COORDINATION AND SUPPORT ACTION

GRAIN2

GREENER AERONAUTICS INTERNACIONAL NETWORKING 2

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ACRONYMS

ACTRI	Aeronautics Computing Technique Research Institute
AGI (formerly EADS-IW)	Airbus Group Innovations
AIRBORNE	Airborne Technology Center B.V.
ASRI	Aircraft Strength Research Institute
ATM	Air Traffic Management
AVIC	Aviation Industries of China
BIAM	Beijing Institute of Aeronautical Materials
BUAA	Beijing University of Aeronautics and Astronautics
CH	China
CIMNE	International Center for Numerical Methods in Engineering
CNT	Communications Navigation and Surveillance
COMAC	Shanghai Aircraft Design and Research Institute
CQU	Chongqing University
CRANFIELD	Cranfield University
DLR	German Aerospace Center
EU	European Union
GRAIN 2	GReener Aeronautics International Networking-2
HIT	Harbin Institute of Technology
INEGI	Instituto de Engenharia Mecanica e Gestao Industrial
KGT	Key Green Technologies
LEITAT	LEITAT Technological Center
NIMTE	Ningbo Institute of Materials Technology and Engineering
NLR	Stichting Nationaal Lucht- en Ruimtevaartlaboratorium
NUAA	Nanjing University of Aeronautics and Astronautics
RTD	Research, Technology & Development
SHM	Structural Health Monitoring
UNIMAN	University of Manchester
ZJU	Zhejiang University

CONTENT

1. INTRODUCTION

This deliverable is an update of the mid-term report due on M16, after the extension of the project from 24 to 32 month total duration. This update conforms the Final report of the project. The document describes the project and its progress both from the management and technical point of view.

2. PROJECT SUMMARY

2.1 Background

As mentioned in the Executive Summary of the Strategic Research & Innovation Agenda, Aviation has an important role to play in reducing greenhouse gas emissions as well as noise and local air quality issues. The continuous increase of air passenger transport generates an increasing use of hydrocarbon fuel with excessive emission of CO2 and NOX (greenhouse gases, pollutants and noise). It is well known that commercial aircraft operations impact the atmosphere by the emissions of greenhouse gases and greenhouse gas precursors, and also through the formation of contrails and cirrus clouds. In 2011, during the Aerodays in Madrid, the EC launched the future of Aeronautics in the ACARE Flight Path 2050 Vision for the Aircraft report containing the ambitious goals on the environmental impact with 90% reduction in NOx emissions, 75% reduction in CO2 emissions per passenger kilometer, and the reduction of the noise by 65%, all relative to year 2000.

To achieve the ACARE Strategic Research & Innovation Agenda green aeronautics technologies will play a more and more dominant role in mastering the challenge on "Protecting the environment and the energy supply". GRAIN2 Supported Action, based on the same collaborative and win-win spirit introduced in former EU-China GRAIN project, will provide inputs and roadmaps for the development of large scale simulation strategies for greener technologies to meet the above future requirements on emissions, fuel consumption and noise. To reach these targets, green technologies efforts will have to be collected and prospected in three major lines: Air vehicle, Air Transport System and Sustainable Energies. Three folds to be investigated as future greening technologies:

1) **Greening the aircraft and the aero engine:** innovative methods and tools for optimized aircraft and aeroengines using best fuel efficiency, optimized propulsion/airframe system allowing the prediction of effects on exhaust emissions of new engines technologies and fuel, Multidisciplinary/Multiphysics Modeling, Simulation, Optimization and Control, new multifunction materials, including environmentally green materials and smart structures;

2) **Greening the operational environment:** utilization of environmentally friendly chemicals, accurate knowledge of the engine exhaust emissions, in particular applied to low or better free emission taxing, new ATM concepts;

3) **Reducing the carbon foot print of aviation via sustainable alternative fuels:** development of biofuels for greenhouse gas emission reduction; increase the knowledge of acceptance conditions at engine aircraft level, optimization of the aircraft/fuel tandem.

2.2 Objectives

GRAIN2 is an international networking project co-funded by the 7thFramework Program (FP07) and by the China Ministry of Industry and Information Technologies Industry Corporation (MIIT). The main objective of GRAIN2 is to focus its greening activities following the Flight Path 2050 Vision for Aircraft en route to the very ambitious challenge "Protecting the environment and the energy supply" in three major following lines: i) greening the air vehicle, ii) greening the Air transport System and iii) Reducing the carbon foot print of aviation via sustainable alternative fuels.

To achieve carefully these objectives four Key Greener Technologies (KGT) are considered:

- KGT1: Propulsion related green technologies (including NOx and CO2reduction, contrails, mission modeling, alternative fuels, …)
- KGT2: Airframe Flight Physics (including Drag reduction, noise reduction, HPC innovative architecture, numerical simulation, …)
- KGT3: Environmental friendly materials and structures (including Smart structures and materials, bio-sourced materials, composite technologies, metal alloys, surface coatings, structural health monitoring, …)
- KGT4: CNS (Communications Navigation and Surveillance)/ATM for greener air transport

A dissemination and communication platform for Collecting and Prospecting Green Applications has also been developed in order to give traversal support to all KGTs.

GRAIN2 will identify innovative R&D methods, tools and HPC environments (supercomputers and GPGPUs) in the different KGTs according to the needs of major aeronautical industries to deeper understand the mechanism of engine exhaust emissions, to improve fuel efficiency and environmental performance, to lower noise for landing gear and high lift surfaces, to introduce new materials with multiple functions, to help significantly the development of biofuels for greenhouse gas emission reduction, etc.

These objectives will be met by the GRAIN2 supporting joint Europe-China networking actions by a series of open dissemination events including single or multi KGT groups, R&D prospecting activities like Open Forums, Workshop, Short Course involving physical modeling, simulation, optimization and control experts from Europe and China in the different KGT areas.

The targeted International Greener Networking critical outcome of GRAIN2 is a green leverage according to the Flight Path 2050 Vision for Aircraft preparing towards future HORIZON 2020 EU-China Coordinated Calls.

3. PROJECT OBJECTIVES FOR WHOLE PROJECT

The objectives of the project, as described in the previous section, are global along the project. The consortium is devoting all the effort to deepen on the mutual collaboration though the technical discussions. These technical discussions are feeding the organized events and meetings. It means, that in addition to the global objectives of the project, which are also objectives for the present period, some more specific objectives can be listed:

- Organization of the Kick-Off meeting, the short course and M16 workshop to launch the technical discussions and establish a path for the technical share among partners. And finally, the organization of the Open Forum and final meeting of the project, where the conclusions have been wrapped up.
- Invite external stakeholders and experts to participate and contribute to the definition of the best topics to collaborate and define research priorities.
- Establish a first analysis of the situation of the selected topics, analysing the state of the art but also looking for an agreement about which topics are more suitable to be developed and which capabilities can contribute Europe and China with.

3.1 KGTs Objectives and overview

The GRAIN 2 project structure features four key technology streams (Key Green Technologies, KGT) that were identified as the most promising ones for making aviation more environmentally friendly. These technologies are:

- **KGT1 - Propulsion related technologies** (including NOx and CO2 reduction, contrails, mission modeling, alternative fuels, …)
- **KGT2 - Airframe Flight Physics** (including Drag reduction, noise reduction, HPC innovative architecture, numerical simulation, …)
- **KGT3 - Environmental friendly materials and structures** (including Smart structures and materials, bio-sourced materials, composite technologies, metal alloys, surface coatings, structural health monitoring (SHM), …)
- **KGT4 - CNS** (Communications Navigation and Surveillance)/ATM for greener air transport

The particular objectives and overview of the different KGTs are described below:

3.1.1 KGT1

KGT1 focusses on the identification of new emerging RTD areas of mutual interest on the different green aspects of propulsion technologies (KGT1) including NOx and CO2 reduction, contrail, emission modeling, alternative energies, etc.

This work package will be decomposed in two parts:

1. The first one, propulsion related green technologies, will be basically oriented to different aspects of traditional engine technologies like noise, fuel consumption, etc.
2. The second one, new energies for aviation, will be oriented to different aspects of sustainable innovative energies for aviation application.

KGT1-2 has been set-up in the frame of the Europe and international engagement in term of emission and reduction. Within Europe, dependence on crude oil is reduced by drop-in liquid fuels from other sources at a competitive cost. This has been facilitated by a coherent research strategy, regulatory enablers and streamlined certification and approval processes and the establishment of sustainable supply chains.

The progressive introduction of fuel cells and battery powered vehicles for ground operations at airports has made an important contribution to reducing the carbon footprint of the aviation sector. Electrical and hybrid-electrical engines have entered the aviation market.

The whole life cycle impact of vehicles, equipment and systems has also been addressed.

The availability of alternative aviation fuel not only has a huge environmental impact but it is vital that manufacturers both in Europe and China try to maintain a position within world competition for the sustainable growth of aviation transport for improving energy independence, lessening global-warming effects, and mitigating the economic uncertainty of crude oil prices. Within Europe, dependence on crude oil is reduced by drop-in liquid fuels from other sources at a competitive cost. This has been facilitated by a coherent research strategy, regulatory enablers and streamlined certification and approval processes and the establishment of sustainable supply chains.

In order to implement and develop this existing approach, the KGT1-2 New energy for aviation proposes to address, in the frame of EU-China cooperation different aspects of sustainable innovative energies for aviation application:

1. Innovative fuels for aeronautics

- Drop-in (sustainable feedstock) and new pathways (Methane, Sugar to Alcohol, etc.)

The aim is to bridge the gap between R&D and industry on innovative fuels for aeronautics; to identify and evaluate possible alternative fuels in compliance with sustainable feedstock; modeling of alternative fuel system design on the characteristics and properties of alternative fuels; to identify and access new pathways for alternative fuels at competitive cost;

2. Electric energy

- Energy storage, fuel cells

3. Engine performance

- Modelling

The aim is to investigate alternative fuel performance in compliance with keeping the same safety level as kerosene in the whole aero-engine system and considering the environmental and economic performance of selected alternative fuels based on the aircraft safety. To analysis alternative fuel combustion performance in a highly coupled integrated engine modeling of alternative fuel safety margin using SoS (System of Systems) in compliance with keeping the same safety level as kerosene in the whole aero-engine system; to assess the emission characteristics of alternative fuels. All these technologies have to be assessed in order to validate their sustainability in terms of environmental, economic and societal impact. This approach has to be closely linked to the transversal KGT5 and rely on the developed tools to achieve this validation (Life Cycle Analysis).

Partners contributions:

- EADS-IW will chair Task 1.2 and will provide the industrial point of view by assessing about the different identified RTD topics in the context of new energies for aviation.

- NUMECA will contribute to Task 1.2 by providing information on current and emerging trends in multiphysics simulation and optimization in aeronautics, from the point of view of software development and user expectations. Particular focus will be put on the future needs on modelling strategies towards high-fidelity simulations necessary for noise and emission reductions.

- LEITAT will contribute by providing information on current and emerging trends in the following topics:
  - Harvesters devices (PV, Thermoelectric, motion…) and power management systems.
  - Modeling and Maximum Power Point Tracking algorithms;
  - Energy storage devices (supercapacitors, lithium-ion, lithium-air batteries) and battery management systems;
  - Power management systems for fuel cells;
  - Ionic Liquids technologies for supporting biomass-to-fuel conversion;
  - Thin film devices for energy generation and storage manufactured by printing processes (screen printing, inkjet).

- BUAA work is aimed to provide reliable methodologies to predict the aero-engine safety implications of alternative aviation fuels and its emission model of possible alternative aviation fuel. The methodologies and tools developed are expected to result in the production of renewable energy by a sustainable way and in compliance with airworthiness. The detailed understanding of the differences and similarities expect to be gained between possible aviation fuel and the conventional aviation fuel regarding chemical components, physical properties, and combustion performance.

- GTE is one of leading research institutes engaged in low emission combustion research in China. GTE focus on lean premixed pre-evaporation (LPP) which includes building up combustion, combustor cooling, fuel jet and atomization etc. In GRAIN KGT1, GTE work is aimed to build prediction emission model of alternative fuel combustion based using CRN. Based on simplified CFD analysis, the present work is aimed at evaluating the potentiality of using a low computational effort modelling approach, to quickly assess emissions. Combined CFD and CRN are used to predict NOx and CO emissions on alternative fuel combustor, making the most of both CFD tools, providing basic fluid dynamics information, and a CRN tool to provide reaction and pollutants information.

