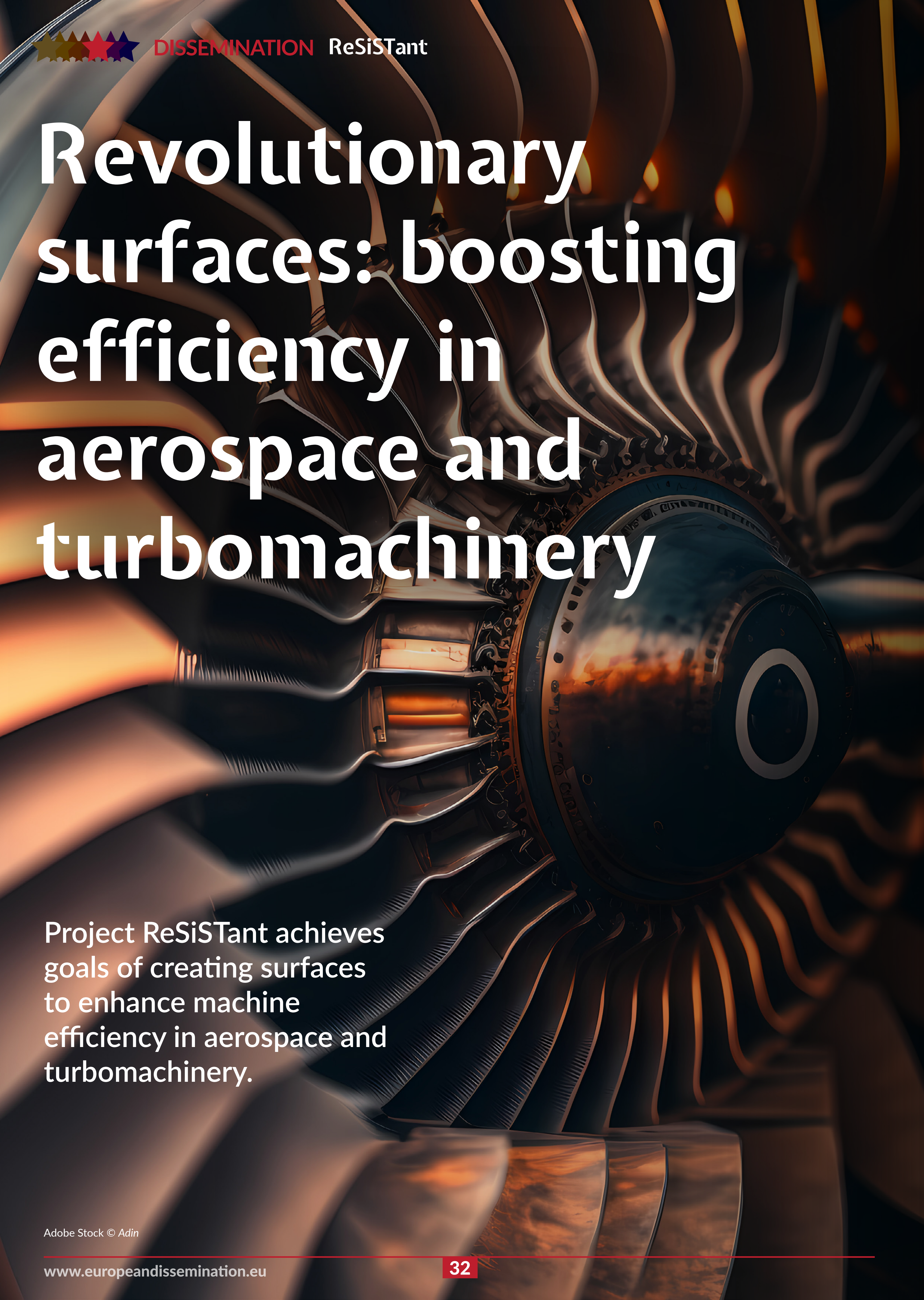


Revolutionary surfaces: boosting efficiency in aerospace and turbomachinery

Project ReSiSTant achieves goals of creating surfaces to enhance machine efficiency in aerospace and turbomachinery.

Adobe Stock © *Adin*

The "ReSiSTant" project—a four-year-long European innovation that began on 1 January 2018—aimed to improve the performance of two industrial pilot lines by using special micro- and nanostructured surfaces to reduce drag. The main goal was to incorporate these newly developed surfaces into aircraft turbofan engines and industrial compressors. The use of these surfaces has the potential to bring about several positive outcomes, such as enhancing efficiency, reducing CO_2 and noise emissions, and eventually having a positive impact on the economy and the environment.

