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PROPFAN BIRD INGESTION TESTING

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ABSTRACT

To face the UDF GE 36 qualification and to understand the results obtained during the TRANSALL composite propeller blade Foreign Object Damages qualification, CEPr has developed a simple modelization of bird impact on turboengines blades, which take the tests installation parameters uncertainty in account.

Preliminary tested in comparison with our experimental results obtained both on High ByPass Ratio engines and propeller, the model is a good description on what can happen and what is the probability of it to happen.

Some results obtained on propeller or propfan models are surprising and have direct consequences on the FOD qualification methods or processes to be used for engines certification.

INTRODUCTION

At the beginning of the theoretical studies realized by CEPr to analyse the TRANSALL foreign object damages (FOD) qualification feasibility, the main questions raised were :

- what might happen during such a bird strike ?

- what kind of differences might we encounter by using High Bypass ratio (HBPR) FOD technology ?

As TRANSALL FOD qualification tests second aim was also to prepare both the test installations and the regulations to the UDF GE 36 qualification, CEPr has tried during its preliminary studies to identify the main differences between four kinds of engines :

- HBPR engines (like CFM 56 or V2500)

- Propeller engines (like TRANSALL or BASTAN propeller)

- Unducted fan (like UDF GE 36)

- Ducted fan engines (like the German CRISP FAN)

As CEPr has decided to study only the first bird impact on the first fan, the last engine category can be joined to the HBPR engines one.

The study was reduced to a simple model development and CEPr aim was to confront the results obtained on HBPR engines to those found during the different CFM56 qualification campaigns. After this, CEPr has tried to define what a propfan would be and what kind of results propfan FOD tests might give.

CEPr has also tried to understand what the uncertainty effects might be on the final results : this explained that the model is both a description of the tests installation and of the engine to be tested. This has been always a major preoccupation, even in HBPR engine FOD testing, to know wether our technology was sufficient or need more improvements : as our technology allows us to cover all the existing cases, only the precision and therefore the quality of the test is now a problem.

MODEL DESCRIPTION

The model being used is divided in two main systems simulated by characteristic numbers :

- the first system is representative of the technology level, the reliability and repetability of our shooting installations. We will find there the installation parameter and their uncertainty such as :

  * shooting authorization time,
  * shooting delay,

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* time spent by the projectile in the gun after detonator explosion,
* gun pressure,
* gun diameter,
* fan-gun distance,
* projectile velocity,
* projectile characteristics (length, diameter, density, etc ...),
* etc..

The first two parameters are representative of the automaton subsystem, the three following ones of the gun subsystem, the distance of the test mounting and the last two ones of the chosen projectile subsystem.

- the second system is representative of the engine type. CEPr has chosen to reduce the engine at its propeller or first fan and therefore the parameters used in the engine system description were :

  * fan or propeller number of blades,
  * blade characteristics as a function of blade radius,
  * critical radius,
  * fan or propeller rotational speed,
  * fan or propeller propulsive torque,
  * etc ...

  When we have tried to understand how to ensure an impact on the second fan, this one was described with the same parameters.

All parameters are described by a gaussian law (mean value, standard deviation) Assuming that they are independent, the results will also obey a gaussian law. This description of parameter uncertainty is conform to French Bureau National de Metrologie recomandations.

The final result given by the model is the bird impact location when it occurs. A probability analysis allows us to transform this result in :

- missing shot rate or impact probability,

- «acting mass» repartition, which is the mass really impacting the blades.

As CEPr wanted to keep the model as simple as possible, many physical aspects of the shots have been simplified or sometimes not considered :

- we have neglected the aerodynamical effects on the projectile during its flight and in the fan volume.

- we have neglected the mechanichal effects of the impacting projectile on the blade and the consequences in terms of rotational speed and vibrations.

- the projectile is described as a sphere or a cylinder and moves along a straight line.

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CEPr in fact has studied in an other program the influence of those parameters : this program, the FODES program (Foreign Object Damages Expert System), is in fact the program which is directly preparing the shots and therefore which must take the secondary effects in account to have a successful shot. In our preliminary study, the secondary effects do not really interfere with the row results and they can be neglected.