- ZJU will provide the information how to prepare the aviation bio-fuels from biomass feedstock including:
  – Bio-fuels from the lignocellulose biomass;
  – Bio-fuels from the microalgae; and Life-cycle assessment of preparation of the aviation bio-fuels.

3.1.2 KGT2

KGT2 focus on the identification of new emerging RTD areas of mutual interest on the different green technologies of Airframe Flight Physics including drag reduction, noise reduction, HPC innovative architecture, numerical simulation, etc.

This workpackage is decomposed in two parts:
1. Drag and CO2 reduction
2. Noise reduction

In line with the overall objectives of GRAIN2 and on the basis of the achievements made in the previous GRAIN project, one of the main objectives in KGT2 is to make one step forward in the exploration of emerging greener technologies of future aircraft, as well as of the tools and methodologies invoked to realize and implement the identified technologies for improved airframe designs. In close interaction with other KGTs, another main purpose is to establish a collaborative platform and network including competent partners and, further to identify and select state-of-the-art technologies, tools and methods of mutual interest in Europe and in China for future collaboration of in-depth technical investigation.

The following project partners are involved in KGT3-1 for Drag and CO2 reduction:

EU Partners	
UPM	EU KGT2-1 chair, available and future IT technologies
CIMNE	Sub-grid scale method for drag reduction numerical analysis
AIRBUS	Industrial point of view

INRIA	HPC
FOI	Reliable numerical modelling and simulations
CIRA	Laminar flow technologies
VKI	Goal oriented error estimation and adaptive higher order discretization methods
SHEFFIELD	Skin friction drag and pressure drag
UNIMAN	Flow control actuators,
RWTH	Adjoint methods for optimization

CH Partners

NUAA	Chinese KGT2-1 chair, RANS and LES methods
FAI	Research on different configurations
ACTRI	Advanced CFD parallel simulation tools
ARI	Analysis and design
NPU	RANS and LES methods
ZJU	HPC
IACAS	Mathematical models and experimental validation of fluid-structure interactions

The following project partners are involved in KGT3-2 for Noise reduction:

EU Partners

FOI	EU KGT2-2 chair, robust CFD and CAA analysis tools
CIMNE	Sub-grid scale method for flow numerical analysis
NUMECA	Advanced noise simulation and predicting tools
INRIA	HPC
VKI	Broadband noise modelling using LES and LEE
RWTH	Adjoint methods for optimization

CH Partners

IACAS	Chinese KGT2-2 chair,
FAI	Research on different configurations
ASRI	New developments of experimentation and optimization
NUAA	RANS and LES methods
NPU	RANS and LES methods

3.1.3 KGT3

KGT3 focusses on the environmental friendly materials and structures, including smart structures and materials, bio-sourced materials, composite technologies, metal alloys, surface coatings, structural health monitoring, and intelligent health management, et.. The main focus is on light-weight materials and recyclable materials but also all those technologies which help to reduce the total weight of an aircraft and technologies which enable the reduction of the usage and maintenance cost (both of time and resources). The overall goal is to reduce the future footprint of aircraft after their lifespan. Within the work package material technologies like composite materials developments and applications, new manufacturing processes, and designs that help to reduce the pollution produced by the involved processes and technologies to enable the recyclability of components are analyzed.

The following project partners are involved in KGT3:

EU Partners	
DLR	EU KGT3 chair, SHM, bio-sourced materials
AGI	analysis and design of composite materials, focused on vegetal fibers
AIRBORNE	state-of-the-art composite manufacturing of primary aircraft structures, novel production methods, automated placement of fiber optic sensors
LEITAT	Surface treatment of fibers, life cycle assessment, bio-sourced resins and fibers, design/simulation
CRANFIELD	bio-sourced and thermoplastic composites, integral metallic structures, hybrid material structures
UNIMAN	surface coating for gas turbines
NLR	SHM, data processing and management, assessment of loads, usage and resulting damage/deterioration

CH Partners	
ASRI	CH KGT3 co-chair, SHM, ground platform for database and processing of on-line SHM data
ACTRI	CH KGT3 co-chair, aircraft condition monitoring and on-board fault diagnosis
BIAM	CH KGT3 co-chair, natural fiber reinforced composites, environmentally friendly manufacturing
COMAC	composite technology, manufacturing, simulation, vegetal fibers, recycling
NUAA	new sensing technology for smart structures, on-line monitoring, aircraft structural life prediction
CQU	relationship of microstructure and mechanical/performance properties of high strength light metal alloys
NIMTE	bio-based polymeric materials, thermosetting resins

3.1.4 KGT4

The high number of new greenfield airports in China that are expected to become operational within the span of this decade bring a fast changing and growing air transport network in China. In addition to that there are the new regulations in China around available airspace for business and general aviation. This creates a vast set of opportunities and challenges for the environmental footprint of the global air traffic system.

Europe has, in the last few decades, gathered a lot of experience around the concepts of Flexible Use of Airspace, Network Management, and greener CNS/ATM systems. Expectations are thus high that significant benefits can be derived from joint R&D in CNS/ATM solutions. WP4 will derive a list of those common R&D interests in CNS/ATM solutions.

A more specific objective is to improve the knowledge and capability of how CNS/ATM systems and technology can be used to reduce environmental footprint. WP4 will mainly focus in new ATM concepts and operational paradigms, along with the associated innovation in CNS systems, procedures and infrastructure. In this context, this workpackage will deal with 4D trajectory management and its role to move in the future an airspace centric ATM to a trajectory centric ATM. Thus, environmentally optimised aircraft procedures will be tackled along with systems, concepts and technologies aiming at increasing the automation levels in ATM.

This KGT4 is closely coordinate with Eurocontrol, SESAR and CleanSky frameworks.

The following project partners are involved in KGT4:

EU Partners	
NLR	EU KGT4 chair, safety, human performance, training, environment, ATM systems, procedures and operations, aircraft operations and systems and research methodologies
HONEYWELL	Industrial point of view and assessing in all CNS/ATM activities
FOI	Robust navigation for improved air traffic management
UPC	4D trajectory management concepts and technologies
EUROCONTROL	Air Traffic Management

CH Partners	
HUST	Chinese KGT4 chair,
ACTRI	generic model-based arithmetic and diagnosis/prognostics model development
BUAA	Electronic Flight Bag (EFB) system

4. PROGRESS OF THE WORK

Accordingly with the global and period objectives the project is progressing as scheduled. The two first events have been organized and the conclusions are in agreement with the expectations. The third event is going to be organized in China at M16. The reports about the State of the art and emerging technologies are finished or almost ready, and extensive technical discussions have been held in the different meetings.

4.1 Kick-Off Meeting and 1st Workshop

The first event has been organized following a workshop structure. Invited speakers both internal and external of the consortium have contributed. The agenda is available on the project website, but a list of contributors is:

- LI Benjian, Deputy Director General, Equipment Manufacturing Industrial Dept. MIIT
"Promoting the China-EU Cooperation in Aeronautics and Innovating Green Aerospace Together"
- Dietrich,Knoerzer, DG RTD – Aeronautics, European Commission
"Europe's Contribution to the Challenges for Sustainable Aviation"
- HUA Jun, Vice-President, CAE
"Sustainable Mobility—Challenges When a Billion Are Ready on Board"
- Pedro Fernández-Rodríguez, General Manager of Airbus Beijing Engineering Centre
"AIRBUS Industrial Strategy in China"
- CHEN Shiyi, Vice-President, PKU
"Accurate Turbulent Model in Computational Aerodynamics"
-Marja Eijkman, Vice President NLR, Director AT-One
"The Role of Europe's Research Establishments in Research and Innovation of Aviation"
- HUANG Jici, Adviser, COMAC
"C919 Aircraft Configuration Baseline Divide and Management"
- Charles Hirsch, President, NUMECA International
"Role and Challenges of Virtual Prototyping in the Aircraft Industry"
-ZHAO Bo, President, ARI/AVIC
"Aerodynamic Development of Civil Aircraft and Ideas on the Future Trend"
- Georg Eitelberg, Director, German Dutch Windtunnel DNW
"A Sustainable Aircraft for the Asian Market: the Jumbo City Flyer"
- YANG Rui, President, IMR
"Titanium Materials and Processes for Greener Aviation"
- Gabriel Bugeda, Jacques Periaux, Co-coordinators GRAIN2, CIMNE/UPC (Spain)
"AeroChina and GRAIN – the experiences with the EU-China RTD networks"
- ZHANG Guoqing, Co-coordinator COLTS, Deputy Chief Engineer, BIAM (China)
"Ti-casting of large structures – the achievements of the COLTS project"
- Ning Qin, Scientific Co-ordinator MARS, Univ. Sheffield (UK)
"The MARS Project – Flow Control inExperiments and Numerics"
- Joeri de Ruytter, Honeywell
"Providing Solutions for Global Challenges is an Art"
- WANG Guoqing, CARERI, China
"BD2-Based PBN Application and Research on GBAS Approach Technology"
- Dave Young, EUROCONTROL
"After SESAR, back to the future"
- ZHAO Yifei, CAUC, China
"Analysis and Optimization of Air Traffic Operation Management under the Context of High Traffic Growth Rate and Large Flows"
- LIU Sheng, HUST, China
"Development of Multi-sensor Packaging for Avionics and Its Reliability Design and Test"

- ZENG Xiaoping,CQU, China
"Situations and Developments for Civil Aviation Mobile Communication"
- Pierre Vialettes, EADS-IW
"New technologies for energy saving and emission reduction in aviation"
- LI Jibao, ACAE, China
"Development and Application of Metallic Foam for Low-emission Combustor Liners"
- Herman Deconinck & Tony Arts, VKI
"Trends in aero-thermodynamics of aeroengines"
- DING Shuiting, BUAA, China
"Engine Safety Evaluation and Airworthiness Technology for Alternative Aviation Fuel"
- ZHOU Chao, PKU, China
"Aerothermal Performance of Different Tip Geometries in High Pressure Turbines"
- ZHOU Jinsong, ZJU, China
"The Research on Biomass Jet Fuel Preparation Techniques"
- ZHANG Jun, BUAA, China
"State-of-the-art CNS/ATM Technologies for Civil Aviation in China"
- Charles Mockett, CFD Software GmbH
"Advanced Hybrid RANS-LES Strategies for Drag Prediction of Complex, Separated Flows"
- ZHENG Yao, ZJU, China
"Selected Topics on Low-Emission Gas Turbine Combustors"
-NicoGauger, Aachen University
"Efficient Optimization and Control in Aerodynamics"
- ZHAO Ning, NUAA, China
"Drag Reduction and Noise Control Based on Flow Control Techniques and Optimal Design"
-ArgirisKamoulakos, Scientific Director, ESI
"Virtual Prototyping for Key Green Technologies in Aviation: Some Key Simulation Challenges"
- Pedro Díez, UPC Barcelona
"The role of scientific and technological societies in the dissemination of the aerospace research and innovation: the E-CAero experience to shape the European landscape"
- YI Xiaosu, BIAM, China
"Research and Development of Multifunctional and Bio-sourced Aeronautical Composites"
- Adel Abbas, Univ. Politecnico Madrid UPM
"Optimisation System for Aircraft Design"
- SUN Xiaofeng, BUAA, China
"Some Innovative Concepts and Methods in the Study of Aircraft Noise"
-Toan Nguyen, INRIA
"High-Performance Computing for Greener Aeronautics"
-ZHENG Yao, ZJU
"Gas Turbine Engines with Ultra Low Emission"
SUN Xiaofeng(BUAA)and Shia-HuiPeng(KTH)
- KGT2 Overview by Co-Chairmen
Working Title: The potential of noise reduction technologies
- Charles Mockett, CFD Software GmbH
"High-fidelity prediction of broadband noise and perspectives for industrialization"
- YAN Qun, ASRI, China

“Development of Acoustics Liner for Turbofan Inlet”
- Herman Deconinck, VKI
“Aerodynamic and Aero-acoustic Optimization of Contra-rotating Rotors”
- LIU Bilong, IACAS, China
“Research Progress on Noise Transmission through Aircraft Panels”
- Ahmad Bilal, LEITAT
“Summary and results of GRAIN 1”
- ZHU Jin, NIMTE, China
“Research Progress for Bio-based Polymer Resin Material”
- Gabriel Bugeda, CIMNE
“Multi-Objective green design optimization of carbon nanotube composite structures”
- LIU Qing, CQU, China
“Fundamental Research and Application Progress of Aviation Aluminum Alloy Materials”
- Marcelo Muller, NLR
“Experience on Aircraft Structural Health Monitoring : from Concept towards Application”
- QIU Jinhao, NUAA, China
“Smart Structure and Key Technologies of SHM”
- Robert Bakker, AIRBORNE
“SHM Development and Applications at Airborne”
- XIAO Yingchun, ASRI, China
“Opportunities and Challenges of Aircraft SHM”
- Nicolas R. Gauger, RWTH Aachen Univ.
“Efficient Optimization and Control in Aerodynamics”
- FU Song, THU, China
“Drag Reduction for the Flow around an Airfoil through Active Flow Control”
- Dr. HosseinZare-Behtash, University of Glasgow
“Driving Forward Aerospace at the University of Glasgow”
- CHEN Yingchun, COMAC, China
“ Greener’ Aerodynamic Design of C919”

The KGT leaders of GRAIN project presented the conclusions from the former project, which has been agreed to be the best starting point of the GRAIN2 project.

