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EVALUATION OF TRANSIENT ENGINE-BEARING-LOADS DUE TO BIRD STRIKES

K RAMACHANDRA, R JAIN and M CHANDRASEKARAN

GAS TURBINE RESEARCH ESTABLISHMENT
MINISTRY OF DEFENCE, GOVERNMENT OF INDIA
CV RAMAN NAGAR, BANGALORE-560093
INDIA

SUMMARY

Importance of bearing-load in aeroengines and its prediction in the event of "Bird-Strike" is dealt with in this paper. A short summary of analytical results obtained for a critical flight condition is presented to highlight the utility of Impact Software in relation to engine bearing design.

Key Words: Engineering, Engines

INTRODUCTION

Many critical failure modes of aeroengines necessitate minimisation of axial thrust loads on engine bearings, particularly in the case of overhung fan rotor bearings. (Fig.1) It is a good design practice to ensure that the direction of these thrust loads on the bearings, due to differential gas pressures inside the engine, do not reverse at any flight phase. While this can be complied with, for almost all engine configurations and flight phases, transient reversal of these axial loads in the event of bird strikes on engine rotor components becomes extremely difficult to handle. These reversals affect the integrity and reliability of bearing locators and shaft locking mechanisms. In extreme cases, these transient loads could result in bearing failures, disc overspeeding, rotor/stator blade rub and spline joint overloading. A realistic, if not most accurate, assessment of these transient axial loads on the low pressure main shaft is an important analysis and design task, for ensuring bearing integrity and minimising other secondary failure modes.

The axial load experienced by the bearings due to 'Bird Strike' is a direct function of engine rotational speed, aircraft forward speed, bird shape, its orientation vis-à-vis engine axis and, more importantly, is dependent on the number of fan blades impacted and the thickness/ camber variation of the blades along its span from tip to hub. Fig.2 is a standard published and well known concept of the bird-debris distribution and resultant force vectors on rotating blades. Fig.3 explains the influence of bird shape on the peak impact force on rotor blade, assumed to be rigid and the bird material to be semi-solid or semi-fluid in behaviour. In practice, however, the assumed bird characteristics is not strictly valid and the rotating blade indeed deforms as a low aspect-ratio cantilever plate of varying thickness. Fig.4 is a typical example of an actual fan blade tested under simulated bird ingestion condition corresponding to "Take-off" phase. One can clearly identify the bending and twisting components of total blade deflection which reduces the impact load translated as axial thrust load on the fan bearing. The exact magnitude, its time variant and peak value cannot be estimated by conventional methodologies, and only experimental measurements on engines or use of impact software will enable the estimation of these transient parameters.

DYTRAN ANALYSIS

One of the Lagrangian-Eulerian explicit impact codes, 'DYTRAN', has been used to simulate the "slice-up" and "squash-up" processes in the proper sequence for the critical flight condition at the tip of the blade. For the assumed length-to-diameter (L/D) ratio of the cylindrical shape of the bird, three consecutive blades are impacted by the bird debris and the deflection pattern, 0.33ms after the initial contact, is shown in Fig.5. Stress pattern under the combined influence of centrifugal load and time dependent bird 'squash-up' phenomenon is shown in Fig.6. The DYTRAN software predicts the pre-set failure criteria which in the case of fan blades could either be 'percentage strain' in the failure region or the magnitude of tip deflection. (Fig.7) While these are common features of impact codes, one can also extract the blade-root reaction along predetermined reference coordinates as a function of time elapsed. Assuming that the rotor, on which the blades are mounted, is an infinitely rigid rotating body transferring the axial component of impact forces on the bearing, through the connecting main shaft without any attenuation, one can predict the time variant of bird-strike related thrust loads on the bearings. Figs. 8, 9 and 10 are typical time transients of impact forces transmitted to the bearings through 'bird squash-up' on three consecutive rotor blades. Superposing and summing up on time scale the resultant axial force on the front thrust bearing of the engine, we get the typical upper bound values for time-force relation shown in Figs. 11 and 12. It is evident that the bird strike at the tip of the blade normally results in thrust reversals in very short time interval of a few milli-seconds. The magnitude of these axial forces may vary from +1700 kgf to -2000 kgf. It is only logical to expect large birds of 1.8 kgf weight to impart much higher axial forces, but in practice the magnitude does not increase in direct proportion to weight of the bird. The increase in axial force on the bearing is due to the larger number of blades chopping down the cylindrical shaped bird, for a given L/D ratio and relative orientation of bird.

One more critical situation, in relation to axial force on the bearing, is the impact of large bird at the root of the blades at high forward speed condition. Being stiffer at the root, the blades are likely to transfer higher forces to the bearings, but the bird mass impacting each blade at the root is smaller. The relative angle of impact on the aerofoil and the velocity are different from those corresponding to the tip hit. The trade-off amongst these various parameters result in additional critical flight conditions which can be identified very effectively using impact codes such as DYTRAN.

CONCLUSIONS

Dytran software has been used to predict the axial thrust load on aeroengine bearings. In a typical blade-tip bird strike case, at take-off condition by a medium size bird, thrust reversals of magnitude equal to approximately 2 tonnes have been predicted.

