Institute of Turbomachinery and Flight Propulsion
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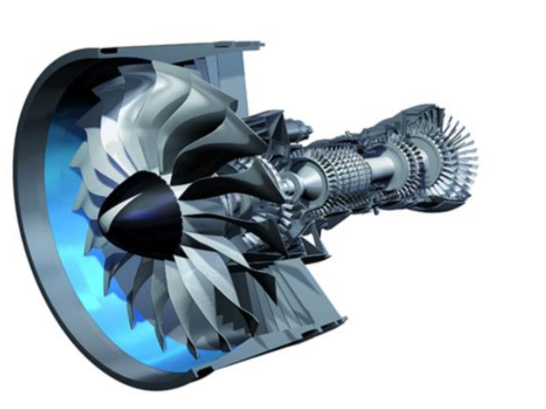

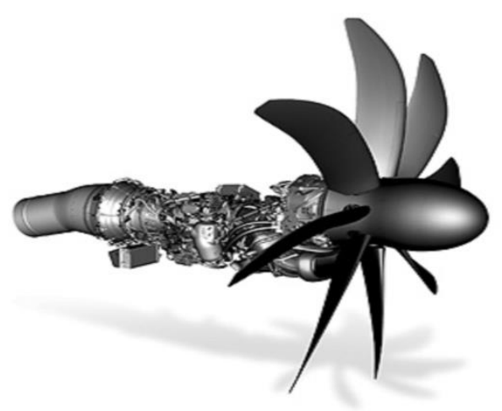

NUMERICAL INVESTIGATION OF WINDAGE HEATING IN HPC SHROUDED STATOR CAVITIES

Introduction

Objectives

Provision of an aero-thermal evaluation basis for selecting the best possible design of the HPC stators for the application

- Definition and validation of evaluation rules concerning aerodynamic efficiency and thermal behaviour.
- Verify numerical quality with existing measurements.