4.1.1 KGT1 Aeroengines and propulsion

As described in the presentation below, the KGT1 group identified 5 main topics to be investigated. These are:

- New design concepts of aeroengines; which includes high pressure turbines, low pressure turbines with one single stage, reduction on the number of fan blades, geared fans, higher bypass ratios, reduction of compressor stages among others. All them are mainly aimed to improve the engine efficiency.
- New materials: use of new materials, like composites to reduce the engine weight and components durability (through new metallic coatings).
- Emission reduction; use of metallic foams, new injectors, and new combustor design to decrease the emissions.

- New measurement techniques to be installed inside the engine to monitor how it is working.
- New energy sources like electrical power, biofuels, hydrogen.

In all the topics the need for a better knowledge means to improve the simulation capabilities and the design methodologies, like CFD or optimization.

4.1.2 KGT2 Flight physics and Noise

The KGT2 group has identified the following prospecting topics aiming to a noise reduction;
- a clear identification of noise source, but also new low-noise configurations,
- propagation analysis,
- flow control techniques

again the simulation capabilities and the experimental techniques are key to enable a real progress.

4.1.3 KGT3 Materials

KGT3 group is aiming to the development and application of new materials for aviation. The topics that have been presented as of interest to be assessed during the GRAIN2 project are:
- Lightweight materials
- Recyclable materials

Focusing on these two main topics they are proposing to investigate on:
- Bio-source materials
- Materials for interiors
- Structural materials
- Hybrid materials with dual functionality (embedded electronics, lightning, …

4.1.4 KGT4 ATM/CNS

KGT4 about ATM and CNS topics had no experience in EU-China collaboration, but as an international issue, the traffic control and ATM problems are common they proposed the main lines to investigate:
- ATM concepts and traffic control paradigms; common rules, smooth integration from one region to another, etc…
- Innovation on Communication systems, infrastructures and operational procedures.
- Reduction of the footprint through optimized traffic strategies

4.2 Short Course

During the Short Course the KGT groups had the opportunity to meet and extend the discussion initiated in China during the first workshop and kick-off meeting. The conclusions obtained were presented by each KGT leader at the end of the short course.

4.2.1 KGT1 Aeroengines and propulsion

Following the initial statements during the kick-off meeting, KGT1 group defined a clear set of topics to investigate on:
- Low-emission combustors and combustion
- Internal flow, aero-thermal aspects and design optimization
- Alternative fuels

In these three topics the consortium has identified both a common interest among Chinese and European communities and a set of common capabilities to face the challenge they represent.
In both sides of the GRAIN2 consortium, but not only within the project partners, there is a huge interest on the development and use of alternative fuels, for example. They know about the need to improve the design of the combustors, and adapt the combustor chambers to new fuels while keeping the same or better engine performance. Industrial partners both in China and Europe are already working on these topics.

4.2.2 KGT2 flight physics and noise

Two main objective for the KGT2; flight physics and noise reduction. Similar techniques are requirements can be obtained from both of them, but slight different perspective is defined.

The KGT2 group focused on flight physics is proposing the following:
- Natural laminar flow control
- Hybrid laminar flow control
- Turbulent boundary layer drag reduction

All three are looking the development of the required technology to implement improvements on viscous drag reduction, mainly skin friction, but also on vortex or induced drag.

The KGT2 group focused on noise has identified the following prospecting;
- a clear identification of noise source, but also new low-noise configurations,
- propagation analysis,
- flow control techniques
- improvement of simulation capabilities and high-performance computing associated to the simulation techniques.

Again the simulation capabilities and the experimental techniques are key to enable a real progress.

4.2.3 KGT3 Materials

KGT3 group is targeting to the development of bio-source materials which fulfil the light-weight and recyclability requirements identified during the kick-off.
The main proposals are focused on the analysis of multi-functional bio-sourced materials aiming specific applications.
- Competitive bio-sourced materials
- Manufacturing process for bio-sourced materials
- Applicability and applications for bio-sourced materials
- Application on the interiors design

- Application on structural components

4.2.4 KGT4 ATM/CNS

The targets of KGT4 are the following:

- Research on network management
- Research on Air traffic control
- Research on airport terminal area control
- 4D trajectories
- Technical enablers
- Environmental impact

4.3 2nd Workshop

The third event, which initially was defined as an asynchronous set of meetings, has been replaced by an Open Workshop. The objectives of the event are still to share and discuss technical aspects and progress on the definition of the research topic where to collaborate. This event is going to take place in Xi`an 5-8 May.

4.1 Final meeting and Open Forum

The final meeting and Open Forum has been organized on the occasion of the Kick-off meetings of the new research project EU-China. 4 projects started on May 2016; namely DRAGY, IMAGE, ECO-COMPASS and EMUSIC, about flow control, aeroacoustics, bio-sourced materials and additive manufacturing. The event, taking the whole week, was divided into two parts was a well-attended and successful meeting which brought the opportunity to deepen in the technical discussion with the contribution of new partners from the 4 projects.

4.2 KGT1 Work progress and achievements

The following section describes the achievements and actions during the reporting period in chronological order.

Kick-off in Hangzhou, CN

The GRAIN 2 project kick-off meeting was held in Hangzhou, China from October 28th – October 30th
2013. During this meeting two parallel and one plenary sessions related to KGT1 was organized. The following presentations were given during these sessions:

4.2.1 Plenary session 3

Plenary Session 3: *Numerical Methods and Flow Control*

Chairpersons: FU Song, THU, Herman Deconinck, VKI

-NicoGauger, Aachen University
"Efficient Optimization and Control in Aerodynamics"

- ZHAO Ning, NUAA, China
"Drag Reduction and Noise Control Based on Flow Control Techniques and Optimal Design"

-ArgirisKamoulakos, Scientific Director, ESI
"Virtual Prototyping for Key Green Technologies in Aviation: Some Key Simulation Challenges"

4.2.2 Parallel Session1B

Parallel Session1B

Propulsion Related Green Technologies

Chairpersons: KGT1 Co-chairmen
ZHENG Yao (ZJU) and Herman Deconinck(VKI)
- KGT1 Overview by Co-Chairmen

Working Title: Technology Trends towards the Greening of Propulsion Systems

- Pierre Vialettes, EADS-IW

"New technologies for energy saving and emission reduction in aviation"

- LI Jibao, ACAE, China

"Development and Application of Metallic Foam for Low-emission Combustor Liners"

- Herman Deconinck & Tony Arts, VKI

"Trends in aero-thermodynamics of aeroengines"

- DING Shuiting, BUAA, China

"Engine Safety Evaluation and Airworthiness Technology for Alternative Aviation Fuel"

- ZHOU Chao, PKU, China

"Aerothermal Performance of Different Tip Geometries in High Pressure Turbines"

- ZHOU Jinsong, ZJU, China

"The Research on Biomass Jet Fuel Preparation Techniques"

- Discussion

In addition to the parallel sessions a poster session has been held in order to introduce EU and CH partners.

4.2.3 Internal KGT meetings

Internal KGT1 sessions were held during the kick-off meeting in order to identify the first steps to be taken during the project. During these meetings the KGT1 partners made an assessment and a summary of their wishes in term of contribution for the development of future technologies for energy for aviation. We have drafted a table of contribution on the KGT1-2 subtopics as showed below:

GRAIN2 Kick-off Meeting Hangzhou October 2013 — EADS INNOVATION WORKS

Summary of Parallel Session

Partner's contribution

Activity	Topic	EADS	LEITAT Technological Center		
Energy Management	• Smart Grid expertise applied to aircraft	X		X	
	• Energy Recovery	X	X	X	
	• Batteries Li-Ion, Li-air	X	X		
	• Photovoltaic • Fuel Cells • Super Capacitators	X	X		
Biofuels	• Sust. Feedstocks	X		X	X
	• Novel pathway to biofuel (Refinery, Novel Catalysts, fuel design)	X	X	X	X
	• Engine Safety & performance			X	

LCA

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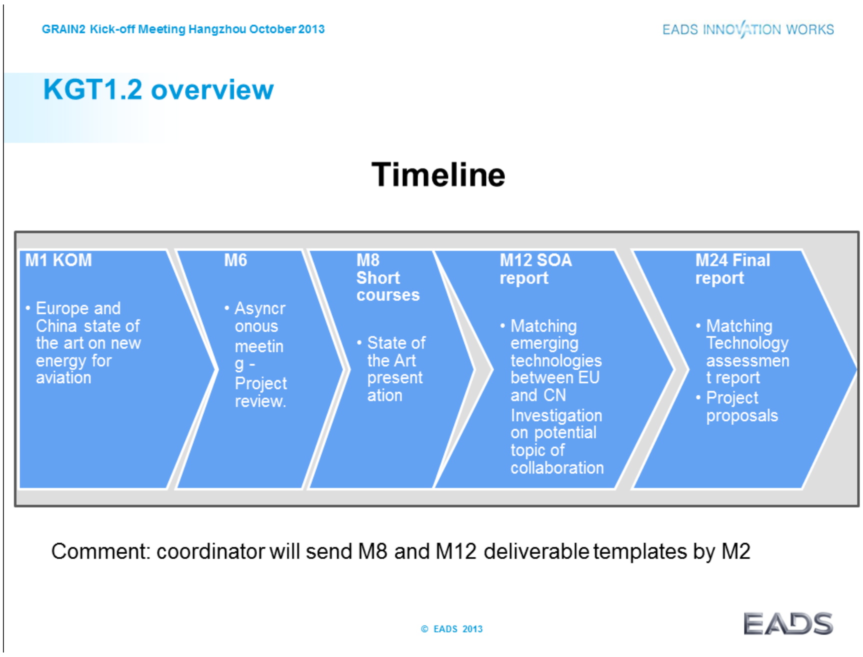
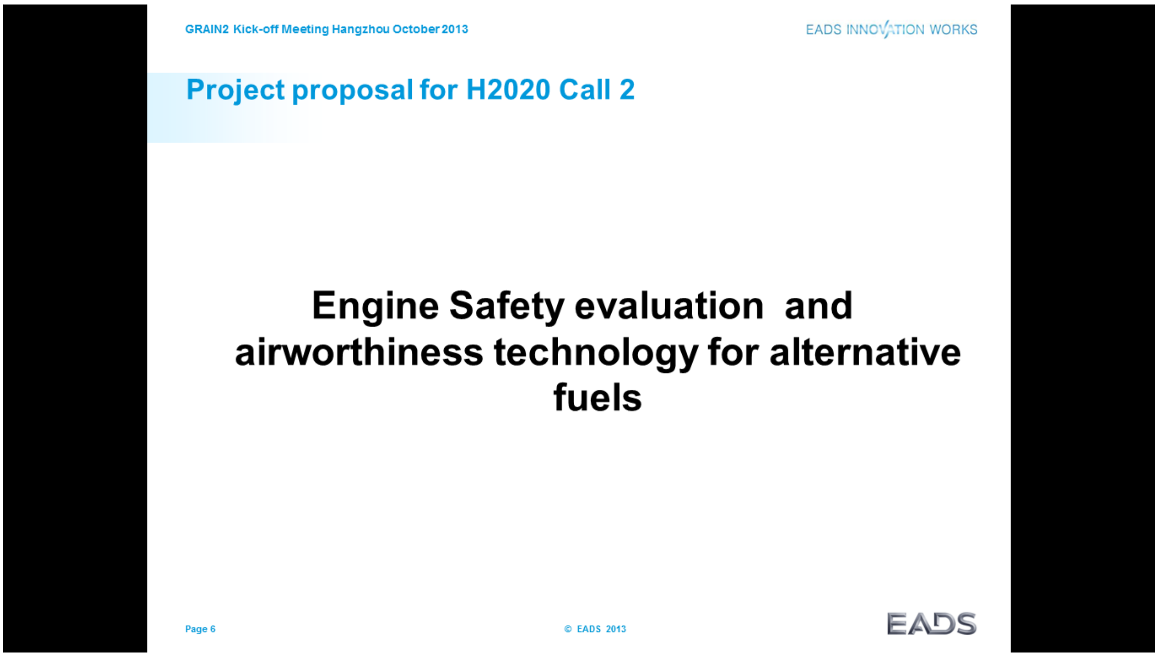
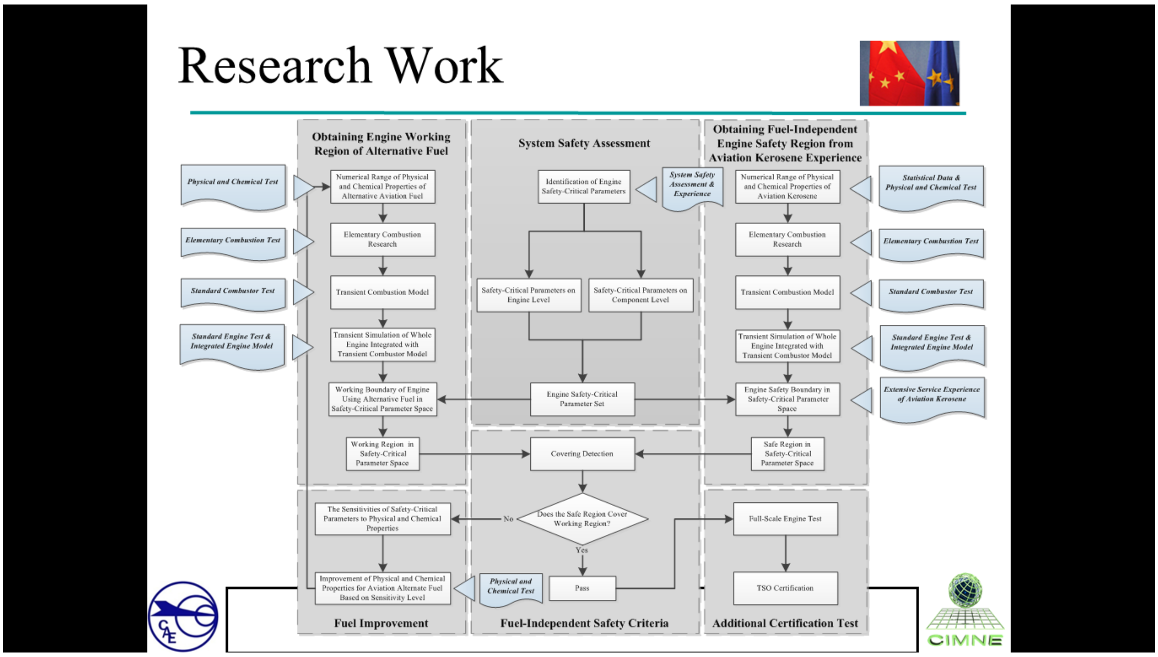
In addition to this table, the partners have agreed on a roadmap for the project:



