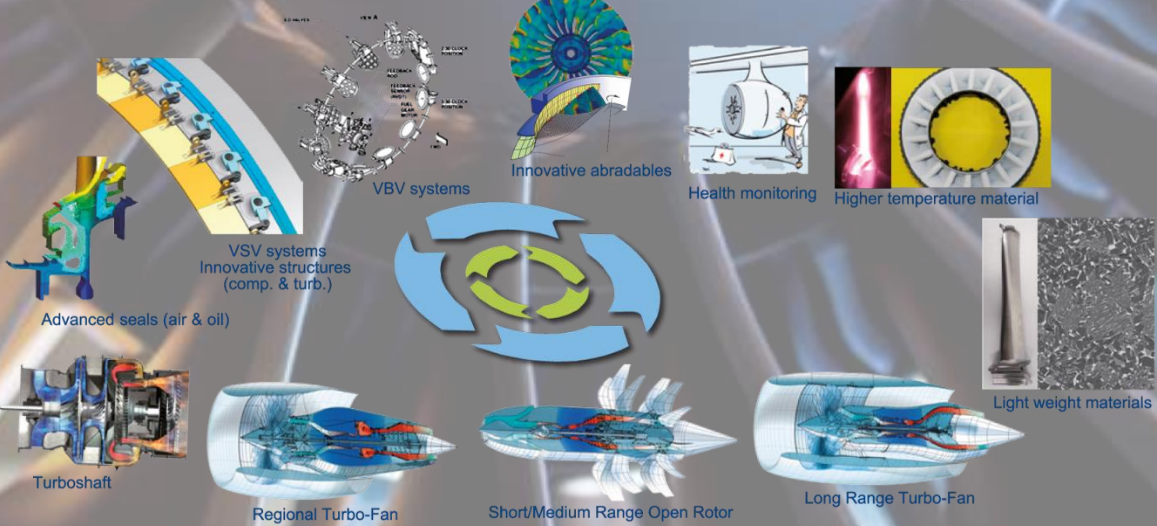
E-BREAK

ENGINE BREAKTHROUGH COMPONENTS AND SUBSYSTEMS

Project Summary Handbook



SEVENTH FRAMEWORK PROGRAMME

Collaborative Project co-funded by the European Commission within the **7th Framework Programme** (2007-2013),
Under Grant Agreement n°ACP2-GA-2012-314366-E-BREAK

PREFACE - FOREWORDS

Congratulations! You have in your hands the Technology Handbook of the European E-BREAK project. The purpose of this document is to disseminate the technical results of the project, how they will affect new engine performance and to give an understanding where the programme came from and the main results achieved.

The aeronautical industry will become increasingly environmentally friendly in the future both in terms of its products and its operations. Aviation currently accounts for 2% of global CO_2 emissions (but 12% of transport emissions) and this figure is expected to grow significantly. This will happen both through continued growth in air travel at a rate of circa 4% per year and secondly because of the continued dependence of the aircraft fleet on oil based fuels while other transport modes are able to more easily switch to "greener" technologies such as batteries and fuel cells. The need to reduce the contributions to these figures has increased the pressure on the aeronautical industry and on engine manufacturers in particular to maximise the efficiency of their products in service and increase the efficiency still further in future products. In Europe these industry aspirations towards greener operations are embodied in the ACARE 2020 targets (50% reduction per passenger kilometre for CO_2 and fuel consumption with an engine contribution of 15 to 20% and NO_x reduction by 80%) and the extension to these horizons in ACARE FlightPath 2050.

For the reasons discussed above and to reduce fuel consumption engine manufacturers are constantly aiming to improve gas turbine efficiency and operational robustness. The drive towards more efficient and reliable engines has resulted in a move toward smaller engine cores (core size has reduced by 50% in 10 years, for a given class of engine) which run hotter and faster at higher pressure ratios and which have longer times between scheduled maintenance. To further improve propulsive efficiency, the by-pass mass flow has also been increasing and hence the fan diameter as well.

Within Europe a number of initiatives and many research programmes have been directed at addressing the technology requirements for meeting these targets such as FP7 and Horizon 2020. Activities within these programmes includes projects for the development of new technologies enabling the design of core components for engines with Ultra-High Overall Pressure Ratio (UHOPR) to increase thermal efficiency and a higher By-Pass Ratio (BPR) to increase propulsive efficiency.

E-BREAK was initiated by the EIMG which coordinates the views of European aero-engines manufacturers; it also involves Europe's leading research institutions as well as SMEs in the field of aeronautics providing innovative and sustainable technologies. E-BREAK dealt with the sub-systems necessary to support the new core engine specifications defined in projects such as LEMCOTEC and NEWAC. It has enabled the future integrated development for Ultra-High OPR engines with adapted and robust sub-systems. It also completed the map of technologies required for UHOPR engine and high BPR engine competitiveness in terms of the reliability and maintainability of the engine. Development *of these new technologies enabled an additional reduction of* CO_2 *emission compared to the 2000 engine generation.*

E-BREAK developed many technology 'bricks' from low Technical Readiness Levels (TRLs) to higher ones where they could be progressed within new engine programmes. These 'bricks' included technologies for compressors, turbines, health management and the sub-systems of the engine core. They are a valuable step to ensure the technical compatibility of a new generation of engine sub-systems with the increased temperature, pressure and mass constraints of future engines imposed by the ACARE targets and related goals.

The E-BREAK project culminated in its Final Workshop at the end of March 2017. This meeting coincided almost exactly with the anniversary of the Treaty of Rome, signed on 25th March 1957. European policies over the past 60 years have helped to build a prosperous economy: monetary stability, a single market that allows free movement of goods, capital, services and people, ambitious research and innovation programs and lastly high standards of environmental protection. European research and innovation programmes such as 'Horizon 2020' and its Clean Sky technology program are outstanding drivers to carry out research to develop the aircraft engines and systems of tomorrow, which will contribute to the arrival of aircraft that are: quieter, cleaner, more fuel efficient, more electric and more economical. In a fast-paced world that is undergoing profound changes, the European Union is contributing to stability and prosperity - a double achievement that must absolutely be preserved.

In conclusion E-BREAK was not only an important technical success, contributing to the long path towards more efficient and environmentally friendly aero-engines, but above all a great human adventure which not only to increased European aerospace industry's leadership and competitiveness, but also helped industry to be more respectful of the environment and therefore of European citizens. Collaborative projects like E-BREAK are a demonstration of what Europe can achieve at its best.

This technology handbook is the opportunity to give an overview of the project objectives and achievements, reflecting the comprehensive work performed during over four and a half years, by 41 highly skilled and committed partners with complementarity expertise, all key players in the aero engine field.

We hope you will find useful information and that you will enjoy reading this handbook as much as we enjoyed working together and compiling the information for you.

Manuel Silva,
E-BREAK Coordinator and Chief Engineer, SAFRAN Helicopter Engines

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ENGINE BREAKTHROUGH COMPONENTS AND SUBSYSTEMS

At SAFRAN Helicopter Engines we look to the future and strive to continually improve the performance and quality of our engines, reducing CO_2 and NO_x emissions and improving power-to-weight ratios. It is a pleasure to see tangible results when looking at our new model engines which, as a direct result of our efforts, generate fuel savings of up to 15% when compared to our existing engines.

To achieve these results, research, especially collaborative research programs like Europe's Clean Sky project, are essential. Clean Sky has contributed a great deal to the success of our Arrano engine.

E-BREAK was a key cooperative step towards the new generation of engines. Through this European project, started in 2012, the partners have studied new technologies to increase the performance of components, subsystems, or materials that held the keys to greener and more efficient engines.

The results are very encouraging and we at SAFRAN Helicopter Engines are very proud to have been selected to coordinate the project. Collaboration is key to innovation, together, our ideas become better and can be implemented sooner. We are grateful to the European Union for allowing us this opportunity and we look forward to other new projects of this kind.

Bruno Even,
President, SAFRAN Helicopter Engines

The results of the EU co-funded FP7 project, E-BREAK, will contribute to making future aircraft more environmental friendly in terms of their greenhouse gas emissions and noise. Support for such endeavours, reflects the priorities of the European Commission, in terms of energy and climate, but also for jobs and growth.

Many of the E-BREAK partners are also contributing to related FP7 projects – such as the still on-going LEMCOTEC, ENOVAL and JERONIMO projects – and were also partners in finished projects – e.g. OPENAIR, SILENCER, DREAM and VITAL.

All these EU co-funded projects are examples, amongst thousands, of how combining complementary competencies can lead to innovation and better products.

While continuing to bear IPR issues in mind, E-BREAK has enabled collaboration on specific subjects between competing industrial organisations.

In addition, such programmes permit the recruitment of young researchers; their involvement in various branches of applied research complements their education.

One difficulty encountered in such technical projects is communication: how is it possible to make the general public – i.e. the tax payers – aware of the positive results that have been co-funded by the European research programmes? We are grateful to E-BREAK for having extended its communication policy beyond the readers of scientific and technical reviews and for having taken resolute steps in communicating to the general public.

Christiane Bruynooghe
Policy Officer for E-BREAK, Direction of Research and Innovation, European Commission

The closure of the E-BREAK project with its Final Workshop in March 2017 coincided almost exactly with the Closing Event of the Clean Sky 1 Programme.
Beyond a large number of aircraft, helicopter or systems demonstrators, Clean Sky 1 focused also largely on the propulsion system development through SAGE, the Sustainable And Green Engines ITD, with over 200 M€ of EU funding over the last 8 years.
SAGE has delivered 6 Engine Projects with 5 Full-Scale Demonstrators already tested or to be completed shortly: a Ground Test of a Geared Pusher Open Rotor concept (SAFRAN), a Ground Test and Flight Test of the Advanced Low Pressure Composite Fan system (Rolls-Royce) on a large 3-shaft Turbofan, a Ground Test of a Geared Turbofan (MTU), a Ground Test of an advanced Turboshaft (SAFRAN Helicopter Engines) and a Ground and Flight Test planned for the Lean Burn Combustion system (Rolls-Royce).
Of course, most of the technology bricks, necessary for the successful demonstration of these advanced propulsion systems are coming together now, but have been initiated years ago, also thanks to the sustained research carried out by the whole European engine industry through the EU Collaborative Research Projects. To name a few : back in FP5 with CLEAN/ANTLE, but more specifically, NEWAC (FP6) and LEMCOTEC (FP7) for Core Engine Technologies, or VITAL (FP6), DREAM (FP7) and ENOVAL (FP7) on Low Pressure Spool and New Engine Architecture Concepts, SILENCER (FP5) and OPENAIR (FP7) for Noise Reduction Technologies.
Still, with the increasing trend to higher BPR and in particular higher OPR concepts, few attention had been brought so far to the engine sub-systems and E-BREAK was really the "missing link" in this development chain. Significant advances were/are needed in materials, sealings, variable systems, heat management, oil systems, control and monitoring systems.
Again, familiar "keywords" when it comes to Clean Sky 2, already focusing on the next generation engines – with even higher by-pass ratios and higher OPR – , and where the technologies developed within E-BREAK will absolutely have to be implemented on the demonstrators to guarantee their successful validation.
So I am very glad to take this opportunity, not only to thank Manuel for his brilliant coordination of the project and the entire E-BREAK Consortium for the excellent work, but for this excellent initiative to publish this book of technologies !
Dissemination is indeed a very important aspect of research through various means of publications, but beyond those, and beyond the several hundreds of deliverables which have been submitted to track the project and store the knowledge, this book of technologies will be "the one" to keep in the bookshelf as the summary of the E-BREAK achievements.
Well done ! And Congratulations to all of you who have contributed to this success !
Jean-François Brouckaert,
Project Officer for SAGE and Engine ITDs, Clean Sky Joint Undertaking

The E-BREAK project is an important cornerstone on the journey to further improve the efficiency of aero-engines and therefore reduce CO_2 and NO_x emissions.

Due to its size and huge European partnership (Level 2), joining engine companies with the supply chain, Universities and Research Institutes, it has been possible to close significant technology gaps regarding components and subsystems for future Ultra-High Overall Pressure Ratio engines by validating these technologies in relevant environments (TRL 5).

E-BREAK and other FP7 aero-engine projects of this level together with national programmes are bridging the gap between pre-competitive research and demonstrators on system or subsystem level, executed in the Clean Sky programme.

With this, technologies are driven to a maturity level ready to be taken over by engine development programmes (TRL 6) and finally introduced in safer aircrafts and helicopters with improved performance and environmental footprint.

Dr.-Ing. Uwe Hessler,
Chairman of the Engine Industry Management Group (EIMG),
Chairman of the IMG4 from the Aerospace & Defence Industries Association of Europe (ASD),
Rolls-Royce Deutschland

People transportation by air is at the heart of Airbus activities since decades. The world population is showing a clear trend toward urban location. As a result, the number and the size of the mega cities are getting larger.

People transportation within these cities is a teething issue. Vahana and CityAirbus / Pop.Up projects are addressing this urban mobility challenge by the mean of autonomous air vehicles. These are full electric concepts adapted to short distance operation with minimum environmental impact. This is a dream for me each time I am stuck in a traffic jam and I look up to the third dimension. I hope this dream will soon become reality at an affordable cost and with the highest safety standards.

Distant city to city air transportation requires more range and higher speed. This should still rely, in the next decades, on large aircrafts requiring highly reliable, low weight and large thrust propulsion systems. As an ordinary traveller, I expect that the formidable chance I have of being able to travel the world at a reasonable cost will continue to exist and even develop.

Airbus market analysis forecasts a doubling of aircraft fleet by 2030. This would have meant also a doubling of aviation environmental impact if no further progress was done on this aspect. This, in itself, justifies the absolute need for developing quieter, lighter, low pollutant and low consumption propulsion systems which will be fitted to lighter and more efficient airframes.

These objectives, with others, are significant ones for ACARE 2020 and have been further reinforced in Flightpath 2050. The targeted improvements are very challenging and require to be worked actively and jointly by all aviation partners. This environmental focus is extremely important for me, as a citizen, but also as a member of the Aircraft industry since this is a key driver of future product design and competitiveness.

The European Commission aviation research projects, and more particularly propulsion research projects, have demonstrated their exceptional ability to bring Europe partners together and in providing the necessary support for the development of innovative technologies.

In this context, E-BREAK project has performed a remarkable task in the domain of propulsion sub systems. Usually, we say that the "devil is in the details" and this sound very true when considering the cores of gas turbines. High bypass, high pressure, high temperature, highly reliable engines would not be possible without significant advances in materials, sealings, variables, heat management, oil, control and monitoring systems.

E-BREAK successfully addressed all these disciplines and I am convinced that the results of this research project will be extremely valuable for the next generation propulsion systems and in our joint effort to meet Flightpath 2050 objectives.

Beyond the technical success, E-BREAK is a perfect example of how European Commission research projects create durable links in between industrial, research and academic partners. I strongly hope that this constructive and collaborative spirit will be maintained and even further developed in the future for the benefit of an environmentally responsible and healthy commercial aviation.

Philippe Mogilka,
Senior Expert in Propulsion Technology and R&T Manager, AIRBUS

With 41 partners from 10 countries the E-BREAK project is a brilliant example for successful EU funded collaborative research in Europe. Thanks to the Level 2 funding instrument in FP7 it is possible to bring together a relevant number of stakeholders from industry, research, academia and SMEs, jointly working together on significant research topics. Creating a critical mass and combining different knowledge and skills is the key to successfully solve ambitious research issues as done in the E-BREAK project.

Furthermore, integrated projects like E-BREAK are an important part of the whole research and development chain: Building on lower TRL Level 1 projects, their results are feeding into the higher TRL Demonstrator Programmes like "Clean Sky". It is obvious that without this type of project there would be a significant gap in the research chain, leading to a lack of "building blocks" for the next Demonstrator Programmes in the mid- and long-term.

Both aspects, building successful consortia as well as ensuring the existence of the whole research chain is of high importance for the Research Establishments. The EREA partners built up significant knowledge, skills and research infrastructures using institutional, national and European funding. With their position between universities, looking at lower TRL and industry, more focusing on higher TRL research they play an important role in bridging the gap between basic research and the industrial Demonstrator Programmes. Projects like E-BREAK provide a perfect platform for the Research Establishments to share these competences in order to support the European aeronautics research.

Volker Krajenski,
Chairman of the Association of European Research Establishments in Aeronautics (EREA ARG), Program Directorate Aeronautics, German Aerospace Center, DLR

The world of aeronautical propulsion has been constantly evolving for several decades. However, many scientific challenges are still ahead of us.

Scientific objectives of E-BREAK were ambitious: increasing the TRL of technology modules is not a usual occurrence within a classical academic context. Such goals motivate us to continuously innovate with thoroughness imposed by research requirements, while constantly looking further towards the industrial application. The research actions conducted in full complementary result in partnerships that often go beyond the scope of the program itself. E-BREAK provided the opportunity for fruitful meetings, first of all on the scientific field between companies and academic partners, in order to discuss and deal with a common problem.

These are encounters between men and women who prepare the technological future of our disciplines, who provide an upstream consolidation of the scientific bases and who ultimately industrialise them, with a common driver to contribute to reduction of polluting emissions impact on the planet. For us, researchers, it is also an opportunity to include both students and young researchers in the actions that are being carried out. We are very proud to have participated in this program, not only for the work done by the research team, the obtained results, the links we have forged with new partners or the ones we have strengthened with the existing ones, but also for the emergence of young talents able to meet high-level scientific ambitions of future programs which is one of the mission of ISAE-SUPAERO at the crossroads between research, training and industrial partnerships

Prof. Xavier Carbonneau
Turbomachine and Propulsion Leader, Aerodynamics, Energetics and Propulsion Department, ISAE-Supaéro

In our day-to-day business, ÅAC Microtec provides high value space solutions and systems to commercial and institutional customers in the global market. As a specialist company, our focus has been on the development of advanced and robust, fault-tolerant designs for critical space applications. Our design experience in dealing with environmental extremities, encountered regularly in space, has provided a key advantage in dealing with the demanding application of greener and more efficient aircraft engines in the E-BREAK programme.

To ÅAC Microtec, E-BREAK has been a valuable collaboration with both the research community and the larger companies in the consortium. The collaboration with Uppsala University's technical team facilitates access to specific technical expertise, while the access to market available to the larger companies in the consortium facilitates access to potential end users and customers, allowing us to develop new products at a lower risk.

Even though our expertise in this programme lies within the miniaturisation of electronics for the space industry, this work has been a great opportunity for us, as an SME, to develop new products for new markets and, leverage existing products in a new field of applications. Working with the E-BREAK team has proved that our products' robustness and versatility in harsh environments can be adapted to provide significant value in new areas of usage.

As a partner in E-BREAK, ÅAC Microtec has strengthened its collaboration network in the aerospace sector and helped us develop further our expertise in sensor and actuator systems for structure monitoring. Working with the larger companies in the consortium has opened new markets for us and established the basis for future collaborations and partnerships.

Mats Thideman,
Chief Executive Officer, ÅAC Microtec AB (SME)

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Cenaero, considered as an SME by the European Commission, is an applied research centre providing to any company, involved in a technology innovation process, high fidelity numerical simulation methods and tools to design more competitive products. Research partner of SAFRAN since 2007, Cenaero is a growing team of 50+ highly skilled engineers and scientists specialized in numerical methods, materials and process modelling, computational fluid dynamics, physics and applied mathematics.

Building upon a longstanding experience in collaborative research at European level, Cenaero has been active in respectively 17 FP6 projects and 24 FP7 projects (one of which, ENOVAL, is still running) and is presently contributing to 5 H2020 projects, 3 of which in the framework of the Clean Sky 2 JTI. These project contributions represent today in the order of 10% of the company's turnover.

The main benefits reaped from the participation in European consortia are both the strengthening of existing academic and industrial partnerships and the relationships established with new partners, as well as visibility and business development opportunities.

In line with its turbomachinery simulation and design expertise built and demonstrated more specifically within its contributions to the VITAL and NEWAC FP6 projects and the DREAM FP7 project, Cenaero contributed to the SP3 of the E-BREAK project through the numerical analysis, in cooperation with SAFRAN AB, of stability enhancement features. More specifically, casing treatments have been numerically assessed for highly loaded boosters so as to support their design and selection.

Next to the Clean Sky JTI, whose 3 complementary instruments (Innovative Technologies, Concept Aircraft and Demonstration Programmes) aim at determining the true potential of selected technologies, brought to a high level of maturity (TRL>6, which is the highest TRL achievable in research) through a realistic environmental assessment, it is worth underling how essential level 1 and 2 projects such as E-BREAK are for innovation, as they are key instruments to support low TRL research, fostering the emergence of breakthrough technologies.

Ingrid Lepot,
Research and Technology Manager, CENAERO (SME)

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Collaborative Project co-funded by the European Commission within the 7th **Framework Programme** (2007-2013),
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E-BREAK RATIONALE

Future aero-engines will need to be more efficient and contribute to the reduction of the environmental impact of air transportation. They must reach the highest standards of performance by reducing emissions and creating savings in operation costs.

Over a number of years the Engine Industry Management Group (EIMG) has launched a number of initiatives to develop future engines within the frame of the European committee research programs.

With many different projects, such as DREAM, VITAL, NEWAC, LEMCOTEC or ENOVAL, EIMG is ensuring the development of innovative technologies in order to reduce fuel burn, emissions and noise (see Engine Industry Research and Development (R&D) Technology Roadmap in the following page).

In order to ensure the technological breakthroughs required to achieve the impacts described above, future aero-engines will have higher overall pressure ratios (OPR) to increase thermal efficiency and higher bypass ratios (BPR) to increase propulsive efficiency. These changes lead to smaller and hotter high pressure cores.

The engine technologies required to increase propulsive efficiency have been addressed in the previous projects listed above. E-BREAK ensures the evolution of the sub-systems' technologies required to adapt to the new constraints of higher temperatures and pressures in the engine core.

The overall goal of these initiatives is to bring all of the technology bricks to a TRL level ensuring that it is possible to integrate them into a new aero-engine generation prior to 2020.

In its 2020 vision the Advisory Council for Aeronautics Research in Europe (ACARE) aims to reduce CO_2 emissions by 50% per passenger kilometre with an engine contribution targeting a decrease by 15 to 20% of the Specific Fuel Consumption (SFC). NO_X emissions will have to be reduced by 80 % and efforts need to be made for other emissions.

E-BREAK is an enabler for the future Ultra-High Overall Pressure Ratio (UHOPR) integrated engine development, completing the efforts of previous or on-going Level 2 programs.

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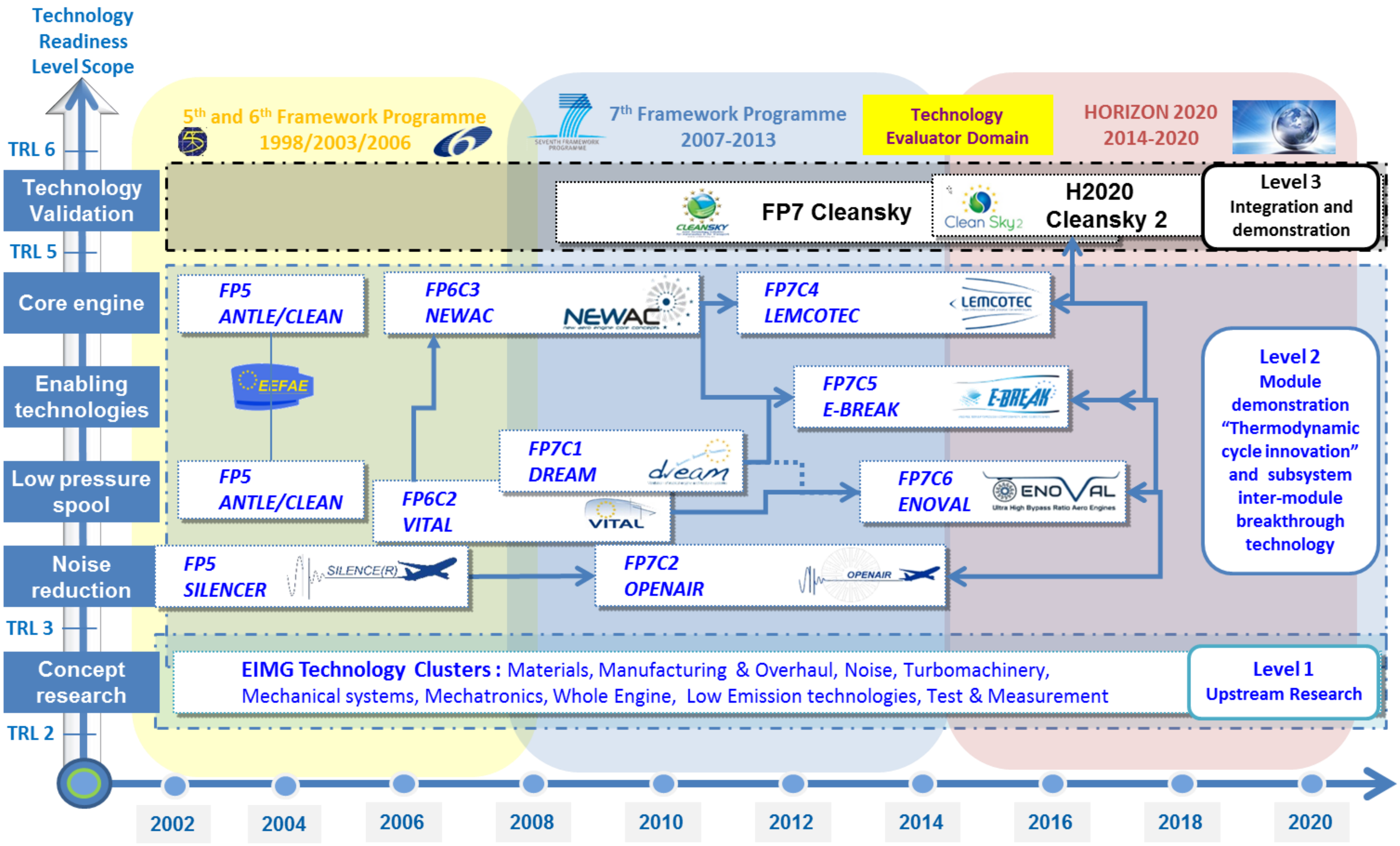
Engine Industry R&D Technology Roadmap: Cooperative EU-funded projects and E-BREAK interrelations with other projects



E-BREAK OBJECTIVES

The main objective of E-BREAK is to develop and validate adapted generic technologies and robust sub-systems and minimise the losses that occur as engine cores get smaller so that the fundamental gains from higher Turbine Entry Temperature (TET), OPR and BPR are realised in an engine environment.

The other E-BREAK objectives are:

1. To bring all those mandatory enabling sub-systems technologies up to TRL 5
2. To provide an additional benefit in CO_2 emissions reduction regarding year 2000 engines, for the most favourable engine/aircraft application and taking into account all past or on-going Research and Technology (R&T) programs. This objective goes beyond ACARE goal.

In order to achieve these objectives, E-BREAK targets sub-system breakthrough technologies through improvements regarding weight, material performance, leakages, clearances for aerofoils, seals and stability of the engine in off-design operations.

Thus, specific technologies are matured within E-BREAK to address and enable solutions on:

- Advanced sealing technologies and oil systems
- Engine variability and thermo-mechanical behaviour
- Health monitoring
- High temperature materials and abradables
- Lighter materials

To reach these technologies E-BREAK called upon a highly skilled consortium gathering together all of the key players of the aero-engine field. The consortium members have been working together for several years through the collaborative projects mentioned in the previous section. E-BREAK also integrates SME and universities with very specific skills required for the development or test of the technologies tackled.

E-BREAK is therefore shaped to develop, validate and integrate specific key subsystem technologies required for UHOPR applications and High Bypass Ratio (HBR) engines up to technology readiness levels of 4 to 5 for compressors, turbines as well as transmission and distributed systems. These technology bricks will afford a valuable step to ensuring the technical compatibility of new generation sub-systems with the increased temperature, pressure and mass constraints of the future engines.

E-BREAK is also intended to keep the European aerospace industry in a leadership position regarding the development, integration and validation of highly efficient and safe aero-engines for the next decades.

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ENGINE BREAKTHROUGH COMPONENTS AND SUBSYSTEMS

European Consortium

The E-BREAK project consortium is composed of 41 partners with complementary resources and skills. The list of partners is available on the E-BREAK public website www.e-break.eu and at the end of this document. Additionally, small and medium enterprises are involved as subcontractors to the partners. 10 European Union (EU) countries are represented in the consortium (Belgium, France, Germany, Italy, Netherland, Poland, Spain, Sweden, Switzerland and United Kingdom).

E-BREAK is coordinated by SAFRAN HELICOPTER ENGINES. The project has a budget of 30 million euros. The research work involves 2,246 person months of effort and 28 test rig facilities of varying complexity (material characterisation to engine test bench) used for technology investigation and validation. The duration of the programme is 54 months (1st October 2012 to 30th March 2017).

STRUCTURE OF THE PROJECT

Managing a project of this scope and ambition required the implementation of monitoring tools, procedures and effective communication between the different partners in order to review and monitor the progress of the highly complex, various and interdependent R&D activities and stakeholders.

E-BREAK is part of continuous European research efforts and a major contributor to the European Engine Industry R&D Technology Roadmap shown earlier. Another key E-BREAK activity is to promote successful uptake and exploitation of results by the European aero-engine industry and its supply chain. To facilitate this, a major dissemination event was held in Brussels in March 2015. During this event named the European Technological Transfer Workshop engine manufacturers, airframers (amongst which was Airbus), National Research Clusters from several EU countries and the European Commission were briefed on the outputs of the project as a result of which had a fruitful exchange on the benefits of E-BREAK and other European collaborative projects. It has been highlighted that in FP7, Level 2 projects developing subsystem technologies (up to TRL 5) were key projects for closing the technological gap between the results provided by Level 1 projects based on applied research (up to TRL3) and the Level 3 Clean Sky Joint Technology Initiative on technology demonstration (TRL6). E-BREAK is a Level 2 project, structured in six technical and one coordinating subprojects. The coordinator is the interface to the European Commission`s Project Officer.

Final Meeting 21st of March 2017 in Bordes, France, SAFRAN Helicopter Engines

The structure of the E-BREAK project is shown in the figure next page.


EUROPEAN COMMISSION
SP7 - Project Management
Project Office :
Julie Charbonneau
Alcimed
Coordinator : Manuel Silva
SAFRAN
General Assembly
all partners
(one partner one vote)
Executive
Management Board
-- SP Coordinators --
IPR Advisory Team
Knowledge Portfolio
Exploitation &
Dissemination Plan
SP1 Leader
Nicolas Tantot
SAFRAN
Overall Specification and Engine Assessment
SP2 Leader
Michael Walsh
UK
Advanced Sealing systems
SP3 Leader
Erik Johann & Thomas Klauke
Deutschland
Engine variability and thermomechanical behaviour
SP4 Leader
S. Selezneff
SAFRAN
Higher temperature material for breakthrough components
SP5 Leader
M. Coppola
Avio Aero
Lightweight materials for breakthrough components
SP6 Leader
André Kando
MTU Aero Engines
Health monitoring

POWER PLANT PLATFORMS

Consistent assessment of E-BREAK technologies and concept benefits with respect to overall project objectives requires the definition of representative aircraft application targets, and corresponding power plant systems. To do so, four target power plant systems are considered in order to cover the following range of engine OPR:

- Helicopter turboshaft power plant (OPR ~ 20)
- Regional turbofan power plant (OPR ~ 50)
- Medium range open rotor power plant (OPR ~ 60)
- Long range turbofan power plant (OPR ~ 70)

These power plant systems answer a consistent set of requirements based on three aircraft application platforms and one helicopter platform:

- Medium weight transport helicopter
- Regional underwing turbofan aircraft
- Medium range rear fuselage open rotor aircraft (inherited from DREAM FP7 project)
- Long range underwing turbofan aircraft (inherited from VITAL FP6 project)

The last three platforms are common with the ones used in the LEMCOTEC project, in order to maximize consistency and capability to crosscheck the outcomes of these two closely related projects.

These airframe platforms feature technology levels that are in line with the ACARE targets approach, i.e. representative of "in service year 2000" technology state of the art.

The corresponding power plants have been designed in order to be representative of a 2020 entry-into-service technology target, which is consistent with E-BREAK technologies maturation ambition. The application of these E-BREAK target platforms on the reference airframe platforms enables extracting the "engine only" impact of each E-BREAK target platform, against which the project targets are defined.

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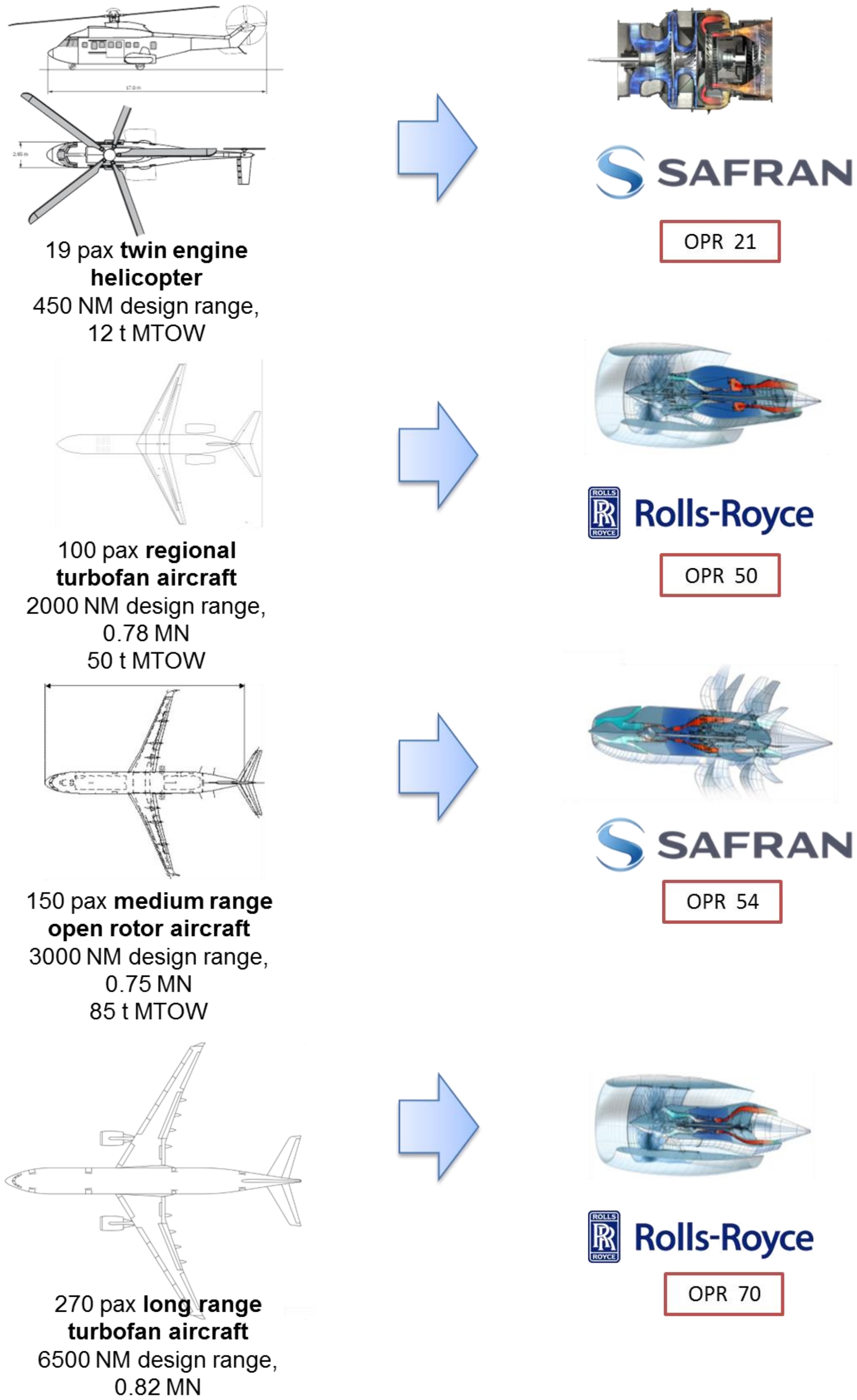
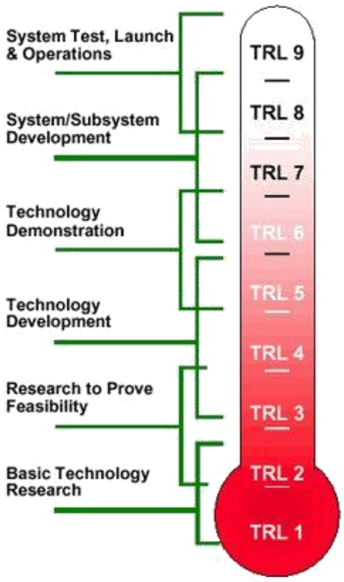
ENGINE BREAKTHROUGH COMPONENTS AND SUBSYSTEMS



KEY DEFINITIONS

Technology Readiness Level



TRL 9 Actual system "flight proven" through successful mission operations
TRL 8 Actual system completed and "flight qualified" through test and demonstration (ground or flight)
TRL 7 System prototype demonstration in "real" environment (i.e. bench engine)
TRL 6 System/subsystem model or prototype demonstration in a relevant environment (i.e. core engine)
TRL 5 Component and/or breadboard validation in relevant environment
TRL 4 Component and/or breadboard validation in laboratory environment
TRL 3 Analytical and experimental critical function and/or characteristic proof-of concept
TRL 2 Technology concept and/or application formulated (report)
TRL 1 Basic principles observed and reported

Technology Applicability to the engine platforms


Technology applicable to the engine platform


Technology potentially applicable to the engine platform


Technology not applicable to the engine platform

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SEVENTH FRAMEWORK PROGRAMME

SP2 RELATED TECHNOLOGIES - Advanced Sealing systems

SP2 Objectives

The work of E-BREAK is to provide enabling technologies to support the new aero-engine architectures which address the ACARE emissions targets.

In order to meet the targets new engine architectures are expected to have higher OPR and BPR. These changes will increase thermal cycle temperatures and the changes will have profound effects on the design of both the secondary air system and the oil system.

The changes above drive the objectives of SP2, foremost of which is to reduce parasitic losses in the air system and hence reduce SFC thus the emphasis on sealing, there is also a need to reduce the weight of systems and for components (including oil) to operate at higher temperatures.

SP2 Advanced Sealing Systems is intended to address the enabling technologies which are required to ensure that the secondary air and oil systems are able to support the new engine architectures. The SP is divided into two distinct parts WP2.1 which addresses air systems, primarily sealing but also thermal shielding and WP2.2 which addresses oil systems.

In addition to the very clear architecture based objectives above there has been a strong desire among the partners to move to more physics based design methods for the various elements of the air and oil systems. Specifically throughout SP2 most of the tasks have involved the development of physics based behavioural models of a process or component and then test and validate that model using experimental measurement on rigs. The drivers for this approach being desire to achieve better design methods which are quicker to use and result in more reliable designs.

Secondary Air Systems (WP2.1)

The secondary air system has several functions including buffering of bearing chambers and thermal shielding of various components.

The focus of the technology development within this part of SP2 was on various methods of air sealing improvement including:

- Piston seal stability
- Advanced brush seals
- Air-Riding Flexible Seal
- Optimisation of carbon seals

In addition to the work on sealing improvement there was also an objective to improve the thermal shielding of rotative parts.

Oil Systems (WP2.2)

Most of the gas turbine engine oil is used as a heat transfer medium for the key elements of the bearing chambers in the engine core, that is to say the bearings and gears. The quantity of oil required to lubricate these elements is very much smaller. A significant driver for some of the work in WP2.2 has been the fact that the temperature in the core will rise in new architectures and the rate of oil degradation will increase hence an objective to better understand the way oil degrades.

There were three technological objectives in WP2.2:

- Optimise breather operation
- Modeling oil flow in bearing chambers
- Oil lifing

Collaborative Project co-funded by the European Commission within the **7th Framework Programme** (2007-2013),
Under Grant Agreement n°ACP2-GA-2012-314366-E-BREAK

SP2 Summary of achievements

In addition to the very clear architecture based objectives described in the section above there has been a strong desire among the partners to move to more physics based design methods for the various elements of the air and oil systems. Specifically throughout SP2 most of the tasks have involved the development of physics based behavioural models of a process or component and then test and validate that model using experimental measurement on rigs. The drivers for this approach being desire to achieve better design methods which are quicker to use and result in more reliable designs.

Secondary Air Systems (WP2.1)

Considerable advances have been made across the whole of the secondary air system in developing validated physics based models of key design phenomena in the areas of:

- Piston seal stability
- Advanced brush seals
- Air-Riding Flexible Seal
- Optimisation of carbon seals
- Thermal shielding of rotative parts.

In most of these activities the approach has included the development of a physics based model of the design behaviour being looked at, the construction of an experimental rig followed by an experimental campaign to capture data for the validation of the physical model and in some instances design data. The models are then validated against the experimental results.

Oil Systems (WP2.2)

Most of the gas turbine engine oil is used as a heat transfer medium for the key elements of the bearing chambers in the engine core, that is to say the bearings and gears. The quantity of oil required to lubricate these elements is very much smaller. Three key activities have been addressed in the programme. These were

- To optimise breather operation. This was achieved by two experimental programmes, one for foam-based breathers and one for vane type breathers. Both of these experimental campaigns were supported by CFD modeling exercises. One of the CFD approaches looked at micro-scale modeling of the metal foam. The other CFD approaches looked at large scale modeling of both vane and foam separators.
- Modeling oil flow in bearing chambers. Several approaches to the CFD and SPH modeling of bearing chambers were employed by the partners. These included mixture models, Volume of Fluid (VoF) and thin film modeling. One of the approaches, thin film modeling has been incorporated in to a commercial CFD code. Heat transfer coefficients have been measured for bearing chamber walls and compared with those calculated with CFD. An engine test has been used to obtain thermal data and validate thermal models of the bearing chamber.
- Oil lifing. A new protocol for the experimental determination of oil degradation has been proposed.