MAIN RESULTS

CEPr study has been divided into two periods : first the impact probability study and comparison with HBPR engines previous experimental results and secondly the uncertainty influence study.

First impact and knocked blade number study

Three engines models were chosen to describe the different engine types considered in the study : they are described in figure 1. Each time, we have studied the bird strike at 90% of the blade radius, which is most of the time the most critical location.

To qualify the model, CEPr has begun its study by HBPR engines in order to compare the results and the real bird strikes experience we had. Figure 2 shows the row results given by the model. Those results were very satisfactory as the knocked blades number was similar to reality : the differences found between the damaged blade number found in real bird strike and the knocked blade number found by the model is in fact easily explained :

1 - by the weak mass impacting the first and the last blade,

2 - by the chosen bird modelization (an ellipsoid model would have given better results than a cylinder one).

We can note on picture 2 that the «certification zone» defined as the zone were authorities might choose the qualification parameters, both in terms of engine rotational speed and bird velocity, is completely inside the 0% missing shots rate zone : this is a particularity of the HBPR engines which make FOD tests relatively easy.

Finally, we can see that the impact location will always be on the leading edge and on the pressure side. The model was coherent with the results found during previous HBPR FOD qualification test campaigns.

As results were good for HBPR engines we have applied the model to propeller engines. Figure 3 indicates the row results scheme obtained. One major difference appears : the «certification zone» is completely outside the 0% missing shots rate zone. Something therefore must be done to adjust the different reference times to avoid high missing shots rate : this result has led CEPr to define precisely the Blade Aimer System [1].

Considering the impact location, CEPr has found that it was possible for an impacting bird to avoid the leading edge and knocking only the pressure or the suction face : this has been confirmed by experimental results for the pressure face impact

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possibility during the TRANSALL propeller FOD qualification [1].

As the model was excellent in its prediction for TRANSALL propeller testing, we have tried to see what kind of results we might expect for propfan engines. For time reason, the study has been restricted to the first fan impact.

The row results obtained are given in figure 4. We can see there that the propfan has a complete different behaviour compared to HBPR engines or propeller : in particular, the «certification zone» is partly inside the 0% missing shots rate. This means that the tests technology used for HBPR engines is not sufficient to guarantee a 0% missing shot rate and therefore the propeller testing technology with the use of a Blade Aimer System is necessary, even if this BAS is less sophisticated than the ones developed for propeller testing.

We found here that a propfan is between the two types of engines : its global behaviour will therefore in fact be also in between and we will have to face for Propfan FOD testing the same troubles as the one encountered for propeller FOD testing.

Uncertainty influence

The second part of the study was much more focused on the test severity and quality. The major parameters are then :

- the «acting mass», which is the total mass impacting the blade,

- the impact location.

In fact those two parameters are completely related and the results found on the first give clear ideas on the second parameter behaviour.

On HBPR engine, as the whole bird is impacting several blades, all the bird mass impacts the propulsor and the parameter to be considered is then the maximum acting mass per blade. Uncertainty becomes a problem to deal with only when you try to avoid double impact on the same blade.

For propeller and propfan, the impact location (in the blade reference system as shown in figure 5) becomes uncertain, due to the main adjustment parameters uncertainty : our model shows us that at given conditions (mean value and standard deviation), the «acting mass» is also described by a gaussian function as a result of the adjustment parameter mathematical independence.

We have studied the influence coefficients of the installation adjustment parameters on the final result. The results obtained showed that :

- the distance between the gun and the first fan has a major influence : increasing this parameter increases subsequently the total uncertainty. This result is backed up by taking in account in a more sophisticated model the trajectory effects due to aerodynamical environment : we have therefore considered that the trend shown by the model was in reality much more important and this has led us to reduce the gun-fan distance for the TRANSALL propeller qualification.

- the bird velocity is acting in the opposite way : the uncertainty is very bad at low velocity shots and tends to decrease at high velocity. This trends can be backed up in a more sophisticated model by the fact that intended velocity uncertainty increases when final bird velocity aimed decreases (Gun modelization results). This has been a real problem to solve for the TRANSALL propeller FOD campaign.

- the engine rotational speed tends also to increase the uncertainty : the main consequence is an increase of the acting mass uncertainty for propfan engines.

