BIRD STRIKE COMMITTEE EUROPE BSCE23/WP68
London, 13-17 May 1996

"AIRCRAFT-SPECIFIC" FOD CERTIFICATION: NEED FOR A RELOOK AT MIL-STANDARD REQUIREMENTS FOR AEROENGINES

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SUMMARY

This paper addresses the issue of severity of impact damage due to Bird-Strike under the present provisions of Mil-standard 5007 D/E. The need for reviewing the standards with reference to failure modes in Aircraft-Fuselage-mounted aeroengines has been explained. Influence of strike on air-intake on bird shape parameters is discussed.

Key Words: Engineering, Engines, Certification Standards, Airframe

INTRODUCTION

Aeroengine 'Bird-Strike' which, on statistical basis, account for more than 20 percent of all aircraft bird-hit incidents, (Fig. 1) has become a major FOD certification requirement. Mil standard 5007 D/E, which forms the 'Reference Document' for the development of an engine for any manned aircraft application, deals with the subject quite rigorously and stipulates stringent requirement to be met. With these specifications as the basis, the following test conditions become operative for any analysis and component/engine test programme, leading to qualification of typically 5000 to 8000 kgf thrust-class engines.

Large Bird (1 to 2)	• Major Structural Damage Tolerated • Total Thrust-Loss Allowed • Total Debris Containment Within the Engine • Safe Engine Shut Down
Medium Bird (1 to 2)	♦ Structural Damage Allowed ♦ Total Debris Containment within the Engine
Small Bird (12 to 20)	♦ No Deterioration in Engine Handling Characteristics and Safe Shut-Down

These broad expectations at critical flight phases are based on a simplistic criterion of 'Engine-Intake Area', without due consideration to the frontal architecture of the engine, location of the engine in the aircraft, the structural details and the aerodynamic interface of the intake-duct vis-à-vis the aircraft fuselage and wings. Importantly, these Mil-Standards do not even differentiate between single engine and twin engine configurations. Fig. 2 compares the critical components of an overhung fan stage with those of a straddle-mounted fan rotor stage. One can visualise a more robust and stiffer fan module in the case of straddle fan rotor stage as compared to that of an overhung case, but the number of critical parts increases in the former. With reference to total-system reliability, a trade-off study, between severity of bird hit on the rotor blade in the overhung case and the increased number of critical parts in the case of straddle mounted fan has to be made.

BIRD SHAPE AND ORIENTATION

The "squash-up" phenomenon of the semi-fluid mass of bird, which ultimately dictates the impact forces and hence the failure modes of engine components, is dependent on the critical aircraft forward speed, the engine rotational speed, the bird shape and orientation at the time of ingestion. A careful analysis of this phenomenon indicates that for a theoretical ellipsoidal bird shape (Fig. 3), assuming ingestion at the tip of the rotor blade in a direction parallel to the engine axis, there are possibilities of bird squash-up, leading to forward bending of blades.

The bird can be impacted by several rotor blades upto even 10 to 12 in number and in extreme cases can just manage to directly hit the stator blades behind the rotor stage, which is a remote possibility. The resulting impact forces on the blade are dependent on the actual momentum change of the bird debris. The evaluation of these transient momentum changes and impact force transients is based on the assumption that the bird has a relative angle of entry on the pressure surface of the rotating aerofoil Figs. (4, 5). This is the typical case for the bird flight path along the engine axis. If the bird is ingested at an angle to the engine axis, which is a more prevalent case, the bird hits the rotor blades in a direction closer to the chord (cc) and, in extreme cases, can even hit the suction surface of the rotating blades. This would result in a totally different failure mode of the blades and also changes the bearing loads.

INFLUENCE OF AIRCRAFT INTAKE

Though the angular ingestion of bird appears to be hypothetical, as far as the engine is concerned, it appears to be a very distinict possibility. This is evident from a scanning and analysis of the bird-strike data from the operating fleet. The type, number and location of engine inside the aircraft fuselage (Fig. 5) dictate the orientation of the bird vis-à-vis the engine axis. Fuselage mounting normally results in higher percentage of angular ingestion as compared to a direct axial "bash" on to the wing mounted engine. In addition to the location of the engine, the geometrical configuration of air-intake duct of the aircraft changes not only the direction of bird mass but also drastically changes the orientation, shape and the velocity of the "ricocheted" bird. Fig. 6 is the schematic layout of the conventional coaxial air-intake to the single fuselage-mounted engine. Even in this case the most probable possibility is an angular ingestion of the bird after being "rebounded" by the intake wall.

