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Thermo-mechanical modeling of a high pressure turbine blade of an airplane gas turbine engine

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Abstract

During their operation, modern aircraft engine components are subjected to increasingly demanding operating conditions, especially the high pressure turbine (HPT) blades. Such conditions cause these parts to undergo different types of time-dependent degradation, one of which is creep. A model using the finite element method (FEM) was developed, in order to be able to predict the creep behaviour of HPT blades. Flight data records (FDR) for a specific aircraft, provided by a commercial aviation company, were used to obtain thermal and mechanical data for three different flight cycles. In order to create the 3D model needed for the FEM analysis, a HPT blade scrap was scanned, and its chemical composition and material properties were obtained. The data that was gathered was fed into the FEM model and different simulations were run, first with a simplified 3D rectangular block shape, in order to better establish the model, and then with the real 3D mesh obtained from the blade scrap. The overall expected behaviour in terms of displacement was observed, in particular at the trailing edge of the blade. Therefore such a model can be useful in the goal of predicting turbine blade life, given a set of FDR data.

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Keywords: High Pressure Turbine Blade; Creep; Finite Element Method; 3D Model; Simulation.

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1. Introduction

In the field of aviation, commercial demands make it necessary for modern gas turbine engines to function under extreme conditions, with a constant drive to push usage time beyond the manufacturer's conservative recommendations, while keeping safety requirements. In any of such instances, critical sections of the engine will eventually be detrimentally affected. That is the case of the high pressure turbine (HPT), where temperatures are the highest in the entire engine (Nadeau 2013).

As with most modern high-performance gas turbine engines, the turbine inlet temperatures in turboprop engines must be raised in order to increase the power output and thermodynamic efficiency (Boyce 2002a), creating a demanding high temperature environment where HPT blades operate. In order to maintain mechanical integrity of the nickel base superalloy blades, both coating and cooling have to be applied to the airfoil (Boyce 2002b, Han 2004).

With the goal of studying the life cycle of the HPT blades, a regional airline operation was featured. This company operates within the Azores islands and also provides flights between São Miguel (in Azores) and Madeira island, as well as between the latter and Gran Canaria island, all these routes being within the North Atlantic region. Its fleet is comprised of four Bombardier DHC8-400 airliners, also known as the Dash 8 Q400, for which the PW150A engine under study was especially designed.

In order to accomplish this work, the in-flight conditions that are recorded on the Flight Data Record (FDR) of this airline operation were analyzed. Using that information, Finite Element Method (FEM) simulations were made and the level of creep deformation that these blades suffer was determined. In order to do this, three different cycles, referred to (using standard airport codes) as SJZ-TER, PDL-HOR and PDL-FNC, with periods of approximately 20 minutes, 1 hour and 2 hours respectively, were studied. With the 1-cycle modeling defined, several successive cycles were then applied and a basic trend was assumed. The differences between each type of flight pattern were then determined and rough predictions on the creep behavior of the HPT blades were made for their expected life of 3000 flight hours.

Nomenclature

b	Reference Dimension
E22	Vertical Strain
EDS	Energy Dispersive Spectroscopy
FDR	Flight Data Record
FEM	Finite Element Method
HPT	High Pressure Turbine
ITT	Inter Turbine Temperature
K_1	Temperature Dependent Material Constant
l	Width of the blade's base
n	Creep Stress Exponent
N	Number of blades
NH	Rotation Speed
r	Radius of the disc
S22	Vertical Stress
SEM	Scanning Electron Microscopy
T	Material Temperature
TIT	Turbine Inlet Temperature
U2	Vertical Displacement
$\dot{\varepsilon}_s$	Steady-State Creep Rate
σ	Stress