However, despite the proven effectiveness of riblets as passive devices for reducing drag, and the clear understanding of how they work, a comprehensive verification of this capability has not yet been achieved. This is primarily due to the challenges associated with conducting experiments, the lack of suitable numerical models, and the need for appropriate materials. Therefore, to make use of these micro- and nanostructures, special development of durable surface materials for rough conditions was necessary. The plan involved nano functionalisation, which included implementing nanostructures and nanoparticles to enhance resistance in challenging environments.

Figure 3: Test engine installed in an engine test cell.

Riblets consist of tiny streamwise grooved surfaces, which reduce the drag in the turbulent boundary layer by up to 8 per cent. Surface modifications such as riblets are the most promising technology that could be applied without additional external energy or an additional amount of air. The project aimed at developing innovative manufacturing technologies by implementing nanostructures and nanoparticles, and two demonstrator lines to assure them.

The project had ten partners from six countries representing key stakeholders such as industry, research centres and

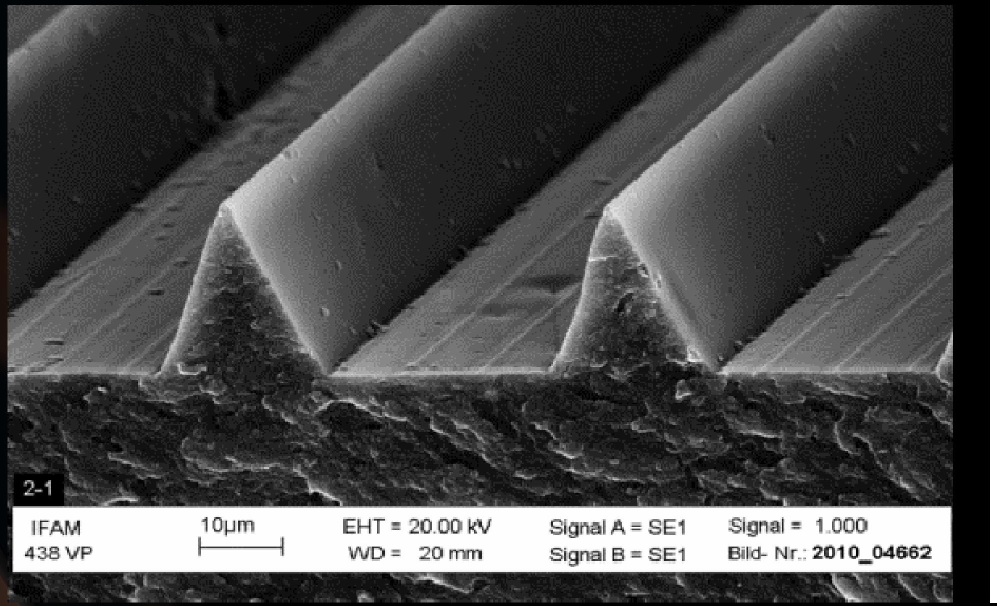


Figure 1: Riblet example.

BIONIC SURFACE TECHNOLOGIES
RINA
IDONIAL CENTRO TECNOLÓGICO
Fraunhofer
GE
MAN
MAN Energy Solutions
Lufthansa Technik
nanto cleantech®
SINGULARITY MATERIALS
RWTH AACHEN UNIVERSITY
TU Graz
Graz University of Technology

Figure 2: Consortium of ReSiSTant project.

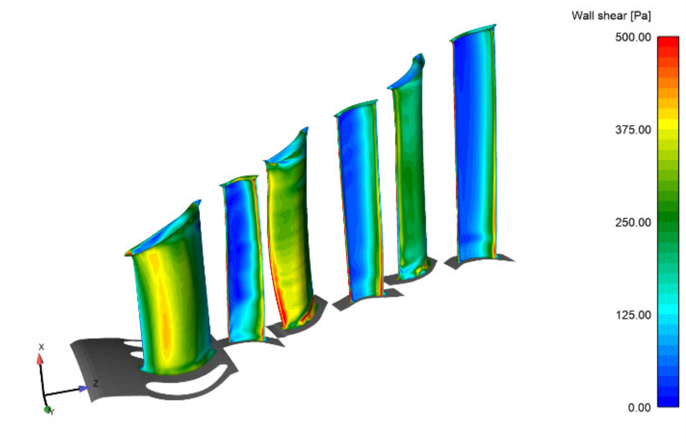


Figure 4: Wall shear stress distribution for DEM 1.

