An overview of the new research infrastructure for rotating labyrinth seals at COMOTI

B Gherman¹, L Flore², R Carlanescu³, M S Enache⁴, O Anghel⁵ and A G Radu⁶
Romanian Research & Development Institute for Gas Turbines-COMOTI, Bucharest, 061126, Romania

¹bogdan.gherman@comoti.ro  
²lica.flore@comoti.ro  
³razvan.carlanescu@comoti.ro  
⁴marius.enache@comoti.ro  
⁵octavian.anghel@comoti.ro  
⁶andrei.radu@comoti.ro

Abstract. In this article will be described the improved test stand for rotating labyrinth seals that will be developed at COMOTI. The present test rig is able to test only a seal configuration in a simplified environment, (air temperature max.150°C, labyrinth diameter max. 300 mm, airflow rate max. 0.35 kg/s, pressure max. 9 bars). The newly improved research infrastructure will be able to increase these limits up to: 800°C temperature, 600 mm labyrinth diameter, 10 kg/s airflow rate and 50 bars pressure. The upgrade performed on to this research facility will comprise of a test rig for experimental measurements; a air supply station with two centrifugal compressors; an air cooling tower; a air tank to store high pressure air and an air heater station capable to supply air with 800°C.

1. Introduction
The development of the aeroengines reached at a high optimization stage from where, the ever-present necessity of emission reduction and efficiency increase it is a challenge harder and harder to fulfill. As the geometries of the main parts are highly optimized and here can be mention the compressor, combustion chamber and turbine, the secondary flows that develop around the main parts, affect strongly the efficiency of the entire turbomachinery. That is why these secondary flows in a turbomachinery are subject to more and more studies and optimizations that try to decrease internal leakages. There are studies that show that the efficiency of the turbine drops significantly due to internal leakage [1], [2], [3] even due to present state-of-the-art solutions. The impact of the internal leakage is major, a 1 % of seal leakage reduction leads to a 1 % thrust increase and a 0.1% decrease in specific fuel consumption, [4]. Thus, the most seal optimization studies focus on the limitation of leakage flow and the flow path optimization.

The experimental approach in these cases is used to validate the solutions identified during the numerical optimization. Thus, it is very important to extract the most valuable information and with the smallest errors for the experimental campaign.
The experimental analysis has two major parts, the test rig development that will simulate in the most appropriate way the real situation in which the seal will be used and secondly the measurement equipment used to capture the flow characteristics with the smallest errors.

In one study [5] the authors used to study a labyrinth seal a rig with atmospheric pressure and temperature at inlet and the vacuum was generated with an air blower and the system incorporated a pressure vessel to compensate pressure fluctuations and to stabilize the flow parameters prior to the test section. The authors argued that using an atmospheric inlet will be no thermal deformation of the seal, thus tip clearance will not modify during tests. Also, the flow measurements were performed by hot-wire anemometry probe and by ISA orifice plate with differential pressure transmitters. The measurements are done in three points to measure properly the seal leakage and to determine the measurement errors, [6], [7], [8]. For flow visualization it was used the schlieren technique, although it is better to use PIV [9],[10], [11] or LDA [12], [13], the authors considered that this method can provide good results also [14]. In another study, regarding labyrinth seals for oil sealing in an aeroengine, [article 2] the authors used an installation [15] capable to study different types of seals, like labyrinth, brush, floating ring and carbon to make an analysis of the labyrinth seals they developed. In this case the air was pressurized with the help of an air blower and heated up with a 100-kW power heater, see Figure 1. As for the oil system is concerned an oil tank, a heater, two oil pumps, a filter and a heat exchanger were provided in the installation. As for the instrumentation used in this study it can be mention the usage of a flow meter with an accuracy of ± 0.5 % while the temperature was measured with 6 six K-type armored thermocouples with a ± 0.2 % accuracy. The pressure on the air and oil paths was measured using pressure sensors with a ± 0.1 % accuracy.

![Figure 1. Scheme of the test section [16]](image1)

![Figure 2. Experimental installation intended for the turbine seal testing in the IPET of the SUT [17]](image2)

![Figure 3. View of the stationary test rig [17]](image3)

In another study, A Szymanski et. al. [17] build another test rig to test a labyrinth seal using a stationary linear model of the seal, see Figure 2&3. The experimental installation used by the authors
has a conical shape inlet designed to reduce/eliminate any flow separation from the boundary layer prior to the test section. This is necessary due to a diameter difference between inlet and test section entrance. In this section there was incorporated a window made of BK7 optical glass, to be able to use a Laser Doppler anemometry technique. Also, the test section is 200 times wider than the examined clearance to reduce the effect of the side walls. Also, on the upper walls were installed total pressure and static pressure probes.

The data acquisition system incorporates a Schmidt 20.500 thermal anemometer to measure velocity distribution, a PC-28 Aplisens pressure transducer and TTP-TKb, J thermocouple for temperature measurement. The tip clearance was also measured by using a feeler gauge. What is more important is that for results validation the authors registered 1000 samples that mean approximately 90 seconds.