Shielded LP turbine discs

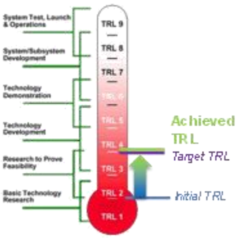
Partners involved

CTA

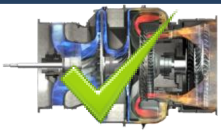
ITP the power of talent

Description

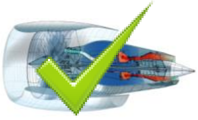
Advanced Shielding of Rotative Parts



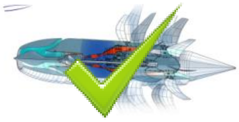
Ref: E-Break initial status / TRL	Initial E-Break objective	Final status
SFC impact	-0.3%	-0.3%
PPS weight impact	--	--
TRL progress	2→4	4



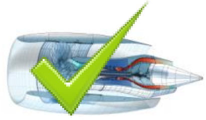
Turboshaft



Regional Turbofan

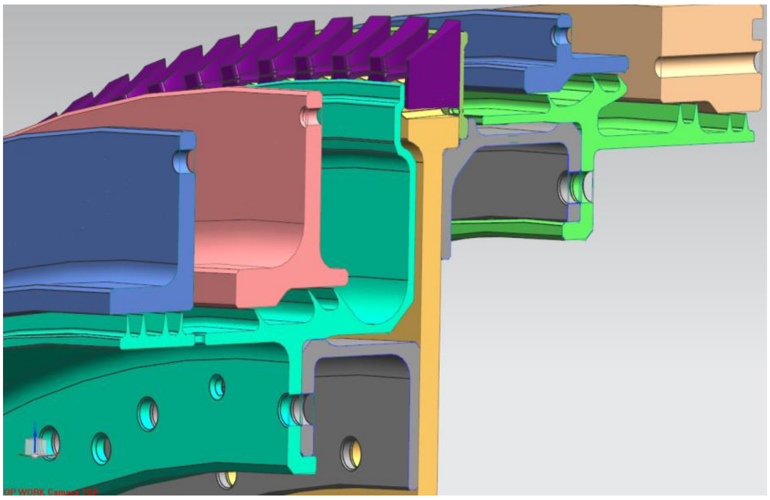


Short/Medium Range Open Rotor

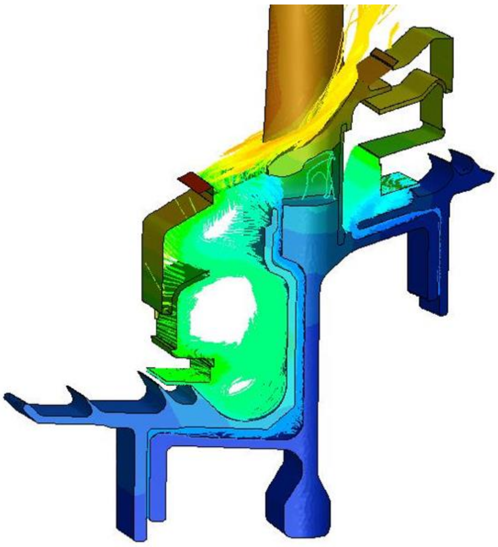


Long Range Turbofan

- **Rationale/Main achievements:**
  - **Review of technology state-of-the-art and Concept Design Review**
  - **Conjugate CFD thermal model of a representative rotor including drum cavity, stator wells and external gas path**
  - **Test data generated for models validation allowing increasing of the technology to TRL4**
- **SFC benefit through secondary air system improvement**
- **Reduction of over 40% of current LPT stator well sealing flow through a reduction of sensitivity of turbine discs temperature to hot gas ingestion**



Test Geometry



Conjugate CFD

Publications/Patent

Patent EP 2 924 237 A1 / US 2015/0275674A1 "Gas turbine rotor" Inventor: Garcia Jose Javier Alvarez, ITP, published 30 sept. 2015

Collaborative Project co-funded by the European Commission within the 7th **Framework Programme** (2007-2013),
Under Grant Agreement n°ACP2-GA-2012-314366-E-BREAK

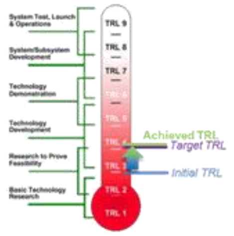
Optimisation of stator by-pass flow

Partners involved

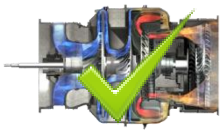
INP Toulouse – ENIT (Ecole Nationale d'Ingénieurs de Tarbes), SAFRAN

Description

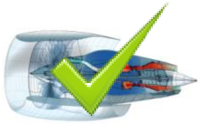
Experimental characterization of labyrinth seal geometries.



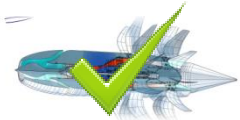
Ref: E-Break initial status / TRL	Initial E-Break objective	Final status
SFC impact	**N/A**	**To be quantified**
PPS weight impact	**N/A**	**N/A**
TRL progress	**3→4**	**4**



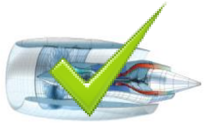
Turboshaft



Regional Turbofan



Short/Medium Range Open Rotor



Long Range Turbofan

Main achievements are:

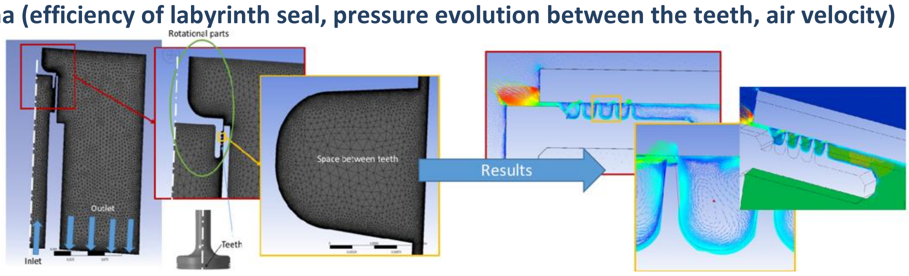
- **Development of a new experimental rig test allowing to test the efficiency of labyrinth seal geometries based on an existing rub-in rig test**
- **Test of the effect of pitch, radial clearance, number of teeth, height of teeth, rotational speed on the labyrinth seal efficiency → classification of the most influential parameters**
- **Validation of the results with 1D model**
- **Development and test of new innovative labyrinth seal geometries (stepped labyrinth and inclined teeth)**

Experimental Process

Differences in seal geometries

- **Development of a parametric CFD model based on experimental campaign and used to understand the phenomena (efficiency of labyrinth seal, pressure evolution between the teeth, air velocity)**

Figure showing numerical modeling process



Publications/Patent

"Test bench and test method for a dynamic sealing system", SAFRAN HELICOPTER ENGINES, J. GURT-SANTANACH, F. CRABOS, S. VAILLANT, P.-E. JACTAT, G. DESSEIN, n° FR2013/052204, international patent n° WO2014/053729 10/04/2014

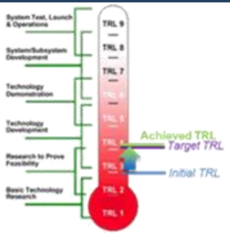
Labyrinth seal/abradable coatings rub-in tests

Partners involved

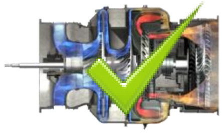
INP ENIT (Ecole Nationale d'Ingénieurs de Tarbes) – SAFRAN

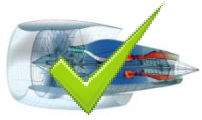
Description

Experimental characterization of the rotor/stator interactions occurring between labyrinth seals and abradable coatings.

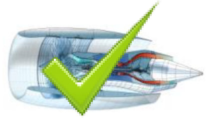


Ref: E-Break initial status / TRL	Initial E-Break objective	Final status
SFC impact	N/A	N/A
PPS weight impact	N/A	N/A
TRL progress	3	4


Turboshaft


Regional Turbofan


Short/Medium Range Open Rotor

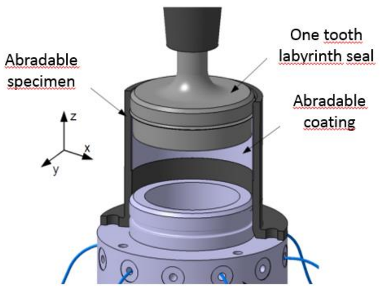

Long Range Turbofan

Successive starts and stops, the thermal expansion and the vibrations might cause direct rub interactions between a rotary seal, known as a labyrinth seal, and a turbo-engine housing coated with a sacrificial abradable material.

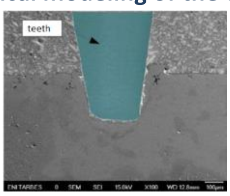
Main achievements:

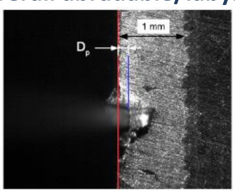
- **Design and development of a new high-speed test rig, in collaboration with INP-ENIT and SAFRAN HELICOPTER ENGINES, to simulate the interactions between labyrinth seals and abradable coatings in similar turbo-engine operating conditions.**

Geometry and rig set up



- **Development of a suitable instrumentation on the test ring to complete missing experimental data used to characterize abradable/labyrinth interactions.**
- **Analysis of the interaction dynamic, through a study with a high speed camera.**
- **Study of the wear mechanisms process of the Al-Si 6% coating based on a complete tribological study.**
- **Investigation of the interaction control parameters and of the seal geometry influence on the abradable coating behaviour.**
- **Analytical modeling of the overall abradable/labyrinth system to identify influential parameters.**





Results of rig testing

Publications/Patent:

C. Delebarre, V. Wagner, J. Paris, G. Dessein, J. Denape, J. Gurt-Santanach, An experimental study of the high speed interaction between a labyrinth seal and an abradable coating in a turbo-engine application., Wear 316 (2014) 109-118.

C. Delebarre, V. Wagner, J. Paris, G. Dessein, J. Denape, J. Gurt-Santanach, The wear mechanisms occurring in a labyrinth seal/abradable contact depending on the incursion depth parameter. Mechanics & Industry 17, 601 (2016)

Collaborative Project co-funded by the European Commission within the **7th Framework Programme** (2007-2013), Under Grant Agreement n°ACP2-GA-2012-314366-E-BREAK

SEVENTH FRAMEWORK PROGRAMME

Piston Seal Stability Improvement

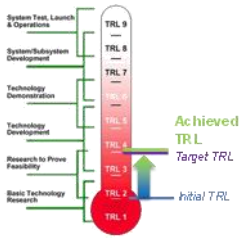
Partners involved

CTA

ITP – the power of talent

Description

Method and concept for stable high pressure piston seals

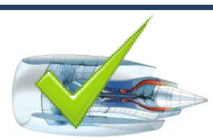


Ref : E-BREAK initial status / TRL	Initial E-BREAK objective	Final status
SFC impact	--	---
PPS weight impact	**Unquantified**	**Depends on the application**
TRL progress	**2 → 4**	**4**

Turboshaft

Regional Turbofan

Short/Medium Range Open Rotor

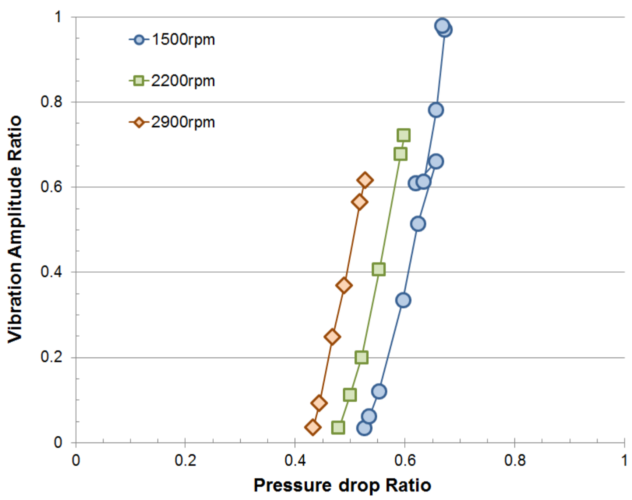


Long Range Turbofan

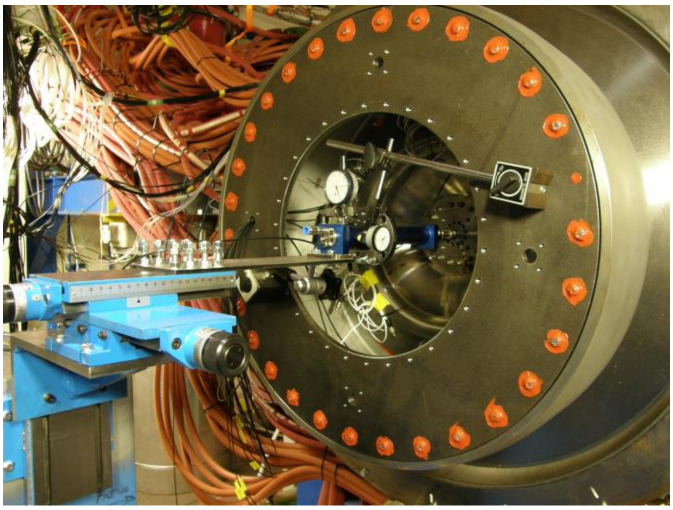
- Rationale/Main achievements:

- **Stability models were created for high pressure piston seal engine representative geometries.**
- **Using these models hardware geometry was designed and manufactured optimizing the dynamic stability of the high pressure piston seal.**
- **The hardware was tested in CTA allowing generation of the experimental data required for the validation of the models and increasing this technology from TRL3 to TRL4.**

- Expected benefit in increasing functional reliability and component life.



Experimental results



Experimental set-up

Publications/Patent

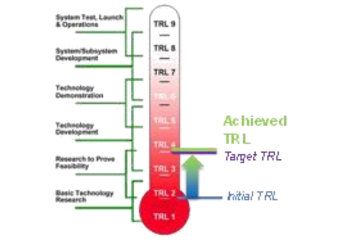
Optimization of stator by-pass flows

Partners involved

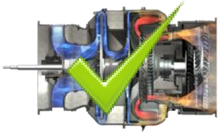
Avio Aero – A GE Aviation Business

Description

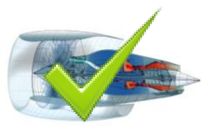
Experimental and numerical analysis of cavity flows for different operating conditions



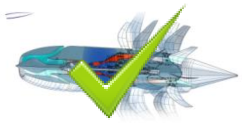
Ref : E-BREAK initial status / TRL	Initial E-BREAK objective	Final status
SFC impact	--	**- 0.05 to -0.1%**
PPS weight impact	**No impact**	**No Impact**
TRL progress	**2**	**4**



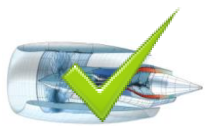
Turboshaft



Regional Turbofan

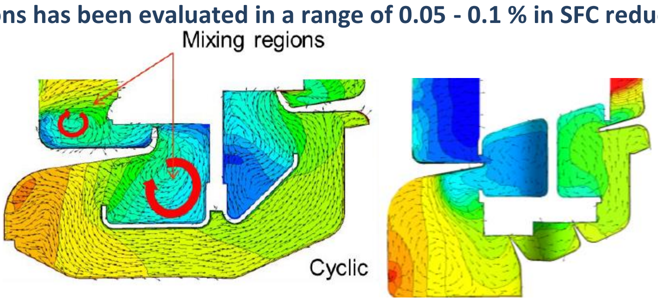


Short/Medium Range Open Rotor

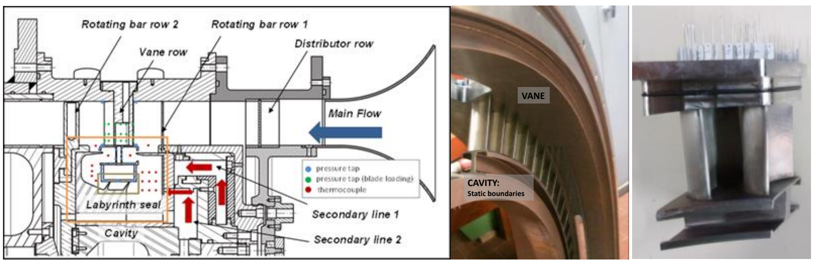


Long Range Turbofan

Main results and achievements:
Fluid dynamic methodology to simulate complete turbine seal cavities with flow path interaction and hot gas ingestion phenomena. Different seal cavities architectures have been compared and ranked on the basis of these parameters.
In parallel experimental apparatus has been upgraded to be able to measure such phenomena and the most promising sealing architecture assembled in the rig and tested. This is a unique way to be able to tune sophisticated numerical model and guarantee the capability to use them in the development of new sealing architectures.
Potential impact of new solutions has been evaluated in a range of 0.05 - 0.1 % in SFC reduction.



Studies of different cavities architectures



Experimental facility layout at University of Genoa Laboratory, and E-BREAK test articles

Publications/Patent

Collaborative Project co-funded by the European Commission within the 7th **Framework Programme** (2007-2013),
Under Grant Agreement n°ACP2-GA-2012-314366-E-BREAK

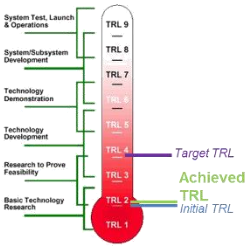
Ultra low leakage piston seals – Air-Riding Flexible Seal

Partners involved

The University of Nottingham — UNITED KINGDOM · CHINA · MALAYSIA
UNIVERSITY OF OXFORD
Rolls-Royce

Description

Seal capable of operating at large diameters where rotor distortions prevent the application of air-riding technology

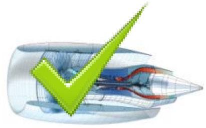


Ref : E-BREAK initial status / TRL	Initial E-BREAK objective	Final status
SFC impact	**-0.2%**	**Unknown**
PPS weight impact	**Increased**	**Increased**
TRL progress	**2→4**	**2**

Turboshaft

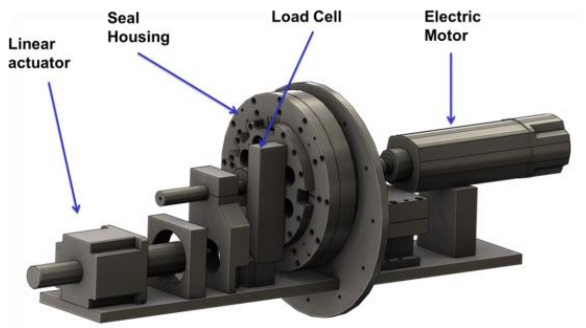
Regional Turbofan

Short/Medium Range Open Rotor

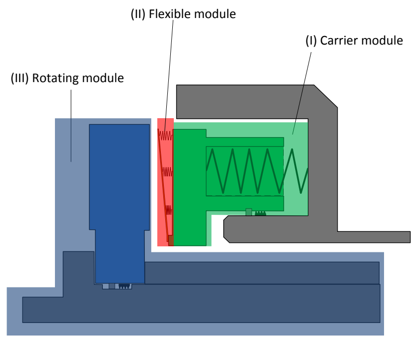


Long Range Turbofan

The technology explored is applicable to large turbofans and short medium range open rotor. Cost and weight considerations mean that it is unlikely to be applicable to either turboshafts or regional turbofans.
The intent at the start of the E-BREAK programme was to take an air-riding flexible seal concept and take it to TRL4. Although considerable progress has been made it was not possible to achieve this goal due to formidable technical difficulties including a high degree of architecture dependence of the seal. It became clear during the programme that there was a need to go back to the original concept and to re-examine it.
There have however been considerable successes in this task. They include:
A detailed analytical and experimental examination of air films in face seals. Understanding of their behaviours is at a far higher level than it was prior to the start of the programme. There has been a detailed assessment of face seal configurations and this has revealed that there is a very narrow design window and that the design is not robust. In order to perform the analytical and experimental examination of the seal analytical tools were developed for both air flow and seal dynamics. An experimental test rig was developed and with a unique capability to measure film characteristics. Good correlations were obtained between the tests and the predictions made with the new analytical tools.
Importantly a new concept for a novel fail-safe air riding seal concept was developed.
This type of seal retains the potential for considerable saving in SFC but it has not been possible to quantify what the value might be from this work.



Oxford test rig design



Air-Riding flexible Seal concept

Publications/Patent

Collaborative Project co-funded by the European Commission within the 7th **Framework Programme** (2007-2013),
Under Grant Agreement n°ACP2-GA-2012-314366-E-BREAK

Advanced High Speed Bearing Chamber Seals - Contacting Carbon seals

Partners involved

Pratt & Whitney
A United Technologies Company

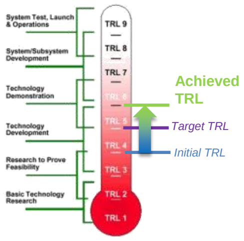
Pratt & Whitney Rzeszów

KIT Karlsruher Institut für Technologie

IMP PAN GDAŃSK

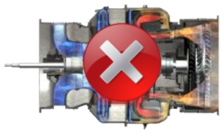
Description

Optimization of carbon seals to improve engine performance

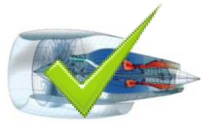


Ref : E-BREAK initial status / TRL	Initial E-BREAK objective	Final status
SFC impact	-0.2%	-0.2%
PPS weight impact		-
TRL progress	4→5	6

Further development (outside E-BREAK) elevated technology up to TRL8.
Currently being introduced to HBR Geared Turbo Fan – operating engines.

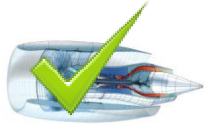


Turboshaft



Regional Turbofan

Short/Medium Range Open Rotor



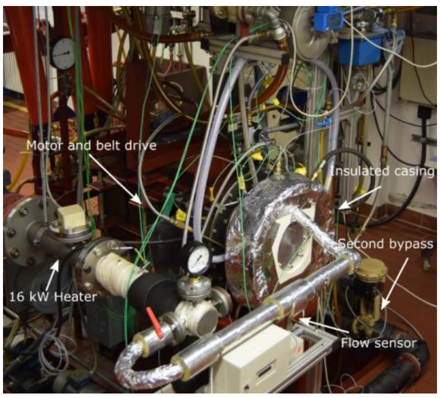
Long Range Turbofan

Main achievements

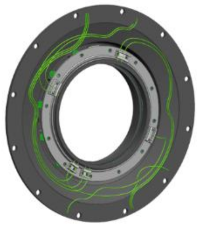
- **New generation of wet face seal technology developed, tested and validated.**
- **Enhanced seal modeling methodology developed to address seal separation and heat generation prediction**
- **Higher fidelity data collected minimize predicted seal heat generation (parasitic losses) and cooling oil requirement. Technology validated at high rubbing speed conditions.**

Activities completed:

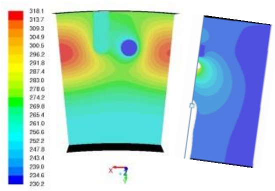
- **Seal runner oil flow parametric test completed (PWR-KIT). *Parameters correlation defined.***
- **Pressure profile factor (K) parametric measurements completed (PWR-KIT). *Parameters correlation defined.***
- **Numerical simulations of oil flow and the heat transfer in a carbon seal runner performed (PWR/IMP). Oil scoop and oil passages optimized.**



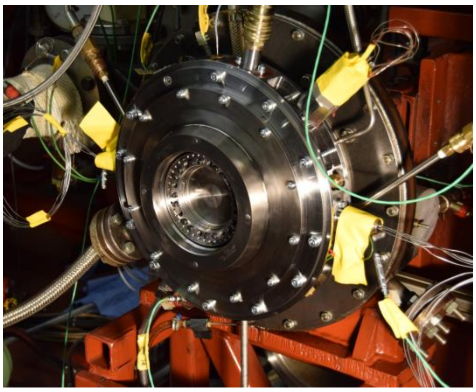
Rig build I
Pressure profile study at variable operating parameters



Instrumented test seal



Seal runner CFD, Heat transfer simulation



Rig build II
Pressure profile study – high power build Runner oil flow parametric tests

Publications/Patent

Pratt & Whitney Wet Face Carbon Seal Technology

Collaborative Project co-funded by the European Commission within the 7th **Framework Programme** (2007-2013),
Under Grant Agreement n°ACP2-GA-2012-314366-E-BREAK

SEVENTH FRAMEWORK PROGRAMME

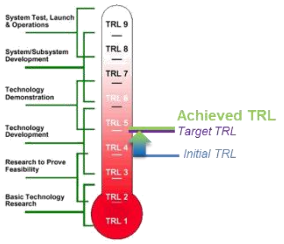
Bearing Chamber Heat Transfer and Oil Film Thickness

Partners involved

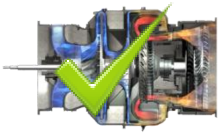
The University of Nottingham (United Kingdom · China · Malaysia), KIT Karlsruher Institut für Technologie, Rolls-Royce, Pratt & Whitney (A United Technologies Company), Pratt & Whitney Rzeszów

Description

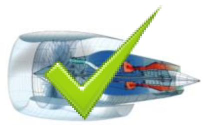
Heat transfer measurement in the bearing chambers



Ref : E-BREAK initial status / TRL	Initial E-BREAK objective	Final status
SFC impact	**-0.2%**	**-0.02%**
PPS weight impact	**--**	**-0.02%**
TRL progress	**4 → 5**	**5**

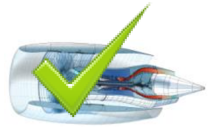


Turboshaft



Regional Turbofan

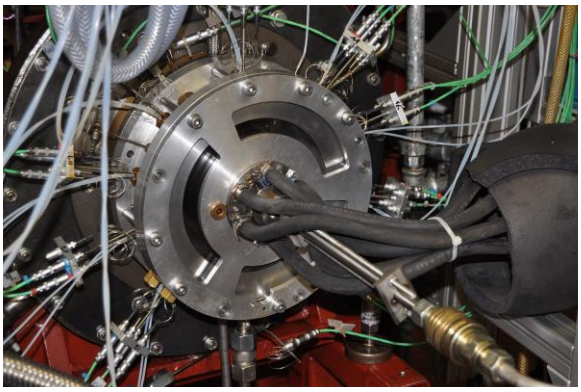
Short/Medium Range Open Rotor



Long Range Turbofan

Main achievements

Extensive measurements of the heat transfer coefficient of an oil film at the wall of a bearing chamber have been made using a unique sensor at KIT. In contrast to previous measurement of the heat transfer coefficient (HTC) which were bulk measurements these measurements were local and showed the variation around the circumference of the chamber.



KIT High Speed Bearing Chamber rig equipped with in-house HTC sensors

In addition to this, further experimental work was done for one partner to measure the thickness of the film on the bearing chamber wall using capacitance sensors.

Analytical work was performed to understand the effect of droplets on the film. It is anticipated that when these values are incorporated into a suitable analytical model of a bearing chamber it will significantly improve the reliability of the design and improve SFC impact.

The minimum SFC saving is 0.02% but may be much higher unfortunately as local values have not yet been applied to a bearing chamber heat balance it is not yet possible to quantify.

Publications/Patent

SEVENTH FRAMEWORK PROGRAMME

Collaborative Project co-funded by the European Commission within the 7th **Framework Programme** (2007-2013),
Under Grant Agreement n°ACP2-GA-2012-314366-E-BREAK

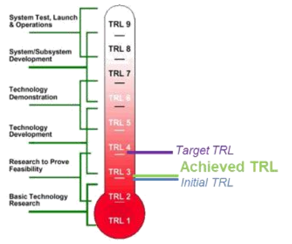
Low oil consumption breather

Partners involved

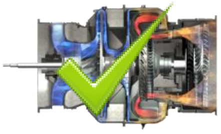
KIT Karlsruher Institut für Technologie · The University of Nottingham (United Kingdom · China · Malaysia) · SAFRAN · Avio Aero (A GE Aviation Business) · Rolls-Royce

Description

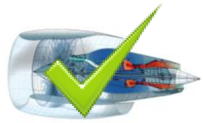
Air/oil separation design and expertise, modeling and validation.



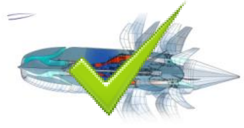
Ref: E-Break initial status / TRL	Initial E-Break objective	Final status
SFC impact	--	**0**
PPS weight impact	--	**-0.5 kg (regional) to - 1 kg (long range)**
TRL progress	**3→4**	**3→3**



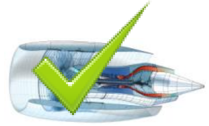
Turboshaft



Regional Turbofan



Short/Medium Range Open Rotor



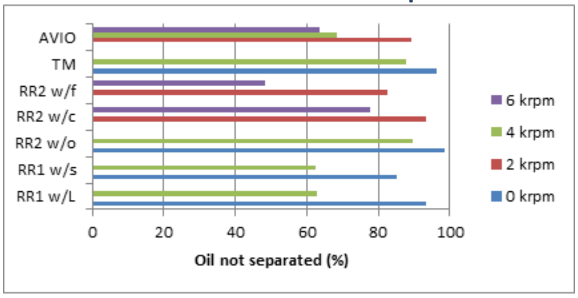
Long Range Turbofan

Main achievements:

The achievements of this task are applicable to breathers used in all engine types. Two types of breather were evaluated in the task the metal foam breather used by two of the partners and a vane type breather used by a third.

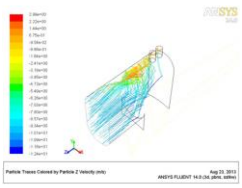
The pressure drop behaviour and capture efficiency of four types of architecture have been measured as has the capture efficiency for the oil. This has been done for more than one droplet distribution.

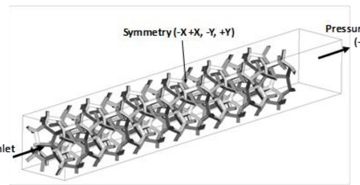
Oil separation percentage for various breather types and geometries



A much better understanding of oil separation has been developed and there is the potential to reduce the amount of oil discharged overboard. It is estimated that this work will result in a 5% reduction in oil loss leading to a weight loss of -0.5 kg regional, -1 kg long range.
In addition to the experimental work models were developed of oil flow in the breathers both at microscopic and macroscopic scales.

CFD simulation of flow in a breather





Approximation of elements flow channels in metal foam for CFD simulation

Publications/Patent

T. Carvalho et al (UNott, KIT), Limitations of a state-of-the-art numerical modeling framework for two-phase flow in aero-engine air/oil separators, GT2016- 56633, ASME 2016, Jun. 2016, Seoul, South Korea; L. Cordes et al (KIT), Experimental study of the pressure loss in aero-engine air/oil separators, published in "The Aeronautical Journal" of the Royal Aeronautical Society, ISABE 2017, Sep 2017, Manchester, UK

Collaborative Project co-funded by the European Commission within the **7th Framework Programme** (2007-2013),
Under Grant Agreement n°ACP2-GA-2012-314366-E-BREAK
SEVENTH FRAMEWORK PROGRAMME

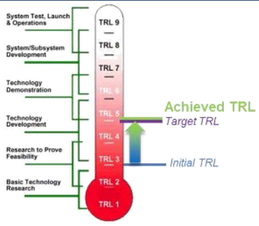
Low oil consumption breather

Partners involved

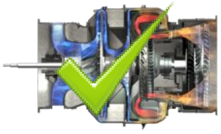
ULB SAFRAN

Description

Air/oil separation design and expertise, modeling and validation.



Ref: E-Break initial status / TRL	Initial E-Break objective	Final status
SFC impact	N/A	N/A
PPS weight impact		Not yet assessed
TRL progress	3→4/5	5


Turboshaft

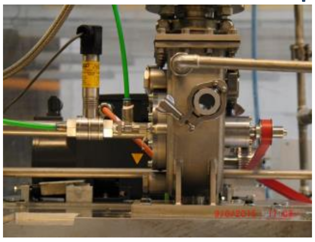

Regional Turbofan

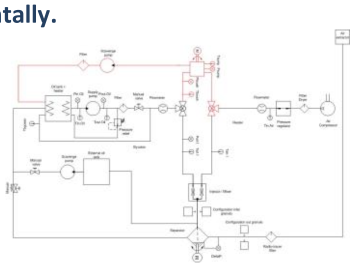

Short/Medium Range Open Rotor


Long Range Turbofan

- **A test bench was developed by the ULB ATM Department in collaboration with SAFRAN HELICOPTER ENGINES. Experimental campaigns under different working conditions can be performed.**
- **A complete experimental methodology was set-up by ULB and SAFRAN HELICOPTER ENGINES to characterize oil injectors (oil droplet distribution) and vane separator efficiency (pressure drops and oil separation).**
- **Two experimental campaigns have been realized at the ULB facility. A typical vane separator design and an improved vane separator were characterized experimentally.**

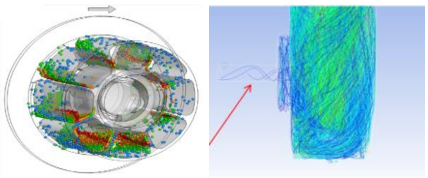
ULB test bench picture





ULB bench basic diagram

- **CFD methodology was developed and validated through comparison with test results:**
  - **Good correlation with pressure drops on both vane separator designs**
  - **Better understanding of oil separation phenomena, by visualizing droplets trajectories**
  - **Cut-off diameter is well estimated by simulation, and gives an idea of the separation efficiency**
  - **Oil consumption trends are not well reproduced and will require more efforts on modeling**



Droplet deposition and droplet motion trajectories visualization

- **An improved vane separator design was proposed based on CFD simulation done on the first design. Clear improvements in terms of pressure drops were performed during this project. Oil consumption has been improved by almost 60% for low rotational speeds but on higher rotational speed the trend becomes less clear and both designs seem to have similar efficiencies.**

Publications/Patent:

"Test bench development for experimental characterization of oil-air two-phase flow for breather in modern aero engine oil system" ,M. Di Matteo, J. Steimes, O. Berten, J.P. Thibault, L. Seguinot, B. Fulleringer, O. Robert, C. Corre and P. Hendrick, ISABE 2017 3 - 8 September, Manchester, UK

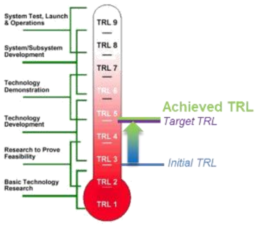
Advanced aero-engine bearing chamber seals testing

Partners involved

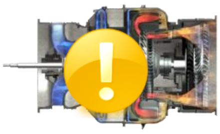
ULB SAFRAN

Description

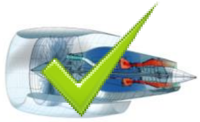
Carbon brush seal experimental characterization and modeling



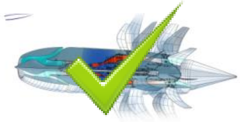
Ref: E-Break initial status / TRL	Initial E-Break objective	Final status
SFC impact	N/A	N/A
PPS weight impact	N/A	N/A
TRL progress	3→4/5	5



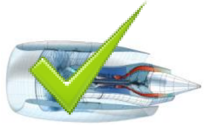
Turboshaft



Regional Turbofan



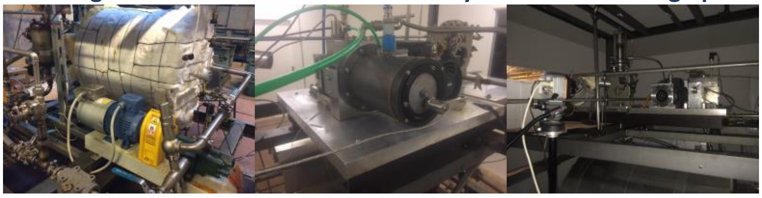
Short/Medium Range Open Rotor



Long Range Turbofan

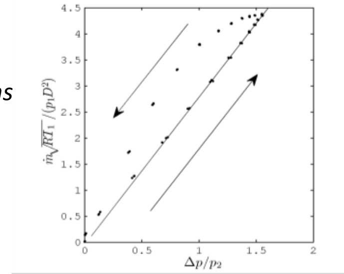
- **Design and development of a test rig by ULB ATM Department, in collaboration with SAFRAN AIRCRAFT ENGINES. It reproduces the severe working conditions brush encountered by brush seals during operation.**

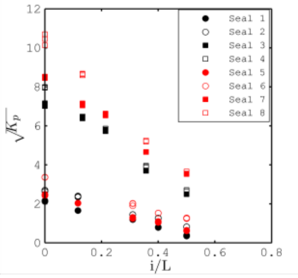
Experimental rig at ULB

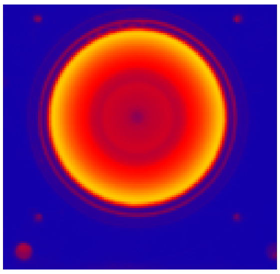


- **Results demonstrating excellent trade-off between low air consumption (-95% compared to labyrinth seals) and low friction torque (order of magnitude of 0.1 Nm) for full scaled brush seals destined for bearing chambers.**
- **Identification and understanding of phenomena acting on the performance of carbon brush seals, under static and dynamic conditions (up to 18.000 rpm), in dry conditions and with the introduction of 100°C lubrication oil.**
- **Full characterization of brush seal performance, through dimensionless prediction models estimating the performance of carbon brush seals in function of the geometrical parameters and operating conditions.**
- **Analysis of heat dissipation, through a study with an IR camera.**
- **Endurance testing performed on an optimized brush seal, for a total duration of 300 hours, with successive applications of a turboshaft low pressure cycle. The life service of a brush seal in these working conditions is estimated to more than 10.000 hours.**

Typical correlations and IR camera image from experiments







Publications/Patent:

"Experimental study of carbon brush seals for aero-engines bearing chambers", Bilal Outirba, Patrick Hendrick. ASME 2014, Düsseldorf, Germany

"Influence of geometrical parameters on the performance of carbon brush seals", Bilal Outirba, Patrick Hendrick. ISABE 2015, Phoenix, Arizona, USA.

"Experimental characterization of carbon fiber brush seals leakage performance in function of the bristle pack geometrical parameters under dry conditions" Bilal Outirba, Patrick Hendrick *(Currently submitted to RAeS)*

Collaborative Project co-funded by the European Commission within the **7th Framework Programme** (2007-2013),
Under Grant Agreement n°ACP2-GA-2012-314366-E-BREAK

SEVENTH FRAMEWORK PROGRAMME

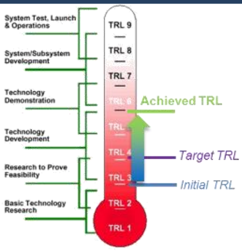
Oil System Bearing Chambers

Partners involved

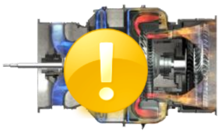
The University of Nottingham UNITED KINGDOM · CHINA · MALAYSIA — Rolls-Royce — IMP PAN GDANSK

Description

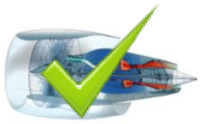
Oil flow modeling and validation in a bearing chamber



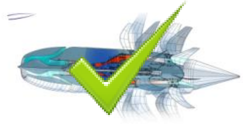
Ref: E-Break initial status / TRL	Initial E-Break objective	Final status
SFC impact	**-0.2 %**	**-0.1%**
PPS weight impact	**25 kg**	**10 kg**
TRL progress	**3→4**	**3→6**



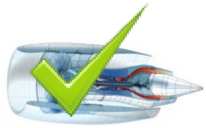
Turboshaft



Regional Turbofan



Short/Medium Range Open Rotor

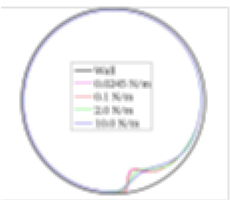


Long Range Turbofan

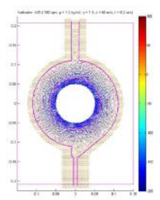
The achievements of this task are applicable to regional turbofans, short/medium range open rotor and long range turbofans. Some of the modeling work may be applicable in turboshafts.

There were three elements to this task – development of new thermal thin film model models of oil flow in a bearing chamber, development of SPH modeling for oil flows, a mixing model approach to rimming type flows and thermal modeling of a chamber and its validation.

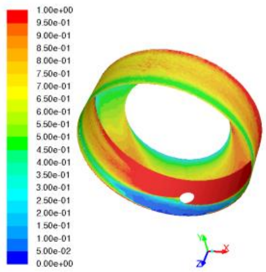
The development of the thin-film model was very successful, it has been incorporated into the commercially available Fluent code produced by ANSYS and subsequently (outside E-BREAK) applied to bearing chamber flows. It is anticipated that this model will contribute to more reliable bearing chamber designs and will also contribute to chamber weight reduction. This model has reached at least TRL 6. The SPH modeling was show to be able to model some oil flows.



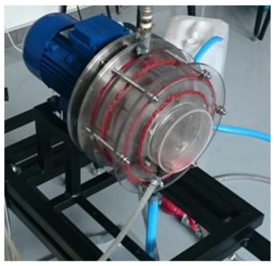
Thin-film model results



SPH simulation results



Film thickness results for DPM Model Ansys code



Laboratory stand of the bearing chamber

The Lagrange-Euler approach (Discrete Particle Methods (DPM) Model Ansys code) was used to simulate the two-phase air-oil flow in the bearing chamber. Good agreement was obtained between the numerical results of the oil film thickness and the experimental data. Proper model of complex two-phase flow in a chamber will improve design methods. The laboratory stand of the bearing chamber was built for validation of the model predictions for the velocity distribution.

Publications/Patent

GT2015 – 43503 Solution strategies for thin film rimming flow modeling B. Kakimpa, H.P. Morvan and S. Hibberd University of Nottingham Technology Centre in Gas Turbine Transmission Systems The University of Nottingham, Nottingham, NG7 2RD, UK

SEVENTH FRAMEWORK PROGRAMME

Collaborative Project co-funded by the European Commission within the **7th Framework Programme** (2007-2013),
Under Grant Agreement n°ACP2-GA-2012-314366-E-BREAK

Oil lifing and degradation prediction methods

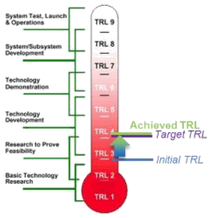
Partners involved

Rolls-Royce

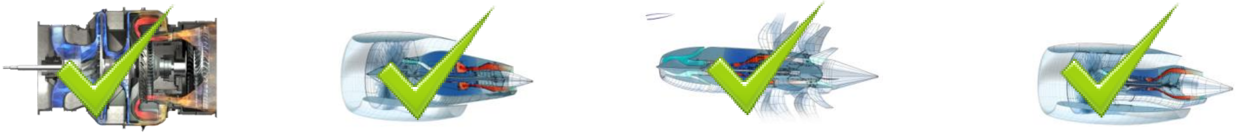
The University of Nottingham
UNITED KINGDOM · CHINA · MALAYSIA

Description

Air/oil separation design and expertise, modeling and validation.