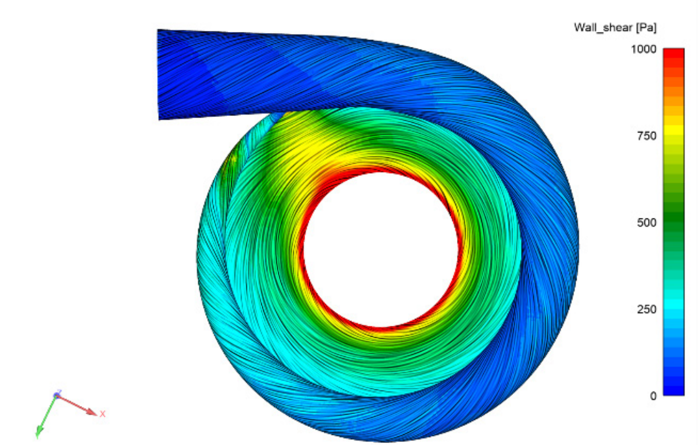


Figure 4: Wall shear stress distribution for DEM 2.

universities. They are bionic surface technologies (Austria, coordinator), RINA (Italy), Fraunhofer-IFAM (Germany), IDONIAL (Spain), General Electric (Germany), Lufthansa Technik (Germany), MAN Energy Solutions (Switzerland), Nanto Cleantech (Israel), RWTH Aachen University (Germany) and Graz University of Technology (Austria).

Dr Andreas Flanschger, coordinator and leader of the ReSiSTant project, received his mechanical engineering and business degree at Graz University of Technology. Flanschger specialises in project management and technical management accounting and, since 2008, has been the co-founder and CEO of bionic surface technologies GmbH (BST). He is part of several different innovative multinational research projects in a managing position.

Throughout the project, the primary focus was on advancing technology in three key areas. Firstly, there was a strong emphasis on showcasing the production of large-scale high ReSiSTant nano- and microstructured surfaces on the two demonstration units. Secondly, the project aimed to integrate various process technologies and steps to demonstrate the complete fabrication chain for the two selected application demonstrators. And finally, significant efforts were made to establish an industrial demonstrator in two distinct fields, specifically aircraft turbofans and industrial compressors.

Computational fluid dynamics (CFD) analysis was conducted, and the mesh was refined for riblet simulations to obtain the distribution of Reynolds numbers, the flow field and the wall shear stress distribution within the test rigs. A precise simulation of the benefit of riblets in a turbofan jet engine and an industrial compressor was carried out, as well as a feasibility study of the material for all demonstrators.

In the case of the industrial pilot of the turbofan demonstrator, CFD simulations show that the first stages of the low-pressure turbine (directly after the combustion chamber) suffer extremely harsh conditions regarding high temperature and wall shear stress (see Figure 4). This has been taken into account in the riblet design (sizes are not represented for confidentiality reasons, but their tiny size makes the application very challenging when coated) and in the material development.

According to the simulations, if the coating thickness is small relative to the passage size, around 1 per cent more isentropic efficiency could be achieved and around 2 per cent more torque on the turbine.

In the case of the industrial pilot of the compressor demonstrator, the diffuser of the compressor suffers similar conditions as the turbine—similar wall shear stress is expected in the compressor's diffuser in comparison with the perviously mentioned turbine under the investigated operaiton conditions (except for the temperature). In this case, the coating was only applied on it due to the accessibility and a smooth coating was developed for that (the riblet effect was studied on the test rig of the RWTH Aachen University). Tests show an increase in efficiency of about 2.5 per cent, which shows the importance of good surface quality on the diffuser part of the compressor. In the test rig, the riblets applied on the volute show an increase in efficiency of of more than 1 per cent depending on the operating conditions.

Figure 6: Riblet application with silicone mould

Previously, different materials were first analysed individually, screening raw materials and coatings for high-temperature riblet coatings. Moreover, the development of materials has been done with the target of achieving the desired dimensions (micrometre scale), and further testing has conducted to optimise the polymeric matrix and validate the process.

