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PROPELLER FOREIGN OBJECTS DAMAGES TESTING

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ABSTRACT

CEPr has proceeded in 1987 and 1988 at new TRANSALL composite propeller foreign object damages (FOD) qualification in its H0 test rig.

Those tests were performed under the JAR-E and FAR 33 regulations spirit : therefore new testing techniques were developed by CEPr to achieve tests objectives.

All the tests being done have given a lot of informations on the difficulties, FOD testing teams might encounter during a propfan or propeller qualification.

Test campaign conclusions indicate clearly that some arrangements must be introduce in the qualification process of such engines in order to find a compromise between test cost and engine reliability.

INTRODUCTION AND HISTORY

For now seven years, CEPr has been involved in propeller foreign object damages (FOD) testing. This new part of the general FOD testing activity is directly related to the high speed propeller concept, call PROPFAN, and the composite material use for old propeller replacement on existing turboprop engines.

After a first campaign performed on a four composite blades BASTAN propeller, CEPr has been involved in the new composite TRANSALL blade qualification in 1987.

In the same period, CEPr has worked a lot on the Unducted Fan GE36 qualification and on what should be changed in both its tests methods and tests installations to ensure a full FOD campaign success [1].

The BASTAN campaign has previously shown the FOD testing in real take-off conditions extreme difficulty for propeller type engines. Due to a lack of time, CEPr was forced to shot the birds in the propeller plane in order to guarantee a successful shot probability as high as possible. (see figures 1 and 2) : it was then obviously necessary to change the propeller blade pitch to recover similar conditions as the aimed ones (take-off conditions).

After the campaign, a complete test analysis has been done : the chosen shooting technology was criticized by CEPr itself for three main reasons :

1 - the missing shot rate was relatively high.

2 - the shots were not repetitive, mainly in term of impact location and impact velocity (see figures 2 and 3),

3 - the propeller mechanical behaviour during the strike was not the same : in particular, it has not been possible to analyse a failed shot completely (10% blade losses during a heavy bird test) and to explain what would have happen in a real take-off or cruise bird strike.

Therefore, new technological studies were done to develop a FOD test rig able of projectiles shooting parallel to the propeller axis.

The choice of such a technology was mainly based on the fact that the only existing FOD engine qualification requirements were the JAR-E and FAR 33 requirements : French qualification authorities have therefore taken those regulations as a base for the demonstrations to be done. In fact, the regulations do not force a bird projectile trajectory parallel to the engine axis, but the common use has always led to such a constraint and authorities are considering this fact as a jurisprudence.

The chosen test rig was the H0 CEPr propeller test rig which allows :

1 - a similar mounting as the aircraft one, which is important in terms of mechanichal global behaviour of the whole propulsive system (see figures 4 and 5),

2 - a real take-off simulations in terms of engine rating and propeller blade pitch,

3 - stresses analysis on one chosen blade.

Four different foreign objects were to be sent at the chosen blade :

- stones
- hailstones (50 mm diameter)
- medium bird (sea gull 0.7 kg)
- heavy bird (sea gull 1.4 kg)

Due to global qualification cost constraints, only six metallic and six composite blades were given for almost 40 shots to perform during the all campaign.

This implies that CEPr test rig development major objective was mainly written in term of missing shots tolerable rate : CEPr choices were mainly based on those missing rates per projectiles :

- stones : 75%
- hailstones : 50%
- birds : 0%

The engine thrust was considered as a qualification parameter.

CEPr FOD TESTING TECHNOLOGY IMPROVEMENTS

To achieve its ambitious objectives, CEPr FOD testing team has mainly worked on the shooting automaton.

Gun, high speed movies and video cameras and their afferent management system were not changed : only little improvements were put to increase the film quality and projectile speed measurement. However, a very long and detailled calibration campaign has been done for each pieces of the test rig in order to know the different FOD parameter uncertainty as best as possible (gun pressure, detonator explosion time, installation electrical repeatability, gun air quality, etc ...).