When the engine is integrated with either split side-intake or top/bottom intake combination, the bird has a tendency to impact the sides of the intake wall, loose its relative velocity, deform into a non-descript shape. This process, which is a random and statistical variable, is dependent on the intake geometrical parameters and stiffness of the intake panels (Fig. 7). An important consequence of the impact phenomenon is the direction in which the bird-debris impacts further on to the rotating blades. Depending on whether it is the right or left side of split intake, or the top or bottom intake, the resultant relative velocity vector varies considerably in both direction and magnitude. The impact force imparted to the blade and the blade bending/twisting response become unpredictable, though in some cases they may be much less structurally damaging to the frontal parts of the engine. A much bigger permutation and combination of bird orientation and direction need to be tried out with the help of "DYTRAN" or any impact-analysis software, before the fan blade geometry is approved for required bird-strike resistance. A relevant doubt which needs to be properly examined and explained is whether there is a possibility for small and medium birds being entrained along the air-stream flow-lines in the intake duct, at certain flight conditions and altitudes (Fig. 8). This condition, if it indeed exists, would impose harsh impact conditions on both rotating and static parts of the engine, very similar to those specified in Mil-Std-5007 D/E. A study of this phenomenon combines the aerodynamic parameters, existing inside the intake duct at various flight conditions, with the impact characteristics of bird material. This uncertainty in bird-shape and strike parameters makes the hardware testing programme, (Fig. 9), much more involved and complicated. A basic question that has to be answered is whether the analysis and testing programmes need to address the case of an engine totally integrated with a specific aircraft hardware or should it focus on a stand-alone propulsion system. The latter case while being mostly relevant to wing-mounted propulsion units does not describe the true operating realities when the engine is fuselage mounted. The requirements spelt out in Mil Std-5007 D/E with reference to bird weight and speed is much more demanding and harsher structurally, as compared to operating realities, if