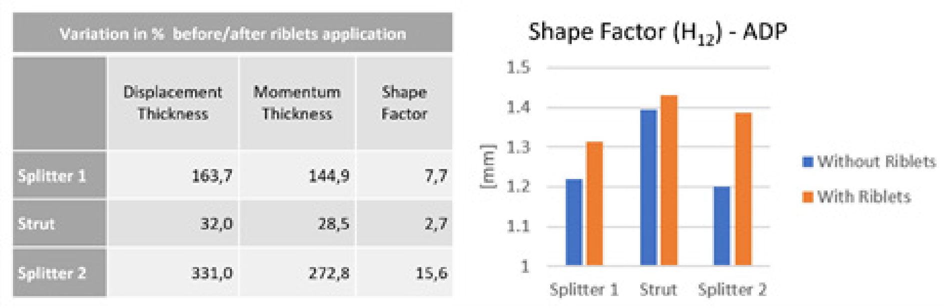
As part of the ReSiSTant project, significant progress was made in the development of riblet coating application. There is a theoretical ideal riblet size for every point of the surface and a real applicable riblet size. To facilitate this coating technology, two new moulds were created, enabling the production of riblets with consistent sizes for specific surfaces. However, a crucial consideration during this process was finding the optimal balance between the manufacturable riblet size and the ideal riblet size for the four machines involved, including two test rigs and two pilot models.

In the case of the turbofan demonstrator,, the design point from both the pilot and test rig was fixed. In the compressor demonstrator, there was more flexibility to adapt the operating point to the riblet size necessities. In the case of Test Rig Two, there were more degrees of freedom (gas, inlet pressure and rotational speed). That is why, in this case, an enormous effort has been made from the simulation side to achieve two different operating points that demand the same riblet size when operating with air and an additional one with helium (application of special interest due to the growing importance of hydrogen in the energy sector). In Pilot two, only the mass flow rate can be adapted, and the dependency of mass flow rate with riblet size has been explained. Moreover, different roughness values have been simulated to gather more knowledge before future test campaigns.

An overall goal of the ReSiSTant project is to produce 'resistant' riblets for the harsh conditions encountered in the pilots after many days of operation. In the test rig case, it is simple to estimate the roughness of the surface. But in the pilot case, the roughness is contingent upon the duration of machine operation. This variability necessitated the calculation of different roughness levels. Roughness increases over time as the machines operate without the protection of nano-coated riblets. The implementation of nano-coated riblets exhibits a prolonged resistance to roughening, resulting in a progressively greater improvement over time when compared to regular surfaces.

Graz University of Technology conducted riblet tests for the ReSiSTant project, utilising a significantly modified subsonic test turbine facility. This facility was

Figure 7: Riblets applied on the airfoils of Pilot 1 at Graz University of Technology.



Variation in % before/after riblets application

	Displacement Thickness	Momentum Thickness	Shape Factor
Splitter 1	163,7	144,9	7,7
Strut	32,0	28,5	2,7
Splitter 2	331,0	272,8	15,6

Figure 8: Riblets were shown to increase the shape factor of the wake of the tested airfoils.

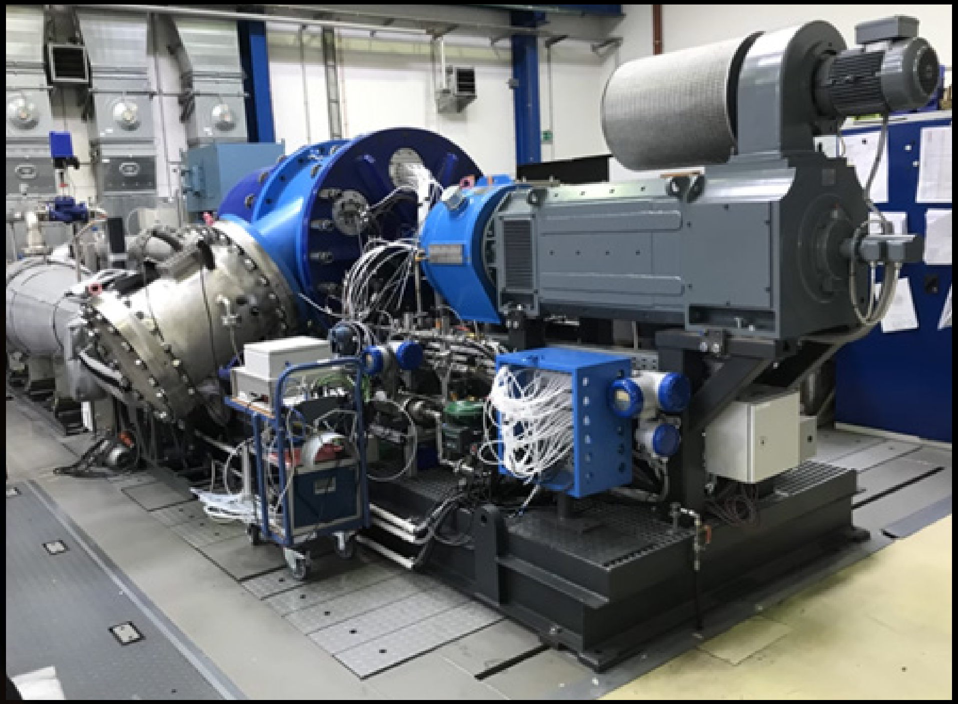


Figure 9: Centrifugal compressor stage test rig at IKDG of RWTH Aachen University.

