Cover Page

Proposal full title: Cooperative Research for Next Generation High Efficiency LP Turbine

Proposal acronym: **COOPERNIK**

Topic addressed (including topic number): ISN-A6 Advanced Improved Efficiency Low Pressure Turbine Unit

Name of the coordinating person: Dorota Kopkowicz (AvioPolska)

List of consortium members(s):

Participant no.	Participant organisation name	Part. Short Name	Organisation Type[1]
1 (Leader)	AVIO Polska Sp. z o.o.	AvioPL	IND
2	Institute of Fluid-Flow Machinery – Polish Academy of Science – Centre for Thermomechanics of Fluid	IMPPAN	RTD
3	Silesian University of Technology – Faculty of Power and Environmental Engineering & Faculty of Materials Engineering and Metallurgy	SUT	RTD
4	Warsaw University of Technology – The Institute of Aeronautics and Applied Mechanics	WUT	RTD
5	Laboratorium Badań Napędów Lotniczych "Polonia Aero" Sp. Zo.o.	PAL	SME

[1] SME (small or medium enterprise), IND (large companies), RTD (research organization)

SUMMARY

COOPERNIK will provide a breakthrough in high efficiency and low noise low pressure turbine for future aero engines.
This breakthrough will be achieved by developing and validating novel technologies for commercial aircraft engines applications and thus provides a key step towards achieving the ACARE environmental goals in terms of emissions.

COOPERNIK will design, manufacture and test some of the critical technologies required to achieve more efficient low pressure turbine for wide body application.
COOPERNIK will also take-up the results of on-going research programs in the field of noise and emissions and will deliver a fully validated, novel technology to enable a 1,5% reduction in fuel burn with respect to 2010 engines and hence contribute to the achievement of the ACARE goals by 2020.

The activities implemented in COOPERNIK will include:

- Development of key technologies for high efficient next generation low pressure turbine
- Validation of technologies through full module low pressure turbine demonstrators

Specific technologies will be developed within COOPERNIK to address and enable solutions on:

- Innovative features for high efficiency light weight LPT blades
- Innovative rotor seal cavities for secondary losses minimization
- High efficiency Active Clearance Control for robust efficiency optimization
- High temperature coatings for high temperature and low weight blades
- Advanced CFD methods for overall efficiency optimization
- Full module experimental validation

COOPERNIK stands on a highly skilled consortium gathering key polish academic excellence together with polish industrial player in the field of turbomachinery, aerodynamics, secondary flows, aero-acoustics, aero-elasticity, materials engineering and advanced design of Low Pressure Turbine system.
The advance and benefits that COOPERNIK will bring to Poland at large in terms of more efficient and environmental-friendly air transport will be disseminated throughout the project to all stakeholders.

Table of Contents

Abbreviations used in this document

ACARE	Advisory Council for Aviation Research and Innovation in Europe
ACC	Active Clearance Control
BPR	By-Pass-Ratio
CDR	Critical Design Review
CFD	Computational Fluid Dynamic
CVD	Chemical Vapour Deposition
EBM	Electron Beam Melting
EIMG	Engine Industry Management Group
EU	European Community
FEM	Finite Element Method
FP	Framework Program
GPU	Graphical Processing Unit
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
IPR	Intellectual Property Rights
LDA	Laser Doppler Anemometry
LPT	Low Pressure Turbine
OPR	Overall Pressure Ratio
PDR	Preliminary Design Review
RANS	Reynolds Averaged Navier-Stokes
RE	Reactive Elements
SFC	Specific Fuel Consumption
SME	Small Medium Enterprise
TRL	Technology Readiness Level
TRR	Test Readiness Review
URANS	Unsteady Reynolds Averaged Navier-Stokes
VPA	Vapour Phase Aluminizing
WP	Work Package

Proposal

1. Scientific and Technical quality

1.1 Rationale

Environmental protection has been and is a chief driver in the development of air vehicles and new transport infrastructure. Added to continuously improving fuel efficiency and their cost impact on the aviation sector, future aero engines will need to be more efficient and contribute to the reduction on environmental impact of air transportation. They must reach some standards of performance by reducing emissions and creating some savings on operation costs.
Aviation world contributes to the climatic change, currently emitting about 2% of man product carbon dioxide emissions. Consequently, growth of aeronautical sector does not comply to capitalize positive effects of new "green" technologies introduction on recent aircraft versions.

EU and the International Civil Aviation Organization (ICAO) are setting very ambitious targets for greenhouses gas reductions. In particular significant technological improvements will also be required to drastically reduce aviation's impact on the environment. By 2050 Europe should have developed technologies allowing a 75% reduction in CO2 emissions per passenger kilometre and a 90% reduction in NOx emissions (compared to the performances of aircraft entering into service in 2000).
Similarly, the International Air Transport Association (IATA) has declared a target to stabilize net CO2 emissions (carbon neutral growth) by 2020 with a long-term goals to reduce aviation net carbon emissions by 50% in 2050 compared to 2005 level.
Therefore Air Transport is an important sector with good business growth opportunity but working in an increasing competitive market and with complex technological challenges to fulfil environmental goals.
Therefore innovation is the major competitive parameter when offering environmentally friendly and operationally efficient products to growing world markets under fierce and increasing competition from existing powers and new entrants.
This is particularly true for the propulsion systems, being the main aircraft system with primary effect on fuel consumption, emissions, noise and life cycle costs.
This sector has put a lot of effort during the last decade to create a vision and strategic research agenda through ACARE, the Advisory Council for Aviation Research and Innovation in Europe.

EIMG consortium has launched since several years some initiatives to develop future engines in the frame of the European Committee research programmes. Within different projects such as Clean Sky JTI Sustainable and Green Engine, DREAM, VITAL, NEWAC or LEMCOTEC, EIMG is ensuring the development of innovative technologies in order to further reduce the fuel burn, emissions and noise.
Avio Group involvement started back in early nineties with the first participation to EU RTD programs since Framework Program 5 (FP5) and it has been increasing in the years through FP6, and FP7 (comprising the important involvement within Clean Sky SAGE program). Moreover activities are presently on-going in view of the preparation of the new EU Framework Program for Research and Innovation recently named Common Strategic Framework Horizon 2020.
To gain access to European programs it is required the support of national programs to develop critical technologies, to mature innovation and to reinforce the SME's and Universities network. In this context, programs like COOPERNIK are great boosters.
To reach those targets, COOPERNIK stands on a highly skilled consortium gathering key polish academic excellence together with polish industrial player in the field of turbomachinery, aerodynamics, secondary flows, aero-acoustics, aero-elasticity, materials engineering and advanced design of Low Pressure Turbine system.

AvioPolska trusts the importance of research and innovation for its competitiveness and is committed to this roadmap moving together with selected polish partners towards the development of green technologies for both short- and medium-term conventional engine and long-term conventional/radical engine.

Objectives and results

The global targets of the COOPERNIK project are:

- To increase the implemented innovative solutions through technology demonstrators,
- To strengthen the cooperation between the polish industry and the leading research institutions,
- To design and manufacture high-technology next generation products, which may enhance the competitiveness of the Polish economy in terms of high-tech products for the aeronautic sector.

In particular, developing and validating innovative design solutions for Low Pressure Turbines should increase the aerodynamic efficiency of the LPT module.

The activities implemented in COOPERNIK include:

- Development of key technologies for high efficient low pressure turbine,
- Develop demonstrator and full module test of a next generation of LPT.

COOPERNIK is complementary to past and existing EU and national projects in the field. It will deal with next-generation Low Pressure Turbines core technologies necessary to support future engine specifications and it will enable future integrated development for Ultra-High OPR and BPR engines with high efficiency and ultra-safe sub-systems.
Specific technologies will be developed within COOPERNIK to address and enable solutions on:

- Advanced whole LPT modelling for overall efficiency optimization
- High efficiency Active Clearance Control for robust efficiency optimization
- Innovative rotor seal cavities for secondary losses minimization
- Innovative features for high efficiency light weight and safe LPT blades
- High temperature coatings for high temperature and low weight blades
- Full module experimental validation

This technological growth is absolutely claimed since Low Pressure Turbine becomes more and more important with Engine By-Pass-Ratio (BPR) increasing trends (more than 20% of engine weight and increasing impact of turbine efficiency on engine SFC that becomes 1: 1) and hence next generation of aircrafts will require more and more challenging LPT design.
In AvioPolska perspective, the new design approach evolution has to be applicable to the most likely future engine configurations like:

- Traditional High-By-pass turbofans for wide body aircrafts (low rotational speed with high stage loadings). Highly efficient LPT coupled with low weight and low noise will be requested together with improved maintainability that is based on an ultra-safe mechanical design.
- Geared Engine Architecture: in this case interaction effects between different disciplines become more and more complex and need to be put under control otherwise performance or mechanical safety could suffer strong penalties and limitations in front of engine requirements.

COOPERNIK is shaped to develop, validate and integrate specific key Low Pressure Turbine technologies required for ultra-high BPR engines up to technology readiness level of 5, affording a valuable step to ensure technical compatibility of new generation of high-efficiency low-weight low-noise Low Pressure Turbine systems.

Consequently COOPERNIK objectives will be:
1- Bring all those mandatory enabling sub-systems technologies up to TRL 5;

2- Provide an additional benefit in emissions leading up to 1,5% reduction in fuel burn related to 2010 engines, for the most favourable engine/aircraft application and taking in account all past or on-going R&T programs. This objective potentially overshoots ACARE goal.

COOPERNIK will contribute to keep the Polish network in a leadership position regarding the development, integration and validation of highly efficient and safe low pressure turbines for the next decades aero-engines.

1.2 Progress beyond the State of the Art

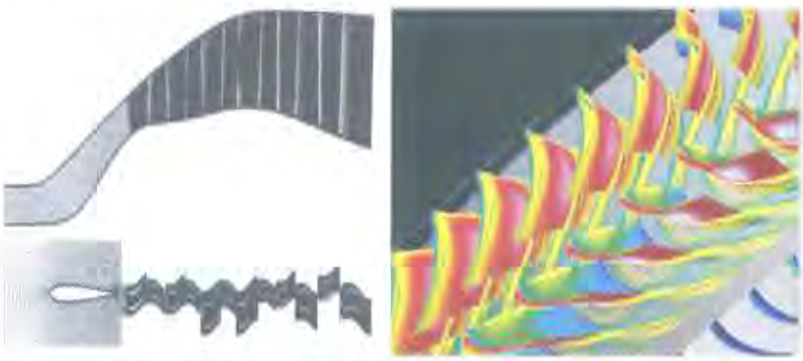
Modern aero-engine turbines have to be designed and optimized with respect to several environmental targets: they have to provide high efficiencies for low fuel burn, and thus low CO2 emissions, and low noise emission.
There is a significant effort aimed toward improving LP turbine efficiency. This is because of the large effect that the efficiency of the LP turbine has on the SFC in comparison to the other modules in the engine. Low pressure turbines already operate at efficiencies well above 90% which makes the challenge of reducing the losses even more difficult.
In the scope of high-efficiency LPT architecture any source of performance loss has to be investigated and minimized.
Those sources can be identified in following main areas:

- Not optimized flow path profiles boundary layers and parasite flows.
- High secondary flows necessary for components cooling and thermal control
- High level of flow path clearances between rotating and stationary parts.

Moreover, the weight of the LP turbine represents over 20% of the engine weight. In order to reduce weight without penalizing the efficiency, the number of airfoils has been reduced in recent years as a result of increases aerodynamic airfoil load. It is known, that depending on the boundary conditions of the airfoil row an optimum airfoil loading exists. Beyond this airfoil load the aerodynamic losses grow and efficiency is impaired. In terms of the design of an LP turbine it is absolutely necessary to be able to accurately predict the performance influence in order to trade this with the weight and cost savings.

1.2.1 Whole LPT modeling

In recent decades CFD capability has greatly increased in terms of time consumption, flexibility, modelling and representation of physics.
In the turbomachinery field, including both aeronautical compressors and turbines, this powerful virtual tool has been widely used mainly for stator and rotor airfoils optimization: the so called 3D design concept has been developed.



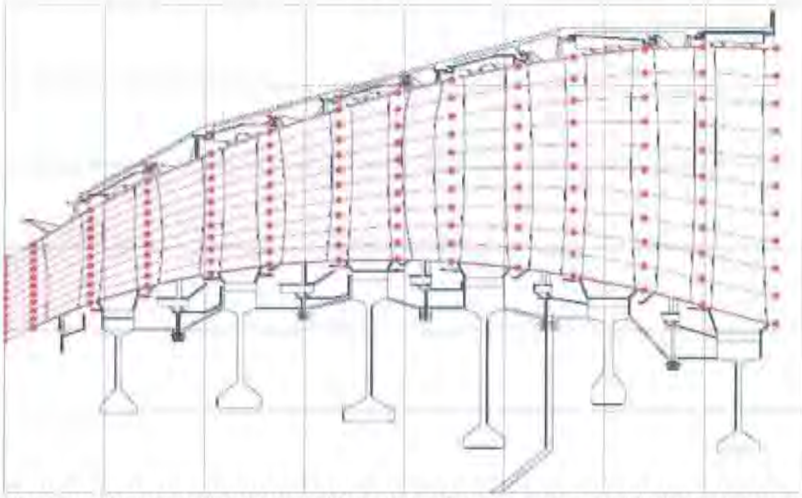
Ideal flow path and airfoils studies and optimization

This is the present state of art. Beyond this limit, we need to consider the whole module architecture.

Further state-of-art aeronautic Low Pressure Turbines (LPT's) are presently characterized by high quality standards thus offering very narrow margins of improvements. As a consequence, for next generation engines, any source of performance loss has to be investigated and minimized in the scope of achieving high-efficiency LPT.
The key sources can be identified in following main areas:

- inter-stage sealing cavities and their interaction with main gas path flow;
- tip clearance zones and their interaction with main gas path flow.

Unsteady effects have to be considered too for a detailed evaluation of the turbine performance to be as closest as possible to engine real operative conditions. This is a strategic issue that can be addressed to significantly improve the LPT simulation and consequently drive turbine design choices focused to reduce the engine fuel burn consumption.



Real flow path investigation with rotor clearances and inter-stage sealing

This part of the planned research is expected firstly to produce important stand-alone results since it can lead to identify new LPT architectures, potentially able to provide significant efficiency improvements in line with targets imposed by the international market. Secondly to highlight and explain complex phenomena occurring during cold flow turbine module testing in Laboratorium Badań Napędów Lotniczych "Polonia Aero" Sp. Zo.o. Plant.

Another important research item is aimed to organize the experimental turbine research in a new way by introducing a scientific rationale in topics like instrumentation and its location selection (driven by CFD analysis), minimum and optimal test matrix definition (so to minimize testing time and costs for assigned test objectives) and quick test data post-processing development that should provide a first outlook on under-testing turbine behaviour.
As a second step in experimental data comprehension, the developed CFD tools and procedures will be used again to highlight detailed phenomena allowing discovering the reasons of specific experimental positive or negative behaviours.
This development will be fundamental for the Laboratorium Badań Napędów Lotniczych "Polonia Aero" Sp. Zo.o. experimental activities devoted to LPT modules technology assessment and performance verification.