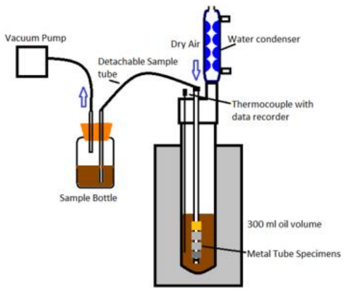


Ref: E-Break initial status / TRL	Initial E-Break objective	Final status
SFC impact	--	N/A
PPS weight impact	--	N/A
TRL progress	3→4	3→4



Turboshaft ***Regional Turbofan*** ***Short/Medium Range Open Rotor*** ***Long Range Turbofan***

There were two strands to the achievements from this part of the programme.
In the first achievement Rolls-Royce UK critiqued the current industry standard protocols for the laboratory assessments of gas turbine oil oxidation. This included testing a variety of oils using current methods. A proposal for improvements was then made. This proposal will be used as the basis for the next international standard in this area. The need for a new standard to evaluate oil degradation by oxidation is driven by the increases anticipated in oil temperature in new engine architectures which will increase the rate of oil degradation by oxidation



Typical experimental test rig

The second achievement was when the experimental results on oil degradation measured by Rolls-Royce UK were taken by UNott: they then deduced a chemical rate equation from the results which they then inserted into a CFD model of oil flow. This demonstrated the concept of using CFD to find areas of high oil degradation within a bearing chamber.
The improved oil oxidation protocol is generally applicable to all modern gas turbine oil type oil types and hence to all engine types in E-BREAK. The combination CFD and a rate equation when fully developed should be applicable to all engine types and has the potential to be developed into a tool to improve engine reliability. This work does not improve SFC or system weight.

Publications/Patent

T. Carvalho et al (UNott, KIT), "Limitations of a state-of-the-art numerical modeling framework for two-phase flow in aero-engine air/oil separators", GT2016- 56633, ASME 2016, Jun. 2016, Seoul, South Korea
L. Cordes et al (KIT), "Experimental study of the pressure loss in aero-engine air/oil separators", published in "The Aeronautical Journal" of the Royal Aeronautical Society, ISABE 2017, Sep 2017, Manchester, UK

Collaborative Project co-funded by the European Commission within the 7th **Framework Programme** (2007-2013),
Under Grant Agreement n°ACP2-GA-2012-314366-E-BREAK

SP3 RELATED TECHNOLOGIES - Engine variability and thermo-mechanical behaviour

SP3 Objectives

The aim of SP3 is to enhance the complex variable mechanical systems (Variable Bleed Systems (VBS) and Variable Stator Vanes (VSV)) and to improve the thermo-mechanical behaviour in rotor-casing matching or active cooling of hot structures. Both aspects have to cope with aggressive new thermodynamic cycles based on LEMCOTEC outputs. SP3 is to provide technologies which are fit for use on future engine designs. New technologies in high bypass ratios, small core size engines, high process and component temperatures and loads are all needed to fulfil this aim. In the first period of the project, the tasks were focused on the provision of definitions and requirements, specifications for new concepts and designs, and investigating parts that could fulfil the future engine requirements on appropriate test rigs. After this concept definition phase, the designs were realized, test rigs were newly built or modified and component testing was started.

WP3.1 is focusing on more precise VSV and VBV system for ultra-high OPR compressors considering higher ambient temperatures, pressures and less hysteresis, reduced friction and enhanced lifetime. Furthermore the knowledge about bird ingestion design requirements for a booster vane should be improved in order to set up design tools and an improved methodology to withstand these loads.

Within WP3.2 passive and adaptive tip clearance control approaches are investigated using different measures as modulated air systems and heat management for tip clearance control, whole engine thermo-mechanical optimisation and improved tip clearance probe development for compressor and turbine application. Additionally blading with decreased sensitivity to tip loss at small blade size is investigated.

The main objective of WP3.3 is to define and analyse concepts and requirements for heat management of main engine structures. The focus is to develop a concept for variable cooling of turbine structures to manage higher temperatures.

SP3 Summary of achievements

Within WP3.1 new bush materials were investigated for future applications in realistic, engine-like running conditions. This ensures extended service intervals and less wear driven fuel burn increase also at raised temperature and load levels. An FEA tool has been used to increase the prediction accuracy, which is reflected in reduced engine mass, higher system accuracy and less maintenance costs. Furthermore a composite hybrid unison ring has been developed and successfully tested in order to compensate for the different thermal behaviour between hot compressor casing and cooler metal unison ring using a bi-metal-like effect. Thus, a reduction in vane mal-scheduling has been achieved especially for small core engines, leading to an increased efficiency, which is essential for future high OPR ratio applications. New vanes design rules have been developed to fulfil the changed certification requirements for new engine architectures, which require a more robust booster in terms of bird debris impact. A new variable bleed valve system was experimentally validated achieving the requirement of the next generation aero-engines in the fields of system performance, overall weight, robustness and maintenance costs.

WP3.2: Enhanced compressor and turbine tip clearance probes were developed and tested aiming to reduce diameter, measurement uncertainties and enable potential for location in hitherto inaccessible stages. The local thermal distortion impact of the tip clearance probes on the casing could be reduced. Therefore, the new tip clearance system should improve the accuracy of the measurement, support thermal matching and finally support accurate thermal model and Whole Engine Model (WEM) calibration. A whole engine optimization tool for the preliminary design phase has been developed aiming at reduced in-service tip clearances, which are driving the efficiency and surge margin of the aero engine. Furthermore, the effect of the modulation of the HPC bore flow on tip clearance has been investigated to gain further increased engine efficiency. The effect of different casing and OPR blade designs on the sensitivity against tip clearance variations around the circumference has been experimentally analysed. Based on these results design rules for less sensitive compressor blades has been established.

Within WP3.3 a novel cooling mechanism for outlet guide vanes was developed and tested to withstand the higher thermal and mechanical loading caused by the increased engine efficiency of future engines. Thus, more cost-efficient materials can be applied in order to prevent high manufacturing and in-service inspection efforts of high-cost high-temperature materials.

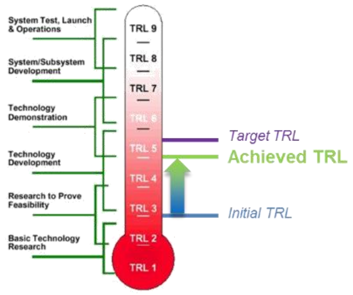
More precise VSV system

Partners involved

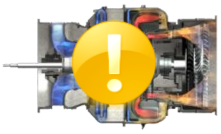
Rolls-Royce

Description

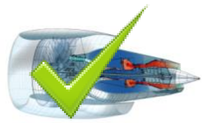
Advanced VSV system for increased robustness and accuracy, improved bushing material for higher temperature and pressure



Ref : E-BREAK initial status / TRL	Initial E-BREAK objective	Final status
SFC impact	**SFC improvement from 1.25° increased vane accuracy and +70°K HPC operating temperature capability**	**SFC improvement from 1.25° increased vane accuracy and +70°K HPC operating temperature capability**
PPS weight impact	**None (same weight)**	**neutral**
TRL progress	**3→5/6**	**5**

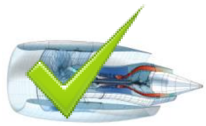


Turboshaft



Regional Turbofan

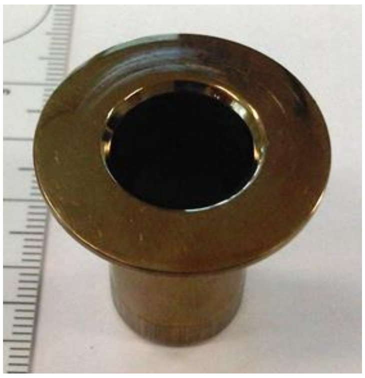
Short/Medium Range Open Rotor



Long Range Turbofan

As the overall pressure ratio (OPR) of future aero engines will be increased, also the variable stator vanes (VSV) bushes have to withstand higher temperatures (operational temperature increase of 70° K) and pressures. Furthermore, the shrunk core size of the more efficient aero engines is more sensitive to bush wear that current in-service engines. Thus, a new state-of-the-art test rig was designed and build at the TU Dresden in order to determine the most suitable high-temperature materials.

Bush type 1



Bush type 2 post test

Composite hybrid unison ring

The accuracy of the VSV system is further increased by the replacement of metal unison ring with the composite hybrid unison ring design, which enables an improvement in VSV angle tolerance of up to 1.25° resulting in a compressor efficiency improvement. This is achieved by the bi-metal effect caused by the combination of a tangentially stiff carbon fibre reinforced outer band and an aluminium inner band, which matches the thermal expansion of the unison ring assembly to the casing.

Publications/Patent

Klauke T.; Soehner D., Drees B., Winkelmann P., Klomp-de Boer R.: Development of a hybrid-unison ring for VSV-systems for new high OPR aero engines, Annual DLR conference 2015, 22.-24. September2015, Rostock, Germany

Collaborative Project co-funded by the European Commission within the 7th **Framework Programme** (2007-2013),
Under Grant Agreement n°ACP2-GA-2012-314366-E-BREAK

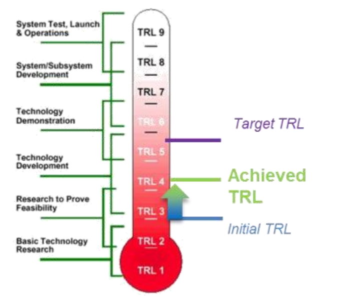
More precise VSV system

Partners involved

SAFRAN

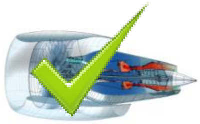
Description

Advanced VSV system with high accuracy and reduced mass

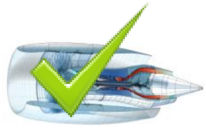


Ref : E-BREAK initial status / TRL	Initial E-BREAK objective	Final status
SFC impact	**SFC improvement from 1° increased accuracy and +70°K HPC operating temperature capability**	**Same vane accuracy maintained**
PPS weight impact	**…**	**-0.6 kg / -57% (composite unison ring) -0.25kg / -30% (optimized bellcrank)**
TRL progress	**3→5/6**	**4 (VSV bushes)**


Turboshaft


Regional Turbofan

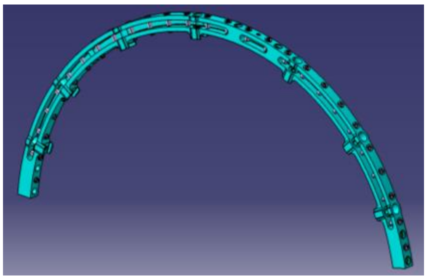

Short/Medium Range Open Rotor

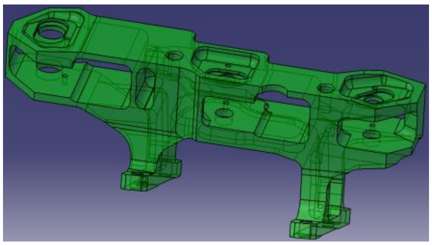

Long Range Turbofan

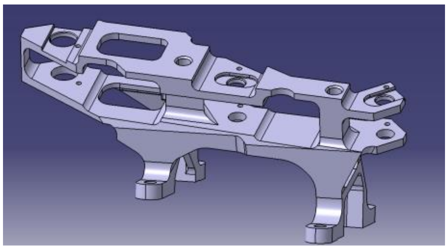
Weight is a key parameter for aero engine components, which is directly related to the fuel consumption. Thus, weight reduction is always an option in order to improve the engine efficiency. Within this task two different methods were applied in order to gain a mass benefit:

First, a standard metal unison was replaced by short fibre reinforced aluminium unison ring with the same accuracy, but with reduced weight (-0.6 kg).

Second, a topology optimisation was carried out on the bellcrank component of the VSV system in order to find the best possible solution in terms of weight reduction without detrimental effects on stiffness and actuation accuracy. Furthermore design constraints from the manufacturing were considered in order to realise a cost-efficient design. Finally, a mass reduction of 0.25 kg was achieved.


Novel short-fibre reinforced metal unison ring


Initial bellcrank design


Optimized bellcrank design with reduced mass

Publications/Patent

Collaborative Project co-funded by the European Commission within the **7th Framework Programme** (2007-2013),
Under Grant Agreement n°ACP2-GA-2012-314366-E-BREAK

Bird strike robustness

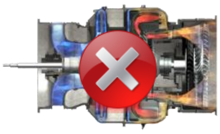
Partners involved

SAFRAN

Description

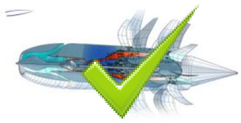
Test and simulation of booster vanes resistant to bird ingestion

Ref : E-BREAK initial status / TRL	Initial E-BREAK objective	Final status
SFC impact	**--**	**5% SM improvement**
PPS weight impact	**To be quantified**	**Not yet assessed**
TRL progress	**2→4**	**5**



Turboshaft

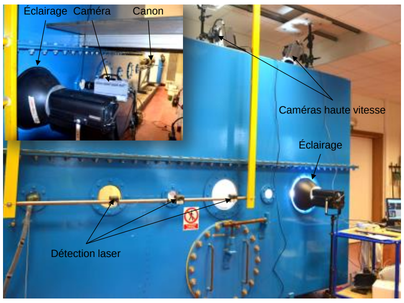
Regional Turbofan



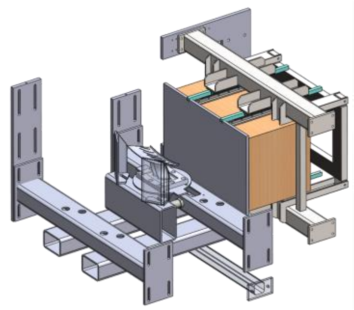
Short/Medium Range Open Rotor

Long Range Turbofan

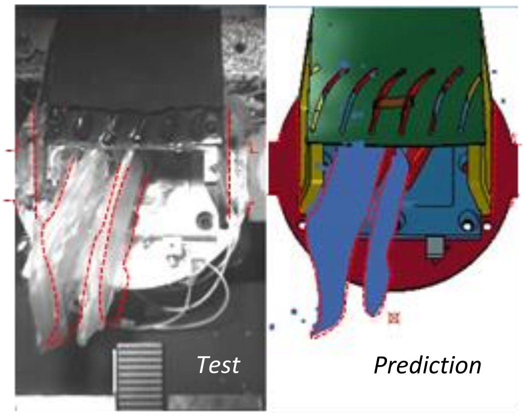
The prediction of the behaviour of a stator vane and the loads acting on a VSV system under bird impact is the key to validate bird ingestion resistant designs. The numerical approach is made using explicit code and the experimental data is obtained thanks to innovative test rig at Ghent University (Belgium). This later allows to quantify the deformation and behaviour of the aerofoil, but also to quantify the loads or impulse acting on them.
The work performed allowed to improve the numerical model up to the point where test results are correctly reproduced by calculation. Many correlation indicators, such as momentum transfer, strain gauges signals, accelerometers, residual deformation, gelatine debris trajectory and residual kinetic energy are used. Overall, the correlation showed very good agreement with the predictions. Therefore, the methodology can be considered at TRL5.



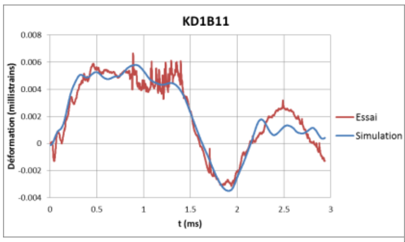
Test facility with instrumentation

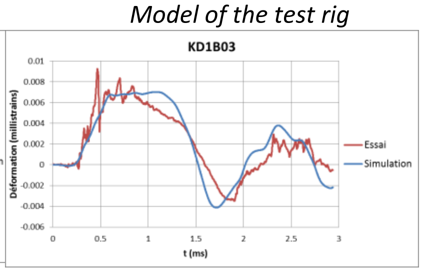


Model of the test rig



Bird strike test and prediction (left: Test, right prediction)





Model validation: Deflection vs. time for two bird shots

Publications/Patent

Allaeys, F. et al., "Development and validation of a set-up to measure the transferred multi-axial momentum of a bird strike on a booster vane." International Journal of Impact Engineering. 2016
Allaeys, F., Luyckx, G., Sarrazin, C., Jovanov, L., Philips, W., "A 3D shape measurement technique that makes use of a printed line pattern." Experimental Mechanics, 54(6), 999–1009, 2014

Collaborative Project co-funded by the European Commission within the **7th Framework Programme** (2007-2013),
Under Grant Agreement n°ACP2-GA-2012-314366-E-BREAK

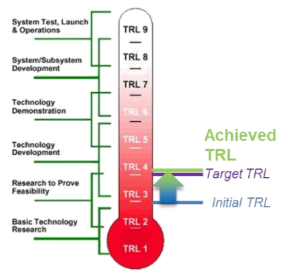
Variable Bleed Vane System

Partners involved

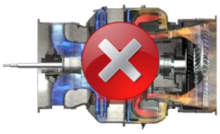
GKN AEROSPACE

Description

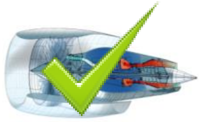
Structural and mechanical design improvement of Variable Bleed Valve System to optimize weight performance



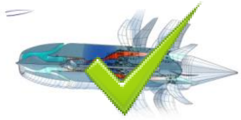
Ref : E-BREAK initial status / TRL	Initial E-BREAK objective	Final status
SFC impact	--	**Not yet assessed but 34% in bleed valve variability**
PPS weight impact	**-10% weight on VBV system**	**-6.4%**
TRL progress	**3→4**	**4**



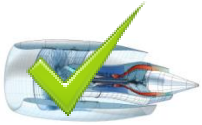
Turboshaft



Regional Turbofan



Short/Medium Range Open Rotor

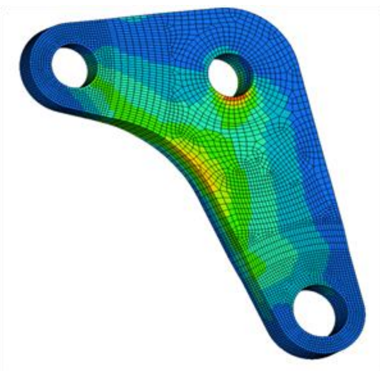


Long Range Turbofan

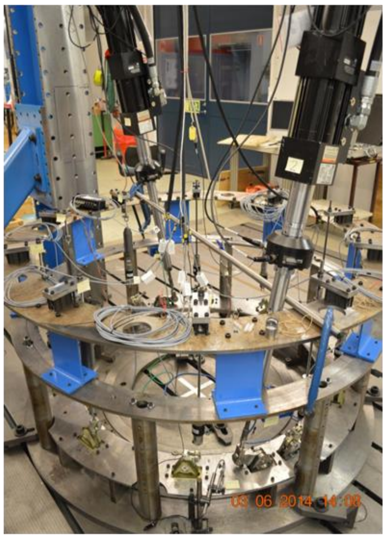
Variable Bleed valve systems have been studied with focus on decreased weight and improved functionality.
The replacement of aluminum alloy components by carbon fiber composite was investigated. Within this assessment thermal environment and loads was found to be suitable for composite application.

- **The developed concepts are validated by detailed FEM analysis.**
- **Total system weight decrease of 6.4% was achieved.**

Innovative analysis methods was developed and validated by a mechanical test with a full scale Variable Bleed System under engine-representative loading. A significant increase in actuation accuracy of +34% was achieved resulting in less fuel consumption and vibration excitation.



Novel lever design



Test of novel VBV system at GKN

Publications/Patent

Collaborative Project co-funded by the European Commission within the **7th Framework Programme** (2007-2013),
Under Grant Agreement n°ACP2-GA-2012-314366-E-BREAK

SEVENTH FRAMEWORK PROGRAMME

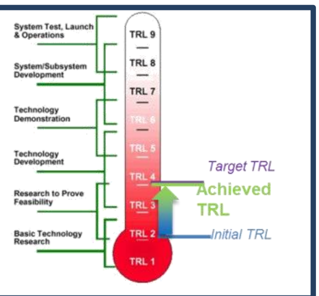
Tip clearance control for compressors

Partners involved

Rolls-Royce

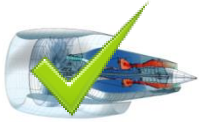
Description

Tip clearance probes development, variable bore flow development, casing thermal time constants study

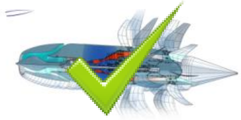


Ref : E-BREAK initial status / TRL	Initial E-BREAK objective	Final status
SFC impact	**-0.2%**	**SFC benefit cannot be realised until TRL level is 8, but work achieved is as per planned and hence driving towards the planned ultimate SFC benefit**
PPS weight impact	--	--
TRL progress	**2→4**	**4**

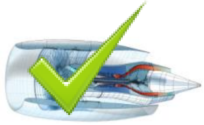
Turboshaft



Regional Turbofan



Short/Medium Range Open Rotor

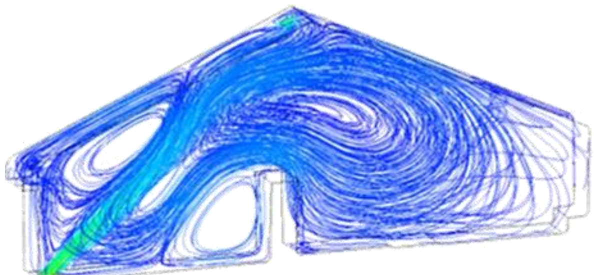


Long Range Turbofan

High OPR/small core size cycles are highly sensitive to HPC tip clearance/efficiency and therefore require advanced combinations of passive and active tip clearance control. This work package investigated the following advances:

Advanced tip clearance probes – reduced diameter tip capacitance probe developed to enable potential installation in new environments where previous probe would have been excessive in size. New, smaller probes have been proved as robust and providing improved performance vs. the previous probe design.

HPC bore flow modulation - Achieving good cruise tip clearances in a HP compressor involves matching cruise closures as closely as possible to the pinch point closure. Matching casing and rotor time constants is therefore essential. One possible way of controlling the thermal response of the compressor rotor is to use fluidic devices to vary the flow through the disc bore. The objective of demonstrating on a rig that fluidic device technology is capable of modulating compressor drum bore flow to multiple levels for compressor tip clearance control has been achieved.



Main Air System Cavity

Casing time constants study - Oxford University studied heat transfer in two types of cavity within a compressor casing to understand the heat transfer characteristics and how the thermal time constants can be modified by change to the local air system features within the casing assembly. The study combined CFD with experimental validation. The study has shown that CFD has the ability to predict the behaviour of current designs, and that it has identified concepts which could reduce SFC by the target 0.2% in the next generation of engines, subject to further investigation.

Publications/Patent

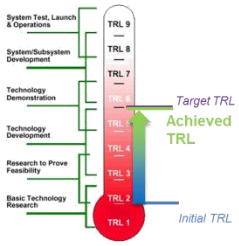
Tip clearance control for turbine

Partners involved

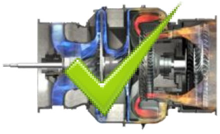
SAFRAN

Description

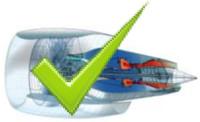
Tip clearance probes for turbine application



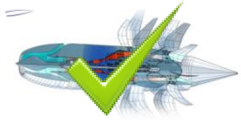
Ref : E-BREAK initial status / TRL	Initial E-BREAK objective	Final status
SFC impact	**-0.2%**	**-0.2%**
PPS weight impact	--	--
TRL progress	**2→6**	**6**



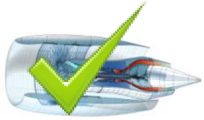
Turboshaft



Regional Turbofan

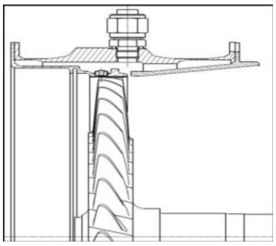


Short/Medium Range Open Rotor

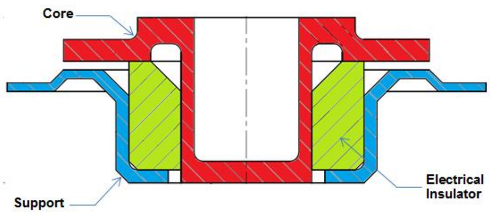


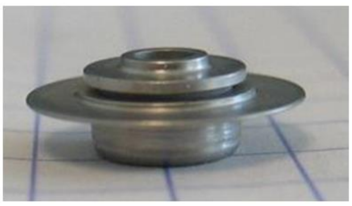
Long Range Turbofan

The high OPR of future engine will not only result in increased aero engine efficiency, but also in higher operation temperatures. A new, more compact turbine tip clearance probe design was developed in order to withstand high temperature environment of up to 750°C. The small design allows being less intrusive for integration on turbine casing. Good results were observed during engine tests: mean tip clearance and its evolution during speed sweep are matching well with results provided by mechanical and thermal predictions.

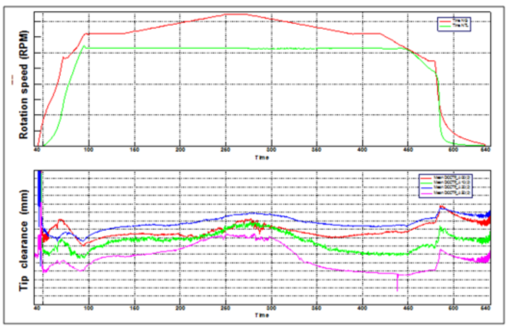


Engine integration





High temperature capacitive sensor



Test results

Publications/Patent

Collaborative Project co-funded by the European Commission within the 7th **Framework Programme** (2007-2013),
Under Grant Agreement n°ACP2-GA-2012-314366-E-BREAK

SEVENTH FRAMEWORK PROGRAMME

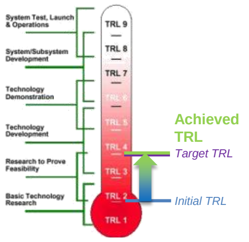
Ultra high OPR blading

Partners involved

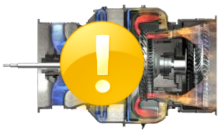
Rolls-Royce

Description

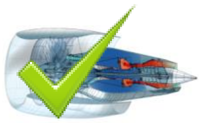
Understand effect of real life clearances on operation of compressor and deduction of more robust blading



Ref : E-BREAK initial status / TRL	Initial E-BREAK objective	Final status
SFC impact	**-0.2%**	**-0.2%**
PPS weight impact	**--**	**Weight neutral**
TRL progress	**2→4**	**4**

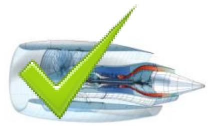


Turboshaft



Regional Turbofan

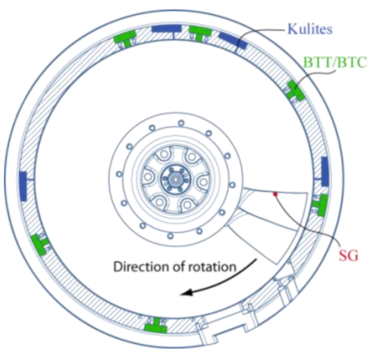
Short/Medium Range Open Rotor



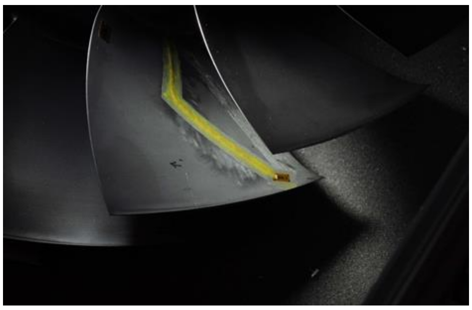
Long Range Turbofan

As the overall thermal efficiency is increased for future high OPR aero engines, the size of the core engine can be reduced keeping the same power output. Not all of the dimensions and clearances can be reduced by the same factor resulting in more pronounced detrimental effects caused by blade tip-casing clearances and casing and/or rotor eccentricity.

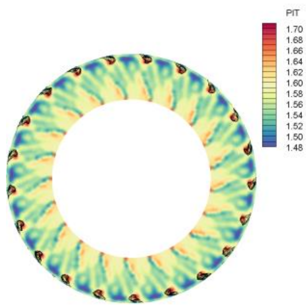
Detailed experimental investigations using a highly instrumented test rig were carried out in order to quantify the impact level on compressor efficiency. The gained knowledge of this test series will enable an improved tip clearance design for future HPC's, more robust and tip-clearance de-sensitized HPC rotor blades with an expected efficiency improvement of -0.2% SFC.



Test set-up



Applied strain gauges on compressor blades



Example of measure pressure distribution

Publications/Patent

SEVENTH FRAMEWORK PROGRAMME

Collaborative Project co-funded by the European Commission within the 7th **Framework Programme** (2007-2013),
Under Grant Agreement n°ACP2-GA-2012-314366-E-BREAK

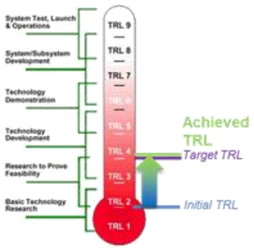
Cooling of turbine structures

Partners involved

GKN AEROSPACE

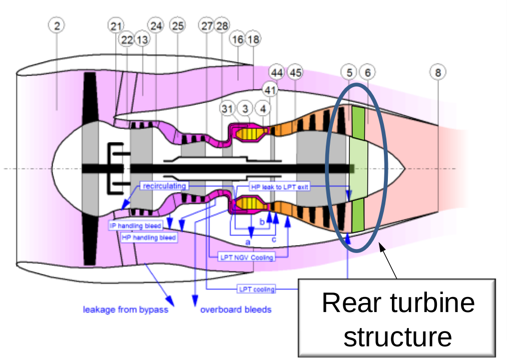
Description

Concept for active variable cooling performance

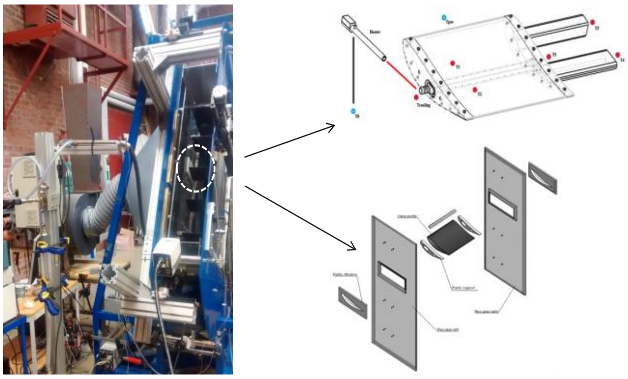


Ref : E-BREAK initial status / TRL	Initial E-BREAK objective	Final status
SFC impact	**Possible SFC improvement enabled by a +50°K LPT exit temperature**	**On target**
PPS weight impact	**N/A**	**N/A**
TRL progress	**2→4**	**4**

Active cooling for engine turbine structures has the potential of allowing an increase of the core engine gas temperature of up to 50°K using conventional material technologies. Several concepts for cooling air injectors were tested in the Chalmers OGV rig. The CFD results showed overall good agreement with experiments. TRL 4 could be claimed and justified by experiments and CFD. The development of control schedules was performed for the active cooling functionality. Also the technology development plan towards a TRL6 was laid as part of this work.



The location of the turbine rear structure in a turbofan engine.



Cooled vane experimental set-up in the Chalmers linear OGV rig

Publications/Patent

Collaborative Project co-funded by the European Commission within the **7th Framework Programme** (2007-2013),
Under Grant Agreement n°ACP2-GA-2012-314366-E-BREAK

SP4 RELATED TECHNOLOGIES - Higher temperature material for breakthrough components

SP4 Objectives

The objectives of SP4 are to give a better understanding of coatings behaviour under severe conditions such as high thermal load or corrosion. Through the six work packages of SP4 several types of coatings were studied, covering a wide range of applications for every module of an engine. Nevertheless, a focus is made on abradable coatings for boosters and HPC and thermal barrier coatings for HPT.

Abradable coatings are sacrificial coatings that allow contact between the rotor part and the stator part, then it is possible to reduce the tip clearance which has a strong impact on the SFC. Abradable coatings are widespread in current engines. Despite their extensive use, there is very little knowledge on the key parameters needed to model the contact between the blade and the abradable. It was a major objective of E-BREAK to determine the link between the manufacturing parameters, mechanical properties obtained and behaviour on an engine or a full scale rub test. This methodology was applied to an existing abradable but development of new abradables with better properties, for example in corrosion, was also an objective of E-BREAK SP4.

The E-BREAK objectives regarding thermal barrier coating development were divided in two axis:

- Evaluation of a new manufacturing process: PS-PVD and optimisation of the bond coat for this application. The PS-PVD is a specific plasma spray able to make non line of sight coverage. Therefore it can be an enabler to coat small parts, or complex parts with TBC.
- Mechanical properties study of Ni based alloys with bond coat to better predict when the ceramic top coat is required.

SP4 Summary of achievements

The outcomes of the E-BREAK project are highlighted below:

- An abradable for booster has been developed from TRL1 to TRL5 in the frame of the project. This abradable exhibits better corrosion resistance than the current product. The new abradable have been tested against titanium blade in condition representative of each E-BREAK platforms. Demonstrations of abradable application have performed on both metallic and composite parts.
- Improvement of modeling tools to predict the wear mechanisms of the abradable and the dynamic response of the blade during the contact.
- A design of experiments has been conducted to select optimized ceramic abradable for high temperature application.
- Important mechanical tests plan have been completed to validate an increase of the maximal use temperature of M247 coated with NiAl.
- Optimisation of PS-PVD process for application on complex small size parts like NGV rings for helicopter engines.

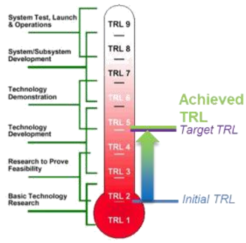
Higher temperature material for compressors abradables

Partners involved

SAFRAN

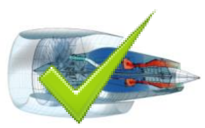
Description

Advanced abradable, resistant to aggressive environment for booster and high temperature HPC. Adaptation to composite casing coating

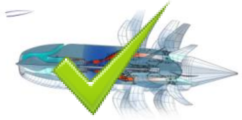


Ref : E-BREAK initial status / TRL	Initial E-BREAK objective	Final status
SFC impact	**-0.3%**	**0.2-0.55% booster efficiency**
PPS weight impact	**0**	**+ 0.3-1.6 kg/booster**
TRL progress	**2 ➔ 5**	**5**

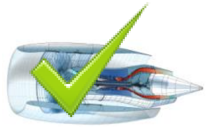
Turboshaft



Regional Turbofan



Short/Medium Range Open Rotor



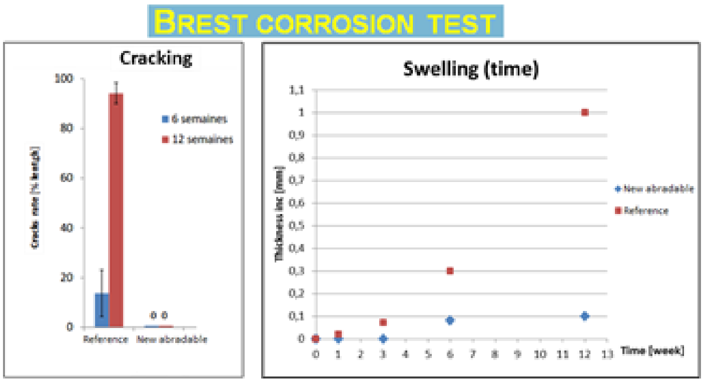
Long Range Turbofan

- Development of a new booster abradable and complete characterization on samples

- Improvements:

- **Corrosion resistance: at least one Shop Visit repair gain (1st booster abradable replacement expected at 2nd or 3rd SV)**

Corrosion resistance results comparison between reference coating and part coated with the new abradable coated developed in E-BREAK



- **Impact on compressor clearances evolution during service : efficiency improved and reducing surge risks**

<u>Calculation of impact on efficiency</u>

The swelling of the abradable is a main cause of the tip clearance increase in service. Therefore the new abradable, will lower the degradation in service of the booster efficiency. As erosion behaviour is the same for the new abradable and the current abradable the following estimation of the gain on efficiency is based only on abradability data.

Data presented are average data of all the stages of a booster

theoretical data	Efficiency loss/ mm of tip clearance increase (%)	Mass flow loss/ mm of tip clearance increase (%)
Business Jet	1.3	-
Small Engine	0.67	1.1
Medium Engine	0.47	0.53

SEVENTH FRAMEWORK PROGRAMME

Collaborative Project co-funded by the European Commission within the **7th Framework Programme** (2007-2013),
Under Grant Agreement n°ACP2-GA-2012-314366-E-BREAK

Measurements on 6 booster vanes	Abradable loss measurements [mm]	Average tip clearance increase (mm)
Abradable loss	**2.1 mm on 20% booster**	**0.42**

Swelling and flacking measurements on 6 different booster stages shows 2.1 mm of wear on 20% of the abradable surface. It's equivalent to a 0.42 mm tip clearance increase on the total abradable surface. The gain on efficiency calculated for a new abradable resistant to swelling is presented in the next table:

Conclusions	Efficiency gain with new abradable (%)	Specific flow capacity increase with new abradable (%)
Business jet	**0.55**	**-**
Small Engine	**0.28**	**0.46**
Medium Engine	**0.2**	**0.22**

- Drawback:

- **Weight impact: density increase from 1.5 to 1.9**
  - **Evaluation of the mass increase for a booster application in function of platforms**

Short range	0.3 kg
Medium range	0.9 kg
Long range	1.6 kg

- Application on metallic and composite parts during the E-BREAK project:

Composite casing coated

Metallic casing coated

- Risks? A full scale rub in test has still to be run to validate a TRL6

Publications/Patent

"Composition and abradable seal of an axial turbomachine compressor housing", Techspace Aero S.A., inventor: Laurent Schuster, EP 3023511 A1, published 25th of May 2016

Collaborative Project co-funded by the European Commission within the **7th Framework Programme** (2007-2013),
Under Grant Agreement n°ACP2-GA-2012-314366-E-BREAK

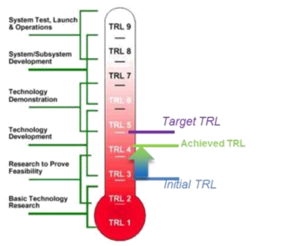
Abradable for high temperature HPC

Partners involved

MTU Aero Engines   SAFRAN

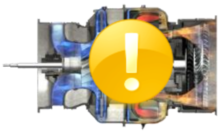
Description

Better understanding of wear behaviour of HPC abradable

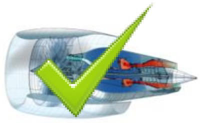


Ref : E-BREAK initial status / TRL	Initial E-BREAK objective	Final status
SFC impact	-0.3%	0
PPS weight impact	0	0
TRL progress	3 ➔ 5	4

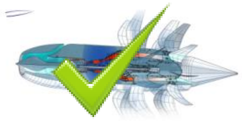
N.B: Abradables tested are already TRL9, the TRL evaluation is on modeling tool



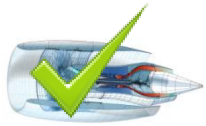
Turboshaft



Regional Turbofan

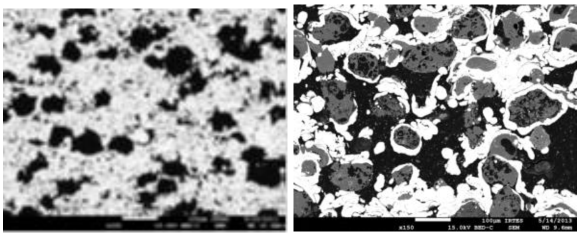


Short/Medium Range Open Rotor



Long Range Turbofan

WP4.2 goal: wear prediction methods improvement, applied to TRL6 HPC abradable concepts to improve their robustness. Same material as today : no impact on weight, process, operating temperatures - Two existing abradables were studied in details in order to better understand the phenomena occurring during a rotor/stator interaction and propose a methodology to characterize abradable properties relevant to model this kind of interactions.



2 microstructures of abradable tested in E-BREAK

The E-BREAK project permits also to optimize the 2 coatings microstructures. When the microstructures were tested, in both case, wear and/or strong heating of the blade tip occurred. From these results, no straight forward reduction of tip clearance can be validated. Nevertheless, thanks to a multi-disciplinary approach, models have been developed that can predict the phenomenon occurring during a rub event. Some refinements are still needed in order to take into account, for example, other abradables or contact at high temperature, but the deployment of these modeling tools will help to design better abradable, and blades that can better sustain strong interactions. The E-BREAK outcomes will therefore strongly participate to the future abradable sealing systems.

