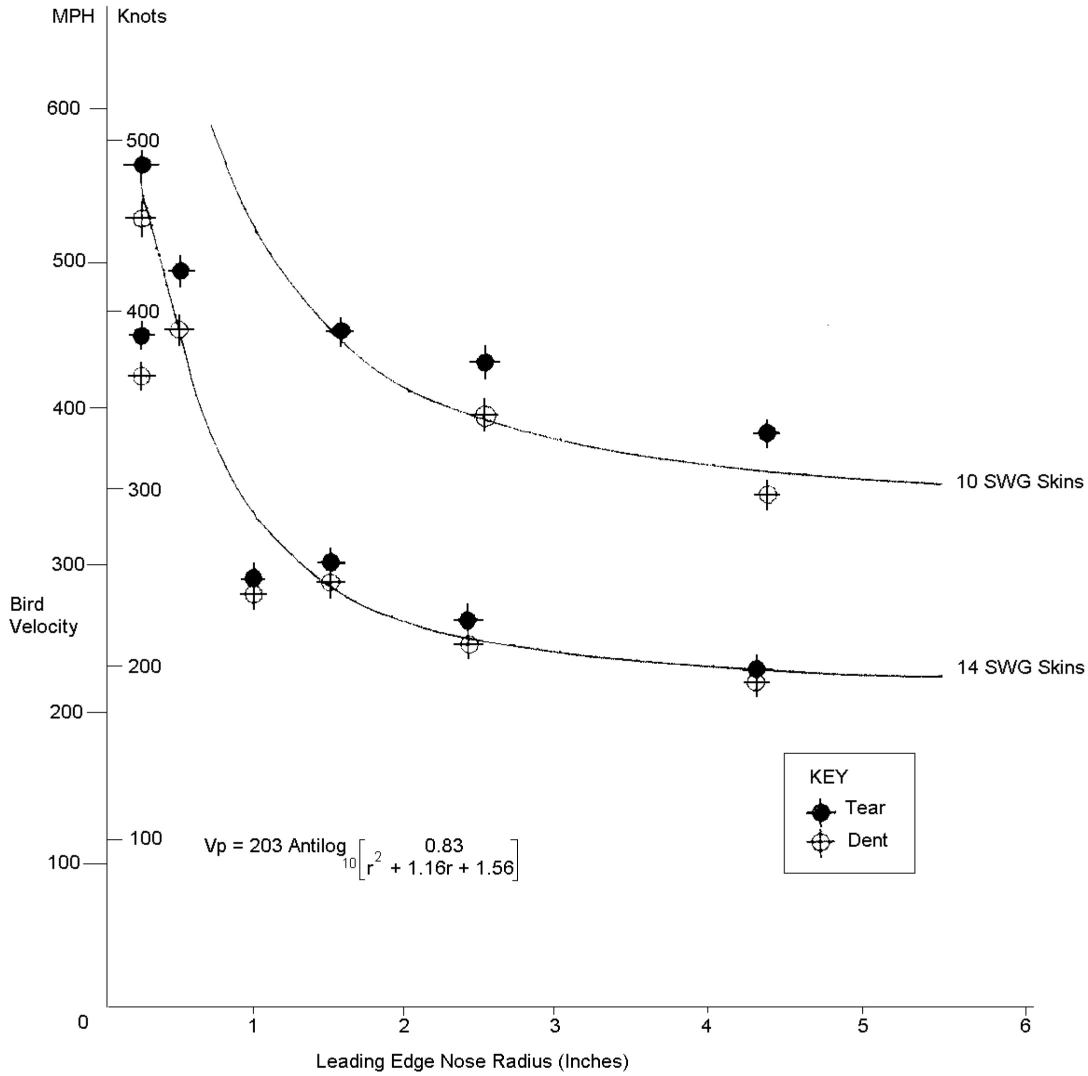


Figure 7 BAe Intelligent Bird Model