1D Numerical Approach for Coupled Fluid-Dynamic and Thermal Analysis of an Active Clearance Control System

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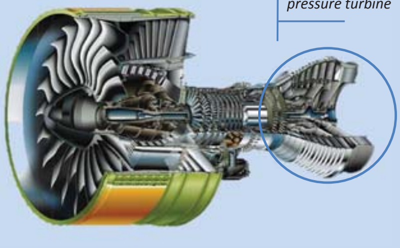
INTRODUCTION

The modern engines for large aircraft transports are designed to achieve the best performance and to reduce the environmental impact and the fuel consumption. The idea at the base of these new designs is to optimize those engine elements, which not long time ago were considered with low benefits-costs impact.
One of these tasks is the leakage flow reduction obtained through engine clearance control. A solution widely adopted on modern aircrafts is the thermal Active Clearance Control (ACC) system, through the air jet impingement cooling, for a Low Pressure Turbine (LPT) case. This system operates in order to cool down the LPT case, thus reducing the clearances during the cruise, with the consequent efficiency improvement.
The present research project proposes a method to simulate the entire LPT ACC system with a 1D approach, capable to couple the fluid-dynamics and the thermal aspects of this engine component. This method consists into a tool that couples two software. The first one simulates the ACC 1D fluid-dynamics, evaluating the overall mass flow and the pressure losses. The second one is an analytical tool accomplishing the ACC heat pick-up analysis. The proposed approach is applied to a Design of Experiment (DOE) performed on this system, focusing on the variations recorded on the overall air mass flow rate.

WHAT?
New design to reduce environmental impact

WHERE?
Aircraft low pressure turbine



HOW!
Active Clearance Control:
- *Requires cold air*
- *Cools down the turbine case*

FLUID-DYNAMICS

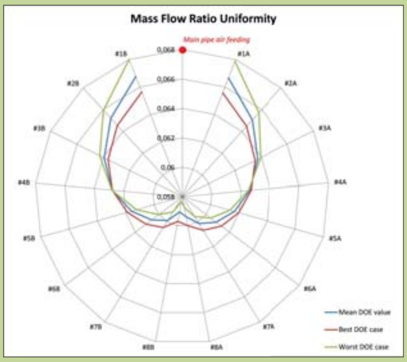
OVERVIEW

Main Goal: To find out those ACC system parameters able to enhance the air mass flow available for the case cooling.

Constraints & Boundaries: System weight and dimensions.

Method: Full Factorial DOE (Design of Experiment), 6 factors, 2 levels; 1D fluid-dynamic analysis with the software ***FloInHance***.

DOE Analyzed Factor	*Min Variation*	*Max Variation*	*Impact on Mass flow*
ACC Air Intake Discharge Coefficient	-10%	+5%	Moderate
ACC Intake Recovery Factor	-100%	+66.7%	Low
Pipe Roughness	-16.7%	+178%	Negligible
Pipe Diameter	-16.7%	0%	High
Axial Header Pipe Tapering	-50%	0%	Negligible
ACC Valve Discharge Coefficient	-15%	+5.9%	Moderate

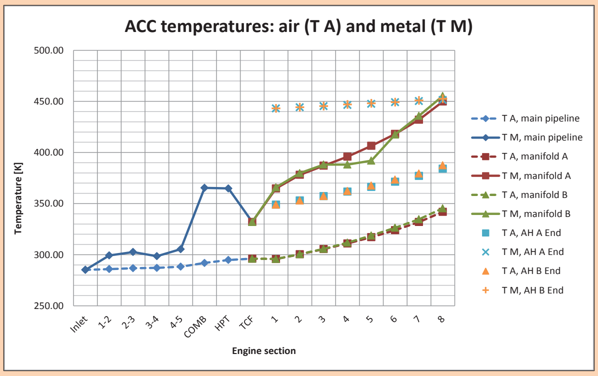


Mass Flow Ratio: Ratio between the mass flow rate entering a certain axial header and the total mass flow rate.

$$MFR = \frac{\dot{m}_{AH,i}}{\dot{m}_{TOTAL}}$$

Thermal Fluid-Dynamic Coupling

THERMAL



OVERVIEW

Main Goal: To evaluate the heat pick-up of the ACC pipelines, due to the heat transfer from the other engine components.

Constraints & Boundaries: Temperatures of the other engine components.

Method: Full Factorial DOE (Design of Experiment), 6 factors, 2 levels; 1D thermal analysis (heat pick-up) with a ***VBA*** tool.

Convective Heat Transfer Coefficient evaluation (Dittus-Boelter correlation) and temperature evolution along the ACC pipes.

CONCLUSIONS

The proposed method carries out ***a coupled fluid-dynamic and thermal analysis*** of the ACC performance. This method is fast and low demanding (around 30 minutes per model).

Model capabilities
- ✓ To set the pipe material and thermal properties
- ✓ To set the external boundaries
- ✓ To set the inlet air boundaries
- ✓ To choose other heat transfer correlations