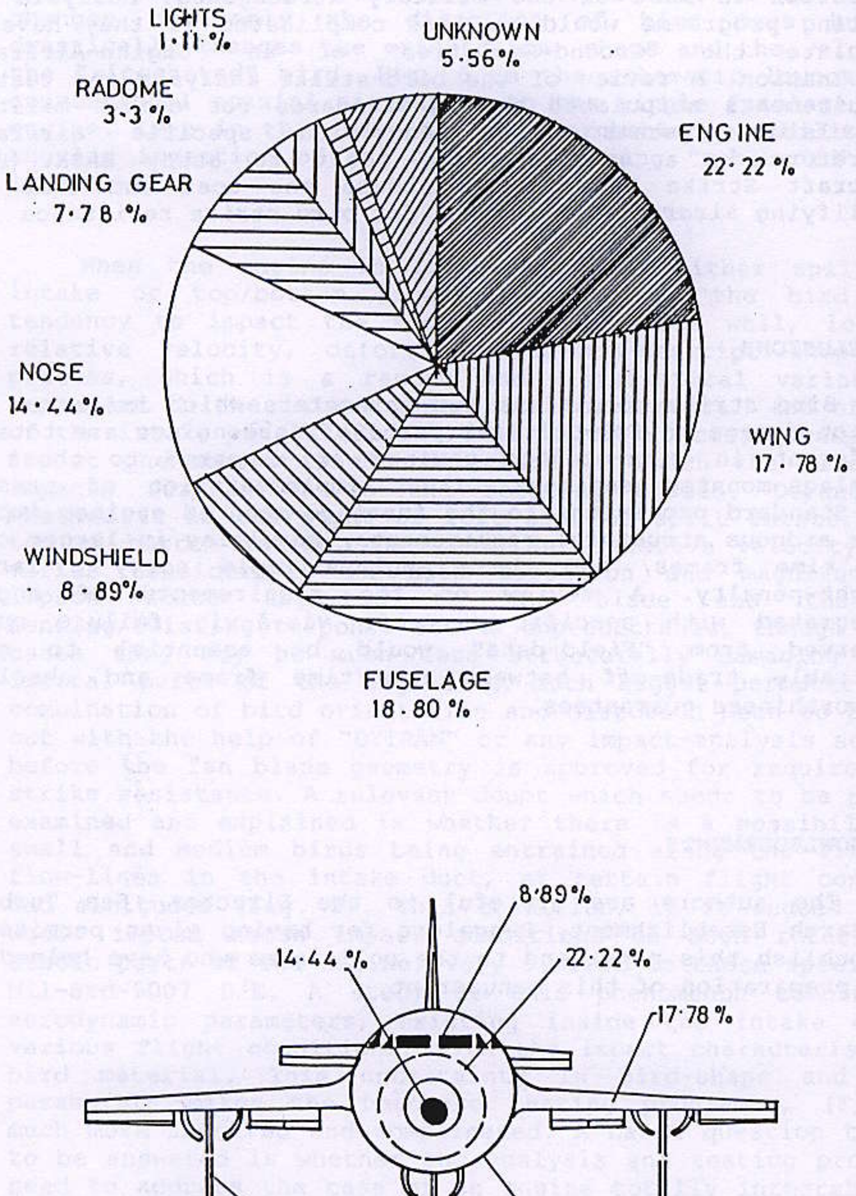


FIG.1 BIRD HIT INCIDENTS

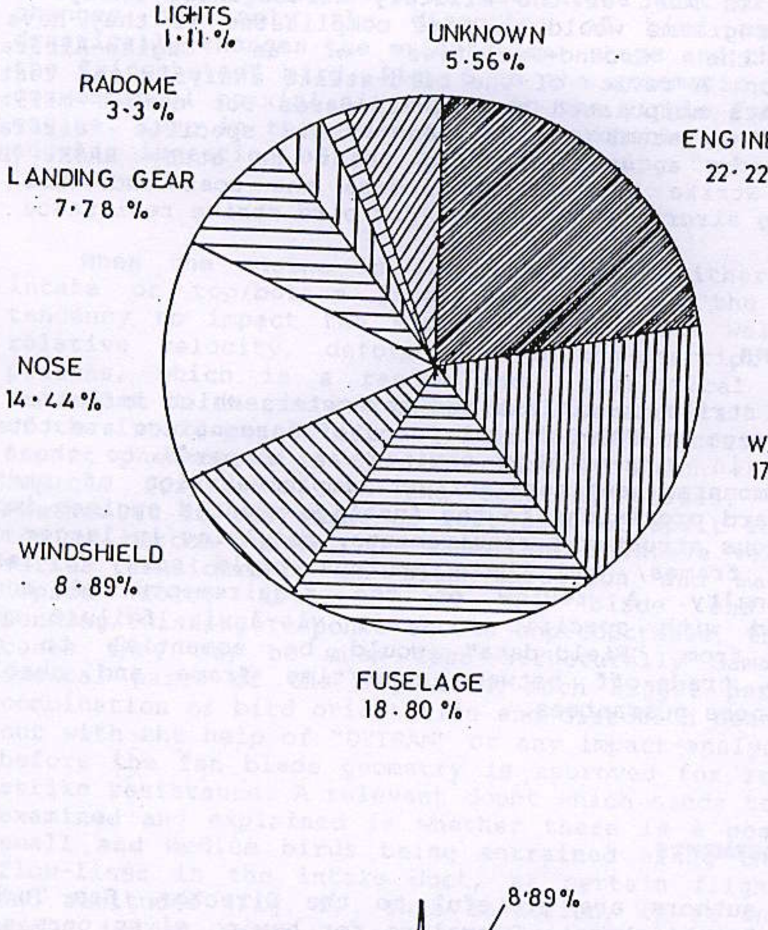


FIG.1 BIRD HIT INCIDENTS

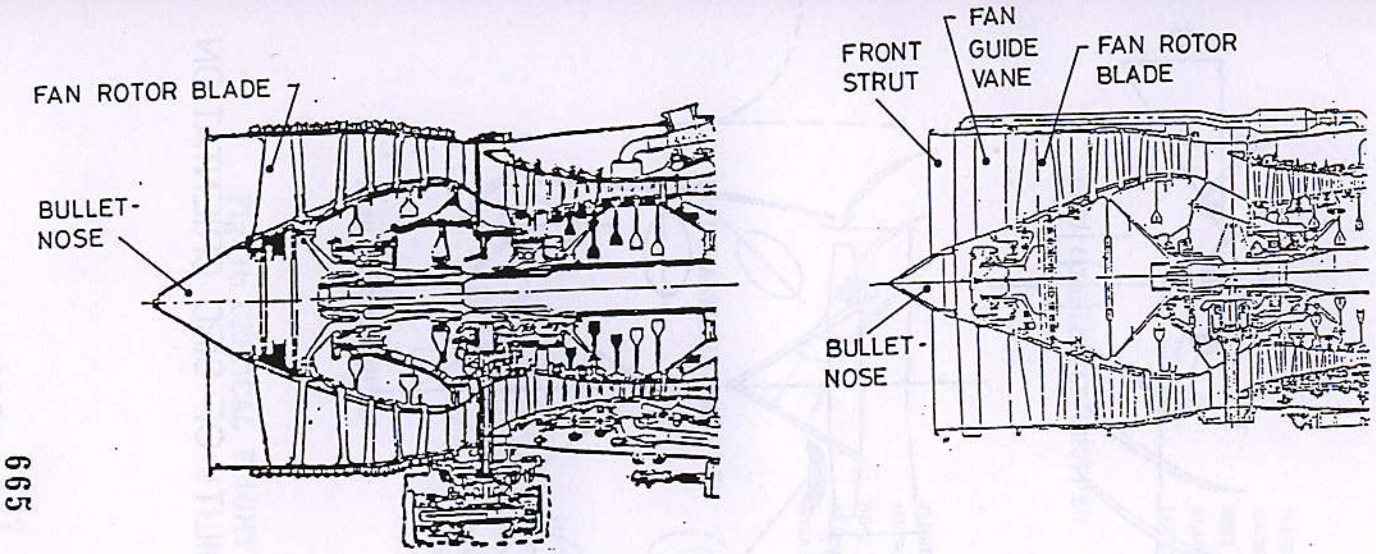


FIG. 2. TWO DIFFERENT FRONTAL ARCHITECTURE OF AEROENGINE

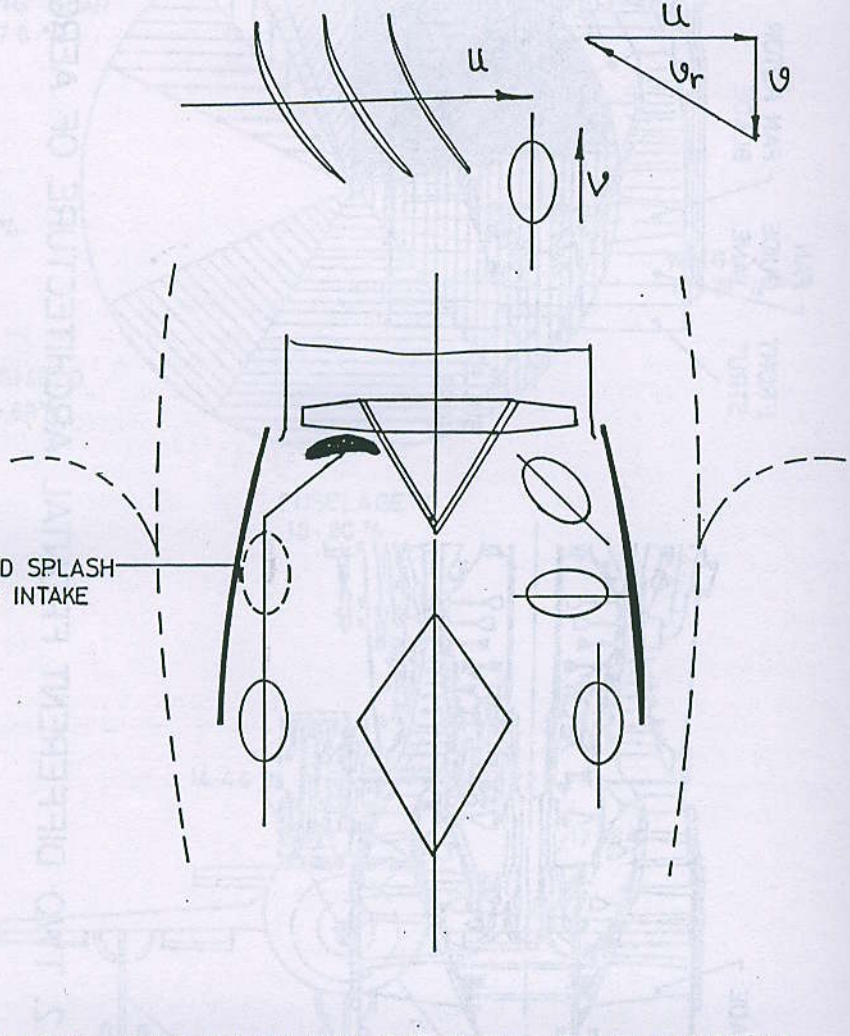
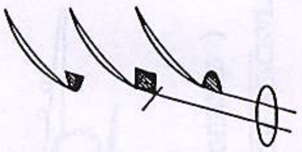
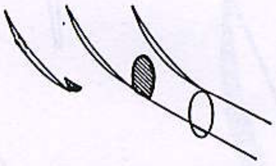


FIG.3a PROBABILITY OF BIRD ORIENTATION



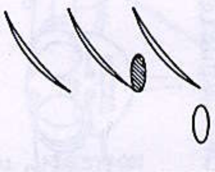
FLIGHT CONDITION : TAKE-OFF
AIRCRAFT VELOCITY = 131 m/s
BIRD WEIGHT = 0.66 kg
BLADE SPEED = 11,020 RPM
LOCATION : TIP