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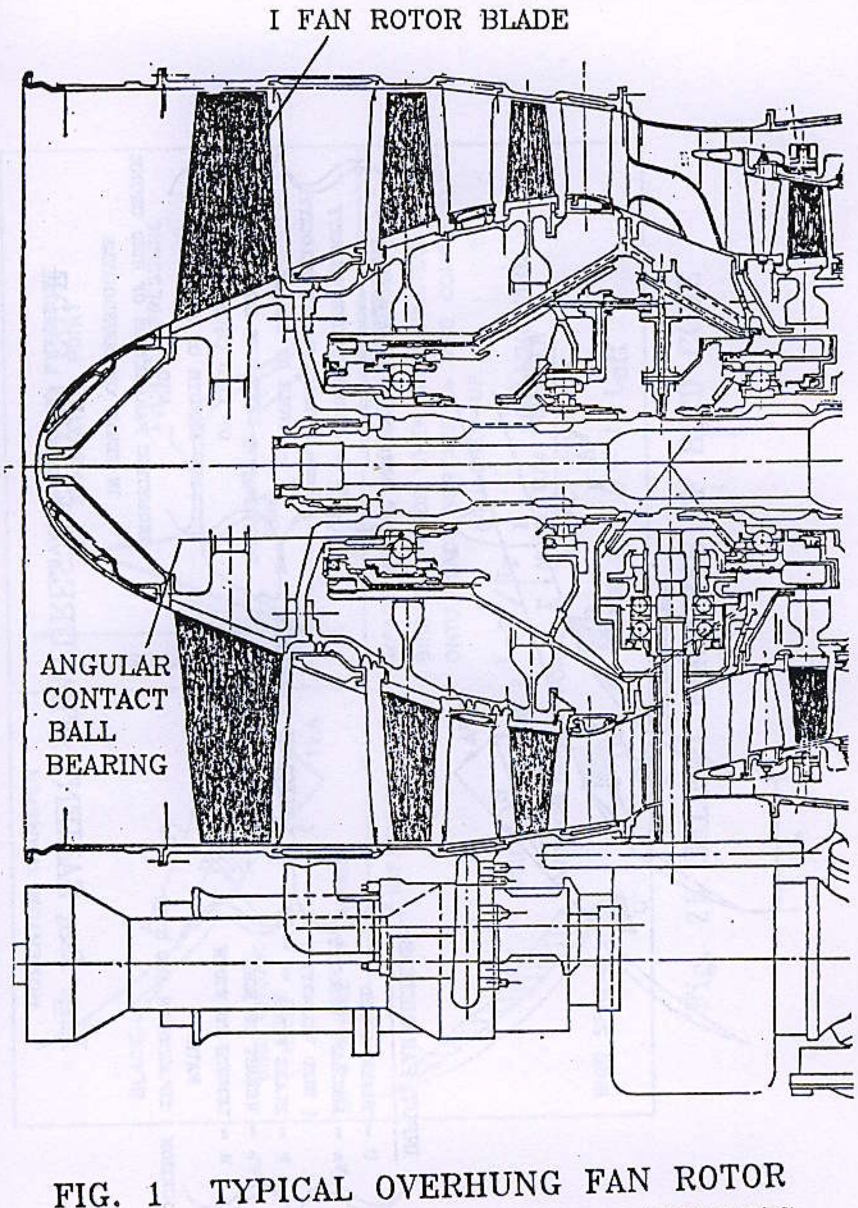


FIG. 1 TYPICAL OVERHUNG FAN ROTOR WITH A FRONT THRUST BEARING

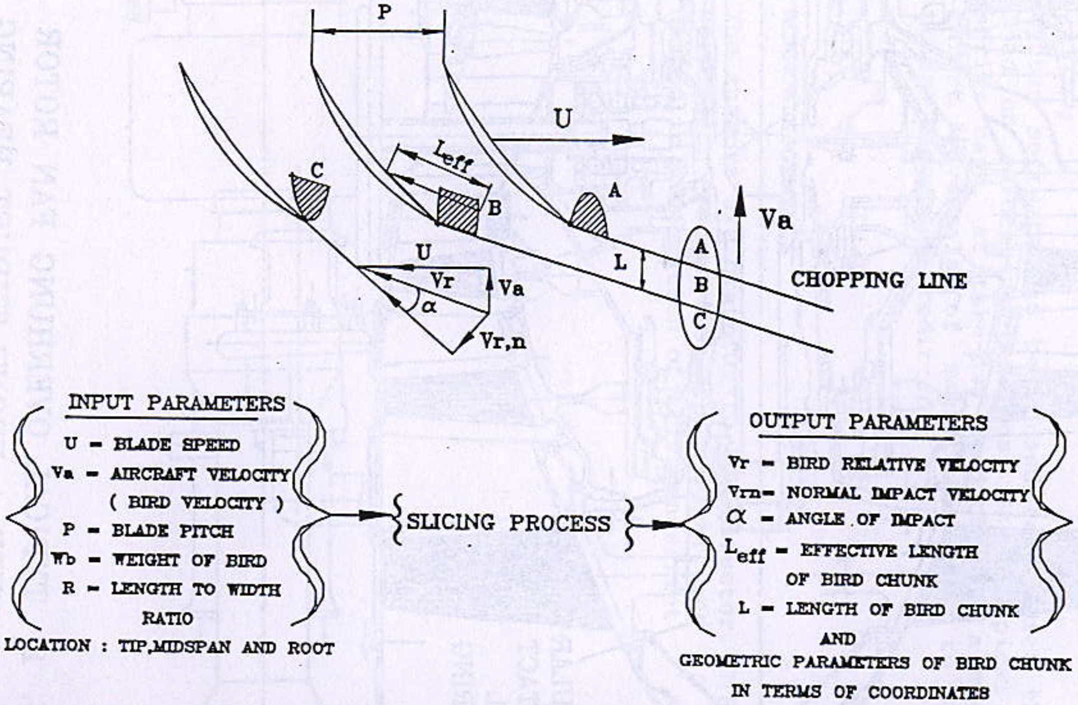
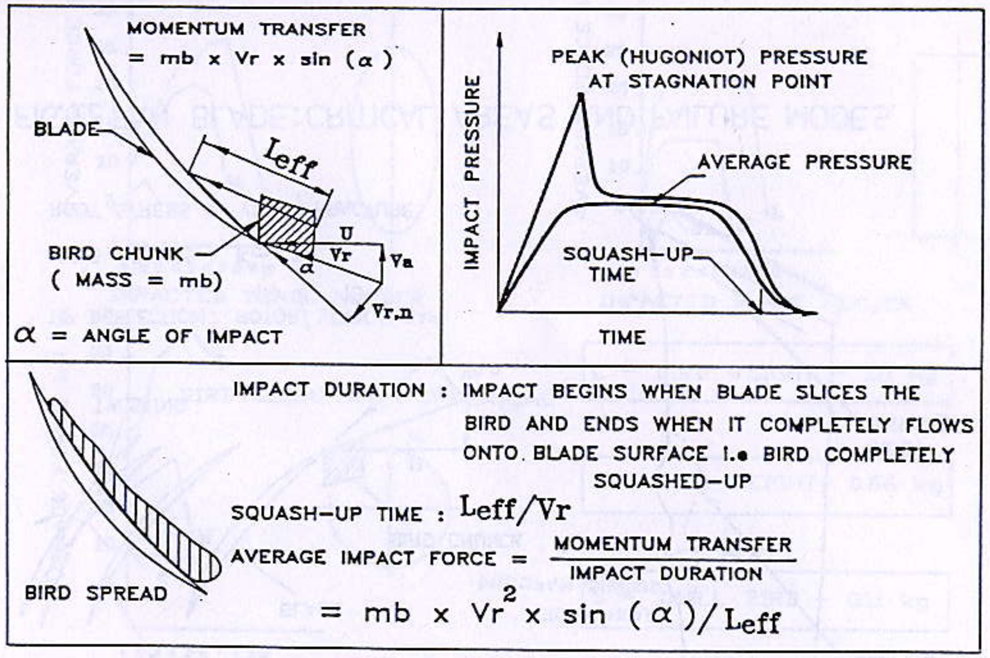