1.2.2 High Efficiency Turbine Case Cooling System

Radial clearances control in LP turbines is done by working on the temperature level of static components (casing). Metal temperatures which are able to guarantee the desired casing deformation value, are obtained by properly cooling, at each mission point, the external surface of the casing with impinging jets using the cold air extracted downstream from the fan stages. This air is fed through a network of tubes / channels (feeding pipes and impinging pipes) that cover the

external part of the case. The technical requirements of an Active Clearance Control system are mainly based on cooling efficiency (lower amount of air or faster response) and total weight. In order to optimize those parameters, geometries of both the ACC and the case will be reviewed as well as ACC material and number of ACC components. Design of an ACC system also needs to take into account that the impinging tube (and so cooling air) are heated by external case radiation, and that the cooling effects must be uniform all around the case. Those topics lead to the need for a complex network of feeding pipes.
Objective of this task is to identify, develop and validate an active cooling system technology for turbine casing able to support the air consumption reduction, applying blowing through the fin directly into the clearance, by draining air from the stagnation zone on the blade leading edge next to the shroud. Goal of the task will be to demonstrate a potential cooling air reduction of 25% with respect to standard Active Clearance Control System ("ACC" system).

1.2.3 Innovative rotor seal cavities

The optimization of a Low Pressure Turbine performances needs to be able to minimize the clearances between static and rotating parts, in order to avoid the by-pass flows around turbine blades and vanes. One of the most important areas for controlling the by-pass flow is the internal seal cavity. The sealing system at the hub of the vanes has in fact as main objective to reduce the flow by-passing the vane itself. The standard solution for this sealing system consists in a labyrinth seal with honeycomb structure as abradable material. Many activities have been carried out in the past in optimizing the blade knifes shapes in order to increase the sealing performances, but no detailed studies are known on the optimization of the seal capabilities working both on knifes and honeycomb cells optimization.

This is mainly due to honeycomb manufacturing capabilities limitation. With the introduction of innovative realization methods, based on the powders sintering, the degrees of freedom of the designer can be highly increased.

The objective is to identify the best structures that can be applied to a seal cavity labyrinth seal in order to increase the sealing performances.

New cavities architectures will be taken into account considering also different sealing positions and its integration with vanes and blades. The goal is to identify an high efficiency sealing system to be included in the cold flow rig for TRL4 achievement.

1.2.4 Next Generation LPT Blades

Coatings

The majority of gas turbines in current service relies upon the use of conventional nickel aluminide diffusion coatings to protect superalloy components from both oxidation and hot corrosion. However, in more extreme environments, predicted turbine blade lives are not being achieved. This breakdown of the protective coating can result in severe metal loss from the blade alloy. A possible solution is to develop improved coating such as Platinum Aluminide, however this solution is highly costly, and being a patented process, currently available only as outsourcing.

The aim of this task is to develop an high efficiency diffusive coating for protection against oxidation:

- Alternative to platinum-aluminide coating (PtAl) for hotter stages of LPT
- With improved performances with respect to current, state-of-the art Vapour Phase Aluminizing (VPA) for colder stages of LPT.

Two innovative coatings will be developed in the frame of this project:

- A diffusive aluminide coating, doped with Reactive Elements (RE), such as Hafnium or Zirconium.

- A coating consisting in galvanic deposition of a (Pt,Pd) layer + VPA or CVD. Pd is cheaper than Platinum and its specific weight is nearly the half.

These innovative coatings are expected to have intermediate oxidation resistance properties between Platinum aluminide and the currently used Low Activity, above pack aluminizing.
The use of Al+RE can increase temperature capability of the parts, and therefore thermal efficiency of the LPT.

This task aims also to become a chance for a process improvement, passing from the currently used process, Vapour Phase Aluminizing (VPA), in which the parts are put on trays, above the reactive (activator + donor), so the surface of the parts are not be contaminated by contact with the powder, to the more advanced Chemical Vapour Deposition (CVD) process.
During CVD, the coating is vaporized outside the coating chamber by reacting donor material with halide forming gasses, controlling the rate of deposition by adjusting the temperature and gas flow rates over or through the work piece.

Gamma titanium aluminides (and aluminides in general) should form a continuous Al_2O_3 (α-Alumina) scale in order to protect themselves from oxidation.
Alumina scales, by virtue of their extremely slow, parabolic rate of growth, are protective at temperatures beyond 1200°C. Unfortunately, during the oxidation of gamma alloys in air, an intermixed Al_2O_3-TiO_2 scale rather than a continuous Al_2O_3 scale is formed. Intermixed Al_2O_3/TiO_2 scales are generally protective only to about 750-800°C. They are less protective than continuous Al_2O_3 scales because TiO_2 has a much higher rate of growth than Al_2O_3. Therefore, coatings have to be developed that form and maintain protective alumina scales over their entire anticipated lifetime.

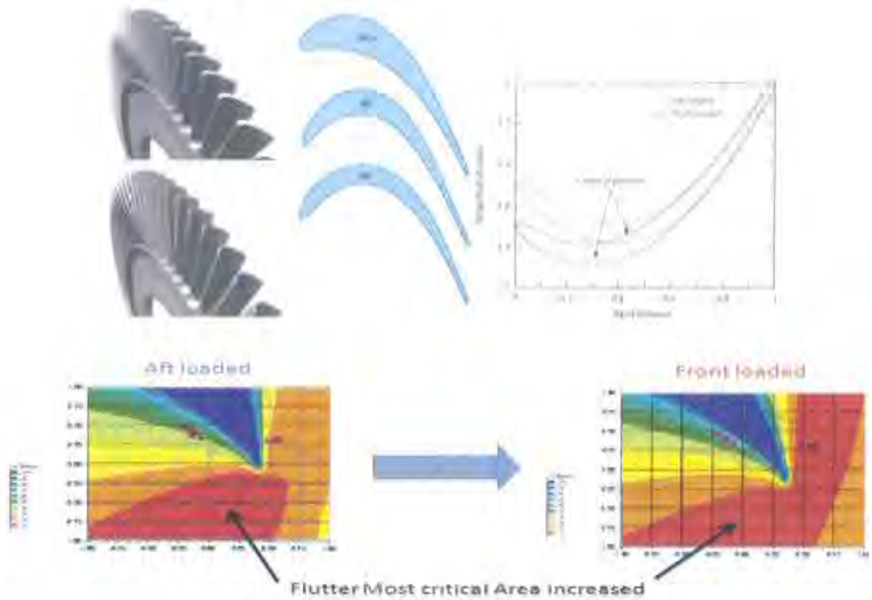
AvioGroup is producing its TiAl components by additive manufacturing, one of the promising technologies to meet the demands for reduction of time and cost in manufacturing. The Electron Beam Melting (EBM) process is an additive manufacturing process that fabricates metallic components – layer by layer – directly from 3-D-CAD data.
The EBM process enables a single component to combine the benefits of high geometrical freedom and functional integration with suitable mechanical properties.

In order to increase the oxidation resistance of TiAl alloy to 850-900°C base technologies for heat-resistant coatings will be developed. The process will be conducted at temperature of 750-900°C. Technology will be based on pack cementation method and diffusion deposition (VPA)

Advanced Blade Design

In next generation engine design, where the driving forces are improving performance, reducing environmental impact, increasing reliability, lowering weight and reducing cost-effective manufacturing, the challenge will be to find the best trade-off between the conflicting aerodynamic and structural demands. Increasingly thinner, lighter, but more loaded and front-loaded blades substantially raise the vulnerability towards flow induced vibrations such as forced response or flutter, leading to a high damage potential. Vibration-related fatigue failures have been, and remain, a major concern for turbo machine manufactures. The correct prediction of the unsteady forces for these aspects is a key to design. In addition, the development of technologies aimed to reduce and control the vibration amplitudes is becoming even more crucial for future turbines.

Several design features are commonly used by LPT manufactures to reduce flutter or vibration attitude, but with some costs in terms of aerodynamic efficiency, manufacturing and weight. Advanced design capabilities and tools are essential for efficiently and promptly manage flutter or resonance problems occurring since the earliest design phase. The improvement of these skills lead to increase considerably the aeroelastic design space opportunities with benefits in terms of increased LPT aero-performance, decreased development cost, reduced weight and consequence manufacturing costs, and the ability to efficiently fix problems occurring on engines at service.



Profile evolutions along the years

1.3 Scientific and Technology methodology and work plan

1.3.1 Overall strategy of the work plan

The COOPERNIK work plan has been organized in five Work Packages:

- **WP1 - Integrated Technology Demonstrator**

WP1 will provide an overall consistency of LPT module and technology specifications and requirements, will monitor and evaluate the technology progress status at LPT system level, through experimental full-module validation tests and will assess the final achievements against the COOPERNIK objectives and ACARE targets and SRIA roadmap.
Throughout COOPERNIK strenuous efforts will be made to mature the technologies under investigation to higher TRL. Therefore technologies will be integrated in large scale ground test beds to validate the technologies at a sub-system level.

- **WP2 - Advanced CFD for Whole LPT modelling**

WP2 will contribute to improve LPT modules performance through the development of a complete virtual simulation framework for the low pressure turbine module (main gas path coupled with Secondary Air System area) by executing trade-off investigations acting on seal geometries, minimizing tip clearance losses and interaction aspects and support experimental campaigns by developing advanced instrumentation strategy and Post-processing Data Reduction System

- **WP3 - High Efficiency Turbine Case Cooling System**

WP3 will identify, develop and validate an active cooling system technology for turbine casing able to support the air consumption reduction. Based on existing impinging solutions a wide range of different geometries of impinging jets and surfaces will be numerically evaluated and experimentally validated. Also different techniques will be taken into consideration and compared with standard one as clearance control effectiveness. Goal of the workpackage will be to demonstrate a potential cooling air reduction of 25% with respect to standard Active Clearance Control System ("ACC" system).

- **WP4 - Innovative rotor seal cavities**

WP4 will identify the best structures that can be applied to a seal cavity labyrinth in order to increase the sealing performances. The work will be performed numerically through CFD approach and experimentally with the static validation of the best identified solutions. AvioPolska will evaluate the impact of the introduction of those technologies on a full-scale low pressure turbine module.

- **WP5 - Next Generation LPT Blades**

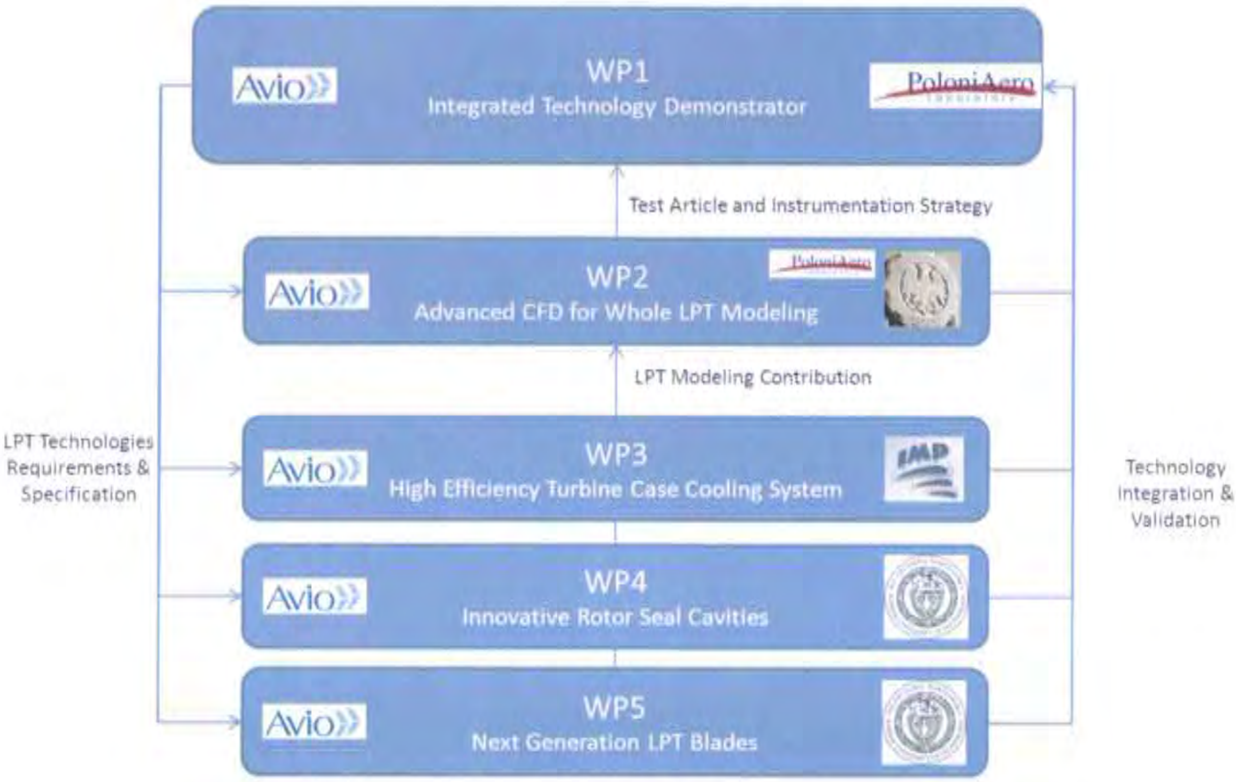
WP5 will be focused to improve LPT modules performance through development of High efficiency oxidation resistant coating for Ni-based superalloys and light weight γ-TiAl alloy and ultra-low vibration technologies for light and safe LPT.

1.3.2 Work plan timing

WP	TASK	Year 1	Year 2	Year 3	Year 4	Year 5
WP1 INTEGRATED TECHNOLOGY DEMONSTRATOR	WP COORDINATION AND TECHNICAL RISK ASSESSMENT					
	LPT TECHNOLOGIES REQUIREMENTS & SPECIFICATION					
	LPT BASELINE TECHNOLOGIES EXPERIMENTAL VALIDATION					
	LPT TECHNOLOGY INTEGRATION					
	LPT TECHNOLOGY ASSESSMENT					
WP 2 ADVANCED CFD FOR WHOLE LPT MODELLING	VIRTUAL MODELLING (BASICS)					
	VIRTUAL MODELLING (DETAILS)					
	SEAL CAVITIES OPTIMIZATION					
	COLD FLOW PRE-TEST SUPPORT					
	COLD FLOW POST-TEST SUPPORT					

WP	TASK	Year 1	Year 2	Year 3	Year 4	Year 5
WP3 HIGH EFFICIENCY ACC	REQ. & CFD VALIDATION					
	HIGH ROUGHNESS SURFACES					
	ACC OPTIMIZATION					
	UNSTEADY ACC					
WP 4 INNOVATIVE ROTOR SEAL CAVITIES	SEAL NUMERICAL OPTIMIZATION					
	SEAL EXPERIMENTAL CHARACTERIZATION					
	TURBINE MODULE FULL SEAL OPTIMIZATION					

WP	TASK		Year 1	Year 2	Year 3	Year 4	Year 5
WP5 NEXT GEN LPT BLADES	COATING	REQUIREMENTS					
		ASSESSMENT VPA PROCESS					
		VPA+RE					
		ALUMINIZING BY CVD METHOD					
		ALUMINIZING PROCESS ON TiAl					
		INDUSTRIAL INSTALLATION CONCEPTION FOR CVD PROCESS					
		TRANSFER TO COMPONENT					
		COST-BENEFIT, INDUSTRIAL AND ENVIRONMENTAL ANALYSIS					
	LOW VIBRATION TECHN	INTERLOCKED BLADED-DISK DESIGN					
		PRELIMINARY DESIGN AND ASSESSMENT					
		TEST ARTICLES & RIG ADAPTATION					
		TEST ARTICLES & RIG HARDWARE					
		COLDFLOW TEST					
		FINAL ASSESSMENT					



COOPERNIK Pert diagram

1.3.3 Work Package List

Work package No[1]	Work package title	Type of activity[2]	Lead participant No[3]	Lead participant short name	Person-months[4]	Start month[5]	End month[5]
1	Integrated Technology Demonstrator	RTD	1	AvioPL	420	1	60
2	Advanced CFD for Whole LPT modelling	RTD	1	AvioPL	170	1	48
3	High Efficiency Turbine Case Cooling System	RTD	1	AvioPL	189	1	36
4	Innovative rotor seal cavities	RTD	1	AvioPL	131	1	48
5	Next Generation LPT Blades	RTD	1	AvioPL	258	1	60
				TOTAL	1.168		

1.3.4 List of Deliverables

Table 2: Deliverables List

Del. no.[6]	Deliverable name	WP no.	Nature[7]	Delivery date[8]	Lead Participant short name
D1.1	First version of LPT technology requirements and specification	WP1	R	6	AvioPL
D1.2	Annual report on Technology Development Plan	WP1	R	12	AvioPL
D1.3	First test campaign specifications	WP1	R	18	AvioPL
D1.4	First test campaign report	WP1	R	26	PAL
D1.5	Second test campaign specifications	WP1	R	32	AvioPL/PAL

1 Work package number: WP 1 – WP n.

2 Please indicate one activity per work package:

RTD = Research and technological development (badania przemysłowe), DEM = Demonstration, if applicable in this call including any activities to prepare for the dissemination and/or exploitation of project results, and coordination activities (prace rozwojowe)

3 Number of the participant leading the work in this work package.

4 The total number of person-months allocated to each work package.

5 Measured in months from the project start date (month 1).

6 Deliverable numbers in order of delivery dates. Please use the numbering convention <WP number>.<number of deliverable within that WP>. For example, deliverable 4.2 would be the second deliverable from work package 4.