Publications/Patent

D. Aussavy et al., "Thermomechanical properties of CoNiCrAlY-Polyester composite coatings elaborated Atmospheric Plasma Spray", 10th international Conference on Local Mechanical Properties 2013

D. Aussavy PhD: Processing, Characterization and modeling of thermomechanical properties of three abradable coatings: NiCrAl-Bentonite, CoNiCrAlY-BN-Polyester and YSZ-Polyester, 2016

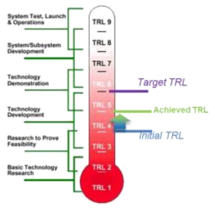
Sprayed abradables for turbine

Partners involved

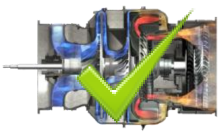
oerlikon metco   SAFRAN

Description

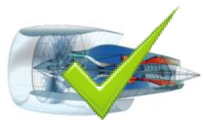
Materials validation to predict the rub-in behaviour for ultra-high temperature sprayed abradables



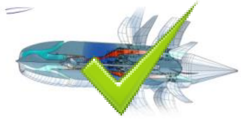
Ref : E-BREAK initial status / TRL	Initial E-BREAK objective	Final status
SFC impact	-	**0.2-0.3% HPT efficiency**
PPS weight impact	-	**0**
TRL progress	**4 → 6**	**5**



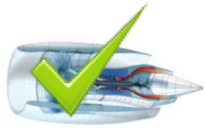
Turboshaft



Regional Turbofan



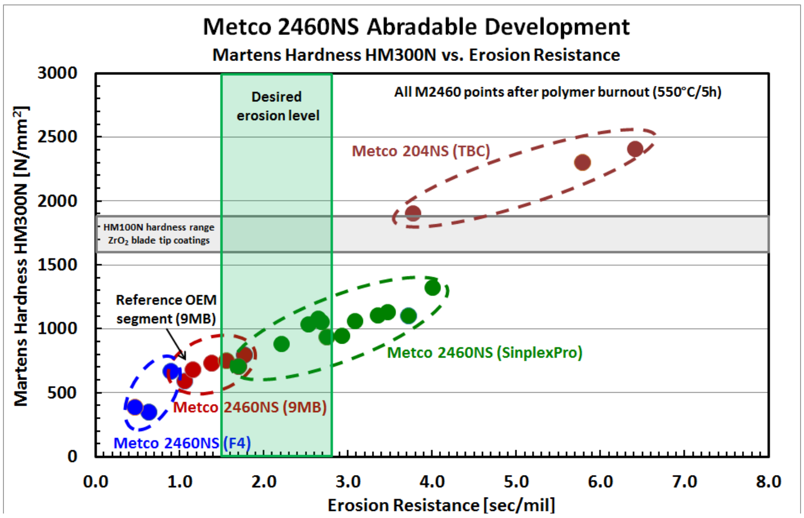
Short/Medium Range Open Rotor



Long Range Turbofan

- **Detailed description of main achievements**
  - **Current situation: rotor-stator contact results in rotor degradation (avoided on high dimensions engines through clearance opening), the objective is to find alternative abradable material able to endure high temperature while keeping abradable property and erosion resistance.**
  - **DOE approach enforced on a current abradable material (Metco 2460NS) to find the optimized range for erosion/abradability compromise.**
  - **Expected benefit: in case of contact, lower clearance impact because locally damaged abradable rather than homogeneously damaged rotor blades**
- **Expected better understanding of abradable thermal behaviour enabling more aggressive clearance design → 0.2 to 0.3 mm clearance reduction, which gives 0.2 to 0.3 % HPT efficiency depending on engine architecture. Risks: robustness of coating properties.**

Hardness vs. erosion resistance properties of Metco 204NS and Metco 2460NS deposited with 3 different plasma gun



Publications/Patent

D. Aussavy et al., "Influence of APS process parameters on morphologies of YSZ-Polyester abradable coatings", ITSC 2015

Collaborative Project co-funded by the European Commission within the 7th **Framework Programme** (2007-2013),
Under Grant Agreement n°ACP2-GA-2012-314366-E-BREAK

SEVENTH FRAMEWORK PROGRAMME

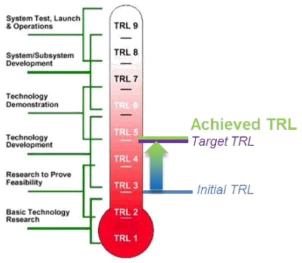
Sealing technologies for labyrinth seals

Partners involved

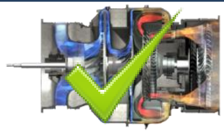
Rolls-Royce

Description

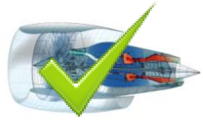
New sealing system with novel liner materials and seal fin shapes to minimize heat generation during incursions on turbines



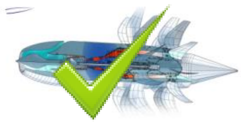
Ref : E-BREAK initial status / TRL	Initial E-BREAK objective	Final status
SFC impact	**-5% leakage flow reduction for individual labyrinth seal-overall impact on SFC to be determined**	**-5%, validation to be finalised**
PPS weight impact	**0**	**0**
TRL progress	**3 → 4/5**	**5**



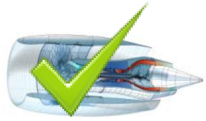
Turboshaft



Regional Turbofan



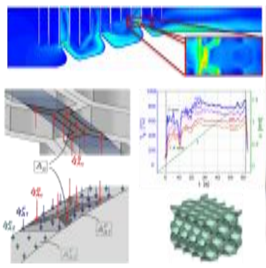
Short/Medium Range Open Rotor



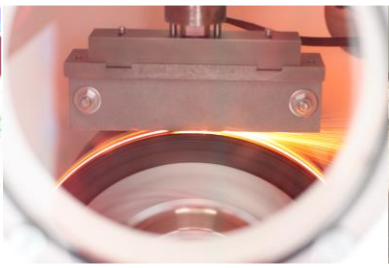
Long Range Turbofan

An increase of the overall pressure ratio (OPR) of future aero engines requires reliable sealing systems over the whole engine lifetime. In labyrinth seals a detrimental wear behaviour, which may result in damages as well, affects the sealing performance.

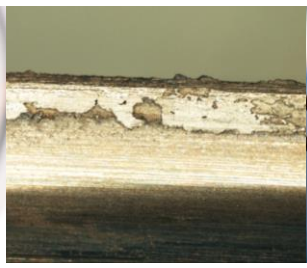
In this project novel sealing systems (abradable liner & seal fins) have been developed and investigated. Thereby, the focus was on a balanced requirement on sealing performance, sealing wear and sealing integrity. In order to validate and verify the proposed systems a new semi-analytical-numerical analysis technique has been developed and new test facilities have been commissioned (TU Dresden full-scale rub-in rig, KIT seal fin wear rig). In addition, analysis and tests like CFD studies, airflow tests, sheet metal rub-in tests and thermo-mechanical fatigue (TMF) tests have supported the assessment of promising candidates for improved sealing systems.



Numerical simulations



Full-scale rub-in rig (TU Dresden)



Seal fin after rub event

Specimen tests

Out of more than 10 different liner materials one liner material (developed in the project) has been down-selected which shows an improved sealing performance (CFD studies & airflow tests) and reduces the seal fin wear considerably (rub-in tests). Furthermore, out of more than 6 different seal fin shapes/topologies a novel seal fin design has been identified which reduces seal fin wear considerably and can be used in combination with the chosen new liner material.

It is planned to test the novel liner material on a demo-engine which is supposed to run in 2019.

Publications/Patent

Pychynski T., Höfler C., Bauer H.-J., "Experimental study on the friction contact between a labyrinth seal fin and a honeycomb stator", J Eng. Gas Turbines Power. 2015, GTP-15-1382, 2015

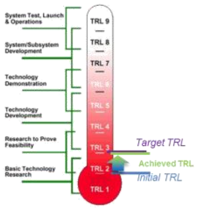
Two patents application on improved sealing systems in progress

Turbine diffusers

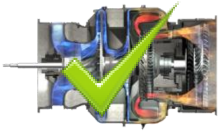
Partners involved

Description

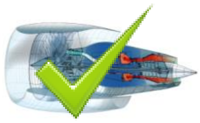
Methodological improvements and extension of use of conventional superalloys for turbine diffusers



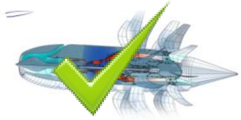
Ref : E-BREAK initial status / TRL	Initial E-BREAK objective	Final status
SFC impact	-	T_{max} +70°C
PPS weight impact	-	0
TRL progress	2→3	3



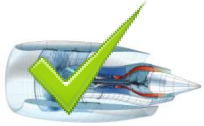
Turboshaft



Regional Turbofan



Short/Medium Range Open Rotor



Long Range Turbofan

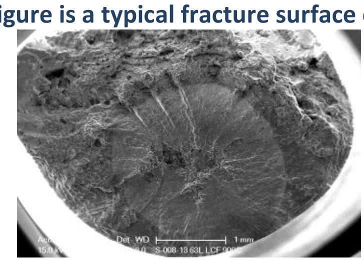
The following mechanical tests have been made to validate the increase of the maximal temperature of use of M247:

Test type	Exposure Conditions	Tests per exposure condition	TOTAL Test Number
Tensile	3	15	45
LCF strain	3	21	63
LCF load	3	14	42
Creep	3	12	36
			186

Samples after thermal exposures are shown in the next figures:

The material properties and microstructure are maintained exposing the material to +70ºC over the max temperature of use.

It has been demonstrated that for a certain period of time the maximum operating temperature for this material can be increased up to 70ºC. The following figure is a typical fracture surface of fatigue test.



Publications/Patent

Collaborative Project co-funded by the European Commission within the 7th **Framework Programme** (2007-2013),
Under Grant Agreement n°ACP2-GA-2012-314366-E-BREAK

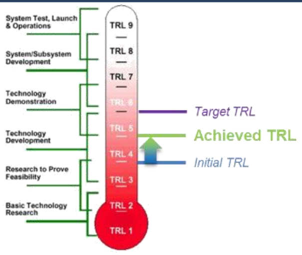
Thermal barrier coating system for complex shape static turbine parts

Partners involved

SAFRAN, ITP (the power of talent), oerlikon metco

Description

Design of a TBC system of a complex shaped part as HPT NGV ring or triple vane segmented NGV. Process cost reduction, improved coating life expectancy



Ref : E-BREAK initial status / TRL	Initial E-BREAK objective	Final status
SFC impact	-	-
PPS weight impact	-	0
TRL progress	4→6	5

Turboshaft | **Regional Turbofan** | **Short/Medium Range Open Rotor** | **Long Range Turbofan**

- **Detailed description of main achievements**
  - **Application of a less line of sight TBC process (Plasma Spray PVD compared to standard EB PVD) on complex shaped NGV like NGV rings or small NGV triplet segments**
  - **Expected benefit: ability to get thermal barrier coating on complex small size parts, especially in areas not reachable by standard TBC processes.**
  - **Expected impact : once TBC coating is feasible, either lower cost material (polycrystalline like MARM247) at iso-temperature (for segmented NGVs), or increased temperature capability for NGV ring (up to +100°C)**
- **No significant impact on weight**

NGV TBC coated by PS-PVD

PS-PVD deposition process

Publications/Patent

ENGINE BREAKTHROUGH COMPONENTS AND SUBSYSTEMS

SP5 RELATED TECHNOLOGIES - Lightweight materials for breakthrough components

SP5 Objectives

The SP5 main objective is to understand the link between the processing routes of different manufacturing processes and relevant microstructure and mechanical properties for new generation γ -TiAl alloys, leading to an improved understanding of fundamental material behaviour.

To achieve that objective, component tests and an engine test have been performed to validate all of the technical aspects studied in the project: material, process, coatings and manufacturing route.
The aim of the WP5.1 was to produce test specimens by different manufacturing processes (casting and Electron Beam Melting (EBM)). Next mechanical tests were performed, the heat treatment was optimized, the microstructure investigated and a study of the influence of bulk and surface defects representative of different manufacturing processes on mechanical properties was performed.

The mechanical characterisation on 3rd generation γ-TiAl alloy showed promising benefits for tensile and fatigue properties. Moreover, a set of test specimens realised by EBM and casting were subjected to further characterizations and the influence of defects typical of the processes routes was evaluated.

The main objectives of the WP5.2 were to develop wear resistant coatings and intermediate layers to avoid wear damage, the improvement of the oxidation/corrosion behaviour of 3rd generation of γ - TiAl alloys by applying protective coatings and to develop shot peening parameters for LPT blade surface work hardening.

Fretting wear and fretting fatigue tests were performed that verified that a high temperature metal alloy as intermediate layer in the blade/root disk slot is suitable to meet the required cycle number without any wear damage.

Collaborative Project co-funded by the European Commission within the **7th Framework Programme** (2007-2013),
Under Grant Agreement n°ACP2-GA-2012-314366-E-BREAK
SEVENTH FRAMEWORK PROGRAMME

Moreover, under cyclic oxidation conditions the samples coated with two different oxidation coatings exhibited a significant improvement in the oxidation resistance as compared with uncoated TiAl. Finally, shot peening parameters have been developed and in the shot peened surface no damage was produced with detrimental effects on mechanical properties.

The aims of the WP5.3 were to optimize production processes, evaluate raw material recyclability, and investigate the capability of conventional non-destructive methods to detect the defects representative of these processes in order to optimize the conditions of post-processing technology. An ElectroChemical Machining (ECM) process has been investigated for 3rd generation of γ-TiAl alloy aerofoils.

Regarding the recyclability of raw material on the EBM side, the influence of powder recycling on its main characteristics has been assessed over 6 cycles. On the casting side, the exclusive use of scrap material is not advisable and will results in a deviation from the specification composition requirements due to material losses during the recycling process. The best solution was achieved mixing 50% of virgin material with 50% of recycled material.

Finally, for what concerns the non-destructive methods, the main output was the improved visibility of cracks with the use of chemical etching before dye-penetrant testing to highlight cracks and remove the surface material which could hide some indications.

The main objectives of WP5.4 were to perform engine test using the produced cast TiAl blades in order to assess TiAl alloy behaviour within a representative environment, perform spin test using forged TiAl blade to assess anti-wear coating behaviour and take TiAl technologies developed in the frame of this subproject to TRL 5/6.

During the project, blades for engine and spin tests have been produced in order to meet the requirements identified. Furthermore Spin test and engine test were successfully performed and the components have been inspected after the tests without any evidence of defects.

SP5 Summary of achievements

The main achievement of SP5 can be summarized as follow:

- Microstructure and heat treatment definition for 3rd generation TiAl alloys produced by casting and EBM;
- Mechanical properties data available for material processed by both casting and EBM;
- Impact of process defects assessed on both casting and EBM materials;
- Development of anti-wear resistant coating and intermediate layer for the TiAl low pressure turbine blade root attachment;
- Development and test of oxidation and corrosion resistant coating;
- Definition of conventional and Ultra-Sonic (US) Shot peening process parameters for the TiAl low pressure turbine blade root and Low Cycle Fatigue (LCF) impact assessed;
- Optimization of EBM and casting processes and metallurgical analysis of raw parts;
- Material recyclability assessed for both casting and EBM processes;
- Definition of typical defects for TiAl alloys from cast and EBM and optimisation of NDT method for detectability;
- ECM process evaluated as machining approach for EBM TiAl blades;
- Production of TiAl blades by casting and EBM and EBM blade machining;
- Spin and Engine tests performed with success.

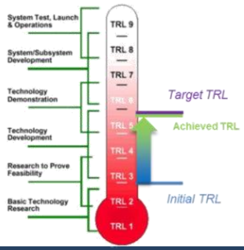
3rd generation TiAl turbine blades by casting definition

Partners involved

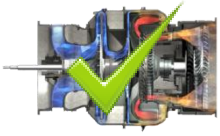
Avio Aero – A GE Aviation Business; SAFRAN

Description

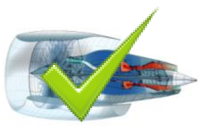
Robust design data and criteria for improved TiAl alloy for casting and improvement of full manufacturing processes



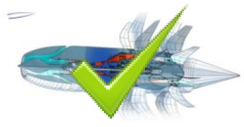
Ref : E-BREAK initial status / TRL	Initial E-BREAK objective	Final status
SFC impact	-	-
PPS weight impact	**-0.5% -3% (depending on engine architecture)**	**Up to -30% on LPT module**
TRL progress	**3→6**	**6**



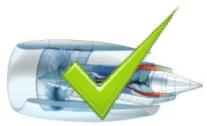
Turboshaft



Regional Turbofan

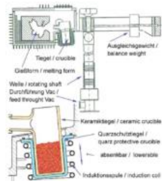


Short/Medium Range Open Rotor

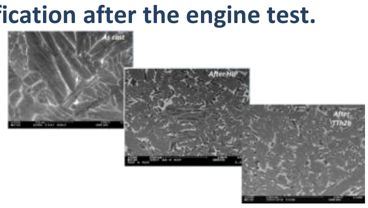


Long Range Turbofan

- **Chemical composition, heat treatment and relevant microstructure have been defined and tested for casting manufacturing process.**
- **A robust database of design curves has been generated.**
  With reference to cast 2nd generation TiAl alloy we get:
  - **Improved mechanical properties but lower ductility**
  - **Improved LCF life (+35% @10^6 cycles and 704/760°C)**
  - **Comparable stress rupture**
- **Trace elements effect and internal defect impact have been evaluated**
- **Very low density (about 4 g/cm³) vs. Ni-base superalloys (about 8 g/cm³). Weight saving up to 30% on LPT module depending on engine configuration.**
- **Temperature application limits for TNM defined at 760°C, comparable to 2nd generation TiAl alloy.**
- **Manufacturing process optimised for casting in order to produce acceptable LPT blade components.**
- **An endurance engine test was performed in order to evaluate the fatigue strength of a power turbine blade in TNM-B1. The test lasted 3000 cycles, around 600 hours, with a maximal temperature in the top of the blade of 760°C.**
- **No blade was broken during this engine test and no cracks have been detected in the TiAl blade root area. Moreover, there was no significant creep of the blades because the dimensional characteristic were always conform to the specification after the engine test.**



Centrifugal casting process



TNM microstructures

TiAl casting blades after engine test

Publications/Patent

A. Denquin et. al, "Effect of small additions of non-metallic elements on high-temperature behavior of gamma alloys", Titanium 2015 conference;

A. Denquin et. al, "Influence of Si and C additions on microstructure and high temperature behavior of the Ti-43.5Al-1Mo-4Nb-0.1B alloy", Materials at high Temperature 2016;

A. Denquin et. al, "Influence of separate Si and C additions on microstructure and high temperature behavior of the TNM γ-TiAl alloy", La Metallurgie, quel avenir! Conference 2016

Collaborative Project co-funded by the European Commission within the **7th Framework Programme** (2007-2013), Under Grant Agreement n°ACP2-GA-2012-314366-E-BREAK

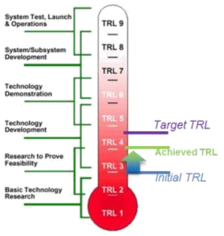
3rd generation TiAl turbine blades by EBM definition and relevant manufacturing process

Partners involved

Avio Aero – A GE Aviation Business
SAFRAN

Description

Robust design data and criteria for improved TiAl alloy for EBM and improvement of full manufacturing processes.



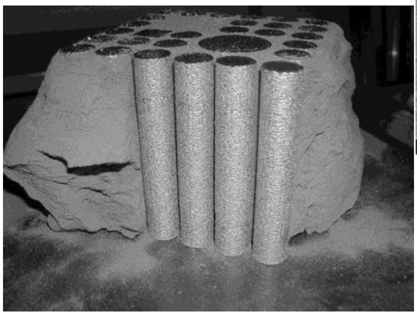
Ref : E-BREAK initial status / TRL	Initial E-BREAK objective	Final status
SFC impact	**-**	**-**
PPS weight impact	**-0.5% -3% (depending on engine architecture)**	**Up to -30% on LPT module**
TRL progress	**4→5**	**4**

Turboshaft ***Regional Turbofan*** ***Short/Medium Range Open Rotor*** ***Long Range Turbofan***

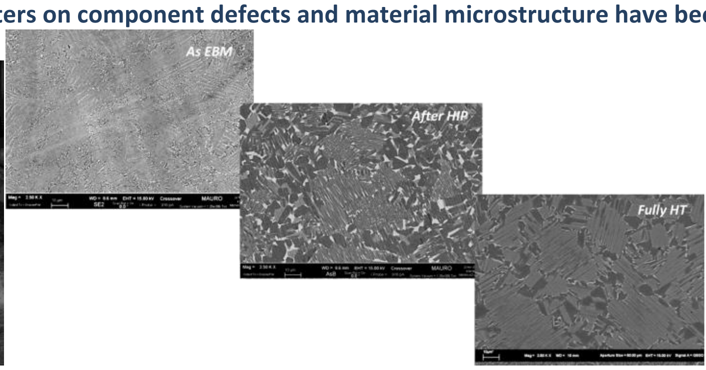
- Chemical composition, Heat Treatment and relevant microstructure have been defined and tested for EBM manufacturing process.
- A robust database of design curve has been generated.
With reference to cast 2nd generation TiAl alloy we get:

- **Improved mechanical properties (+100%0,2YTS and +65%UTS @ RT)**
- **Improved LCF life (+80% @10000 cycles and 704/760°C)**
- **Comparable ductility and stress rupture**
- **Comparable crack propagation limits**

- Trace elements effect and internal defect impact has been evaluated
- Temperature application limits for TNM defined at 760°C, comparable to 2nd generation TiAl alloy
- Very low density (about 4 g/cm^3) vs. Ni-base superalloys (about 8 g/cm^3). Weight saving up to 30% on LPT module depending on engine configuration.
- Manufacturing process optimised for EBM in order to produce acceptable LPT blade components
- Impact of significant process parameters on component defects and material microstructure have been evaluated



TNM EBM specimens



TNM microstructures

TiAl EBM blade

Publications/Patent

S. Biamino et. al, "TiAl alloys produced by Electron Beam Melting" Intermetallics 2013;
M. Filippini, S. Beretta, "Fatigue strength in gamma-TiAl produced by additive manufacturing: a few lessons learnt", Intermetallics 2015.

Collaborative Project co-funded by the European Commission within the 7th **Framework Programme** (2007-2013), Under Grant Agreement n°ACP2-GA-2012-314366-E-BREAK

SEVENTH FRAMEWORK PROGRAMME

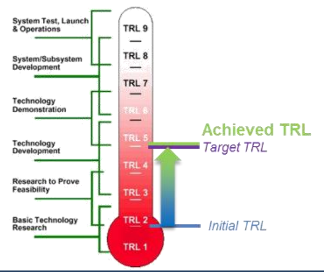
Anti-wear coatings for 3rd generation of TiAl LPT Blades

Partners involved

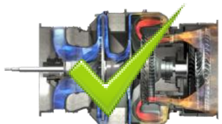
MTU Aero Engines

Description

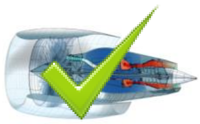
Wear resistant coatings for TNM blades



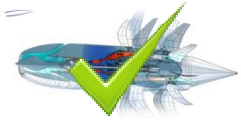
Ref : E-BREAK initial status / TRL	Initial E-BREAK objective	Final status
SFC impact	**No impact**	**No impact**
PPS weight impact	**No impact**	**No impact**
TRL progress	**2 → 5**	**5**



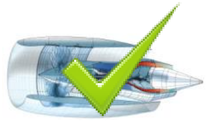
Turboshaft



Regional Turbofan

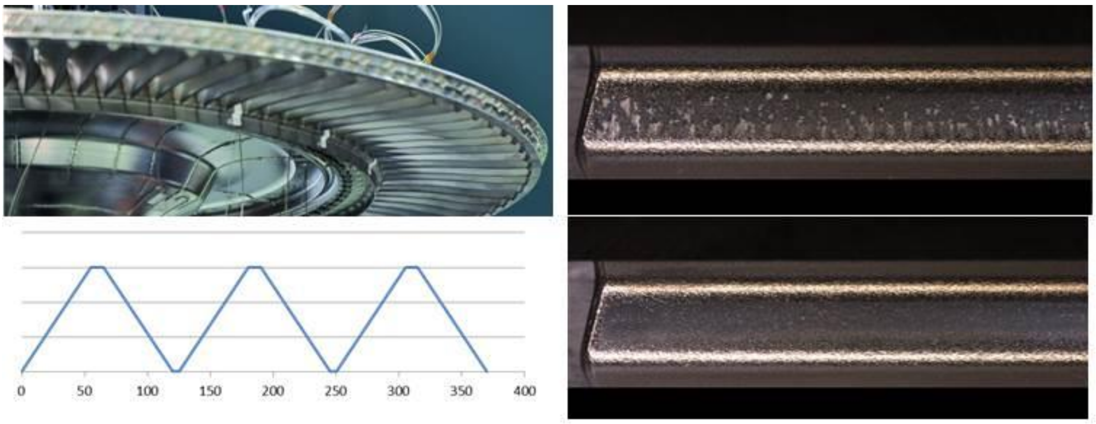


Short/Medium Range Open Rotor



Long Range Turbofan

- **Options for wear resistant coatings and intermediate layers have been tested and selected for spin rig tests in order to increase the wear resistance of TiAl blades (typically brittle material).**
- **Based on preliminary test (fatigue-fretting and wear test), the best solution resulted to be the intermediate layer between blade root and disk notch. Intermediate layer has been selected to perform the spin rig test.**
- **Intermediate layer solution has demonstrated a significant increase in wear resistance of TNM blades after 20000 h spin test.**
- **Longer service time for TNM blade due to intermediate layer introduction (costs 3-5 €/blade); after 20000 h in service is possible to replace the intermediate layer only instead of the blade.**



Spin test rig and test cycles; TiAl blade root, tested without intermediate layer between blade root and disk notch, with fretting wear traces; TiAl blade root tested with intermediate layer between blade root and disk notch, without fretting wear traces

Publications/Patent

A. Werner, "Wear protection for turbine blades made of titanium aluminide", 2014 TMS Annual Meeting & Exhibition.

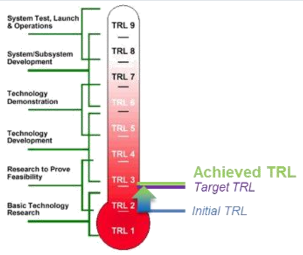
Coatings and Surface Treatment for TiAl LPT Blades

Partners involved

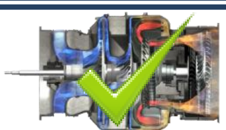
SAFRAN

Description

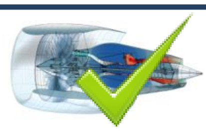
Anti-oxidation/corrosion coating for Ti48-2-2 and 3rd generation of TiAl alloys



Ref : E-BREAK initial status / TRL	Initial E-BREAK objective	Final status
SFC impact	**No impact**	**No impact**
PPS weight impact	**No impact**	**No impact**
TRL progress	**2 → 3**	**3**

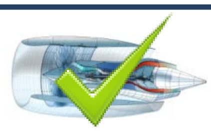


Turboshaft



Regional Turbofan

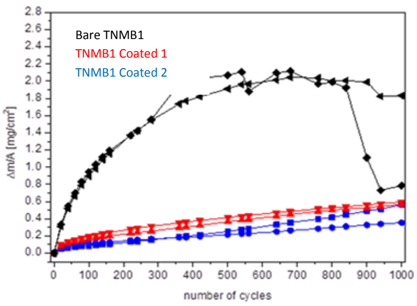
Short/Medium Range Open Rotor



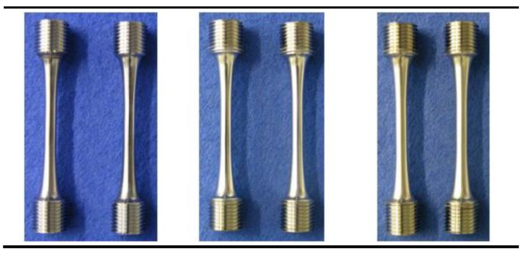
Long Range Turbofan

All TiAl alloys suffer from fast oxidation degradation from 850°C and embrittlement at high temperature exposure.
2 different coatings defined and pertinent process (plasma sputtering) successfully tested.
Both coatings showed better oxidation resistant from 850°C onwards for 2nd generation TiAl alloy and TNM alloy.
TNM mechanical properties (tensile) with coating tested exhibit some decrease at room temperature after high temperature exposure. More tests are needed to fully understand the impact of coating.
Corrosion tests have demonstrated that coatings are not efficient to protect TiAl against high temperature corrosion.
To reach TRL4, the coatings homogeneity on complex shapes have to be investigated.
The duration for applying coating is about 8 hours for 10 µm and the installation to deposit these type of coatings costs about 500 K€
The coating cost depends on:

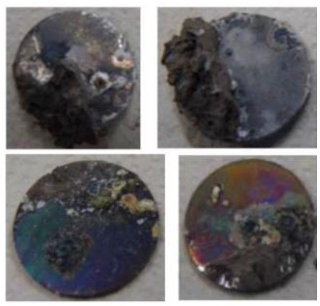
- **The shape complexity of the part**
- **The amount of parts to coat**



1h - cyclic oxidation resistance at 850°C on TNM-B1 alloy



Uncoated and coated tensile specimens



Uncoated and coated TNM coupon after 5h corrosion testing

Publications/Patent

D. Aussavy et. al, "Thermomechanical properties of CoNiCrAlY-Polyester composite coatings elaborated Atmospheric Plasma Spray", 10th international Conference on Local Mechanical Properties 2013;
N. Laska et. al, "Oxidation behavior of γ-TiAl alloys coated with intermetallic Ti-Al-Cr based layers", Intermetallics conference 2015;
G. Martin, P. Sallot, "Snecma application of γ-TiAl alloys for low pressure turbine blades: development phase, mass production and new opportunities", 5th International Workshop on Titanium Aluminides 2016;

Collaborative Project co-funded by the European Commission within the **7th Framework Programme** (2007-2013),
Under Grant Agreement n°ACP2-GA-2012-314366-E-BREAK

SEVENTH FRAMEWORK PROGRAMME

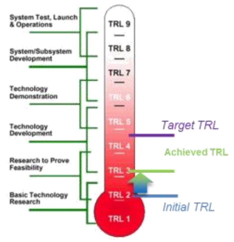
Shot peening influence on fatigue performances of TiAl alloys

Partners involved

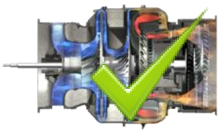
SAFRAN

Description

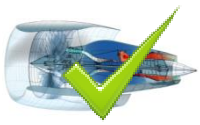
Shot peening for Ti48-2-2 and 3rd generation of TiAl alloys



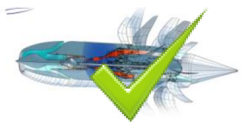
Ref : E-BREAK initial status / TRL	Initial E-BREAK objective	Final status
SFC impact	**No impact**	**No impact**
PPS weight impact	**No impact**	**No impact**
TRL progress	**2 → 4/5**	**3**



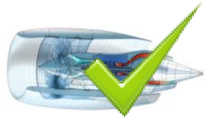
Turboshaft



Regional Turbofan

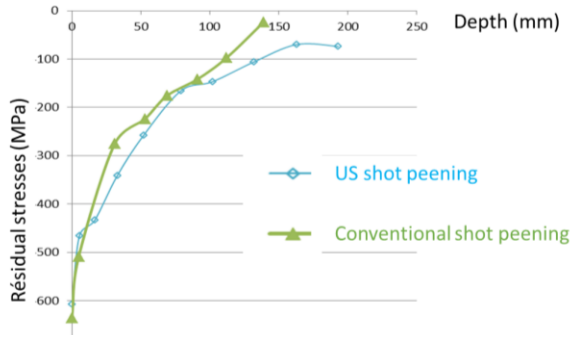


Short/Medium Range Open Rotor



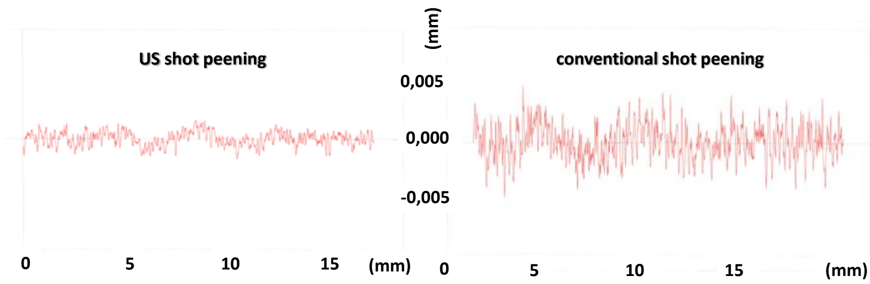
Long Range Turbofan

- **The impact of the conventional and ultrasonic shot peening on the fatigue properties of TNMB-1 alloy has been evaluated.**
- **Both shot peening were realized for a same Almen intensity in order to compare their impact.**

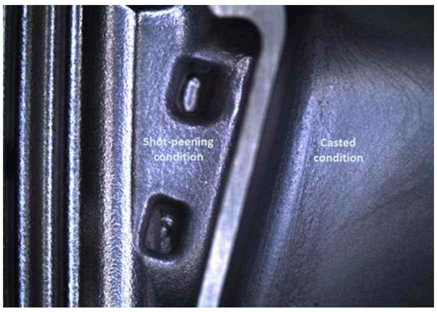


Residual stress comparison between US shot peening and conventional shot peening

- **The main results have demonstrated that, compared to the conventionally shot peened specimens, the US shoot peened ones presents:**
  - **A better typical endurance limit (+20%) at room temperature.**
  - **A lower surface roughness.**



Roughness profile on US and conventional shot peening blade surface



Visual different between shot peening and casted condition blade

Publications/Patent

Collaborative Project co-funded by the European Commission within the **7th Framework Programme** (2007-2013),
Under Grant Agreement n°ACP2-GA-2012-314366-E-BREAK

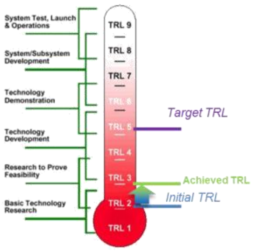
ECM process optimization for TNM TiAl alloy

Partners involved

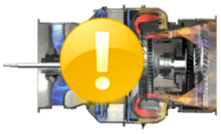
Avio Aero
A GE Aviation Business

Description

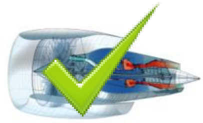
Improvement of machining process for TNM blades



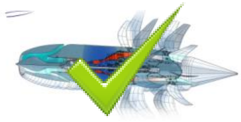
Ref : E-BREAK initial status / TRL	Initial E-BREAK objective	Final status
SFC impact	**No impact**	**No impact**
PPS weight impact	**No impact**	**No impact**
TRL progress	**2 → 5**	**3**



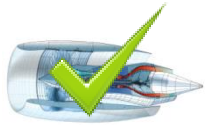
Turboshaft



Regional Turbofan



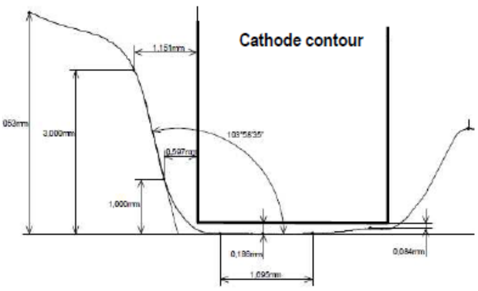
Short/Medium Range Open Rotor

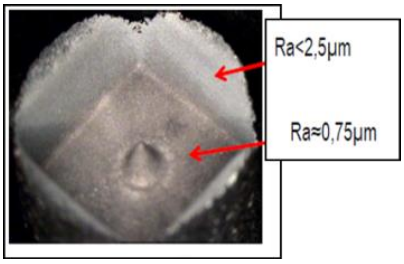


Long Range Turbofan

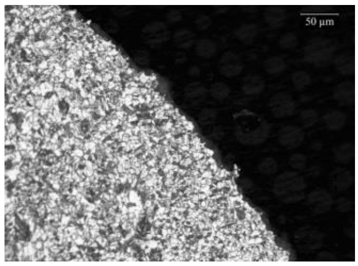
- **The workability of TNM alloy by the ECM machining was comparable to 2nd generation TiAl alloy.**
- **Tests performed with different ECM approaches and different machine parameters:**
  - **Square and spherical shape cathode to simulate fillet and aerofoil machining**
  - **With and without cathode oscillation and combined technique in order to evaluate the best parameters**
  - **Metallurgical analysis has highlighted no significant impact of the ECM on the base material**
- **The test has provided evidences of achieved surface roughness and pertinent feed rate.**
- **Feasibility of this technology has been proved in order to decrease machining time for overstock removal on TiAl components.**

Cathode geometries

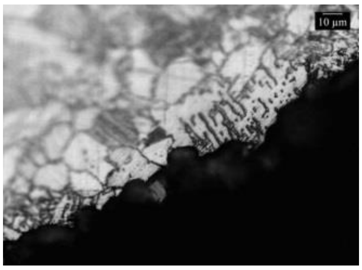




Test scheme and TNM specimen after machining



Combined PECM machining



PECM with cathode oscillation

Surface and microstructure of machined TNM specimens

Publications/Patent

Collaborative Project co-funded by the European Commission within the **7th Framework Programme** (2007-2013),
Under Grant Agreement n°ACP2-GA-2012-314366-E-BREAK

Recycling processes for TiAl manufacturing process

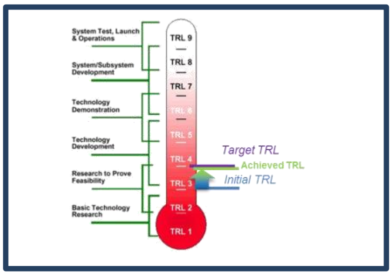
Partners involved

Avio Aero – A GE Aviation Business

IME – Die Metallurgen

Description

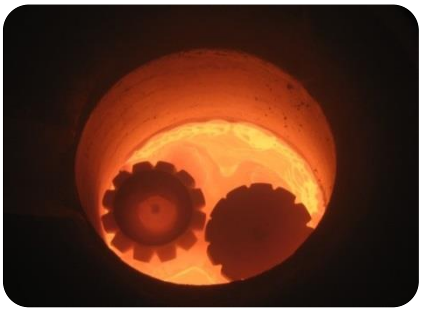
Development of recycling method for cast and EBM Ti48-2-2



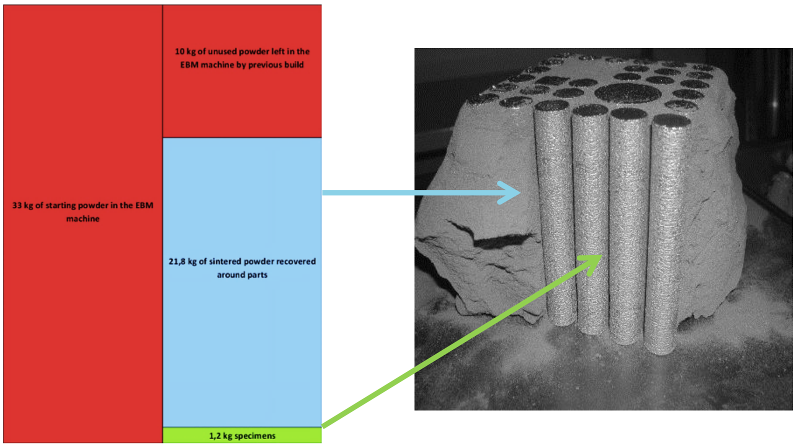
Ref : E-BREAK initial status / TRL	Initial E-BREAK objective	Final status
SFC impact	**No impact**	**No impact**
PPS weight impact	**No impact**	**No impact**
TRL progress	**3 → 4**	**4**

Turboshaft ***Regional Turbofan*** ***Short/Medium Range Open Rotor*** ***Long Range Turbofan***

- **Recycle process defined for both casting and EBM processes**
- **Feasibility proved in order to match specification limit requirements**
  - **For the casting process, the best solution was achieved mixing 50% of virgin material with 50% of recycled material.**
  - **For the EBM process, the unused and sintered powder that remains after the building job was mixed to new powder and re-used with success up to 6 cycles. Achieved results have suggested the feasibility of a higher number of recycling cycles.**



Melting process of scraps parts for casting recycle



Powder sampling scheme and specimens after EBM

Publications/Patent

P. Spiess, et. al, "A material loop closing recycling technology of Y-TiAl from precision cast LP turbine blades", CIT Journal 2015

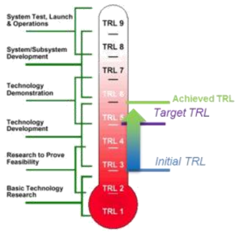
Non Destructive Testing to detect defects in TiAl casting blades

Partners involved

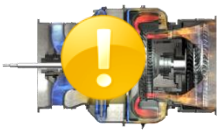
SAFRAN

Description

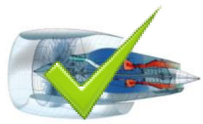
Capability of conventional NDT to detect defects in Ti-48-2-2 and TNM blades



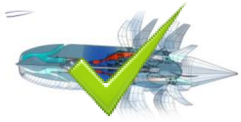
Ref : E-BREAK initial status / TRL	Initial E-BREAK objective	Final status
SFC impact	**No impact**	**No impact**
PPS weight impact	**No impact**	**No impact**
TRL progress	**3 → 5**	**6**



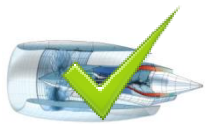
Turboshaft



Regional Turbofan

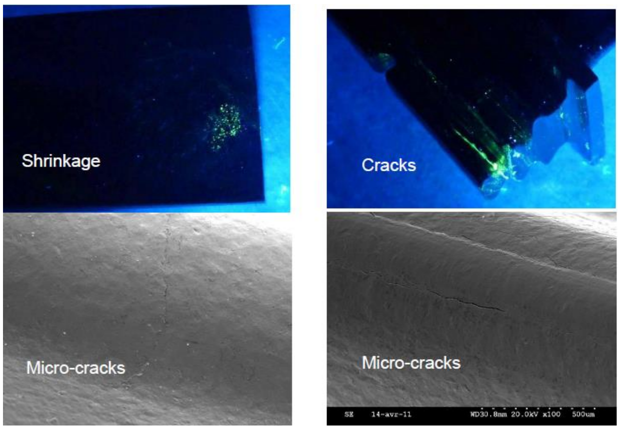


Short/Medium Range Open Rotor



Long Range Turbofan

- **Here are the typical anomalies which can be observed on cast TiAl blades:**
  - **Cracks**
  - **Cold shuts**
  - **Hot spots**
  - **Shrinkages**
  - **Gas porosities**
  - **Inclusions**



Typical anomalies observed on cast TiAl blades by dye penetrant testing

- **Various NDT methods were considered such as conventional and micro-tomography, X-rays, shearography and dye-penetrant testing**
- **Concerning dye-penetrant testing, several tests demonstrated that a pre-chemical etch is useful to highlight cracks and remove the surface material which could hide some indications.**

Publications/Patent

Collaborative Project co-funded by the European Commission within the **7th Framework Programme** (2007-2013),
Under Grant Agreement n°ACP2-GA-2012-314366-E-BREAK

SP6 RELATED TECHNOLOGIES - Health monitoring

SP6 Objectives

The objectives of SP6 are to mitigate the operational risks from the introduction of new engine technologies, maintain their SFC-benefits through the engine life cycle and allow for new opportunities in the design space of engine development. For this purpose the following health monitoring technologies have been investigated:

- Failure diagnosis to mitigate risks due to increasing system complexity, e.g. failures in variable geometries, and degradation diagnosis to assess performance degradation such as erosion, corrosion or fouling in the presence of increasingly high pressures and temperatures.
- Performance prognosis, i.e. a condition-based forecast of remaining useful life until the next maintenance action.
- Predictive Maintenance, i.e. in this context the ability of predicting the performance gain of a maintenance action based on the individual engine's service record and a data base of the shop visits of all engines in the past.
- On-line structure health monitoring with failure detection and actual measurement of degradation to increase availability and reduce maintenance cost as well as to reduce required design margins and hence save weight.