Fig. 2a. SALIENT FEATURES OF BIRD CODE



IMPACT DURATION : IMPACT BEGINS WHEN BLADE SLICES THE BIRD AND ENDS WHEN IT COMPLETELY FLOWS ONTO BLADE SURFACE i.e BIRD COMPLETELY SQUASHED–UP

SQUASH–UP TIME : Leff/Vr

$$\text{AVERAGE IMPACT FORCE} = \frac{\text{MOMENTUM TRANSFER}}{\text{IMPACT DURATION}}$$

$$= mb \times Vr^2 \times \sin(\alpha) / L_{eff}$$

Fig. 2b. SALIENT FEATURES OF BIRD CODE

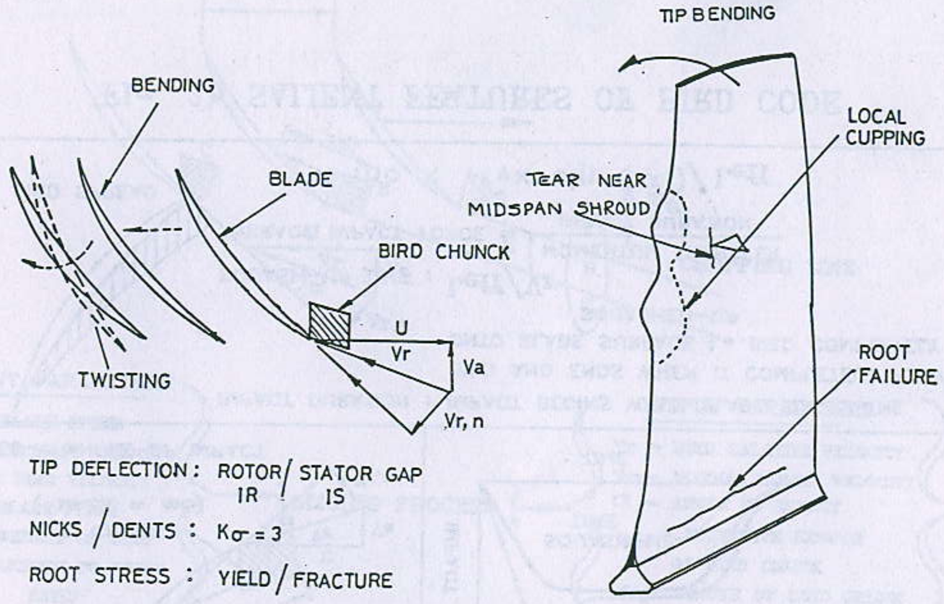


FIG. 2c. FAN BLADE: CRITICAL AREAS AND FAILURE MODES.

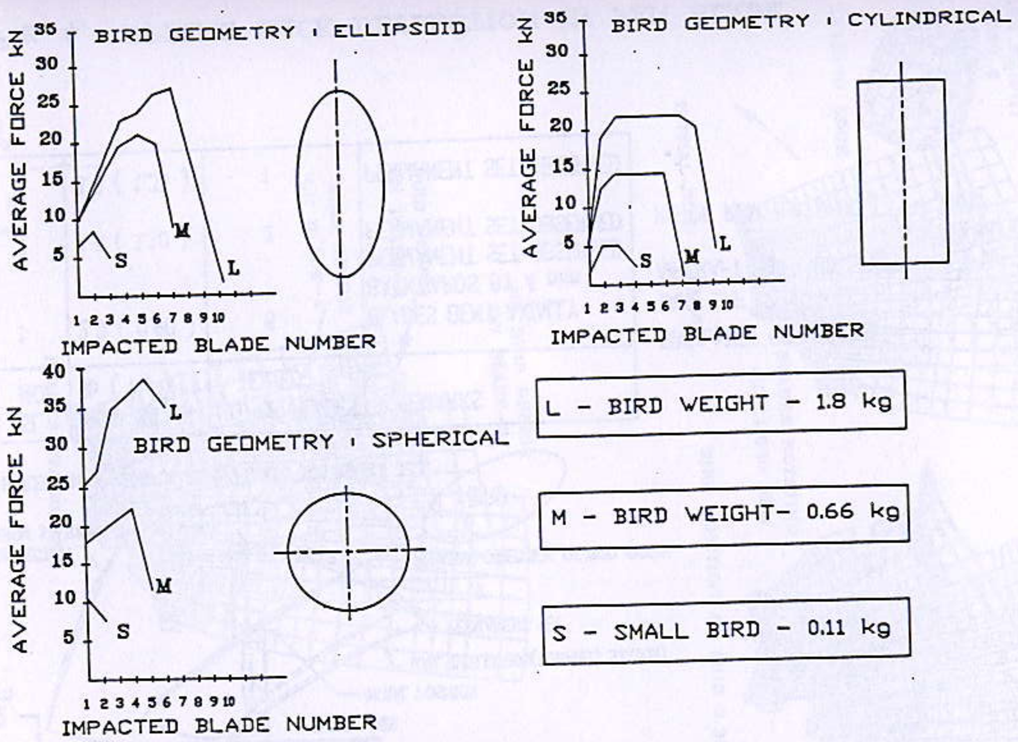
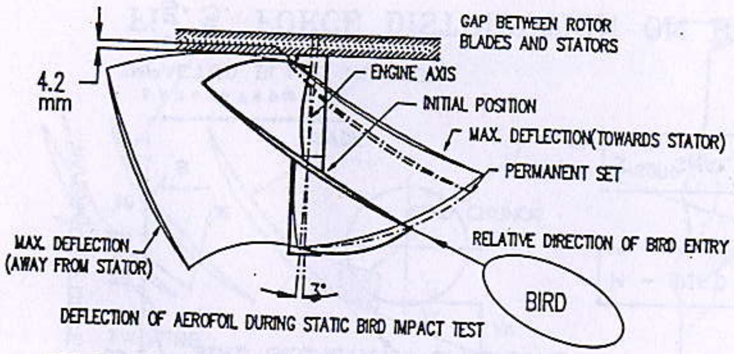