BIRD COMPLETELY CHOPPED



FLIGHT CONDITION : CRUISE
AIRCRAFT VELOCITY = 374 m/s
BIRD WEIGHT = 0.38 kg
BLADE SPEED = 9700 RPM
LOCATION : TIP

BIRD PARTIALLY CHOPPED



FLIGHT CONDITION : DIVERSION
AIRCRAFT VELOCITY = 252 m/s
BIRD WEIGHT = 0.26 kg
BLADE SPEED = 5700 RPM
LOCATION : MIDSPAN

BIRD NOT CHOPPED

Fig. 3b. CRITICAL FLIGHT PHASES

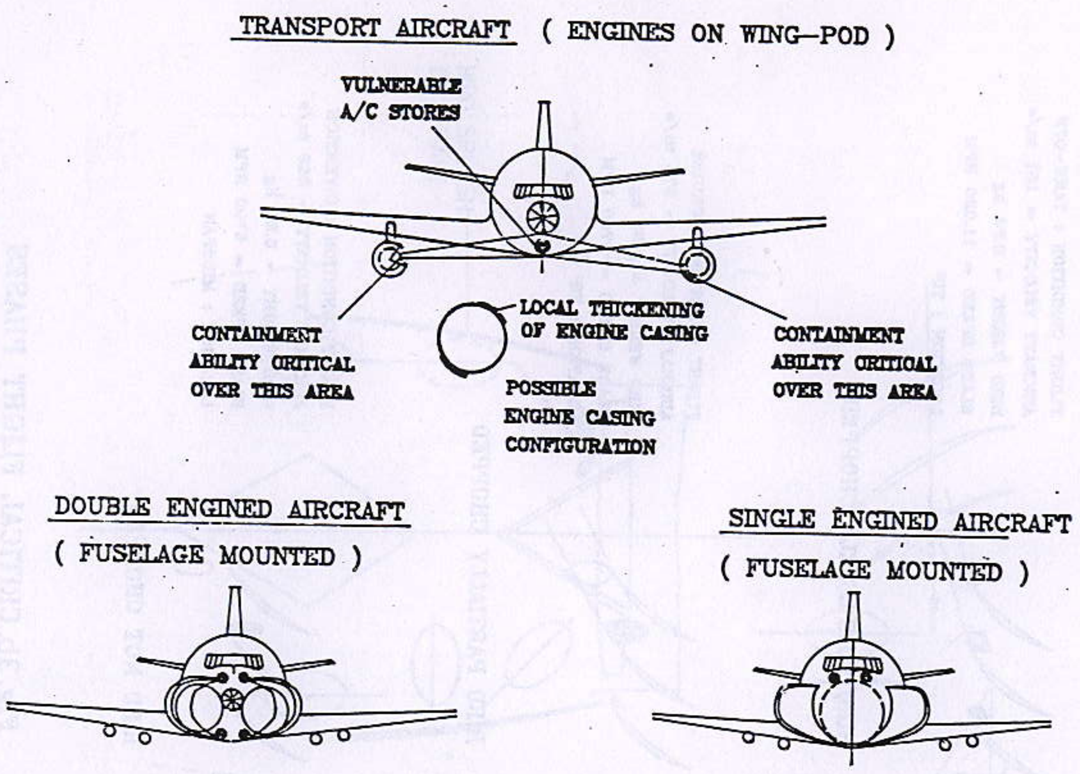


FIG. 4. LOCATION OF VULNERABLE AIRCRAFT STORES

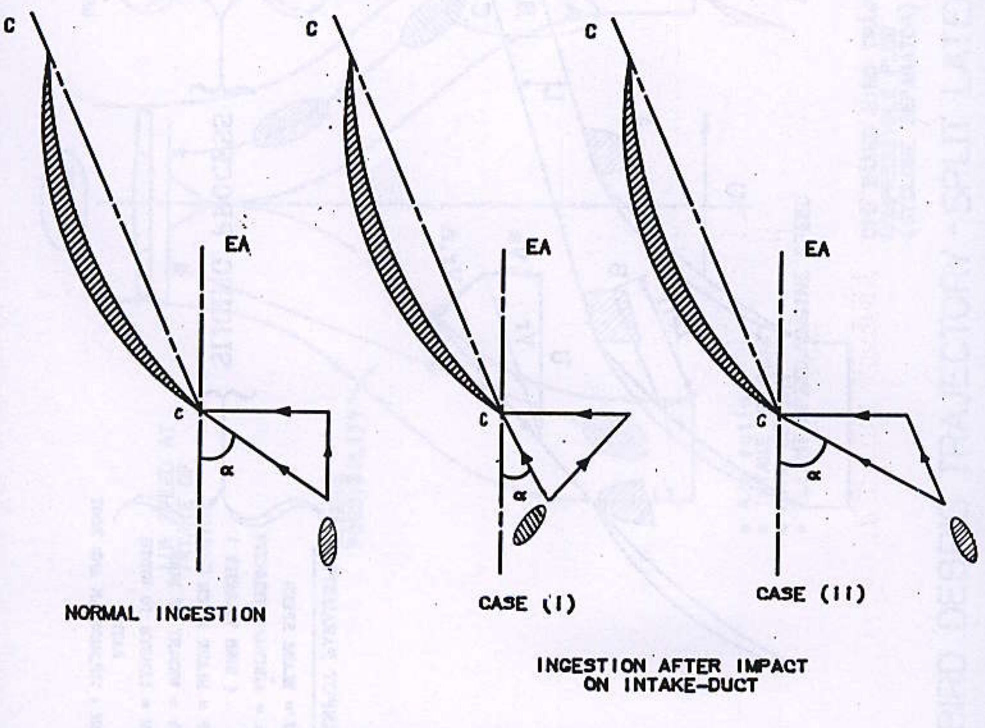
