Experimental Measurements of Static Pressure in the Inter-Turbine Duct of a Gas Turbine

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Abstract: - The paper presents the static pressure experimental measurements carried out at the Romanian Research and Development Institute for Gas Turbines COMOTI in order to allow the geometrical optimization of Inter - Turbine Duct of a two spools gas turbine engine designed and manufactured by SE Ivchenko – Progress, Ukraine, as a function of the gas turbine operating regime (mass flow rate) and speed. The Inter - Turbine Duct experimental assembly has been designed, manufactured and measured at COMOTI.
The static pressure was measured circumferentially and axially on the inner and outer casings and along one of the struts. The static pressures were measured as a function of the pre-swirling angle, which simulates the influence of the high pressure turbine rotational speed located upstream of the Inter turbine duct in the real gas turbine, as well as for three operational regimes, without the pre-swirlers modules. The experimental data highlights separation regions occurring for 0° and 15° air stream pre-swirling, stronger for the latter case. The operational regime was found not to influence significantly the static pressure distribution along the strut or along the casings.

**Key-Words:** Gas turbine, Static pressure measurements, Inter – Turbine Duct optimization

### 1 Introduction

The work presented here was carried out at INCDT COMOTI aiming at providing experimental measurements for the first design of an Inter-Turbine Duct (ITD), including the manufacturing of an ITD experimental assembly, the test rig setup and its adaptation for the measurements. The experimental measurements consisted in measurements of the static pressure in the ITD, in order to support the ITD optimization process, along with total pressure and velocity angle measurements (to be published). The static pressure measurements presented herein served as validation data for CFD optimization studies carried out by partners in the research project. The measurements have been performed at different turbine operating regimes (i.e. mass flow rates and turbine rotational speeds, translated into the ITD inlet flow angles), in order to evaluate the pressure distribution as a function of the turbine operating regime and to identify separation regions. Similar, but less detailed measurements, have been reported earlier [1,2,3,4].

Several other parameters, such as actual mass flow rate, total temperature, and ambient conditions, have also been measured in order to allow for the proper definition of the operating regime.

### 2 Experimental Setup

The experimental facilities include a thermo – gasdynamic complex for the study and the experimentation of liquid, gas, biomass or biomass derivatives (bio-fuels) fuel combustion, heat transfer, thermal resisting coating, and industrial or aircraft micro gas turbine engines, mandatory assisted during experimentation by a tri-sonic air blowing station, equipped with 2,000 m3 air tanks, able to provide air up to a pressure of 16 bar and a velocity up to Mach 3. The compressed air station provides air to the test rig through 3 air lines, with mass flow rates up to 10 kg/s, pressures up to 14 bar, and air temperatures up to 800 K. The experimental test rig of the complex is equipped with high precision ultrasonic flow meters, thermocouple probes, and pressure transducers. A detailed diagram of this line, with pictures of the components is provided in fig. 1.

![Experimental rig diagram](image)

**Fig. 1:** Experimental rig diagram

On this test rig, a modular experimental ITD assembly was manufactured and mounted, to best simulate the functioning conditions of the ITD while on the engine. The ITD assembly is presented in fig. 2 and 3 and has 6 major subassemblies:

1. The Inlet cone, with the purpose of adjusting the flow section from the circular pipe of the test rig to the annular inlet section of the ITD;
2. The Inlet Guide Vane module (IGV), with the role of pre-swirling the flow at the inlet of the ITD, simulating the presence of the high pressure turbine upstream of the ITD. For this work, 3 different IGV modules were alternatively used, each of them designed for a different angle: 0°, 15° and 30°;
3. The ITD, consisting of a Shaped channel and 4 Struts;
4. The Low Pressure Turbine vane row (LPT), which is the actual engine part downstream of the ITD, and aerodynamically continues the struts;
5. An Annular constant section that continues the LPT outlet section;
6. The Outlet cone, which ensures the flow section is restored to the circular section of the testing. The static pressure measurements have been carried out on the outer and inner casings of ITD and on the
strut walls, by means of pressure holes drilled in the respective walls, see fig. 4. For each of the casings, a number of 24 holes with a diameter of 0.65 mm have been drilled by electro charge, and the information was collected through separate nozzles and then to a pressure transducer that reads all the pressures, one at a time, 3 channels per second. The same solution was applied for the inner casing, but the nozzles were fixed on the inside of the inner casing, and the pressure information from them was exited through 15 mm holes drilled in each of the 3 struts that were not instrumented.