Fig. 3. FORCE DISTRIBUTION ON BLADE CASCADE



DEFLECTION OF AEROFOIL DURING STATIC BIRD IMPACT TEST

SL. NO.	BIRD WT. IN lb (Kg)	NO. OF BLADES TESTED	REMARKS
1	2.0 (0.90)	6	BLADES BENT AXIALLY BACKWARDS BY 4 mm PERMANENT SET OBSERVED
2	2.5 (1.10)	2	PERMANENT SET OBSERVED
3	3.0 (1.35)	1	PERMANENT SET OBSERVED

SIMULATED CONDITIONS:
TAKE OFF
AIRCRAFT FORWARD SPEED = 0.4 M (132 m/s)
ROTOR RPM (LP SPOOL) = 11017

Fig. 4. SPRING BACK DEFLECTION IN FAN BLADE

BIRD IMPACT AT TIP LOCATION

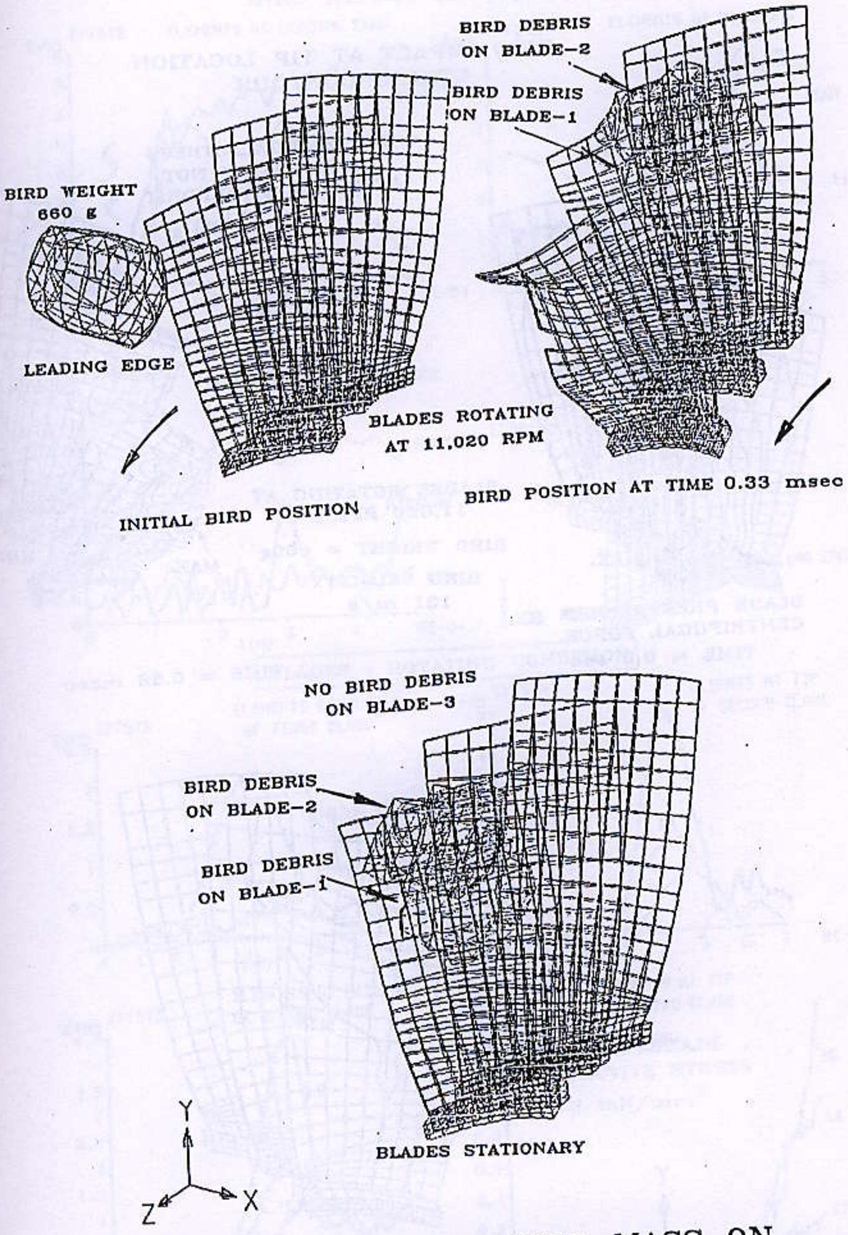


FIG. 5 FLOW OF BIRD MASS ON ROTATING & STATIONARY BLADES

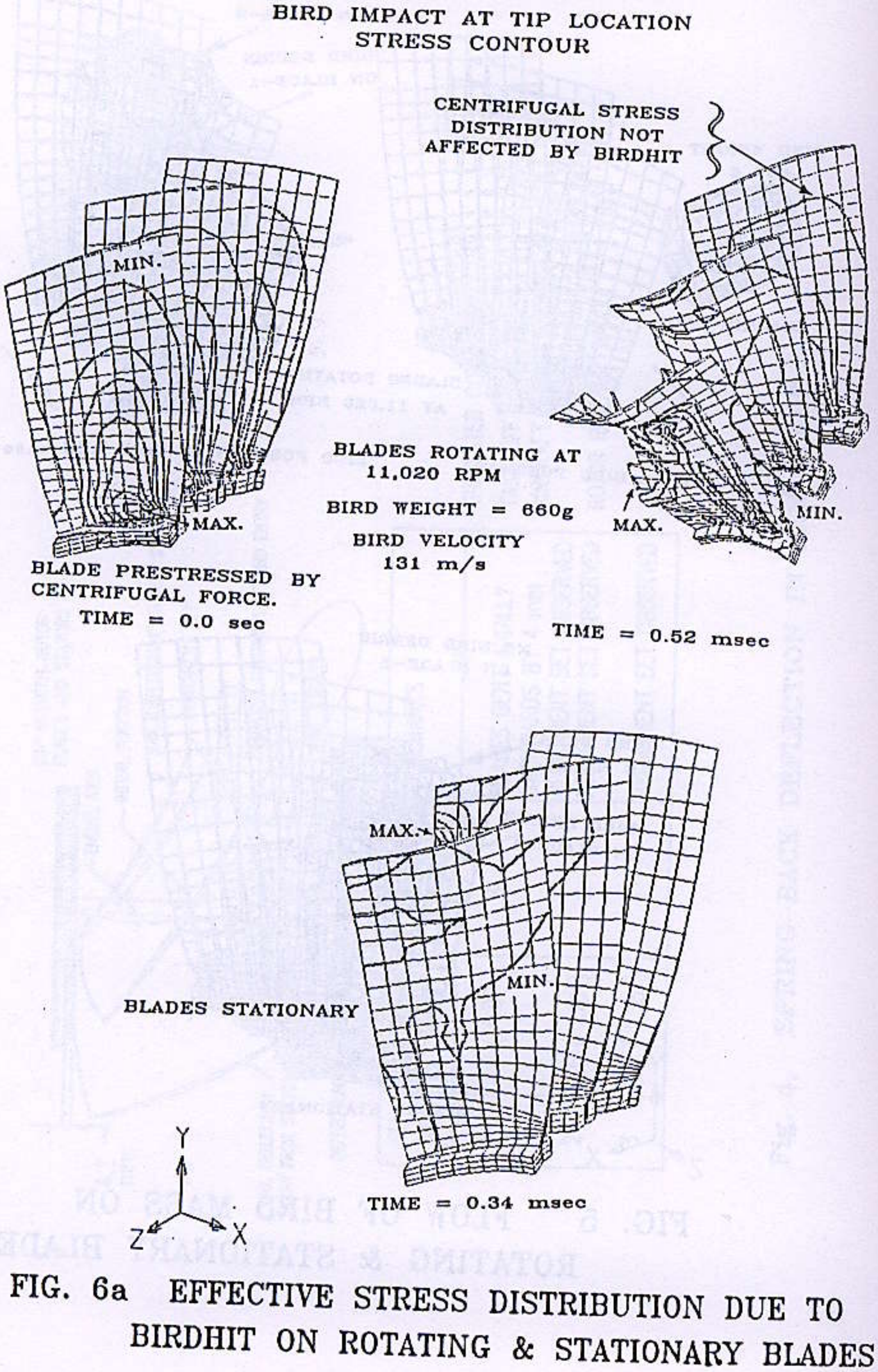
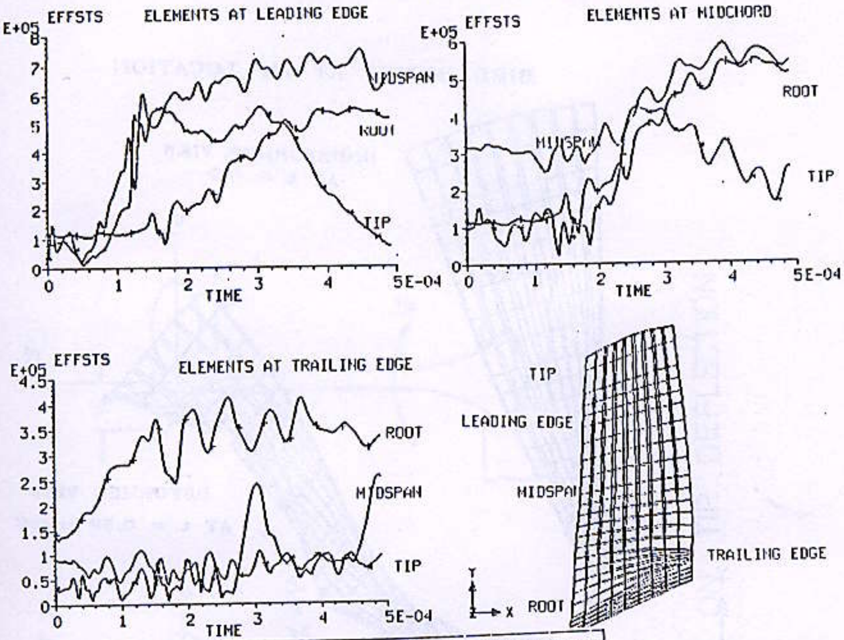
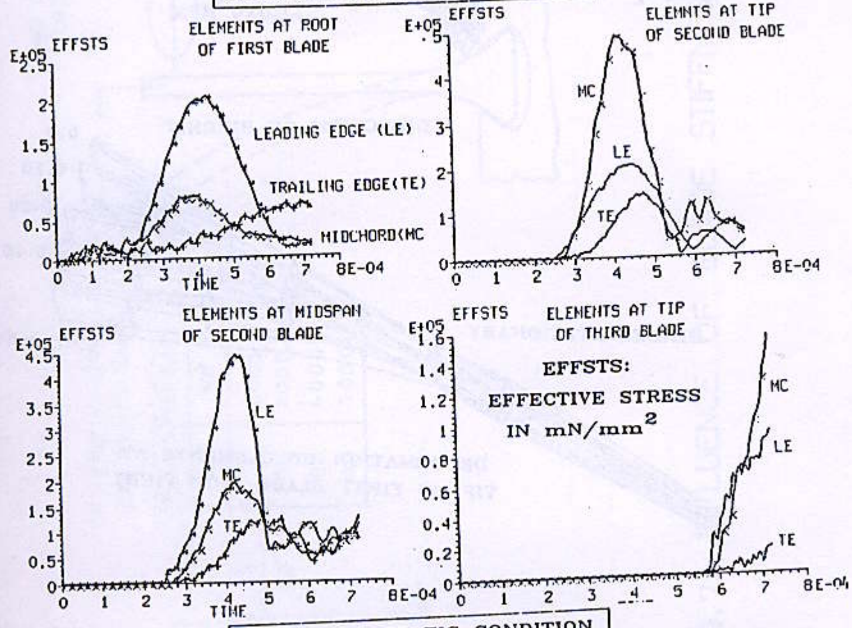