Eventually, we have been discussing about a potential project we could propose to the European Commission and the METI for a future joint research program:





Research Work Package

	Sub-projects
1	**Safety-Critical Parameters Identification Based on Engine System Safety Assessment**
2	Kerosene Service Data Analysis
3	**Fuel Physical & Chemical Research**
4	Elementary Combustion Test & Model
5	**Transient Standard Combustor Test & Model**
6	**Transient Standard Engine Test & Transient Whole Engine Modeling**
7	Obtaining Safety/Working Region in Safety-Critical Parameter Space
8	**Global Sensitivity Analysis**
9	**Fuel Refinement & Fuel System Design**
10	Rule Making

No feedbacks from MIIT and the European Commission have been given so far.

Consortium meetings

The outcome of the collection of research topics and tools has been discussed among the consortium during face to face meetings in China, in parallel with international conferences held in China on October 2014.

Besides these face to face meetings, several phone conference and email exchanges have led to the set-up of intermediary reports.

Open Workshop, IT

The short course of the GRAIN 2 project was held at CIRA in Capua, Italy from July 1st – July 4th 2014. During this workshop two sessions related to KGT3 were held. The following presentations were given during these sessions:

Parallel Session5A ***Propulsion related green technologies*** **Chairpersons: Herman Deconinck, VKI& DING Shuiting, BUAA** – Frédéric Eychenne, Airbus *"Sustainable Aviation: The Airbus Approach"* – ZHENG Yao, ZJU *"Topics on Low Emission Combustion and Combustors"* – Tony Arts, VKI *"Experimental techniques for aerodynamics in low Pressure Turbines"*
Lunch Break
Parallel Session 6A ***Propulsion related green technologies*** **Chairpersons: Pierre Vialettes, Airbus Group Innovations & ZHENG YAO, ZJU** – DING Shuiting, BUAA *"Topics on Alternative Fuels for Aeronautics"* – Ingrid LEPOT, CENAERO *"Multidisciplinary Surrogate-Assisted Design Strategies for the Aero-Mechanical Optimization of* *Contra-Rotating Open Rotors"* – FENG Zhenping, XJTU *"Multidisciplinary and Multiobjective Optimization Design for Turbomachinery"*

A specific KGT meeting has then be held to coordinate on the coming deliverables, including state of the art, emerging technologies and research topics to be addressed in the last phase of GRAIN2, and as well as a guidance and recommendation for the EC and METI for future call for proposals.

Dissemination of results and communication around GRAIN2

Common presentation with members of the consortium has been made during several symposium or events.

In the frame of the Sino-Europe Green Aviation Collaborative Innovation Alliance, BUAA and Airbus Group are setting-up, a communication has been done to gather academics and industrials to participate to the future call for proposals. Communication has been done to imperial College London, SAFRAN, Chinese Academy of Science, COMAC, AVIC, CAAC.

A presentation on “Sustainable Aviation Fuels: The AIRBUS Approach” has also be made during the “2014 Green Aviation international Forum” held in November 2014 in BUAA. Airbus Group approach in the frame of GRAIN2 has been presented.

4.3 KGT2 Work progress and achievements

4.3.1 KGT2 Main Objectives

Will focus on the identification of new emerging green technologies, of mutual interest, for Airframe Flight Physics related to drag reduction, noise reduction, HPC innovative architecture and numerical simulation.

The workpackage consists of three tasks:
1. Drag and CO2 reduction
2. Noise reduction
3. Numerical design and simulation tools

In line with the overall objectives of GRAIN2 and on the basis of the achievements made in the previous GRAIN project, one of the main objectives in KGT2 is to make one step forward in the exploration of emerging greener technologies of future aircraft, as well as of the tools and methodologies invoked to realize and implement the identified technologies for improved airframe designs. A second main purpose is to establish a collaborative platform and network including competent partners and, further to identify and select state-of-the-art technologies, tools and methods of mutual interest in Europe and in China for future collaboration of in-depth technical investigation.

4.3.2 Work Approach (KGT2)

Work will be organized in two steps. First, the most relevant technologies in the KGT fields and their level of development in both European and Chinese sides will be identified. This identification task will be supported by the contributions of all participants during the different dissemination actions and asynchronous meetings organized by the GRAIN2 network. The common interest from the European and Chinese participants in the identified technologies will be ensured.

The second step will be the identification of the most promising technologies for future collaborative activities with European and Chinese participation. The objective here will be to be prepared for the generation of future collaborative projects for the joint development of new technologies in the context of the KGT areas.

These two steps will be supported by the discussions on the events of the project, under the supervision of the KGT leader and the agreement of the industrial partners. Both the leader and the industrial will work to align the KGT conclusions with the European and Chinese industrial interest.

4.3.3 Partners and Partner-Proposed Technical Themes

The participation of partners in Tasks 2.1 and 2.2 is given in the following table.

Table: Involvement of partners in the two tasks of KGT2

CN Partner	Involved Tasks		EU partner	Involved Tasks	
ACTRI	2.1		Airbus	2.1	2.2
ARI	2.1	2.2	CFDB	2.1	2.2
ASRI		2.2	CIMNE	2.1	2.2
BUAA		2.2	CIRA	2.1	
FAI	2.1	2.2	INRIA	2.1	2.2
IACAS		2.2	KTH	2.1	2.2
NUAA	2.1	2.2	NUMECA	2.1	2.2
NPU	2.1		RWTH	2.1	2.2
THU	2.1	2.2	Glasgow	2.1	2.2
XJTU		2.2??	UPM	2.1	2.2
ZJU	2.1		USFD	2.1	
			VKI	2.1	2.2

4.3.4 Description of work

4.3.4.1 Task 2.1 Drag and CO2 reduction (A. Abbas UPM)

Activities in task2.1 KGT2 will be related with aircraft drag and weight reduction technologies and HPC numerical simulation technologies. This will include:

- Study of the state of the art of all corresponding technology in Europe and China.
- Identification and analysis of future and emerging technologies,
- Prospective of existing technologies that could be transferred from other fields which enable the reduction of drag to directly affect consumption (SFC) and related CO2 emissions control.

- Technologies evaluation on aircraft level will be developed identifying possible benefits.
- KGT2 will also focus on the study and analysis of present and future IT technologies which will facilitate and speed up the development of new technologies for large scale simulation and optimization in aeronautics.
- Time-to-market and aircraft design cost reduction technologies based on high performance computation resources will be analyzed.

Remark: a clear indication of the expected progress towards the objectives of Horizon 2020 and 2050 that can be expected from the different technologies dealt in KGT2 could be an interesting conclusion of this new state of the art study. This could pave the way towards the selection of the most promising technologies to be jointly pursued.

4.3.4.2 Deliverables

Report on the stat of the art for drag reduction and simulation technologies.

4.3.4.3 Proposal for Technology Themes

From previous experiences in projects such as GRAIN and others EU and national initiatives, one can identify and assess key aerodynamic technologies that offer the potential for the challenges of the Horizon 2020 to be met.
These technologies can be categorized into two different groups. First, technologies for viscous drag reduction (mainly skin friction) and the elimination of flow separation through the application of passive and active "flow control" strategies. Second, technologies aimed to reduce aircraft vortex (or induced) drag, targeting aircraft configuration optimization.

For the first group, and for the sake of the present report, this can be summarized in:

1. Natural Laminar Flow control NLFC
2. Hybrid Laminar Flow Control HLFC
3. Turbulent boundary layer drag reduction

WG1: Natural Laminar Flow Technology

Partners:
Airbus, KTH, **CIRA**, Sheffield, UNIMAN, UPM,
FAI, ARI, ACRI, THU,
WG leaders (proposed)**:** CIRA/FAI

Significant research experience in drag reduction technologies has been gained over the past years supported by a dedicated EU programme. Several drag reduction concepts have been investigated with emphasis on laminar flow technologies. A net fuel saving of about 10% could be achieved by the laminarisation of flow over the wing, tails and nacelles.
Many European research projects investigated design challenges for Natural Laminar Flow wings. However, remain still several issues to be investigated and matured. Transition mechanisms, design uncertainties, manufacture imperfections and operation related surface

contamination effects on transition,…etc together with other issues are considered as important issues for the successful application of NLF technology.
Although much progress has been made in this field, the main problem, especially for large transport aircraft, is the TRL which remains still far from allowing significant achievements at an industrial level. It would therefore be desirable to make a joint effort in the operational management of laminar aircraft. This would allow a significant increase in TRL, and, at the same time, it would guarantee the protection of the know-how of European and Chinese partners.
The responsibility of KGT2 then is to identify and assess in details the stat-of-the art of this technology. This should include design tools and processes, TRL of all involved technologies and plan for future work.

WG2: Hybrid Laminar Flow Control HLFC

Partners:
Airbus, **CIRA**, Glasgow, Sheffield, UPM, KTH,
FAI, **ACRI**, UNAA,
WG leaders (proposed)**:** CIRA/ACRI

Extensive research has been undertaken both at a national and European level to mature Hybrid Laminar Flow by suction. A number of successful demonstrations in wind tunnels and flight have been carried out. The technological challenges are now largely non-aerodynamic – dealing with suction surfaces, suction system design, the integration of the complex system solutions into the wing, nacelle, fin and horizontal tail primary structures.
In this case, too, the TRL increase generated by a proper operational management of this technology could be a good field of joint research.
The responsibility of KGT2 then is to identify and assess in details the stat-of-the art of this technology. This should include design tools and processes, TRL of all involved technologies and plan for future work.