For the strut on which static pressure measurements have been carried out, 6 holes of 0.5 mm in diameter holes were drilled on its suction side wall, and 6 on its pressure side wall, at the mean radius, all of them corresponding to individual larger holes that are connected through the strut’s flange to same type of nozzles, and then through hoses to a similar pressure transducer to the one used for the casings. The pressure transducer reads all the pressures, one at a time, 3 channels per second.

The coordinates of the static pressure measurement points are given in Table 1.

Table 1: Coordinates of measurement points

<table>
<thead>
<tr>
<th>No.</th>
<th>x [mm]</th>
<th>y [mm]</th>
<th>z [mm]</th>
<th>r [mm]</th>
<th>θ [°]</th>
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<td>1</td>
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<td>35.619</td>
<td>534.850</td>
<td>69.562</td>
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<td>70.575</td>
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<td>3</td>
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<td>41.588</td>
<td>552.250</td>
<td>72.029</td>
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<td>4</td>
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<td>44.898</td>
<td>560.950</td>
<td>73.753</td>
<td>127.5</td>
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<tr>
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<td>48.306</td>
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<td>578.350</td>
<td>77.352</td>
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<td>587.050</td>
<td>78.902</td>
<td>134.2</td>
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<tr>
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<td>58.021</td>
<td>595.750</td>
<td>80.076</td>
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<td>9</td>
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<td>31.751</td>
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<td>15</td>
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<td>600.950</td>
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<td>587.050</td>
<td>78.902</td>
<td>128.4</td>
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</table>
Also in Table 1, the circumferential coordinate in a cylindrical axis forms an orthogonal system with the first two. with respect to the vertical strut location, and the \( x \) axis is the axis of the inlet section, the \( x \) axis is the axial direction, and the \( z \) axis forms an orthogonal system with the first two.

Also in Table 1, \( r \) is the radial coordinate, and \( \theta \) is the circumferential coordinate in a cylindrical coordinate system centred in the same origin.

### 3 Results

The static pressures were measured circumferentially and axially on the inner and outer casing and along one of the struts in the locations given in Table 1.

The static pressures were measured as a function of the pre-swirling angle, which simulates the influence of the high pressure turbine rotational speed, as well as for three operational regimes, without the IGV pre-swirlers.

The operational regime is defined by the mass flow rate, along with the total temperature and total pressure at the inlet of the experimental assembly, under the Mach number similarity criterion [5]:

\[
G_{\text{red}} = \frac{\sqrt{T_i^*}}{p_i^*}
\]

where \( G_{\text{red}} \) is the reduced mass flow rate, \( \dot{M} \) - mass flow rate, \( p^* \) is the total pressure, \( T^* \) is the total temperature, and the index \( i \) denotes the inlet section.

The three studied IGV configurations, respectively for three pre-swirling modules were:

- Module 1, with a pre-swirling angle of 0°;
- Module 2, with a pre-swirling angle of 15°;
- Module 3, with a pre-swirling angle of 30°.

The operational regime in the first experimental campaign was found to be \( G_{\text{red}} = 0.332 \), with a 2% accuracy.

The three studied regimes, defined by their reduced mass flow rates within 2% accuracy, were:

- Regime 1, with reduced mass flow rate of 0.234;
- Regime 2, with reduced mass flow rate of 0.256;
- Regime 3, with reduced mass flow rate of 0.267.

As noted earlier, the static pressures were measured on one ITD strut and on the inner and outer casings, as described below.

#### 3.1 Static pressures along the ITD strut

Figs. 5–7 present the static pressure distribution along the ITD strut for each pre-swirl angle. Figs. 8–10 present the static pressure distribution along the ITD strut for each operational regime. The pressure is given with respect to the measuring location, and is represented as a value, in [kPa] along the normal to the strut profile.

Considering the influence of the pre-swirl angle, the 0° Module 1 presents a higher static pressure on the convex side of the strut. Along each side, the static pressure is higher towards the leading and trailing edge (slightly higher at the leading edge, due to the stagnation bubble located there) and lower in the
middle, but the pressure variation is less significant on the concave side of the strut.

Fig. 5: Static pressure distribution along the strut profile for Module 1

Fig. 6: Static pressure distribution along the strut profile for Module 2

Fig. 7: Static pressure distribution along the strut profile for Module 3

For the 15° Module 2, as the incidence angle of the flow changes, the pressure ratio on the two sides of the strut changes as well, with a higher value on the concave side. Along both sides in this case, the static pressure is higher towards the leading and trailing edge and lower in the middle.