In parallel, theoretical studies were launched : they led us to the conclusion that a blade aimer system (BAS) was obviously the only solution of our problem : coupled to a little FOD managing system improvement, a BAS would allow us to choose the blade to be knocked against and would also be self learning capable if a lot of shots were not successful.

Blade aimer system

Blade aimer system original idea is a World War I aircraft machine gun firing system derivative : this old system allows to shoot the machine gun through the propeller without damaging the blades by synchronisation with the propeller rotating velocity. BAS principle is just the opposite : firing all the time in the propeller blade.

BAS implies a very good knowledge of the different time spent by the projectile and the aimed blade between the shooting authorization and the impact.

To ensure the time spent by the blade between the shooting authorization and the impact, BAS is mainly based on a stroboscopic video system whose frequency is related to the propeller rotational speed. View of the aimed blade is taken by the stroboscopic system and the test engineer can choose the blade to be knocked against by acting on a shooting time delay. In order to increase accuracy, the minimum time step possible was the micro-second (in accordance with the automaton internal clock frequency). This delay is automaticaly taken in account by the automaton during the firing sequence. (figure 6)

Through this visualisation concept, BAS allows also a very good survey of the impacted blade after shot during the five minutes engine stabilisation.

Gun calibration

The time spent by the projectile between the firing authorization and the impact is put in the automaton as a time delay constant : it is a result issued from the calibrations campaign and which might be corrected if some engine influence appears.

This constant is in fact the most important parameter to characterize : therefore it has been necessary to improve our uncertainty analysis during the calibrations : as a consequence, the reutilization of old calibration shots was almost impossible.

New calibrations shots at given firing conditions were done in order to measure all the different times which characterize the projectile trajectory :

- time between shooting authorization and detonator explosion,

- time spent by the projectile inside the gun after the detonator explosion,

- time spent by the projectile to cover the distance gun propeller plane.

The second parameter is mainly related to gun air pressure and final bird velocity. Each parameter was measured and its uncertainty was calculated : then influence coefficients between the different uncertainty were calculated and analysed. They were also compared to the different adjustment parameters such as shooting delay, air pressure, bird mass, projectile carrier mass, etc ...

Knowing the major uncertainty causes, some methods improvements have been develop to reduce them. At least, the bird velocity uncertainty has been reduced

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Although each calibration campaign was seriously done, the propeller effects were not simulated : as their influence was badly known, CEPr was rapidly convinced that at the beginning of each projectile shooting campaign, some shots would be non successful and therefore, the first shots were always considered as «calibration shots». CEPr objective was to reduce those adjustment shots under 5 shots for stone projectile and under 2 shots for birds.

QUALIFICATION METHODOLOGY

As no existing regulations might be applied, French military qualification authorities have chosen the JAR-E regulations as a discussion base : however it was most important to check if the damages encountered during the qualification tests were comparable to those seen by AIR FORCE and NAVY on their bases or by RATIER in its overhaul workshops.

In parallel with the TRANSALL qualification, two kinds of comparisons have been developed :

1 - shots on static blades under load [2] were performed in order to establish the differences between composite and metallic blades in same conditions,

2 - shots on rotating metallic blades were previously done and results (deformation set) compared to the real damages seen in repair workshops.

With all those results, CEPr and RATIER have tried to predict what kind of behaviour the composite blade would have during rotating FOD tests. In fact, the analysis of results has shown that :

- shooting parallel to the propeller axis was the most representative solution,

- results observed on metallic blades were entirely similar to those encountered during real bird strikes.

The choice of take-off conditions and the calibrated projectiles was confirmed by the conclusions of both comparative tests. It has been therefore decided to keep the JAR-E regulations for the TRANSALL propeller qualification, but to restrict the projectile number to one per shot, which was the most reasonable number in terms of impacting bird density as our theoretical studies have shown us.