WG3: Turbulent boundary layer drag reduction

Partners:
Sheffield, Glasgow, UNIMAN, CIMNE, CFDB, UPM, KTH, VKI,
NUAA, FAI, NPU,
WG leaders (proposed)**:** Sheffield/NUAA

Even if the application of laminar flow technology is successful, a significant proportion of turbulent skin friction drag will still be present on the airframe, mainly on the fuselage. Riblet technology is considered an aerodynamically mature technology that could offer modest reductions (7% skin friction drag reduction) in aircraft turbulent drag. However, issues such as developing models for drag reducing measures to be used with RANS to assess the overall impact of riblets on the aircraft drag are perhaps still missing. Also, given such a riblet model, it's parameters could be left free for an adjoint optimization, which would show the regions on the aircraft where riblet application has the highest overall benefit.

On the other side, considerable effort must be applied to improve manufacturing technologies and material properties if these are to be successfully deployed on an aircraft without an adverse impact on maintenance.
Others examples are the use of dimples and distributed roughness elements technologies currently investigated. This passive treatment typically gives small levels of drag reduction and may not be attractive due to the costs associated with their implementation.
The responsibility of KGT2 then is to identify and assess in details the stat-of-the art of this technology. This should include design tools and processes, TRL of all involved technologies and plan for future work.

For the second group, the technologies to be considered are mainly targeting the geometries /configurations (either classical or innovative) optimization. This also may include optimization for active flow control devices application:

WG4: Drag/Noise Reduction Based Optimization

Partners:
RWTH, CIMNE, CIRA, CFDB, UPM, UPC,
NUAA, **THU**, ZJU,
WG leaders (proposed)**:** RWTH/THU

Pursuing a high aspect ratio wing solution for the aircraft or adopting a wing tip device if the aircraft is span limited can reduce vortex drag at a given lift coefficient. The Aerodynamics of high aspect ratio wings for 'Proactive Green' wings has been extensively investigated in several projects. Further multidisciplinary work at an aircraft concept level is. Conventional wingtip devices are considered mature and Large Winglets were largely investigated. The outcomes of these activities highlight the need for further research to address multidisciplinary, aero-elastic and structure aspects of their design.
Non-conventional innovative configurations also offer many advantages with respect to drag and Natural Laminar Flow (NLF) application. Mature and robust optimization tools and processes are a key technology helping.
Also passive flow control devices could be subject to adjoint optimization. For example, there are VG models that simulate VGs using body forces. The parameters of these could be optimized as a design tool (where best to place VGs and with what heights/angles). This can also be applied to others passive flow control devices.
Here the techniques of uncertainty quantification might play a decisive role to reduce the design and development costs, and to ensure the actual feasibility of low drag aircraft.
The responsibility of KGT2 then is to identify and assess in details the stat-of-the art of this technology. This should include design tools and processes, TRL of all involved technologies and plan for future work.

Numerical Simulation and HPC

Numerical simulation is foreseen to provide a tremendous increase in aircraft design efficiency and quality over the next decade. Improvements in physical modeling of flight physics as well as aircraft structures and systems will be mapped to multidisciplinary models of the aircraft which could be executed in acceptable time on future HPC systems. The “Digital Aircraft” concept will enable engineers to drive the aircraft development process in a flexible and efficient way towards an overall optimized product.
Industrial numerical simulation tools, however, are still presently suffering two main drawbacks that prevent their full industrial deployment for massive applications. They are: not very **efficient** consuming excessively large computational time for problems of industrial relevance, and the reliability and **accuracy** of the solutions at flight extremes leading to separated unsteady flows. These two deficiencies are very much linked to:

WG5: Efficiency

Partners:
INRIA, CFDB, KTH, CIRA, VKI, Sheffield, UPM
THU**, ZJU**, NPU,
WG leaders (proposed)**:** INRIA/ZJU

HPC is the norm today for large-scale multidiscipline and multi-scale simulations and optimization. It spreads vigorously in many areas, ranging from biology and pharma to powerplant simulation and auto and aircraft design. However, recent studies point out that the current HPC applications hardly use 20-25% of the supercomputers peak performance. The current Top500 list shows also that the world most powerful computers reach several petaflops peak performance, e.g., 7 PetaFlops for the K computer and 2.5 PF for IBM BlueGene /Q.
The observed lack of efficiency exhibited by the existing HPC applications is therefore a challenge to both computer scientists and applications designers and users, including aircraft design bureaus.
The goal of this WG5 on HPC activity is to identify avenues for the most appropriate use of HPC power, and to suggest best practices recommendations.
A state-of-the-art study will first examine the current paradigms underpinning HPC, from both the hardware and system’s perspectives. This includes multi and many core machines, memory hierarchies (HDD, SSD, DRAM), hybrid machines (CPU+GPU, FPGA), and parallel as well as distributed environments (clouds, grids, clusters, …).
A second aspect will focus on application requirements for best HPC efficiency in the aeronautics sector, including flight dynamics simulation, design optimization, drag and noise reduction. It will focus on modeling, implementation, resource allocation, programming, algorithmic aspects (communication avoiding algorithms, parallel blocks, …), hierarchical parallelization, parallelism extraction (loops, …), locality characteristics, etc. Another issue will focus on fault-tolerance, in order to cope with hardware and system failures at runtime for long-running simulation applications (days, weeks, …). An overview of current techniques supporting faul-tolerance will provide insights on existing and upcoming issues and solutions

(fault-tolerant MPI, Algorithm-Based Fault-Tolerance, aka ABFT, code and data duplication and migration, etc).
A comprehensive set of issues and recommendations, focusing on best practices, along with users expectations in terms of application design, implementation, deployment, monitoring and steering, will be produced and included in the KGT2 Deliverables.
Is perhaps, as proposed during the KGT2 discussion in Hangzhou, to work on closing the gap between HPC new/innovative architectures and numeric in industrial codes.
The responsibility of KGT2 then is to identify and assess in details the stat-of-the art of this technology. This should include design tools and processes, TRL of all involved technologies and plan for future work.

WG6: Physical Modeling (including flow-induced noise generation)

Partners:
CFDB, KTH, CIRA, VKI, Sheffield, UPM
THU, **ZJU**, NPU,
WG leaders (proposed)**:** CFDB/ZJU

Is important to highlight that the appearance of separation, either insipient or massive, is a critical design point. This effect is directly coupled to either buffet appearance or maximum lift properties of the aircraft, which is a limiting factor in take-off and landing performance. The prediction of maximum lift depends on the ability of the turbulence model to detect the local separation and to describe the extension of the separation up to the massive breakdown of the flow. This is still a problem not accurately predict by the existing turbulence models.
Turbulence modelling subject is widely considered for further development in many EC projects (FLOMANIA, DESider, ATAAC, Go4Hybrid,...etc). KGT2 here can analysis the existing stat of the art turbulence models and best practices and try to define the way forward.

The responsibility of KGT2 then is to identify and assess in details the stat-of-the art of this technology. This should include design tools and processes, TRL of all involved technologies and plan for future work.

4.3.4.4 Task 2.2 Noise Reduction (Shia-Hui Peng KTH)

Activities in Task 2.2 of KTG2 concern a EU-China collaborative identification of methodologies and technologies in aerodynamic and aero-acoustic design and analysis of greener aircraft towards lower airframe noise (AFN) emission. This is closely related to the AF flow physics around, typically, high-lift configurations, landing gears, nacelle/pylon and fuselage surface, where flow-generated noise sources are present due to intensive aerodynamic fluctuations/oscillations.

The general objectives in Task 2.2 are twofold:

- To identify the state-of -the-art methodologies and technologies applied to aero-acoustic design and analysis in relation to airframe noise reduction.

- To establish an effective EU-China collaborative platform working on noise-reduction approaches and, ultimately, to set up relevant EU-China collaborative projects.

Aiming at AF noise reduction, three main technical topics will be covered in Task 2.2, namely, (a) *Aero-acoustic noise sources*; (b) *Noise radiation*; and (c) *Low-noise AF configurations*, by means of the following activities in the GRAIN2 network.

- Study of the state of the art of noise-reduction technologies
- Study of the state-of-the- art methodologies in design of low-noise AF configuration and in analysis of AF noise.
- Exploration of the potential to improve further existing noise-reduction technologies in conjunction with new/emerging techniques
- Evaluation of TRL of emerging technologies that may lead to reduced AFN emission
- On the basis of above studies, identification of the most potential technologies /methodologies and, subsequently, formulating selected topics in the framework of new EU-China collaborative projects to comply with the up-to-date/future need of aeronautic applications.

Along with low-noise technologies, the methodologies employed in AFN analysis include numerical simulation and experimental measurement techniques. In numerical simulations, a systematic analysis of aeroacoustic noise invokes CFD (Computational Fluid Dynamics) to target near-filed noise sources and CAA (Computational Aero-Acoustics) to address far-field noise propagation. Obviously, exploration of relevant HPC technologies forms an important part of the activities concerning simulation methodologies in Task 2.2. In the framework of large-scale CFD/CAA , the HPC activities will be undertaken together with Task 2.1, with particular focus on, among others, aalgorithms for flexible and efficient parallization, effective data management and M2M communication patterns, with the purpose to improve computational efficiency in aerodynamic and aeroacoustic simulations.

4.3.4.5 Deliverables

Two deliverables are planned in the GRAIN2 DoW, which will be formulated jointly with Task 2.1.
D2.1: Preliminary report on Emerging RTD areas of KGT2 (month 12)
D2.2: Report on Emerging RTD areas of KGT2 (month 24)
The deliverables will be proceeded with an intermediate report on the state-of-the-art technologies for AF noise reduction and the methodologies applied in AFN analysis.

4.3.4.6 Proposal for Technology Themes

At the GRAIN2 kickoff meeting, involved partners have identified a number of technical topics based on previous research activities in terms of numerical simulations and experimental measurements. In general, the proposed/identified technical topics are covered by the three main themes mentioned above, namely,

1. Aero-acoustic noise source
2. Aero-acoustic noise propagation
3. Low-noise AF configuration

Accordingly, three working groups (WG) are set up. Each WG will cover a set of relevant subtopics, undertaking activities in relation to AF noise reduction by means of collaborative review of corresponding technologies and methodologies.

WG 1 Aero-acoustic Noise Source

Partners:
Airbus, CFDB, CIMNE, KTH, NUMECA, Glasgow, VKI, RWTH, ARI, BUAA, FAI, IACAS, THU,
WG leaders (proposed)**:** KTH/THU

The activity in this WG concerns technologies of manipulating/controlling AF noise sources due to unsteady aerodynamic flow phenomena. Obviously, in-depth understanding of airframe flow physics in connection to noise generation is the first step, followed by a systematic review of noise-control technologies and related methodologies applied to comprehensive analysis of flow-induced aero-acoustic noise sources.

The activities in this WG are distributed on two technical subtopics.

A. *Methodologies for improved reliability in analysis and modelling of noise generation*, in terms of
   - Advanced modelling of flow physics in relation to flow-induced noise generation
   - Effective modelling and formulation of noise sources for industrial use
   - Experimental techniques of measuring noise-source intensity
B. *Technologies of controlling and manipulating noise sources (noise control)*, generated typically by
   - High-lift (HL) devices
   - Landing-gear (LG) systems
   - Propeller, turbofan shocks
   - Propulsion systems and jets (incl. e.g., nacelle and chevron)
   - Turbulent boundary-layer excitation (over fuselage in relation to cabin noise)

Task 2.2 will further evaluate possible penalties of using noise-control technologies on overall aerodynamic performance of aircraft (in relation to drag reduction and lift enhancement).

WG 2 Aero-acoustic Noise Radiation

Partners:
CFDB, KTH, NUMECA, Glasgow, VKI, RWTH, ASRI, BUAA, FAI, NUAA, IACAS, THU

WG leaders (proposed)**:** VKI/BUAA

The activity in this WG is related to methodologies employed in analysis of aero-acoustic noise propagation and scattering, and to technologies of dissipating/absorbing acoustic sound wave for noise reduction.

The activities in this WG include two technical subtopics.