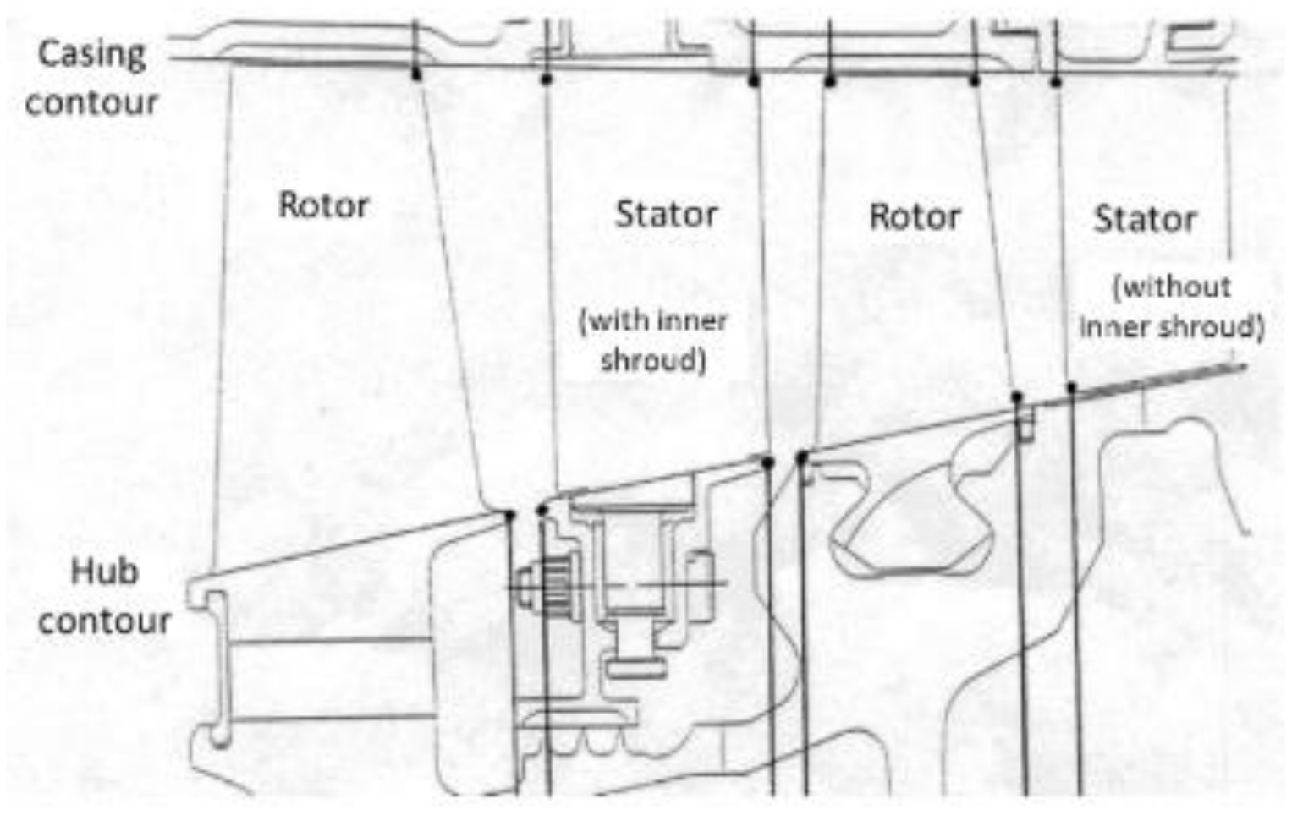

Fig. 1 Stator Stages with and without an inner Shroud

Baseline configuration

The baseline configuration consists of two and a half stages of an HPC and an IAS cavity. The cavity is beneath the 3rd stator stage and is a stepped labyrinth. The rotor-stator interfaces are mixing planes, and the cavity-main gaspath are frozen rotor. In the baseline configuration, the cavity walls are smooth and adiabatic.

Fig. 2 Overview of the Simulation Domains

Validation and Flow Field

Validation Method

The simulations were validated by experiments carried out before this study. Focusing on the cavity, three total temperature and two static pressure probes were placed and studied. Circumferential averaging was performed to compare the total temperature of the simulations. This involves averaging the local total temperature values over small square volumes at the probe locations. This allows validation of the windage heating and total temperature rise.