SP6 Summary of achievements

Within the E-BREAK project, researchers from ÅAC Microtec, GKN Aerospace, MTU Aero Engines, SAFRAN HELICOPTER ENGINES and University of Uppsala have developed several technologies up to a technology readiness level of 4 to 6 to achieve their objectives. All technologies have been validated based on historical in-flight data records, dedicated sub-assembly test rigs or full engine tests. The results from SP6 are:

- A library of four algorithms based on pattern recognition and model-based analysis for engine failure and degradation diagnosis.
- Two supplementary algorithms for short- and medium term performance prognosis.
- A process for predicting and planning the impact of maintenance practices on engine performance.
- Prototype hardware for structural health monitoring embedded in several fan outlet guide vanes including sensors, wireless power supply and data transmission and central data acquisition node.

Collaborative Project co-funded by the European Commission within the **7th Framework Programme** (2007-2013),
Under Grant Agreement n°ACP2-GA-2012-314366-E-BREAK

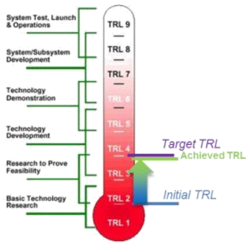
Engine performance diagnosis

Partners involved

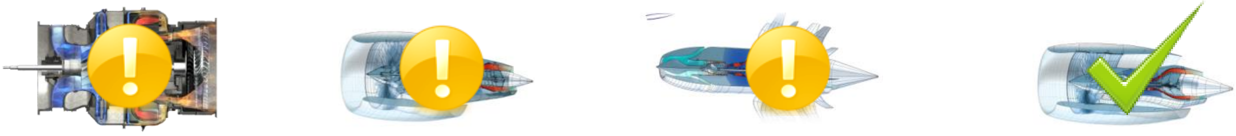
MTU Aero Engines

Description

Development of methodology for performance diagnosis based on limited instrumentation

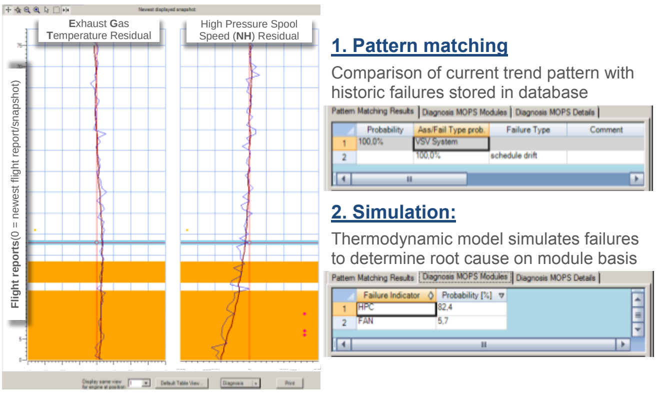


Ref : E-BREAK initial status / TRL	Initial E-BREAK objective	Final status
SFC impact	**-0.5 %**	**No direct impact ➔ contribution to availability**
PPS weight impact	**--**	**--**
TRL progress	**2 ➔ 4**	**4**



Turboshaft ***Regional Turbofan*** ***Short/Medium Range Open Rotor*** ***Long Range Turbofan***

During the engine life cycle its performance, i.e. fuel consumption, maximum temperatures and ability to deliver the desired thrust, can be affected in two ways. First there are failures and second there is degradation. Failures may occur due to foreign object damage like bird strikes or due to unanticipated sub-system malfunction like a blockage in the variable stator vane actuation system. Failure diagnostics are a way to mitigate perceived and actual reliability issues with sub-system malfunction for new higher temperature and OPR core technologies. For this purpose within E-BREAK work package 6.1 a 2-step failure diagnostics algorithm has been developed:



Failure diagnosis (right) based on engine flight data (left)

Engine health monitoring is estimated to potentially turn about 20% of all unscheduled engine maintenance into scheduled maintenance and in turn improve engine reliability or availability by 20%. An internal evaluation by MTU indicates, that failure diagnostics contributes an approximate 1%pt to this 20% potential.

Performance degradation occurs continuously and is a result of “wear and tear”, specifically abrasion, corrosion, erosion and fouling (particulate residue on aerofoils).

Diagnosis of performance degradation is a technology to quantify component thermodynamic efficiency loss due to the overall effect of “wear and tear”.

A major challenge for this technology is to overcome the limitations in state-of-the-art instrumentation with intelligent analysis algorithms.

Degradation diagnosis is major step towards enabling the technology of “Post maintenance performance prediction”.

Publications/Patent

Freund et al.: Entwicklung und Validierung eines Verfahrens zur Zustandsanalyse eines Flugtriebwerks anhand der Standardinstrumentierung auf Basis der Methode der kleinsten Fehlerquadradte. German DGLR Conference, Sep 16-18 2014.

Abdulllahi et al.: Model-Based In-Flight Condition Monitoring Tool for Aero Engine Diagnosis. ISABE, Oct 25-30 2015.

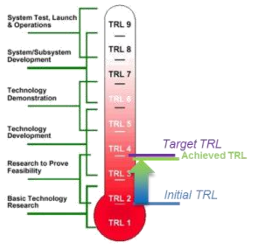
Engine performance prognosis

Partners involved

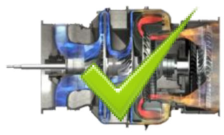
MTU Aero Engines — SAFRAN

Description

Development of methodology for performance prognosis



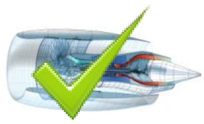
Ref : E-BREAK initial status / TRL	Initial E-BREAK objective	Final status
SFC impact	**-0.5 %**	**No direct impact → contribution to availability**
PPS weight impact	**--**	**--**
TRL progress	**2 → 4**	**4**



Turboshaft

Regional Turbofan

Short/Medium Range Open Rotor



Long Range Turbofan

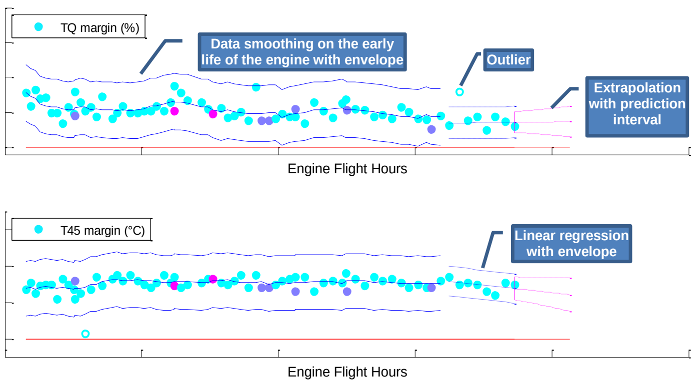
Degradation of engine performance during the engine's life cycle is unavoidable. At some point performance margins like Exhaust Gas Temperature Margin (EGTM), Inter-Turbine Temperature Margin (ITTM) and Torque Margin (TQM) are reached. Effective line maintenance like engine core washing can delay the expiration time, but at some point the engine has to undergo shop maintenance to recover performance.

However, the planning of line and shop maintenance challenges in two ways:

- **Corrective action shall be planned without the need for visual inspection or partial disassembly of the engine**
- **Spare parts and resources shall be available when and where they are needed to reduce AOG (aircraft on ground) times and TAT (turn-around-time) in the shop**

Hence prognosis of engine performance is required. In SP6 four prognosis algorithms have been developed that allow forecasting of the remaining useful life based on adaptive time series extrapolation of Exhaust Gas Temperature Margin (EGTM), Interturbine Temperature Margin (ITTM) and Torque Margin (TQM). This enables adjustments in line maintenance (e.g. engine wash) in order to maintain performance margins and hence condition-based engine life.

Within E-BREAK two different approaches for short- and medium-term prognosis have been developed and validated with in-flight data from Turboshaft and Long Range Turbofan engines. Application to the Regional Turbofan and Short/Medium Range Open Rotor is possible but has not been tested within the project.



Prognosis Charts for Torque and T45 Margin

Publications/Patent

Vogel et al.: Klassifikation von Einflussfaktoren auf das Alterungsverhalten von Serientriebwerken unter Verwendung von Flugdaten. German DGLR Conference, Sep 22-24 2015.

Collaborative Project co-funded by the European Commission within the 7th **Framework Programme** (2007-2013),
Under Grant Agreement n°ACP2-GA-2012-314366-E-BREAK
SEVENTH FRAMEWORK PROGRAMME

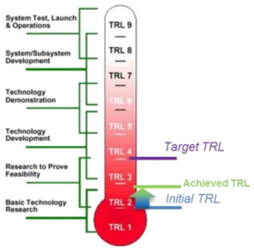
Post maintenance performance prediction

Partners involved

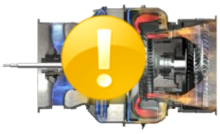
MTU Aero Engines

Description

Methods for work scope analysis for engine performance recovery



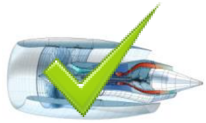
Ref : E-BREAK initial status / TRL	Initial E-BREAK objective	Final status
SFC impact	**-0.5 %**	**-0.38 %**
PPS weight impact	--	--
TRL progress	**2 ➔ 4**	**3**



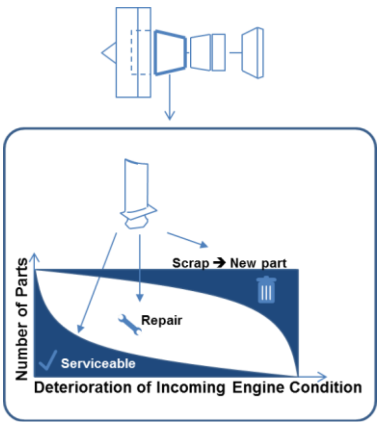
Turboshaft

Regional Turbofan

Short/Medium Range Open Rotor



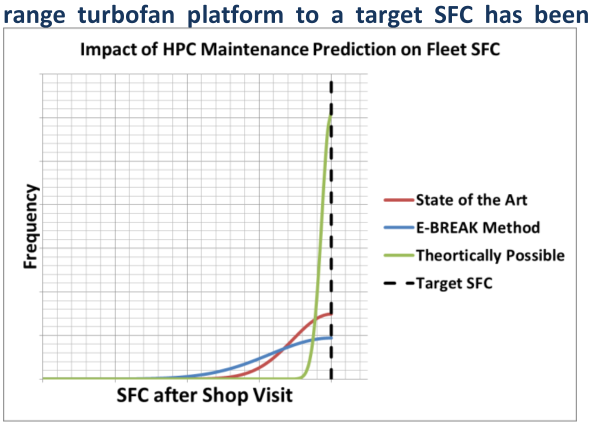
Long Range Turbofan



Ideal mix of parts for engine restoration during shop visit

The objective of this technology is to predict the performance improvement of an engine that will be achieved during a shop visit. The boundary conditions for the prediction is the incoming condition of the engine in terms of component performance (thermodynamic efficiency) and cycles since last shop visit. The degree of freedom in the prediction is the mix of serviceable old aerofoils, repaired aerofoils and new aerofoils.

Before E-BREAK predicting overhaul performance improvement was based on simple average values for three work scope classes. To assess the potential for SFC and/or life gain potential of the E-BREAK methodology, its predictive variance for restoring a fleet of engines of the E-BREAK long range turbofan platform to a target SFC has been evaluated.



Impact of prediction accuracy on SFC

This variance has been compared to the state of the art and to the theoretically achievable limit given by process uncertainties.
Comparing the variances show that using the predictive model developed in E-BREAK for HPC and HPT efficiency restoration, the fleet SFC may be improved by ~0.38 %. However theoretically possible would be ~0.74 %.

Publications/Patent

Kuschke et al.: Assessment of In-Service Measurement Uncertainty and its Impact on Performance Recovery Analysis of Overhauled Civil Turbofan Engines. ISABE, Sep 9-13 2013.
Kuschke et al.: Assessment of Modeling Uncertainties Impact on Performance Recovery Analysis of Overhauled Civil Turbofan Engines. ISABE, Sep 9-13 2013.
MTU Aero Engines AG: Method for performing Maintenance on an Engine. Erfinder: Kuschke, J.; Kando, A.; Tsalavoutas, A. Publication Date: 01.04.2015. Application Date: 30.09.2013. EU, EP2853970 A1.

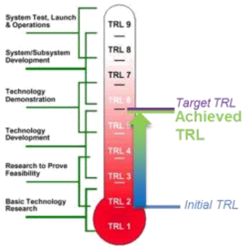
Variable geometry monitoring

Partners involved

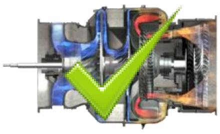
SAFRAN

Description

Methods to improve early detection of failure precursors in variable geometry actuation and identify degradation patterns



Ref : E-BREAK initial status / TRL	Initial E-BREAK objective	Final status
SFC impact	??	**No direct impact → contribution to availability**
PPS weight impact	--	--
TRL progress	**2 → 6**	**6**



Turboshaft

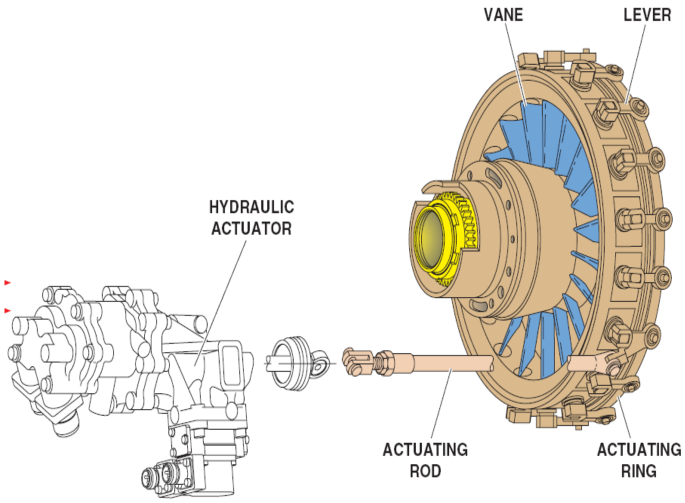
Regional Turbofan

Short/Medium Range Open Rotor

Long Range Turbofan

A few IGV (Inlet Guide Vane) root ruptures have been encountered in the SAFRAN HELICOPTER ENGINES fleet as well as a few events of IGV seizing. The monitoring method of IGV kinematic is currently manual and implies disassembly of the actuator / vanes tie rod liaison. This maintenance is not easy due to liaison accessibility, resulting in engine disassembly.
The IGV reliability rate is highly impacting complete engine reliability rate. Then, a continuous or quasi continuous (upon each engine stop for example) monitoring would enable installation of variable geometry (as IGV) on helicopter turboshaft engine without a prohibitive impact on direct maintenance cost (DMC).

A monitoring function based on comparison between the actuator behaviour and an actuator model loaded into the engine digital control unit has been developed.



Assembly of IGV Actuator and IGV

Publications/Patent

Collaborative Project co-funded by the European Commission within the **7th Framework Programme** (2007-2013),
Under Grant Agreement n°ACP2-GA-2012-314366-E-BREAK

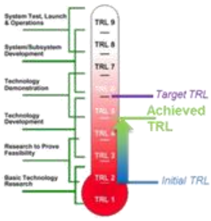
Airpath monitoring

Partners involved

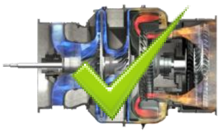
SAFRAN

Description

Methods to improve early detection and localization of degradation in the airpath and combustion chamber



Ref : E-BREAK initial status / TRL	Initial E-BREAK objective	Final status
SFC impact	**-0.5%**	**-0.5%**
PPS weight impact	**--**	**--**
TRL progress	**2 ➔ 6**	**5**



Turboshaft

Regional Turbofan

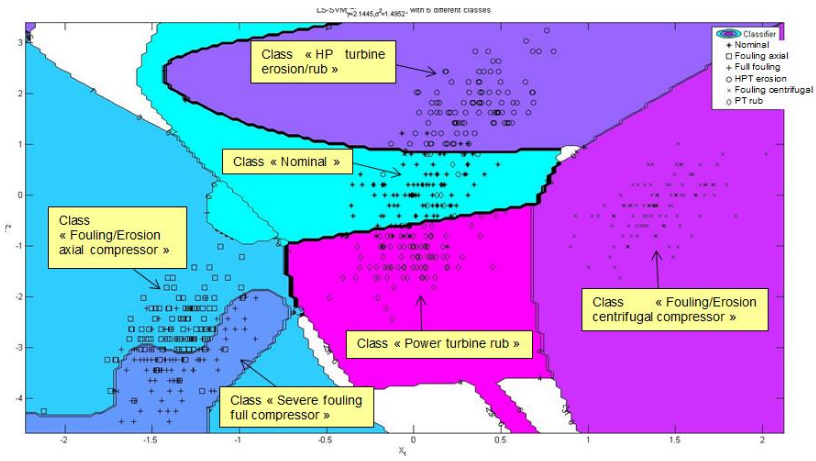
Short/Medium Range Open Rotor

Long Range Turbofan

A gas path diagnostic system has been defined and developed using a machine learning technique called a Support Vector Machine (see figure below) and an additional sensor on a test bench. This system has shown a good performance and thus improved significantly the technical maturity of the turboshaft diagnostic. A learning database has been created using both actual data of engines tested on bench with an additional sensor and simulated data. To become mature and statistically valid, the learning database still has to be trained on new cases of degradation.

This innovative diagnostic system combined with the prognostic algorithm developed within EBREAK task T613 in collaboration with MTU represents a major step towards the implementation of the Prognostic Health Monitoring (PHM) of helicopter engines.

These progresses in Prognostic Health Monitoring systems create new opportunities of maintenance costs savings, availability improvement, faster troubleshooting, fuel consumption diminutions and CO_2 emissions reductions. A direct result is, that line (e.g. engine wash practices to remove compressor fouling) and shop maintenance (e.g. restoration of compressor or turbine erosion or rub) can be optimized to improve post maintenance engine performance by an average 0.5% SFC compared to the state of the art.



Visualization of degradation data classes identified with support vector machines.

Publications/Patent

Structure monitoring

Partners involved

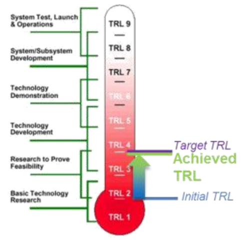
UPPSALA UNIVERSITET

GKN AEROSPACE

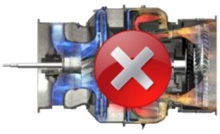
ÅAC Microtec

Description

Concepts, methods and sensors for health monitoring of engine structures



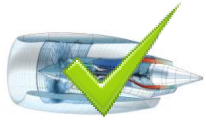
Ref : E-BREAK initial status / TRL	Initial E-BREAK objective	Final status
SFC impact	--	--
PPS weight impact	-0.15%	-0.15%
TRL progress	2 ➔ 4	4



Turboshaft

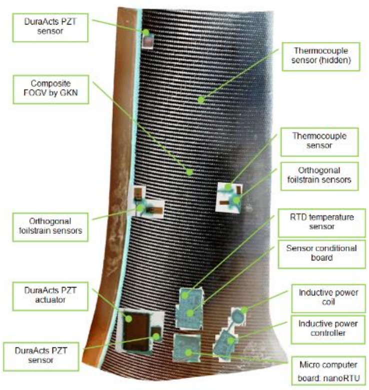
Regional Turbofan

Short/Medium Range Open Rotor



Long Range Turbofan

- **Fan outlet guide vanes (FOGVs), engine mounts and thrust lugs are identified as candidates for weight reduction, enabled by SHM. Early damage detection enables reduced residual strength loads requirements by 15% (according to 85% limit load certification criteria) and hence weight by 5%.**
- **To demonstrate the features of a SHM system 2 prototypes for fan OGV configurations with embedded SHM has been manufactured and tested.**



Fan outlet guide vane with embedded electronic

- **Two FOGVs are equipped with built in sensors: 2 foil strain, 2 PZT (PieZo-electric Transducer) sensors, 1 PZT combined actuator/sensor, 2 thermocouples, 1 reference temperature**
- **One FOGV has built-in sensor conditional and microcomputer boards and a system for wireless power and data transmission (only power works). The PZTs are not included in this OGV.**
- **All electronics and sensors are integrated into the structure during the RTM process at 180 centigrade. No loss of function during manufacturing, but one foil strain sensor position were lost during the manual instrumentation and loss of contact for one PZT due to epoxy resin in the nano- RTU™ (Remote Terminal Unit, a micro computer board from ÅAC) contact on one FOGV.**
- **All tests indicates unchanged structural properties of these FOGVs compared to the normal ones.**
- **A number of tests has been performed and the results are documented and the final TRL target of 4 is reached.**

Test rigs for full assembly (left) and part (right) fan OGV SHM system validation

Publications/Patent

Collaborative Project co-funded by the European Commission within the **7th Framework Programme** (2007-2013),
Under Grant Agreement n°ACP2-GA-2012-314366-E-BREAK

SEVENTH FRAMEWORK PROGRAMME

E-BREAK DISSEMINATION: PUBLICATION OVERVIEW

Collaborative Project co-funded by the European Commission within the **7th Framework Programme** (2007-2013),
Under Grant Agreement n°ACP2-GA-2012-314366-E-BREAK

E-BREAK DISSEMINATION: LIST OF PUBLICATIONS

Paper Name	Authors	Event	Date	Location
Assessment of In-Service Measurement Uncertainty and its Impact on Performance Recovery Analysis of Overhauled Civil Turbofan Engines	Jonathan Kuschke (MTU) André Kando (MTU), Holger Schulte (MTU) Stephan Staudacher (Institute of Aircraft Propulsion Systems (ILA), University of Stuttgart)	ISABE 2013	9-13 Sep. 2013	Busan, South Korea
Assessment of Modeling Uncertainties Impact on Performance Recovery Analysis of Overhauled Civil Turbofan Engines	Jonathan Kuschke (MTU) André Kando (MTU), Holger Schulte (MTU) Stephan Staudacher (Institute of Aircraft Propulsion Systems (ILA), University of Stuttgart)	ISABE 2013	9-13 Sep. 2013	Busan, South Korea
TiAl alloys produced by Electron Beam Melting	S. Biamino (Polito) F. Pelissero (Avio), S. Sabbadini (GE AVIO), P. Fino (Polito), M. Pavese (Polito), C. Badini (Polito)	Intermetallics 2013	30 Sep. to 3 Oct. 2013	Kloster Banz, Germany
Feasibility of a novel 3D shape measurement technique for test specimens subjected to bird strike using a printed line pattern	F. Allaeys, C. Sarrazin, G. Luyckx	21st DYMAT Technical Meeting	18-20 Nov. 2013	London, UK
Thermomechanical properties of CoNiCrAlY-Polyester composite coatings elaborated Atmospheric Plasma Spray.	Delphine AUSSAVY (IRTES-LERMPS), Rodolphe BOLOT (IRTES-LERMPS), François PEYRAUT (IRTES-M3M, (UTBM), Ghislain MONTAVON (IRTES-LERMPS), Serge SELEZNEFF (SAFRAN AE)	10th international Conference on Local Mechanical Properties	6-8 Nov. 2013	Czech Republic
Results for Intermetallics 2013 presentation		Intermetallics 2013	30 Sep. to 3 Oct. 2013	Kloster Banz, Germany
Hybrid structures in aero engines	F. Kocian, P.-B. Ebel, B. Drees, K. Schulze, J. Hausmann, H. Voggenreiter (German Aerospace Center and Institute of Structures and Design)	Deutscher Luft- und Raumfahrtkongress 2013	10-12 Sep. 2013	Stuttgart, Germany

Collaborative Project co-funded by the European Commission within the 7th **Framework Programme** (2007-2013),
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Pore-level numerical simulation of open-cell metal foams with application to aero engine separators	Thiago Piazera de Carvalho, Hervé P. Morvan, David Hargreaves (Unott)	Proceedings of the ASME Turbo Expo 2014	16-20 June 2014	Düsseldorf, Germany
Wear protection for turbine blades made of titanium aluminide	André Werner (MTU Aero Engines AG)	2014 TMS Annual Meeting & Exhibition	16th to 20th Feb. 2014	San Diego, California, USA
High speed interaction between an abradable coating and a labyrinth seal in turbo-engine application	C. Delebarre (SAFRAN HE), V. Wagner, J.Y. Paris , G. Dessein, J. Denape (Université de Toulouse, ENIT), J. Gurt-Santanach (SAFRAN HE)	Proceedings of Joint Conference on Mechanical, Design Engineering & Advanced Manufacturing	18th - 20th June 2014	Toulouse, France
An approach for predicting the flow regime in an aero engine bearing chamber	Wolfram Kurz (KIT), Hans-Jörg Bauer (KIT)	Proceedings of the ASME Turbo Expo 2014	16-20 June 2014	Düsseldorf, Germany
Influence des paramètres du procédé APS sur la morphologie de revêtements abradables YSZ-Polyester	Delphine AUSSAVY, Rodolphe BOLOT, Ghislain MONTAVON (IRTES-LERMPS), Julien Gurt-Santanach (SAFRAN HE)	Matériaux 2014	24-28 Nov. 2014	Montpellier France
Bird strike experiments and simulations on the booster of a jet engine	F. Allaeys, G. Luyckx, W. Van Paepegem (Ghent University, BE)	"Young stress analyst" contest at ICEM 16	7 - 11 July 2014	University of Cambridge, UK
An experimental study of the high speed interaction between a labyrinth seal and an abradable coating in a turbo-engine application	C. Delebarre, V. Wagner, J.Y. Paris , G. Dessein, J. Denape (Université de Toulouse, ENIT), J. Gurt-Santanach (SAFRAN HE)	Journal "WEAR" Volume 316, Page 109 to 118, ELSEVIER edition	4th March 2014	
Advances in European Technology Programmes Session 1: "Setting the Scene: Achievements of completed EU (L2) projects" Joint	Stefan Donnerhack (MTU), John Whurr (RRUK), Nicolas Tantot (SAFRAN AE)	Joint presentation from ENOVAL engine owner at ENOVAL KOM-Panel	28th Oct. 2013	Freising, Munich, Germany
Optimisation of fuel consumption and surge margins by adaptation of engine thermodynamic cycle to different mission requirements by means of variable nozzles	Khaled Zarati, Xavier Carbonneau, Sébastien Duplaa (ISAE, Université de Toulouse), Nicolas Tantot (SAFRAN AE)	ISABE 2015	25-30 Oct. 2015	Phoenix, AZ, USA

Influence of APS process parameters on morphologies of YSZ-Polyester abradable coatings	Delphine AUSSAVY, Rodolphe BOLOT, Ghislain MONTAVON, François Peyraut, Julien GURT-SANTANACH, Serge Selezneff	ITSC 2015 LONG BEACH, International Thermal Spray Conference & Exposition	11-14 May 2015	Long Beach, USA
Entwicklung und validierung eines verfahrens zur zustandsanalyse eines flugtriebwerks anhand der standardinstrimentierung auf basis der method der kleinsten fehlerquadrate	Ch. Freund, H. Abdullahi, A. Kando (MTU)	German DGLR conference	16 - 18 Sep. 2014	Augsburg, Germany
Thin-film flow over a rotating plate: an assessment of the suitability of VoF and eulerian thin-film methods for the numerical simulation of isothermal thin-film flows	B. Kakimpa, H.P. Morvan and S. Hibberd	ASME Turbo Expo 2015: Turbine Technical Conference and Exposition GT2015	15-19 June 2015	Montreal, Canada
Solution strategies for thin film rimming flow modeling	Bruce Kakimpa, Herve Morvan, Stephen Hibberd	ASME Turbo Expo 2015: Turbine Technical Conference and Exposition GT2015	15-19 June 2015	Montreal, Canada
Solution strategies for the numerical simulation of shear-driven thin-film rimming flows	Bruce Kakimpa, Herve Morvan, Stephen Hibberd	ASME Turbo Expo 2015: Turbine Technical Conference and Exposition GT2015	15-19 June 2015	Montreal, Canada
Influence of APS process parameters on morphologies of YSZ-Polyester abradable coatings	D.AUSSAVY, R.BOLOT, G.MONTAVON, F.PEYRAUT, G.SZYNDELMAN, J.GURT-SANTANACH, S.SELEZNEFF	ITSC 2015 International Thermal Spray Conference & Exposition	11-14 May 2015	Long Beach, USA
Experimental study on the friction contact between a labyrinth seal fin and a honeycomb stator	Tim Pychynski Corina Höfler, Hans-Jörg Bauer	ASME Turbo Expo 2015:Power for Land, Sea and Air GT2015	15-19 June 2015	Montreal, Canada

Bauhaus luftfahrt 2014 yearbook article on BHL FP7 level 2 project involvements		Annual yearbook of Bauhaus Luftfahrt (BHL)	6 July 2015	Ottobrunn, Germany
Oxidation behaviour of γ-Ti-Al alloys coated with intermetallic Ti-Al-Cr based layers	Nadine Laska, Reinhold Braun, Stéphane Knittel	Intermetallics 2015 (Conference)	28th Sep 2nd Oct. 2015	Bad Staffelstein Germany
Fatigue strength in γ-Ti-Al produced by additive manufacturing: a few lessons learnt	Mauro Filippini , S. Beretta	Intermetallics 2015	28th Sep 2nd Oct. 2015	Bad Staffelstein Germany
Engine performances and surge margins optimization by variable nozzle area	Khaled Zarati, Sébastien Duplaa, Xavier Carbonneau (ISAE, Université de Toulouse), Nicolas Tantot (SAFRAN AE)	ISABE 2015	25-30 Oct. 2015	Phoenix, AZ, USA
Model-Based in-flight condition monitoring tool for aero engine diagnosis	Abdullahi H.H, Freund Ch. , Kando A.H	ISABE 2015	25-30 Oct. 2015	Phoenix, AZ, USA
A material loop closing recycling technology of γ-Ti-Al from precision cast LP turbine blades	Peter Spiess, Marek Bartosinski, Todor Stoyanov, Julio Aguilar, Bernd Friedrich	CIT Journal		
Pore-scale numerical investigation of pressure drop behaviour across open-cell metal foams	T. P., de Carvalho; Morvan, H. P.Hargreavess,D. Oun, A. Kennedy, A.	Transport in Porous Media	July 2015	
Development of a hybrid-unison ring for VSV-systems for new high OPR aero engines	Thomas Klauke, Dirk Söhner, Björn Drees, Peter Winkelmann, Ronald Klomp-de Boer	annual DLR conference	22-24 Sep. 2015	Rostock, Germany
Effect of Small Additions of Non-Metallic Elements on High-Temperature Behavior of Gamma Alloys	Anne Denquin, Zhao Huvelin, Mikael Perrut, Agnès Bachelier-Locq, Loris Signori, Shigehisa Naka	Titanium 2015 in the scope of TMS 2015,	18 August 2015	San Diego, CA, USA
Klassifikation von einflussfaktoren auf das alterungsverhalten von serientriebwerken unter verwendung von flugdaten	H. Vogel, A. Kando, H. Schulte, S. Staudacher	German DGLR conference	22-24 Sep. 2015	Rostock, Germany
Performance investigations of cycle-integrated parallel of hybrid turboshafts	P.Vratny, S.Kaiser, A.Seitz, S. Donnerhack	ASME 2016 Turbo Expo	13-17 June 2016	Seoul, South Korea
Advanced aero-engines technology enablers (an overview of the European project E-BREAK)	Manuel Silva, Nicolas Tantot, Michael Walsh, R. Nyatando, Erik Johann, Thomas Klauke, Serge Selezneff, Michele Coppola, André Kando	ASME 2016 Turbomachinery Technical Conference & Exposition	13-17 June 2016	Seoul, South Korea

Processing, characterization and validation of thermomechanical properties of three abradable coatings: NiCrAl-bentonite, CoNiCrAlY-BN-polyester and YSZ-polyester.	Delphine Aussavy	ASME 2016 Turbomachinery Technical Conference & Exposition	13-17 June 2016	Seoul, South Korea
Calibration of real and substitute birds through analysis of momentum, impact force and residual energy in bird strike tests on three rigid targets: flat plate, wedge and splitter	Frederik Allaeys, Geert Luyckx, Wim Van Paepegem, Joris Degrieck	ASME 2016 Turbomachinery Technical Conference & Exposition	13-17 June 2016	Seoul, South Korea
Performance investigations of cycle-integrated parallel of hybrid turboshafts	P.Vratny, S.Kaiser, A.Seitz, S. Donnerhack	ASME 2016 Turbo Expo	13-17 June 2016	Seoul, South Korea
E-BREAK: Engine-Breakthrough Components and Subsystems Advanced Aero-Engines Technology Enablers	Manuel Silva, Nicolas Tantot, Michael Walsh, Rose Nyatando, Erik Johann, Thomas Klauke, Serge Selezneff, Michele Coppola, André Kando	Aerodays 2015	20-23 Oct. 2015	London, UK
Cycle-integrated parallel hybrid topology		Annual Year book of BHL	2016	Ottobrunn, Germany
European Commission RTD Success Stories : New aircraft engine parts will reduce fuel consumption	Manuel Silva (SAFRAN HE)	http://ec.europa.eu/research/infocentre/article_en.cfm?id=/research/headlines/news/article_16_05_30_en.html?infocentre&item=Infocentre&artid=39656	30 May 2016	EC website
Development and validation of a set-up to measure the transferred multi-axial impact momentum of a bird strike on a booster vane	Frederik Allaeys, Geert Luyckx, Wim Van Paepegem and Joris Degrieck	International Journal of Impact Engineering		
Influence of Si and C additions on microstructure and high temperature behaviour of the Ti-43.5Al-1Mo-4Nb-0.1B alloy	Anne Denquin, Zhao Huvelin, Loris Signori, Agnès Bachelier-Locq, Mikael Perrut, Shigehisa Naka	Special edition of the journal “Materials at high Temperature”		
SNECMA application of У-TiAl alloys for low pressure turbine blades: development phase, mass production and new opportunities	Guillaume Martin, Pierre Sallot (SAFRAN AE)	5th International Workshop on Titanium Aluminides	28th August 2nd Sep. 2016	Tokyo, Japan

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Influence of separate Si and C additions on microstructure and high temperature behaviour of the TNM γ-TiAl alloy	Anne Denquin, Zhao Huvelin et Mikael Perrut (ONERA)	Présentation at conférence: « La Métallurgie, quel avenir ! »	27 June to 1st July 2016	St Etienne, France
A set-up to measure the transferred multi-axial impact momentum of a bird strike on a booster vane	Frederik Allaeys, Geert Luyckx, Wim Van Paepegem, Joris Degrieck	SAMPE-Europe conference	13 - 15 Sep. 2016	Liege, Belgium
Influence of minor elements additions on microstructure and high temperature behaviour of the Ti-43.5Al-1Mo-4Nb-0.1B alloy	Zhao Huvelin, Anne Denquin, Loris Signori, Mikael Perrut, Agnès Bachelier-Locq and Shigehisa Naka	Workshop TiAl	27th August to 2nd Sep. 2016	Tokyo, Japan
The European Project E-BREAK: Technology enabler for Advanced Aero-Engines	Manuel SILVA, Nicolas TANTOT, Serge SELEZNEFF, Mike WALSH, John SCHOFIELD, Erik JOHANN, Thomas KLAUKE, Michele COPPOLA, André KANDO	GREENER AVIATION 2016	11-13 Oct. 2016	Brussels, Belgium
Numerical and experimental investigation of the shock and steady state pressures in the bird material during bird strike	Frederik Allaeys, Geert Luyckx, Wim Van Paepegem and Joris Degrieck			
Influence of geometrical parameters on the performance of carbon brush seals	Bilal Outirba, Patrick Hendrick	ISABE 2015	25-30 Oct. 2015	Phoenix, Arizona, USA
Experimental characterization of carbon fibre brush seals leakage performance in function of the bristle pack geometrical parameters under dry conditions	Bilal Outirba, Patrick Hendrick	ISABE 2017	3-8 Sep. 2017	Manchester, UK
Test bench development for experimental characterisation of oil-air two-phase flow for breather in modern aero engine oil system	M. Di Matteo, J. Steimes, O. Berten, J.P. Thibault, L. Seguinot, B. Fulleringer, O. Robert, C. Corre and P. Hendrick	ISABE 2017	3-8 Sep. 2017	Manchester, UK
Experimental study of carbon brush seals for aero-engines bearing chambers	Bilal Outirba, Patrick Hendrick	ASME 2014	16-20 June 2014	Düsseldorf, Germany

Experimental study of the pressure loss in aero-engine air/oil separators	L. Cordes et al (KIT)	ISABE 2017	3-8 Sep. 2017	Manchester, UK
Limitations of a state-of-the-art numerical modeling framework for two-phase flow in aero-engine air/oil separators	T. Carvalho et al (Unott, KIT)	ASME 2016	13-17 June 2016	Seoul, South Korea
E-BREAK Presentation	Manuel Silva (SAFRAN HE)	LEMCOTEC 1st Workshop	22-23 Oct. 2013	Potsdam, Germany
LEMCOTEC Technologies	Ralf von der Bank (RRD)	ETTW	05-06 March 2015	Brussels, Belgium
E-BREAK Integration into EU cooperative projects frame	Nicolas Tantot (SAFRAN AE)	ETTW	05-06 March 2015	Brussels, Belgium
Power plant structures basics	Erik Johann (RRD)	ETTW	05-06 March 2015	Brussels, Belgium
An introduction to power plant health monitoring concepts	André Kando (MTU)	ETTW	05-06 March 2015	Brussels, Belgium
Materials in power plants	Michele Coppola (GE AVIO), Serge Selezneff (SAFRAN AE)	ETTW	05-06 March 2015	Brussels, Belgium
Engine variable devices	Thomas Klauke (RRD)	ETTW	05-06 March 2015	Brussels, Belgium
Engine air and oil systems basics	Mike Walsh (RRUK)	ETTW	05-06 March 2015	Brussels, Belgium
E-BREAK – Overview and Preliminary Results	Manuel Silva (SAFRAN HE)	LEMCOTEC 2nd Workshop, M60 Review	6 Dec. 2016	Potsdam, Germany
Thermogravimetric investigation on oxidation kinetics of complex Ti-Al alloys	Oxana Ostrovskaya, Claudio Badini, Giorgio Baudana, Elisa Padovano, S. Biamino (Polito)	The Journal Intermetallics		

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E-BREAK DISSEMINATION: LIST OF POSTERS

Posters Name	Partners	Event	Date	Location
Validate key technologies enabling future high performance engine operating at higher pressure and temperature with no compromise on operability, availability and maintainability	All	E-BREAK Technology Transfer Workshop	05-06 March 2015	Brussels, Bureau Aquitaine Europe
Variable cycle devices on turbofan and turboshaft engines – performance and weight assessments	ISAE-Chalmers (presenter : Khaled Zarati)	ETTW	05-06 March 2015	Brussels, Belgium
Hybrid energy propulsion system and associated health monitoring stakes	BHL (presenter : Patrick Vratny)	ETTW	05-06 March 2015	Brussels, Belgium
Advanced aero-engine bearing chamber seals testing	ULB (B. Outirba and P. Hendrick)	ETTW	05-06 March 2015	Brussels, Belgium
Optimisation of stator by-pass flows	ENIT	ETTW	05-06 March 2015	Brussels, Belgium
An updated numerical formulation for thin-film flow with heat transfer (=thin film)	Dr Bruce Kakimpa, Prof. Herve P. Morvan, Dr Stephen Hibberd	ETTW	05-06 March 2015	Brussels, Belgium
Application of SPH to bearing chamber with thin films, jet flows and droplets	A. Kruisbrink, T. Yue, H.P. Morvan and F.R. Pearce	ETTW	05-06 March 2015	Brussels, Belgium
Oil lifing and degradation	RRUK	ETTW	05-06 March 2015	Brussels, Belgium
Low leakage piston seals	J Garratt (RRUK), A Ibrahim, D Gillespie (Oxford Univ), C Foord (UNOTT)	ETTW	05-06 March 2015	Brussels, Belgium
Oil breather performance characterization testing	. Steimes, O. Berten (ULB), L. Seguinot, C. Corre, J.-P. Thibault (LEGI), Y. Cazaux (SAFRAN HE)and P. Hendrick (ULB)	ETTW	05-06 March 2015	Brussels, Belgium
High temperature self-lubricating bushes	Thomas Klauke, RRD	ETTW	05-06 March 2015	Brussels, Belgium
Variable stator vane weight and precision improvement	Pierre-Alain Sebrecht, (SAFRAN AE)	ETTW	05-06 March 2015	Brussels, Belgium

