3.1 Summary

This thesis analyzes the way the presence of instrumentation wires influence the windage heating in a rotor-stator cavity. To ensure a successful investigation, different parameters from real engine flights and testing conditions were used. Engine tests are necessary to validate these calculated values. However, there is a possibility that the values from the model and the test data may not be reflecting the production standard engine. In order to guarantee a better understanding of the differences between the measured test data and the calculated values from the models, a numerical study was conducted. It was performed through reconstruction of the effects in which the models need to be corrected. This is done to ensure that the values match with the production standard.

This investigated cavity is typically found between the high pressure turbine and a stationary component, such as rear bearing chamber. The cavity is known for collecting the instrumentation mounted to the rotor wall and cable routing throughout it. The presence of instrumentation influences the flow pattern resulting in local changes in the heat transfer. This behavior helps accurately predict the behavior of the production engine.

The starting point of this thesis was a comparison between two different mesh creating programs, in order to find the optimal one. Both programs *Boxer* and *Centaur are* using different approaches in setting up the mesh. Hence, the built mesh quality, computation time and calculated windage were compared. Considering that instrumentation wires need to be modeled on the wall, Centaur is better suited for these requirements.

Afterwards, a study to find a mesh was performed. It predicts the assumed effects within a sufficient computation time. The CFD calculation is done with the superior *k-ω*-SST turbulence model for rotating problems. The turbulence model is used to reproduce the viscous sub-layer with the help of *k-ω* model. In addition, it reproduces the free vortex, through switching to the *k-s* model in the outer area. Modelling the viscous sub-layer was necessary to obtain the results of the scrutinized instrumentation attached to the rotor wall.

As a result, the least possible coarse mesh is used, due to convergence problems on coarser mesh settings. Nevertheless, the calculation delivers results in a moderate computational time with a deviation of 2% to the finest mesh, which is acceptable.

3.1 The main aspect of this thesis is the impact of instrumentation on windage effects,*Summary*

which leads to the differences in the measurement and the model values. Therefore, an influence parameter analysis was needed. First of all, general influence of instrumentation in a rotor-stator cavity is investigated. For that, a 4° model with and

without instrumentation is used. As it turns out, the instrumentation wire leads to additional wall shear stress, due to the form drag and viscous forces. This directly contributes to the windage equation.

The parameter analysis emphasizes that a linear trend appears with spool speed variation for different amounts of instrumentation. Moreover, the power conditions are depending on the different boundary conditions, such as spool speed, inlet mass flow and temperature. The conditions have a linear trend over the variation on the amount of cables as well.

The variation of the inlet mass flow shows that less mass flow has slighlty differences in windage heating from the nominal condition. On the other hand, doubling up the inlet mass flow leads to bigger deviation from the nominal one, although the air temperature did not change much in comparison to the nominal air temperature. The reason for this is that a higher mass flow in the cavity has a bigger impact on the windage heating, due to more contribution of the instrumentation wires on the rotor drag. Higher velocities at the inlet appear plausible with the continuous equation. The result is a throughflow of the fluid throughout the cavity with higher velocity magnitude. In that case, the air temperature did not change much compared to the nominal one.

Another point of investigation was the shape of the instrumentation. First, the wires were changed in the thickness within the cable tolerances, later with an even broader increase of the thickness. The result was slight differences in windagethat were calculated in these cases.
Furthermore, shortening up the cable into its half led to a decrease of 25% in comparison to the longer wire. Additionally, a circumferential mounted cable was investigated. It was assumed that a circumferential cable, which is laid in the flow direction will not have a big impact.
The outcome was that circumferential cables with a small gap to each other, increase the windage within 2% deviation in comparison to the case without instrumentation. This is insignificantly low in comparison with 44% increase of windage with radial mounted cables at the same sector size model. This knowledge should be considered when a cable routing is done.

A much bigger impact has the interaction of the cables. A reduced gap size led to a non-linear decrease of the windage results. Due to computing error with the mesh settings, the cables could not be modeled right next to each other. It is assumed that this configuration will decrease the windage effect distinctly. This needs to be considered when the instrumentation wires are attached to the engine components. Nevertheless, the result is that a smaller gap between the cables decreases notably regarding the windage heating.

The last variation was the inlet swirl ratio. A lower swirl ratio in the inlet had a high impact on windage heating. This was due to the additional rotor work done on the fluid, leading to an increase in the wall shear stress in windage heating.

All in all, the investigation about the instrumentation wires attached to the rotor wall led to a better understanding of how they influence the test data. The acquired data is the base of this thesis that enable more accurate predictions of the impact of instrumentation on windage effects. Correlations were found for different parameters in dependence of the amount of attached wires. As a result, a windage prediction for a wide range of cable quantity can be read on the compiled plots. With the variation of the inlet swirl ratio, it is now possible to make a statement about similar cavities with different initial conditions at the inlet. With the gained understanding in this thesis, a read-across with other similar cavities can be accomplished.