specifically designed for conducting comprehensive investigations related to aerodynamics, aeroacoustics and aeroelasticity. It can replicate engine-relevant conditions, enabling a wide range of complex measurements to be conducted with precision. Measurements with different aerodynamic probes were performed for a baseline configuration and a configuration with riblets. The results show a lower wall shear stress and a higher shape factor for the riblet configuration. Lower wall shear stress indicates lower friction in the boundary layer of the airfoils. The shape factor is a measure of turbulence intensity in the boundary layer. Riblets aim to reduce friction in the laminar sublayer of a boundary layer. As a result, they can help to improve the efficiency of an aero engine.

In the final evaluation of the compressor demonstrator, the measured results were analysed, and the potential efficiency gain with the nanocoating was estimated using scientific estimations and the data obtained from the tests. At pressure levels higher than 5 bar, the nanocoating can be associated with at least 1 per cent efficiency gain for the entire stage.

Several issues prohibited a more detailed investigation. Since the used compressor is part of an air supply infrastructure it is only equipped with basic instrumentation needed for safe operations, thus detailed measurements, similar to a test rig, were not possible. Furthermore, the surface of the diffusor was heavily corroded, a typical state in turbo machines when operating over longer periods. This corrosion had to be removed before applying the nanocoating to allow adhesion. However, a certain performance improvement can already be achieved by removing the corrosive layer. With the use of a Moody diagram, the two effects—removal of the corrosion and nanocoating—were separated and the efficiency increase from the nanocoating was determined.

Concerning business modelling activities, two main strategies have been identified for the commercialisation of the ReSiSTant project outcomes, namely the nanoriblets and the related technologies behind (nanoriblets design algorithms, nanocoating formulations, nanocoating materials and manufacturing process technology). The first strategy is the establishment of a new company with the specific task of commercialising nanoriblets under an EPC scheme. This seems to be the best idea in order to coordinate all partners' contributions to the selling process. Another possible strategy investigated is the concession of a certain technology to a partner in order to provide a turnkey solution to customers. For example, NCT or LHT could sell nanoriblet coatings, or BST could commercialise optimisation algorithms. IFAM could sell tailored riblets and nanocoating composition solutions, etc. These strategies have been detailed by means of the Osterwalder Business Model Canvas approach without a distinction related to the sector of application of the nano riblet, being the target market the only significant difference.

Figure 10: Riblet application on the volute of the centrifugal compressor, Demonstrator 2.

PROJECT SUMMARY

ReSiSTant targets the optimisation of two industrial pilot lines by using micro and nanostructured surfaces for drag reduction. The objectives are to implement newly developed surfaces into aircraft turbofan engines and industrial compressors. The positive effects of using such surfaces could give benefits in terms of efficiency, CO_2 and noise emission reduction, and a positive economic and ecological impact.

PROJECT PARTNERS

There are ten partners from six countries, representing key stakeholders such as industry, research centres and universities. They are BST (Austria, coordinator), RINA (Italy), Fraunhofer-IFAM (Germany), IDONIAL (Spain), General Electric (Germany), Lufthansa Technik (Germany), MAN Energy Solutions (Switzerland), Nanto Cleantech (Israel), RWTH Aachen University (Germany) and Graz University of Technology (Austria).

PROJECT LEAD PROFILE

Andreas Flanschger received his mechanical engineering and business degree at Graz University of Technology. He specialises in project management and technical management accounting. He has been co-founder and CEO of bionic surface technologies GmbH since 2008. He is part of several different innovative multinational research projects in a managing position.

PROJECT CONTACTS

Dr Andreas Flanschger
Bionic Surface Technologies, Coordinator
Liebenauer Hauptstrasse 2-6;
8041 Graz (Austria)

☎ +43 316 232159
✉ flanschger@bionicsurface.com
🌐 www.bionicsurface.com

FUNDING

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 760941.