Simulation, testing and correlation of bird impact on booster vanes	Hicham Benabou (SAFRAN AB)	ETTW	05-06 March 2015	Brussels, Belgium
Variable bleed system development for increased robustness, reliability and performance	GKN	ETTW	05-06 March 2015	Brussels, Belgium
Tip clearance probes for turbines application	Laetitia Muller (SAFRAN HE)	ETTW	05-06 March 2015	Brussels, Belgium
Ultra high OPR robust blading	RRD	ETTW	05-06 March 2015	Brussels, Belgium
Active cooling of turbine structures	Richard Avellan (GKN)	ETTW	05-06 March 2015	Brussels, Belgium
Abradable development test to perform		ETTW	05-06 March 2015	Brussels, Belgium
Influence of process parameters on mechanical properties of modified thermal barrier coatings	Delphine Aussavy (LERMPS)	ETTW	05-06 March 2015	Brussels, Belgium
Sprayed seals & advanced liner materials modeling labyrinth seal rubs		ETTW	05-06 March 2015	Brussels, Belgium
Thermal barrier coating system for complex shape static turbine parts using PS-PVD		ETTW	05-06 March 2015	Brussels, Belgium
Surface engineering on lightweight TiAl for breakthrough components	Stéphane Knittel (SAFRAN AE)	ETTW	05-06 March 2015	Brussels, Belgium
Engine tests with TNM alloy	Laurie Leost (SAFRAN HE)	ETTW	05-06 March 2015	Brussels, Belgium
The 3rd generation TiAl alloys for high speed LPT blades: TNM alloy and EBM manufacturing process	Michele Coppola (GE AVIO)	ETTW	05-06 March 2015	Brussels, Belgium
Online engine failure diagnosis	André Kando (MTU)	ETTW	05-06 March 2015	Brussels, Belgium
Engine performance prognosis	Helena Vogel (MTU) with help of François Faupin (SAFRAN HE)	ETTW	05-06 March 2015	Brussels, Belgium
Actuator monitoring : inlet guide vane (IGV)	François Goudet (SAFRAN HE)	ETTW	05-06 March 2015	Brussels, Belgium
Structure health monitoring of aero engine structures	Dan Ring (GKN) Johann Bjurstrom (AAC)	ETTW	05-06 March 2015	Brussels, Belgium

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Turboshaft gas path monitoring	François Faupin (SAFRAN HE)	ETTW	05-06 March 2015	Brussels, Belgium
PROJECT MANAGEMENT (project management)	Manuel Silva (SAFRAN HE) – ALCIMED	ETTW	05-06 March 2015	Brussels, Belgium
PROJECT MANAGEMENT (technical)	Manuel Silva (SAFRAN HE) – ALCIMED	ETTW	05-06 March 2015	Brussels, Belgium
E-BREAK SP1 – SP2 – SP3	All	London Aerodays 2015	20-23 Oct. 2015	London, QE II Center
E-BREAK SP4 – SP5 – SP6	All	London Aerodays 2015	20-23 Oct. 2015	London, QE II Center
UTC in Aerodynamics and Heat Transfer – Air-Riding Flexible Face Seal (ARFS)	Amir Ibrahim, Prof David Gillespie	ASME 2016 Turbomach inery Technical Conference & Exposition	June 13-17, 2016	Seoul, South Korea
Influence of minor elements additions on microstructure and high temperature behaviour of the ti-43.5Al-1Mo-4Nb-0.1B alloy	ONERA	Workshop TiAl	27th Aug – 2nd Sep. 2016	Tokyo, Japan
SP1 (WP1.2) - Variable cycle devices on turbofan and turboshaft engines – Performance and weight assessments	ISAE, Chalmers, University, SAFRAN, GKN	E-BREAK 2nd Technology Transfer Workshop	21-22 March 2017	Bordes, France
SP1 (WP1.2) - Hybrid Energy Propulsion Systems & Associated Health Monitoring Stakes	MTU, BHL	ETTW2	21-22 March 2017	Bordes, France
SP2 - Air Systems Sealing and Oil Systems	RRUK, SP2 Partners	ETTW2	21-22 March 2017	Bordes, France
SP3 - Improved Core Efficiency	RRD, SP3 Partners	ETTW2	21-22 March 2017	Bordes, France
SP3 - Improved Variable Systems	RRD, SP3 Partners	ETTW2	21-22 March 2017	Bordes, France
SP3 - Variable Cooling Systems	RRD, SP3 Partners	ETTW2	21-22 March 2017	Bordes, France
SP4 - Higher temperature materials for breakthrough components	SAFRAN AE, SP4 Partners	ETTW2	21-22 March 2017	Bordes, France

SP5 - Lightweight Materials for Breakthrough Components - New Gamma-TiAl alloy for LPT Blade -	GE AVIO, SP5 Partners	ETTW2	21-22 March 2017	Bordes, France
SP6 - Engine Health Monitoring Engine Condition Diagnostics & Prognostics	MTU, SP6 Partners	ETTW2	21-22 March 2017	Bordes, France
SP6 - Engine Health Monitoring Monitoring Systems on Part Level	MTU, SP6 Partners	ETTW2	21-22 March 2017	Bordes, France
SP6 - Engine Health Monitoring Predictive Maintenance	MTU, SP6 Partners	ETTW2	21-22 March 2017	Bordes, France
SP7 - Management, Exploitation & Dissemination	SAFRAN HE, Alcimed	ETTW2	21-22 March 2017	Bordes, France
E-BREAK Engine Breakthrough Components and Subsystems	SAFRAN HE, Alcimed	ETTW2	21-22 March 2017	Bordes, France
Validate key technologies enabling future high performance engine operating at higher pressure and temperature with no compromise on operability, availability and maintainability	SAFRAN HE, Alcimed	ETTW2	21-22 March 2017	Bordes, France

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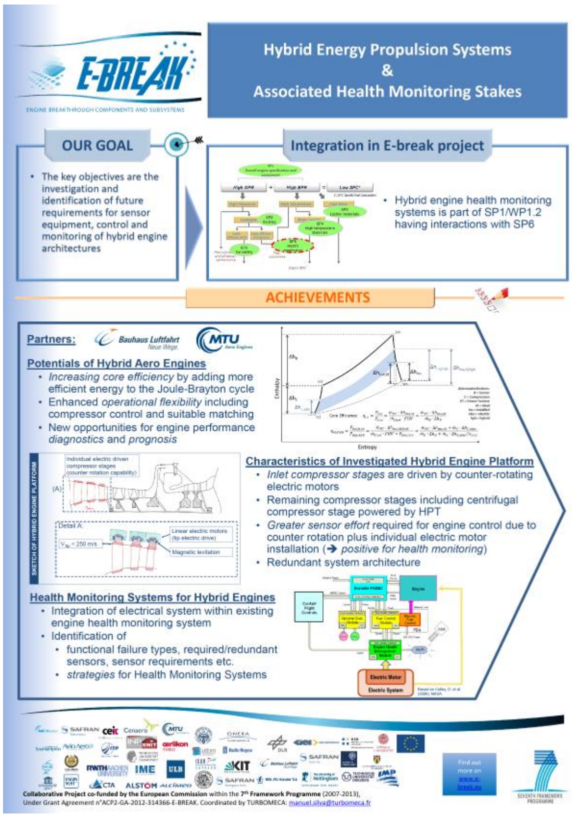
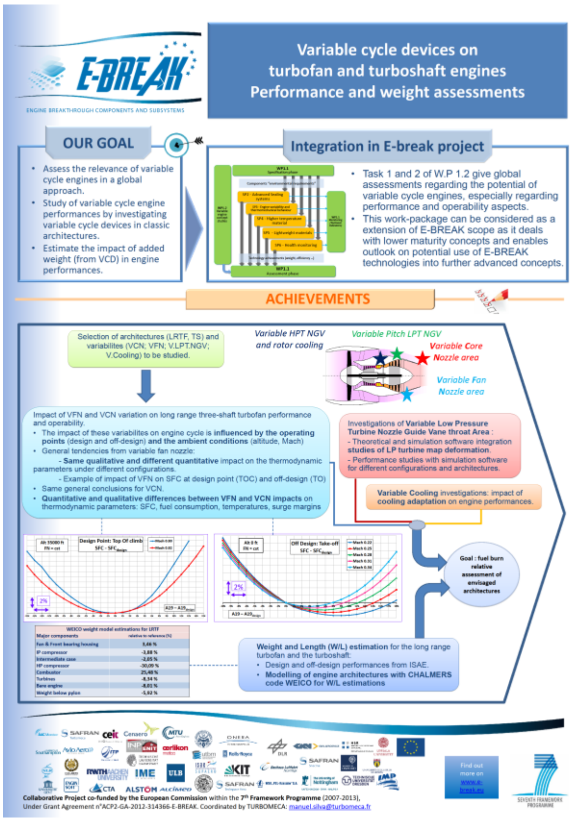
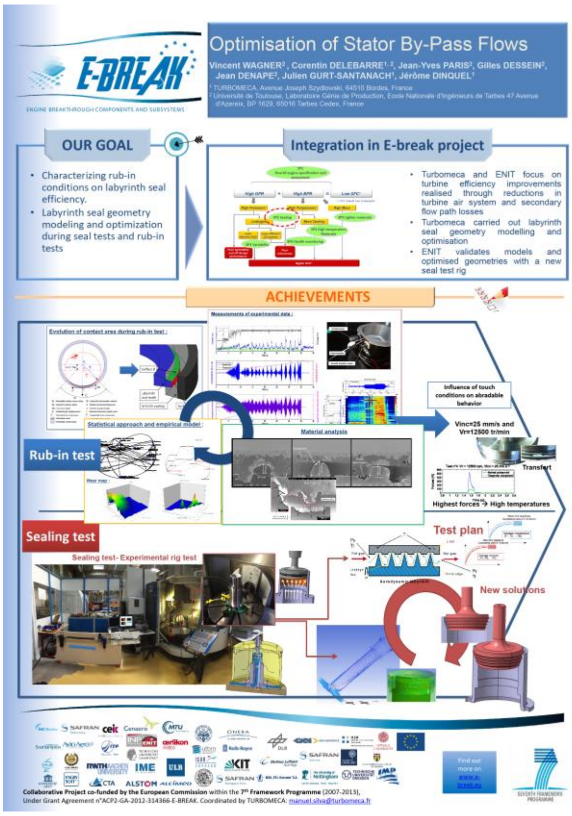
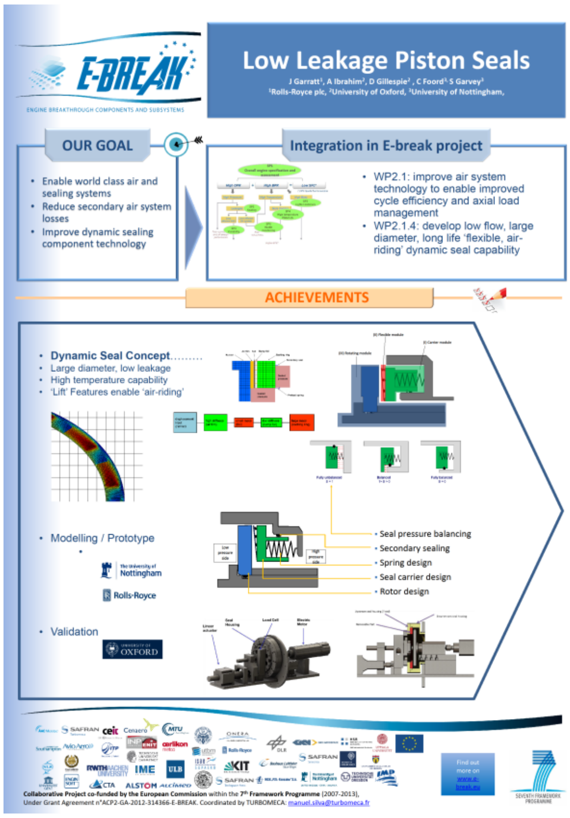
1[ST] E-BREAK Technology Transfer Workshop Posters (2015)

ENGINE BREAKTHROUGH COMPONENTS AND SUBSYSTEMS









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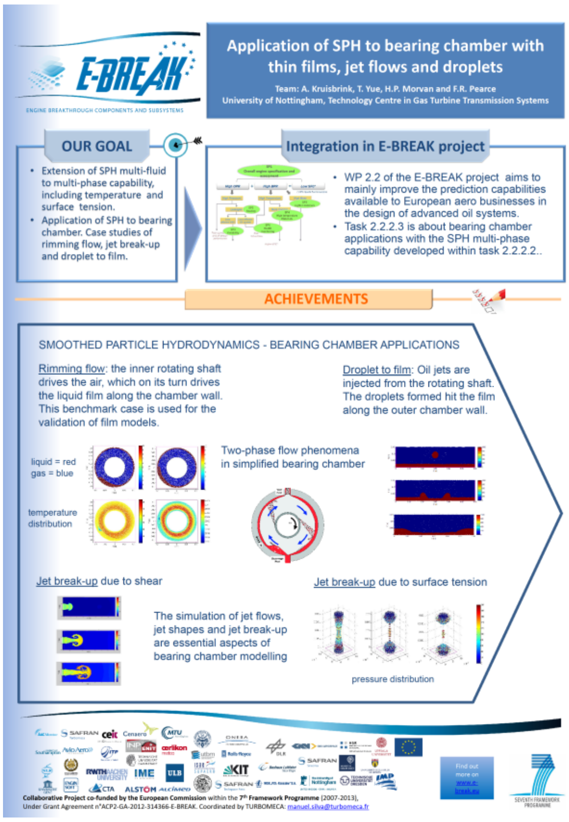
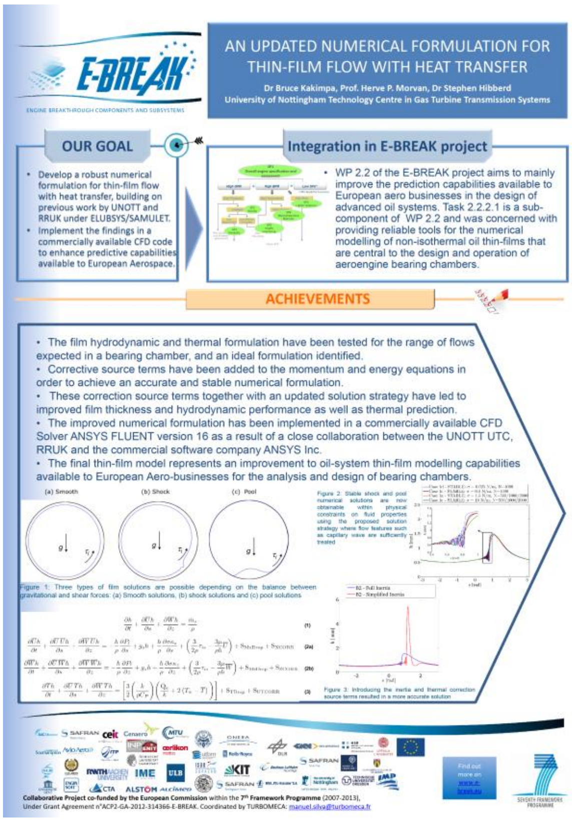
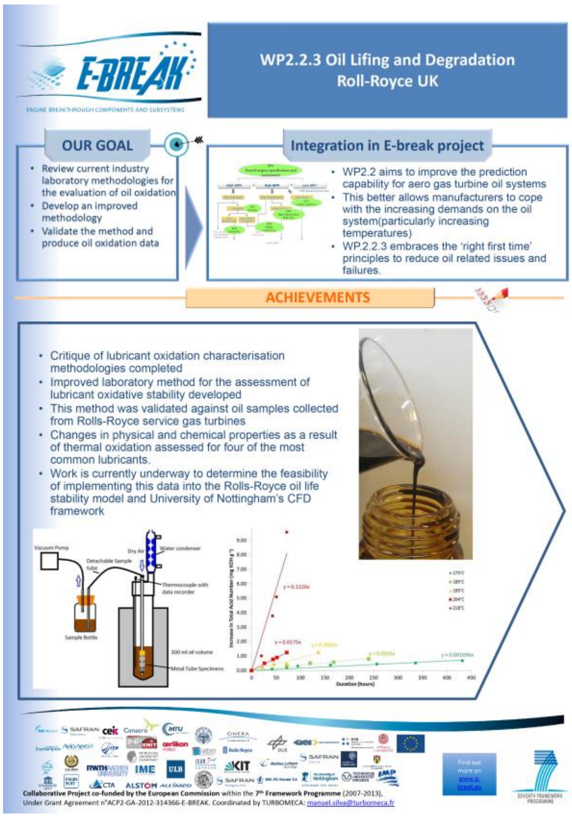
SEVENTH FRAMEWORK PROGRAMME


Application of SPH to bearing chamber with thin films, jet flows and droplets
Team: A. Kruisbrink, T. Yue, H.P. Morvan and F.R. Pearce
University of Nottingham, Technology Centre in Gas Turbine Transmission Systems
OUR GOAL
Extension of SPH multi-fluid to multi-phase capability, including temperature and surface tension.
Application of SPH to bearing chamber. Case studies of rimming flow, jet break-up and droplet to film.
Integration in E-BREAK project
WP 2.2 of the E-BREAK project aims to mainly improve the prediction capabilities available to European aero businesses in the design of advanced oil systems.
Task 2.2.2.3 is about bearing chamber applications with the SPH multi-phase capability developed within task 2.2.2.2..
ACHIEVEMENTS
SMOOTHED PARTICLE HYDRODYNAMICS - BEARING CHAMBER APPLICATIONS
Rimming flow: the inner rotating shaft drives the air, which on its turn drives the liquid film along the chamber wall. This benchmark case is used for the validation of film models.
Droplet to film: Oil jets are injected from the rotating shaft. The droplets formed hit the film along the outer chamber wall.
liquid = red
gas = blue
temperature distribution
Two-phase flow phenomena in simplified bearing chamber
Jet break-up due to shear
Jet break-up due to surface tension
The simulation of jet flows, jet shapes and jet break-up are essential aspects of bearing chamber modelling
pressure distribution
Collaborative Project co-funded by the European Commission within the 7th Framework Programme (2007-2013),
Under Grant Agreement n°ACP2-GA-2012-314366-E-BREAK. Coordinated by TURBOMECA: manuel.silva@turbomeca.fr


AN UPDATED NUMERICAL FORMULATION FOR THIN-FILM FLOW WITH HEAT TRANSFER
Dr Bruce Kakimpa, Prof. Herve P. Morvan, Dr Stephen Hibberd
University of Nottingham Technology Centre in Gas Turbine Transmission Systems
OUR GOAL
Develop a robust numerical formulation for thin-film flow with heat transfer, building on previous work by UNOTT and RRUK under ELUBSYS/SAMULET.
Implement the findings in a commercially available CFD code to enhance predictive capabilities available to European Aerospace.
Integration in E-BREAK project
WP 2.2 of the E-BREAK project aims to mainly improve the prediction capabilities available to European aero businesses in the design of advanced oil systems. Task 2.2.2.1 is a sub-component of WP 2.2 and was concerned with providing reliable tools for the numerical modelling of non-isothermal oil thin-films that are central to the design and operation of aeroengine bearing chambers.
ACHIEVEMENTS
The film hydrodynamic and thermal formulation have been tested for the range of flows expected in a bearing chamber, and an ideal formulation identified.
Corrective source terms have been added to the momentum and energy equations in order to achieve an accurate and stable numerical formulation.
These correction source terms together with an updated solution strategy have led to improved film thickness and hydrodynamic performance as well as thermal prediction.
The improved numerical formulation has been implemented in a commercially available CFD Solver ANSYS FLUENT version 16 as a result of a close collaboration between the UNOTT UTC, RRUK and the commercial software company ANSYS Inc.
The final thin-film model represents an improvement to oil-system thin-film modelling capabilities available to European Aero-businesses for the analysis and design of bearing chambers.
(a) Smooth
(b) Shock
(c) Pool
Figure 1: Three types of film solutions are possible depending on the balance between gravitational and shear forces: (a) Smooth solutions, (b) shock solutions and (c) pool solutions
Figure 3: Introducing the inertia and thermal correction source terms resulted in a more accurate solution
Collaborative Project co-funded by the European Commission within the 7th Framework Programme (2007-2013),
Under Grant Agreement n°ACP2-GA-2012-314366-E-BREAK. Coordinated by TURBOMECA: manuel.silva@turbomeca.fr


WP2.2.3 Oil Lifing and Degradation
Roll-Royce UK
OUR GOAL
Review current industry laboratory methodologies for the evaluation of oil oxidation
Develop an improved methodology
Validate the method and produce oil oxidation data
Integration in E-break project
WP2.2 aims to improve the prediction capability for aero gas turbine oil systems
This better allows manufacturers to cope with the increasing demands on the oil system(particularly increasing temperatures)
WP2.2.3 embraces the 'right first time' principles to reduce oil related issues and failures.
ACHIEVEMENTS
Critique of lubricant oxidation characterisation methodologies completed
Improved laboratory method for the assessment of lubricant oxidative stability developed
This method was validated against oil samples collected from Rolls-Royce service gas turbines
Changes in physical and chemical properties as a result of thermal oxidation assessed for four of the most common lubricants.
Work is currently underway to determine the feasibility of implementing this data into the Rolls-Royce oil life stability model and University of Nottingham's CFD framework
Duration (hours)
Collaborative Project co-funded by the European Commission within the 7th Framework Programme (2007-2013),
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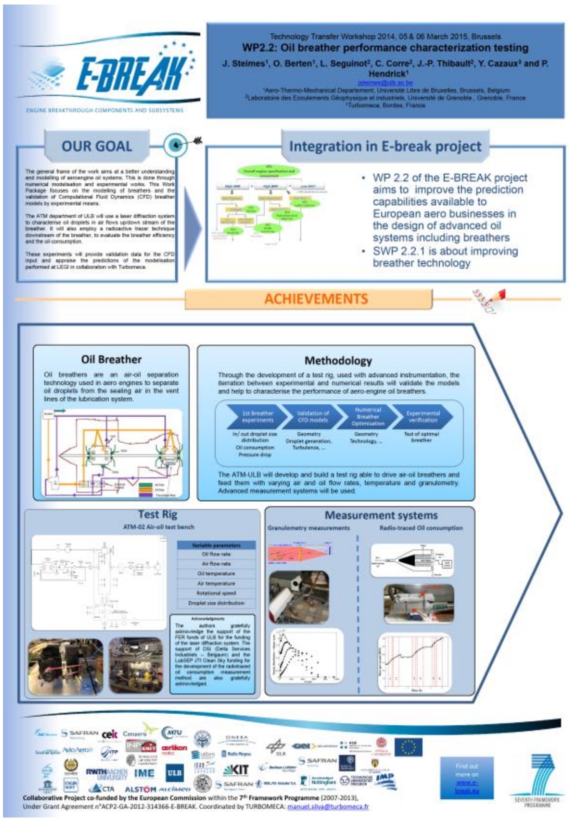
Technology Transfer Workshop 2014, 05 & 06 March 2015, Brussels
WP2.2: Oil breather performance characterization testing
J. Steimes, O. Berten, L. Seguinot, C. Corre, J.-P. Thibault, Y. Cazaux and P. Hendrick
OUR GOAL
Integration in E-break project
WP 2.2 of the E-BREAK project aims to improve the prediction capabilities available to European aero businesses in the design of advanced oil systems including breathers
SWP 2.2.1 is about improving breather technology
ACHIEVEMENTS
Oil Breather
Methodology
Test Rig
Measurement systems
Collaborative Project co-funded by the European Commission within the 7th Framework Programme (2007-2013),
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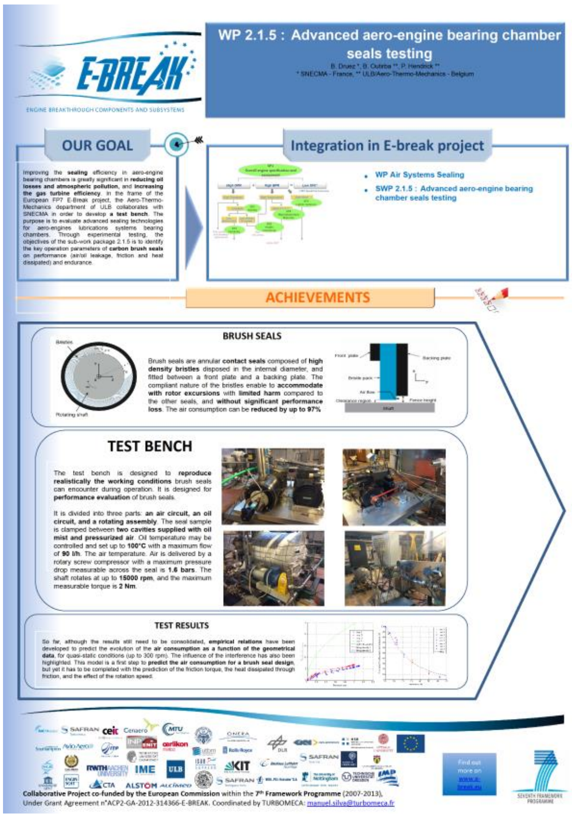
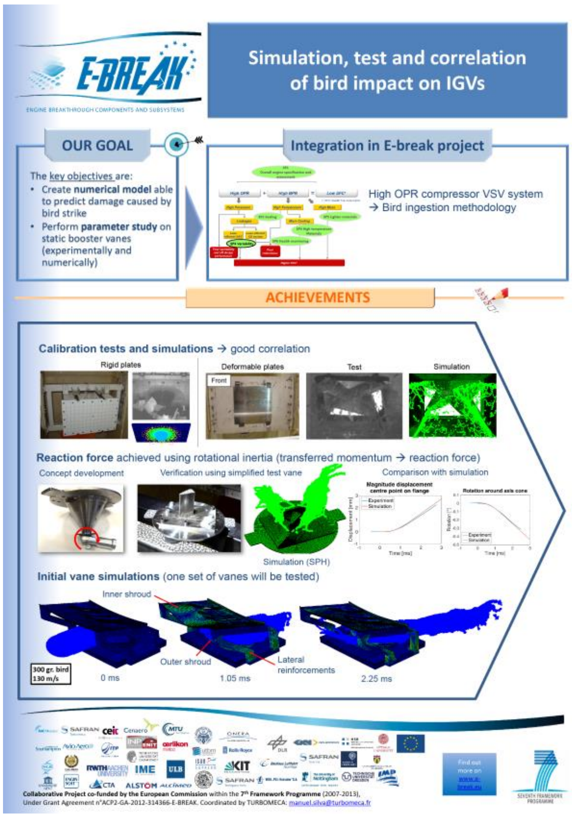
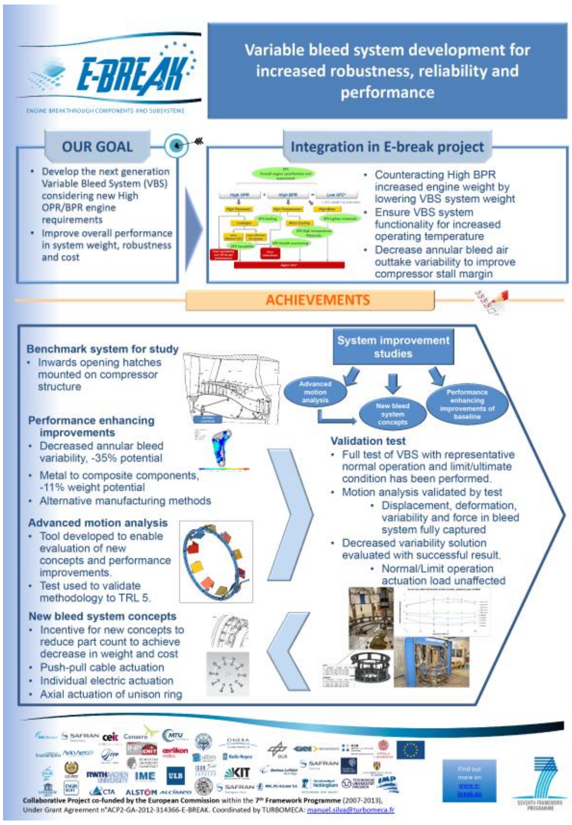
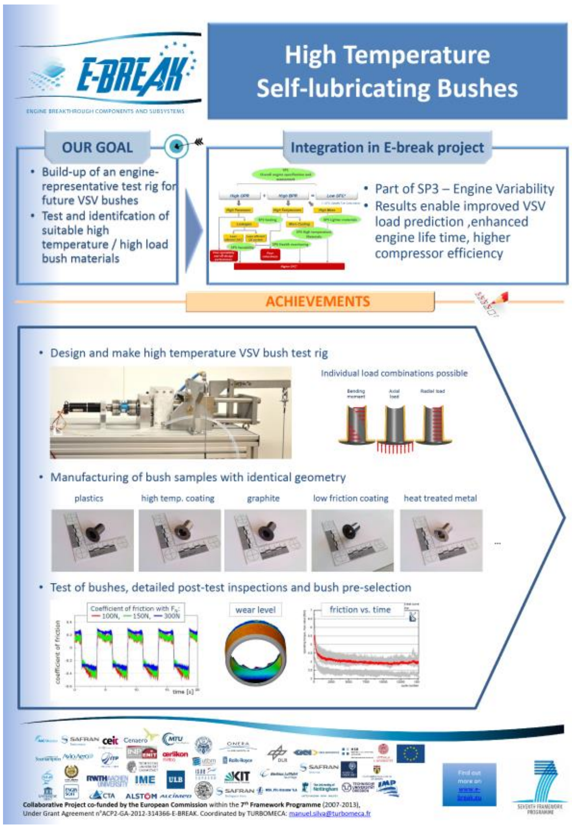
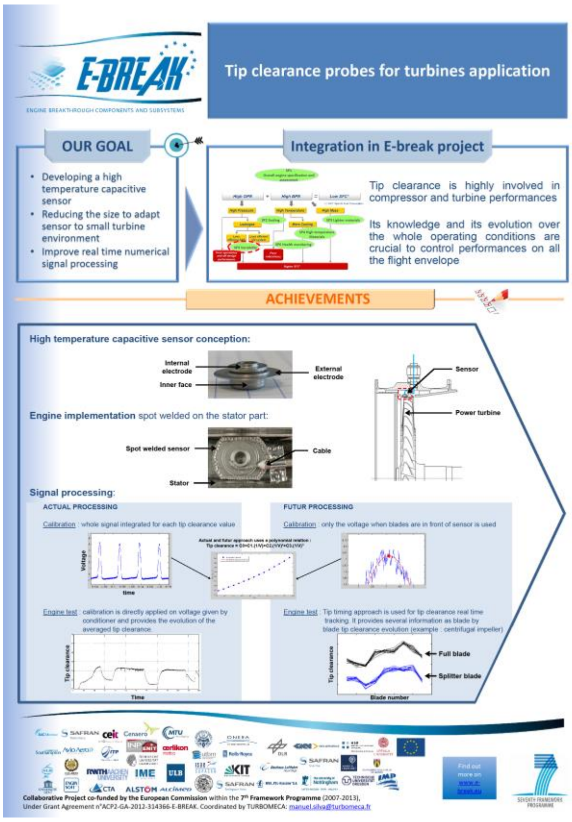








Collaborative Project co-funded by the European Commission within the **7th Framework Programme** (2007-2013),
Under Grant Agreement n°ACP2-GA-2012-314366-E-BREAK
SEVENTH FRAMEWORK PROGRAMME


E-BREAK
Tip clearance probes for turbines application
OUR GOAL
Developing a high temperature capacitive sensor
Reducing the size to adapt sensor to small turbine environment
Improve real time numerical signal processing
Integration in E-break project
Tip clearance is highly involved in compressor and turbine performances
Its knowledge and its evolution over the whole operating conditions are crucial to control performances on all the flight envelope
ACHIEVEMENTS
High temperature capacitive sensor conception:
Engine implementation spot welded on the stator part:
Signal processing:
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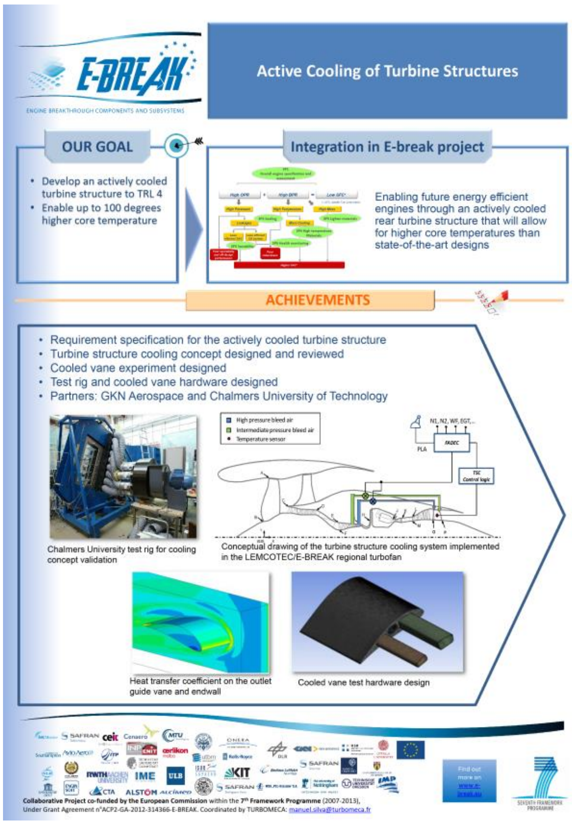
E-BREAK
Active Cooling of Turbine Structures
OUR GOAL
Develop an actively cooled turbine structure to TRL 4
Enable up to 100 degrees higher core temperature
Integration in E-break project
Enabling future energy efficient engines through an actively cooled rear turbine structure that will allow for higher core temperatures than state-of-the-art designs
ACHIEVEMENTS
Requirement specification for the actively cooled turbine structure
Turbine structure cooling concept designed and reviewed
Cooled vane experiment designed
Test rig and cooled vane hardware designed
Partners: GKN Aerospace and Chalmers University of Technology
Chalmers University test rig for cooling concept validation
Conceptual drawing of the turbine structure cooling system implemented in the LEMCOTEC/E-BREAK regional turbofan
Heat transfer coefficient on the outlet guide vane and endwall
Cooled vane test hardware design
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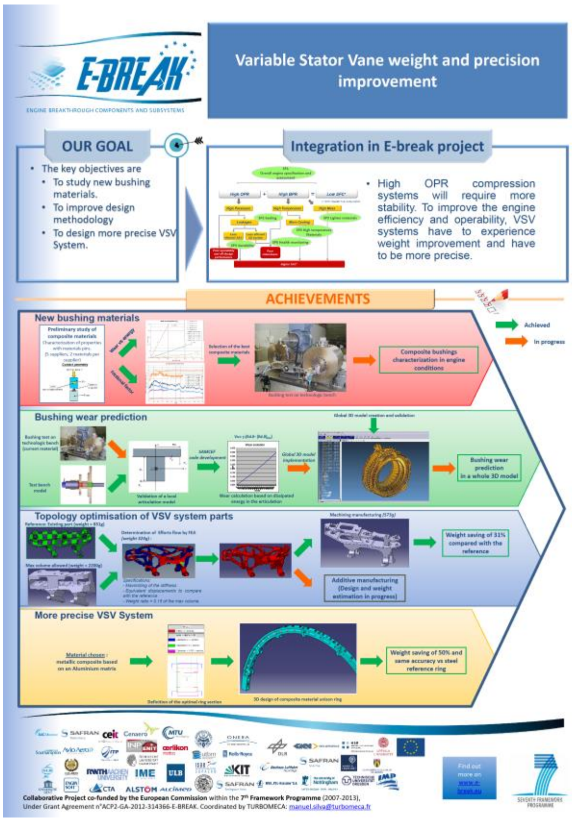
E-BREAK
Variable Stator Vane weight and precision improvement
OUR GOAL
The key objectives are
To study new bushing materials.
To improve design methodology
To design more precise VSV System.
Integration in E-break project
High OPR compression systems will require more stability. To improve the engine efficiency and operability, VSV systems have to experience weight improvement and have to be more precise.
ACHIEVEMENTS
New bushing materials
Achieved
In progress
Bushing wear prediction
Topology optimisation of VSV system parts
More precise VSV System
Collaborative Project co-funded by the European Commission within the 7th Framework Programme (2007-2013),
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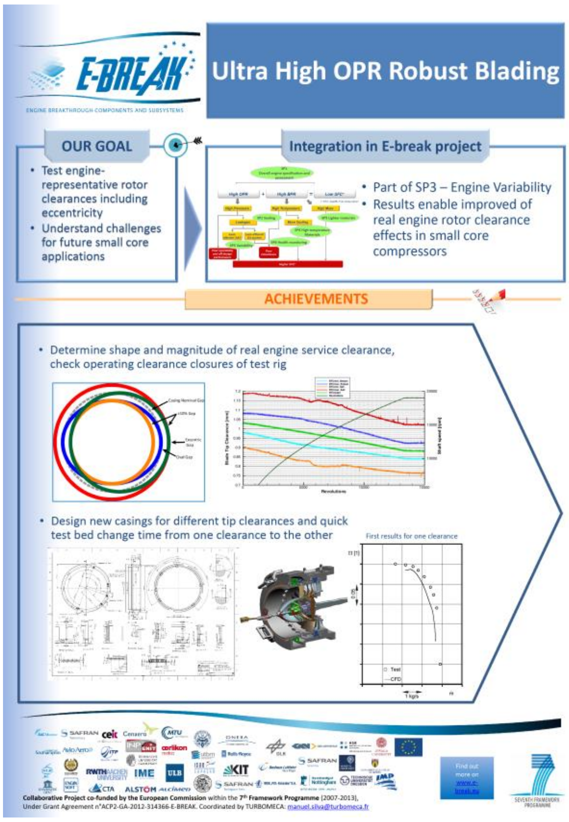
E-BREAK
Ultra High OPR Robust Blading
OUR GOAL
Test engine-representative rotor clearances including eccentricity
Understand challenges for future small core applications
Integration in E-break project
Part of SP3 – Engine Variability
Results enable improved of real engine rotor clearance effects in small core compressors
ACHIEVEMENTS
Determine shape and magnitude of real engine service clearance, check operating clearance closures of test rig
Design new casings for different tip clearances and quick test bed change time from one clearance to the other
First results for one clearance
Collaborative Project co-funded by the European Commission within the 7th Framework Programme (2007-2013),
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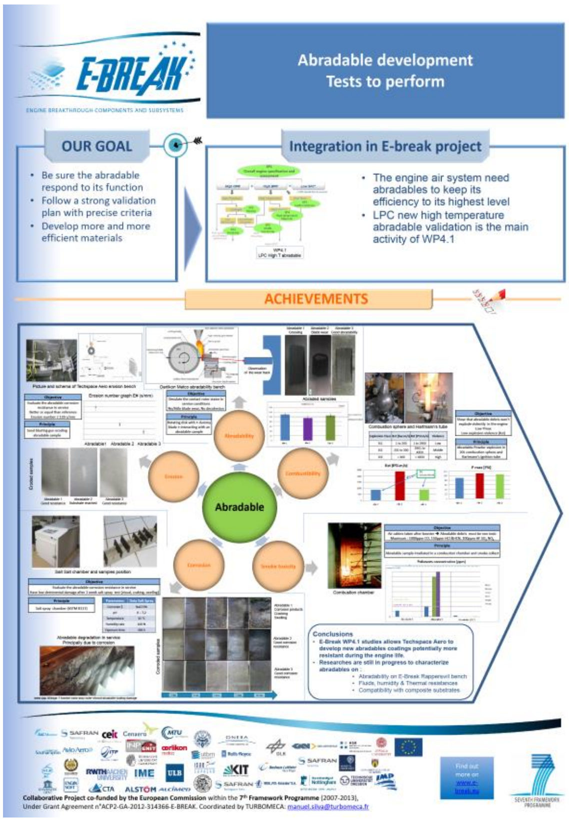

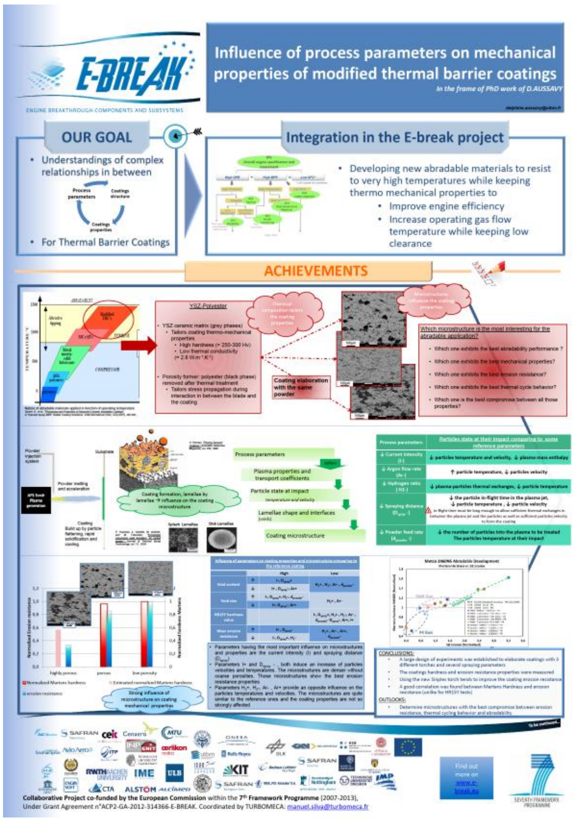

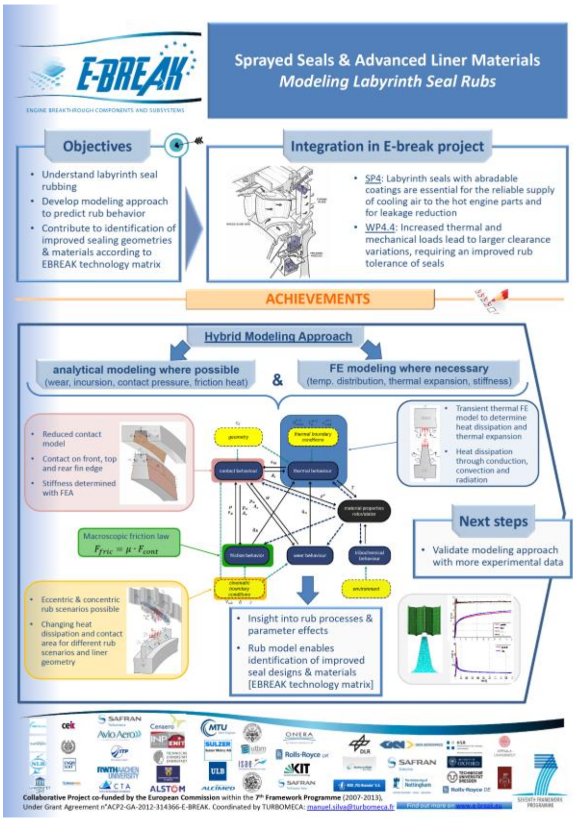

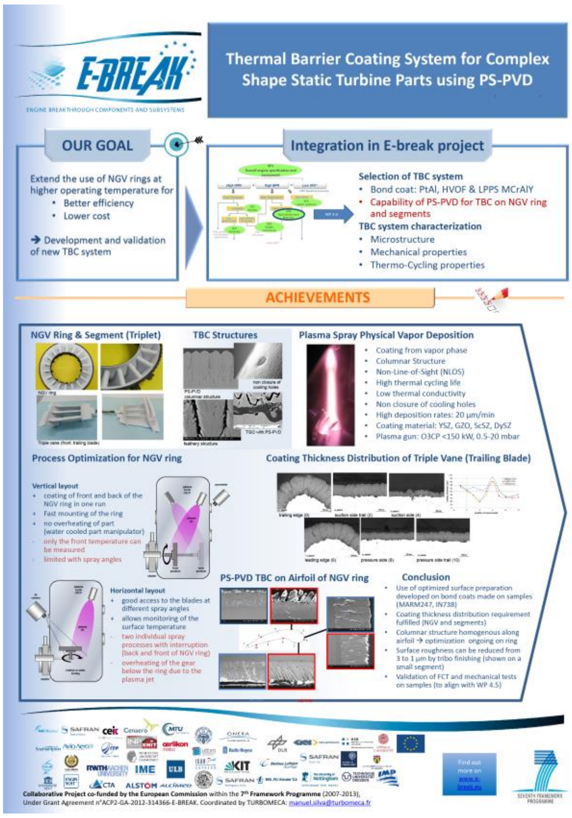

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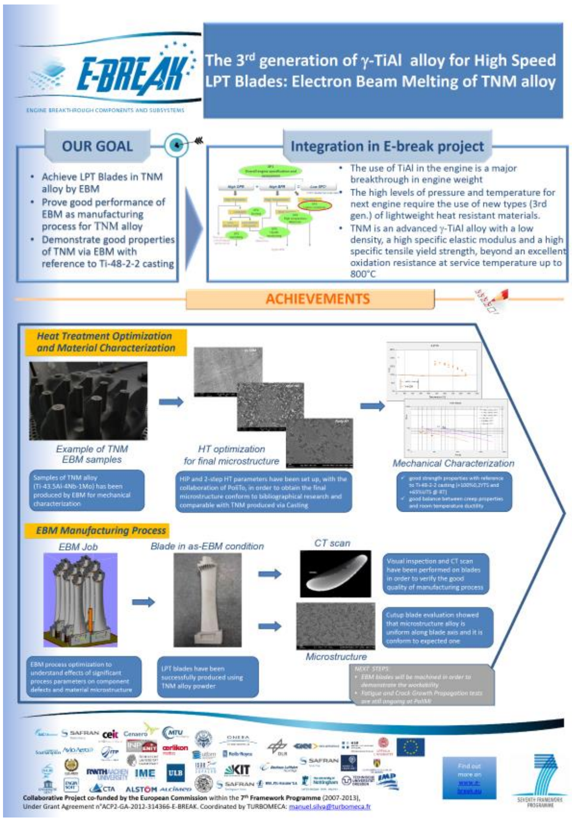
SEVENTH FRAMEWORK PROGRAMME