FIG. 6a EFFECTIVE STRESS DISTRIBUTION DUE TO BIRDHIT ON ROTATING & STATIONARY BLADES

BIRD IMPACT AT TIP LOCATION



BLADES : ROTATING CONDITION



BLADES : STATIC CONDITION

FIG. 6b TIME–TRANSIENT OF BIRD STRIKE STRESS IN FAN BLADES

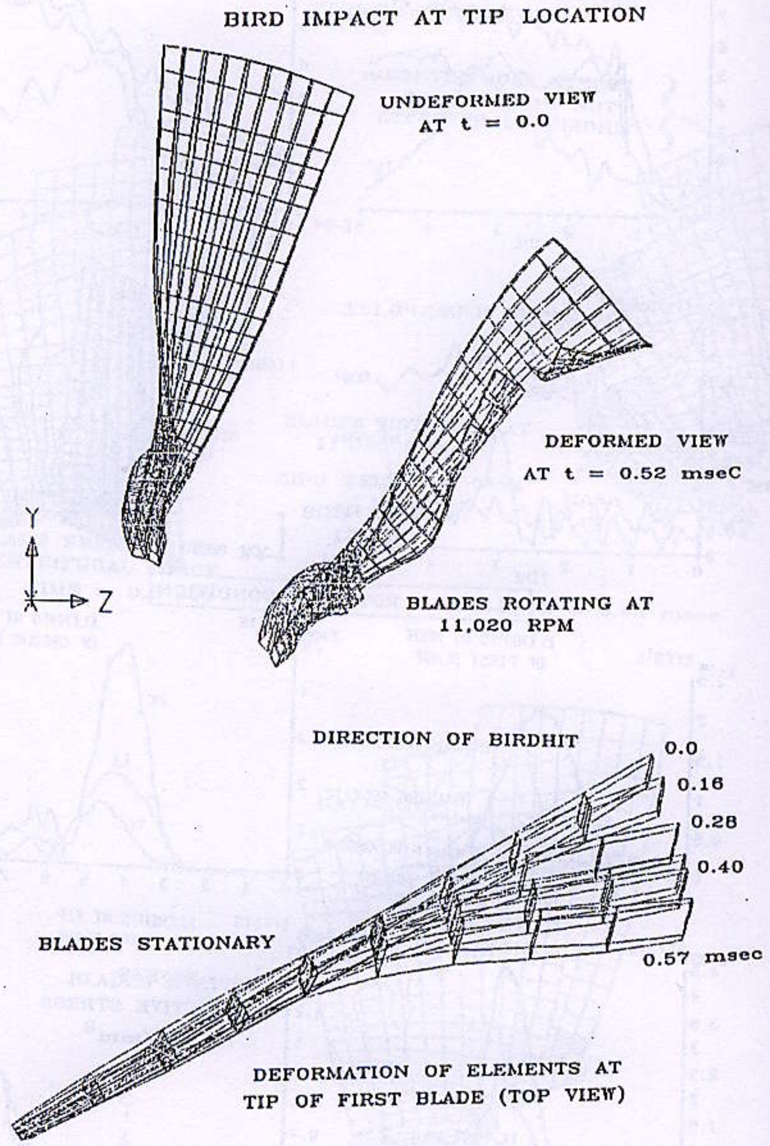
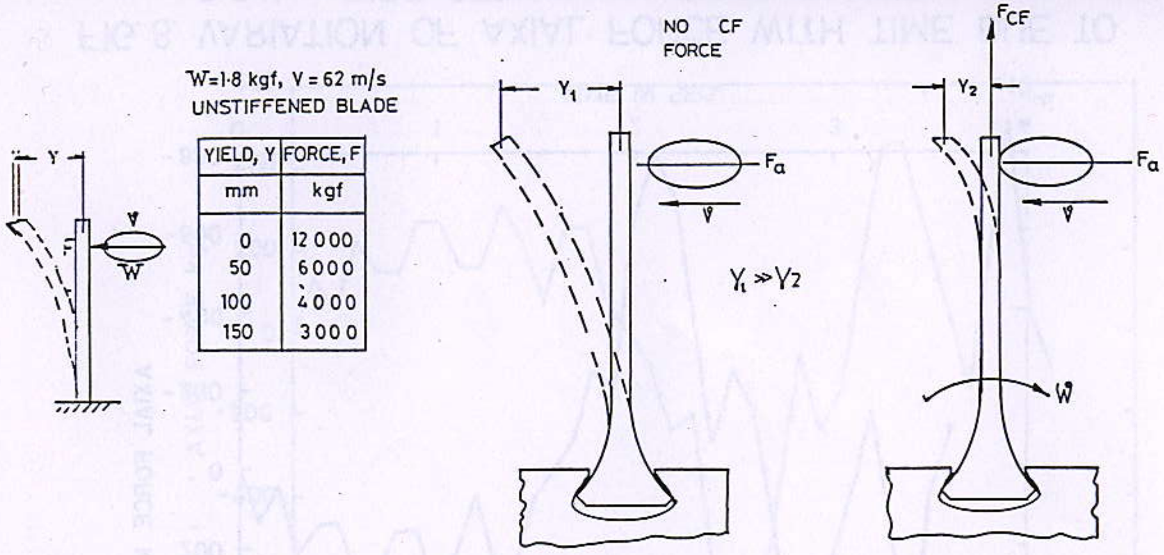