In this article will be described the improved test stand for rotating labyrinth seals that will be developed at COMOTI.

2. Experimental Facility Description
The experimental facility from COMOTI has a supply unit that can deliver pressurized air at 16 bars, at a flow rate of 1 kg/s, see Figure 4. The air is delivered to a tank with 16 m^3 capacity that will assure a steady delivery of the mass flow at a certain pressure.

![Figure 4. The screw compressor and the air tank that deliver air to the labyrinth facility](image)

The air is heated prior to the test section with the help of an electrical heater, see Figure 5, capable to deliver a maximum temperature of 900 K at 0.3 kg/s.

![Figure 5. Heater Description](image)

The rotor disk of the experimental labyrinth seal is driven by a 52 KW DC Motor with 2000 rpm at nominal regime and 4200 rpm at maximum speed. The speed multiplier has a capacity of 120 kW at
nominal regime and a maximum output speed of 23,000 rpm. It is Bi-rotational, with journal bearings and carbon seals and has a pressurized lubrication system.

![Image of DC Motor and Speed Multiplier]

**Figure 6.** The speed multiplier (a) and the DC motor (b)

**Figure 7.** Lubrication and Cooling System

The lubrication system that serves the DC Motor and the speed multiplier has an oil tank of 120 l with a mass flow rate of 32 l/min and a maximum pressure of 6 bars, also the nominal filter fineness is 6 microns, see Figure 7. The constructive solutions of the experimental module seen in Figure 8 are fulfilling the requirements for such analysis and the test stand can be developed in the future for different configurations and special instrumentations. The available instrumentation is given in the table below.

![Image of Test Bench]

**Figure 8.** Test bench overview

3. The Improved Experimental Facility Description

The scalability of the labyrinth seal technology has yet to be proven. The specific objectives of the complementarity project relate directly with this goal, aiming to create and develop the research infrastructure, experimental and numerical, able to validate the application of this concept for significantly higher mass flow rates, higher temperatures and higher-pressure ratios. The main result of the project is a novel research infrastructure consisting of an experimental testing, including an air supply station, an air heater station, command and control systems, dedicated measurement equipment, processing and data acquisition systems. The accuracy of the experimental investigation and of the numerical modeling need also be improved in order to increase the depth of the knowledge gained in the field.

Specifically, the objectives of the project are:

- Expand the capabilities of the experimental research infrastructure to handle experimental programs for characterization the airflow through rotating labyrinth seals.
- Diversify the available instrumentation to increase experimental measurement accuracy and sensors robustness under harsh environmental conditions.
• Expand the computational, processing and data acquisition infrastructure to allow an increase in modeling complexity and data processing resolution for testing of rotating labyrinth seals.

The test rig used by AIRSEAL project is able to test only a seal configuration in a simplified environment, according with call requirements (air temperature max. 150°C, labyrinth diameter max. 300 mm, airflow rate max. 0.35 kg/s, pressure max. 9 bars). The extended research infrastructure, proposed by INFRASEAL project, will be able to increase this limit up to: 800°C temperature, 600mm labyrinth diameter, 10 kg/s airflow rate and 50 bars pressure. By INFRASEAL infrastructure COMOTI can develop other programs, as well as new engine architectures, contributing to ACARE SRA goals.

Thus, the proposed test rig with a high air flow rate and natural gas flow will allow testing the scalability of the combustor concept, studied under other Clean Sky 2 Work Packages and platforms (WP 8 - Reliable and more efficient operation of small turbine engines, program area: ENG/SAT).

The existing experimental research infrastructure, in COMOTI facilities, consists of an integrated thermo-gas dynamic 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 using liquid, gas or biomass (bio-fuels) fuels. The thermo-gas-dynamic complex, however, must be assisted during experimentation by an external air supply station, not belonging to COMOTI and not easily available.

The upgraded air supply line can provide mass flow rates up to 10 kg/s, pressures up to 50 bar, and air temperatures up to 350°C. The airline can be equipped with a combustor chamber which can be fueled either by natural gas, or by liquid fuel, able to raise the working fluid temperature up to 800°C. It is important to note that if the above-mentioned combustors will be used to heat up the fluid to the required temperature (up to 800°C), the working fluid is not pure air, but a mixture of flue gas and air. For the experimental study of labyrinth seal with height mass flow rates, the capabilities of the experimental research infrastructure will be expanded by an upgrade of the existing experimental facility, by designing, building and commissioning the following facilities (Fig.9):

• Test rig for experimental measurement, equipped with air and fuel lines, and with independent command and control chambers;
• Air supply station composed by two lines (compressor and centrifugal air blower) capable to provide a maximum exhaust pressure of 50 bar, and a mass flow rate of 10 kg/s, at a maximum temperature of 185°C (the maximum pressure and mass flow rate will not be reached simultaneously);
• Air cooling tower to control the temperature of the supplied air;
• Air tank to store the high-pressure air supplied by the air supply facility for the purpose of optimizing the energy consumption during the experimentation programs, and to boost the mass flow rate and air flow capabilities of the experimental test rigs for limited periods of time.
• Air heater station included a combustor chamber capable to provide air at 800°C.

