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

Rudolf P.M. Rademakers¹*, Thomas Kächele¹, and Reinhard Niehuis¹

Abstract
Bent inlet configurations find their application within the field of civil and military aviation as well as in stationary gas turbines. The distorted flow in such ducts can have a major influence on the performance, stability, and durability of the gas turbine. Both experimental and numerical approaches are generally applied during the design and optimization of inlet systems. The last decade high fidelity numerical simulations became very popular in this field of research, however, experimental investigations are essential for the calibration, validation, and optimization of numerical simulations. Experimental data is moreover necessary to assess the influence of combined pressure-swirl distortions on the performance of the entire propulsion system. The Institute of Jet Propulsion made major efforts to integrate a highly complex inlet duct in a test set-up with the state-of-the-art MexJET turbofan engine. This set-up enables the assessment of combined pressure-swirl distortion and its influence on the engine and makes investigations on inlet-compressor interactions possible. This paper describes the six main project phases, which include the definition, design, development, and integration of this highly bent inlet system at the engine test bed of the Institute of Jet Propulsion.

Keywords
bent inlet duct - pressure and swirl inlet distortion - engine test bed

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INTRODUCTION

A bent inlet configuration is used for the air supply of e.g.: an auxiliary power unit of a civil aircraft, a highly integrated propulsion system of a military aircraft, or a stationary gas turbine in container configuration. Within such inlet ducts combined pressure-swirl distortions occur, which typically have a 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 the first edition of the Aerospace Information Report (AIR) 1419 [1] in 1983. This document reviews relevant contributions regarding research on inlet pressure distortion. 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] in 2010 to summarize current knowledge with respect to inlet swirl distortion. The latter document also addresses the lack of knowledge regarding 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 estimate the global influence of a certain inlet distortion on the behavior of the compressor system. Such models are essential in the early design phase of an integrated inlet-propulsion system, however, cannot be used for detailed assessment of aerodynamic phenomena since the internal compressor flow is not simulated. A high fidelity Computational Fluid Dynamics (CFD) simulation of a distorted compressor (e.g. Barthmes et al. [4] and Haug et al. [5]) enables the assessment of internal aerodynamics, however, CFD cannot directly predict the influence 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. [6]). This approach is well suited for the visualization of 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 provoke inlet-type distortions (e.g. Rademakers et al. [7], [8]). In this case the engine can be included within analyses but the internal duct flow is only simulated. Hence, CFD simulations of the inlet...
duct 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 test readiness. This process was divided in six phases, which are nonetheless interrelated. The latter means that for each major decision within the project all upcoming project phases had to be taken into account. It was of particular importance that all engineering decisions in the beginning of the project were conceived properly. Mistakes in the initial phases of a project usually lead to extensive additional costs and have a negative influence on the overall success of the project.

PHASE 1) PROJECT DEFINITION

1.1 Goals
The project comprises four major goals. First, experimental data from a full-scale inlet duct being tested at the ETF will be used for the validation and optimization of numerical simulations. Second, the influence of a combined pressure-swirl distortion on the performance of both the compressor system as well as the entire jet engine is of interest. Third, interactions between inlet and compressor will be assessed and finally, the experimental set-up allows the integration of additional devices for e.g. research on flow optimization within the bent inlet system.

1.2 General project constraints
The described project is conducted in cooperation with MTU Aero Engines AG. The MexJET turbofan engine (see also Chapter 3.4) was hence chosen as test vehicle due to the broad experiences of MTU Aero Engines AG with this propulsion system. The MexJET engine is operated at the ETF (see Fig. 1) at the Institute of Jet Propulsion and thus the bent inlet duct was specifically designed for experimental investigations within this engine test bed.

The design of the duct’s geometry was performed in cooperation with MTU Aero Engines AG applying CFD simulations. Using CFD data during the design process was the best possible approach although the desired experimental set-up is meant to provide data for the validation and optimization of e.g. the same CFD simulations. This means that all decisions within the design process of the inlet duct had to be made with a lot of care. In the early stages of the project a preliminary CFD set-up was validated with data from an experimental test case presented by Wellborn et al. [9]. This approach is very common and was recently also presented by e.g. Brehm et al. [10] as well as Fiola and Agarwal [11]. Details regarding the CFD simulations are not presented here but will be overviewed in a future paper.