CAMPAIGN MAIN RESULTS

CEPr is not realy qualified to present in detail the results obtained during the TRANSALL qualification campaign : however, important facts were seen and will be recorded here.

The composite blade behaviour has been judged better than the old metallic one, mainly in term of deformation permanent set and material health. In particular, the nickel base metallic protection against erosion put on the blade leading edge was not damaged and the glue used was very satisfactory. No composite delamination has been observed : this result is very good considering that more than 30 birds have been shot on 4 blades often at similar impact location. As a matter of fact, no composite blade has been changed during the all campaign.

A surprising result is the fact that the impact location can sometimes avoid the leading edge of the blade, which is always the case for HBPR engines : this confirms our theoretical studies [3].

MAIN PROBLEM RAISED

As said before, the uncertainties calculated and observed on the different FOD test installation parameters have been studied in order to analyse more precisely the impact time dispersion. The different calculations hypothesis led us to think that the impact time repartition can be describe as a gaussian function [3]. Subsequently, the relative distance between the blades and the bird at a given time is also a gaussian function.

Comparing this result to the one obtained in an High Bypass Ratio (HBPR) engine qualification [3], CEPr has confirmed during the tests that only one part of the bird mass was really impacting the blade : as a matter of fact, in an HBPR engines bird strike test, the whole mass of the bird takes part in the shock, almost equaly distributed on several blades.

As during some shots, we have been capable to analyse how the bird was cut by the blade, we have experimentaly found that the «acting mass» implied in the impact is almost a gaussian curve as well (figure 7).

Then the main problem raised after a shot was perform was :

IS THE TEST BEING DONE THE MOST SEVERE ONE ?

In other words, is a one shot qualification test really reliable ?

CEPr experience leads to the conclusion that you can guarantee for a one bird shot, the projectile would not miss the blade : little installation improvements at low investment costs are sufficient. However, it is more difficult to control and reduce the FOD main parameter uncertainty : a noticeable reduction implies most of the time a subsequent change of technology and therefore a complete installation renovation at high investment costs (for example, just try to imagine what should be done to control and to make repetitive a real bird trajectory between the gun exhaust and the blade).

Due to the lack of time (qualification date to be respected), CEPr has not tried to improve more its FOD testing system : we have defined what seemed to be the worse impact (in term of blade radius) and we have perform 10 shots at similar conditions, in order to have a consequent data base and to be sure that approximatly half of the bird mass has one time knocked against the blade.

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As said above, the results of those shots have confirmed the gaussian repartition.

Not only the mass effects can differ, but also the impact location : as for HBPR engine you are always sure that most of the shot will be on the leading edge, for the propeller blade, the impact can be on the pressure face or on the suction face depending on the bird or propeller rotating velocity. This fact backs up the uncertainty related to the severity of the bird impact.

CONCLUSION

Facing the propeller FOD qualification, CEPr has developed new shooting installations and new testing methods which are very satisfactory.

It seems however that the choice of JAR-E regulations will lead to some practical difficulties related to the uncertainty of the FOD installations main parameters. In fact, as for HBPR engines there is no need to define how a bird is impacting a fan blade, for a propeller a new parameter is necessary to describe the strike severity : we call it «acting mass». Unfortunatly this parameter is difficult to characterize through real strike statistics analysis and therefore has to be imposed by the reglementations.

To reduce the cost of propeller FOD qualification tests, the use of static blades under load seems to be a sensible solution, mainly in terms of costs : however, it does not replace the complete engine test which can be done only on a rotating turboprop equiped with its propeller and all its equipments.

The question of the shots number necessary to meet the imposed «acting mass» is then also a regulation decision to make, considering the test installation capacities and the engine performances.

The very encouraging results, we have on static blades under load campaign show that a mix of the two testing methods is necessary : the static blade campaign will ensure, that the blade can resist to all kind of bird strike and the rotating propeller FOD test will show that the all propulsive system can support a foreign object strike.