Fig. 8: Static pressure distribution along the strut profile for Regime 1

Fig. 9: Static pressure distribution along the strut profile for Regime 2

Fig. 10: Static pressure distribution along the strut profile for Regime 3
As the incidence angle further increases, the trend maintains and accentuates for the 30° Module 3. The concave side static pressure becomes even higher than the convex side pressure, while the static pressure starts to increase more pronouncedly towards the leading edge, in comparison to the trailing edge, due to the stagnation bubble that starts extending from the trailing edge.

The reduced mass flow rate influence on the strut static pressure is observed for a configuration with no IGV, hence is similar to the 0° Module 1 case, with a higher static pressure on the convex side of the strut and a more pronounced variation on the same side, and a slightly higher leading edge value. Overall, the static pressure increases with the increase in the reduced mass flow rate, but the profiles look otherwise similar.

3.2 Static pressures along the inner and outer casings

On the inner and outer casing, for Module 1, figs. 11 – 12 present the circumferential static pressure distributions at the axial location of 560.9 mm, and respectively 587.05 mm on both the inner and the outer casing, and fig. 13 presents the axial static pressure distribution along the axial line defined in Table 1.

For Module 2, the circumferential static pressure distributions along the inner and outer casing at the same axial locations are provided in figs. 14 – 15, and the axial pressure distribution is provided in fig. 16, while for Module 3, the same data is presented in figs. 17 – 18, respectively in fig. 19.

For Module 1, at the first axial location, the static pressure is higher on the inner casing than on the outer casing and lower at the second axial location. However, as the pre-swirl angle increases, the situation in the first axial location changes and the static pressure becomes higher on the outer casing for both axial locations, due to the changes in the flow pattern induced by the change in the flow incidence angle.

Fig. 11: Circumferential static pressure distribution at 560.90 mm along the inner and outer casing for Module 1

Fig. 12: Circumferential static pressure distribution at 587.05 mm along the inner and outer casing for Module 1

Fig. 13: Axial static pressure distribution along the inner and outer casing for Module 1

Fig. 14: Circumferential static pressure distribution at 560.90 mm along the inner and outer casing for Module 2
at hole 5, and for Module 3 at hole 8 on both casings.

It is also noteworthy that at the first axial location, for Module 0, the pressure is higher at hole 1 for both cases, but the situation changes gradually with the increase in the pre-swirl angle, such that for Module 2 the maximum static pressure is registered at hole 5, and for Module 3 at hole 8 on both casings.

The same circumferential shift in the position of the static pressure maximum with the increase of the pre-swirl angle can be observed, partially and at a slower rate, for the second axial location as well. Thus, the position of the static pressure peak at 587.05 mm is at hole 2 (outer) and 3 (inner) for the 0° pre-swirl angle, at hole 5 (outer) and 6 (inner) for the 15° pre-swirl angle. For the 15° pre-swirl angle, the static pressure peak remains at point 5 for both casings. This may be explained by the creation of a vortex at the strut leading edge, its position being controlled by the incidence angle, but which slowly dissipates further downstream.

In the axial direction, the general tendency of the static pressure is to increase with the distance from the ITD inlet. Deviations from this trend can be noted in the region near the strut leading edge for the 15° module on both casings, and for the 0° module on the outer casing indicating possible separation regions that expand from the Module 1 to the Module 2, and fade away for Module 3.
The influence of the reduced mass flow rate on the circumferential and axial static pressure profiles on the inner and outer casings is much less significant, all the profiles being quite similar to the Module 0 case, as expected. The only notable influence is the overall increase in the static pressure levels with the increase in the reduced mass flow rate.

The static pressure circumferential distribution at the same two axial locations and the axial static pressure distribution along the inner and outer casing are given in figs. 20 – 21 and respectively fig. 22 for Regime 1, in figs. 23 – 24 and respectively fig. 25 for Regime 2, in figs. 26 – 27 and respectively fig. 28 for Regime 3.
4 Conclusion

An experimental Inter - Turbine Duct has been designed, manufactured and installed on the test rig facility, described here. Two experimental campaigns have been carried out, to assess the influence of the operational regime and of the pre-swirling angle on the pressure distribution along the ITD struts and casings, and the results were collected and analyzed here. The static pressure measurements along the casing and on the strut profile indicated that separation regions occur in the experimental domain for both the 0º and the 15º modules, stronger for the latter case.

The influence of the operational regime on the static pressure distribution was found to only increase the static pressure levels with the increase in the reduced mass flow rate, without altering the pressure profiles on the strut or on the casing. The measurements presented here, along with other experimental data gathered during the same experimental campaigns served as validation data for CFD optimization studies carried out by partners in the research project.

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