A. *Methodologies for reliable CAA analysis of noise propagation and scattering*, in terms of
   - High-order, low-dissipative numerical schemes
   - Reliable/robust CAA boundary conditions
   - CAA mesh quality and uncertainty in noise predictions
   - Effective acoustic analogy methods for industrial use
   - Fully coupled CFD/CAA methods
   - Techniques of noise measurements
B. *Technologies for controlling and manipulating noise propagation and scattering*, focusing on
   - Fuselage scattering and shielding
   - Noise radiation of internal sources, e.g., Nacelle and turbofan, in relation to damping/absorbing of sound waves
   - Cabin noise propagation and control, in relation to vibro-acoustic noise and low-frequency noise

WG 3 Low-Noise Airframe Configurations

Partners:
Airbus, CFDB, CIMNE, KTH, NUMECA, VKI, RWTH, ASRI, BUAA, FAI, IACAS, NUAA, THU,
WG leaders (proposed)**:** CIMNE (or RWTH)/NUAA

Targeting low-noise airframe configurations, the activities in this WG are to explore the technologies and methodologies in design optimization and in analysis of airframe configuration towards alleviation of noise generation and emission. Obviously, the activities in this WG is closely associated to those in WG 1 and WG 2, where the explored technologies and methodologies may support the assessment and evaluation of airframe configuration in terms of noise reduction.

The activities in this WG include two technical subtopics.

A. *Methodologies for aero-acoustic optimization of AF configurations*, with restriction of zero/minimal aerodynamic penalty. This may include
   - Aerodynamic layout/shape optimization targeting minimized noise generation
   - Aero-acoustic optimization for reduced noise radiation and scattering

B. *Methodologies for aero-acoustic assessment of AF configurations*, as well as *technologies for optimal integration of noise/flow control devices for low-noise (and low-drag) AF configurations*. The activities are related to
   - Assessment and evaluation of low-noise AF configurations
   - Integration of noise/flow control devices with AF configuration for noise/drag reduction.

It is further noted that, in numerical analysis of noise generation and propagation, the computational grid resolution is very demanding, which leads usually to very time-consuming (and costly) computational effort. In conjunction with the activities in Task 2.1, as well as in other KGTs of the GRAIN2 network, wherever large-scale numerical simulation is concerned, innovative HPC architecture will also be addressed in Task 2.2 aiming at improving computational efficiency in CFD and CAA analysis of airframe system. The HPC activities, monitored by INRIA, will be jointly carried out with Task 2.1.

4.3.5 Kick-off in Hangzhou, CN

Two parallel sessions have been organized and delivered on the 1st GRAIN2 workshop.
The introduction of the sessions was used to introduce the point of view of the GRAIN2 KGT2 consortium regarding the technologies available, and the main research interest on this topic.
The keywords were cabin noise, airframe noise, noise sources and propagation, low noise configurations, high performance computing.

Parallel Session 2A

Noise Reduction Technologies

Chairmen: KGT2 Co-chairmen
SUN Xiaofeng(BUAA)and Shia-HuiPeng(KTH)

- KGT2 Overview by Co-Chairmen

Working Title: The potential of noise reduction technologies

- Charles Mockett, CFD Software GmbH
  "High-fidelity prediction of broadband noise and perspectives for industrialization"
- YAN Qun, ASRI, China
  "Development of Acoustics Liner for Turbofan Inlet"
- Herman Deconinck, VKI
  "Aerodynamic and Aero-acoustic Optimization of Contra-rotating Rotors"
- LIU Bilong, IACAS, China
  "Research Progress on Noise Transmission through Aircraft Panels"

- Discussion

Parallel Session 3B

Technologies for Reduced Drag Reducing CO2 Emission

Chairmen: KGT2 Co-chairmen
ZHAO Ning (NUAA) and Adel Abbas (UPM)

- KGT2 Overview by Co-Chairmen
  Working Title: Technologies and methods for enhanced drag reduction
- Nicolas R. Gauger, RWTH Aachen Univ.
  "Efficient Optimization and Control in Aerodynamics"
- FU Song, THU, China
  "Drag Reduction for the Flow around an Airfoil through Active Flow Control"
- Dr. HosseinZare-Behtash, University of Glasgow
  "Driving Forward Aerospace at the University of Glasgow"
- CHEN Yingchun, COMAC, China
  " 'Greener' Aerodynamic Design of C919"

- Discussion

4.3.6 Wrap-up Session of KGT2

Following the GRAIN2 kick-off meeting in Hangzhou, October 30, 2013, a brainstorming session was organized for each specific KGT. The WP2 "Airframe Flight Physics" met, and the corresponding KGT2 identified three activities, namely: 1- Drag and CO2 Reduction, 2- Noise Reduction and 3- High Performance Computing. The HPC activity met including 20 participants, and the discussion was moderated by Adel Abbas from UP Madrid. This memo focuses on the activity labeled as "High-Performance Computing". It summarizes the goals of this activity and participants.
HPC is the norm today for large-scale multidiscipline and multi-scale simulations and optimization. It spreads vigorously in many areas, ranging from biology and pharma to powerplant simulation and auto and aircraft design. However, recent studies point out that the current HPC applications hardly use 20-25% of the supercomputers peak performance. The current Top500 list shows also that the world most powerful computers reach several petaflops peak performance, e.g., 7 PetaFlops for the K computer and 2.5 PF for IBM BlueGene /Q.
The observed lack of efficiency exhibited by the existing HPC applications is therefore a challenge to both computer scientists and applications designers and users, including aircraft design bureaus.
The goal of this KGT2 HPC activity is to identify avenues for the most appropriate use of HPC power, and to suggest best practice recommendations.

A state-of-the-art study will first examine the current paradigms underpinning HPC, from both the hardware and system's perspectives. This includes muti and many core machines, memory hierarchies (HDD, SSD, DRAM), hybrid machines (CPU+GPU, FPGA), and parallel as well as distributed environments (clouds, grids, clusters, …).
A second aspect will focus on application requirements for best HPC efficiency in the aeronautics sector, including flight dynamics simulation, design optimization, drag and noise reduction. It will focus on modeling, implementation, resource allocation, programming, algorithmic aspects (communication avoiding algorithms, parallel blocks, …), hierarchical parallelization, parallelism extraction (loops, …), locality characteristics, etc. Another issue will focus on fault-tolerance, in order to cope with hardware and system failures at runtime for long-running simulation applications (days, weeks, …). An overview of current techniques supporting faul-tolerance will provide insights on existing and upcoming issues and solutions (fault-tolerant MPI, Algorithm-Based Fault-Tolerance, aka ABFT, code and data duplication and migration, etc).
A comprehensive set of issues and recommendations, focusing on best practices, along with users expectations in terms of application design, implementation, deployment, monitoring and steering, will be produced and included in the KGT2 Deliverables.
Participants (some missing names)

Charles Mockett	Charles.mckett@cfd-berlin.com
Nicolas Gauger	gauger@mathcces.rwth-aachen.de
Song Fu	fs-dem@tsinghua.edu.cn
Konstantinos Kontis	kostas.kontis@glasgow.ac.uk
Adel Abbas	adel.abbas@upm.es
Xiaodong Li	lixd@buaa.edu.cn
Li Li	westlili@163.com
Shia-Hui Peng	shpeng@kth.se
Ninj Qin	n.qin@shef.ac.uk
Jacques Periaux	jperiaux@gmail.com
Toan Nguyen	toan.nguyen@inria.fr

4.3.7 Short Course

The contribution of the KGT2 on the organization of the Short course was four parallel sessions.

Parallel Session 1A

Airframe Flight Physics

Chairpersons: Adel Abbas, UPM & SUN Xiaofeng (BUAA, China)
- DUAN Zhuoyi, FAI
  "Natural Laminar Wing Design and Numerical Simulation on Flow Control Technology"
- Eusebio Valero, UPM

"Review on drag reduction technologies"

Parallel Session 2A

Airframe Flight Physics

Chairpersons: Shia-Hui Peng, KTH & DUAN Zhuoyi, FAI

- GAO Zhenghong, NPU
  "Robust Design of NLF Airfoils"
- Daniel Redondo, Airbus
  "Innovative configurations for drag reduction"
- LI Li, ACTRI
  "Performance Analysis of a Low Dissipation of AUSM+ Scheme for All Speed"

Parallel Session 3A

Airframe Flight Physics

Chairpersons: Adel Abbas, UPM & FU Song, THU

- Piergiorgio Ferrante, NUMECA
  "Efficient methodologies for tonal Engine noise prediction, including liners"
- HUANG Wenchao, ASRI
  "Hybrid Numerical Method for Fan Noise Propagation Simulation and Reduction Assessment"

Parallel Session4A

Airframe Flight Physics

Chairpersons:Shia-Hui Peng, KTH & DUAN Zhuoyi, FAI

- Beckett Y. Zhou and Nicolas R. Gauger, RWTH
  "Towards optimal aeroacoustic designs - A discrete adjoint approach"
- LI Xiaodong, BUAA
  "Numerical Simulation of Gust Cascade Interaction Noise with Soft Wall Treatment "
- Ning Qin, Sheffield university
  "Turbulent boundary layer drag reduction technologies"

4.4 KGT3 Work progress and achievements

The following section describes the achievements and actions during the reporting period in chronological order.

4.4.1 Kick-off in Hangzhou, CN

The GRAIN 2 project kick-off meeting was held in Hanzhou, China from October 28th – October 30th 2013. During this meeting two parallel sessions related to KGT3 were organized. The following presentations were given during these sessions:

Session 2B – Environmentally Friendly Materials	
Chairmen	YI Xiaosu (BIAM) Maksim Danilov (DLR)
KGT3 Overview by Co-Chairmen	*Application of environmentally friendly materials in aviation*
Ahmad Bilal, LEITAT	*Summay and result of GRAIN 1*
ZHU Jin, NIMTE	*Research Progress for Bio-Based Polymer Resin Material*
Gabriel Budega, CIMNE	*Multi-objective green design optimization of carbon nanotube composite structures*
LIU Quin, CQU	*Fundamental Research and Application Progress of Aviation Aluminium Alloy Materials*

Session 3A – Environmentally Friendly Smart Structures	
Chairmen	NIU Wensheng (ACTRI) Florian Raddatz (DLR)
KGT3 Overview by Co-Chairmen	*State-of-the-art and potential of smart structures for aviation*
Marcelo Muller, NLR	*Experience on Aircraft Structural Health Monitoring: from Concept* *towards Applicatio*
QIU Jinhao, NUAA	*Smart Structure and Key Technologies of SHM*
Robert Bakker, AIRBORNE	*SHM Development and Applications at Airborne*

In addition to the parallel sessions a poster session has been held in order to introduce EU and CH partners.
Internal KGT3 sessions were held during the kick-off meeting in order to identify the first steps to be taken during the project. During these meetings the KGT3 partners agreed to first gain a more detailed understanding of each other's research areas and the tools that each partner could contribute to future projects. This approach has been presented to the other KGT groups and was considered to be a very promising way of identifying and communicating common research interests and capabilities.

Identification of research areas and available tools/capabilities
In order to assess the project partners common research areas and capabilities and to get a more detailed and clear overview of the involved institutions an Excel table containing the project partners, their respective research areas and the available tools (e.g. manufacturing, testing or computing capabilities) has been created and refined during several telephone conferences and e-mails. The table is laid out in such a way that each partner could fill in which tool can be made available for different research areas. This allows the identification of the most relevant research areas to the consortium and shows which capabilities are available, which are missing in the consortium and which might be over-represented.

Table 1 shows a version of this table displaying research topics vs. available tools. The listing of a project partner indicates that this partner is willing to provide the respective tool/capability for future research projects in the respective area.

In order to further evaluate the relevance of the individual research areas to the consortium Table 1 has been resorted to count the number of research partners willing to contribute to each research area. The result is shown in Table 2a and Table 2b. The count shows the most relevant research areas:

- Environmentally friendly materials
  - Development and application of bio-sourced materials (5/2)
  - Recycling of composite materials (2)
  - Environmentally friendly production (2)
- Smart Materials
  - Energy Storage (2)
- Structural Health Monitoring
  - SHM using fiber optic sensors (4)
  - Aircraft structural life prediction (4)
  - Structural integration of sensors (3)

The tables can be further resorted to show the availability of tools and capabilities in the consortium independent of the research areas. The result is shown in Table 3. This overview shows that the tools are distributed rather evenly. In many cases tools are available to more than one partner without having specifically over-represented capabilities.