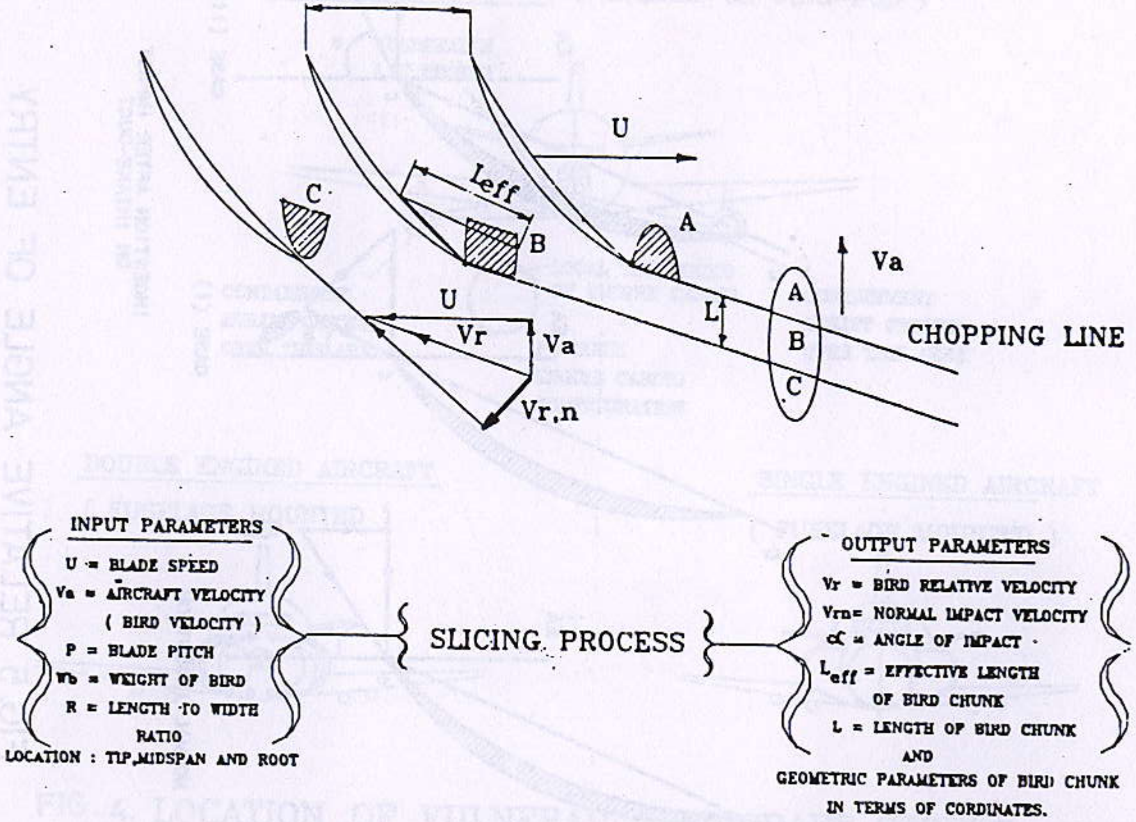


FIG. 5 RELATIVE ANGLE OF ENTRY



INPUT PARAMETERS

U = BLADE SPEED
Va = AIRCRAFT VELOCITY
(BIRD VELOCITY)
P = BLADE PITCH
Wb = WEIGHT OF BIRD
R = LENGTH TO WIDTH RATIO
LOCATION : TIP,MIDSPAN AND ROOT

OUTPUT PARAMETERS

Vr = BIRD RELATIVE VELOCITY
Vrn= NORMAL IMPACT VELOCITY
α = ANGLE OF IMPACT
L_{eff} = EFFECTIVE LENGTH OF BIRD CHUNK
L = LENGTH OF BIRD CHUNK
AND
GEOMETRIC PARAMETERS OF BIRD CHUNK IN TERMS OF CORDINATES.