Bibliography

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[2] STATIC BLADES UNDER LOAD FOD TEST PROGRAM
JP DEVAUX WP** BSCE 20

[3] PROPFAN BIRD STRIKE TESTING
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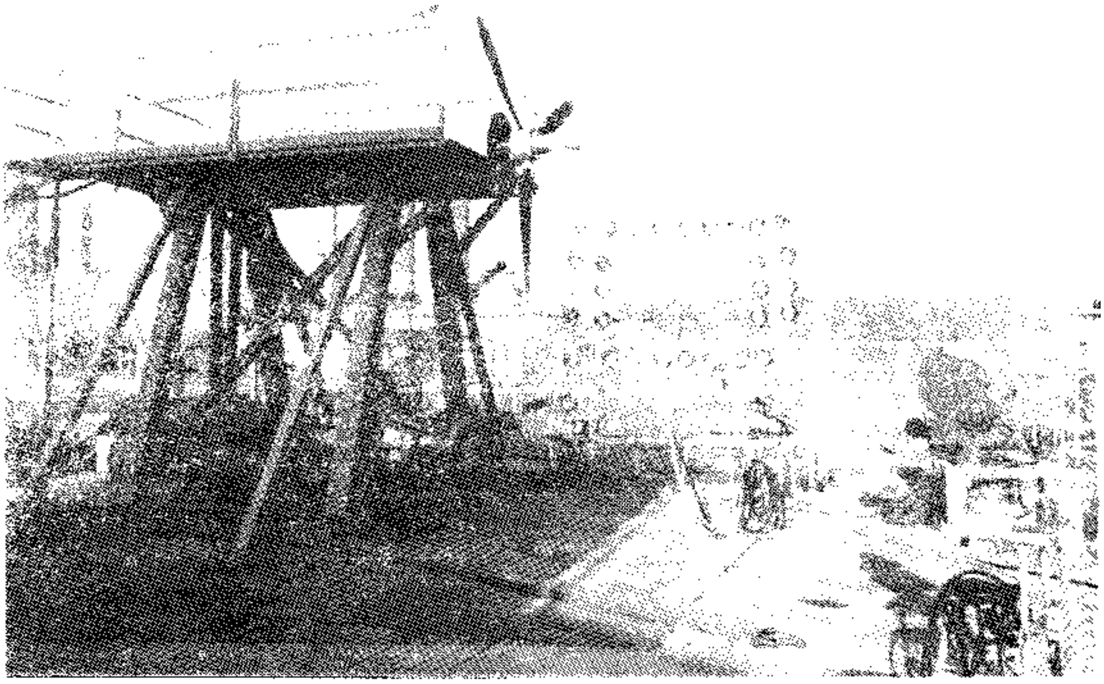


Figure 1 : BASTAN FOD TESTING INSTALLATIONS
(Photo CEPr 85-211)

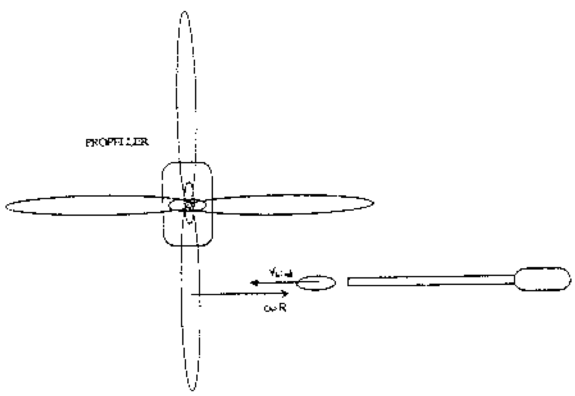
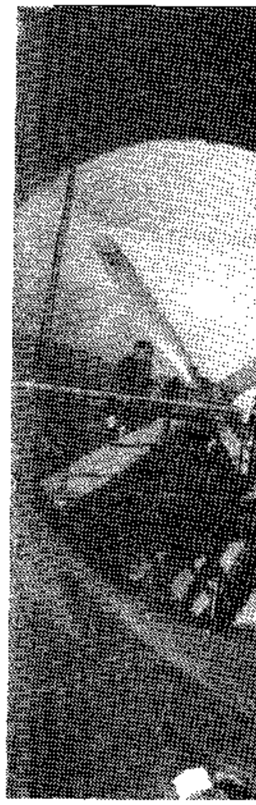