STUDY FIRST GENERAL CONCLUSIONS

CEPr is still going on with the study : however some general conclusions are now clear and let us think, propfan FOD testing for qualification purposes will not be as so simple as HBPR engines ones and will probably similar to the propeller FOD qualification process.

If the certification authorities choice is to maintain the actual philosophy (shooting several birds at an engine in real take-off conditions), two problems are to be solved :

1 - we have to find the right engine and gun mounting for UDF Propfan or Propeller to allow the engine to be at the right conditions (mainly for the blade pitch and the aerodynamical effects) without disturbing the engines global performances : this solution was chosen for TRANSALL propeller FOD qualification because the engine mounting was still existing.

2 - we also have to be sure during a multi-bird shot that all the birds are impacting the fan or the engine and that the global impact is representative of a real severe bird strike.

On TRANSALL propeller, CEPr study has concluded that only one bird was needed. This was a result of a bird density analysis : we have assume that the JAR-E bird number requirements is related to a bird flock density and we have calculated the equivalent HBPR area (in term of aerodynamical blockage) and deduced the bird number. However, to ensure that the worst cases have been covered, CEPr has performed 10 shots at similar conditions : this induces a very high testing cost both in term of tested material and direct test costs.

Doing the same thing for propfan will lead to 1 to 3 birds shots depending on the fan diameter, blade chord and pitch angle. Therefore, the number of shots necessary to ensure that the most damaging cases have been covered is obviously higher and so the testing costs.

It is then clear that new FOD qualification processes have to be find in order to replace or reduce direct shots parallel to the engine axis at take-off conditions. Some solutions trends can be presented very here quickly : none of them is really satisfactory and the final solution might perhaps be a mix of all.

1 - developing the static blade under load tests techniques : presently used to define the critical zones, this testing techniques could be used to analyse the deformation set induced all along the propeller blade to be certified. Once the deformation set are obtained, the blades are mounted on the propulsive system to check the thrust and the dynamical integrity. This method induces a good understanding of what might differ between real bird strikes and simulated strikes. Comparative test on existing engines are obviously a necessity.

2 - single shot testing on rotating fans : this solution is obviously reducing the global number of shots, but cost reduction is relatively low compared to the volley shot solution. The problem of the relations between reality (multiple impacts) and the qualification test is still present and will therefore induce as well comparative tests on existing engines.

CONCLUSION

The CEPr study has led to conclude that the propfan testing technology choice is mainly depending on the regulations rules and demonstration processes which will be use for such engines.

Between the propeller type and HBPR engines types, propfan FOD behaviour comes up more to the first type, considering that the missing shots rate is different from zero and that only one blade can be knocked.

Therefore, it seems very important to work more on propeller statistics in order to analyse the regulations main parameters such as the bird number, the impact locations, etc...

The regulation choice is then a very long process based on specialist discussions to find a compromise between qualification reliability (certification tests have covered the worst FOD cases) and testing costs, taking also in account the bird menace evoluion and the impact of new technologies.

Bibliography

[1] PROPELLER FOREIGN OBJECT DAMAGES TESTING
JP DEVAUX WP** BSCE 20

	HBPR	PROPFAN	PROPELLER
Rotational Speed	5000 rpm	1500 rpm	1000 rpm
Blade Number	36	8	4
Chord length	0.15 m	0.20 m	0.40 m
Blade Take Off pitch	25°	#35°	#30°
Fan diameter	1.5 m	1.6 m	2.0 m
Critical radius	90%	90%	90%

