Evaluation of Weight Estimation Methods for Aero Engines & Pre-Design of Low Pressure Turbine Discs

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Notation

σ_r	Radial stress
r	Radius
y	Width
ν	Poisson's raito
ρ	Material density
ω	Rotational speed
E	Youngs's Modulus
β	Thermal expansion coefficient
T	Temperature
m_T	Gradient for linear temperature law

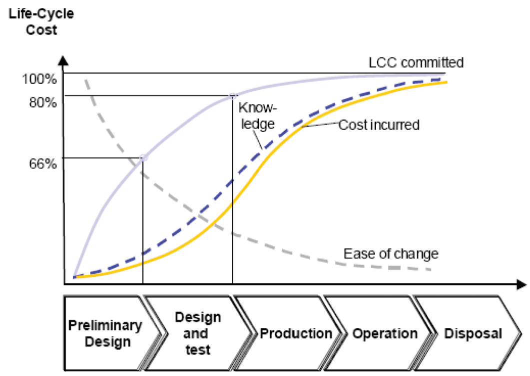

Figure 1: Life cycle costs of aero engines[1]

1 Introduction

As global air traffic increases and the world's reserve in fossil resources nears an end, consumption becomes evermore a key design parameter in the conception of new aircraft. Both aircraft range and consumption per passenger-mile depend on intelligent engine design allowing maximum thrust at minimum fuel burn, which can be measured by the engine's Specific Fuel Consumption(SFC). The quality of an engine is, however, influenced by more parameters than just the SFC. Construction and weight of the airplane's wing root is, for example, impacted by the engine weight. Increased engine weight leads to structural reinforcement, meaning added weight, at the wing root which in turn causes shorter range and lower payload. A profound understanding of the impact that performance changes have on engine weight is therefore needed. This understanding is mostly needed at an early design phase, at best in the conceptual design phase. As Figure 1 shows, changes are most easily implemented during the early stages of a project. For that matter, a study on engine weight estimation in the preliminary design phase was carried out at the department for preliminary engine design of MTU Aero Engines in Munich, Germany. The study was undertaken between March and August 2009. Engine manufacturers, such as MTU Aero Engines, dispose of several methods of estimating engine weight at a preliminary design stage. Each of these methods have drawbacks and limitations. The study was therefore aimed to determine these limitations and to compare the methods agains each other. Furthermore, a detailed analysis of preliminary disc design of low pressure turbines (LPT) was conducted.

2 Preliminary study

To allow a better understanding of preliminary design methods for engine weight estimation, a conclusive study of different methods is carried out. Three existing methods for weight estimation are currently used at MTU Aero Engines. The first, weight estimation according to Sagerser[2] and Franciscus[3], is a method covering a wide range of components. It is developed with analytical component models and empirically determined coefficients. The second, weight estimation by scaling, estimates engine weight by scaling components with similar components of reference engines. The third method, estimation by mechanical design, uses simplified geometrical models, obtained by structural analysis, to obtain weights.
Furthermore, a second part of the study is aimed to give a better understanding of the design of discs, which are an important part of aero engines. For that matter, an exemplary study based on LPT discs is conducted. Its purpose is to give a better understanding of the qualitative and quantitative impact of different parameters on preliminary disc design. The findings of this study shall be used to establish the necessary criteria for these parameters, thus allowing high quality preliminary disc design.

3 Main study

The engine weight is estimated using the MTU inhouse tool for preliminary engine design, MOPEDS. The models of two engines are set up and calibrated to give correct data for performance and aerodynamics parameters. The estimated weights of the components are then compared with real component data. The source of possible errors are discussed and the methods compared with each other. For disc analysis, the impact of five different parameters is investigated. The parameters are the disc's rim temperature, hub temperature, rim load, rim width and rim radius. Using the inhouse program for disc calculation, TurboWPT, the three stages of the LPT of a selected engine are simulated. TurboWPT is a program which models discs as an assembly of partial discs of constant width. For a disc of constant width and linear temperature distribution, the differential equation describing radial stress