PHASE 2) GEOMETRY DEFINITION OF A HIGHLY BENT ENGINE INLET

The bent inlet duct (see Fig. 2) is the main component of the set-up. After the definition of the project goals the inlet geometry was designed in an iterative process while considering a set of design restrictions. It was distinguished between:
- pre-design-restrictions (Chapter 2.1) and
- post-simulation-limitations (Chapter 2.2).

The pre-design-restrictions were defined once and then taken into account for every single iteration of duct design. The post-simulation-limitations were compared with the CFD results of each duct geometry under investigation.

2.1 Pre-design-restrictions

2.1.1 Integrability
The diameter of both the duct intake plane and the duct outlet plane had to be equal to the fan diameter of the MexJET engine. This makes a modular usability of existing and new components in the same test set-up possible (see e.g. Chapter 3). Furthermore, the available space within the facility was determined.

2.1.2. Comparability with CFD
Three matters were considered to avoid difficulties with CFD simulations later on.

![Figure 1. Visualization of the airflow within the Engine Test Facility (ETF) by Muth et al. [12]](image-url)
The engine mass flow is a key parameter for the comparison between CFD results and experimentally obtained data. This yields the requirement to measure engine mass flow in the experimental set-up as accurate as possible. A slight non-uniform flow pattern enters the intake plane of the engine in a standard test set-up (with solely a conventional air meter installed upstream of the engine) due to the particular design of the ETF (see Fig. 1). The flow does not enter the test cell horizontally but it is guided through an inlet tower causing this initial inlet distortion. The deflected air inflow does not negatively influence a secure operation [12] but decreases the accuracy of engine mass flow measurements. It was hence decided to position the intake plane of the bent duct at an angle of 45° to the intake plane of the test vehicle in the direction of the sound absorbers in the ETF’s air inlet tower.

It was chosen to design an inlet, which is symmetrical in the xz-plane (see Fig. 2). In the first place, CFD simulations of the entire ETF can only be conducted for a symmetrical set-up [12]. Furthermore, large scale unsteady flow phenomena are expected to occur within a highly bent inlet phenomena. A symmetrical inlet geometry eases the general assessment of internal aerodynamics and especially the determination of the unsteady behaviour of e.g. the flow separation. Overall it is noted that investigations on a symmetrical geometry enhance the comparability between experimental and numerical results.

Sharp edges in the geometry were avoided since the flow in such edges is difficult to measure in an experiment and moreover difficult to resolve in a numerical set-up.

2.2 Post-simulation-limitations

2.2.1 Aerodynamics

The flow velocity within the entire inlet system was limited to subsonic flow \( (Ma < 1) \) to avoid choking of the internal flow. In addition, highly dynamic flow phenomena such as oscillating shock waves occurring in the case of local supersonic flow conditions within the inlet duct are difficult to predict. It would hence be difficult to consider the loads due to such phenomena for the design and manufacturing of both the carbon fiber inlet duct and measurement instrumentation being installed within or downstream of the inlet duct. Downstream propagating dynamic flow phenomena can moreover have a negative impact on the stability and durability of the first compressor stage.
During the experiments the flow pattern within the outlet plane of the duct will be measured with five-hole probes. The utilized probes are applicable for measuring flow with swirl angles up to 30° and thus the expected flow angles should not exceed this level of swirl distortion.

### 2.2.2 Engine limitations
The MexJET engine is based on the Eurojet EJ200 engine. During the development of the latter turbofan engine an extensive amount of data was gathered regarding limitations on inlet distortion for the engine’s Low Pressure Compressor (LPC). It could hence be assured that the inlet distortions being provoked within the bent inlet duct are compatible with the engine capability.

### 2.3 Final geometry of the bent inlet duct
After an extensive iterative process the final geometry of the duct (see Fig. 2) was defined. Figure 3 shows the predicted aerodynamic condition of the flow within the Aerodynamic Interface Plane (AIP) of the duct for the engine at its maximum power setting. It is noted that the AIP is defined by the SAE [1] as a designated measurement plane between the inlet system and the engine face. For the described setup the AIP is equal to the duct outlet plane. The flow in the AIP will be measured with five-hole probes at 120 positions (see Chapter 4.3 for details).

The so-called Jet Engine Data Analysis Software (JEDAS) was in-house developed for an optimal comparison between data from numerical and experimental investigations. This tool assesses the flow data from both CFD simulations and experiments in the same manner. Each plot in Fig. 3 is hence based on 120 values for the respective flow properties as they will be determined during the experimental investigations.