Tools / Research topics	Environmentally friendly materials					Smart materials			Structural Health Monitoring												Aditional topics
	Bio-sourced materials	Application of Bio-sourced material	Recycling of composite materials	Fire protection	environmentally friendly production	Energy storage	Function integration	Other sensing capabilities	SHM using fiber optical sensors	SHM using guided waves	New sensing technologies	Structural integration of sensors	Layout of sensor networks	Smart stiffeners	SHM capability analysis and selection guidelines	Condition-based maintenance	Aircraft structural life prediction	System integration	Signal processing and analysis	SHM for TBC of turbine blades	Advanced aluminium alloys
Composite manufacturing			EADS-IW			EADS-IW															
Autoclave	DLR, NLR	DLR, NLR	DLR	DLR	NLR	NLR				DLR		DLR	DLR								
Press	DLR, NLR	DLR, NLR		DLR	NLR	NLR				DLR		DLR	DLR								
Further equipment																					
Bio-based resins production	NIMTE																				
Oven	DLR, NLR	DLR, NLR		DLR	NLR	NLR				DLR		DLR	DLR								
Fiber placement	NLR	NLR			NLR	NLR				DLR		DLR	DLR								
RTM	DLR, NLR	DLR, NLR		DLR	NLR	NLR				DLR		DLR	DLR								
Metal processing																					CQU
Simulation																					
Composite FEM	Cranfield, CIMNE, DLR			DLR	CIMNE				Cranfield	DLR	Cranfield	Cranfield, DLR	DLR	Cranfield			Cranfield, CIMNE				
Manufacturing simulation	CIMNE				CIMNE																
CFD	CIMNE																				
HPC	CIMNE									DLR		DLR	DLR								
Full life fatige damage model																	ASRI				
Testing						EADS-IW															
Static	Cranfield, DLR	DLR							Cranfield, NLR	DLR	Cranfield	Cranfield, DLR, NLR	DLR				NLR			NLR	
Dynamic (Impact)	Cranfield								Cranfield, NLR		Cranfield	Cranfield, DLR, NLR					Cranfield, NLR			NLR	
Dynamic (Fatigue)	Cranfield, DLR	DLR							NLR	DLR		DLR, NLR	DLR				NLR			NLR	
Material testing									NLR			NLR					NLR			NLR	CQU
CAI	Cranfield, DLR	DLR							Cranfield	DLR	Cranfield	Cranfield, DLR	DLR								
Non-destructive	Cranfield, DLR	DLR						UGLA	UGLA	DLR		DLR	DLR							NLR, UGLA	
Fire resistance	DLR	DLR		DLR																NLR	
Chemical analysis																				NLR	
Thermo-mechanic																					CQU
SHM															ASRI			ACTRI AVIC			
Fiber optics								UGLA	ASRI, Cranfield, NLR, UGLA			NLR	NLR		NLR	NLR	NLR			UGLA	
Sensor integration										DLR		ASRI (MEMS)	DLR, NLR		DLR, NLR	NLR	NLR				
Sensor design										DLR			DLR, NLR		DLR, NLR	NLR	NLR				
Guided waves										ASRI, DLR			DLR		DLR				DLR		
Acoustic emission										ASRI											
Laser vibrometry										DLR			DLR		DLR				DLR		
Hardware integration, data fusion																		ASRI			
Signal processing										DLR			DLR		DLR				ACTRI AVIC, DLR		
CVM											NLR										
Other tools																					
Design study		Cranfield					Cranfield														
Optimization tools	CIMNE				CIMNE								ASRI								
Phase field modeling																					CQU
Micro structure characterization																					CQU

Table 1: KGT3 Overview, Research Topics vs. Tools

Partners	Research topics	Environmentally friendly materials					Smart materials		
		Bio-sourced materials	Application of Bio-sourced material	Recycling of composite materials	Fire protection	environmentally friendly production	Energy storage	Function integration	Other sensing capabilities
Partners	ACTRI, AVIC								
	ASRI								
	CIMNE	1				1			
	CQU								
	Cranfield	1	1					1	
	DLR	1		1	1				
	EADS-IW			1			1		
	NIMTE	1							
	NLR	1	1			1	1		
	UGLA								1
Contributors		**5**	**2**	**2**	**1**	**2**	**2**	**1**	**1**

Table 2a: KGT3 Partners vs. Research topics

Partners	Research topics	Structural Health Monitoring												Aditional topics
		SHM using fiber optical sensors	SHM using guided waves	New sensing technologies	Structural integration of sensors	Layout of sensor networks	Smart stiffeners	SHM capability analysis and selection guidelines	Condition-based maintenance	Aircraft structural life prediction	System integration	Signal processing and analysis	SHM for TBC of turbine blades	Advanced aluminium alloys
Partners	ACTRI, AVIC										1	1		
	ASRI	1	1		1	1		1		1	1			
	CIMNE									1				
	CQU													1
	Cranfield	1		1	1		1			1				
	DLR		1											
	EADS-IW													
	NIMTE													
	NLR	1		1	1	1		1	1	1			1	
	UGLA	1											1	
Contributors		**4**	**2**	**2**	**3**	**2**	**1**	**2**	**1**	**4**	**2**	**1**	**2**	**1**

Table 2b: KGT3 Partners vs. Research topics

Tools	Partners										Σ
	ACTRI, AVIC	ASRI	CIMNE	CQU	Cranfield	DLR	EADS-IW	NIMTE	NLR	UGLA	
Composite manufacturing							1				**1**
Autoclave						1			1		**2**
Press						1			1		**2**
Bio-based resins production								1			**1**
Oven						1			1		**2**
Fiber placement						1			1		**2**
RTM						1			1		**2**
Metal processing				1							**1**
Simulation											**0**
Composite FEM			1		1	1					**3**
Manufacturing simulation			1								**1**
CFD			1								**1**
HPC			1								**1**
Full life fatige damage model		1									**1**
Testing							1				**1**
Static					1	1			1		**3**
Dynamic (Impact)					1				1		**2**
Dynamic (Fatigue)						1			1		**2**
Material testing				1					1		**2**
CAI					1	1					**2**
Non-destructive						1			1	1	**3**
Fire resistance						1			1		**2**
Chemical analysis									1		**1**
Thermo-mechanic				1							**1**
SHM	**1**	**1**									**2**
Fiber optics		1			1				1	1	**4**
Sensor integration		1				1			1		**3**
Sensor design						1			1		**2**
Guided waves		1				1					**2**
Acoustic emission		1									**1**
Laser vibrometry						1					**1**
Hardware integration, data fusion		1									**1**
Signal processing	1					1					**2**
CVM									1		**1**
Other tools											**0**
Design study					1						**1**
Optimization tools		1	1								**2**
Phase field modeling				1							**1**
Micro structure characterization				1							**1**

Table 3: KGT3 Partners vs. Tools

4.4.2 EU Members Web Conferences

The outcome of the collection of research topics and tools has been discussed among the EU members in two telephone conferences (May 28th and June 17th 2014). Based on this collection it has been agreed to produce a document containing possible collaboration topics.

4.4.3 Open Workshop, IT

The first open workshop in the course of the GRAIN 2 project was held at CIRA in Capua, Italy from July 1st – July 4th 2014. During this workshop two sessions related to KGT3 were held. The following presentations were given during these sessions:

Session 3B – Environmental friendly materials and smart structures	
Chairmen	QIU Jinhao (NUAA) Markus Kleineberg (DLR)
QIU Jinhao, NUAA	*Research on the Relationship between the Material Properties and the Loading Cycles of Composites using Laser-Generated Lamb Waves Method*
Kostas Kontis, University Glasgow	*Thermographic Phosphor Systems and Thermal Barrier Coatings*

Session 4B – Environmental friendly materials and smart structures	
Chairmen	YI Xiaosu (BIAM) Markus Kleineberg (DLR)
XIAO Yingchun, ASRI	*Research on the Structure Health Monitoring Methods Based on Piezoelectric sensors*
Xiang Zhang, Cranfield University	*Modelling and prediction of damage and failure of light-weight composite aerostructures*
NIU Wensheng, ACTRI	*Signal Processing and Health Assessment in Structural Health Monitoring*

In addition to the presentations given during the parallel sessions possible future collaboration topics have been discussed with all KGT3 partners. The following innovative aspects of multi-functional bio composites have been identified:

- Competitive bio-sourced matrix, fibres, core materials and functionality integration (e.g. toughness, electrical conductivity, damping, FST, etc.)
- Through thickness reinforcement to compensate possible lack of matrix performance
- Advanced manufacturing technology using the bio-sourced and multifunctional materials
- Adapted health monitoring strategies to improve maintenance efficiency

The general understanding of these topics is that bio-sourced materials can be produced more environmentally friendly than conventional materials. However, the performance of bio-sourced materials is much lower. This can be compensated in part by through-thickness reinforcement. Although the mechanical properties might not reach the level of currently used materials, this can be compensated by considering multifunctional aspects. For example a bio-sourced panel for the aircraft interior might be thicker and slightly heavier than a conventional panel but does not require additional measures for acoustic damping because the panel itself has very high damping capabilities. On the other hand, lower mechanical performance might be acceptable if the integrity of the structure is reliably monitored using an integrated SHM system. This SHM system can also – independent of the material – contribute to make the aircraft maintenance more efficient by transforming the current strictly scheduled inspection interval into a more demand-driven maintenance. This also includes the structural life prediction of the aircraft and may contribute to safely extend the usage beyond the initially planned life-time. Figure 1 illustrates the enhancement of bio-sourced composite materials by including mechanical reinforcement, multi-functionality and SHM.

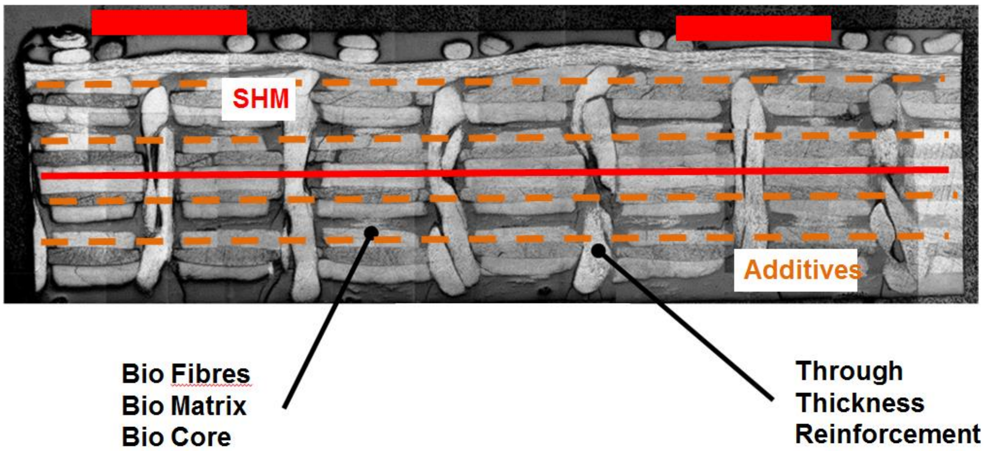


Figure 1: Enhancement of bio-sourced composite materials by including though-thickness toughening, multi-functionality and SHM

Table 4 gives an overview of possible target structures for enhanced bio-sourced materials and corresponding research aspects.

Target structure	
Cabin	• Acoustic Damping • Fire/Smoke/Toxicity Characteristics • Comfort • Cost
Fairing Components (e.g. Belly Fairing)	• Geometrical complexity • Energy absorption • Load-bearing capacity • Effectiveness • Cost
Leading/Trailing Edge Devices	• Lightning strike protection • Structural integrity • Abrasion protection

	• Anti-/Deicing • Geometrical accuracy

Table 4: Possible target structures and research aspects for enhanced bio-sourced composite materials

The possible contents of future research projects that were identified during the workshop are:

- Application driven material composition and system integration (Material characterization, mechanical properties, health monitoring strategies)
- Simulation of processes, structural behavior and design Optimization
- Detailed design of selected components and systems
- Processing trials and functionality tests

In order to validate the benefits of the developed materials and technologies the following validation approaches can be considered:

- Life Cycle Comparison with State-of-the-Art and Recyclable Products
  (Required Energy, Environmental Impact, …)
- Applicability Check
  (Chance to fulfill today's and future requirements, …)
- Maturity Check
  (Availability of Products, Quality Assurance Concepts,…)

4.4.4 Gathering of possible research activities in work package structure

In order to obtain a more structured description of the research activities that can be performed in future research activities a draft for a work package description has been started by the EU partners. This structure is as follows:

1. Materials with improved ecological footprint
   1.1. Raw materials
      1.1.1. Bio-sourced textiles and prepregs
      1.1.2. Second-life oil-based preforms and prepregs
      1.1.3. Additives
   1.2. Material processing
      1.2.1. Handling and preforming of bio-sourced materials
      1.2.2. Handling and preforming of second-life oil-based fibres
      1.2.3. Infiltration and polymerization process
   1.3. Material properties
      1.3.1. Mechanical properties
      1.3.2. Further properties
      1.3.3. FEA
2. Design for improved ecological footprint
3. SHM

4. Recycling and waste handling
    4.1. Recycling of bio-based materials
    4.2. Recycling of oil-based fibres
5. Life cycle monitoring and analysis

A further pursuit and modifications of this structure will be discussed at the Open Workshop in Xi'an.

