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Case study: Analysis of the response of an aircraft structure caused by a propeller blade loss

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ABSTRACT

One of the most severe failures in an aircraft provided with turboprops is an airscrew blade loss. Design precautions must be taken to minimize the hazards to the airplane in the event of a propeller blade failure. One of the hazards which must be considered include structural damage, and the airplane must be designed for the imbalance loads resulting from the failure. The structure must absorb the dynamic loads while the rest of the aircraft continues flying. If the energy of the phenomenon increases until it behaves uncontrollably, the engine could be detached from the structure. There must be devices which react to decrease the risks of critical failure for the rest of the structure. This article is mainly focused on the response of the structure after the break of a propeller blade until the end of the phenomenon. The detached propeller blade is also studied in terms of the size that is lost and its influence on the system behavior. Moreover the effects of stiffness and strength changes on the engine mounting system are analyzed. The research covers different parameters which can influence the phenomenon, including flight condition, propeller rotational frequency, and angular position where the blade is lost. The engine and the engine mounting system have been modeled in a finite element method (FEM). The simulations are run in an explicit solver and the simulation methodology includes failure of elements and non-linear behavior.

1. Introduction

If we consider their low number of failures modern aircraft are definitively reliable. In particular, aero engines are operated thousands of hours before they are removed from service for scheduled inspection. Moreover, those inspections further delayed every day as it is outlined on [1]. Nevertheless, there are unusual occasions when the engine malfunctions. Each powerplant installation, must be established in order that no single failure or malfunction or probable/possible combination of failures will jeopardize the safe operation of the airplane.

Nevertheless, if the probability of a structural failure is extremely remote the failures of those elements do not need to be considered. Each powerplant must be configured and isolated from the others to allow for operation and there must be means for stopping the rotation of any engine individually in the event of malfunction. An inoperative engine does not constitute a safety issue since airplanes with several engines are designed to fly under such circumstance. In fact most engine shutdowns are left unnoticed by the passengers of commercial flights and they can be the consequence of phenomena like a bird strike, hail or ice strike, debris impact or natural phenomena such as ice formation on the propeller blade, axis or hub.

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These episodes can cause damage to the engine and aircraft structure. A proper analysis of these failures can be applied to improve future designs. The analyzes are not trivial due to the non-linearity of many of the problems which occur among them; Pérez et al. [2] explains how to deal with non-linear topics in structural dynamics.

Certification authorities take all of these events into account through modification of the design loads or by minimizing the hazard to the structure, Kinnersley and Roelen [3] studies the contribution of design to accidents, Bin [4] explains the key points of aero engine containment requirements in FAR Part 33 or [5,6] where the bird strike and icing are analyzed from a certification point of view. There are incidents which imply direct consequences to the aircraft structure such as uncontained engine failure, uncontained fan blade impact or uncontained high energy rotating machinery failure, Zhang and Li [7] and Wang et al. [8] study them from a certification point of view. There are articles which analyze the probability or risk of these incidents as [9]. According to the regulation authorities, the airplane must be capable of successfully completing the flight, and thus the aero engine has to withstand such a failure without leading to a major hazard to the aircraft. For new propeller developments projects; the authorities are still requesting a full engine test campaign for certification. Certification without new testing, using technical analysis methods, has only been allowed in case of minor changes from a previous engine design. However as research improves and the simulation tools become more reliable each day, this will save money and time in the near future.

One of the most severe failures is an airscrew blade loss [10,11]. In some cases it is impossible to prevent severe vibration due to cracks in the propeller hub that could result in propeller blade loss, loss of control, and possible damage to the airplane. The hazards which must be considered include damage to structure and vital systems due to impact of a failed or released blade and the unbalance created on the airscrew by such failure or release [12]. The state of the finite element technology is prepared to provide output results like estimated forces, vibrations and deformations from a test simulation. This article studies the response of the structure after the break of a propeller blade through a finite element model following the work developed in [13,14] where the root cause of a propeller blade fracture is under investigation and where an analytical method for predicting the transient non-linear response of a complete aircraft engine system due to the loss of a fan blade is developed.

The response of the structure after a propeller blade loss varies radically with the flight conditions, propeller frequency, dimension of the blade loss, angular position where the blade is lost and how it is lost. Diken and Alnefaie [15] analyzes some of these effects on a flexible rotor. These aspects are also analyzed in this paper. Furthermore, the flexibility of the wing, the stiffness of its fitting or the structural damping are also determining factors of the phenomenon, Dygadlo and Sobieraj [16] and Mello [17] analyze the effects of these aspects on a helicopter. During the investigation some hypothesis were made at the beginning; the instantaneous application of the imbalanced load for example, were also questioned and studied.

This paper is organized as follows. Section 2 explains the blade loss phenomenon analyzed in this paper. Sections 3 and 4 describe the model used to simulate the event, the philosophy and decisions made and the results produced. Finally Section 5 completes the conclusions in order to verify the achievement of the aim of the investigation, to be able to study this particular engine failure.

2. Blade loss phenomenon

A propeller blade progresses through the air along an approximate helical path as a the result of its forward and rotational velocity components. To rotate the propeller blade, the engine exerts torque. This momentum is reacted by the blade

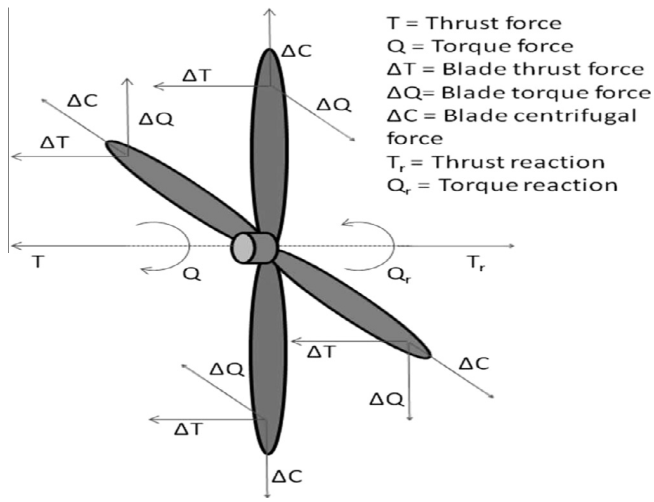

Fig. B.1. Resultant aerodynamic forces over the blades.