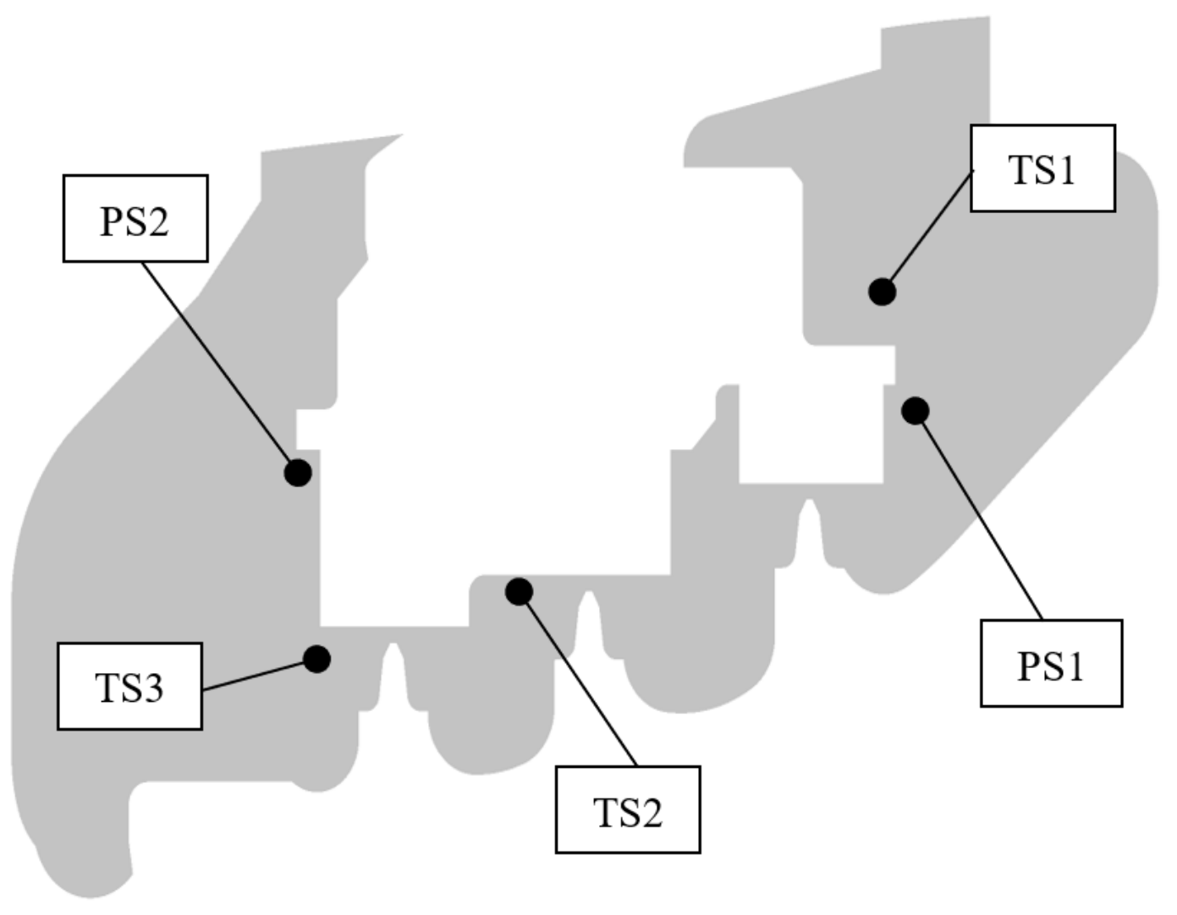

Fig. 3 Overview for the Locations of the Pressure and Total Temperature Measurement Points

Flow Field

The velocity was normalised by its maximum value in the cavity and plotted on the mid-plane. Vortices and flow paths were observed. Higher velocity values were also evident at the rotor wall, which transfers energy to the fluid, increasing its circumferential velocity via shear forces. These forces are then dissipated over a larger radial distance. The core swirl ratio (CSR) plot below clearly demonstrates this effect.