FIG. 7a DEFORMATION PATTERN IN BLADE AEROFOIL



YIELD, Y	FORCE, F
mm	kgf
0	12 000
50	6000
100	4000
150	3000

FIG. 7b. INFLUENCE OF BLADE STIFFNESS ON TIP DEFLECTION

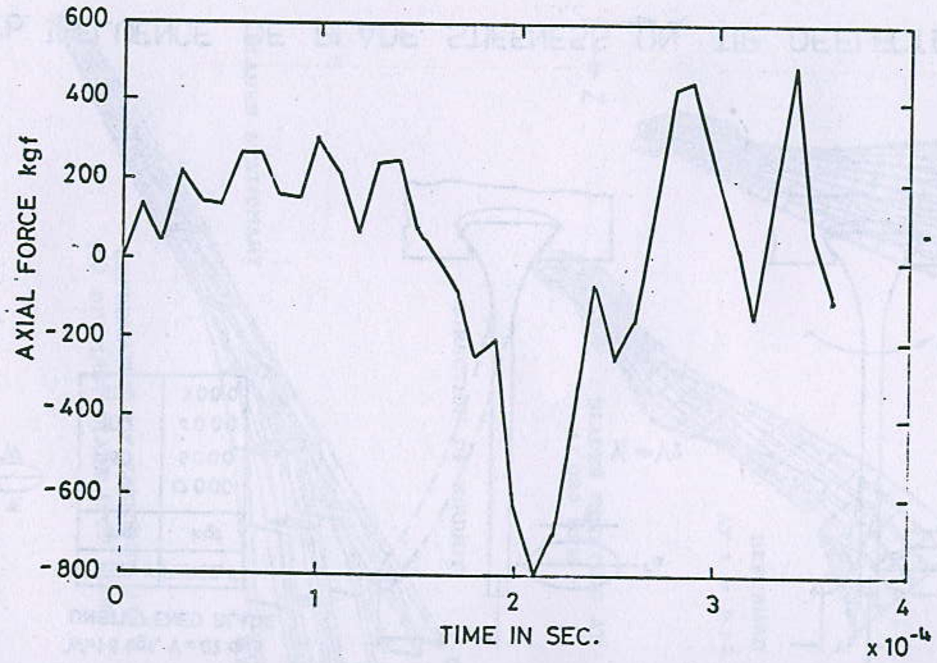


FIG. 8. VARIATION OF AXIAL FORCE WITH TIME DUE TO 0.9 Kg. BIRD STRIKE ON FIRST BLADE

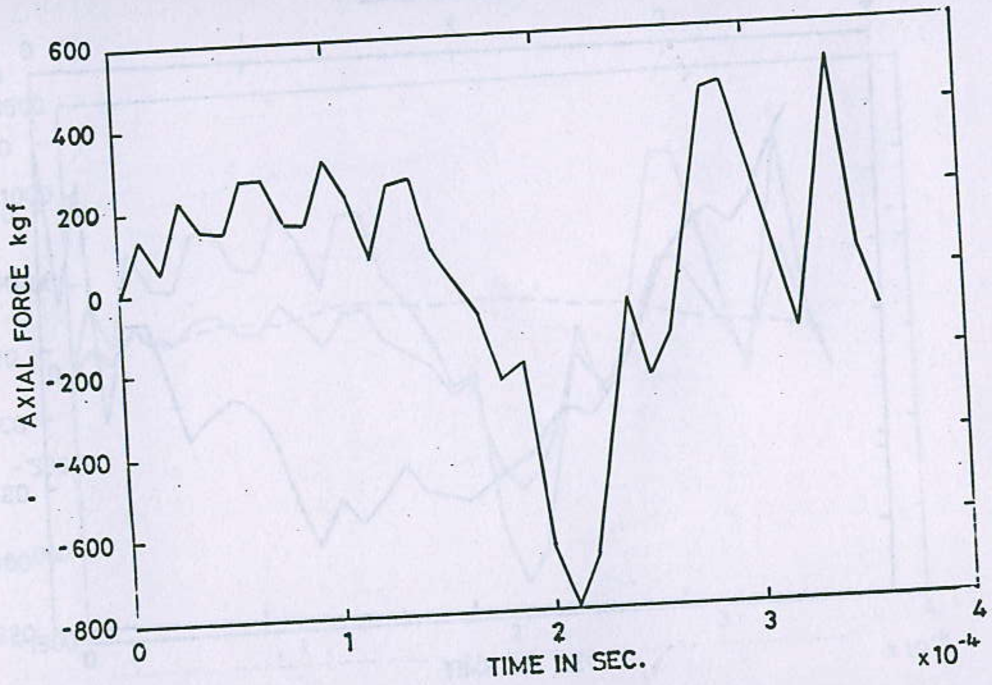


FIG. 9. VARIATION OF AXIAL FORCE WITH TIME DUE TO 0.9 Kg. BIRD STRIKE ON SECOND BLADE

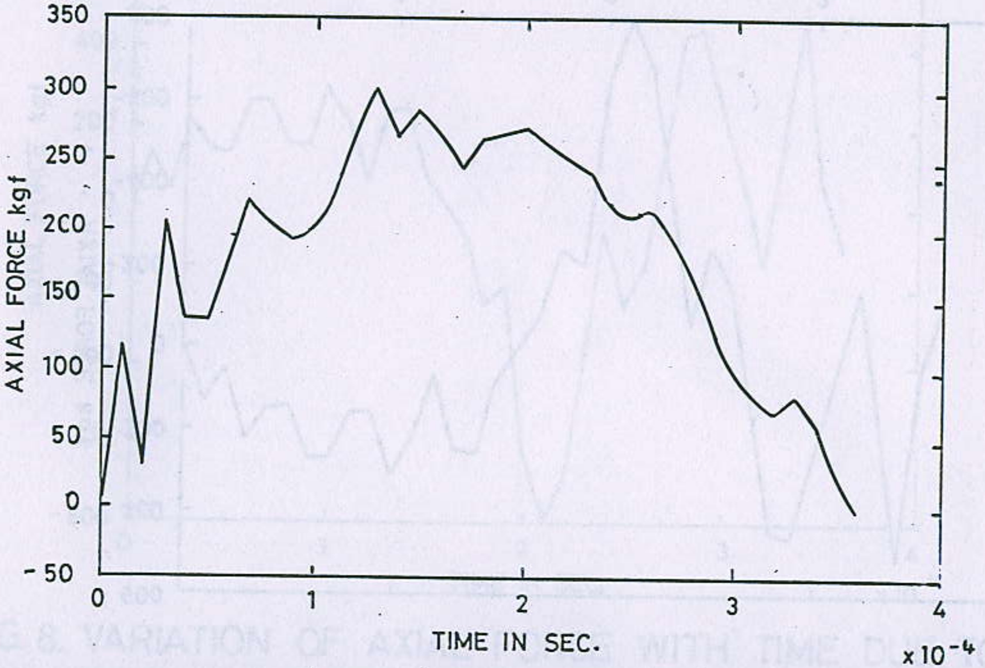


FIG. 10. VARIATION OF AXIAL FORCE WITH TIME DUE TO 0.9 Kg. BIRD STRIKE ON THIRD BLADE

x 10^{-4}