The 3rd generation of γ-TiAl alloy for High Speed LPT Blades: Electron Beam Melting of TNM alloy
OUR GOAL
Achieve LPT Blades in TNM alloy by EBM
Prove good performance of EBM as manufacturing process for TNM alloy
Demonstrate good properties of TNM via EBM with reference to Ti-48-2-2 casting
Integration in E-break project
The use of TiAl in the engine is a major breakthrough in engine weight
The high levels of pressure and temperature for next engine require the use of new types (3rd gen.) of lightweight heat resistant materials.
TNM is an advanced γ-TiAl alloy with a low density, a high specific elastic modulus and a high specific tensile yield strength, beyond an excellent oxidation resistance at service temperature up to 800°C
ACHIEVEMENTS
Heat Treatment Optimization and Material Characterization
Example of TNM EBM samples
HT optimization for final microstructure
Mechanical Characterization
EBM Manufacturing Process
EBM Job
Blade in as-EBM condition
CT scan
Microstructure
LPT blades have been successfully produced using TNM alloy powder
Collaborative Project co-funded by the European Commission within the 7th Framework Programme (2007-2013),
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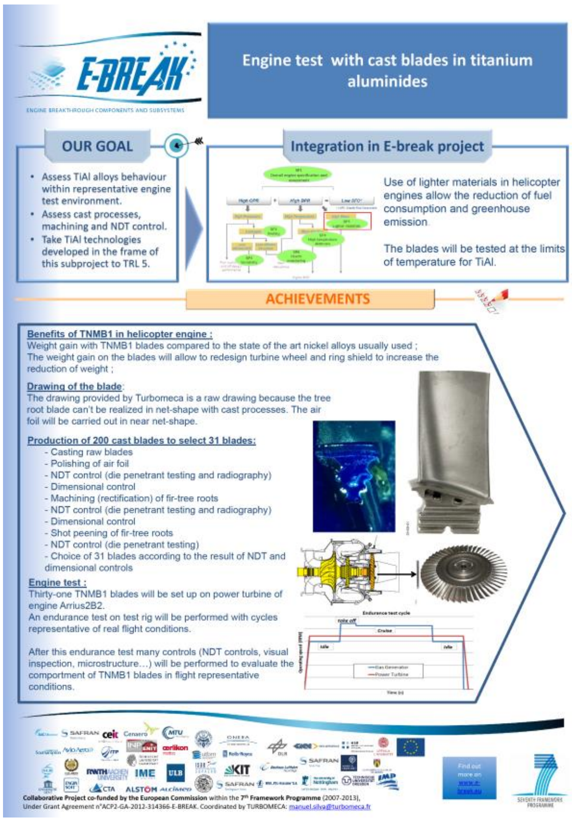
Engine test with cast blades in titanium aluminides
OUR GOAL
Assess TiAl alloys behaviour within representative engine test environment.
Assess cast processes, machining and NDT control.
Take TiAl technologies developed in the frame of this subproject to TRL 5.
Integration in E-break project
Use of lighter materials in helicopter engines allow the reduction of fuel consumption and greenhouse emission.
The blades will be tested at the limits of temperature for TiAl.
ACHIEVEMENTS
Benefits of TNMB1 in helicopter engine :
Weight gain with TNMB1 blades compared to the state of the art nickel alloys usually used ;
The weight gain on the blades will allow to redesign turbine wheel and ring shield to increase the reduction of weight ;
Drawing of the blade:
The drawing provided by Turbomeca is a raw drawing because the tree root blade can't be realized in net-shape with cast processes. The air foil will be carried out in near net-shape.
Production of 200 cast blades to select 31 blades:
- Casting raw blades
- Polishing of air foil
- NDT control (die penetrant testing and radiography)
- Dimensional control
- Machining (rectification) of fir-tree roots
- NDT control (die penetrant testing and radiography)
- Dimensional control
- Shot peening of fir-tree roots
- NDT control (die penetrant testing)
- Choice of 31 blades according to the result of NDT and dimensional controls
Engine test :
Thirty-one TNMB1 blades will be set up on power turbine of engine Arrius2B2.
An endurance test on test rig will be performed with cycles representative of real flight conditions.
After this endurance test many controls (NDT controls, visual inspection, microstructure…) will be performed to evaluate the comportment of TNMB1 blades in flight representative conditions.
Endurance test cycle
Collaborative Project co-funded by the European Commission within the 7th Framework Programme (2007-2013),
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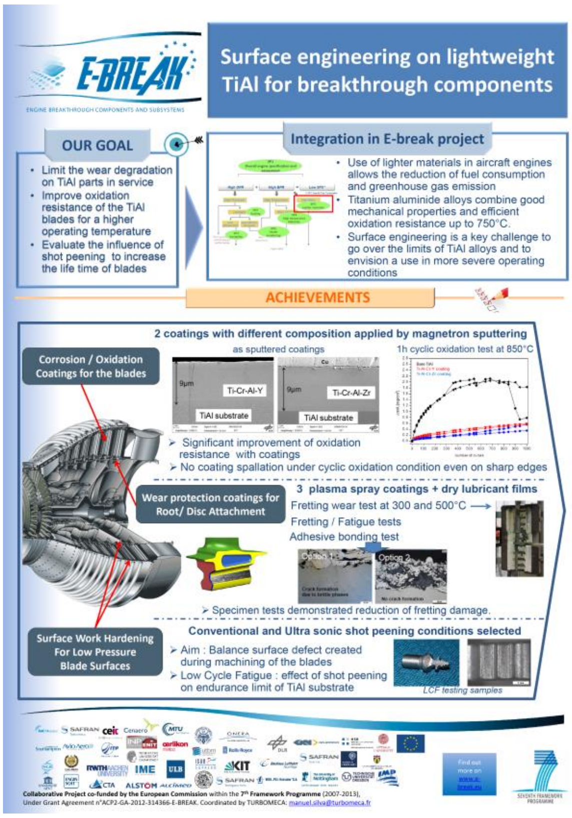
Surface engineering on lightweight TiAl for breakthrough components
OUR GOAL
Limit the wear degradation on TiAl parts in service
Improve oxidation resistance of the TiAl blades for a higher operating temperature
Evaluate the influence of shot peening to increase the life time of blades
Integration in E-break project
Use of lighter materials in aircraft engines allows the reduction of fuel consumption and greenhouse gas emission
Titanium aluminide alloys combine good mechanical properties and efficient oxidation resistance up to 750°C.
Surface engineering is a key challenge to go over the limits of TiAl alloys and to envision a use in more severe operating conditions
ACHIEVEMENTS
2 coatings with different composition applied by magnetron sputtering
as sputtered coatings
1h cyclic oxidation test at 850°C
Ti-Cr-Al-Y
Ti-Cr-Al-Zr
TiAl substrate
Corrosion / Oxidation Coatings for the blades
Significant improvement of oxidation resistance with coatings
No coating spallation under cyclic oxidation condition even on sharp edges
3 plasma spray coatings + dry lubricant films
Wear protection coatings for Root/ Disc Attachment
Fretting wear test at 300 and 500°C
Fretting / Fatigue tests
Adhesive bonding test
Specimen tests demonstrated reduction of fretting damage.
Conventional and Ultra sonic shot peening conditions selected
Surface Work Hardening For Low Pressure Blade Surfaces
Aim : Balance surface defect created during machining of the blades
Low Cycle Fatigue : effect of shot peening on endurance limit of TiAl substrate
LCF testing samples
Collaborative Project co-funded by the European Commission within the 7th Framework Programme (2007-2013),
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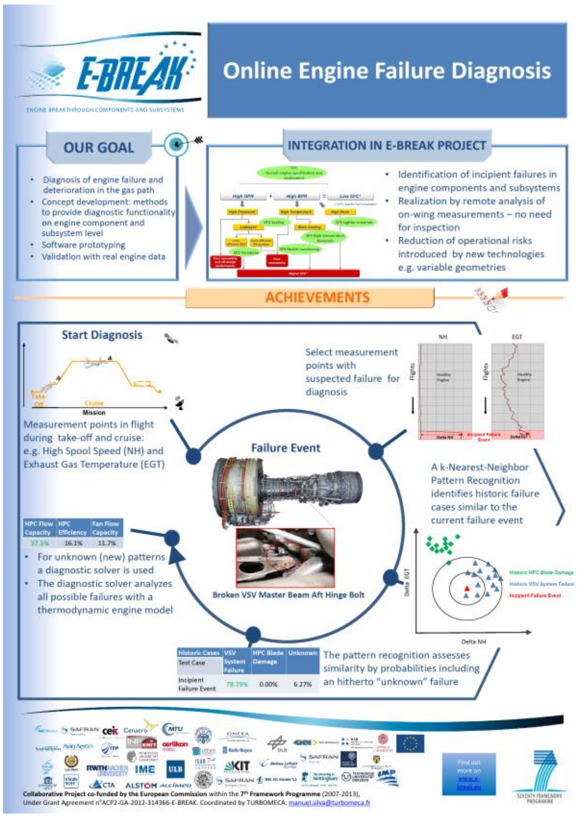
Online Engine Failure Diagnosis
OUR GOAL
Diagnosis of engine failure and deterioration in the gas path
Concept development: methods to provide diagnostic functionality on engine component and subsystem level
Software prototyping
Validation with real engine data
INTEGRATION IN E-BREAK PROJECT
Identification of incipient failures in engine components and subsystems
Realization by remote analysis of on-wing measurements – no need for inspection
Reduction of operational risks introduced by new technologies e.g. variable geometries
ACHIEVEMENTS
Start Diagnosis
Measurement points in flight during take-off and cruise: e.g. High Spool Speed (NH) and Exhaust Gas Temperature (EGT)
Select measurement points with suspected failure for diagnosis
Failure Event
Broken VSV Master Beam Aft Hinge Bolt
A k-Nearest-Neighbor Pattern Recognition identifies historic failure cases similar to the current failure event
For unknown (new) patterns a diagnostic solver is used
The diagnostic solver analyzes all possible failures with a thermodynamic engine model
The pattern recognition assesses similarity by probabilities including an hitherto "unknown" failure
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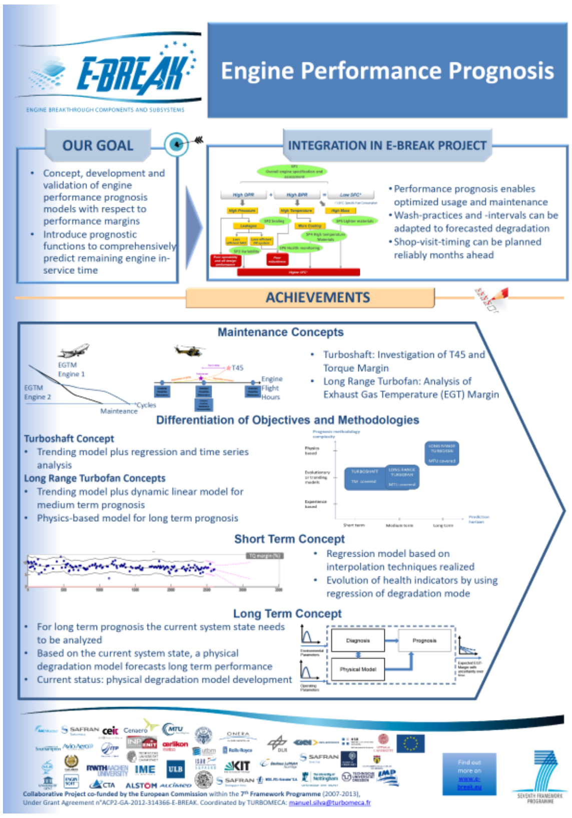

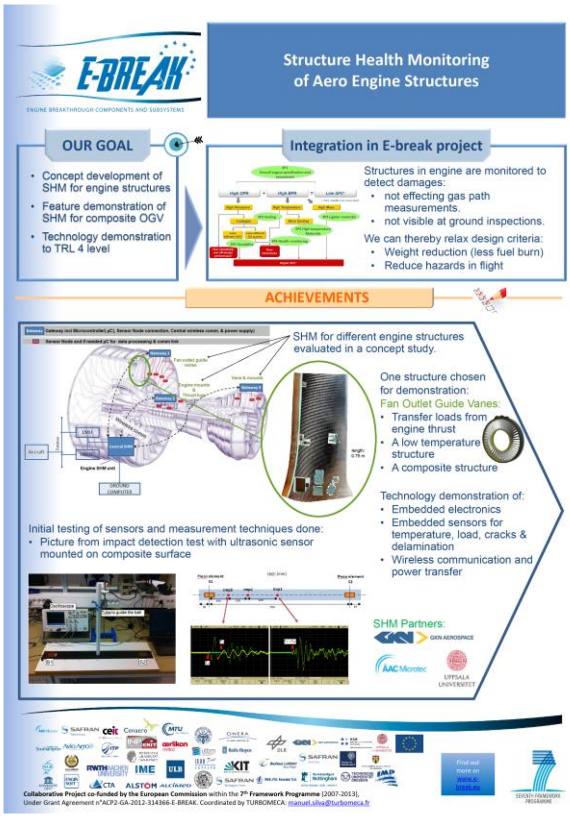

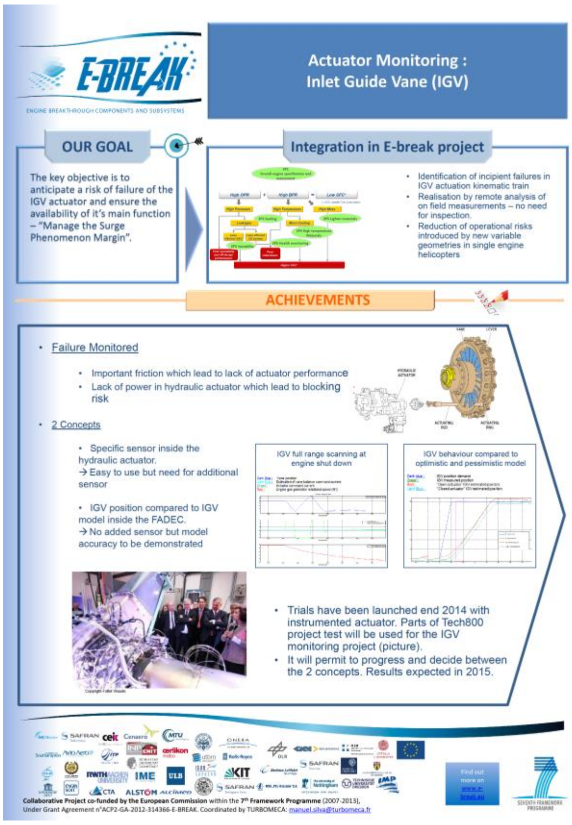

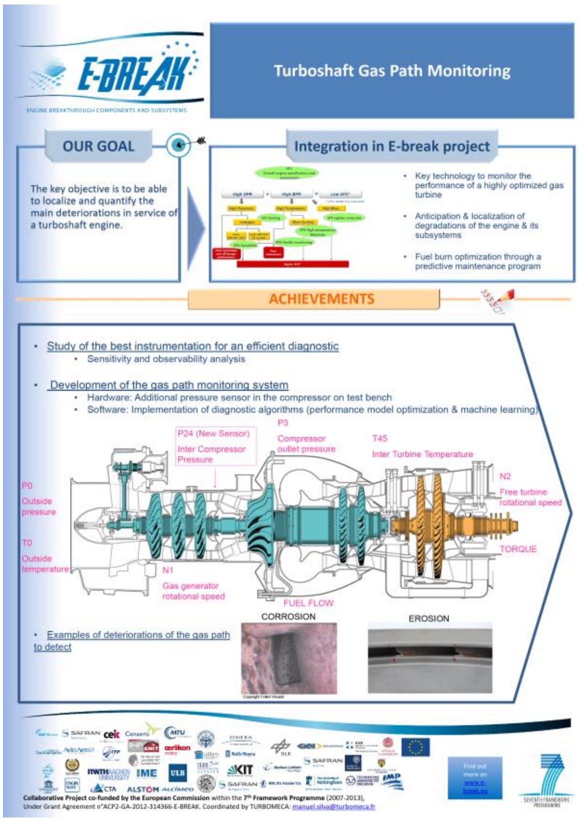

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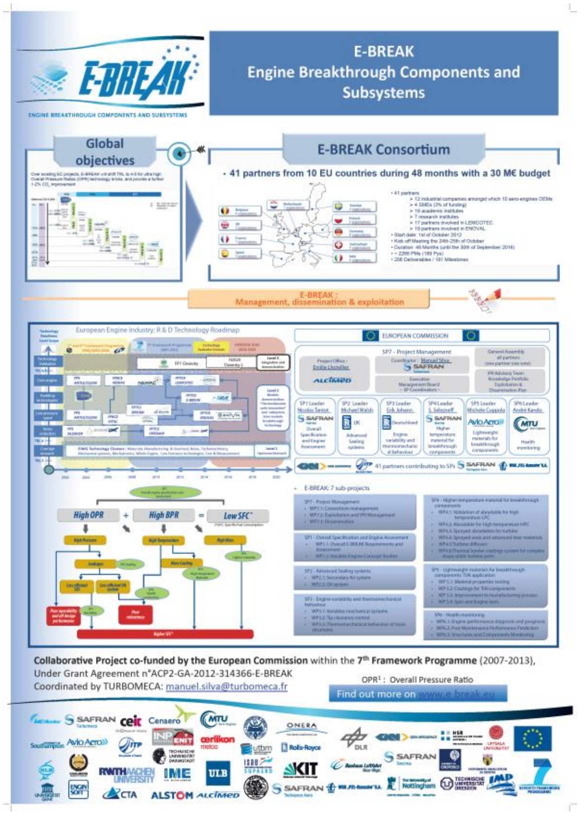
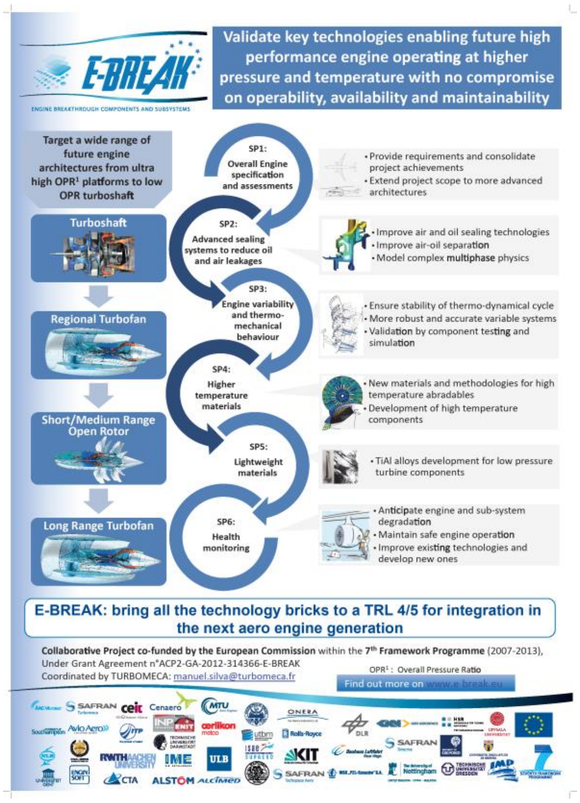

E-BREAK
Engine Breakthrough Components and Subsystems
Global objectives
E-BREAK Consortium
• 41 partners from 10 EU countries during 48 months with a 30 M€ budget
E-BREAK : Management, dissemination & exploitation
High OPR
High BPR
Low SFC
Collaborative Project co-funded by the European Commission within the 7th Framework Programme (2007-2013),
Under Grant Agreement n°ACP2-GA-2012-314366-E-BREAK
Coordinated by TURBOMECA: manuel.silva@turbomeca.fr
OPR¹ : Overall Pressure Ratio
Find out more on www.e-break.eu


Validate key technologies enabling future high performance engine operating at higher pressure and temperature with no compromise on operability, availability and maintainability
Target a wide range of future engine architectures from ultra high OPR¹ platforms to low OPR turboshaft
Turboshaft
Regional Turbofan
Short/Medium Range Open Rotor
Long Range Turbofan
SP1: Overall Engine specification and assessments
SP2: Advanced sealing systems to reduce oil and air leakages
SP3: Engine variability and thermo-mechanical behaviour
SP4: Higher temperature materials
SP5: Lightweight materials
SP6: Health monitoring
• Provide requirements and consolidate project achievements
• Extend project scope to more advanced architectures
• Improve air and oil sealing technologies
• Improve air-oil separation
• Model complex multiphase physics
• Ensure stability of thermo-dynamical cycle
• More robust and accurate variable systems
• Validation by component testing and simulation
• New materials and methodologies for high temperature abradables
• Development of high temperature components
• TiAl alloys development for low pressure turbine components
• Anticipate engine and sub-system degradation
• Maintain safe engine operation
• Improve existing technologies and develop new ones
E-BREAK: bring all the technology bricks to a TRL 4/5 for integration in the next aero engine generation
Collaborative Project co-funded by the European Commission within the 7th Framework Programme (2007-2013),
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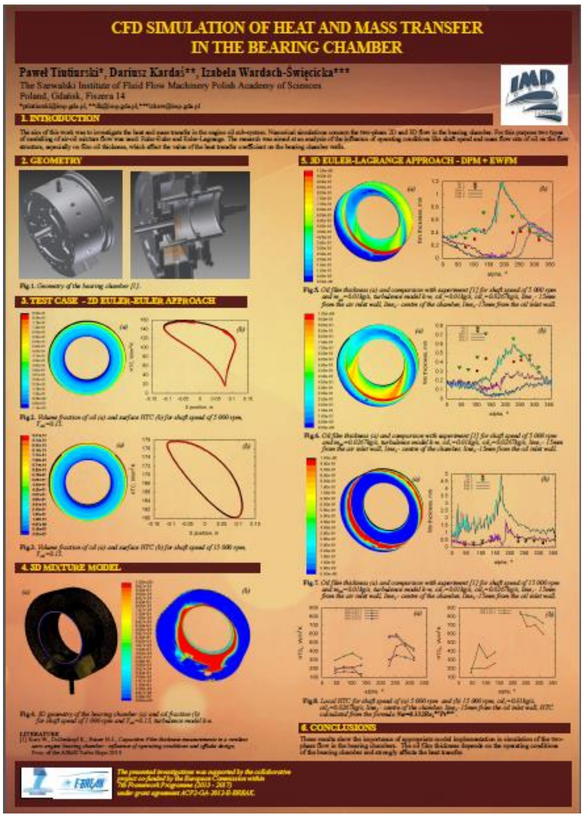
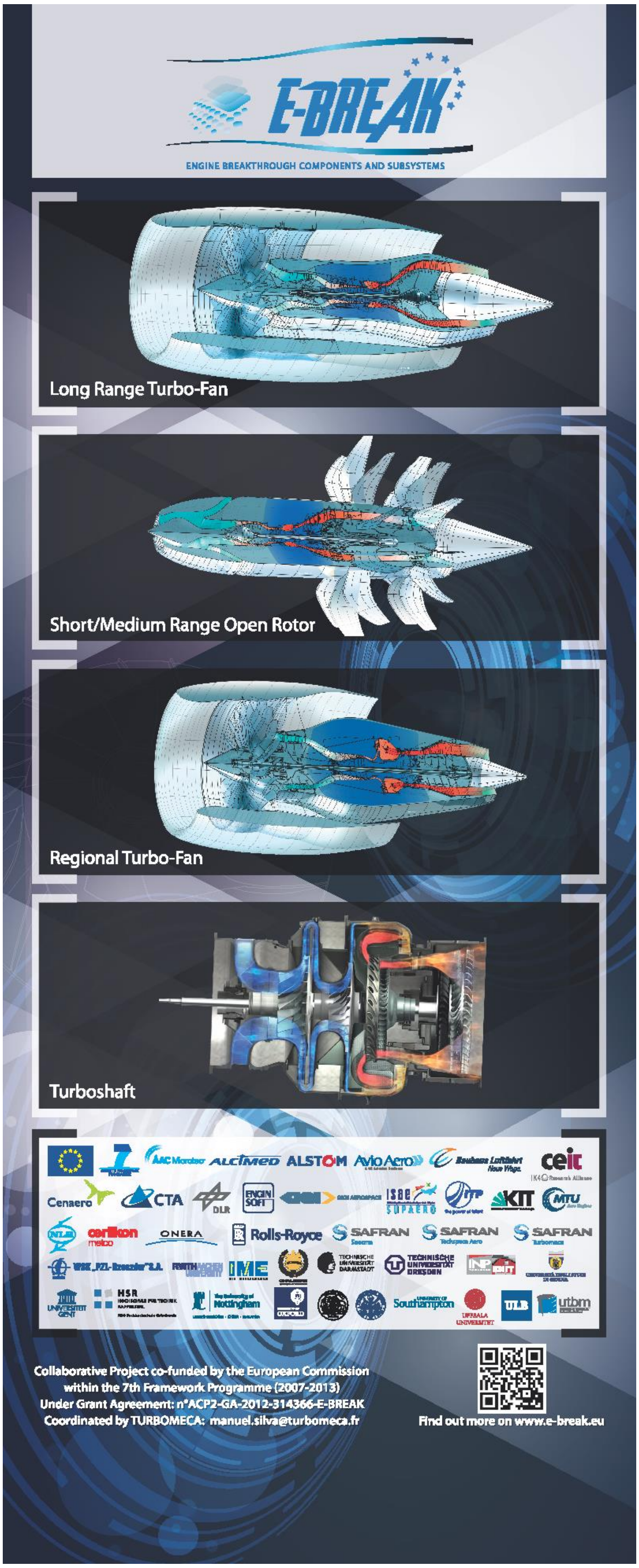

CFD SIMULATION OF HEAT AND MASS TRANSFER IN THE BEARING CHAMBER
1. INTRODUCTION
2. GEOMETRY
3. TEST CASE - 2D EULER-EULER APPROACH
4. 3D MIXTURE MODEL
5. 3D EULER-LAGRANGE APPROACH - DPM + EWFM
6. CONCLUSIONS

E-BREAK ROLL-UP POSTER



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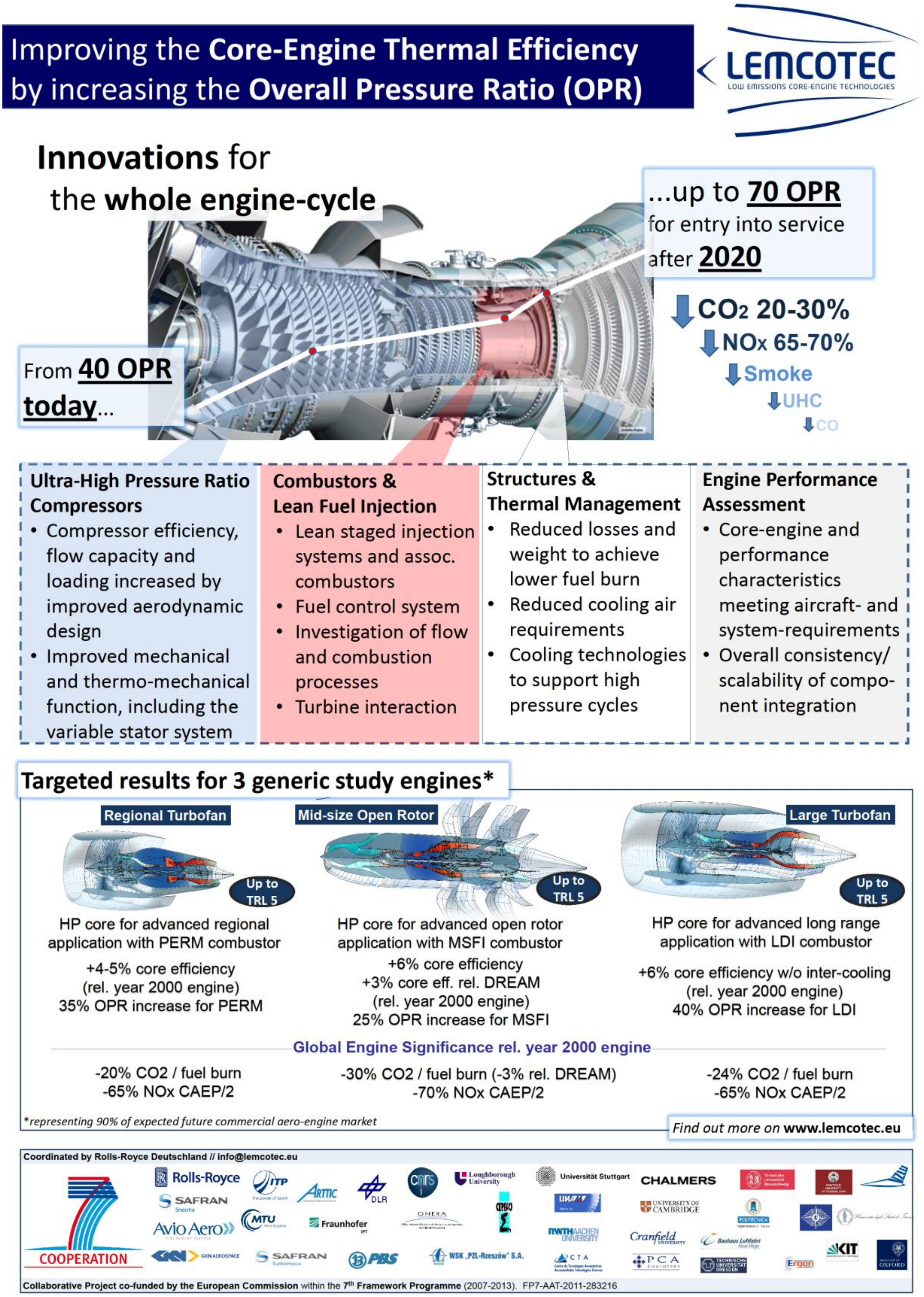
LEMCOTEC Technology Transfer Workshop Poster (2015)



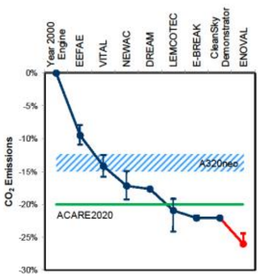
ENOVAL Technology Transfer Workshop Poster (2015)

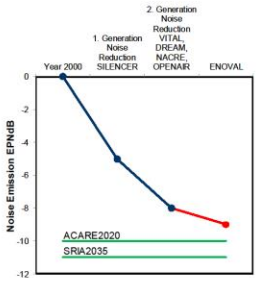
ENOVAL
Ultra High Bypass Ratio Aero Engines

ENOVAL – Engine Module Validators

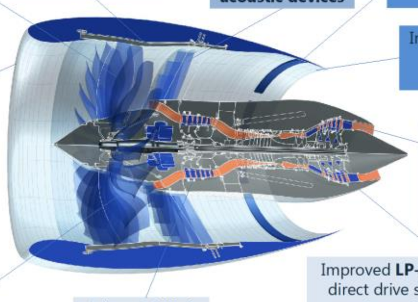
What is ENOVAL about?

- Reduce **fuel burn (-3% to -5%), noise (-1.3dB) and other emissions** of ducted geared and non-geared turbofan engines
- by **Ultra High Bypass Ratios** (UHBR up to 20:1) for improved propulsive efficiency
- and **Ultra High Overall Pressure Ratios** (UHOPR up to 70:1) through more efficient, compact and light weight turbo machinery





ENOVAL Breakthroughs and Technologies



- **Expanding the design space for turbofans up to BPR 20**
- **Enabling a Geared fan drive system for large engines**
- **Introduction of a Variable Area Fan Nozzle**

Project Structure & Organization

35 project partners (11 industries + 5 SMEs + 10 universities + 9 research institutes)

- SP1: Integration and assessment; Future Propulsor Concept Studies
- SP2: Fan modules and nacelle for small to medium size engines
- SP3: Fan modules, nacelle and intermediate case for large engines
- SP4: Low pressure spool technologies incl. Gearbox, LPC, ITC, LPT, TEC modules

Further Information

ENOVAL is a collaborative project which received funding from the European Union Seventh Framework Programme (FP7) under grant agreement n°604999.

For more information, visit www.enoval.eu

Coordinated by MTU: edgar.merkl@mtu.de

EUROPEAN COMMISSION

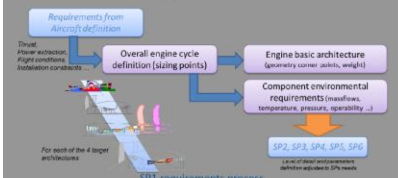
European Commission

E-BREAK

Engine BREAK through Components and Subsystems

TM (33, **Manuel Silva**), 2012-2016

SP1 Engine Assessment



SP1 requirements process

In order to enable a consistent integration of all E-BREAK technologies within a common frame, a top-down approach to requirements is done in SP1:

4 high levels airframe platforms are defined, guiding the definition of corresponding powerplants, ranging from heavy helicopter engine to long range turbofan engine.

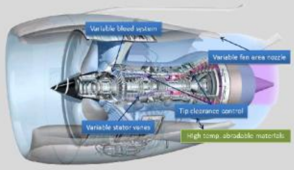
SP1 also aims at expanding E-BREAK technology applicability range outside of these architectures, by considering lower maturity concepts around variable cycle engines and hybrid combined gas generators. These exploratory studies are enforced by a team of academic partners, under industrial guidance.

SP2 Advanced Sealing Systems

Vane separator test rig. Built to asses the performance of a vane oil air separator
Photograph courtesy of ULB.

New engine architectures with higher OPR and BPR require a step change in the design of oil and air systems. The enabling technologies to support these changes are addressed by SP2. In current engines air is often lost through seals reducing the efficiency of the system, in SP2 effort is made to improve seals of several different types to reduce air losses. Oil is used in a jet engine to lubricate the bearings and gears, but mostly as a heat transfer medium removing heat from the core and reducing the temperatures within the bearing chamber. In SP2 technologies and tools to improve oil system performance and reliability are developed.

SP3 Variable Engine Systems



Variable systems of future aeroengines will undergo more challenging constraints regarding temperatures, pressure and wear. Furthermore shrunk core engines with smaller blade and vane dimensions will require an increased actuation accuracy as the overall tolerances cannot be scaled down with the same order of magnitude.

Within SP3 innovative, precise and low friction-low wear variable mechanisms such as variable bleed/stator vane systems and new high efficient adaptive cooling mechanism were developed in order to enable a secure, stable and efficient operation also at off-design conditions.

E-BREAK (Engine BREAK through Components and Subsystems) will contribute to reducing air traffic emissions by adapting sub-systems to new constraints of temperature and pressure supporting LEMCOTEC. The main technological objective of E-BREAK is to develop, validate and integrate specific key sub-system technologies required for ultra-high OPR applications and high BPR engines up to technology readiness levels of 4 to 5. E-BREAK will target sub-systems breakthrough, through improvements regarding mass reduction, material resistance, sealing technologies, oil systems, abradables, tip clearance control, stability of the engine in off-design operations and health monitoring. These initiatives will bring all technology bricks to a TRL level ensuring the possibility to integrate them in a new aero engines generation around 2020 and beyond.

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European Union funding
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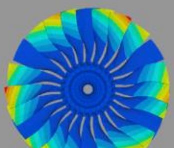
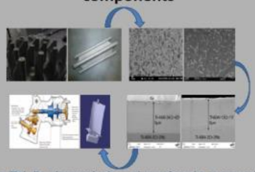
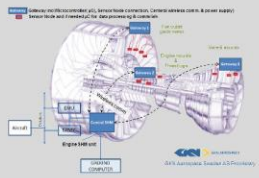
E-BREAK

Engine BREAK through Components and Subsystems

TM (33, **Manuel Silva**), 2012-2016

SP4 Higher temperature material for breakthrough	SP5 Lightweight materials for breakthrough components	SP6 Engine Health Monitoring
	 *3rd generation TiAl alloy characterization and manufacturing processes improvements*	
The objectives of SP4 are to develop a methodology for the design of abradable coatings and to apply it to develop solutions for high temperature application. Then, all the domains of material sciences are involved from manufacturing optimization to models development. The potential outcomes will act as enabler for the 50 K higher temperature with better understanding of clearance control evolution and rub mechanisms at high temperature. Development of new materials and damage prediction will also permit to increase lifespan of coatings. This will also improve the fuel consumption together with the mechanical data obtained at very high temperature.	The SP5 main objective is to understand the link between the processing route of different manufacturing processes and relevant microstructure and mechanical properties, leading to an improved understanding of fundamental material behavior. To achieve that, component tests and an engine test will be performed to validate all of the technical aspects studied in the project: material, process, coatings and manufacturing route.	The objectives of SP6 are to mitigate the operational risks from the introduction of new engine technologies, maintain their SFC-benefits through the engine life cycle and allow for new opportunities in the design space of engine development. This will be achieved through new sensor architectures, data evaluation and analysis for monitoring and prognosis of engine performance, actuators and structural health. First results include a structures monitoring mockup and new remote diagnosis software prototypes for incipient failure analysis.

E-BREAK (Engine BREAK through Components and Subsystems) will contribute to reducing air traffic emissions by adapting sub-systems to new constraints of temperature and pressure supporting LEMCOTEC. The main technological objective of E-BREAK is to develop, validate and integrate specific key sub-system technologies required for ultra-high OPR applications and high BPR engines up to technology readiness levels of 4 to 5. E-BREAK will target sub-systems breakthrough, through improvements regarding mass reduction, material resistance, sealing technologies, oil systems, abradables, tip clearance control, stability of the engine in off-design operations and health monitoring. These initiatives will bring all technology bricks to a TRL level ensuring the possibility to integrate them in a new aero engines generation around 2020 and beyond.