FIG. 6 SLICING ACTION OF BIRD DURING INGESTION

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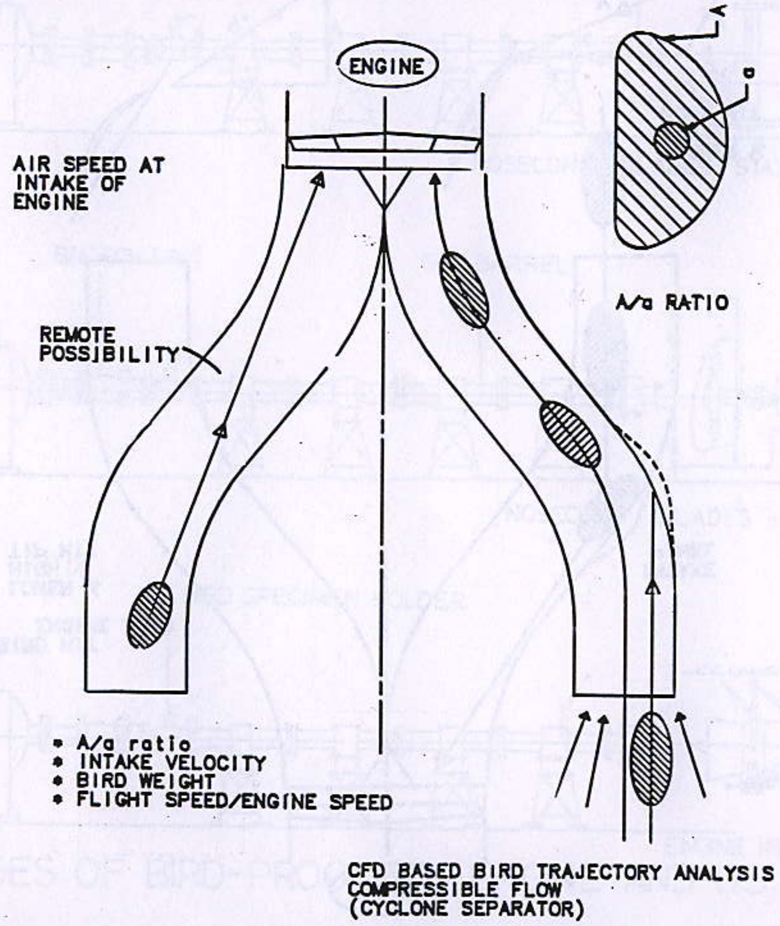

