Thermodynamic and Rotordynamic Assessment of Conventional and Ultra-High Bypass Ratio Engines

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Long Abstract

Introduction

In the age of globalization with the progressive development of economically important regions, an infrastructural air traffic networking is indispensable. It is important to make this point-to-point networking as efficient as possible and thus, reducing the travel and landing/take-off time crucially. This requires the usage of smaller airports provoking increased noise and CO_2 emissions for the population living around regional airports. Therefore, the Advisory Council for Aeronautics Research in Europe (ACARE) published in 2011 its "'Flightpath 2050"' guidelines [1]. Besides, a reduction in direct operating costs must be sought as well. Therefore, within the German Research Foundation (Deutsche Forschungsgemeinschaft, DFG) the Collaborative Research Centre 880 (CRC 88o: Fundamentals of High Lift for Future Civil Aircraft) has embraced these challenges to investigate in technologies to combine them in a future-oriented aircraft [2].

The promising technology of an over-wing aircraft configuration with an ultra-high bypass ratio (UHBR) engine is used (figure 1). The higher the bypass ratio the larger the diameter of the engine itself, compared to conventional gas turbines. The larger the fan diameter the larger the bypass mass flow with a lower bypass nozzle velocity. This increases the propulsive efficiency hence the specific fuel consumption (SFC) drops. However, according to the larger engine diameter, dynamic influences, such as the gyroscopic moment need to be taken into account which is particularly important.

Thus the aim of this paper is, on the one hand, to show the thermodynamic advantages of an UHBR-engine compared to a conventional engine. On the other hand the resulting structural dynamical influences due to larger bypass ratio are presented and investigated.

1. Methods

1.1 Thermodynamic Approach

As explained in the introduction part, an over-wing aircraft configuration is utilized. Thereby, several aircraft operating points are identified previously which the engines have to cope with. This includes safety operating points as well.

Within the CRC 880 two engines types with slightly different cycles have been investigated and designed by using GasTurb 12 [3]. As a technology readiness level the year 2015 has been chosen for determining component materials and efficiencies by using reference [4].

The first engine is a conventional turbofan engine with a bypass ratio (BPR) of five and an overall pressure ratio (OPR) of 36. The turbine entry temperature (TET) reaches 1360 K during top-of-climb (TOC) with a maximum temperature of 1778 K during take-off. One fan stage, three intermediate compressor (IPC) stages, ten high pressure compressor (HPC) stages, two high pressure turbine (HPT) stages and five low pressure turbine (LPT) stages are required for this conventional tow-spool turbofan model.

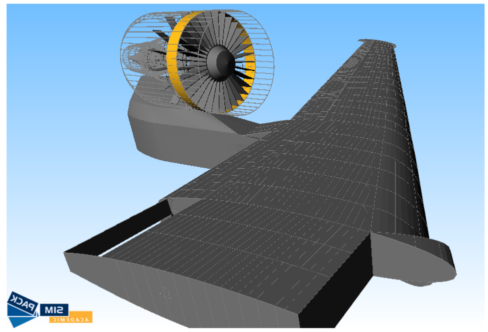

Figure 1. Multibody model of the over-wing integrated uhbr engine.

The second engine is an UHBR engine with a gearbox between the fan and the IPC and a corresponding different thermodynamic cylce. The fan stage rotates with a much lower rotational speed. The BRP is around 17 with an OPR of 70. Hence, a TET of 1750 is required at TOC. This results in a SFC achievement of 18.7 %.

1.2 Multi Body Simulation

The rotordynamic simulation is performed with an multibody formulation (SIMPACK) combined with a finite element description (Ansys). Within this hybrid approach the flexible components are modelled as FE bodies, modal reduced via the Craig-Bampton method [5] and afterwards implemented in the multibody model.

$$[M^r]\{\ddot{u}^r\} + ([G^r(\Omega)] + [C^r])\{\dot{u}^r\} + ([K^r] - [K_c^r(\Omega)])\{u\} = \{F^r(\Omega)\} \tag{1}$$

Hence the degrees of freedom u^r are approached via Modshapes t_k and their amplitudes $q_{k(t)} : \sum_{k=1}^{r} t_k q_{k(t)}$. Due to the growing diameter of the UHBR engine, gyroscopic effects as a result of tilting/whirling of the turbine stages need to be taking into account carefully in form of the gyroscopic matrix $G^r(\Omega)$(w.r.t. eq. 1). Considering different design points not only the rotational speed but thrust induced forces $F^r(\Omega)$ by the gas turbine components need to be evaluated carefully regarding the engine-wing interaction. The topological and substantial approach for the engine models is the same as from [6].

References

[1] Advisory Council for Aeronautics Research In Europe (ACARE). Flightpath 2050 - Europe's Vision for Aviation. 2011.

[2] R. Radespiel and W. Heinze. Sfb 880: Fundamentals of high lift for future commercial aircraft. *CEAS Aeronautical Journal*, 5(239-251), 2013.

[3] Joachim Kurzke. *GasTurb 12 - Design and Off-Design Performance of Gas Turbines.*

[4] Hubert Grieb. *Projektierung von Turboflugtriebwerken.* Birkhaeuser, 2004.

[5] R. R. Jr. Craig and M. C. C. Bampton. Coupling of substructures for dynamic analysis. *AIAA Journal*, 6(7):1313–1319, 1986.

[6] T. S. Mueller and H. Hennings. Rotordynamic validation of a twin rotor-bearing system considering gyroscopic forces and bearing dynamics with a multibody formulation: Application to a geared uhbr gas turbine. In *DLRK*, 2016.