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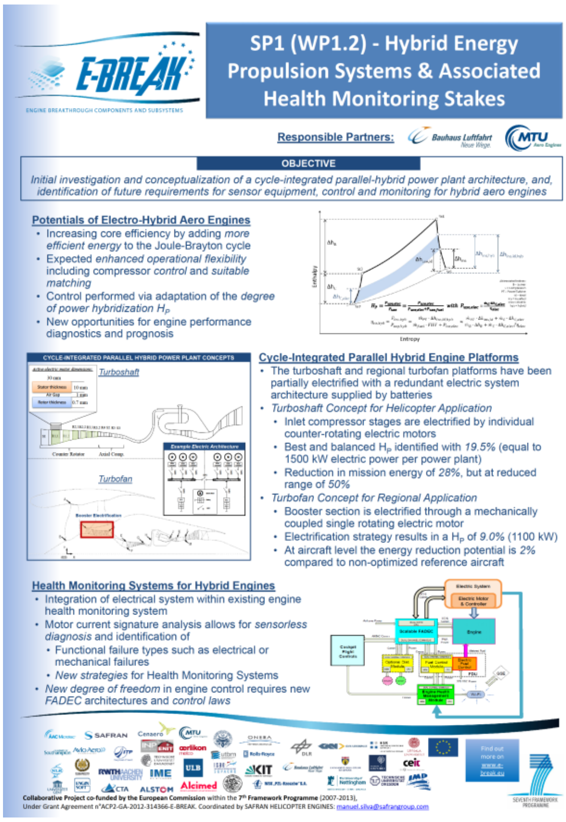
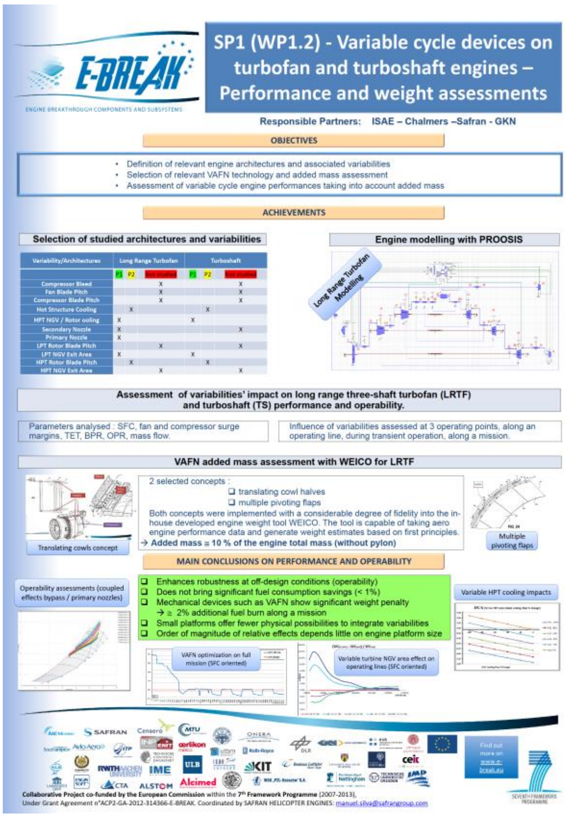
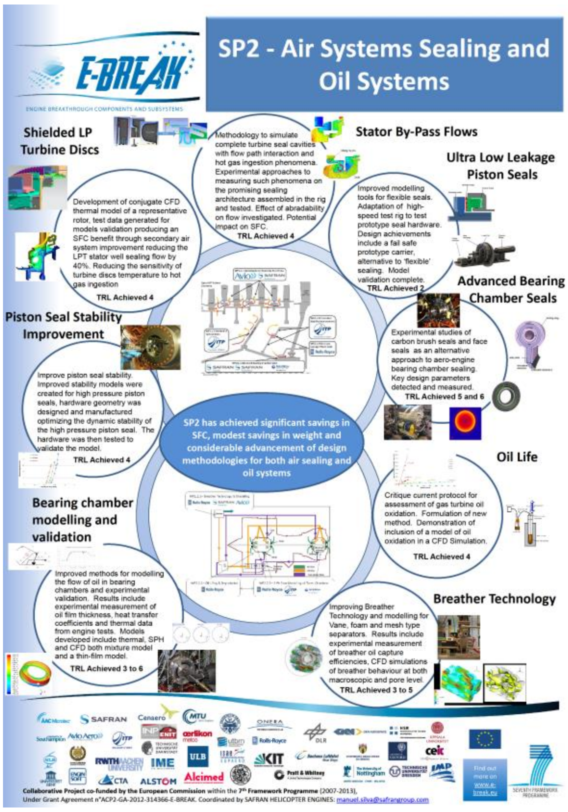
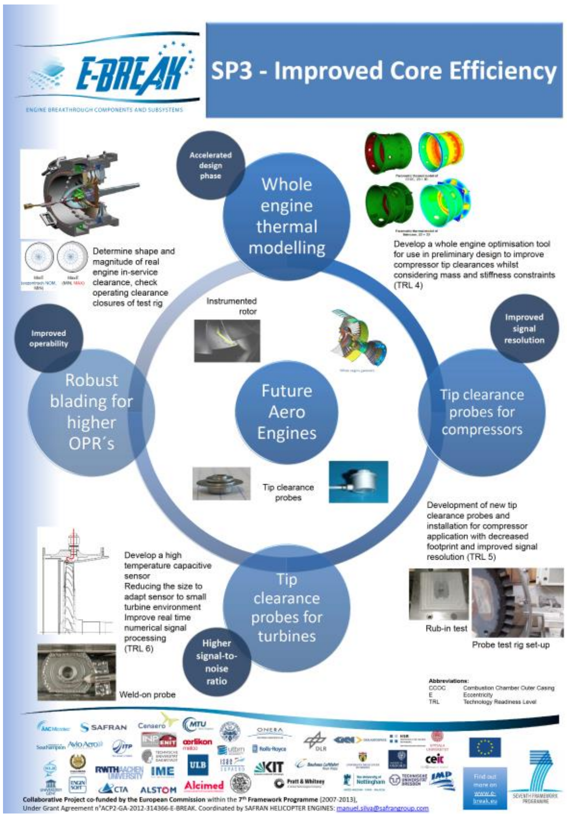
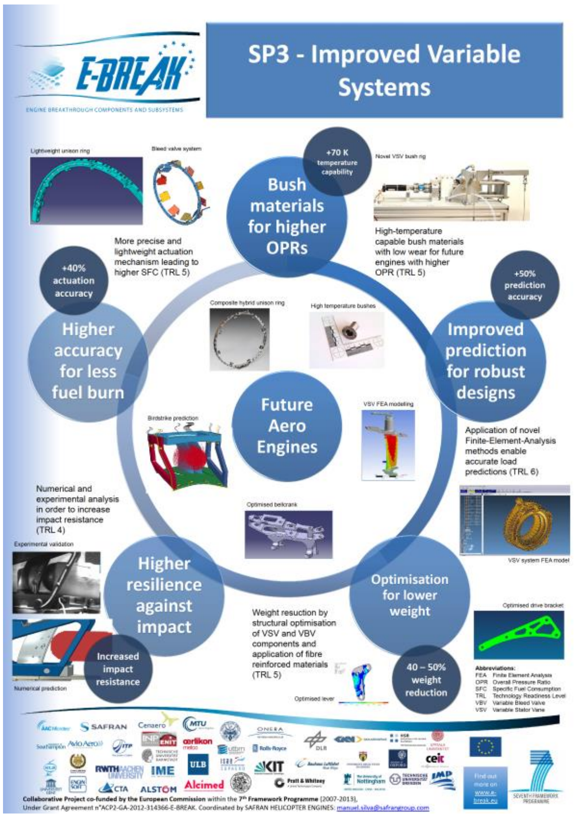
2ND E-BREAK TECHNOLOGY TRANSFER WORKSHOP POSTERS (2017)

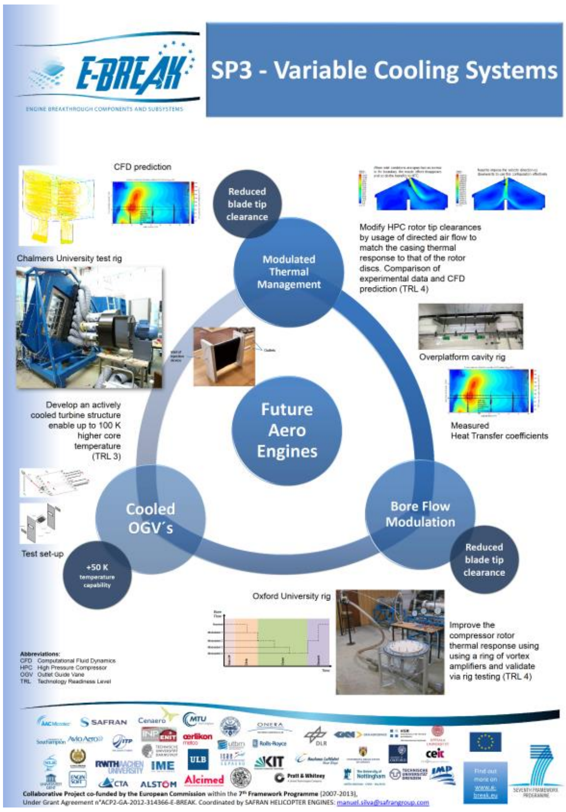


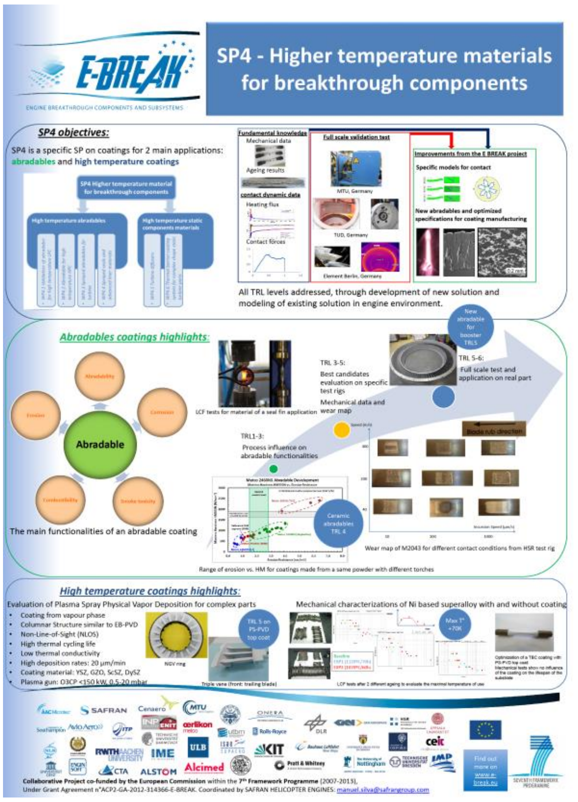


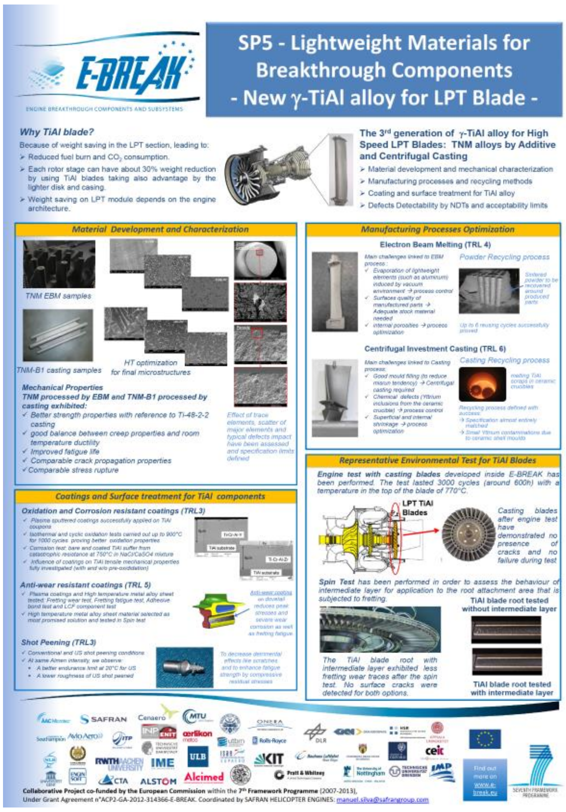












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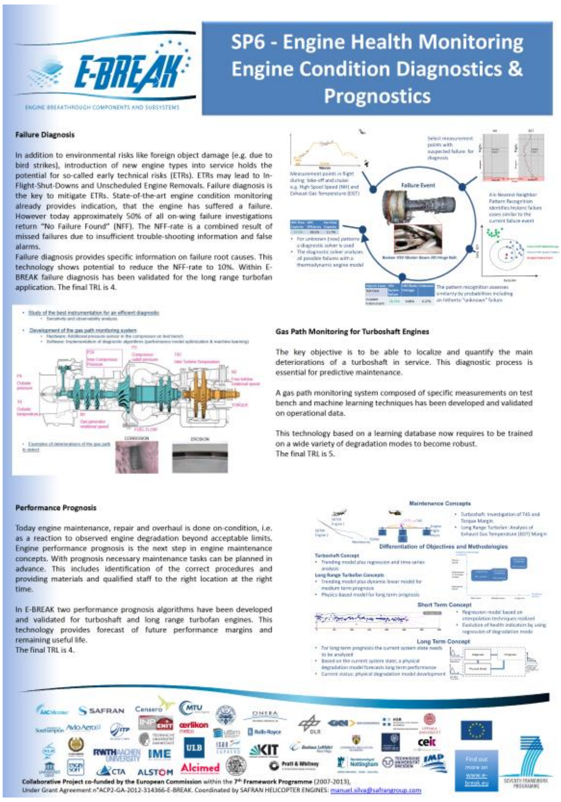
ENGINE BREAKTHROUGH COMPONENTS AND SUBSYSTEMS
SP6 - Engine Health Monitoring
Engine Condition Diagnostics & Prognostics
Failure Diagnosis
In addition to environmental risks like foreign object damage (e.g. due to bird strikes), introduction of new engine types into service holds the potential for so-called early technical risks (ETRs). ETRs may lead to In-Flight-Shut-Downs and Unscheduled Engine Removals. Failure diagnosis is the key to mitigate ETRs. State-of-the-art engine condition monitoring already provides indication, that the engine has suffered a failure. However today approximately 50% of all on-wing failure investigations return "No Failure Found" (NFF). The NFF-rate is a combined result of missed failures due to insufficient trouble-shooting information and false alarms.
Failure diagnosis provides specific information on failure root causes. This technology shows potential to reduce the NFF-rate to 10%. Within E-BREAK failure diagnosis has been validated for the long range turbofan application. The final TRL is 4.
Failure Event
Gas Path Monitoring for Turboshaft Engines
The key objective is to be able to localize and quantify the main deteriorations of a turboshaft in service. This diagnostic process is essential for predictive maintenance.
A gas path monitoring system composed of specific measurements on test bench and machine learning techniques has been developed and validated on operational data.
This technology based on a learning database now requires to be trained on a wide variety of degradation modes to become robust.
The final TRL is 5.
CORROSION
EROSION
Performance Prognosis
Today engine maintenance, repair and overhaul is done on-condition, i.e. as a reaction to observed engine degradation beyond acceptable limits. Engine performance prognosis is the next step in engine maintenance concepts. With prognosis necessary maintenance tasks can be planned in advance. This includes identification of the correct procedures and providing materials and qualified staff to the right location at the right time.
In E-BREAK two performance prognosis algorithms have been developed and validated for turboshaft and long range turbofan engines. This technology provides forecast of future performance margins and remaining useful life.
The final TRL is 4.
Maintenance Concepts
Differentiation of Objectives and Methodologies
Short Term Concept
Long Term Concept
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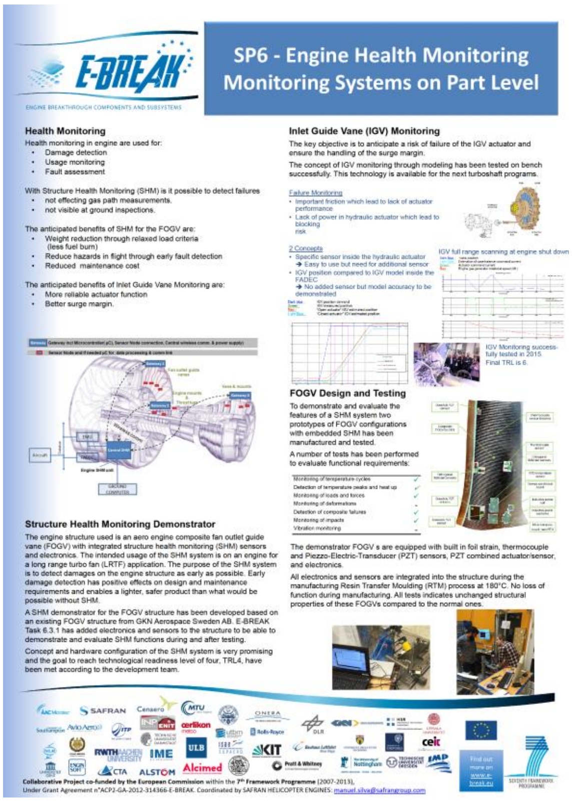
SP6 - Engine Health Monitoring
Monitoring Systems on Part Level
Health Monitoring
Health monitoring in engine are used for:
• Damage detection
• Usage monitoring
• Fault assessment
With Structure Health Monitoring (SHM) is it possible to detect failures
• not effecting gas path measurements.
• not visible at ground inspections.
The anticipated benefits of SHM for the FOGV are:
• Weight reduction through relaxed load criteria (less fuel burn)
• Reduce hazards in flight through early fault detection
• Reduced maintenance cost
The anticipated benefits of Inlet Guide Vane Monitoring are:
• More reliable actuator function
• Better surge margin.
Inlet Guide Vane (IGV) Monitoring
The key objective is to anticipate a risk of failure of the IGV actuator and ensure the handling of the surge margin.
The concept of IGV monitoring through modeling has been tested on bench successfully. This technology is available for the next turboshaft programs.
Failure Monitoring
• Important friction which lead to lack of actuator performance
• Lack of power in hydraulic actuator which lead to blocking risk
2 Concepts
• Specific sensor inside the hydraulic actuator → Easy to use but need for additional sensor
• IGV position compared to IGV model inside the FADEC → No added sensor but model accuracy to be demonstrated
IGV full range scanning at engine shut down
IGV Monitoring successfully tested in 2015. Final TRL is 6.
FOGV Design and Testing
To demonstrate and evaluate the features of a SHM system two prototypes of FOGV configurations with embedded SHM has been manufactured and tested.
A number of tests has been performed to evaluate functional requirements:
Monitoring of temperature cycles
Detection of temperature peaks and heat up
Monitoring of loads and forces
Monitoring of deformations
Detection of composite failures
Monitoring of impacts
Vibration monitoring
Structure Health Monitoring Demonstrator
The engine structure used is an aero engine composite fan outlet guide vane (FOGV) with integrated structure health monitoring (SHM) sensors and electronics. The intended usage of the SHM system is on an engine for a long range turbo fan (LRTF) application. The purpose of the SHM system is to detect damages on the engine structure as early as possible. Early damage detection has positive effects on design and maintenance requirements and enables a lighter, safer product than what would be possible without SHM.
A SHM demonstrator for the FOGV structure has been developed based on an existing FOGV structure from GKN Aerospace Sweden AB. E-BREAK Task 6.3.1 has added electronics and sensors to the structure to be able to demonstrate and evaluate SHM functions during and after testing.
Concept and hardware configuration of the SHM system is very promising and the goal to reach technological readiness level of four, TRL4, have been met according to the development team.
The demonstrator FOGV s are equipped with built in foil strain, thermocouple and Piezzo-Electric-Transducer (PZT) sensors, PZT combined actuator/sensor, and electronics.
All electronics and sensors are integrated into the structure during the manufacturing Resin Transfer Moulding (RTM) process at 180°C. No loss of function during manufacturing. All tests indicates unchanged structural properties of these FOGVs compared to the normal ones.
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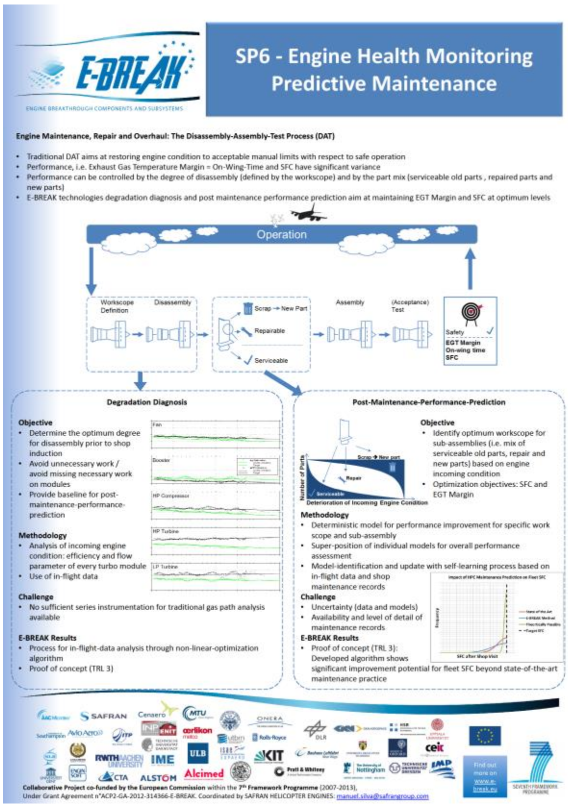
SP6 - Engine Health Monitoring
Predictive Maintenance
Engine Maintenance, Repair and Overhaul: The Disassembly-Assembly-Test Process (DAT)
• Traditional DAT aims at restoring engine condition to acceptable manual limits with respect to safe operation
• Performance, i.e. Exhaust Gas Temperature Margin = On-Wing-Time and SFC have significant variance
• Performance can be controlled by the degree of disassembly (defined by the workscope) and by the part mix (serviceable old parts , repaired parts and new parts)
• E-BREAK technologies degradation diagnosis and post maintenance performance prediction aim at maintaining EGT Margin and SFC at optimum levels
Operation
Workscope Definition
Disassembly
Scrap → New Part
Repairable
Serviceable
Assembly
(Acceptance) Test
Safety
EGT Margin
On-wing time
SFC
Degradation Diagnosis
Objective
• Determine the optimum degree for disassembly prior to shop induction
• Avoid unnecessary work / avoid missing necessary work on modules
• Provide baseline for post-maintenance-performance-prediction
Methodology
• Analysis of incoming engine condition: efficiency and flow parameter of every turbo module
• Use of in-flight data
Challenge
• No sufficient series instrumentation for traditional gas path analysis available
E-BREAK Results
• Process for in-flight-data analysis through non-linear-optimization algorithm
• Proof of concept (TRL 3)
Post-Maintenance-Performance-Prediction
Objective
• Identify optimum workscope for sub-assemblies (i.e. mix of serviceable old parts, repair and new parts) based on engine incoming condition
• Optimization objectives: SFC and EGT Margin
Methodology
• Deterministic model for performance improvement for specific work scope and sub-assembly
• Super-position of individual models for overall performance assessment
• Model-identification and update with self-learning process based on in-flight data and shop maintenance records
Challenge
• Uncertainty (data and models)
• Availability and level of detail of maintenance records
E-BREAK Results
• Proof of concept (TRL 3): Developed algorithm shows significant improvement potential for fleet SFC beyond state-of-the-art maintenance practice
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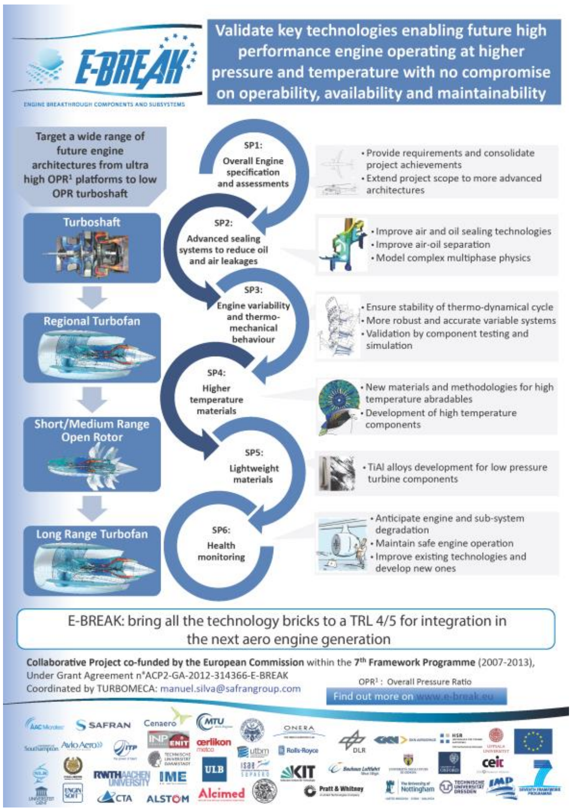
Validate key technologies enabling future high performance engine operating at higher pressure and temperature with no compromise on operability, availability and maintainability
Target a wide range of future engine architectures from ultra high OPR¹ platforms to low OPR turboshaft
Turboshaft
Regional Turbofan
Short/Medium Range Open Rotor
Long Range Turbofan
SP1: Overall Engine specification and assessments
SP2: Advanced sealing systems to reduce oil and air leakages
SP3: Engine variability and thermo-mechanical behaviour
SP4: Higher temperature materials
SP5: Lightweight materials
SP6: Health monitoring
• Provide requirements and consolidate project achievements
• Extend project scope to more advanced architectures
• Improve air and oil sealing technologies
• Improve air-oil separation
• Model complex multiphase physics
• Ensure stability of thermo-dynamical cycle
• More robust and accurate variable systems
• Validation by component testing and simulation
• New materials and methodologies for high temperature abradables
• Development of high temperature components
• TiAl alloys development for low pressure turbine components
• Anticipate engine and sub-system degradation
• Maintain safe engine operation
• Improve existing technologies and develop new ones
E-BREAK: bring all the technology bricks to a TRL 4/5 for integration in the next aero engine generation
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Under Grant Agreement n°ACP2-GA-2012-314366-E-BREAK
Coordinated by TURBOMECA: manuel.silva@safrangroup.com
OPR¹ : Overall Pressure Ratio
Find out more on www.e-break.eu

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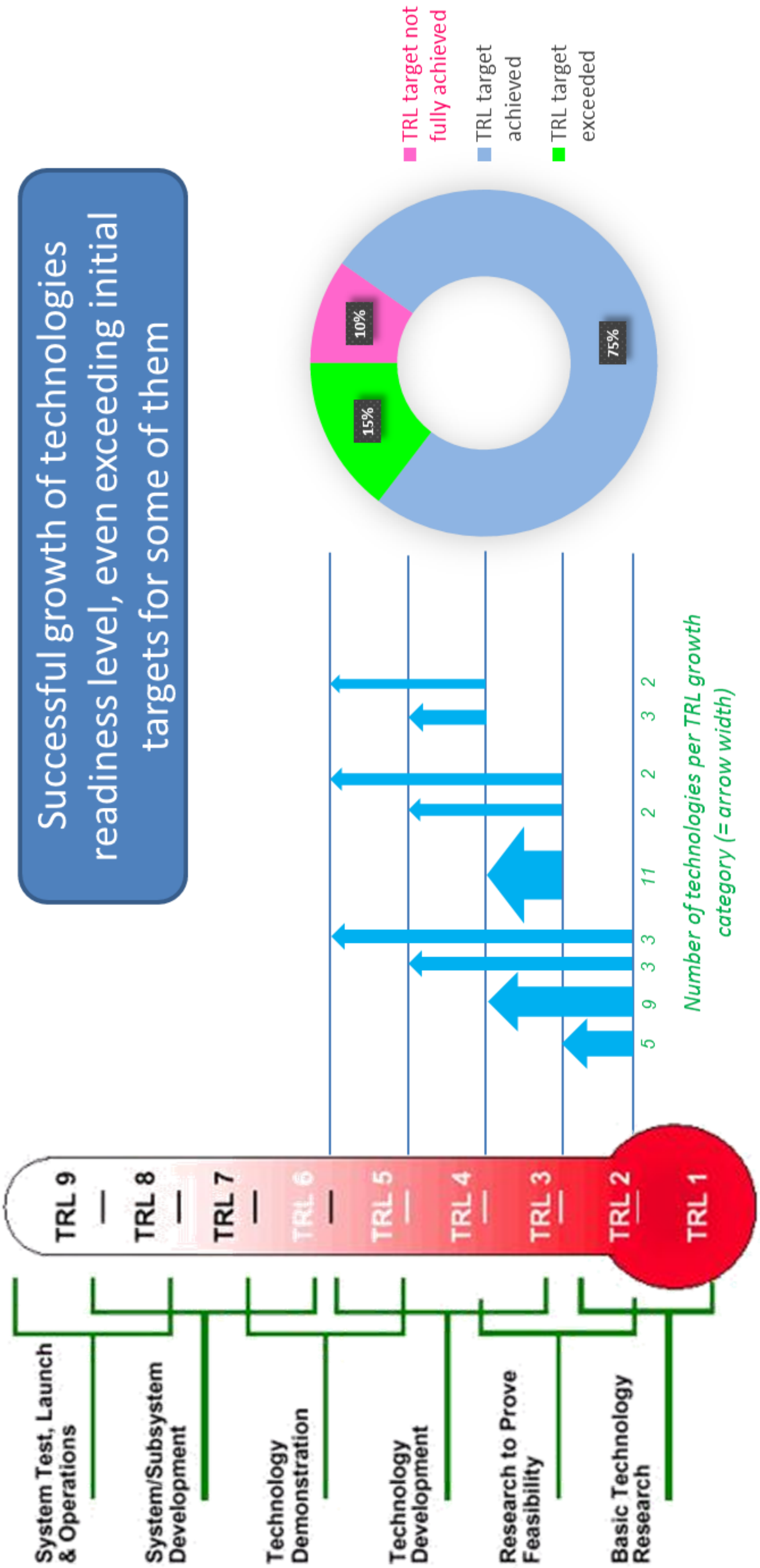
E-BREAK PROJECT CONTRIBUTION TO TRL PROGRESS



PRELIMINARY MARKET OVERVIEW: TECHNOLOGY IMPACTS PER ARCHITECTURE

Technology label	Turboshaft	Regional Turbofan	Short/Medium Range Open Rotor	Long Range Turbofan
Optimisation of stator bypass flow (labyrinth seal geometries) (SP2)	Improved SFC through advanced secondary air system with lower leakages			
Disk heat shields (SP2)	Improved SFC through advanced LPT secondary air system requiring less cooling flows			
Low air consumption seal cavity for turbines (SP2)	Improved SFC through advanced turbines secondary air system			
Chamber seals – Contacting carbon seals (SP2)	Improved SFC through advanced secondary air system		No direct benefit, but enabler to a geared configuration	Improved SFC through advanced secondary air system
Bearing chamber heat transfer and oil film thickness improvement (SP2)	Improved SFC through lower secondary air need			
Low oil consumption breather (SP2)	N/A	Lower weight due to reduced oil need		
Oil system – Improved bearing chamber design (SP2)	N/A	Improved SFC through lower secondary air system need, at the expense of slight weight increase		
Advanced VSV system (SP3)	N/A	Weight reduction on VSV unison ring and bellcrank	N/A	Weight reduction on VSV unison ring and bellcrank
Booster VSV resistant to birdstrike (SP3)	N/A	N/A	Improved robustness enabling to reduce booster surge margin and improve booster efficiency	N/A
Advanced VBV system (SP3)	N/A	Reduced VBV system weight		
Compressor tip clearance control (SP3)	N/A	Improved SFC through better compressor efficiency (reduced tip clearances)		
Turbine blade to blade tip clearance control (SP3)	Improved SFC through better turbine efficiency (reduced tip clearances)			
Ultra high OPR blading (SP3)	N/A	Improved SFC through better compressor efficiency	N/A	Improved SFC through better compressor efficiency
New sealing geometry for turbine abradables (SP4)	N/A	Improved SFC through reduced turbine clearance with abradable	N/A	Improved SFC through reduced turbine clearance with abradable
New LPC abradable (SP4)	N/A	Improved SFC through better booster efficiency, at the expense of slight weight increase		
Sprayed abradables for turbines (SP4)	Improved SFC through reduced turbine clearance with abradable			
Various technologies enabling TiAl LP turbine blades (SP5)	Improved weight through higher material density on LPT module			
Engine performance diagnosis (SP6)	No SFC impact ; improved availability			
Engine performance prognosis (SP6)	No SFC impact ; improved availability			
Post-maintenance performance prediction (SP6)	Improved SFC			
Structures monitoring (SP6)	N/A	Improved weight through fan OGVs mass reduction	N/A	Improved weight through fan OGVs mass reduction

Key :

N/A	Not applicable to this architecture
Black	On target vs initial objectives
Purple	Shortfall vs initial objectives
Green	Initial objectives exceeded

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ABBREVIATIONS USED IN THIS DOCUMENT

ACARE	Advisory Council for Aeronautical Research in Europe
AIDA	Advanced Intermediate Duct Aerodynamics (FP6 project)
ANTLE	Affordable Near Term Low Emissions engine for technology validation (part of the FP5 EEFAE project)
AOG	Aircraft On Ground
ARFS	Air-Riding Flexible Seal
ASD	AeroSpace & Defence Industries Association of Europe
BE	Belgium
BPR	By Path Ratio
CAEP	Committee for Aviation Environment Protection
CDR	Critical Design Review
CFD	Computational Fluid Dynamics
CH	Switzerland
CLEAN SKY	'The Greening of Air Transport' Joint Technology Initiative
CLEEN	Continuous Lower Energy, Emissions and Noise
CO_2	Carbon dioxide
CTA	FUNDACION CENTRO DE TECNOLOGICAS AERONAUTICAS
DE	Deutschland
DLD	Direct Laser Deposition
DMC	Direct Maintenance Cost
DOE	Design Of Experiment
DPM	Discrete Particle Methods
DREAM	validation of Radical Engine Architecture systeMs (FP7)
EBM	Electron Beam Melting
EB-PVD	Electron Beam Physical Vapour Deposition
E-BREAK	Engine BREAKthrough components and subsystems
EC	European Commission
ECM	ElectroChemical Machining
EEFAE	Efficient and Environmentally Friendly Aircraft Engines (FP5 project)
EGT	Exhaust Gas Temperature
EGTM	Exhaust Gas Temperature Margin
EIMG	Engine Industry Management Group (sub-body of the ASD – IMG4)
EIS	Entry Into Service
ELECT-AE	European Low Emissions Combustion Technology in Aero-Engines (FP6)
ENIT	Ecole Nationale d'Ingénieurs de Tarbes
ENOVAL	ENgine mOdule VALidators
ERA	Environmental Responsible Aviation
EREA	Association of European Research Establishments in Aeronautics
ES	Spain
ETTW	European Technological Transfer Workshop
EU	European Union
EMB	Executive Management Board
FAA	Federal Aviation Authority
FEA	Finite Element Analysis
FEM	Finite Element Model
FOD	Foreign Object Damage
FOGV	Fan Outlet Guide Vane

FP	Framework Programme
FR	France
HBR	High Bypass Ratio
HCF	High Cycle Fatigue
HP	High Pressure
HPC	High Pressure Compressor
HPT	High Pressure Turbine
HTC	Heat Transfer Coefficient
ICAO	International Civil Aviation Organisation
IMG4	Industrial Management Group of the industrial aeronautical sectors for airframe, engines, equipment and air traffic management
IPR	Intellectual Property Right
IR	Infra-Red
IT	Italy
ITD	Integrated Technology Demonstrator
ITTM	Interturbine Temperature Margin
JTI	Joint Technology Initiative
KIT	Karlsruhe Institute of Technology
KOM	Kick-Off Meeting
LCF	Low Cycle Fatigue
LEMCOTEC	Low Emissions Core-engine TEChnologies
LP	Low Pressure
LPC	Low Pressure Compressor
LPPS	Low Pressure Plasma Spray
LPT	Low Pressure Turbine
LR	Long Range
MN	Mach Number
MTOW	Maximum Take Off Weight
NDT	Non Destructive Testing
NEWAC	NEW Aero engine Core concepts (FP6 project)
NGV	Nozzle Guide Vane
Ni	Nickel
NL	Netherlands
NM	Nautical Miles
Nm	Newton metre
NO_x	Nitrous Oxide
OGV	Outlet Guide Vane
OPR	Overall Pressure Ratio
PECM	Precision ElectroChemical Machining
PHM	Prognosis Health Monitoring
PL	Poland
PS-PVD	Plasma Spray Physical Vapour Deposition
PWR	PRATT & WHITNEY RZESZÓW
PZT	PieZo-electric Transducer
R&D	Research and Development
R&T	Research and Technology
RRD	Rolls & Royce Deutschland
RRUK	Rolls & Royce plc
RTD	Research and Technological Development

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RTU	Remote Terminal Unit
SAFRAN AB	SAFRAN AERO BOOSTERS
SAFRAB AE	SAFRAN AIRCRAFT ENGINES
SAFRAN HE	SAFRAN HELICOPTER ENGINES
SAGE	Sustainable And Green Engines (Clean Sky technology demonstrator)
SE	Sweden
SFC	Specific Fuel Consumption
SHM	Structure Health Monitoring
SILENCE(R)	Significantly LowEr Community Exposure to aircraft noise (FP5 project)
SM	Surge Margin
SME	Small and Medium Enterprise
SMR	Small and Medium Range
SO_x	Sulphur Oxides
SP	Sub-Project
SPH	Smooth Particle Hydrodynamic
SV	Shop Visit
TA	Techspace Aero => SAFRAN AERO BOOSTERS
TAT	Turn-Around-Time
TBC	Thermal Barrier Coating
TET	Turbine Entry Temperature
TMF	Thermo Mechanical Fatigue
TQM	Torque Margin
TRL	Technology Readiness Level
TRL 1	Basic principles observed and reported
TRL 2	Technology concept or application formulated (report)
TRL 3	Analytical and experimental critical function and/or characteristic proof-of concept
TRL 4	Component and/or breadboard validation in laboratory environment
TRL 5	Component and/or breadboard validation in relevant environment
TRL 6	Subsystem prototype demonstration in relevant environment (i.e. core engine)
TRL 7	System prototype demonstration in “real” environment (i.e. bench engine)
TRL 8	Actual system completed and “flight qualified” through test and demonstration (ground or flight)
TRL 9	Actual system “flight proven” through successful mission operations
UHOPR	Ultra-High Overall Pressure Ratio
UK	United Kingdom
ULB	UNIVERSITE LIBRE DE BRUXELLES
UNott	The University of Nottingham
US	Ultra-Sonic
UTS	Ultimate Tensile Stress
VBS	Variable Bleed System
VBV	Variable Bleed Vane
VITAL	enVIronmenTALly friendly aero engine (FP6 project)
VoF	Volume of Fluid
VSV	Variable Stator Vane
WEM	Whole Engine Model
WP	Work Package
YTS	Yield Tensile Stress

LIST OF THE 41 PARTNER ORGANISATIONS

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GE AVIO	IT	UNIVERSITEIT GENT	BE
INDUSTRIA DE TURBO PROPULSORES	ES	OFFICE NATIONAL D'ETUDES ET DE RECHERCHES AEROSPATIALES	FR
MTU AERO ENGINES	DE	POLITECNICO DI MILANO	IT
ROLLS-ROYCE DEUTSCHLAND	DE	POLITECNICO DI TORINO	IT
ROLLS-ROYCE	UK	OERLIKON METCO	CH
SAFRAN AIRCRAFT ENGINES	FR	UNIVERSITY OF OXFORD	UK
ALCIMED	FR	BAUHAUS LUFTFAHRT	DE
SAFRAN AERO BOOSTERS	BE	UNIVERSITE LIBRE DE BRUXELLES	BE
GKN AEROSPACE ENGINE SYSTEMS SWEDEN	SE	UNIVERSITA DEGLI STUDI DI GENOVA	IT
PRATT & WHITNEY RZESZÓW SPÓŁKA AKCYJNA (PRATT & WHITNEY RZESZÓW S.A.)	PL	TECHNISCHE UNIVERSITAET DARMSTADT (INSTITUTE OF GAS TURBINES AND AEROSPACE PROPULSION)	DE
CENTRE DE RECHERCHE EN AERONAUTIQUE	BE	HOCHSCHULE FÜR TECHNIK RAPPERSWIL (HSR IPEK)	CH
AAC MICROTEC	SE	UPPSALA UNIVERSITET	SE
ALSTOM	UK	UNIVERSITY OF NOTTINGHAM	UK
IME - RHEINISCH-WESTFAELISCHE TECHNISCHE HOCHSCHULE AACHEN, INSTITUT FÜR STRAHLANTRIEBE UND TURBOARBEITSMASCHINEN	DE	TECHNISCHE UNIVERSITÄT DRESDEN, INSTITUT FÜR LEICHTBAU UND KUNSTSTOFFTECHNIK	DE
CENTRO DE ESTUDIOS E INVESTIGACIONES TECNICAS	ES	STICHTING NATIONAAL LUCHT- EN RUIMTEVAARTLABORATORIUM	NL
CHALMERS TEKNISKA HOEGSKOLA	SE	UNIVERSITY OF SOUTHAMPTON UTC	UK
FUNDACION CENTRO DE TECNOLOGICAS AERONAUTICAS	ES	DEUTSCHES ZENTRUM FUER LUFT UND RAUMFAHRT	DE
INSTITUT SUPERIEUR DE L'AERONAUTIQUE ET DE L'ESPACE	FR	ECOLE NATIONALE D'INGENIEURS DE TARBES	FR
KALSRUHER INSTITUT FÜR TECHNOLOGIE	DE	ENGINE SOFT	IT
INSTYTUT MASZYN PRZEPLYWOWYCH - POLSKIEJ AKADEMII NAUK (INSTITUTE OF FLUID-FLOW MACHINERY, POLISH ACADEMY OF SCIENCES)	PL		

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Under Grant Agreement n°ACP2-GA-2012-314366-E-BREAK

E-BREAK CONSORTIUM

Kick Off Meeting 24th of October 2012 in Bordes, France, SAFRAN Helicopter Engines

Final Meeting 21st of March 2017 in Bordes, France, SAFRAN Helicopter Engines

SP LEADERS CORE TEAM

SP1 Leader
Nicolas Tantot
SAFRAN

SP2 Leader
Mike Walsh
Rolls - Royce UK

SP3 Co-Leader
Thomas Klauke
Rolls - Royce D

SP3 Leader
Erik Johann
Rolls - Royce D

SP4 Leader
Serge Selezneff
SAFRAN

SP5 Leader
Michele Coppola
GE AVIO

SP6 Leader
André Kando
MTU

SP7 Co-Leader
Julie Charbonneau
ALCIMED

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Project information

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Total budget:	30 M€
EU Contribution:	18 M€
Duration :	54 months
Starting date:	1st of October 2012
End date:	30th March 2017
Technical domain:	Propulsion
Nationalities:	10 European Union countries
Coordinator:	SAFRAN HELICOPTER ENGINES
EC Officer :	Christiane Bruynooghe

SP7 Leader
Manuel Silva
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Project Coordinator and Chief Engineer

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I would also like to acknowledge the work of all partners, companies, universities, research centres and other contributors participating in the programme.

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Finally I would like to acknowledge the SP leaders for their patience, support and friendship throughout the arduous life of the project. Without their help and contribution, this handbook, and, in fact the overall project would not have been possible. A huge massive THANK YOU to André Kando, Emilie Lhotellier, Erik Johann, Julie Charbonneau, Michele Coppola, Mike Walsh, Nicolas Tantot, Serge Selezneff and Thomas Klauke!

We hope you found useful information and that you enjoyed reading this handbook as much as we enjoyed working together and compiling the information for you.

Manuel Silva,
E-BREAK Coordinator and Chief Engineer, SAFRAN Helicopter Engines

E-BREAK

ENGINE BREAKTHROUGH COMPONENTS AND SUBSYSTEMS

Find out more on **www.e-break.eu**

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SEVENTH FRAMEWORK PROGRAMME