Validation of a Physically Enhanced Sub idle Compressor Map Extrapolation Method

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Long Abstract

Introduction

Gas turbine engine starting performance simulation is an inevitable section for engine performance analysis and starting control schedule design. Several gas turbine engine starting performance simulation models were developed, among which the component maps based model is regarded the most practical one because of the detailed information it provided [1].

However, component maps for sub idle region are usually unavailable. And in order to get it, several map extrapolation methods were developed. In 2000, Kurzke [2] [3] developed a tool named Smooth C for compressor maps extrapolation based on estimated zero speed line and some items deducted from incompressible similarity laws. A different method in which the exponents of incompressible similarity laws were modified to take the compressible effects into consideration was developed in 2001 by Sexton [4]. In 2007, Sexton's method was simplified by Gaudet [5], which was then validated by Hönle [6] in 2013. In 2002, Jones [1] compared the existing map extrapolation methods and suggested that the zero speed line be either calculated, measured or estimated to transform extrapolation into interpolation and to obtain more reliable results. Following Jones' suggestion, in 2007, Howard [7] created the zero speed curve using the generic coefficients obtained from 3D CFD simulation and the curve was used to create the compressor sub idle maps. Then in 2010, Zachos [8] [9] pushed Howard's work a step forward by employing zero speed corrected torque line and developed a physically enhanced method for sub idle compressor map generation. However, the results of Zachos's methodology was not validated against experimental data due to the insufficient data available for sub-idle operation.

In 2013, the sub idle compressor map of Allison 250 engine with rotating speed down to 10% in forms of corrected mass flow, pressure ratio and efficiency was measured by Hönle [6]. Meanwhile, the locked rotor characteristic in forms of pressure ratio and torque curves were also provided in his work which allows sub idle compressor map generation employing the physically enhanced method. Therefore, the deduced compressor map can then be validated with sub idle map test data provided by Hönle [6] and used in engine starting simulation model which can further be validated with Allison engine starting test data.

In this paper, the sub idle compressor map of Allison 250 engine will be generated employing Zachos' [8] [9] physically enhanced method basing on locked rotor characteristic measurement data provided by Hönle [6]. The generated sub idle compressor map will then be validated with sub idle compressor map test data. In conjunction with engine starting simulation model, the completed compressor map will be used to generate the starting performance of Allison 250 engine. Simulation result will also be validated with engine starting test data. Some special concerns regarding to engine starting modelling will be discussed in this paper.

1. Methods

The methods utilized in this paper consist mainly three parts, that is, the physically enhanced map extrapolation method, engine starting performance modelling and validation of the method.

1.1 Physically enhanced map extrapolation method

The first step of this method is the rearrange of compressor map. As is suggested by Kurzke[3] [10] and Zachos [8] [9], it is necessary to describe the sub idle compressor map with corrected mass flow, corrected torque and pressure ratio as functions of Beta and corrected rotating speed. Corrected torque is calculated with the parameters in existing above idle maps using the following equations:

$$T_{cor} = T_{STD} * \frac{30}{\pi} C_p \frac{m_{cor}}{N_{cor}} \left(\pi_c^{\frac{k-1}{k}} - 1 \right) / \eta_c$$

Then the Allison 250 engine sub idle compressor map will be generated utilizing the physically enhanced extrapolation method [9] in conjunction with locked rotor characteristics measured by Hönle [6].

1.2 Engine starting performance modelling

Engine simulation model based on component maps will be utilized for engine start modelling. For engine transient maneuver simulation, some special aspects should be considered properly, such as the momentum inertia effects, volume effects and engine parts heat soakage. Regarding to engine starting modelling, more factors should be emphasized, among which the sub idle combustion characteristics is regarded one of significant importance. In sub idle region, the combustion efficiency is dominated by fuel evaporation rate. Thus, an evaporation controlled efficiency should be utilized, as is suggested in reference [8] and [10].

1.3 Simulation and validation

The validation of this method will be conducted from two aspects. The first aspect is the validation of generated sub idle compressor map against the test data. But as stated by Hönle [6], unacceptable measurement uncertainty was encountered in sub idle map measuring when the rotating speed is below 25%. So the second aspect is, as a supplementary, the validation of Allison 250 engine starting performance simulation result against engine starting test data.

Hereby, the author would thank Dr. Wolfgang Erhard and Martin Kerler from Institute of Flight Propulsion, Technical University of Munich for the test data they provide and their kind suggestions.

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