![Figure 9. Schematic view of INFRASEAL new facilities for rotating labyrinth seals characterization](image-url)
The targeted infrastructure will be instrumented by a number of sensors for static and total pressure, static and total temperature, and wall metal temperature. The existing measurement equipment consists in temperature and pressure probes and sensors, temperature resisting rakes, thermo-resistors, Venturi flow meters, as well as advanced measurement equipment will be used for the determination of the instantaneous three-dimensional flow velocity field (Particle Image Velocimetry - PIV), the mean temperature field (Rayleigh thermometry), or the NOx concentration field (Laser Induced Fluorescence - LIF).

**Table 1.** Existing and proposed technical characteristics of COMOTI air testing infrastructure.

| Parameter                  | Existing facilities | Upgraded facilities |
|----------------------------|---------------------|---------------------|
| Mass flow rate             | 0.35 kg/s           | 10 kg/s             |
| Pressure                   | 15 bar              | 50 bar              |
| Temperature                | 150°C               | 800°C               |
| Max. labyrinth seal diameter | 300 mm             | 600 mm              |

A general view of existing and under construction facilities for rotating labyrinth seals characterization is presented in Figure 10.

**Figure 10.** General view of existing and under construction facilities for rotating labyrinth seals characterization Existing (blue), Extended (yellow), Other Comoti’s research facilities (gray)

This research infrastructure will be expanded in the project through the acquisition and commissioning of new independent research and experimentation installations, machines, equipment and instruments, dedicated to large air flow characterization and advanced combustor chamber studies:

- High speed pressure and temperature measurement system, including probes, transducers, dynamic calibration systems, and connection to the test rig central computer;
- High precision air and fuel (liquid and gaseous) flow rate measurement equipment for high temperatures and pressures;
- Upgrade of the existing LASER PIV instantaneous velocity measurement system for tomography measurements in a three-dimensional volume and for high and very high speed velocity flows, including the flow seeding system;
• Upgrade of the LASER PLIF instantaneous free radicals concentrations in turbulent air flow measurement system for tomography measurements in a three-dimensional volume, and temperature calibration by RAMAN spectroscopy;
• Schlieren high speed flow visualization system, high speed video camera and boroscopes for visible and ultraviolet light;
• High frequency hot wire anemometry system for the measurement of instantaneous velocities;
• Infrared thermo-vision system;
• Measurement systems for high and low frequency force and displacement and vibrations;
• High precision, automated, command and control systems for flow direction air and probe positioning in the experimental field;
• High speed, multi-channel data acquisition system;
• Acoustic monitoring and noise damping systems;
• Command and control software for the experimental facility and data analysis software for the analysis of experimental data;

The project is based on the innovative techniques, and makes use also of the latest developments in the field of labyrinth seal testing and flow characterization. Various modern equipment’s and processing methods will be used.

One of the ground-breaking innovations which the infrastructure will be able to measure the radial clearance during testing runs while the rotor (disk + labyrinth seal) is rotating. In this way, the real clearance value during testing could be used in optimizing the mathematical model of the sealing.

Another ground breaking innovation is that by automatically controlling the test vehicle, the testing time will be reduced. Another way to reduce the time is to reduce the number of operations done in order to prepare the test vehicle. The automation of the test bench will ensure constant working parameters and eliminates human factor errors, the testing process being independent of the operator. The degree of automation will be carefully analyzed during the design phase. Optimization of the testing procedures refers here mainly to the sequence of tests, the sequence of changing parameters in such a way to minimize the dead times.

The development and improvement of the research infrastructure in the field of GTE turbines and combustors will boost the present research activities by COMOTI and it will facilitate the development of new fundamental and applied research activities and directions to match the European quality and competence levels in the field of GTE components and bladed machines. These new research themes will enable reaching a higher understanding of the processes and phenomena that take place within a GTE and will support the development and testing, up to a market readiness level, of innovative components and equipment of enhanced scientific and economic value.

4. Conclusions
The INFRASEAL project with its major outcomes (research infrastructures) will be able to describe in full details the capabilities of different seals, which will be built to increase the level of understanding in the seal dynamics behavior and the confidence in the relevant predictive tool. A successful completion of the project will have a significant impact on the labyrinth seal design time and, consequently, cost, as it allows the removal of most of the time consuming control strategies, of research and testing. Furthermore, the proposed concept and approaches will enable a better optimization. The aim of project is to aid at improving the environment control techniques for the aerospace facilities by at least 10% in terms of efficiency, with respect to present efficiency values. This will enable a more efficient design of the LPT, with impact not only economically, but also on the operation.

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