$$\sigma_r'' + \left(\frac{3}{r} + \frac{y'}{y}\right)\sigma_r' + \left(\frac{(2+\nu)\,y'}{yr} + \frac{y''}{y} - \frac{y'^2}{y^2}\right)\sigma_r = \ldots - (3+\nu)\,\rho\omega^2 - \frac{E\beta}{r}T'$$

is solved as

$$\sigma_r = \sigma_0 + kr^{-2} - \frac{3+\nu}{8}\rho\,(\omega r)^2 - \frac{E\beta}{3}m_T r$$

where σ_0 and k are constants. For the parametric analysis, only one parameter is varied at the time. The resultant discs are analysed both with regards to quantity (weight) as well as with regards to quality (geometry). The changes in disc design are explained by a theoratical analysis of the changes in stress states. In addition to the the five parameters, the influence of the models used for both material data and temperature are investigated. Figure 2 shows the differences between three models for the temperature distribution within one of the modeled discs. For high rim temperatures a deviation of up to 15% can be observed between the the different temperature models.

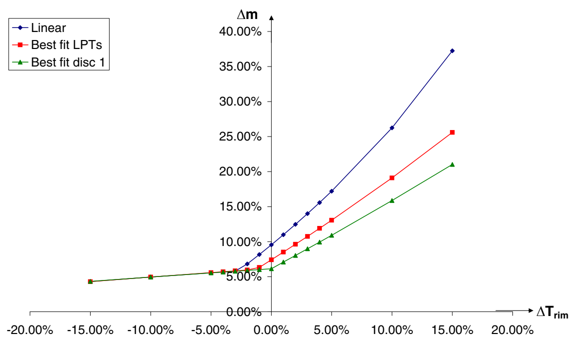

Figure 2: Weight estimation error of a disc for different temperature distributions

4 Conclusion

In the course of thesis, weight estimation by mechanical design is shown to produce good results for the weight estimation of turbo components. It has also been shown that this method covers only 36% of the total engine weight. Weight estimation based on scaling on a component basis as well as according to Sagerser or Franciscus have been shown to cover most of the engine weight. However, analysis showed the quality of their estimation not to be satisfactory for all components. Errors of up to 140% were observed.

It is furthermore shown that all of the five investigated parameters have an important impact on disc weight. Their variation within a range of ±15% caused a variation of disc weight in the double-digit percentage. It has also been shown that changes in disc design are not always continuous as the design depends on multiple requirements. Furthermore, the model of material data has been shown to have small impact on disc weight. The observed deviations were around 1%. The impact of the temperature model has been shown to be up to 15% for cases where the design of the disc's hub section is limited by the burst margin.

This project has shown both the importance of initial parameters for disc design and the uncertainty involved in the estimation of these parameters. As a consequence, better models for estimating these parameters are necessary in order for an improved preliminary disc design. For example, temperatures at the disc rim and hub are presently not well estimated and require further work. It is recommended by the author that said models are established and integrated in the MTU preliminary design tool MOPEDS. The analysis has also shown the importance of the question, whether hub design is limited by tangential stress or burst margin. During this work, the applied safety factors for these criteria have been calibrated to be met exactly at the discs' true design. In the process of applied preliminary disc design this is, however, not possible. It is therefore recommended that the approach used for setting these factors, be subjected to further research.

References

[1] O. Arago, S. Bretschneider, and S. Staudacher, editors. *A Unit Cost Comparison Methodology For Turbofan Engines*, number GT2007-27485 in ASME Turbo Expo 2007, 2007.

[2] D.A. Sagerser, S. Lieblein, and R.P. Krebs. EMPIRICAL EXPRESSIONS FOR ESTIMATING LENGTH AND WEIGHT OF AXIAL-FLOW COMPONENTS OF VTOL POWERPLANTS. Technical Memorandum TM X-2406, NASA, 1971.

[3] L. Franciscus. Interim computer program for estimating aircraft engine weight and dimensions on a component basis. Technical Memorandum TM X-73404, NASA, 1976.