7 Please indicate the nature of the deliverable using one of the following codes:
R = Report, **D** = Demonstrator, **O** = Other

8 Measured in months from the project start date (month 1).

D1.6	Second test campaign report	WP1	D	40	PAL
D1.7	Final report on technology assessment	WP1	R	50	AvioPL/PAL
D1.8	Periodic Report	WP1	R	12,24,36, 48	AvioPL
D1.9	Final Report	WP1	R	60	AvioPL
D2.1	Report on the commercial SW validation by available benchmark cases provided by AvioPolska.	WP2	R	12	WUT
D2.2	Report on cross-validation of in-house code with commercial one for several test cases.	WP2	R	18	WUT
D2.3	Report on advanced instrumentation strategy and test matrix selection for turbines test case(s) provided by AvioPolska.	WP2	R	18	WUT
D2.4	Report on algorithms for prediction of wake-induced transition basing on the RANS technique.	WP2	R	24	WUT
D2.5	Report describing the implementation of capabilities for full virtual simulation of low-pressure turbine modules.	WP2	R	24	WUT/AvioPL
D2.6	Report on the fast Post-Processing Data-Reduction-System.	WP2	R	24	WUT/AvioPL
D2.7	Report on full validation of the virtual simulation of the low pressure turbine module using data provided by partners (available ones) and AvioPolska.	WP2	R	30	WUT/AvioPL
D2.8	Report on multi-objective optimization method and its implementation within the CFD simulation environment.	WP2	R	30	WUT
D2.9	Report on the performance of the proposed instrumentation strategy verified on experiments performed by WUT.	WP2	R	30	WUT
D2.10	Report on the benchmark results for the Post Processing Data Reduction System.	WP2	R	36	WUT
D2.11	Report on parametric approach and resulting optimized geometries obtained by full virtual CFD simulation of the low pressure turbine module.	WP2	R	42	WUT/AvioPL
D2.12	Periodic Report	WP2	R	12,24,36, 48	AvioPL
D2.13	Final Report	WP2	R	60	AvioPL
D3.1	Requirement of ACC system	WP3	R	3	AvioPL
D3.2	Validation of ACC methodology	WP3	R	6	IMPPAN
D3.3	Report and measurement data: End of test on high roughness surfaces	WP3	R	8	IMPPAN
D3.4	Report final results on enhancement techniques	WP3	R	13	IMPPAN
D3.5	Report and experimental data: completion	WP3	R	16	IMPPAN

	of test campaign				
D3.6	Report and experimental data: testing of optimized solution	WP3	R	22	IMPPAN
D3.7	Engine assessment with new technology	WP3	R	24	AvioPL
D3.8	Feasibility study on unsteadiness impingement	WP3	R	14	IMPPAN
D3.9	Conclusion of numerical activity in unsteadiness	WP3	R	25	IMPPAN
D3.10	Report and experimental data. End of experiment on unsteadiness	WP3	R	25	IMPPAN
D3.11	Report: flow curtain technique performance applied to tip clearance control (CFD)	WP3	R	25	IMPPAN
D3.12	Experimental results on air curtain techniques	WP3	R	36	IMPPAN
D3.13	Periodic Report	WP3	R	12,24,36, 48	AvioPL
D3.14	Final Report	WP3	R	60	AvioPL
D4.1	Standard honeycomb performance evaluated through CFD approach	WP 4	R	6	SUT
D4.2	High Performance Sealing concept identification	WP 4	R	17	SUT
D4.3	Sealing Optimization (CFD) – List of final geometries to be realized and tested	WP 4	R	24	SUT
D4.4	LPT performances with new geometries	WP 4	R	24	AvioPL
D4.5	Report and measurement data: Performance test results on standard geometry	WP 4	R/O	15	SUT
D4.6	Report and measurement data: Performance test results on innovative geometry	WP 4	R/O	24	SUT
D4.7	Turbine Seal Cavity Redesign with innovative solution (CFD and proposed geometry)	WP 4	R	34	SUT
D4.8	Periodic Report	WP4	R	12,24,36, 48	AvioPL
D4.9	Final Report	WP4	R	60	AvioPL
D5.1	Determination of requirements for novel high temperature coatings	WP 5	O	4	AvioPL
D5.2	Assessment of the efficiency of aluminizing by VPA	WP 5	R	20	AvioPL
D5.3	Modification of aluminide coating produced by VPA with reactive elements	WP5	R	36	AvioPL
D5.4	Development of aluminide coatings deposited by CVD and modification of aluminide coatings using RE and PtPd	WP 5	R	48	AvioPL
D5.5	Diffusion aluminide coating produced by	WP 5	R	48	AvioPL

	pack cementation method and by VPA method on gamma titanium aluminide alloy				
D5.6	Conception of industrial installation for CVD process.	WP 5	R	60	AvioPL
D5.7	Transfer to component of the most promising coating and process	WP 5	D	60	AvioPL
D5.8	Cost-benefit analysis, industrial and environmental analysis.	WP5	R	60	AvioPL
D5.9	Preliminary Interlocked bladed-disk design	WP5	R	6	AvioPL
D5.10	Preliminary design and assessment of the low vibration technology	WP5	R	18	AvioPL
D5.11	Test Articles and Rig Adaptation Detailed Design	WP5	R	24	AvioPL
D5.12	Test Article and Rig hardware procurement	WP5	R	30	AvioPL
D5.13	Coldflow test	WP5	R	36	AvioPL
D5.14	Final Assessment	WP5	R	42	AvioPL
D5.15	Periodic Report	WP5	R	12,24,36, 48	AvioPL
D5.16	Final Report	WP5	R	60	AvioPL

1.3.5 List of Milestones

Table 3: Milestones List

Milestone number	Milestone name	Work package(s) involved	Expected date [1]	Means of verification[2]
MS1.1	First test campaign specifications	WP 1	18	Specification published
MS1.2	Second test campaign specifications	WP 1	32	Specification published
MS1.3	Annual review	WP1	14. 26, 38, 50	Review report available
MS1.4	Final review	WP1	60	Review report available
MS2.1	Avio turbine test case (main gas path)	WP 2	4	Data output delivered
MS2.2	Avio turbine selected for experiments to be instrumented	WP 2	8	Data output delivered
MS2.3	Avio low pressure turbine data for full simulation validation	WP 2	24	Data output delivered
MS2.4	Full virtual CFD simulation of the low pressure turbine module implemented and available	WP 2	24	Capabilities acquired and first results available

[1] Measured in months from the project start date (month 1).

[2] Show how you will confirm that the milestone has been attained. Refer to indicators if appropriate. For example: a laboratory prototype completed and running flawlessly; software released and validated by a user group; field survey complete and data quality validated.

MS2.5	Optimization results (revision of sealing, clearances etc.) obtained by the full virtual CFD simulation	WP 2	42	Data output available
MS2.6	Advanced instrumentation methodology	WP 2	30	Practices available
MS2.7	Fast Data Reduction system available for turbine experimental investigation	WP 2	30	Data output available
MS2.8	Annual review	WP2	14. 26, 38, 50	Review report available
MS2.9	Final review	WP2	60	Review report available
MS3.1	Availability of test section for basic configuration	WP 3	4	Data output available
MS3.2	Availability of new test section	WP 3	10	Data output available
MS3.3	Decision point on first solution to be investigated	WP 3	11	Data output available
MS3.4	Selection of optimized solution	WP 3	19	Data output available
MS3.5	Test calibration & preliminary experiment	WP 3	19	Data output available
MS3.6	Availability of experimental facility for unsteadiness effects	WP 3	29	Facility available
MS3.7	Availability of high roughness plates	WP 3	5	Plates available
MS4.8	Annual review	WP3	14. 26, 38, 50	Review report available
MS4.9	Final review	WP3	60	Review report available
MS4.1	Experimental apparatus set up	WP 4	12	Apparatus available
MS4.2	Availability of first honeycomb prototype (standard geometry)	WP 4	12	Prototype available
MS4.3	Availability of innovative honeycomb prototypes (innovative geometry)	WP 4	20	Prototype available
MS4.4	Annual review	WP4	14. 26, 38, 50	Review report available
MS4.5	Final review	WP4	60	Review report available
MS5.1	Requirements for novel antioxidation coatings	WP 5	4	Coatings available
MS5.2	Characterization of a diffusion aluminide coating produced by VPA method	WP 5	20	1- thickness, 2- microstructure, 3- isothermal oxidation tests, 4- cyclic oxidation tests, 5- mechanical tests.
MS5.3	Diffusion aluminide coating produced by VPA modified by reactive elements and definition of a quality control method.	WP5	36	1-thickness, 2-microstructure, 3-isothermal oxidation tests, 4-cyclic oxidation tests, 5-mechanical tests.
MS5.4	Diffusion aluminide coating produced by CVD and CVD+RE and diffusion aluminide coating modified by Pt-Pd.	WP 5	48	1- thickness, 2- microstructure, 3- isothermal oxidation tests, 4- cyclic oxidation tests,

				5- mechanical tests.
MS5.5	Diffusion aluminide coating produced by pack cementation method and by VPA method on gamma titanium aluminide alloy.	WP5	48	1-thickness, 2-microstructure, 3-isothermal oxidation tests, 4-cyclic oxidation tests, 5-mechanical tests.
MS5.6	Technological assumptions for industrial CVD application	WP 5	60	Technical assumption of CVD system
MS5.7	Transfer to the component of the most promising coating and process	WP 5	60	Production of components made of SX and DS Ni-based superalloys and gamma TiAl with novel coatings. Cut up of a real component.
MS5.8	Cost-benefit analysis, industrial and environmental analysis.	WP5	60	Analysis available
MS5.9	Annual review	WP5	14. 26, 38, 50	Review report available
MS5.10	Final review	WP5	60	Review report available

1.3.6 Work package description

Work package number	WP 1	**Start date or starting event:**		M1		
Work package title	Integrated Technology Demonstrator					
Work package leader	AvioPolska					
Activity Type[1]	RTD					
Participant number	1	5				
Participant short name	AvioPL	PAL				
Person-months per participant:	60	360				

Objectives

The high level objectives of WP1 are to:

- Provide an overall consistency of LPT module and technology specifications and requirements;
- Monitor and evaluate the technology progress status at LPT system level, through experimental full-module validation tests;
- Assess the final achievements against the COOPERNIK objectives and ACARE targets and SRIA roadmap.

WP1 will integrate the technologies developed in WP2, WP3, WP4 and WP5 on a whole LPT Module to achieve the COOPERNIK targets.
An important role of WP1 is to provide a consistent monitoring of the technology status against the targets by performing intermediate and final technology evaluations and iterations.

The technical objectives of WP1 are to:

- Define and provide corresponding reference LPT baseline

[1] Please indicate one activity per work package:
RTD = Research and technological development (badania przemysłowe); DEM = Demonstration (prace rozwojowe);

- Define perimeter, metrics and methods suitable for an assessment at overall aircraft level
- Evaluate and compare the technologies developed in COOPERNIK taking into account technical feasibility on LPT system level including economic and environmental aspects as well as applicability in product and services.
- Perform experimental full scale test campaign for LPT performance evaluation
- Assess technology improvements and readiness levels
- Hold regular technical risk assessment reviews associated with all of the technologies.
- Provide Technical Leader for the COOPERNIK project
- Contribute to COOPERNIK dissemination & training activities

Description of work

The WP1 is divided into the following task:

Task 1.0. WP Coordination. This task covers the management activities of the WP, assuring the coordination of the work, its dissemination, proper exploitation, technology transfer and training. It's required to:

- coordinate timely production of deliverables and internal and contractual periodic reporting,
- monitor and report the WP progress, the results, the technical status,
- monitor the necessary changes to the work plan accordingly to the decision making bodies,
- develop the relevant means for, and organize, the dissemination and communication of WP results,
- manage the regular risk assessment session to identify technical risks associated with various technologies. Identify mitigation plan and future work required to reduce identified risks. The COOPERNIK Technical Leader will also participate to these sessions together with the COOPERNIK Project Manager.
- to coordinate financial and administrative issues,
- to manage the costs traceability.

AvioPolska will lead Task 1.0 and, together with the involved partners, ensure all inputs and outputs are provided with respect to the agreed schedule

Task 1.1: LPT Technologies Requirements & Specification

Provide LPT module specifications to WP2, WP3, WP4 and WP5 for each technology to be developed and tested

- Design requirements
- Design conditions
- Performance assessment requirements.

The Module specifications will be refined during an iterative process and the output from the Expert Advisory Group, if needed.

Task 1.2 Technology integration

Task 1.2 will validate the different technologies by rig tests across the whole design space with a minimum of two full-module experiments, which will lead to TRL=5 for the investigated technologies. The first test campaign will be focused on technology reference evaluation testing a state-of-the-art multi stage low pressure turbine with the aim at measuring the performance to be improve, creating a baseline for LPT modeling simulation and evaluating the instrumentation strategy to be implemented for full-module enhanced LPT demonstration.

The multistage turbine cold flow will work in similitude to the aerodynamic design point. Performance data as well as exit flow conditions will be gathered through dedicated instrumentation as a function of Reynolds number. High level instrumentation will be applied.

With a detailed numerical investigation (WP2) the combination of the core technologies will be performed to integrate the results of the two full-module test campaign and to prove that the efficiency targets can be achieved.

Task 1.3: LPT Technology Improvement Assessment

Assess and compare the technologies developed COOPERNIK taking into account technical feasibility on system level as well as economic and environmental aspects.

Identify potential bottlenecks that could prevent the effective use of the results for their application in product and services.

Assess the TRL progress robustness through dedicated Phase & Gate Methodology.