### Table 2. Experimental set-up

<table>
<thead>
<tr>
<th>I. Airmeter</th>
<th>V. Measurement rake</th>
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<tr>
<td>II. Decoupling element</td>
<td>VI. Decoupling-element</td>
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<tr>
<td>III. Segment</td>
<td>VII. MexJET test vehicle</td>
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<tr>
<td>IV. Bent Duct</td>
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</table>

**PHASE 3) INLET INTEGRATION WITHIN THE ENGINE TEST FACILITY**

The bent engine inlet duct is the main component but a set of additional components were, however, necessary for the integration of both the duct and extensive instrumentation. These components (see Tab. 2) were defined in the third phase of the project and introduced in the following subsections. The entire experimental set-up is schematically depicted in Fig. 4. Details regarding the instrumentation within each of the components is illustrated in Chapter 4.

#### 3.1 Airmeter
The bellmouth airmeter (Fig. 4, Pos. I) is used to provide an undistorted homogeneous inlet flow at the intake plane of the bent duct. In the first place this contributes to an accurate engine mass flow measurement (see Chapter 2.1.2). It is in addition noted that an initial flow distortion within the intake plane of a bent duct can be amplified throughout the duct as it was shown by Rademakers et al. [13]. The bellmouth is hence installed under an angle of 45° to be in line with the flow, which enters the test section through the sound baffles within the inlet tower of the ETF (see Fig. 1).

#### 3.2 Decoupling elements
A decoupling element is integrated at both Pos. II and Pos. VI (see Fig. 4) to mechanically decouple the bent duct from the test vehicle (Pos. VII) as well as the glass fiber bellmouth airmeter (Pos. I) because of two reasons. First, vibrations within the bent duct may not be transferred into other components and vice versa. Secondly, both decoupling elements simplify the boundary conditions of the Finite Element Model (FEM) simulations on the carbon fiber duct (see Chapter 5.2).

#### 3.3 Exchangeable segment
A module with a standardized width of 180 mm can be installed at Pos. III as well as Pos. V within the set-up. The width of this segment is fixed at 180 mm since an already existing device for the installation of distortion screens, has the same dimensions. Furthermore, a traversable measurement rake was specifically designed within the scope of this project (see Chapter 4.3) and can also be installed at both positions.

#### 3.4 MexJET test vehicle
The MexJET turbofan engine (Fig. 4, Pos. VII) is a state-of-the-art test vehicle based on the Eurojet EJ200, which is generally known as the powerplant of the Eurofighter Typhoon multirole combat aircraft. Fundamental changes were made compared to the EJ200 turbofan engine to ensure a safe operation within the ETF. The test vehicle had its maiden test run at the ETF in the year 2012. For detailed information regarding the integration of the test vehicle at the ETF it is referred to Bindl et al. [14]. Some general MexJET performance data is given in Tab. 3.

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**Figure 4. Overview of the experimental set-up**

**Table 2. Experimental set-up**

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PHASE 4) DEFINITION OF INSTRUMENTATION

A detailed definition of instrumentation could start with the general set-up being defined. This was a crucial phase within the project since this step is strongly interrelated with other project phases and essential for a successful fulfilment of the overall project goals (see Chapter 1.1).

4.1 Bellmouth airmeter

The design and instrumentation of the bellmouth airmeter is according to common guidelines of the American Society of Mechanical Engineers [15]. It is equipped for engine mass flow measurements with eight static pressure taps, four exchangeable total pressure probes, and one total temperature probe. Both the static pressure taps and the total pressure probes are equally distributed in circumferential direction. The adapters for the total pressure probes are standardized and can also be used for the integration of other probes such as boundary layer probes (see Fig. 5), which were designed within the scope of the current project.

4.2 Bent engine inlet

In total 149 adapters for wall static pressure sensors, two adapters for mid-size probes, and one large mounting adapter were integrated within the bent inlet duct. The optimal positions of these adapters were determined by means of CFD. It is referred to Chapter 5.1 for details regarding the instrumentation itself.

