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# Parametric analysis of a highly dynamical phenomena caused by a propeller blade loss

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ABSTRACT

Dynamic phenomena can jeopardize the structural integrity of aerospace structures and engineers have developed different strategies to analyze them. One of the most highly dynamical and severe failures in an aircraft provided with turboprops is an airscrew blade loss. This article analyzes this event using implicit and explicit finite element methods including non-linear behaviors, damages, and several types of failures trying to identify the key parameters in the failure sequence. The model includes non-deterministic variables and studies its stochastic behavior through series of Monte Carlo simulations. The influence of lost blade size is studied in detail as well as the effect of stiffness and strength variations on the engine mounting system through elastomeric devices. In the paper, different parameters that can influence the phenomenon are studied, including propeller rotational frequency, structural damping, and angular position where the blade is lost.


## 1. Introduction

Reliability is one of the main concerns in aircraft design and operation. For instance, aero engines are operated thousands of hours before they are removed from service for scheduled inspections. The rate of occurrence per airplane departure for propulsion system malfunction plus inappropriate crew response accidents has remained essentially constant for many years as it is mentioned on reported study [1].

Several episodes can be the cause of engine malfunction: bird strike, hail or ice strike, debris impact, ice formation on the propeller blade, axis or hub. Even in the unusual occasions of engine malfunctions, the powerplant installation design makes that no single failure or malfunction jeopardizes the safe operation of the airplane. Each powerplant is isolated from the others and configured in order to stop the rotation of any engine individually if necessary. An inoperative engine does not constitute a safety issue since airplanes are designed to fly under such circumstance.

The most severe failures occur when it is impossible to prevent severe vibration transmission to the structure of the airplane. These are the following: propeller unbalance at assembly, bearing failure or, particularly, a crack in the propeller hub that can possibly result in propeller blade loss. The engine mounting system (EMS) must be designed to absorb these vibrations and, if necessary, detach the engine from the structure before fatal structural damages may occur. In aviation safety databases [2] can be seen more than 470 engine occurrences since 1919 (powerloss, fire, flame-out, fuel issues, propeller reverse pitch, simulated engine failure, *etc.*), including more than 50 uncontained failure engine occurrences, other 48 engine separation occurrences and at least other 30 turboprop blade separation occurrences since 1943. The last was the 1st of November of 2014 where a de Havilland DH-114 Heron aircraft made an

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emergency landing following the in-flight separation of a turboprop, the prop struck other engine causing substantial damage as it is documented in [3].

A proper analysis of these failures will improve future designs but is not an easy task due to the non-linear nature of their dynamics. [4], for instance, explains how to deal with non-linear topics in structural dynamics. Meanwhile, certification authorities take these events into account through modifications of the design loads or by minimizing the hazard to the structure. In this regard, the contribution of design to accidents [5], the key points of aero engine containment requirements in FAR Part 33 [6], the bird strike and icing analysis from a certification point of view [7] and [8], have all been reported.

Some incidents such as uncontained engine failure, fan blade impact, and high energy rotating machinery failure have direct consequences to the aircraft structure. These were studied and reported from a certification point of view by [9] and [10]. The analysis of the probability and/or risk of these incidents were also reported [11]. According to the regulation authorities, the airplane must be capable of successfully complete the flight, thus the aero engine has to withstand such a failure without leading to a major hazard to the aircraft. For new propeller developmental projects, a full engine test campaign is mandatory for certification. Only in case of minor changes from a previous engine design, the certification has been allowed without new testing using technical analysis methods.

Recently, an analytical method for predicting the transient non-linear response of a complete aircraft engine system due to the loss of a blade has been developed by means of a finite element model [12]. The response of the structure after a propeller blade loss depends radically on the flight condition, propeller frequency, blade loss size, angular position where the blade is lost and how it is lost. Furthermore, the flexibility of the wing, the stiffness of this fitting, and the structural damping are also determining factors behind the phenomenon. Nevertheless, the assumption of deterministic values for certain parameters is difficult to maintain. Some parts of the engine mounting system break (specially the elastomeric devices) during blade loss, and the breaking points or values at which they occur are subjected to non-deterministic fluctuations. It is of interest to carry over the analysis to a more realistic stochastic situation. However, the huge number of relevant variables makes nearly impossible to do a detailed study of the complete system.

In order to reduce the number of variables in this case study, a more simplified model that keeps the qualitative global behavior of the system is introduced, as obtained and reported in literature [12]. A series of Monte Carlo simulations are also accomplished to analyze deeply the elastomeric collapse sequence. This versatile methodology is explained in Section 4.1 and it is able to perform the analysis with any variability of input parameters.

This paper is organized as follows. Section 2 explains the blade loss phenomenon. Sections 3 and 4 describe the model used to simulate the event, the philosophy, and decisions made and the load cases analyzed. Finally Section 5 shows the results and in Section 6 the main conclusions are described.

## 2. Turboprop blade loss phenomenon

Turboprop engines have fewer moving parts offering greater reliability due to the smooth, vibration-free operation and have longer time between overhaul than other types of engines. Turboprop aircraft are generally more efficient at altitudes of 20,000 to 30,000 ft and at medium speeds and they normally last more hours before they have to stop for inspection. As a drawback, the probability of a blade loss due to unnoticed crack growth increases. This is deeply studied in [13] where a crack grew and a propeller blade detached completely.

Concerning the unbalance that the phenomenon produces, it is important to explain that to rotate the propeller blade, the engine exerts torque. This momentum is reacted by the blade sections in the opposite direction in terms of lift and drag force components as

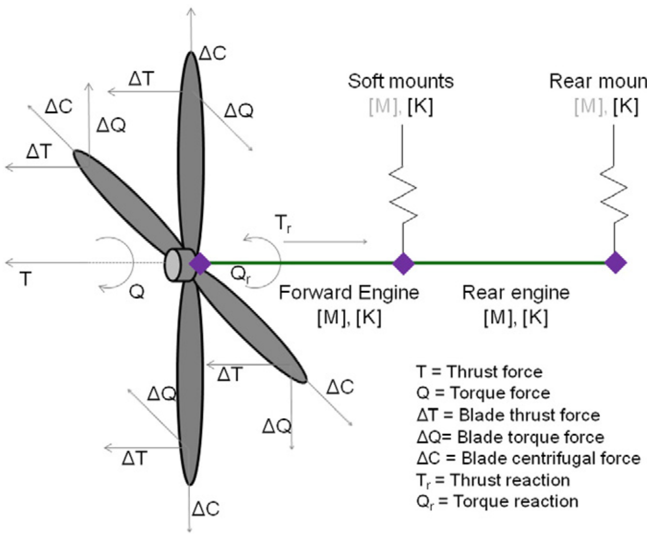


**Fig. 1.** Aerodynamic forces over the blades and engine scheme.