Deliverables

D1.1 First version of LPT technology requirements and specification - AvioPL
Month of delivery: 6

D1.2 Annual report on Technology Development Plan- AvioPL
Month of delivery: 12

D1.3 First test campaign specifications- AvioPL
Month of delivery: 18

D1.4 First test campaign report - PAL
Month of delivery: 26

D1.5 Second test campaign specifications – AvioPL/PAL
Month of delivery: 32

D1.6 Second test campaign report – PAL
Month of delivery: 40

D1.7 Final report on technology assessment – AvioPL/PAL
Month of delivery: 50

D1.8 Periodic Report - AvioPL
Periodic report to summarize technical activities and administrative figures.
Month of delivery: 12,24,36,48

D1.9 Final Report - AvioPL
Final report to summarize technical activities and administrative figures.
Month of delivery: 60

Work package number	WP 2	**Start date or starting event:**			M1		
Work package title	Advanced CFD for Whole LPT modelling						
Work package leader	AvioPolska						
Activity Type[1]	RTD						
Participant number	1	4	5				
Participant short name	AvioPL	WUT	PAL				
Person-months per participant:	60	80	30				

Objectives

Research will be dedicated to improve LPT modules performance through development of the following topics:

[1] Please indicate one activity per work package:
RTD = Research and technological development (badania przemysłowe); DEM = Demonstration (prace rozwojowe);

1) Virtual modelling and improvement of LPT's module performance:
- Development/improvement of virtual simulation of a complete low pressure turbine module (main gas path coupled with Secondary Air System area).
- Optimization of the module performance by executing trade-off investigations acting on seal geometries, minimizing tip clearance losses and interaction aspects.

2) Experimental modelling of LPT's module performance:
- Development of advanced instrumentation strategy and Post-processing Data Reduction System.

Description of work

Task 2.0. WP Coordination. This task covers the management activities of the WP, assuring the coordination of the work, its dissemination, proper exploitation, technology transfer and training. It's required to:
- coordinate timely production of deliverables and internal and contractual periodic reporting,
- monitor and report the WP progress, the results, the technical status,
- monitor the necessary changes to the work plan accordingly to the decision making bodies,
- develop the relevant means for, and organize, the dissemination and communication of WP results,
- manage the regular risk assessment session to identify technical risks associated with various technologies. Identify mitigation plan and future work required to reduce identified risks. The COOPERNIK Technical Leader will also participate to these sessions together with the COOPERNIK Project Manager.
- to coordinate financial and administrative issues,
- to manage the costs traceability.

AvioPolska will lead Task 2.0 and, together with the involved partners, ensure all inputs and outputs are provided with respect to the agreed schedule

Task 2.1: Virtual modelling (basics)

Validation of the virtual modelling approach using RANS/URANS commercial solver for a complete detailed investigation of a Low Pressure Turbine module. Preparation of specific automatic set-up procedures allowing to generate and run computational cases for turbine geometries (stators and rotors only constituting the main gas path area). Comparison with numerical/experimental benchmarks delivered by AvioPolska and other available from research partners.
Verification with the results obtained by the self-developed in-house code.
Preparation of a numerical procedure to perform a complete numerical test matrix investigation of a hardware to be used as guidelines during the test investigations.

Task 2.2: Virtual modelling (details)

Extension of the RANS/URANS simulation capability to include details like inter-stage sealing cavities, rotor tip clearance zones, etc.. This is a strategic area that can be addressed to significantly improve the LPT thermodynamic efficiency and consequently reduce the engine fuel burn consumption.
Full virtual CFD simulation of the low pressure turbine module, with extension of specific automatic set-up procedures for complex geometries.
Verification with numerical/experimental results.
Improvement (if needed) of algorithms inside the commercial solver to correctly predict the wake-induced transition with the RANS technique.
This detailed modelling methodology will be used in post-test phases for the numerical-experimental comparisons of the results to better understand specific experimental evidences.

Task 2.3: Seal cavities optimization

Parametric study for optimization of the seal geometry to minimize clearance losses.

Introduction and implementation of multi-objective optimization method based on the surrogate model approach. Coupling of the optimization method with the full virtual CFD simulation of the low pressure turbine module.
Objective is the full optimization of the LPT geometry to minimize clearance and sealing losses.

Task 2.4: Cold Flow Pre-Test support
Development of advanced instrumentation strategy applied to a multistage turbine, based on the DoE and Uncertainty Management approaches.
Validation of the methodology on the benchmark cases provided by AvioPolska and selected experiments performed in the transonic and cascade Wind tunnels of WUT. This task will use results from task 2.1 to help defining proper instrumentation for the experimental hardware, in line with test objectives.

Task 2.5: Cold Flow Post-Test support
Development of a fast Post-Processing Data-Reduction-System with the purpose of crossvalidation of experimental and simulation results basing on the most advanced reduction techniques.
Implementation on modern highly data-parallel GPU architectures. Final validation of the Post Processing Data-Reduction-System for the benchmarks provided by AvioPolska.

Deliverables

D2.1 Report on the commercial SW validation by available benchmark cases provided by AvioPolska - WUT
Month of delivery: 12

D2.2 Report on cross-validation of in-house code with commercial one several test cases-WUT
Month of delivery: 18

D2.3 Report on advanced instrumentation strategy and test matrix selection for turbines test case(s) provided by AvioPolska - WUT
Month of delivery: 18

D2.4 Report on algorithms for prediction of wake-induced transition basing on the RANS technique - WUT
Month of delivery: 24

D2.5 Report describing the implementation of capabilities for full virtual simulation of low-pressure turbine modules – WUT/AvioPL
Month of delivery: 24

D2.6 Report on the fast Post-Processing Data-Reduction-System – WUT/AvioPL
Month of delivery: 24

D2.7 Report on full validation of the virtual simulation of the low pressure turbine module using data provided by partners (available ones) and AvioPolska – WUT/AvioPL
Month of delivery: 30

D2.8 Report on multi-objective optimization method and its implementation within the CFD simulation environment – WUT
Month of delivery: 30

D2.9 Report on the performance of the proposed instrumentation strategy verified on experiments performed by WUT – WUT
Month of delivery: 30

D2.10 Report on the benchmark results for the Post Processing Data Reduction System – WUT
Month of delivery: 36

D2.11 Report on parametric approach and resulting optimized geometries obtained by full virtual CFD simulation of the low pressure turbine module – WUT/AvioPL
Month of delivery: 42

D2.12 Periodic Report - AvioPL
Periodic report to summarize technical activities and administrative figures.
Month of delivery: 12,24,36,48

D2.13 Final Report - AvioPL
Final report to summarize technical activities and administrative figures.
Month of delivery: 60

Work package number	WP 3	**Start date or starting event:**			M1		
Work package title	High Efficiency Turbine Case Cooling System						
Work package leader	AvioPolska						
Activity Type[1]	RTD						
Participant number	1	2					
Participant short name	AvioPL	IMPPAN					
Person-months per participant:	60	129					

Objectives

The optimization of a Low Pressure Turbine performances needs to be able to minimize the clearances between static and rotating parts, in order to avoid the by-pass flows around turbine blades and vanes.

A typical method for controlling those clearances is to actively control the engine case temperature, and then the static parts radial displacement, during the different flight conditions. An impinging system can be used in order to cool the external case especially in cruises operation. The impinging air is normally taken from a section downstream of first stages of the fan and, as it is compressed air, its usage has direct impact on engine performance. The goal for future engine will be to set up the capability to control the case displacement using a reduced amount of air.

Objective of this workpackage is to identify, develop and validate an active cooling system technology for turbine casing able to support the air consumption reduction.

Based on existing impinging solutions a wide range of different geometries of impinging jets and surfaces will be numerically evaluated and experimentally validated. Also different techniques will be taken into consideration and compared with standard one as clearance control effectiveness.

Goal of the workpackage will be to demonstrate a potential cooling air reduction of 25% with respect to standard Active Clearance Control System ("ACC" system in the following).

Description of the work

Task 3.0. WP Coordination. This task covers the management activities of the WP, assuring the coordination of the work, its dissemination, proper exploitation, technology transfer and training. It's required to:

- coordinate timely production of deliverables and internal and contractual periodic reporting,

[1] Please indicate one activity per work package:
RTD = Research and technological development (badania przemysłowe); DEM = Demonstration (prace rozwojowe);

- monitor and report the WP progress, the results, the technical status,
- monitor the necessary changes to the work plan accordingly to the decision making bodies,
- develop the relevant means for, and organize, the dissemination and communication of WP results,
- manage the regular risk assessment session to identify technical risks associated with various technologies. Identify mitigation plan and future work required to reduce identified risks. The COOPERNIK Technical Leader will also participate to these sessions together with the COOPERNIK Project Manager.
- to coordinate financial and administrative issues,
- to manage the costs traceability.

AvioPolska will lead Task 3.0 and, together with the involved partners, ensure all inputs and outputs are provided with respect to the agreed schedule

Task 3.1: Requirements and CFD validation. There is a need to prove that the methods used by IMP PAN are satisfactory for the realization of the project. This will include CFD validation but also some experiments is simplified test section to validate the experimental procedures.

Task 3.2: High roughness surfaces. First a simple test section will allow to check the quality of IMPPAN experimental work. This test section will allow to further to test the cooling effectiveness of increased roughness.

Task 3.3 : ACC optimization. Has the objective to identify an impinging cooling solution with higher efficiency than standard one. Investigations will be carried out considering different jets and/or impinging surfaces solutions. Validation of the most promising solutions will be done experimentally. It is foreseen to reach TRL=4.

Task 3.4 : Unsteady ACC. Has the objective to study the pulsating impingement technique applied to Active Clearances Control Systems. Different studies, available in literature, demonstrated that pulsating jets could reach to higher heat exchange efficiency with respect to stationary one. The study will be carried out both numerically and experimentally. It is foreseen a TRL=3.

Deliverables

D3.1 Requirement of ACC system - AvioPL
Month of delivery: 3

D3.2 Validation of ACC methodology - IMPPAN
Month of delivery: 6

D3.3 Report and measurement data: End of test on high roughness surfaces - IMPPAN
Month of delivery: 8

D3.4 Report final results on enhancement techniques - IMPPAN
Month of delivery: 13

D3.5 Report and experimental data: completion of test campaign - IMPPAN
Month of delivery: 16

D3.6 Report and experimental data: testing of optimized solution - IMPPAN
Month of delivery: 22

D3.7 Engine assessment with new technology - AvioPL
Month of delivery: 24

D3.8 Feasibility study on unsteadiness impingement - IMPPAN
Month of delivery: 14

D3.9 Conclusion of numerical activity in unsteadiness - IMPPAN
Month of delivery: 25

D3.10 Report and experimental data. End of experiment on unsteadiness - IMPPAN
Month of delivery: 25

D3.11 Report: flow curtain technique performance applied to tip clearance control (CFD) - IMPPAN
Month of delivery: 25

D3.12 Experimental results on air curtain techniques - IMPPAN
Month of delivery: 36

D3.13 Periodic Report - AvioPL
Periodic report to summarize technical activities and administrative figures.
Month of delivery: 12,24,36,48

D3.14 Final Report - AvioPL
Final report to summarize technical activities and administrative figures.
Month of delivery: 60

Work package number	WP 4	**Start date or starting event:**		M1		
Work package title	Innovative rotor seal cavities					
Work package leader	AvioPolska					
Activity Type[1]	RTD					
Participant number	1	3				
Participant short name	AvioPL	SUT				
Person-months per participant:	60	71				

Objectives:

The objective of this work package is to identify the best structures that can be applied to a seal cavity labyrinth seal in order to increase the sealing performances. The work will be performed numerically through CFD approach and experimentally with the static validation of the best identified solutions. AvioPolska will evaluate the impact of the introduction of those technologies on a low pressure turbine module.
In detail each task will have the following objectives:

Task 4.0: Coordination and Programme Management. Has the objective to cover the management activities of the WP, assuring the coordination of the work, its dissemination, proper exploitation, technology transfer and training.

Task 4.1: Seal numerical Optimization. Has the objective to identify the best sealing architectures (cells, shroud and knife shapes) that could optimize the sealing performances. The activity will be performed numerically through CFD approach.

Task 4.2: Seal Experimental Characterization. Has the objective to experimentally validate the previously identified most promising solution, by creating same prototypes and testing them in SUT.

[1] Please indicate one activity per work package:
RTD = Research and technological development (badania przemysłowe); DEM = Demonstration (prace rozwojowe);

Task 4.3: Turbine module full seal optimization. Has the objective to use the results obtained in Subtask 1 and 2 to perform a full optimization of a turbine sealing system. This optimization will be done using integrated approach available at AvioPolska, and upgraded where necessary for this specific application with the support of SUT. New cavities architectures will be taken into account considering also different sealing positions and its integration with vanes and blades. The goal is to identify a high efficiency system to be included in the cold flow rig for TRL=4 achievement.

Description of the work

Task 4.0. WP Coordination. This task covers the management activities of the WP, assuring the coordination of the work, its dissemination, proper exploitation, technology transfer and training. It's required to:

- coordinate timely production of deliverables and internal and contractual periodic reporting,
- monitor and report the WP progress, the results, the technical status,
- monitor the necessary changes to the work plan accordingly to the decision making bodies,
- develop the relevant means for, and organize, the dissemination and communication of WP results,
- manage the regular risk assessment session to identify technical risks associated with various technologies. Identify mitigation plan and future work required to reduce identified risks. The COOPERNIK Technical Leader will also participate to these sessions together with the COOPERNIK Project Manager.
- to coordinate financial and administrative issues,
- to manage the costs traceability.

AvioPolska will lead Task 4.0 and, together with the involved partners, ensure all inputs and outputs are provided with respect to the agreed schedule

Task 4.1: Seal numerical Optimization. The following activities are planned:
Rubbed Honeycomb performances. A study of rubbed honeycomb will be performed. On the basis of the elaborated model for referential seal the model including the geometry defects in honeycomb land will be proposed. A comparison of leakage parameters between standard and rubbed geometries will be done. The impact of rubbing on sealing performances will be defined. The important aim of this study is a determination of the influence of varying axial and radial positions of the rotor fins on the leakage.

Honeycomb concept identification. A conceptual study of the most suitable cell configurations of the seal honeycomb will be carried out. The different cells geometries will be elaborated and prepared for numerical assessment. The study will be carried out for the basic configuration of the seal in stationary conditions. The main parameters that influence the sealing performance will be identified. The assessment of the impact and sensitivity of design parameters will be performed. On this basis the possible cells configurations will be identified that potentially improve the sealing performances. The main challenge in this task is to propose the cell configuration for performances improving.

Sealing Optimization. In this study the seal cavity optimization will be performed. The configuration of the full tip/hub cavities with new honeycomb land geometry will be considered. The optimal seal geometry will take into account the results of the previous research on honeycomb geometry and also the potential new "knifes shapes". New configuration could include also some modification of seal cavity architecture. The optimization process will require a selection of the most adequate optimization method for the task, development of an effective algorithm for the calculation and modifications of the numerical model. This work will be done in order to formulate the proposal of new honeycomb sealing geometry.

Engine LPT redesign & 2D modelling. On the basis of the previous results, AvioPolska will update the turbine thermal models and will evaluate the performance of the full module comparing it with the baseline one.

Task 4.2: Seal Experimental Characterization. The following activities are planned:

Experimental apparatus set up. The test stand for stationary seal measurements will be designed and manufactured in the cooperation with the external partner. The instrumentation for honeycomb measurements will be completed. The elements of the measuring system will be mounted and the preliminary tests will be performed. The tests of the stand together with measurement equipment will be carried out. The necessary adjustment to the LDA system will be done. The features of the test stand and measuring system will be identified.

Test Article Modelling and design. Selection of honeycomb geometries for experimental work will be made. Design of honeycombs for testing will be performed. It must include experimental stand specifications, measurement technique requirements and manufacturing specifications (powder sintering technique).

Prototypes manufacturing. On the basis of the design previously defined, some parts of prototypes will be manufactured in AvioPolska using the powder sintering technique. Parts not in additive manufacturing will be in charge of SUT. All components will be instrumented, assembled and tested in SUT.

