Identification and Testing of a Highly Dynamic Linear Actuation System for Active Compressor Stabilization

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Long Abstract

Introduction

New aircraft engines have to meet ambitious requirements regarding fuel consumption and efficiency, yet provide maximum operational safety throughout their lifetime. In some cases, these demands are in conflict, for example if the engine's compression system is considered. For maximum pressure ratio and efficiency, a high aerodynamical blade loading is advantageous. However, a higher loading increases the risk of aerodynamic compressor instability.

In order to resolve this conflict, the Institute of Jet Propulsion at the University of the German Federal Armed Forces is developing a new method of air injection for compression systems on a Larzac 04 turbofan engine. The subject of air injection has been under investigation for many years, with very promising results. It was demonstrated that air injection can significantly increase the surge margin of a jet engine compressor [1]. Latest experiments revealed that the utilization of the ejector effect can help to raise both effectiveness and efficiency of air injection systems [3]. Based on the gathered experiences, an advanced ejector injection system (EIS) was designed from scratch.

The EIS is able to start the air injection on demand, when compressor stall or surge is imminent. A powerful real-time algorithm is utilized to detect stall precursors. Using this algorithm, compressor instabilities can be predicted with high accuracy across the entire operating range [2]. However, the time between the detection of the stall precursor and the occurrence of the compressor instability is very short (24 ms at maximum power). This requires a fast response of the EIS. Therefore, a highly dynamic actuation system, comprised of three linear motors was identified and tested extensively.

1. Installation on the EIS

The ejector and therefore the entire EIS are designed axis-symmetric. Figure 1 shows the composition of the EIS schematically. Primary and secondary mass flow are mixed in the internal ejector geometry, creating the injection mass flow. The injection mass flow is released onto the tip region of the compressor directly upstream of the Larzac 04 low pressure compressor. The variable area nozzle can also be closed completely and thus, be utilized as a valve.

Due to the axis-symmetric design, the nozzle casing is comprised of three rings, which form the injection nozzle. The essential part for the functionality of the nozzle is the moving ring, which has to traverse in upstream direction in case of an imminent stall event to open the injection nozzle.

For this task, three actuators are distributed around the annulus of the EIS.

2. Requirements

One of the most important requirements is the achievement of the extraordinary performance of traversing 40 mm in about 20 ms, which results in accelerations of more than 20 g. Besides, the three actuators must move synchronously, in order to avoid a tilting of the moving ring. Furthermore, many additional requirements regarding precision, integration, handling, and control were defined.

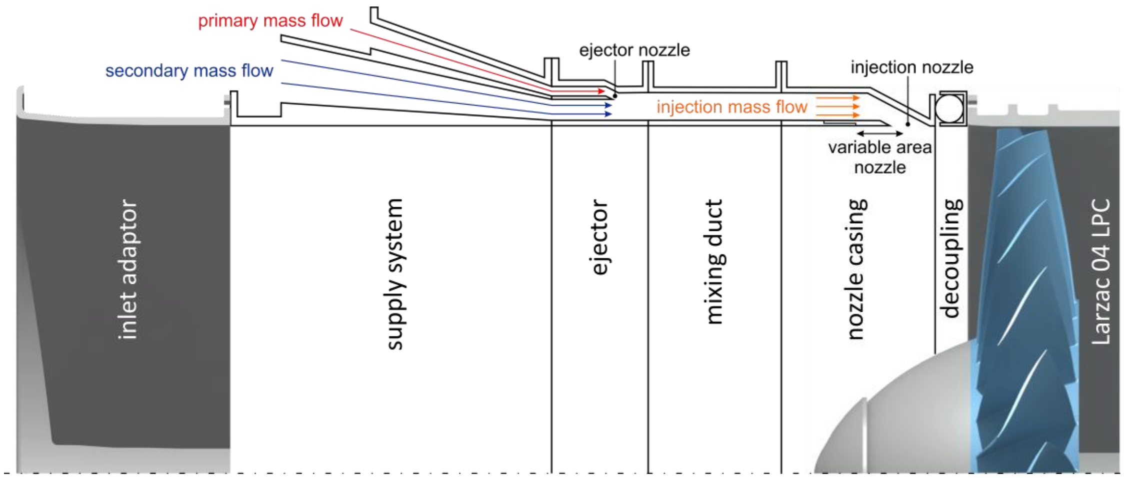

Figure 1. Schematic of the EIS

3. Selection

The selection of the actuation system was carried out, utilizing the top-down-method. First, the type of force generation was selected, then the mode of action, and the construction method of different actuator types were evaluated. In conclusion, only a servo tube linear motor could fulfill all requirements. This type of linear motor is comprised of a cylindrical slider (secondary part), carrying permanent magnets and an enclosing stator (primary part) with cylindrical windings. The primary part is stationary whereas the secondary part can move in the direction of the cylinder axis.

Finally, it was determined, which manufacturer and which specific motor to choose, utilizing motor performance calculation tools.

4. Standalone tests

In order to ensure that the actuation system reaches the required performance, the motors were tested on a standalone testbed first. The comparatively simple test setup was designed to emulate the installation conditions of the EIS.

As the friction coefficient of the bearings in the EIS is unknown, the precise actuation force is also unknown. Therefore, different axial forces can be simulated on the testbed, by applying normal force to the testbed's bearings.

During the tests, the motor moved 50 mm, which is the largest distance that the EIS mechanism can traverse. This is a worst-case scenario, as the slider is not fully covered by the windings in the outer position and therefore, cannot reach maximum performance. Two control setups (P-controller and PID-controller) were tested at different load settings.

The results confirmed the expectations and are presented in the full paper.

5. EIS tests

In order to ensure that the entire actuation system reaches the required performance, the motors were finally tested on the EIS. For these tests, the EIS was operated in standalone mode. Results regarding the motor performance, the inner aerodynamics, and the outlet aerodynamics are presented in the paper.

6. Conclusion

The integration of the actuation system in the EIS is an important milestone for the ejector tip injection. Now, the EIS can be utilized for active compressor stabilization on the Larzac 04 turbofan engine. The extraordinary performance of the actuation system allows for stall suppression throughout the entire operating rage.

References

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