Figure 2 : BASTAN FOD TESTING INSTALLATION SCHEME



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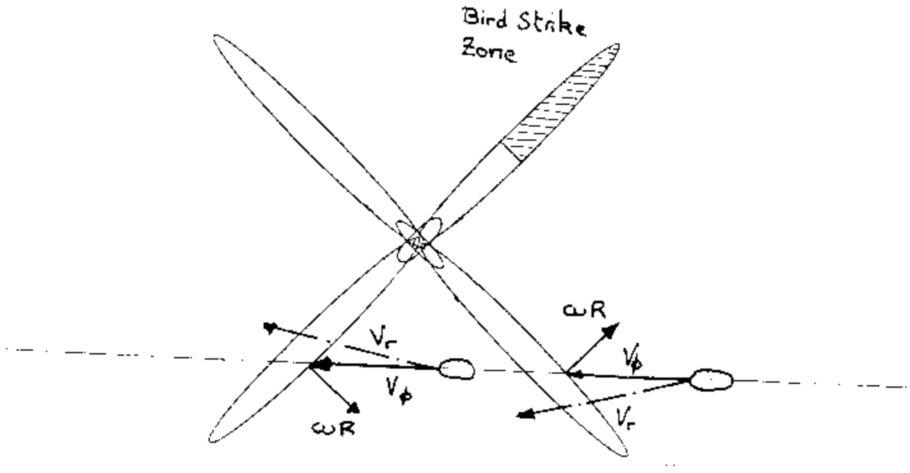

