Integration of a Highly Bent Engine Inlet within an Engine Test Facility

Rudolf P.M. Rademakers, Thomas Kächele, and Reinhard Niehuis
Institute of Jet Propulsion, University of the German Federal Armed Forces Munich

Long Abstract

Introduction

Bent inlet configurations find their application within the field of civil and military aviation as well as in stationary gas turbines. Within such inlet ducts combined pressure-swirl distortions occur, which typically result in negative impact on performance, stability, and durability of the entire gas turbine. During the last decades a lot of research was conducted regarding inlet total pressure distortions. The Society of Automotive Engineers (SAE) published in 1983 the first edition of the Aerospace Information Report (AIR) 1419 [1], which overviews relevant contributions within this field of research. Nevertheless, the consideration of inlet swirl distortion is becoming more important due to the increasing demands on integrated inlet-compressor systems and hence the SAE introduced the AIR 5686 [2] to summarize current knowledge with respect to inlet swirl distortion. Latter document also addresses the lack of knowledge about the interactions between both pressure and swirl distortion, which consequently will be a major subject for future research.

Research on combined pressure-swirl distortion is ideally conducted by combining numerical and experimental approaches. Preliminary results can rapidly be generated by using the parallel compressor theory [3] to model the compressor system. Such models are essential in the early design phase of an integrated inlet-compressor system but cannot be used to assess aerodynamic phenomena. High fidelity CFD simulations (e.g. Barthmes et al. [4]) enable the assessment of internal aerodynamics, however, CFD cannot directly predict the influences on the performance of the gas turbine and computations are still very expensive in terms of computation time. Moreover, in all cases the set-up of a numerical simulation needs to be validated, which makes experimental investigations necessary.

In the open literature two different kinds of experimental set-ups for research on inlet distortion are often described. First, duct configurations can be investigated in a wind tunnel (e.g. Vakili et al. [5]). This approach is well suited to visualize the internal aerodynamics within the inlet duct, however, the upstream propagating effects from the compressor system are neglected and the influence on the performance, stability, and durability of the gas turbine cannot be assessed. Second, distortion generators can be installed upstream of the gas turbine to evoke inlet-type distortions (e.g. Rademakers et al. [6]). In this case the engine can be included within analysis but the flow in the duct is only simulated. Hence, CFD simulations of the inlet cannot be validated and the assessment of inlet-compressor interactions is not possible.

An experimental set-up of the entire inlet-propulsion system has not previously been presented in the open literature by the knowledge of the authors. The Institute of Jet Propulsion hence made major efforts to integrate a highly bent inlet duct within the Engine Test Facility (ETF) for experimental investigations with the state-of-the-art MexJET turbofan engine. This paper describes the entire integration process of a bent inlet duct within the ETF from the first sketch until entry into service of the inlet-propulsion system.

Phase 1. Definition of the project goals and restrictions

The project comprises four major goals. First, experimental data from a full-scale inlet being tested at the ETF will be used for the validation of numerical simulations. Second, the influence of a combined pressure-swirl distortion on the performance of both the compressor system and the entire propulsion system is of interest. Third, interactions between inlet and compressor will be assessed and finally, the experimental set-up will allow the integration of devices for research on passive flow control.

Phase 2. Definition of a highly bent inlet geometry

The bent inlet duct (see Fig.1, Pos. 4) is the main component of the set-up. Many CFD simulations were conducted in the definition phase of the duct geometry. The combined pressure-swirl distortion being evoked within this duct should be large enough to have measurable inlet-compressor interactions. The distortion should on the other hand be within the limitations according to the engine specification documents to assure a safe operation of the test vehicle at all operating points.

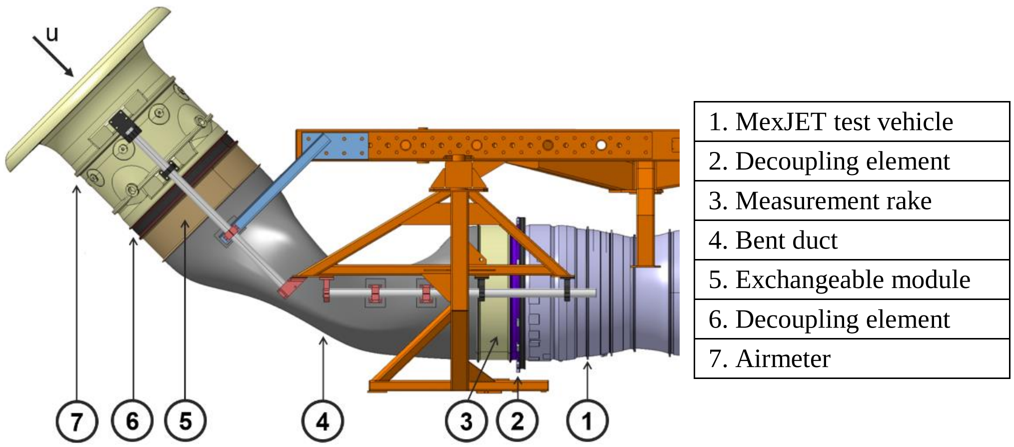

Figure 1. Overview of the experimental set-up

Phase 3. Integrability check

The integrability check did highly depend on restrictions, which were defined in the first phase of the project. Many iterations between both the second and the third phase were necessary to satisfy all requirements. These iterations were very time consuming but of crucial importance because a modification on one of the main components in a later stadium of the project would lead to heavily increased costs. A lot of know-how with regards to engine inlet design was gained. This knowledge will be summarized in the full paper.