4.3 Traversable measurement rake

A measurement rake (see Fig. 6), which is traversable in circumferential direction was developed within the scope of the current project. The rake is equipped with three different kinds of probes. Six standard pitot probes (see Fig. 7a) are installed within the boundary layer (three probes at the top side and three probes at the bottom side of the rake) to enable an estimation of the boundary layer thickness. Ten five-hole probes (see Fig. 7b) are positioned equally spaced along the rake. In total the flow pattern in the AIP will be measured at 120 positions (see Fig. 8) by displacing the rake in circumferential direction. An in-house tool presented by Rademakers et al. [16] was used to confirm that this approach does lead to an optimal inlet distortion assessment by means of both total pressure and swirl distortion coefficients. Two additional pitot probes are equipped with a Kulite® pressure transducer (see Fig. 7c). These special pitot probes are installed within the outer region of the AIP where the flow unsteadiness is expected to be the most pronounced.

Extensive numerical structural analyses (static as well as dynamic) were conducted during the design process of the previously described device to ensure a safe operation over the entire operating range of the MexJET engine. A detailed summary of respective results is nevertheless not within the scope of this paper. It is noted that four strain gauges are installed in the rake to monitor its state while operating the MexJET engine.

4.4 Engine Instrumentation

The MexJET turbofan engine has a three stage LPC, which is of primary interest while investigating engine inlet distortions. Four rakes with both pressure and temperature probes are installed at the exit of the LPC. It is expected that the distortion provoked by the bent inlet duct will be mixed out throughout the three stages of the LPC. This observation was also made during experimental investigations by Rademakers et al. [7] where severe inlet distortions interacted with the two-stage LPC of the Larzac 04 jet engine.

Table 3. Engine performance data [14]

<table>
<thead>
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<th>Parameter</th>
<th>Value</th>
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<tr>
<td>$F \approx 47 \text{kN}$</td>
<td></td>
</tr>
<tr>
<td>$d_{\text{fan}} \approx 740 \text{ mm}$</td>
<td></td>
</tr>
<tr>
<td>bypass ratio (BPR) $\approx 0.4$</td>
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<tr>
<td>$m \approx 70 \text{ kg/s}$</td>
<td></td>
</tr>
<tr>
<td>$\Pi_{\text{LPC}} \approx 4.2$</td>
<td></td>
</tr>
<tr>
<td>$\Pi_{\text{HPC}} \approx 6.2$</td>
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</table>
Four rakes are hence expected to be adequate to measure the LPC pressure ratio ($\Pi_{LPC}$) with sufficient accuracy. Thrust and fuel flow are moreover measured for additional engine performance assessment.

4.5 Instrumentation within the test bed
An upgrading of the instrumentation within the ETF was not necessary. Pressure and temperature is measured at several positions within the test cell and can be used to set up the boundary conditions of CFD simulations. Data regarding the relative humidity is obtained from a meteorological office, which is located at the same university campus as the Institute of Jet Propulsion.

4.6 Data acquisition
A state of the art data acquisition system based on National Instruments (NI) PXIe hardware and NI LabVIEW software was already available at the ETF [17]. This system can be utilized for all four jet engines, which are operated at the ETF. Usually this system is used solely for monitoring of the test bed and the test vehicle.

The applicable measurement hard- and software highly depends on the goals within a certain project. The existing data acquisition system was hence extended with a system based on the NI cRIO platform enabling a data acquisition being tailored for a specific test set-up. In the case of current investigations the high performance NI cRIO 9082 system with multiple NI9144 extension chassis and NI LabVIEW software is utilized for pressure (both low and high frequency), vibration, strain gauge, and temperature measurements. The development of this data acquisition system is described by Rademakers et al. [18]. Furthermore, a stepper motor is controlled by the same system to displace the measurement rake in circumferential direction.

The vast majority of all pressure measurements will be conducted at relative low frequencies. It was hence focused during the establishment of the data acquisition system on enabling a large amount of pressure measurements simultaneously. The entire test set-up with the bent inlet duct consists of 280 pressure probes and taps (MexJET engine instrumentation not included). The data acquisition system can sample up till 240 pressure values simultaneously with a maximal sampling rate ($f_s$) of 1 kHz.

PHASE 5) DESIGN AND DEVELOPMENT OF A BENT ENGINE INLET

5.1 Design
The design of the duct did depend on the definition of instrumentation and could hence start in the fifth phase of the project. The duct design mainly comprised the integration of five kinds of adapters into the carbon fiber structure. These adapters are either used for the installation of instrumentation (see Fig. 9; Pos. I to Pos. III and Chapter 5.1.1 to 5.1.3) or mounting of the duct in the experimental set-up (see Fig. 9; Pos. IV and Pos. V).