Figure 3 : BASTAN FOD TESTING PRINCIPLE

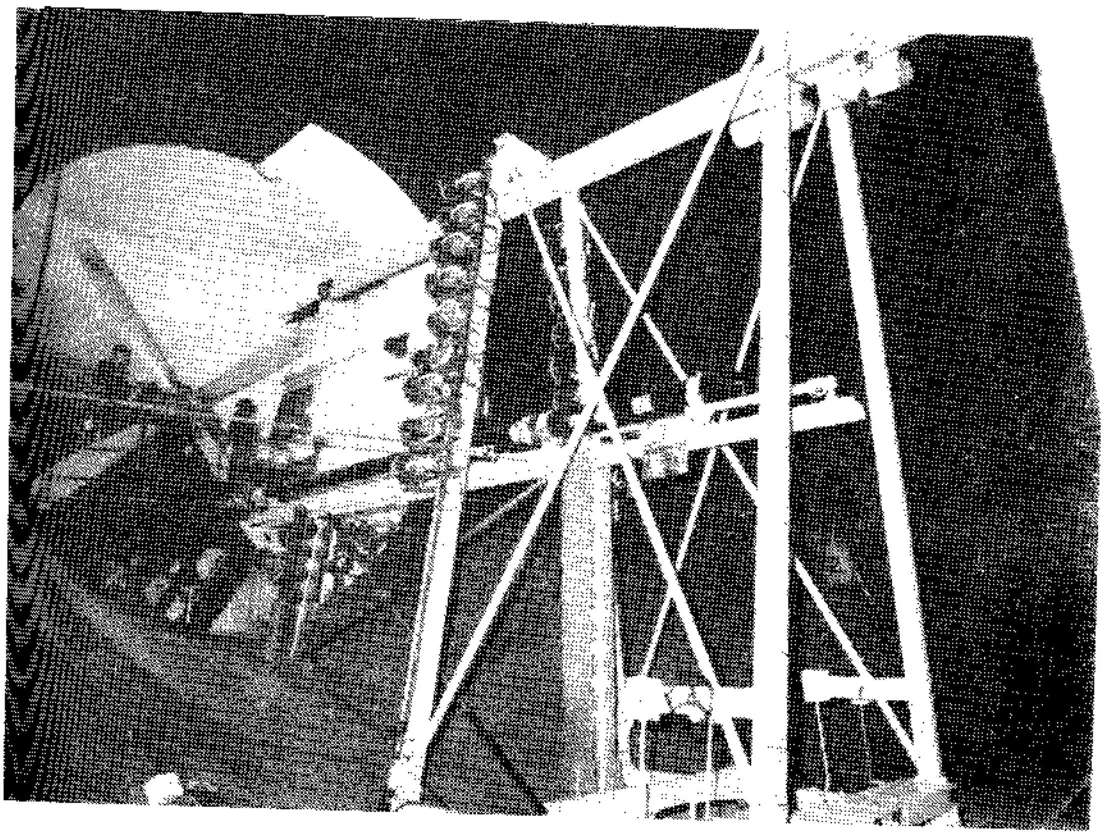

Figure 4 : TRANSALL FOD TESTING INSTALLATION
(Photo CEPr 87-5566)

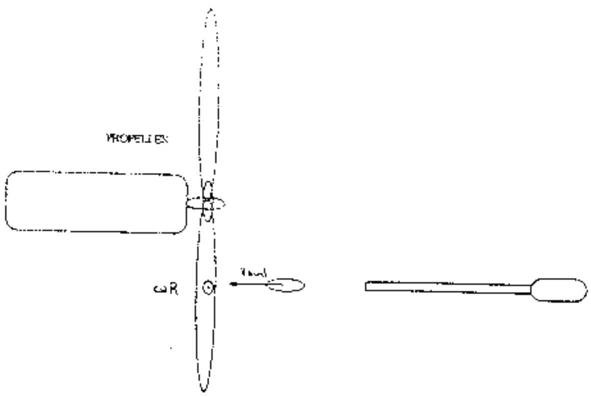

Figure 5 : TRANSALL FOD TESTING INSTALLATION SCHEME

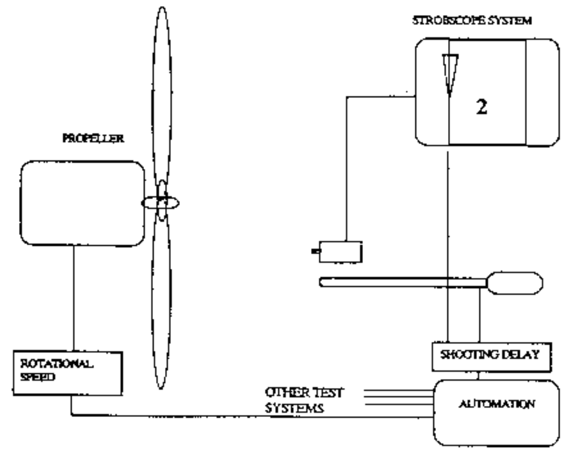

Figure 6 : BAS SCHEME

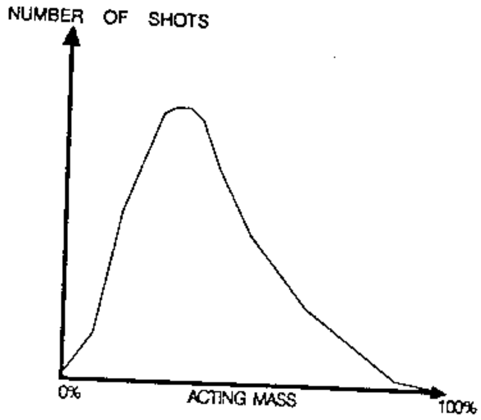

Figure 7 : ACTING MASS REPARTITION