FIG. 10. VARIATION OF AXIAL FORCE WITH TIME DUE TO 0.9 Kg. BIRD STRIKE ON THIRD BLADE

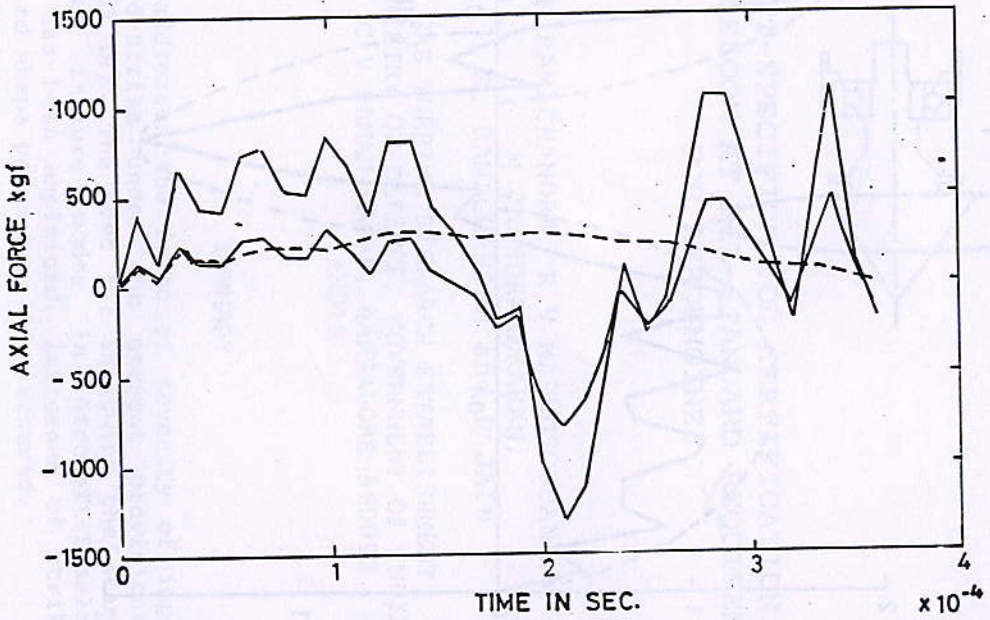


FIG. 11. COMPOSITE PLOT OF AXIAL FORCE WITH TIME DUE TO 0.9 Kg. BIRD STRIKE

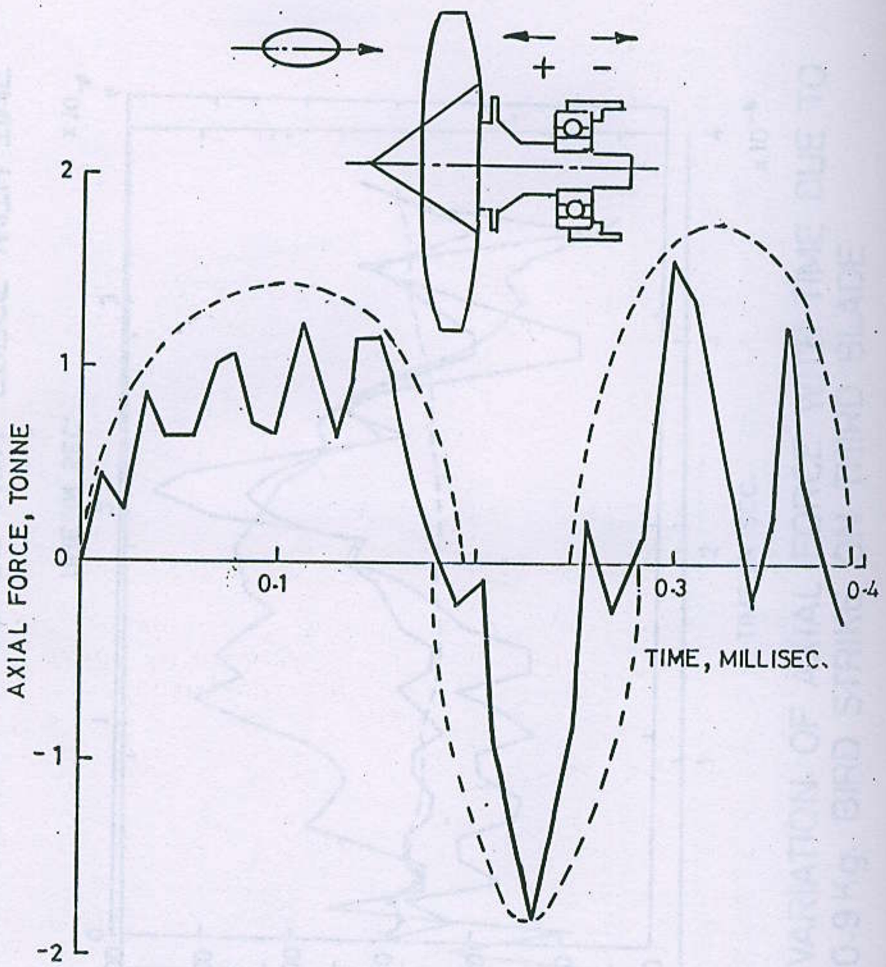


FIG.12. RESULTANT AXIAL FORCE ON L P SHAFT BEARING

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

K RAMACHANDRA, R V MADHUSOODANAN,
M CHANDRASEKARAN,
S. RAMACHANDRA and R JAIN

GAS TURBINE RESEARCH ESTABLISHMENT
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C V RAMAN NAGAR, BANGALORE-560093
INDIA

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