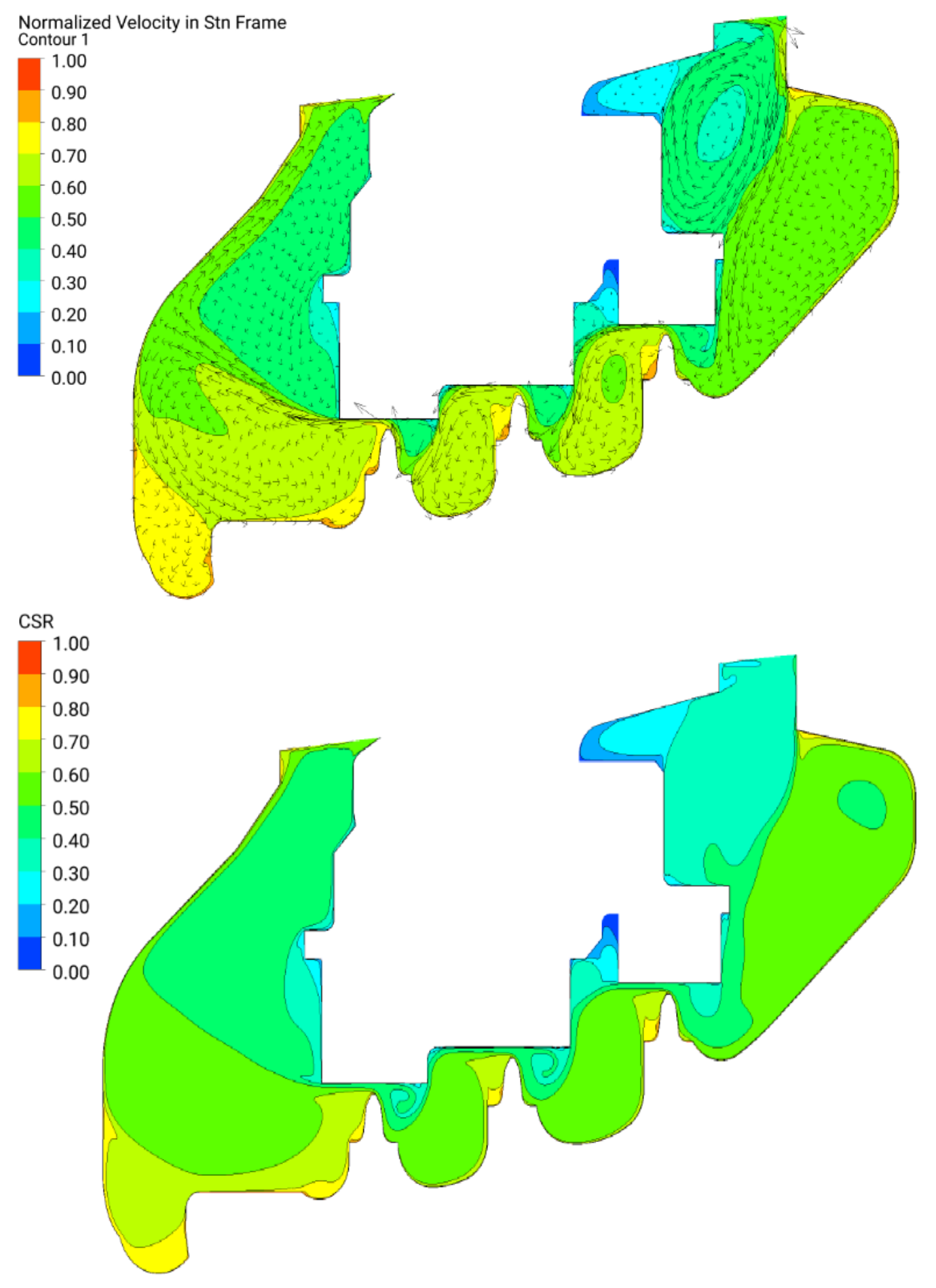

Fig. 4 Normalized Velocity (above) and CSR (below) Field in Cavity Mid-Plane for the adiabatic Take-Off Case