Figure 1 : ENGINES TYPES CHARACTERISTICS

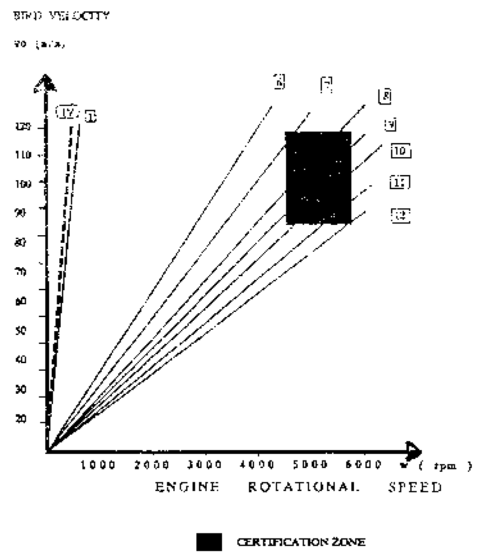

Figure 2 : HBPR KNOCKED BLADES MODEL RESULTS

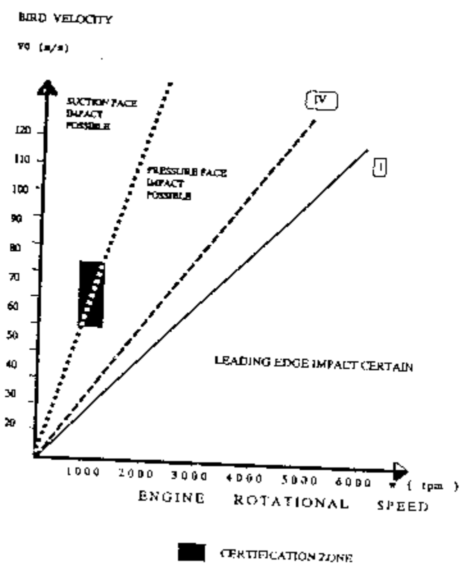

Figure 3 : PROPELLER KNOCKED BLADES MODEL RESULTS

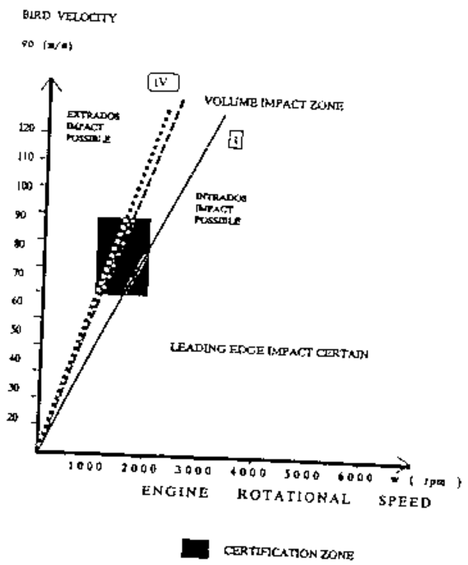

Figure 4 : PROPFAN KNOCKED BLADES MODEL RESULTS

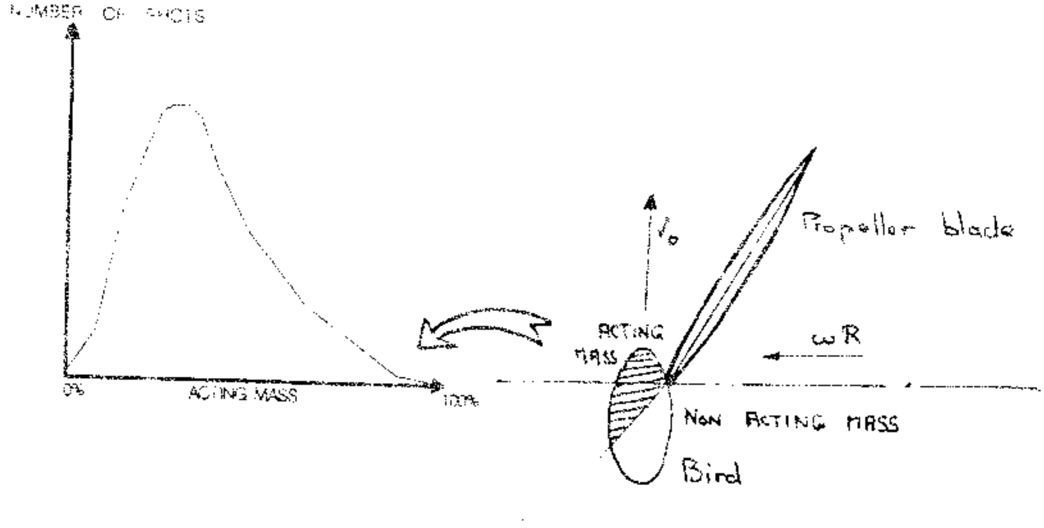

Figure 5 : ACTING MASS REPARTITION

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