Test and Technology Validation. The measurements of a standard sealing system based on reference honeycomb configuration will be done and the results will be compared with CFD results. The assessment of this standard solution will be made. The measurements of innovative identified solution will be then performed. The measurement data will be elaborated and honeycombs performance characterised. The assessment of proposed geometries for improved performances will be formulated. As the test will be performed statically, a method for transferring the measured results on real rotating condition will be set up based on a numerical approach.

Task 4.3: Turbine module full seal optimization.

Has the objective to use the results obtained in Tasks 1 and 2 to perform a full optimization of a turbine sealing system. This optimization will be done using integrated approach available at AvioPolska, and upgraded where necessary for this specific application with the support of SUT. New cavities architectures will be taken into account considering also different sealing positions and its integration with vanes and blades. The goal is to identify a high efficiency system to be included in the cold flow rig for TRL=4 achievement.

Deliverables

D 4.1 Standard honeycomb performance evaluated through CFD approach - SUT
The model of seal land with honeycomb will be elaborated. The model makes it possible to assess the performance of the seal on the basis of CFD approach. A comparison of leakage parameters between standard and rubbed geometries will be done.
Month of delivery: 6

D 4.2 High Performance Sealing concept identification - SUT
Different honeycomb concepts will be proposed and evaluated by the use of CFD technique. The assessment of the different sealing concepts has the goal to propose the cell configuration for performances improving.
Month of delivery: 17

D 4.3 Sealing Optimization (CFD) – List of final geometries to be realized and tested - SUT
The objective is to identify the best sealing architectures (cells, shroud and knife shapes) that could optimize the sealing performances. The activity will be performed numerically through CFD approach.
Month of delivery: 24

D 4.4 LPT performances with new geometries - AvioPL
Month of delivery: 24

D 4.5 Performance test results on standard geometry - SUT

The measurements of a standard sealing system based on reference honeycomb configuration will be done and the results will be compared with CFD results. The assessment of the standard solution will be made.
Month of delivery: 15

D 4.6 Performance test results on innovative geometry - SUT
The measurements of innovative solution will be performed. The aim of this study is to characterize the performance of novel honeycomb geometry. The assessment of the novel seal geometry will be performed for static as well as for rotating conditions.
Month of delivery: 24

D 4.7 Turbine Seal Cavity Redesign with innovative solution (CFD and proposed geometry) - SUT
Month of delivery: 34

D4.8 Periodic Report - AvioPL
Periodic report to summarize technical activities and administrative figures.
Month of delivery: 12,24,36,48

D4.9 Final Report - AvioPL
Final report to summarize technical activities and administrative figures.
Month of delivery: 60

Work package number	WP 5	**Start date or starting event:**			M1	
Work package title	Next Generation LPT Blades					
Work package leader	AvioPolska					
Activity Type[1]	RTD					
Participant number	1	3				
Participant short name	AvioPL	SUT				
Person-months per participant:	165	93				

Objectives
Research will be dedicated to improve LPT modules performance through development of High efficiency oxidation resistant coating for Ni-based superalloys and light weight γ-TiAl alloy and ultra-low vibration technologies for light and safe LPT.

The role of Silesian University of Technology is to provide the lab scale research for novel coatings and processes. Due to advanced equipment and considerable experience, the research team will provide a substantial contribution to the research project. Silesian University will perform isothermal, cyclic oxidation tests in order to assess the oxidation protection efficiency of the coating. Advanced microstructure analysis, phase and chemical composition, microstructure analysis of samples after isothermal and cyclic oxidation tests in order to assess the structure and morphology of developed coatings will be performed by Institute for Ferrous Metallurgy. Mechanical properties will be tested in static tensile test and low and high cycle fatigue tests in Institute of Aviation which is certified in mechanical testing.
AvioPolska role is to provide the industrial implementation of the developed research, perform the mechanical characterization of the coated specimens and provide the component to be coated for a final assessment of the novel coating. A strong interaction with the interpretation and the evaluation of the experimental results is foreseen between the two partners.

[1] Please indicate one activity per work package:
RTD = Research and technological development (badania przemyslowe); DEM = Demonstration (prace rozwojowe);

As far as Task 5.2 is concerned, the main objectives are:

1. to develop innovative technologies to be used to mitigate vibration levels due to flutter or forced response phenomena
2. to develop advanced simulation techniques for the prediction of flutter and forced response simulations and compare them with experimental results

Task 5.0. WP Coordination. This task covers the management activities of the WP, assuring the coordination of the work, its dissemination, proper exploitation, technology transfer and training. It's required to:

- coordinate timely production of deliverables and internal and contractual periodic reporting,
- monitor and report the WP progress, the results, the technical status,
- monitor the necessary changes to the work plan accordingly to the decision making bodies,
- develop the relevant means for, and organize, the dissemination and communication of WP results,
- manage the regular risk assessment session to identify technical risks associated with various technologies. Identify mitigation plan and future work required to reduce identified risks. The COOPERNIK Technical Leader will also participate to these sessions together with the COOPERNIK Project Manager.
- to coordinate financial and administrative issues,
- to manage the costs traceability.

AvioPolska will lead Task 5.0 and, together with the involved partners, ensure all inputs and outputs are provided with respect to the agreed schedule

Task 5.1: High efficiency oxidation resistant coating for Ni-based superalloys and γ-TiAl alloy

Description of work

Subtask 5.1 Determination of requirements for novel coatings developed on SX and DS Ni-based superalloys and γ-TiAl.

Subtask 5.2 Development of parameters for aluminizing process by VPA on DS/SC Ni-based superalloys, capable of producing a coating with necessary life requirements (microstructure, oxidation and mechanical properties).

Subtask 5.3 Development of parameters for aluminizing with reactive elements by VPA on DS/SC Ni-based superalloys, capable of producing a coating with necessary life requirements. Definition of a quality control method for innovative coatings.

Subtask 5.4 and Subtask 5.6 Development of parameters for aluminizing process by CVD and aluminizing with RE modification by CVD and PtPd coating with VPA aluminizing on DS/SC Ni-based superalloys, capable of producing a coating with necessary life requirements. Conception of industrial installation for CVD process.

Subtask 5.5 Development of parameters for aluminizing process by pack cementation and for aluminizing process by VPA on γ-TiAl alloy, capable of producing a coating with necessary life requirements.

Subtask 5.7 Coating of a real component (turbine blade).

Subtask 5.8 Cost benefit analysis, industrial and environmental analysis.

Task 5.2 – Low vibration technologies

A special interlocked bladed-disk will be designed in order to obtain a configuration prone to vibrate.

Several technologies will be preliminary studied in order to mitigate the vibration level. Some possible concepts that will be considered are the following:

- Interlocking design
- Mistuning

- Impulsive dampers
- Profile cut-back
- Lattice structure

All the previous technologies will be applied to the high vibration designed configuration. The most promising technologies will be developed with more details and tested on coldflow. The technology effectiveness will be assessed by measuring the effect on vibration level with respect to the baseline configuration (no technologies applied).

Deliverables

D5.1 Determination of requirements for novel high temperature coatings. - AvioPL
Requirements concerning new heat resistant coatings deposited on SX and DS Ni-based superalloys and on γ-TiAl alloy will be defined within the task. Reference samples produced by AvioPolska on industrial installations will be provided. Materials for investigations will be provided. Parameters of heat treatment for the applied SX and DS nickel alloys and for γ-TiAl alloy will be determined.
Month of delivery: 4

D5.2 Assessment of the efficiency of aluminizing by VPA. - AvioPL
Technology basics of diffusion aluminizing using VPA method on SX and DS Ni-based superalloys on laboratory and industrial scale will be developed within the task. The aluminized samples will then be heat treated according to appropriate procedures. Microstructure investigations of the coatings will be performed (XRD, SEM, EDS, S/TEM). Cyclic and isothermal oxidation tests will be conducted. Mechanical properties will also be tested in static tensile test and low and high cycle fatigue tests.
Month of delivery: 20

D5.3 Modification of aluminide coatings deposited by VPA with reactive elements. - AvioPL
Technology basics of diffusion aluminizing using VPA with reactive elements on laboratory and industrial scale will be developed within the task. The aluminized samples will then be heat treated according to appropriate procedures. Microstructure investigations of the coatings will be performed (XRD, SEM, EDS, S/TEM). Cyclic and isothermal oxidation tests will be conducted. Mechanical properties will also be tested in static tensile test and low and high cycle fatigue tests. Definition of a quality control method for innovative coatings.
Month of delivery: 36

D5.4 Development of aluminide coatings deposited by CVD and modification of aluminide coatings using RE and PtPd. - AvioPL
Technological basics of CVD aluminizing of SX and DS nickel alloys on a laboratory scale will be developed, but also technological basics of aluminide coatings modification with reactive elements such as Hf and Zr using CVD method and technological basics of (PtPd)Al coatings deposition will be developed in this task. The influence of technological processes parameters on the structure of aluminide coatings will be determined. Microstructure investigations of coatings will be performed. Cyclic and isothermal oxidation tests will be conducted. Mechanical properties will also be tested in static tensile test and low and high cycle fatigue tests.
Month of delivery: 48

D5.5 Diffusion aluminide coating produced by pack cementation method and by VPA method on gamma titanium aluminide alloy. - AvioPL
Technological basics of heat resistant coatings deposition on γ-TiAl alloys in the temperature range of 750 – 900°C will be developed. The possibility of diffusion aluminide coatings deposition using pack cementation method and VPA method on γ-TiAl alloys will be assessed. The main technological parameters for coating deposition process will be developed. Microstructure investigations will be performed. Cyclic and isothermal oxidation tests will be conducted. Mechanical properties will be tested in static tensile test and low and high cycle fatigue tests.
Month of delivery: 48

D5.6 Conception of industrial installation for CVD process. - AvioPL

Guidelines for a prototype installation and aluminizing technology using CVD method on the industrial scale will be developed. The main parameters of the technological process will be presented. Equipment for industrial aluminizing processes using CVD on SX and DS Ni-based superalloys will be described.
Month of delivery: 60

D5.7 Transfer to the component of the most promising coating and process. - AvioPL
Technological processes of coatings deposition on turbine blades made of SX and DS Ni-based superalloys and on turbine made of γ-TiAl alloy will be performed for the coatings that exhibit the most beneficial set of properties in laboratory and industrial tests. Cut up of the coated components. Microstructure investigations of the coatings will be performed.
Month of delivery: 60

D5.8 Cost-benefit analysis, industrial and environmental analysis. - AvioPL
The objective of this task is to draw on environmental, cost and socio-economic data, collected in all the tasks, and provides the means to assess the impacts and benefits of the deposition of oxidation resistant coatings on Ni-based superalloys and on γ-TiAl.
Month of delivery: 60

D5.9 Preliminary Interlocked bladed-disk design.
A coldflow layout will be designed as a reference for the low vibration technology development. In particular, a bladed-disk concept will be developed in order to obtain high vibration levels in the coldflow test. Within this task also the main specifications regarding the coldflow test and instrumentation will be released.
Month of delivery: 6

D5.10 Preliminary design and assessment of the low vibration technology.
The proposed technologies will be applied on the reference configuration. Numerical activities will be also performed in order to adapt the current design tools and estimate the impact of the new features. A preliminary assessment will be performed at the end of this task in order to identify the most promising technologies (efficacy and impact on performance, cost, reliability, noise and emission)
Month of delivery: 18

D5.11 Test Articles and Rig Adaptation Detailed Design.
The design of reference coldflow and selected technologies will be finalized within this task through the following phases: Concept Design, Preliminary Design, Detailed Design.
Month of delivery: 24

D5.12 Test Article and Rig hardware procurement
TA and Rig hardware procurement in order to perform the planned tests.
Month of delivery: 30

D5.13 Coldflow test
The first test campaign will focus on the baseline configuration (prone to vibrate) and the reference level of vibration will be measured. Secondary, the identified technologies coming from deliverable WP5.2.2 will be tested and the benefits will be measured.
Month of delivery: 36

D5.14 Final Assessment

Based on the test results coming from deliverable D5.13 the design tools will be updated and validated. The tested technologies will be assessed (efficacy and impact on performance, cost, reliability, noise and emission).
Month of delivery: 42

D5.15 Periodic Report - AvioPL
Periodic report to summarize technical activities and administrative figures.
Month of delivery: 12,24,36,48

D5.16 Final Report - AvioPL
Final report to summarize technical activities and administrative figures.
Month of delivery: 60

1.3.7 Summary of staff effort

Table 5

Participant no./short name	WP1	WP2	WP3	WP4	WP5	Total person months participant
AvioPL	**60**	**60**	**60**	**60**	**165**	**405**
IMPPAN			129			129
SUT				71	93	164
WUT		80				80
PAL	360	30				390
Total for WP	420	170	189	131	258	1.168
					Total person months	

1.3.6 Significant risks, and associated contingency plans

The following tables provide an assessment of the potential risks one could rationally expect for the COOPERNIK Project. The risks have been subdivided into general project risk and scientific/technical risks.
For each possible problem, the probability of occurrence (scale: low-1; low-medium-2; medium-3, medium-high-4; high-5) and the impact on the project have been judged as reasonably as possible. In order to lower these risks, the team has identified numerous ways to avoid and mitigate the problems and offer possible back-up plans if needed.

WP	Risk	Probability of occurrence	Possible impact on project	Avoidance / Mitigation / Contingency Plans
1	Delay in cold flow test facility readiness for full module campaign	2	3	Anticipate as soon as possible the procurement of critical parts and/or identify potential subcontractors in advance.
1	Technology improvements do not achieve required targets	1	2	Define (already during design) alternative routes to achieve the objectives; hold regular internal assessment reviews to decide on way forward

2	Delay in acquiring the correct geometry data for computations	1	2	Use of the generic/literature data to allow for early validation of whole LPT modelling
2	Delay in purchasing of computing hardware	3	2	Temporary use of the existing/available computing hardware for reduced size test cases
2	Unsatisfactory validation of whole LPT modelling capability	2	2	Continuous improvements and cross-validation with results of other WP's related to elements included into the whole LPT model
3	Large discrepancies between AvioPolska data and IMP PAN results for the reference case	1	2	Mutual decision on continuing efforts to improve coincidence of results and to start realisation of the investigations. Following check point will be comparison of IMP PAN CFD results with own experiments.
3	Too long period of introductory analysis and design of the test sections (CFD and experimental validation, jet pulsation methods)	1	1	Postponement of measurements, optimisation of measurements schedule. Earlier start of the task CFD and experimental validation to avoid similar problems
3	Experimental measurements delayed	2	2	Reconsideration of the measurement program, postponement of Deliverables.
4	Complex and time consuming tender process.	1	1	Split of purchase of stationary and rotating test rigs.
4	Delay in the measurement equipment assembly and testing	2	2	Postponement of measurements, rearrangement of measurements schedule
4	Delay in experimental measurements	2	2	Rearrangement of the measurement program, Deliverables postponement.
5	Handling of devices working at high temperature. Dangerous technical gases used for technological processes.	1	1	Following the workplace regulations. The laboratory is equipped with detection systems, alarm systems and exhaust systems for dangerous gases
5	Access to confidential information of the consortium member. Lack of information necessary to the appropriate duration of	1	1	Signing of the confidentiality agreement. Biannual meetings between members of the consortium responsible of the ongoing WP. Teleconferences discussing the current

	the WP.			progress of the ongoing work.
5	Failure to meet the terms of materials delivery by an external company.	2	1	Realization of the orders ahead of time. Silesian University of Technology has a certain stock of materials.
5	Complex process of tender documentation preparation. Tender invalidation. Protest of the companies participating in the tender procedure.	1	1	Realization of the tender procedures ahead of time.