Heat Pickup Sensitivity Studies

Total Temperatures in Labyrinth

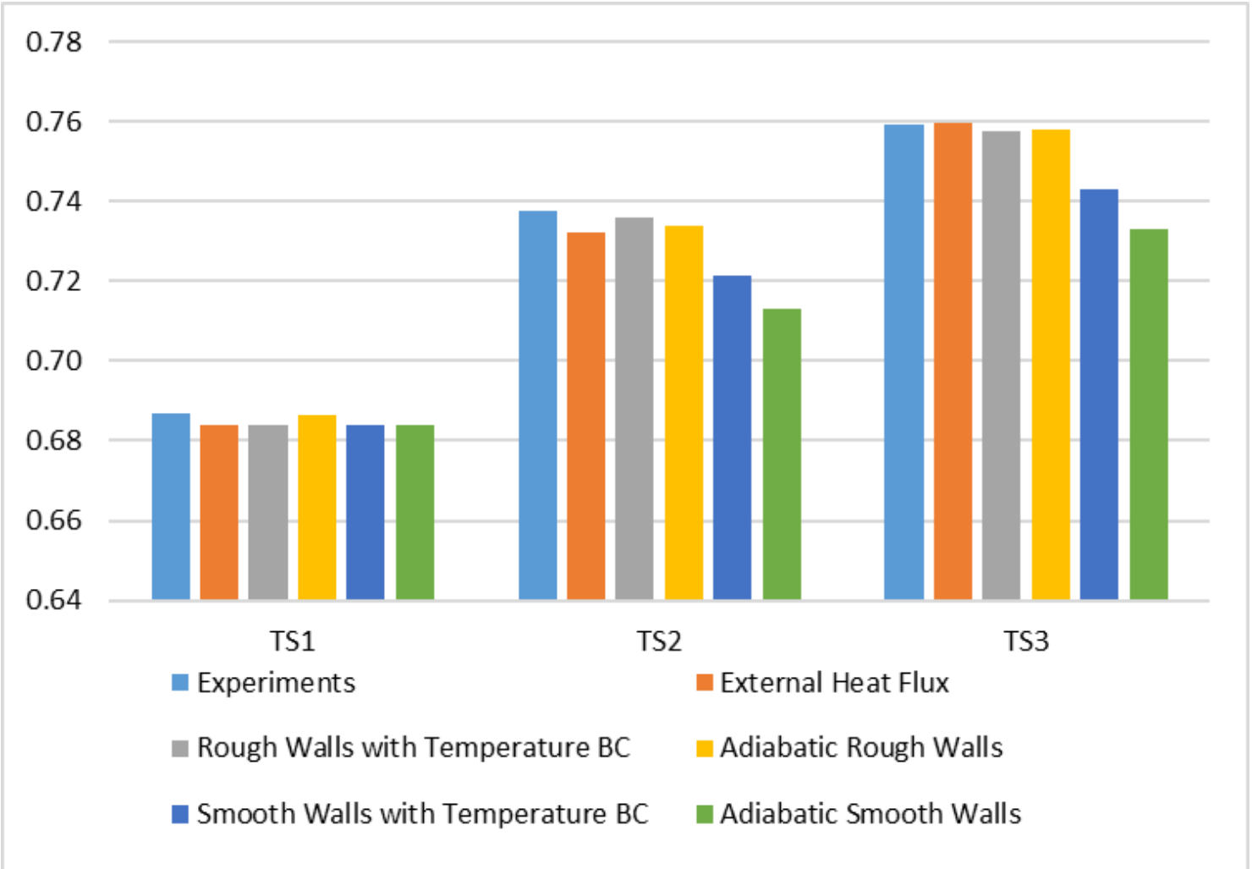

Fig. 5 Normalized Total Temperature Values on the Measurement Points for the Take-Off Cases

The total temperatures for the takeoff simulations have been depicted. As can be seen, even though the starting total temperature is similar in all cases, the adiabatic case with smooth walls tends to underestimate the heating. This has been compensated using rough walls, temperature boundary conditions or heat flux.