All adapters were designed with a flange to securely integrate the adapter between different layers of carbon fiber laminate. An aluminum or a non-corrosive steal was chosen as material depending on the respective influence on the eigenfrequencies of the entire inlet system (see Chapter 5.2.2).

5.1.1. Sensors
In total 149 aluminum adapters (see Fig. 9; Pos. I) were integrated for the measurement of static pressure at the duct’s wall surface. Different sensors can be installed within these adapters. Generally a brass sensor consisting of a drill-hole ($d_{\text{sensor}} = 1 \text{ mm}$) with a nipple on the outer side of the duct will be installed during experimental investigations.
(see Fig. 10). A tube is used to connect this type of sensor with a pressure transducer. Alternatively, a sensor with an integrated Kulite® pressure transducer can be installed in this adapter. This enables unsteady wall static pressure measurements with maximum sampling rates up to \( f_s = 300 \text{ kHz} \) to assess e.g. the unsteady manner of flow separation within the duct.

The adapters were preferably placed at positions, which are of interest for future CFD validation. Nevertheless, the ultimate position as well as the design of both the adapters and the sensors were defined such that local deviations of the smoothness of the duct’s inner wall surface are reduced to a minimum.

In total 40 adapter were positioned along the upper and lower centerline within the symmetry plane of the duct (23 adapter at the top side and 17 adapters at the bottom side). The density of adapters at the top side is increased within the region where flow separation is expected to occur. 109 adapters were positioned within five different cross-sectional areas. It is noted that the first and the last of the cross-sections were placed as close as possible to the duct’s intake and outlet plane, respectively.

5.1.2. Probes
Two adapters (see Fig. 9; Pos. II) were integrated near the duct’s intake plane. These adapters have a standardized geometry to enable the installation of various probes. In most of the cases a boundary layer probe (see Fig. 5) will be installed to determine the boundary layer thickness of the flow entering the bent inlet duct.

5.1.3. Larger devices
A large mounting adapter was integrated at the upper side of the duct (see Fig. 9; Pos. III) marginally upstream of the position at which the flow is expected to separate from the duct’s surface. It was determined with CFD simulations that the position of flow separation does not significantly change over the operating range of the test vehicle. A similar observation about the position of flow separation in an s-

duct inlet was made by Rademakers et al. [13] during experimental investigations on a small scale s-duct engine inlet.

The adapter enables the installation of a custom made cover, which is 400 \text{ mm} width and 225 \text{ mm} in length. The shape of this cover at the inside of the duct is equal to the original shape of the duct geometry. For the first experimental tests the cover is equipped with 21 drill holes for wall static pressure measurements. The cover can, however, easily be replaced in future test campaigns with a cover including extensive instrumentation or devices for e.g. passive or active flow control.

5.2 Development
Numerical structural analyses were conducted to determine the best composition for the carbon fiber structure. The stiffness and strength of the structure were assessed by means of static FEM analysis and the eigenfrequencies were determined with dynamic FEM analysis. All three properties of the structure (stiffness, strength, and eigenfrequencies) were mainly influenced by two variables: first, the thickness of the structure and second, the local orientation of the carbon fiber layers. It is noted that changing both variables has a complex influence on either the stiffness, strength, or eigenfrequencies of the structure. This makes both static and dynamic FEM analysis highly interrelated and thus an iterative process for the optimal definition of the carbon fiber structure was necessary.

5.2.1 Static FEM analysis
The forces acting on the surface of the duct during a stationary operation over the entire operating range of the MexJET engine were derived from CFD simulations (see Fig. 11) and used as input data for static FEM simulations to determine the stiffness and strength of the structure. Figure 11 shows the maximal expected aerodynamic loads acting on the structure for the engine at maximum power setting.
A deformation of the structure while operating the test vehicle should be reduced to a minimum to assure the comparability with CFD simulations. The thickness was finally set to 7.45 mm for the entire structure to reduce the deformations to a minimum. A further increase of the laminate thickness would unfortunately have a negative influence on the eigenfrequencies of the structure.

The strength safety factor

\[ S_{\text{strength}} = \frac{\varepsilon_{\text{local, max}}}{{\varepsilon_{\text{limit}}}} \]  

indicates the ratio of the maximum local deformation in the structure and the maximum tolerable local deformation of the carbon fiber composition. With \( S_{\text{strength}} > 11.2 \) within the entire model the strength requirements are easily fulfilled for the model of the inlet duct with a wall thickness of 7.45 mm.