2. Implementation

2.1 *Management structure and procedures*

2.1.1 COOPERNIK management approach

The COOPERNIK consortium comprises 5 partners that, because of their multi-disciplinary expertise, contribute to the achievement of the ambitious objectives of the COOPERNIK project. The COOPERNIK results have to be gathered to have a major contribution to the aircraft engine sector and to meet the expectation from the participants.

The COOPERNIK partners are aware that combining technical challenges with collaboration are key factors for the success of this initiative and the project management structure has to be defined to the specific project context. The COOPERNIK project organization ensures the integration of skills, resources and activities to reach the global project targets and results.

The starting point for the COOPERNIK management structure is the experience of the partners lessons learnt and the exploitation of methods and tools that have proved to be efficient. The project management structure has several levels, designed to adapt the strategy of the scientific and technical activities to the constantly evolving international scientific context, implementing the global project strategy and optimizing resource usage and outcomes of the project.

The COOPERNIK management structure is defined to reach the following objectives:

- Ensure timely and qualitative achievement of the project objectives, including risk mitigation, recovery plans and quality control,
- Coordinate the activities of COOPERNIK at the consortium level,
- Provide decision making, quality control and conflict resolution mechanisms to support the project consortium and its evolution,
- Support implementation of changes in the activities and the consortium, including new entrants if and when needed,
- Provide timely and efficient financial and administrative coordination of the project,
- Support the activities of the consortium especially the ones that need a strong coordination, for instance dissemination, innovation management, preparation for exploitation activities, or preparation of certification,
- Coordinate and provide interfaces for conjunct action with stakeholders and important decision makers.

2.1.2 *COOPERNIK management organization and plan*

The main research tasks are organized in 5 work packages corresponding to the main COOPERNIK research domains. Each of these work packages has its own set of tasks.
The management at the global level ensures governance and coordination of the whole project and its relations with the NCBiR.

The COOPERNIK project management plan considers two aspects:

- The **management organization**,
- The **project management principles** that have been agreed by the COOPERNIK partners to implement all issues not covered by the NCBiR and indispensable to make the project operational and viable. These principles are being formalized in a consortium agreement to be signed before the project start and which have been already agreed during the proposal.

The plan also handles three different important aspects of the project management:

- Decision making – handling contractual issues (and approving changes) regarding consortium agreement, changes in the project specification, budget and funds distribution policy, quality assurance policy, consortium structure, IPR principles, publications and confidentiality issues.
- Operational management – implementing decisions taken by the decision bodies regarding implementation of the work, follow-up of work done, providing logistics for all coordination tasks, supporting and coordinating reporting, financial and administrative management.
- Advisory and assessment – advising the decision making bodies about how the project should evolve according to results obtained and evolution of the state-of-the-art and the market. Assessing the work done and the way it is done according to a project quality plan containing a description of milestones and results (especially the way to evaluate them qualitatively and quantitatively) and a permanent monitoring of the evolution of the external context of the project.

The COOPERNIK management plan will be documented through a series of short documents ("COOPERNIK project management guidelines") covering the main project management issues, including quality and risk management.

2.1.3 *COOPERNIK organizational structure*

Decision making

COOPERNIK will be co-ordinated by AvioPolska. The highest decision making body of COOPERNIK also responsible for the project strategy is the General Assembly.

The **General Assembly** is composed of one representative of each partners (Members). The General Assembly will be responsible for:

- Changes to the Consortium Plan, including the Consortium Budget;
- Strategic orientations of the project, programme of activities;
- Determining information required from the partners;
- Entrance of new contractors and sub-contractors;
- Content, finances and intellectual property rights.

The Coordinator shall chair all meetings of the General Assembly, unless decided otherwise by the General Assembly.
The **COOPERNIK Coordinator** (AvioPolska) is the legal entity responsible for all aspects of the interface between Parties and the NCBiR, and for the overall coordination of the project as well as for administrative and financial content. The COOPERNIK coordinator's responsibilities will be to:

- monitor compliance by the partners with their obligations,
- keep the address list of Members and other contact persons updated and available,

- collect, review and submit information on the progress of the Project and reports and other deliverables (including financial statements and related certification) to the NCBiR
- prepare the meetings, propose decisions and prepare the agenda of General Assembly meetings, chairing the meetings, preparing the minutes of the meetings and monitoring the implementation of decisions taken at meetings,
- transmit promptly documents and information connected with the Project including copies of accession documents, changes of contact information to the Parties, and also information such as the date of delivery of the periodic technical and management reports to the NCBiR,
- administer the Community financial contribution and fulfilling the financial tasks,
- provide, upon request, the Parties with official copies or originals of documents which are in the sole possession of the Coordinator when such copies or originals are necessary for the Parties to present claims.

Operational bodies

The **Programme Management Committee** is composed of the management referents of the 5 partners involved in COOPERNIK. It will be in charge of:

- implementing the technical orientations decided by the General Assembly;
- evaluating the Management Risk Reduction;
- preparing the programme of activities, the budget and the allocations;
- tracking the Deliverables status;
- implementing the Annual Review.

The Programme Management Committee chairperson is the Project Manager, appointed by COOPERNIK Coordinator.

The **Technical Coordination Committee** is composed of:

1) the work package leaders,
2) the technical referent of each partner.

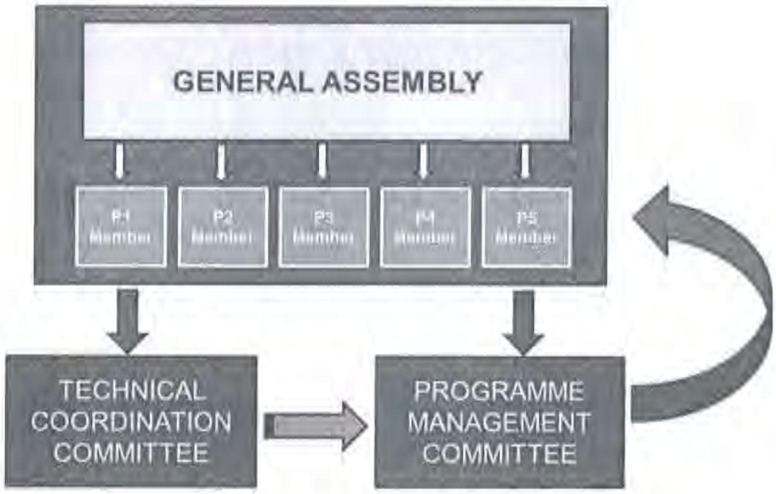
Work package leaders have been selected among the key scientists involved in the project. The Technical Coordination Committee chairperson, **Technical Leader**, is appointed by the COOPERNIK Coordinator. It will be in charge of:

- implementing the quality plan and the risk management plan within each WP;
- executing of the overall technical objectives of its WP during the project lifetime;
- implementing the dissemination and training;
- evaluating the state of the progress and executing of changes according to the project needs and practices;
- implementing the Annual Review.

The Technical Coordination Committee reports and interacts with the Programme Management Committee through

1) Progress reports;
2) Proposals on programme and on task.

The Programme Management Committee and the Technical Coordination Committee will meet every two months.



COOPERNIK organizational structure

Scientific and technical management

The scientific and technical management is organized at Work Packages level under the responsibility of the following partners:

1. WP1 will be led by **AvioPolska**
2. WP2 will be led by **AvioPolska**
3. WP3 will be led by **AvioPolska**
4. WP4 will be led by **AvioPolska**
5. WP5 will be led by **AvioPolska**

Each WP leader will appoint work package and task leaders who will be operationally responsible for the technical activities within their work packages or tasks. Each of the work package leaders will be responsible for reporting on their work packages to the Technical Coordination Committee and the COOPERNIK Coordinator.

Finally, to assess and validate the project output, COOPERNIK will implement:

- **Internal technical reviews** – PDRs, CDRs and TRRs – to which most major project milestones will be attached. In these reviews, each organization will involve their key experts in the fields from engineering and manufacturing departments to perform this assessment. Output from these technical reviews will be documented in a formal report including acceptance or not plus recommendations from the review team. Such approach corresponds to existing internal industrial procedures that have proven their effectiveness over the years.
- A dedicated **Expert Advisory Group** ensures the COOPERNIK developments are in line with the aviation industry needs and requirements.
- A **quality review process** for each deliverable to check if the document and corresponding technical output match the initial requirements, correspond to the level of quality expected by the participants and provide an exploitable documentation
- A **set of indicators** to follow the progress of the work from a management (deliverables approved, milestones, achieved, person-months and budget consumption, Gantt, risk criticality curves) or a technical (estimated SFC gain, noise level, gas emissions from alternative fuels, etc.) nature.
- A **risk management plan** to follow the major potential risks with mitigation plans and back-up plans whenever needed. At the management level, the risk management plan will be focused on **preventing delays**. In particular, all tests will be prepared with readiness plans to monitor any manufacturing issue, availability issue and installation issue.
- **Procedures for recovery plans** will also be set-up right from the beginning to ensure proper action plans in case of any problem that might have an impact on the planning, the budget or the expected project measurable targets

2.2 *Participant(s)*

2.2.1 AvioPolska – Project Leader

Avio Polska sp. z o.o. is a part of AvioGroup international industrial group, a leader in the aerospace industry. The company launched its operation in 2001 in Bielsko-Biała as a part of FiatAvio Polska, and from 2003 onwards the AvioGroup, including AvioPolska, has become an entity independent from Fiat.
Avio Polska focuses its activity on manufacturing carried out in the Manufacturing Center and R&D activity pursued by its own Research and Development Center.

There are over 70 engineers employed in the Research and Development Center. They work in the following teams:

- FEM analyses –Turbines
- FEM analyses – Gears
- Heat flow/CFD (FEM)
- Non-linearity/fatigue (FEM)
- CAD designing

In the computational center based on computational servers there is MSC Patran/Nastran/Marc/Pthermal, Ansys, Unigraphics software used, as well as our own tools for fatigue analyses, dynamic characteristics analysis etc.
Scope of works performed by the Design Department comprises:

- strength analysis of the components of aeroengines (turbines, gearboxes, housings, shafts) in linear and non-linear scope;
- fatigue analyses;
- dynamic analyses;
- heat flow analyses;
- analyses and optimization of the flow of working medium;
- virtual instrumentation of an engine, procedures for carrying out and servicing of bench tests;
- system analysis (WEM)
- creating prototypes in electronic form
- elaborating technical documentation
- technological validation
- designing instrumentation for tests

The facility in Bielsko is still developing. We are increasing manufacturing capability now which will result in broadening offer of the Manufacturing Center, as well as services of repair provided by it. It will cause also an increase in competence and expertise of the Research and Development Center. The cooperation with Polish higher schools (Warsaw University of Technology, Military University of Technology, Silesian University of Technology in Gliwice, University of Bielsko-Biała) have beneficial effects on making our company more innovative.
The low pressure turbine is one of the main engine modules. It drives the low pressure compressor or the fan by taking energy from the hot gas coming from the engine combustion chamber and high pressure turbine.
AvioGroup began developing its design, manufacturing, testing and product support capability on important military programs (RB199 for the MRCA Tornado and EJ200 for the EF200 "Typhoon"). Today AvioGroup is designing, developing and producing complete low pressure turbine modules, including for the commercial turbofan, as well as complete MR&O of the turbine of both military and commercial engines: GE90, CF6-80C2/E1, FM56 Family, PW 308, TRENT 500, CT7-8, GEnx, LMS 100 - Aeroderived gas turbine and LM6000 - Aeroderived gas turbine.

Key personnel:

Dorota Kopkowicz-Wilczak, MSc - AvioPolska Engineering Center – Heat Transfer group, she graduated The Technical University of Rzeszów in 2001 Aviation Department (specialization: Aircraft Engines). Has been working in AvioPolska since September 2001, first in Structural Analysis group and from 2004 in Heat Transfer group, From 2007 head of Heat Transfer Group in AvioPolska, responsible for analysis performed in Heat Transfer groups in civil , military and research projects.

Tomasz Borzecki, PhD – he graduated The Technical University of Lodz in 1999 and he started the scientific work as assistant of the professor at The Institute of Turbomachinery of the Technical University of Lodz in 2000. He spent 4 months in l'Ecole Central de Lyon in 2001 where he occupied numerical investigations of fluid flow through the inlet vane cascade with a big scale. He held a PhD from Technical University of Lodz in 2005. He participated in many domestic scientific programs and he was involved in cooperation with industry. In the years 2006-2007 he worked at l'Office National d'Etudes et Recherches Aérospatiales – ONERA as postdoc engineer. He has been working in AvioPolska as CAE engineer since October 2007. He is responsible for CFD analysis in civil, space and military projects now.

Rafał Robak, MSc – AvioPolska Engineering Center – Lifing group. He's graduated in 2007 from Silesian University of Technology; Mechanical Department. During last semester started work in AvioPolska as CAE Constructor. He participates in many projects involving static structural analysis, crack propagation and dynamic analysis as well. During past years in scope of work were also optimization tasks to improve durability of the engine components and propeller gearboxes. Experienced in superelement technology suitable to analyze whole engine model (WEM) systems.

Tomasz Micał, MSc - he graduated The Technical University of Lodz in 2001 (branch of the University in Bielsko-Biała). In the years 2001-2003 he worked for the automotive industry in Italian research and development centers as CAD and CAE engineer. He has been working in AvioPolska as CAE engineer since November 2003. He is responsible for Heat Transfer analysis in civil and military projects now.

Łukasz Pyclik, MSc – Department of Turbine. He obtained MSc degree from University of Science and Technology in Krakow in 2011 specializing in moulds constructing for pressure casting with particular emphasis on design and simulation programs. He is member of AGH Scientific Circle "ZGAREK". He was co-organized Festival of Science in Krakow in years 2009-2011 on behalf of Faculty of Foundry Engineering. In 2010, he cooperated with Grupa Kety on Facility of Ingot and Facility of Die Manufacturing. Since 2011, he is employee in Avio Polska on position of constructor responsible for materials application.

2.2.2 Institute of Fluid-Flow Machinery – Polish Academy of Science – Centre for Thermomechanics of Fluid

The Institute (Instytut Maszyn Przepływowych im Roberta Szewalskiego Polskiej Akademii Nauk) is the second largest institute in the Polish Academy of Sciences. The Institute employs about 200 people, of whom 80 are scientific researchers. There are 20 professors and 35 scientists with doctoral degrees. The Institute is the leading organisation in IMP PAN in the field of fluid mechanics, multiphase flows, thermodynamics and heat exchange, laser measurement techniques, machinery dynamics, tribology and diagnostics of energy production machinery. The thematic orientation of its research concerns aerodynamics, solid mechanics and energy conversion in flows including plasma and lasers.

The department of Transonic Flows and Numerical Methods combines experimental and numerical approaches to study the physics of shock wave and boundary layer interaction. In the last decade, interaction control has been one of the main topics of research. The transonic wind tunnel, commissioned in 1996, is well equipped for pressure measurements and optical methods. Numerical simulations of viscous, compressible and 3-D flows are run on a computer cluster at the Academic Computer Centre TASK, the largest in Poland.

One of important research fields is experimental investigation of heat exchange, mainly in the internal channels of cooled blades. Effect of film cooling on the blade surface has been also studied in the research team.

The research is carried out in cooperation with many institutions in Europe as DLR, ONERA, CIRA and the universities of Karlsruhe and Cambridge. There is also cooperation with industry partners as RR, AvioGroup, SNECMA.

IMP PAN including Transonic Laboratory is supervised by the Polish Centre of Accreditation, the IMP standards (NC 155 on 10.04.2003) comply to ISO 9001:2000.

The participation of the IMP PAN to the present project is related to Active Clearance Control. Optimization of presently available systems with innovative ideas is the main topic. There will be also a new concept related to a new flow control of gap flow over a shroud.