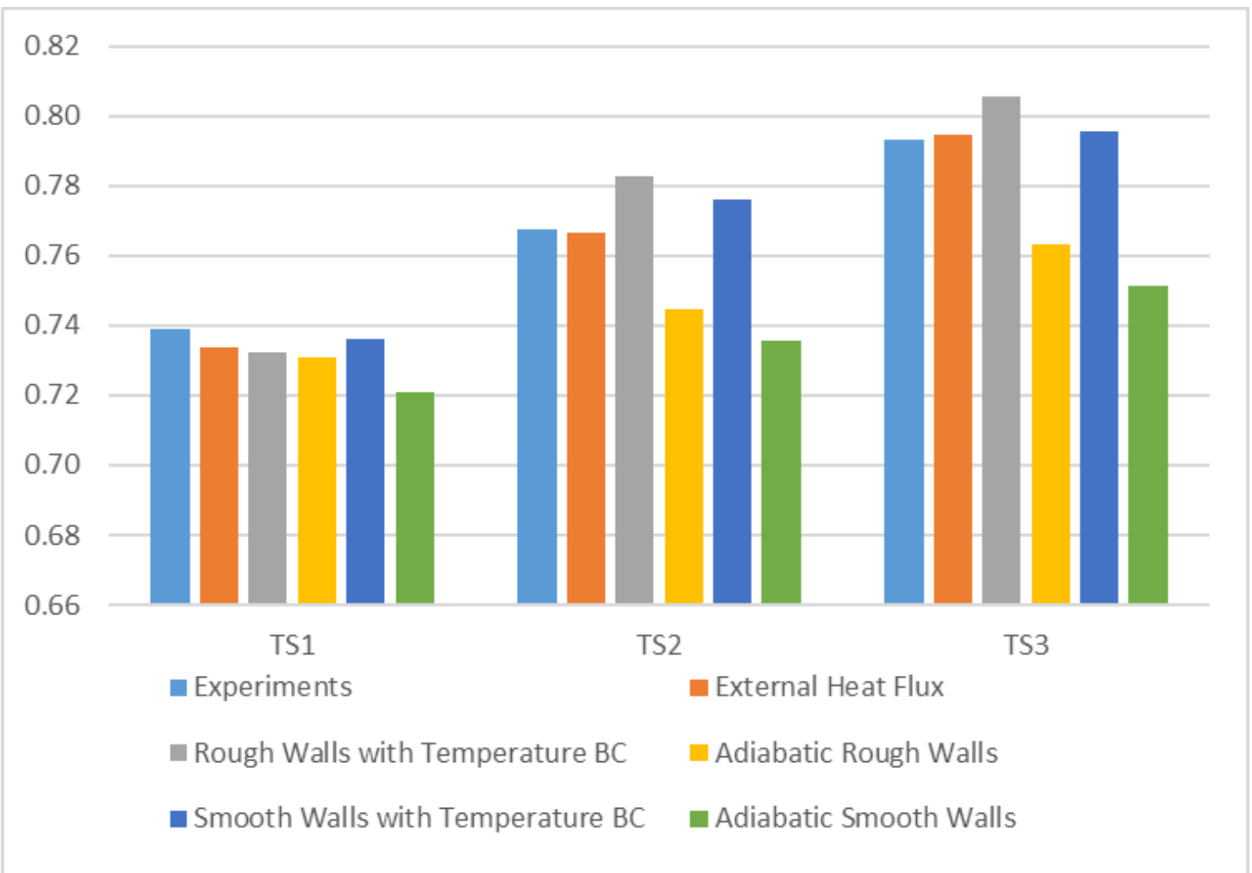

Fig. 6 Normalized Total Temperature Values on the Measurement Points for the Ground Idle Cases

Like in the take-off case, the baseline ground idle simulations underestimate the heat pickup. Here, the effect of wall roughness is much vaguer. This is due to the lower rotational speeds at the rotating walls and lower shear stresses transferred to the fluid.

Windage Heating vs. Conductive Heating

The total enthalpy rises across the labyrinth sealing are calculated and tabled below. The values are also split into windage heating and conductive heating parts to better understand the flow phenomena.

The adiabatic cases only include the windage heating part. As for the takeoff, the pronounced effect of roughness can be observed through the increase in the windage heating. Hence, the compensation for the lack of total enthalpy rise can be achieved.

In ground idle cases, the effect of wall roughness is much lower than that of conductive heating caused by the static temperature boundary conditions or the heat flux. Under many, the material is in contact with a fluid colder and slower than in takeoff, which causes a more significant increase of enthalpy through a heat flux.

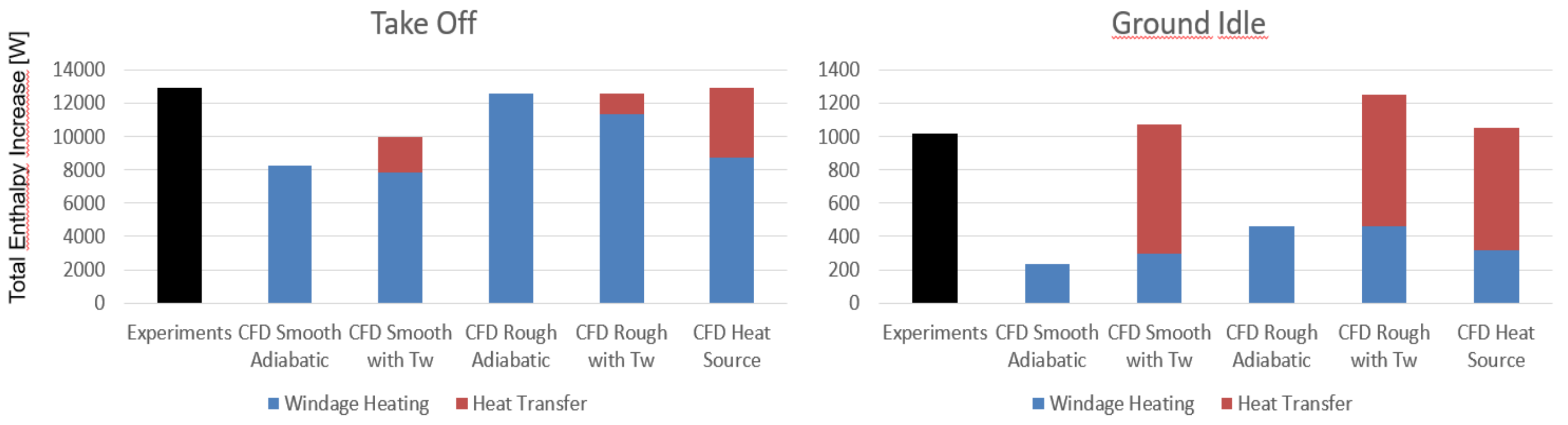

Fig. 7 Total Enthalpy Increase for Take Off (left) and Ground Idle (right) cases

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