Figure 2. Overview of the inlet instrumentation

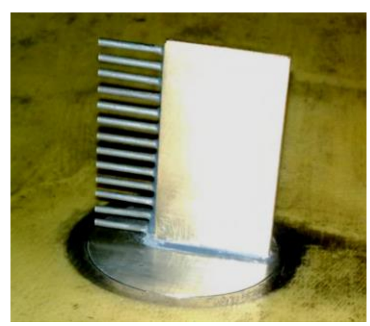

Figure 3. Boundary layer probe

Phase 4. Definition of instrumentation

The MexJET gas turbine (see Fig.1, Pos.1) was chosen for current investigations. This state-of-the-art test vehicle is based on the Eurojet EJ200, which is generally known as the powerplant of the Eurofighter Typhoon. Its Low Pressure Compressor (LPC) is of main importance while investigating inlet distortions and thus four rakes with both pressure and temperature probes are installed at the exit of the LPC. Modules with a standardized connection flange can be installed at both Pos.3 and Pos.5 (see Fig.1) within the set-up. During the major part of the testing campaign a measurement rake (equipped with five-hole as well as pitot probes for low and high frequency pressure measurements) will be installed at Pos.3 to measure the engine inlet distortion being evoked within the bent inlet duct. The rake is traversable in circumferential direction. In total 150 adapters (see Fig.2), which can be used for different purposes, have been integrated in the carbon fiber structure of the inlet duct. In the standard configuration a static pressure sensor is installed within the adapter. Additional adapters are integrated in the carbon fiber structure to enable the installation of e.g. boundary layer probes (see Fig.3) within the inlet duct. A bellmouth airmeter (see Fig.1, Pos.7) is used to provide an undistorted inlet flow for the bent inlet system and enables an accurate measurement of the engine mass flow.

Phase 5. Design and development of main components

The main components of the set-up have been designed with the support of FEM analysis. The forces, which act on the duct surface (see Fig. 4) were derived from CFD simulations as input data for the FEM model. The design of the traversable measurement rake (see Fig.5) was also supported with FEM analysis. All crucial issues during the design process will be discussed in the paper.

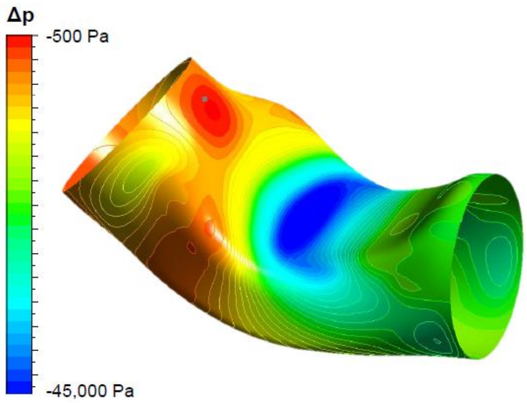

Figure 4. Forces acting on the duct structure

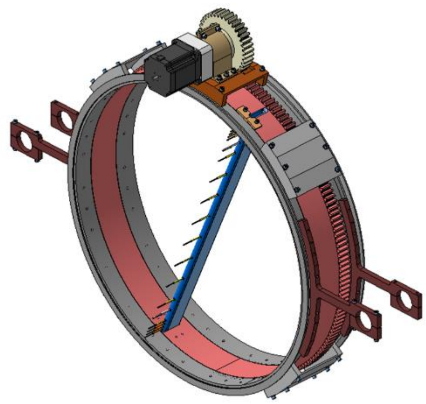

Figure 5. Design of the traversable measurement rake

Phase 6. Commissioning of the test set-up

Preliminary results will be available after the first testing campaign. The set-up will be taken into service by the end of July 2015.

References

[1] Society of Automotive Engineers, "Inlet Total-Pressure Considerations for Gas Turbine Engines", Aerospace Information Report 1419, Rev. B, 2013.

[2] Society of Automotive Engineers, "A Methodology for Assessing Inlet Swirl Distortion", Aerospace Information Report 5686, 2010.

[3] Mazzawy, R.S., "Multiple Segment Parallel Compressor Model for Circumferential Flow Distortion", J. Eng. Gas Turbines Power 99(2), pp. 288-296, April 1977.

[4] Barthmes, S., Haug, J. P., Lesser, A, and Niehuis, R., "Unsteady CFD Simulation of Transonic Axial Compressor Stages with Distorted Inflow", Proceedings of the 4th International Symposium "Simulation of Wing and Nacelle Stall", Braunschweig, Germany, December 2014.

[5] Vakili, A., Wu, J.M., Liver, P., and Bhat, M.K., "Measurements of Compressible Secondary Flow in a Circular S-Duct", AIAA-83-1739, Proceedings of the 16th Fluid and Plasma Dynamics Conference, Danvers, MA, USA, July 1983.

[6] Rademakers, R.P.M., Bindl, S., and Niehuis, R., "Influence of Secondary Flow within Integrated Engine Inlets on the Performance and Stability of the Larzac 04 Compressor System", ISABE-2015-22148, Proceedings of the 22nd International Symposium on Air Breathing Engines, Phoenix, AZ, USA, October 2015.