FIG. 7 BIRD DEBRIS TRAJECTORY -SPLIT LATERAL AIR-INTAKE

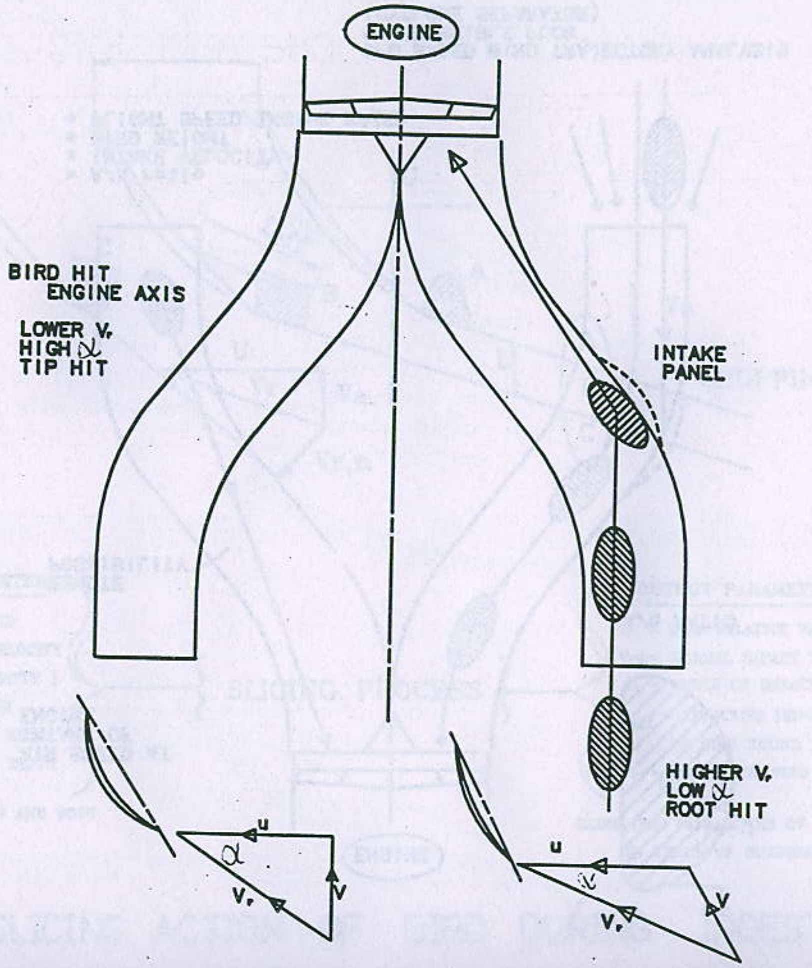

Fig.8. BIRD TRAJECTORY MEDIUM SMALL BIRDS

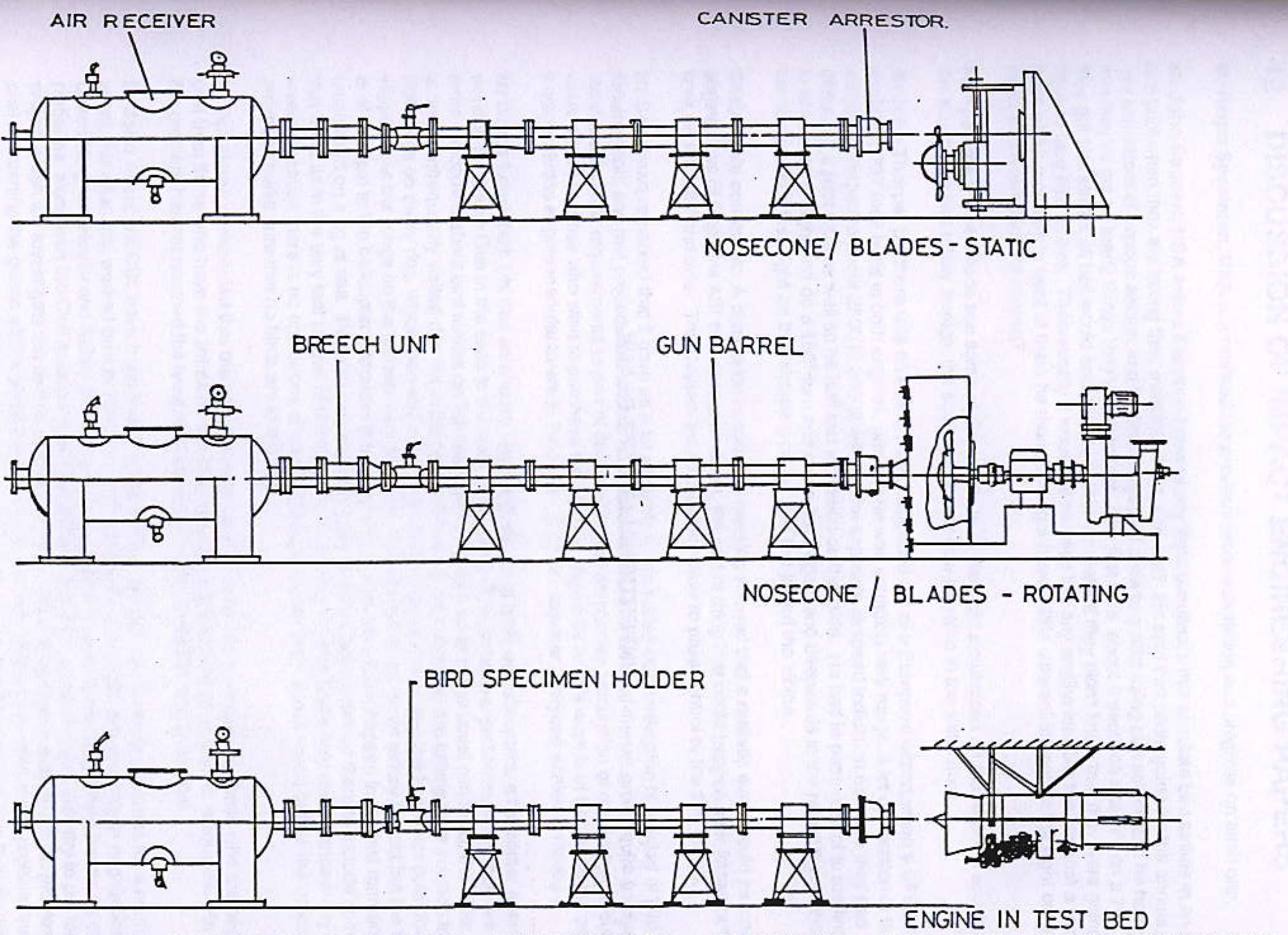

FIG. 9 THREE STAGES OF BIRD-PROOFING ENGINE AND ITS COMPONENTS