Key personnel:

Piotr Doerffer is a Professor at IMPPAN and a Head of the Department of Transonic Flows and Numerical Methods, and deputy director of IMPPAN for Projects and Infrastructure. He has taken part in many research projects and organised several international conferences. On a European level, he has participated in EUROSHOCK I and II, and the organization of the 5th ISAIF in Gdansk and participation in the AITEB project of the 5th FP. He also took part in the 6FP projects: AITEB-2, FLIRET and TLC. He coordinated the UFAST project and now is coordinating the TFAST project.
The research work will be carried out by four main co-workers. **Dr Ryszard Szwaba, Dr. Pawel Flaszynski and Janusz Telega, MSc and Fernando Leonardo Tejero Embuena.**. All are experienced scientist in the respective field of their activity. They are taking leading role in the realisation of EC projects mentioned above. In case of necessity there is possibility to involve more people for the planned research.

2.2.3 Silesian University of Technology

Faculty of Power and Environmental Engineering & Faculty of Materials Engineering and Metallurgy

The Silesian University of Technology (SUT) is one of the biggest in Poland, currently educating about 30 000 students on 14 Faculties in 48 engineering disciplines. The Faculties cover the whole range of engineering disciplines. The Silesian University of Technology is an active partner of the European students exchange within the framework of the Erasmus programme, on the basis of over 145 bilateral agreements with European universities.

The Faculty of Power and Environmental Engineering employs 47 professors and associate professors and 105 PhDs. The Faculty has the highest category (category A) of the Ministry of Science and Higher Education. Its research work covers among the others the following fields: design of power machinery, operation and diagnostics of power machinery and facilities, a research on mass and heat transfer, thermal and nuclear power engineering, industrial air-conditioning, design and operation of combustion engines.

The Institute of Power Engineering and Turbomachinery (IPET) belongs to the biggest Institutes of this Faculty. The research is carried out in cooperation with many European universities and big international companies as EDF, GE Energy, Alstom, AvioGroup, Hitachi. The Institute is involved in many research projects. IPET is a leader of national strategic programme, which is devoted to CCS technology. The Institute of Power Engineering and Turbomachinery consists of 5 departments. The Department of Turbomachinery and Power Systems, which will support research in the project, has over 30 years' experiences in both Experimental and Computational Fluid Dynamics. The laboratories comprise the steam transonic tunnel and test rigs for axial compressor, fan as well as pump measurements. In experiments the most sophisticated techniques are used, such as Laser Doppler Anemometry (LDA) or Schlieren technique. The CFD research are performed using the in-house CFD codes as well as the commercial CFD codes like AnsysCFX. The numerical calculations are performed on an efficient in-house computer cluster which allows analysing large numerical tasks.

In the present project IPET will be contributing to seal numerical optimization, seal experimental characterization and turbine module full seal optimization. The research team of the Department has high qualifications for performing both numerical and experimental tasks.

Key personnel:

Prof. Lucjan Swadzba, Silesian University of Technology, Gliwice, Faculty of Materials Engineering and Metallurgy, Institute of Materials Science, 40-019 Katowice, Poland

Graduated from AGH University of Science and Technology in Cracow. He received a PhD, habilitation and professor degree in Materials Engineering from Silesian University of Technology. The scientific degrees were related to his experience and achievements in the field of surface engineering and technology for aircraft industry.

Author of more than 200 articles, 12 patents, 20 international presentations and 40 in Poland. He was the leader of 30 research projects concerning technologies for aircraft industry. He led scientific projects on coatings technology in close cooperation with WSK, PWC, PWA and AVIO-Polska. Many of his projects were implemented to production.

His team was awarded the Certificate of Excellence by Pratt&Whitney Canada twice for implementation of technology for erosion and high temperature resistant coatings.

Currently, Prof. Lucjan Swadzba is Head of Heat Treatment and Surface Engineering Department at Institute of Materials Science, Silesian University of Technology. The department is equipped with modern technological and research equipment for CVD and PVD technology processes and for coatings evaluation, e.g. non-destructive assessment, thermal conductivity and diffusivity measurements, oxidation kinetics analysis, cyclic and static oxidation tests, burner rig test, hot corrosion test and metallographic examination.

Dr inż. Bogusław Mendala, area of interest: high temperature coatings and thermal barrier coatings, high temperature corrosion, Ni-based and TiAl alloys, PVD, VPA, CVD, EB-PVD and APS technologies.

Mgr inż. Bartosz Witala, area of interest: high temperature coatings and thermal barrier coatings, Ni-based and TiAl alloys, pack cementation, VPA, CVD, MPECVD, PVD and EB-PVD technologies. Master's thesis title: "Apparatus characterization and base technology investigation of diffusion aluminide coating deposited by CVD method on Ni-based superalloys", PhD thesis title: "Development of technological basics for columnar ceramic TBC deposition using MPECVD method on nickel superalloys".

Mgr inż. Radosław Swadźba, area of interest: high temperature coatings and thermal barrier coatings (TBC), high temperature oxidation, nickel and titanium based alloys, VPA, pack cementation, EB-PVD, nondestructive evaluation of TBCs, scanning SEM and scanning transmission electron microscopy S/TEM, Focused Ion Beam FIB. PhD thesis title: "Structure degradation of bond coatings in thermal barrier coatings on a single crystal heat resistant nickel superalloy under high temperature oxidation conditions".

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2. *R. Swadźba, M. Hetmańczyk, J. Wiedermann,* ***L. Swadźba****, G. Moskal, B. Witala, K. Radwański, Microstructure degradation of simple, Pt- and Pt+Pd-modified aluminide coatings on CMSX-4 superalloy under cyclic oxidation conditions, Surface and Coatings Technology 215 (2013) 16–23*
3. *R. Swadźba, J. Wiedermann, M. Hetmańczyk,* ***L. Swadźba****, B. Witala, G. Moskal, B. Mendala, Ł. Komendera, Microstructural examination of TGO formed during pre-oxidation on Pt-aluminized Ni-based superalloy, Materials and Corrosion, in print*
4. *R. Swadźba, M. Hetmańczyk, M. Sozańska, B. Witala,* ***L. Swadźba****, Structure and cyclic oxidation resistance of Pt, Pt/Pd-modified and simple aluminide coatings on CMSX-4 superalloy, Surface & Coatings Technology 206 (2011) 1538–1544*
5. M. Góral, ***L. Swadźba****, G. Moskal, G. Jarczyk, J. Aguilar, Diffusion aluminide coatings for TiAl intermetallic turbine blades, Intermetallics 2011 vol. 19 iss. 5, s. 744-747*
6. *R. Swadźba, J. Wiedermann, M. Hetmańczyk,* ***L. Swadźba****, B. Witala, G. Moskal, B. Mendala, Ł. Komendera, Microstructural examination of TGO formed during pre-oxidation on Pt-aluminized Ni-based superalloy, EFC Workshop: Beyond Single Oxidants, 2012, Frankfurt am Main, Germany – Award for the best presentation in poster session*
7. G. Moskal, ***L. Swadźba****, M. Hetmańczyk, B. Witala, B. Mendala, J. Mendala, P. Sosnowy, Characterization of microstructure and thermal properties of $Gd_2Zr_2O_7$-type thermal barrier coating, J. Eur. Ceram. Soc. 2012 vol. 32 iss. 9, s. 2025-2034*

Włodzimierz Wróblewski, PhD, DSc –Professor at Silesian University of Technology (SUT). In the years 1992-1993 was a fellow of Humboldt Foundation at the RWTH Aachen/Germany. He has been engaged in the research on the compressible flows in turbomachinery, conjugate heat transfer and multiphase flows. He has many years' experience in training of young scientists and students. Since 2006 he has been Deputy Director of the Institute. He is the Head of the Department of Turbomachinery and Power Systems. He has been involved as leader or experienced researcher in the national scientific projects. He was a SUT leader in international project DREAM.

Tadeusz Chmielniak, PhD, DSc, Prof. – Full professor at Silesian University of Technology, many years director of the Institute of Power Engineering and Turbomachinery. He is an expert in the field of fluid dynamics and flow machinery, he is an author of many books and reaserch papers in this field. Leader of many research projects.

Sławomir Dykas, PhD, DSc –He is graduated (MSc) in Aircraft Engineering at Rzeszów University of Technology (1992). In the years 2000-2003 he worked at the University in Karlsruhe (TH) and Munich (MUT). He is an associate professor at SUT. He participated in many international as well as domestic research projects. His research work concentrates on the CFD modeling of flows in turbomachiery, CAA modeling and experimental investigation of steam transonic flows.

Other persons involved

Name	Current Position	Domain of expertise
Michał Strozik, PhD	Assistant Professor	Measurement systems
Michał Strozik, PhD	Assistant Professor	Fluid flow measurements, electronics engineer
Krzysztof Bochon, PhD	Specialist	CFD modelling, software developer
Sebastian Rulik, PhD	Assistant	CFD modelling, IT specialist

2.2.4 Warsaw University of Technology – The Institute of Aeronautics and Applied Mechanics Silesian University of Technology

Faculty of Power and Environmental Engineering & Faculty of Materials Engineering and Metallurgy

Description of organization

The Institute of Aeronautics and Applied Mechanics is one of the largest Institutes of Politechnika Warszawska (Warsaw University of Technology) which is ranked first among universities offering Engineering Degree in Poland. The Institute (founded in 1928) employs 120 people and is devoted to research and education in the general areas of Aeronautics, Robotics and Machine Design. It provides 4-year courses for Engineering Degree, subsequent 2-year courses for Master Degree and 4-year Ph.D. studies. The total number of students exceeds 1200.

The research activity covers: Aerodynamics, Computational Fluid Dynamics, Flight Dynamics, Aircraft Design, Avionics, Robotics and Biomechanics. The Institute was/is involved in numerous 5-7-FP projects: ABOUTFLOW, ADVANCE, ADIGMA, ADFCS, APROSYS, APSN, CAPECON, ESPOSA, EVPSN, HIRET, FLOWHEAD, HELIX, IDIHOM, M DAW, NACRE, NEFS, NICE-TRIP, SEA-AHEAD, SIDER, SIMSAC, TALOS, THOMO, UAV NET, VITES, VULCAN.

Specific skills and role in this project

The Aerodynamic group has over 25 years' experience in developing numerical methods and codes as well as over 70 years of experience in experimental aerodynamics in subsonic and transonic regimes. At present research and expertise related to the proposal include:

- Development of robust optimisation methodologies using RSM methods and gradient information, one-shot methods for gradient based optimisation, development of discrete adjoint CFD code using Automatic Differentiation tools
- Simulation of complex (multiphase) flows
- Development of grid generation and adaptation algorithms
- Experiments and instrumentation for transonic unsteady flows.

Presently the group is taking part in IDIHOM, ESPOSA, ABOUTFLOW and UMRIDA FP7 projects related CFD analysis and design for aeronautic industry.

Key personnel

Dr.Jerzy Majewski, senior researcher has over 15 years of CFD development/research experience, participant of numerous national and European projects (e.g., HiReTT, M-DAW, NACRE, ADIGMA, FLOWHEAD, IDIHOM).

Dr. Slawomir Kubacki, senior researcher has over 10 years of experience in simulation of complex flows, working on laminar-turbulent transition modeling, participant in FLOWHEAD, ESPOSA, IDIHOM EU projects.

Dr. Zbigniew Nosal, senior researcher working over 20 years on experiments in transonic unsteady flows, participant of the ESPOSA EU project.

MSc. Lukasz Laniewski-Wollk, Ph.D. student working on response surface approach for optimization (adjoint enriched Kriging, relative expected improvement, robust optimization, topological optimisation), participant of FLOWHEAD, ABOUTFLOW, UMRIDA projects.

2.2.5 Laboratorium Badań Napędów Lotniczych "Polonia Aero" Sp. Zo.o.

The Cold Flow Turbine Test Facility will be built in Zielonka near Warsaw. It will be the largest and most modern laboratory of its kind worldwide, and will be used to carry out industrial R&D in the aeronautical industry, including the testing of engine turbine prototypes as well as technological demonstrators used in the production of aero engines.(Total cost: 188,790,177.27 zł - European Regional Development Fund financing: 160,386,650.68 zł - Polish State Budget financing: 28,303, 526.59 zł).

The initiators of the project are, on the one hand, some of the most well-known Polish specialists in the field of turbine research from Warsaw University of Technology and Military University of Technology and, on the other hand, industrial partners including Avio S.p.A. and Military Aircraft Works No. 4 SA (Wojskowe Zak_ady Lotnicze Nr 4 S.A.) in Warsaw, who established a scientific-industrial consortium in 2008, the Aircraft Propulsion Research Laboratory - "Polonia Aero" (Laboratorium Badań Napędów Lotniczych).
The aim of the consortium is to build a network of laboratories, resulting in a synergy effect, to conduct advanced research in the field of turbine flow aerodynamics, with each project fully functional and independent.
The main laboratory will be located at Polonia Aero, while the others will be located directly at the universities participating in the project. The advantage of the project is the great support it will give to industrial R&D; it is not only attractive for scientific reasons but also for the development of industrial technologies. Avio's R&D Dept. developed the design of the laboratory together with the American Company ASE. The laboratory will lay the foundations for obtaining European financing, and industrial R&D contracts with the world largest aeronautical companies.

Key personnel:

Filip Sęk: studied in 1998 - 2003 at Warsaw University of Technology, Faculty of Power and Aeronautical Engineering (Aeronautics, Aircraft engines). Since 2003 to 2009 worked for LOT Polish Airlines as a Powerplant Engineer managing all aspects of on-wing, of-wing (shop) maintenance as well as continuous airworthiness of the entire fleet of PW100 series turboprops (over 30 engines).
In paralell he was a part-time certified technical instructor at both LOT and EuroLOT training centres. In 2009 has joined AvioPolska as a person responsible for MRO (Maintenance, Repair and Overhaul) to support AvioPolska in realization of MRO contracts with local, both civil and military operators.
Starting from 2012, he also fully supports AvioPolska in realization of offset programs in Poland. Recently he became member of Polonia Aero team, dedicated to coordination of activities within the design, construction, tender as well as fabrication phase.

2.3 *Resources to be committed and cost justification*

Table 6: Cost in categories for each work package

All COOPERNIK partners have thoroughly evaluated their tasks and duties within the project and calculated the corresponding budgets and efforts. The total budget for the 5 partners in COOPERNIK adds to 46,9 MPLN. The personnel effort of the COOPERNIK project accounts for 1168 person months. An overview of the costs is shown in Table below.
The largest share of the direct costs is personnel costs (32%) and materials and other OP (32%), followed by Equipments (16%) and Subcontracting (4%), due to the specialised and complex capability for mechanical testing and microstructure analysis which are not all available at the partners themselves.