**5.2.2 Dynamic FEM analysis**

Many different set-ups were simulated and assessed. It is not within the scope of this paper to discuss all results in detail. The final results are summarized in the following.

**Blade Passing Frequency (BPF)**

Upstream propagating flow instabilities from the LPC while working in transonic conditions were considered as main source for a possible excitation of the eigenmodes of the duct’s structure. Such flow phenomena most likely propagate upstream with the Blade Passing Frequency (BPF). Figure 12 shows the safety margin between the first 25 eigenfrequencies of the duct structure and the BPF of the test vehicle’s LPC. Hence, it is not expected that the duct’s eigenmodes can be excited by flow phenomena propagating upstream with the BPF.

**Engine Order 1 and 2 (EO1 and EO2)**

In the following the first six eigenmodes of the structure will be considered as so-called “critical eigenmodes” for further analysis. The modes represent the first, second, third, and fourth bending mode as well as the first and second torsion mode of the structure. In addition to the comparison with the BPF these modes are compared with the first and second engine order of the LPC in Fig. 13. The graph shows that there is no overlapping between the critical eigenfrequencies and the first two EOs.

The third eigenmode of the structure did attract special attention. It is a bending mode with a local deformation at the bottom side of the duct as shown in Fig. 14. A vibration sensor will be installed at the position where the deformation of this specific mode is expected to be maximal although an excitation by upstream propagation flow phenomena from the compressor system is not expected according to Figs. 12 and 13. It is noted that all other “critical eigenmodes” show a global deformation of the structure. Such eigenmodes are generally difficult to excite.
PHASE 6) COMMISSIONING OF THE SET-UP

The manufacturing of all components started after a successful completion of the fifth project phase. The carbon fiber bent inlet duct is shown in Fig. 15 and hence ready for entry into service. Preliminary results will be available after the first test run, which is planned for the year 2016.

7. SUMMARY AND OUTLOOK

During six highly interrelated project phases a novel set-up for experimental investigations was established at the Institute of Jet Propulsion. The geometry of a highly bent engine inlet duct was designed (phase 2) in consideration of four main project goals, which were defined during the initial phase of the project. Additional components were defined (phase 3) to enable the integration of the final inlet duct design at the ETF. The instrumentation of the entire set-up was then specified (phase 4) such that experimental data can be obtained for a successful fulfillment of all project goals. Finally, the bent inlet duct including the integrated instrumentation was developed (phase 5) mainly by applying numerical structural analyses to assure a safe operation in the test environment with the MexJET turbofan engine. The manufacturing of all components is completed and the commissioning of the set-up (phase 6) is expected to take place in the year 2016.

In the first place the experimentally obtained data will be used for the calibration, validation, and optimization of CFD simulations. The experiments will moreover contribute to the understanding of the interdependency of both pressure and swirl distortions within an inlet system and an assessment of the influence of a combined pressure-swirl distortion on the performance and stability of the propulsion system will be possible.

A special adapter is integrated upstream of the position where a large flow separation within the duct is expected to occur. A part of the duct’s wall is hence exchangeable and and additional devices for investigations on e.g. flow control within an engine inlet can be installed here in a future stage of the project.

ACKNOWLEDGEMENTS

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NOMENCLATURE

Symbols

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<th>Unit</th>
<th>Description</th>
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<tr>
<td>(d)</td>
<td>[mm]</td>
<td>diameter</td>
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<tr>
<td>(F)</td>
<td>[kN]</td>
<td>thrust</td>
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<td>(f_s)</td>
<td>[Hz]</td>
<td>sampling rate</td>
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<td>(\varepsilon)</td>
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<td>(\Pi)</td>
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<td>pressure ratio</td>
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Abbreviations

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<td>AIP</td>
<td>Aerodynamic Interface Plane</td>
</tr>
<tr>
<td>AIR</td>
<td>Aerospace Information Report</td>
</tr>
<tr>
<td>BPF</td>
<td>Blade Passing Frequency</td>
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<tr>
<td>CFD</td>
<td>Computational Fluid Dynamics</td>
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<tr>
<td>cRIO</td>
<td>compact Reconfigurable In-Output</td>
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