Work package		Equipment (A)	Land and buildings (G)	Subcontracting (E)	Materials & Other OP (Op)	Other (O)	Total cost WP
WP 1	5.449.420	4.752.000	0	0	10.886.400	1.687.026	22.744.846
WP 2	2.325.106	891.309	0	0	238.172	474.309	3.928.896
WP 3	2.858.717	216.000	0	259.200	561.600	607.907	4.503.424
WP 4	1.979.625	545.504	0	0	862.392	475.203	3.862.724
WP 5	3.905.533	1.051.069	0	1.682.563	3.943.838	1.249.235	11.832.238
Total cost for category	**16.518.401**	**7.455.882**	**0**	**1.941.763**	**16.492.402**	**4.493.680**	**46.902.128**
						Total cost (PLN) :	

2.3.1 *Equipment (category A)*

Partner	WP	Estimated cost (kPLN)	Description
1 – Avio Polska (CO)	1 - 5	1728	Software Licences
3 – Silesian University of Technology	4	330	Measurement facility: • Installation of a compressed air system • Fabrication of the test rig for stationary measurement • Fabrication of the test rig for rotating measurement • Fabrication of seals elements • The measurement elements, sensors and data accusation system
	5	619	• Device for tightness testing of gas installations, • Furnaces for cyclic oxidation tests, • Equipment for material surface preparation, for sample preparation and for oxides analysis.
4 – Warsaw University of Technology	2	459	• Software Licences • Extension of existing computer cluster
5 – Laboratorium Badań Napędów Lotniczych "Polonia Aero" Sp. Zo.O.	1	4.320	• Cold Flow Rig adaptation • Instrumentation procurement

2.3.2 *Subcontracting (category E)*

Partner	WP	Estimated cost (kPLN)	Supplier	Description
1 – Avio Polska (CO)	5	994	Institute of Aviation (Warsaw)	Mechanical Testing (tensile, HCF and LCF) of Ni-Based and TiAl specimens with innovative coatings
2 – Institute of Fluid Flow Machinery	3	259	To be defined	Manufacturing rig sections for the university tests
3 – Silesian University of Technology	5	689	Institute for Ferrous Metallurgy (Gliwice)	Microstructure analysis of Ni-Based and TiAl specimens with innovative coatings (both as-coated and after isothermal and cyclic oxidation testing)

2.3.3 *Materials & Other Operational Costs (category Op)*

Partner	WP	Estimated cost (kPLN)	Description
1 – Avio Polska (CO)	3	216	TAs Procurement
	4	475	TAs Procurement
	5	2.354	TAs Procurement
	5	864	TAs Procurement
	1-5	433	• Travels • Cost for dissemination
2 – Institute of Fluid Flow Machinery	3	259	• Academic licenses for NUMECA • Maintenance, consumables, small equipment • Travels
3 – Silesian University of Technology	4	301	• Materials for TAs • Dissemination of research results: meetings, conferences, publications and banners • License and tecs fees of the commercial software: eq. Ansys, LabView • Current completion of the hardware: PC's, computer cluster elements
	5	639	• Ceramics, plastic materials, electric components and consumable, • Components for construction and installation of a stand for cyclic oxidation tests, for coatings and for heat treatment, • Travel and training.
4 – Warsaw University of Technology	2	152	• Model and experimental instrumentation • Travel • Training
5 – Laboratorium Badań Napędów Lotniczych "Polonia Aero" Sp. Zo.o.	1	8.640	Test Articles procurement for Cold Flow Rig experimental validation (Test 1 on baseline Turbine & Test 2 on enhanced Turbine)
	1	2.160	Consumable for test

3. Impact

3.1 Expected impacts

3.1.1 Economic context

Global air traffic is forecast to grow at an average annual rate of 4.5 to 5% in the next 20 years. This high level of growth makes the need to address the environmental penalties of air traffic all the more urgent. Consequently, Europe's aviation industry faces a massive challenge to satisfy this growing demand whilst ensuring economic, safe and environmentally friendly air travel.
Engines are the main contributors to CO2 and NOx emissions from aircraft and are a large contributor of noise. The quantity of these harmful gases emitted into the atmosphere is controlled by operational factors as well as engine and aircraft design technologies. This is why ACARE specifies that the engine require a 15- 20% CO2 reduction when the overall aircraft (and operations) requires a 50% reduction. As well as the harmful environmental and societal effects of aircraft noise and pollution, there are operational restrictions on the airlines themselves in order to comply with national or local regulatory aspects such as landing quotas and night flights etc. with cost and impact for the industry.
Large investments have already been made in Europe and the US through R&D programmes and collaborations to reduce negative environmental effects of aircraft use and research is providing the technologies to improve the performance of existing engine components
Radically innovative engine structures and architectures need consequently to be investigated in order to achieve a more significant reduction of noise and pollution. Such reductions will only be achieved by reconsidering completely, in a first step the different key LPT technologies with innovative, breakthrough designs and in a second step in assembling and optimising these components in new LPT configuration.

Together with the need for further emissions reductions, a huge effort is required to maintain global leadership for aviation in Europe and meeting the needs of its citizens. Thus the top level objectives addressed by 'Flightpath 2050' are transposed in the Strategic Research and Innovation Agenda (SRIA) into five challenges:

- Challenge 1: Meeting market and societal needs
- Challenge 2: Maintaining and extending industrial leadership
- Challenge 3: Protecting the environment and the energy supply
- Challenge 4: Ensuring safety and security
- Challenge 5: Prioritising research, testing capabilities and education

COOPERNIK will directly answer this challenge by exploring, designing and testing innovative and enabling technologies needed to reach a reduction of fuel burn estimated around 1,5 % related to the state-of the-art (2012 engines)

3.1.2 Contribution to maintaining and extending industrial leadership

Aviation is vital for the self-sustainability of society. It supports jobs, investment and tourism as well as opening up the social and leisure benefits to all citizens wherever they live via the increasing use of regional airports. Air transport must remain economically feasible for the citizen who should not have to bear the full cost of environmental drawbacks via higher air flight prices.
Aviation is a key enabler in economic development, providing and enhancing access to both regional and global markets. It drives business, travel and tourism exports and it creates employment around the globe. Aviation also contributes greatly to raising living standards and alleviating poverty, which is conducive to less environmental degradation and a more sustainable society. Air transport provides 28 million jobs world-wide – and is expected to provide 31 million by 2015. The total economic impact of air transport on gross world output is at least 1150 billion

Euros. At European airports the combined direct and indirect employment generate 4000 jobs per million of passengers served. Furthermore the location of an airport has an impact on regional industry and businesses not to mention the tourist and leisure industry benefits which generates in Europe 700 million Euros per day. 40% of the world's goods trade is carried by air. It is therefore essential that the aviation industry is able to grow, as its benefits are economically and socially multi-fold.
In Europe the aero-engine industry alone directly employs 770004 people with many other jobs dependent on its success. COOPERNIK will play a key role in enabling polish manufacturers to consolidate their market share in a business now worth 10 billion Euros and forecast to treble over the next 20 years. This will encourage the development and growth of new and existing SMEs and at the same time, through reduced emissions facilitate sustainable growth via increased opportunities for more recreational travel and in improved quality of leisure time for citizens in Europe and around the world.

3.1.3 Reducing the fuel burn

In terms of numbers, in the next 20 years, Airbus foresees a demand of 28,200 new passenger and freight aircraft representing a market value of $4 trillion with a very large part in expanding regions. Boeing is even more optimistic with 34,000 aircraft in the same period.
In this market, operating costs are driving airlines to operate the most efficient aircraft. Low cost carriers are in particular driving a strong demand in this direction. These operators have made important optimisations of their process to reduce costs. Fuel prices are an almost unswayable factor to be mainly addressed by more efficient aircraft and engines: in 2001, fuel cost represented 13% of the total operating cost, now being around 33% and the forecast for 2031 is 40%.
Delivering the engine technologies that will reduce fuel consumption will consequently make the providers more competitive to maintain their position and to increase their leadership against newcomers who cannot break the technology barriers set out through decades of continuous investments in Europe.
In terms of financial impact for airline operators, the saving in fuel expected together with COOPERNIK along with on-going parallel initiatives should lead to significant operating cost reduction. For example, annual fuel for an A320 flying around 3,000 hours, 2 hours each flight, and a gallon at $ 2.90 (today's cost) represents a yearly fuel cost of about $ 8m18. A reduction of 1,5% in fuel consumption means a significant saving of about 50,000 gallons of fuel a year, a saving that will increase over the years with an ever increasing fuel price.

3.1.4 Contribution to protecting the environment

Air Transport is an important sector with good business growth opportunity but working in an increasing competitive market and with complex technological challenges to fulfill environmental goals.
This sector has put a lot of effort during the last decade to create a vision and strategic research agenda through ACARE, the Advisory Council for Aviation Research and Innovation in Europe. ACARE has established in common agreement with private and public EU stakeholders the "ACARE vision for 2020 " and now a revised "Strategic Research Agenda and a Vision beyond 2020 (Towards 2050)" which details the foreseen evolution of the sector. As a consequence the Aeronautics Sector in Europe is currently jointly working towards the main goals of:

1) Meeting societal & market needs developing a safe, reliable, affordable and quite future air transport system with a zero emission balance integrated in other transport modes to provide seamless transport to the European citizen.
2) Maintaining and extending industrial leadership in the worldwide competitive market.
3) Protecting the environment and the energy supply.
4) Ensuring safety and security.
5) Prioritizing research, testing capabilities & education.

COOPERNIK will focus on developing and validating system technologies for Low Pressure Turbines to improve the performance and to gain an high efficiency and responds to the impact expectation set out in the general EU programme. The overall target of COOPERNIK is to reduce fuel burn by up to 1,5%.

In particular, COOPERNIK indirectly contributes on the one hand to meet the citizens needs for mobility and on the other hand helps to increase the acceptance of such mobility impacts in local communities, extending industrial leadership in the worldwide competitive market with new entrants (China, India, Russia) and existing competitors (US, Brazil, Canada). The main goal of the aviation industry is to reduce aviation's environmental impact in the face of ever-increasing demand.

3.2 Dissemination, exploitation of project results, and management of intellectual property

Dissemination activities in COOPERNIK will take place at three main levels:

- Demonstrate the benefits for the citizen of collaborative R&T at European level in the aero engine sector, notably regarding environment and competitiveness,
- Publish scientific and technical papers in conferences, journals, web sites, etc. regarding the COOPERNIK technology,
- Establish a joint strategy with airframers about the future use of the COOPERNIK technology and expectations of users (airliners).

The COOPERNIK objectives in terms of dissemination and exploitation will be:

- develop and validate innovative system technologies for high efficiency LPT,
- develop the synergies between partners with the purpose to gather all results ,
- raise the awareness of the importance of COOPERNIK actions for further R&T, dissemination, regulation and collaboration activities to inform political people and to support NCBiR policies in this area,
- to ensure that the potential impact of the project will be achieved at industrial and societal levels. This objective will be achieved by implementing dissemination and communication measures towards and with the stakeholders,
- Draw a common roadmap for technology adoption with the different stakeholders to be able to produce engines incorporating,
- the COOPERNIK technology and meeting future environmental standards, get them accepted by airframers and airliners, and finally certified by certification authorities.

These objectives will be achieved through the following dissemination actions:
1. **Press campaign:** a high-profile pan-European press campaign will be set-up to communicate to the European citizens at large the expected impact of the innovative technologies on future air transport.

2. **COOPERNIK public website**: A public website will be set-up to present the main benefits from COOPERNIK in terms of
- Impact for the citizen regarding noise and gas emission,
- Technical and industrial achievements and
- Return of investment, i.e. demonstrating the importance of research spending at European level

3. **COOPERNIK Communication materials:** (posters, flyers, brochures, newsletters, etc.) for different target public levels from the general public (focusing on environmental issues) and for the aeronautics stakeholders (focusing on environmental benefits and cost saving) and the scientific community (focusing on innovative technologies).

All these documents will be made available on the web site and given away in the COOPERNIK workshop.

4. **Technology transfer:** actions will be done for the engineering and manufacturing departments of the European engine manufacturers and for their supply chain. This transfer will be done in the form of targeted workshops further to critical design reviews of the technologies of each sub-project. These actions will take place at work package level and will mainly aim at
- Informing them of the COOPERNIK technology component specifications and future needs from the engine manufacturers and
- Gaining feedback on potential fabrication and manufacturing possibilities and restraints associated to the COOPERNIK technologies.

5. **Scientific publications and presentations in key journals and aeronautic conferences:** In particular, the following conferences are targeted:

- Fluid Mechanics Conference 2014 (Kraków) and 2016, ASME Turbo Expo 2015,
- European Turbomachinery Conference 2015 and 2017, ASME Turbo Expo 2016
- International Conference on Metallurgical Coatings and Thin Films 2014
- International Conference on Metallurgical Coatings and Thin Films 2015
- International Conference on Metallurgical Coatings and Thin Films 2016
- International Conference on Metallurgical Coatings and Thin Films 2017
- Turbine Forum 2014
- Turbine Forum 2016
- EUROSUPERALLOYS 2014
- SUPERALOYS 2015
- EUROSUPERALLOYS 2016
- SUPERALOYS 2017
- ASME - Expo-turbo - 2014 Duesseldorf June 16-20 2014 and next edition in 2015, 2016 (every year until the end of the project)
- ETC - Europen Turbomachinery Conference –next - 11th in 2015 and next every two years

6. **Position papers:** The Innovation Management Team will be a major contributor as those position papers will be used to develop a vision of market evolution, to identify further steps towards industrialization and to get support of all stakeholders – industry, research organizations and public authorities.

7. **University training and PhD courses:** to be delivered by the universities involved in COOPERNIK: Silesian University of Technology, Institute of Fluid Flow Machinery, Air Force Institute of Technology, Warsaw University of Technology. Institute of Aeronautics and Applied Mechanics

8. **COOPERNIK output workshop for the aeronautical industry:** COOPERNIK will organize a dedicated technical workshop to present the main project results to the aeronautics industry and academia. This workshop should open discussions and further collaborations to address the next steps, mostly how to bring the technology to a higher TRL level and to further improve the results from the lessons learnt in the project.

9. **Participation to other workshops**: COOPERNIK will participate in workshop organized by other projects when relevant to COOPERNIK dissemination policy.

3.2.1 IPR Management

Intellectual Property Rights and all other legal issues will be defined through the Consortium Agreement.
The general principles are:

- "Background" : means all patents, designs, copyright (including copyright in software), database rights, know-how, proprietary information and any other intellectual property rights, excluding Foreground, in the field and which are necessary for the exploitation of Foreground in accordance with the Consortium Agreement.
- "Foreground" : means the results, including information, whether or not they can be protected, which are generated under the COOPERNIK project and regulated with the Consortium Agreement.

Related to IPR Management, the IPR Team will perform the following tasks:

1. **COOPERNIK exploitation and dissemination plans and knowledge portfolio management**: The subprojects will generate IPRs related to new foreground. Participants involved in COOPERNIK but possibly not directly in the same sub-project may need access to this foreground to perform their own research or for use.
   The IPR team will have the task to:
   - Collect information on the foreground generated in an COOPERNIK Knowledge Portfolio Agree, the standard access conditions within the project and for exploitation
   - Update accordingly the COOPERNIK Exploitation and dissemination plans
   - Monitoring the Foreground generated under the COOPERNIK Project.

2. **Knowledge protection**: The IPR Team will
   - Advise and support protection when required (patent, copyright, etc.)
   - Identify background: collect, update and maintain the list of the major background required to implement COOPERNIK.

3. **Publications**: the IPR Team will propose a general policy regarding publications and deliver authorization under the control of the Coordinator and the General Assembly.

4. **Consortium Agreement maintenance and evolution**: the IPR Team will maintain the Consortium Agreement and prepare corresponding decisions of the General Assembly, in particular, related to the modifications of the background, termination of participation and entrance of partners.

5. **Access rights and possible conflict resolution**: the IPR Team will
   - Handle and moderate discussions related to accessing the background and foreground to be granted according to the needed information to carry out the tasks involved in the work Packages.
   - More generally, moderate and propose fair solutions to any possible conflict related to IPRs.

3.2.2 Individual exploitation on partner level

All universities and research organizations involved in COOPERNIK in addition have common exploitation plans:

- Publications and patents related to COOPERNIK technologies,
- Use of the COOPERNIK generated knowledge for future research,
- Transfer of the generated knowledge and experience to industrial partners,
- Involvement in future projects for further related research, including commercial projects,
- Training and consulting for the aeronautics industry,
- Strengthening of collaborations with the industry,
- Enhanced visibility in the aviation and in particular aero engine sector.