4.4.5 Preparation of proposal for EU Call from Grain

Although it is not an explicit task of Grain 2 the currently ongoing preparation of a proposal for the call *H2020-MG-2015_SingleStage-A* can also be linked to the Grain 2 network because it involves many of the partners, especially the DLR Institute of Composite Structures and Adaptive Systems, which was not involved in Grain, but is now involved in Grain 2 and is coordinating the preparation of the proposal. The consortium of the proposal includes the following partners:

- EU Partners:
    - DLR (coordinator)
    - AGI, France
    - UNIMAN
    - CIMNE
    - LEITAT
    - University of Patras
    - INEGI
- CH Partners
    - BIAM (coordinator)
    - Tongji University
    - NIMTE
    - HIT
    - Shandong University
    - COMAC
    - AVIC GA

4.5 KGT4 work progress and achievements

KGT4 was a new KGT compared to those defined in GRAIN project. This makes a difference with other KGT, which did not require a deep state-of-art analysis. Then, the first duty was to describe the available technologies nowadays.

4.5.1 State of the art

The conclusions of this analysis are:

- What was already foreseen at the beginning of the project has proven to be the case; both the European and Chinese region are in a phase of changing the concept of operation in order to cope with the anticipated strong growth in air traffic. Both regions have acknowledged that the current concept of operation and its supporting technology will not be able to cope with the future traffic demands. Trajectory Based Operations (TBO) is in the agenda of both regions, while the required supporting technologies (or changes in technologies) are also very much aligned with each other.
- The growth in air traffic in China is yet facing different challenges compared to Europe. The planned construction of many new airports and the gradual opening of airspace to General Aviation in China brings a different set of challenges than the creation of the European Single Sky. In addition, the maturity of region-wide network management is also different in both regions. Where Europe has benefitted to a great extend from the set up and working of the Central Flow Management Unit at EUROCONTROL, the Chinese region has only recently taken up initiatives on more coordinated and more efficient network management. As a result, the maturity of technology and the needed changes for reaching a true Trajectory Based Operation are different in both regions.
- The ongoing research in both regions addresses similar technologies. However, it was clear that the European research agenda is a lot more coordinated, both in terms of regional development and alignment of technological progress. It is also supported by an overarching long term European ATM Master Plan. The Chinese Civil Aviation Authorities have put forward the Strategic Plan of Building China's Civil Aviation Power, in which the strategic goal of building next generation of ATM system has been defined. However, a systematic development framework and technological road maps are still under way in China.
- To conclude, the KGT4 team have confirmed that the current state of technology and research, and the targeted concept of operations in both regions, clearly identify a big potential for joint and coordinated future research work. Those areas will be worked out in Deliverable D4.2 and document the respective additional benefits of a joint and coordinated approach.

4.5.2 Hangzhou workshop

KGT4 contributed to the 1st workshop in Hangzhou. KGT2 delivered a parallel session in the workshop.

Parallel Session 1A
CNS/ATM for Greener Air Transport
Chairpersons:KGT4 Co-chairmen BAI Jie(CAUC) and Luc de Nijs(NLR)
- KGT4 Overview by Co-Chairmen

Working Title: Technologies and Procedures for Greener Air Transport - Joeri de Ruytter, Honeywell *"Providing Solutions for Global Challenges is an Art"* - WANG Guoqing, CARERI, China *"BD2-Based PBN Application and Research on GBAS Approach Technology"* - Dave Young, EUROCONTROL *"After SESAR, back to the future"* - ZHAO Yifei, CAUC, China *"Analysis and Optimization of Air Traffic Operation Management under the Context of High Traffic Growth Rate and Large Flows"* *- LIU Sheng, HUST, China* *"Development of Multi-sensor Packaging for Avionics and Its Reliability Design and Test"* *- ZENG Xiaoping,CQU, China* *"Situations and Developments for Civil Aviation Mobile Communication"* - Discussion

4.5.3 Short Course

The contribution of KGT4 on the Short course took shape as two parallel sessions:

Parallel Session 5B ***CNS/ATM for greener air transport*** Chairpersons: Luc de Nijs, NLR & BAI Jie, CAUC - SUN Xiaomin, CARERI *"Continuous Descent Operation Technology based on Multi-constellation Satellite Navigation"* - Bart Klein Obbink, NLR *"Evidence based safety cases"* - ZHAO Yifei, CAUC *"New Exploration to Calculate Sector Capacity Instead of Post Evaluation"*
Parallel Session 6B ***CNS/ATM for greener air transport*** Chairpersons: Luc de Nijs, NLR & BAI Jie, CAUC

- Xavier Prats, UPC
"Towards trajectory based operations: an optimal control application"
- LIU Wenxue, ACTRI
"Applicability Analysis of Air-Ground Broadband Communication in Avionics"
- Michael Schnell, DLR
"The current status in aeronautical communications development"

4.5.4 Assessment on the emerging technologies

KGT4 partners are working on the identification of the future technologies and common research interest. There are some key points which are surely of common interest, but a large list of potential topics where the collaboration is possible. Just to mention one example, the deployment of procedures to integrate General Aviation in the Chinese Aerospace is key for China while Europe has a large experience. The task is on-going.

5. DISSEMINATION ACTIONS

Different activities have been performed for the dissemination of GRAIN2 outputs. The most important ones are the GRAIN2 public events, like the workshops in Beijing and Xi`an and the short course in Capua. The project webpage is also a useful tool for the dissemination of the project activities including the coming events (www.cimne.com/grain2/).

In addition to that, the activities of GRAIN2 have been disseminated through two different presentations:

CSA: GRAIN, Greener Europe - China Networking in Aeronautics through projects GRAIN and GRAIN2, G. Bugeda 3rd EASN Association International Workshop on AeroStructures. October 9-11, 2013 in Milano, Italia.

GRAIN2 Project: GReener Aeronautics International Networking-2 - Overall Presentation, G. Bugeda 4th EASN Association International Workshop on Flight Physics & Aircraft Design. October 27-29, 2013 in Aachen, Germany.

Finally, GRAIN2 activities and main outputs will also be presented during the coming AERODAYS in London 20-23 October 2015.

6. TECHNOLOGICAL CHALLENGES IDENTIFIED BY THE GRAIN2 CONSORTIUM

After more than 10 years of collaboration between EU and China a lot of opportunities have been identified. These are based on the high research capabilities on both sides and the large infrastructures available for industry and research.

Also some big challenges have been identified which are originated by the growing air traffic in China and its integration at an international level, the development of new aviation products and the extension of some green aeronautical technologies to other transport modalities.

The different GRAIN2 KGTs have already identified RTD topics for future collaboration. Here below we list the synthesis of these topics. Additional details can be seen in the following sections.

KGT1: Propulsion related green technologies

Propulsion

1. Low Pressure Turbine (LPT) aerodynamics and heat transfer
2. Multidisciplinary design and optimization of turbomachinery components.

New Energy for Aviation

1. Safer and more efficient certification of Aviation Alternative Fuel (AAF)

Two key subjects are proposed for aero-thermodynamical research in aircraft engines

KGT1-1: Propulsion related green technologies-PROPULSION

Low Pressure Turbines

The demand for higher bypass ratios in modern commercial jet engines requires the low-pressure turbines at the exit of the engine:

- to provide an increasingly larger power output allowing a direct drive of large fans without penalizing the global efficiency.
- At the same time, their design asks for a reduction of the turbine blade count and/or
- the implementation of new, lighter materials of in order to save weight and/or secure lower manufacturing and operating costs.

This eventually implies an increase of the aerodynamic load on each blade, towards the development of very high or even ultra-high lift airfoils. These are characterized by

- a high velocity peak on the suction side,
- followed by a significant diffusion.
- The resulting strong adverse pressure gradient along this surface may possibly induce a separation of the boundary layer, particularly at low Reynolds number, This may finally cause a significant loss in lift and a consequent drop in engine efficiency.

For large commercial turbofans, a loss in LP turbine efficiency of the order of 2 % may occur between sea-level take-off conditions and high-altitude cruise flight (where the Reynolds number drops by almost one order of magnitude). Consequently, deep analysis, understanding and prediction capabilities are of utmost importance to secure an efficient engine design.

This implies the need for both

- accurate time-resolved measurements (including higher order turbulence characteristics) at engine similar conditions (Mach and Reynolds number, turbulence, upstream/downstream unsteadyness)
- high fidelity computational methods, going far beyond the classical RANS approaches, not very satisfactory at the lowest Reynolds numbers.

Today’s experimental and computational approaches probably provide an acceptable mean flow description and global (integrated) performance (loss) parameters, but many of them fail in the description of higher order statistical characteristics. It therefore remains a major area for further basic and applied research in this particular area of the turbine.

Based on several research programs conducted in US and Europe over the last decade, the so-called ‘geared-fan’ engine architecture appears very promising as the future engine architecture. The principle is to choose for a small size, fast low pressure turbine (reducing therefore its volume and weight) and to introduce a gearbox between the low rpm - large fan and the high rpm - small LP turbine.

- Reynolds number issues are still present,
- Mach number issues (transonic flow, shocks) appear as well.
- Moreover, considering the higher rotational speed of the turbine, structural issues will also develop.

This calls for a multidisciplinary design strategy. Competences need again to be developed both from the experimental and the numerical side.

Multi-disciplinary optimization

Not so long ago, the design of a component was dominated by the experience gained during previous designs and simple correlations. Prototypes were built and tested, and improvements were proposed based on the newly acquired knowledge.

Nowadays, Computational Fluid Dynamics tools are in continuous development for aerodynamics, heat transfer, structural mechanics, aero-acoustics, vibration … issues. They start to be introduced (unfortunately not all of them at the same time) into the design process as an alternative to the time consuming and very expensive tests in experimental facilities. Designs are immediately tested by CFD, requiring (for each new individual design) a few hours of computational time. The iterative nature of the design, however, has remained in most of the cases … and classical CFD remains costly (especially in time). At the end, experiments are still made on the final design for a final validation of the product and of the CFD predictions. This information is an important feedback to verify and validate the models as they can reveal their shortcomings and can be used to improve them.

However, new challenges arise. The shortening of the design cycle, to adapt to rapidly changing market demands, and the increase of the performance are nowadays the main challenges in component design. Many different designs need to be evaluated and compared. Improvements are obtained by carefully examining the effect of each parameter on the performance of the design. Choices such as the material of a part and its shape can be evaluated in terms of e.g. strength, efficiency, manufacturability, overall production cost, etc.

However, the large amount of parameters that can be independently modified complicates the task, and increases the classical CPU time. In order to get much faster responses, the last years have seen a large development of so called optimization algorithms, coupled to 'Meta-Models' (also known as complex 'interpolations'). These algorithms, such as e.g. genetic algorithms (the optimization) coupled to e.g. a neural network (the Meta-Model or the 'interpolator') allow to explore the design space with a speed which is 3 or 4 orders of magnitude higher than a classical CFD approach. The challenge is of course to define the correct objective functions and constraints and to correctly 'train' the Meta-Model to provide accurate predictions. The main challenge here is to apply this approach in a multi-disciplinary environment. This challenge also calls for the availability of multi-disciplinary accurate measurements and/or high fidelity CFD methods in order to support the training of the various Meta-Models.

KGT1-2: Propulsion related green technologies-NEW ENERGY FOR AVIATION

Safer and more efficient certification of Aviation Alternative Fuel (AAF)

The availability of alternative aviation fuel not only has a huge environmental impact but it is vital that manufacturers both in Europe and China try to maintain a position within world competition for the sustainable growth of aviation transport for improving energy independence, lessening global-warming effects, and mitigating the economic uncertainty of crude oil prices. "Drop-in" fuels are defined to substitute for kerosene without change of aero-engine and aircraft as well as infrastructure. Accordingly, the current standard specification for alternative fuel (ASTM 7566-13) have been deduced from the jet fuel specification properties (ASTM 1655) based on as same as kerosene, which results in high cost in fuel refinement. Since the difference between alternative fuels and kerosene in components, only testing of physical and chemical properties cannot confirm the security of alternative fuel in aero-engine. Therefore, the certification process of alternative fuel includes the testing of physics and chemistry, the testing of fit-for-purpose, hot section testing, component testing, and system test according to ASTM D4054, which results in fuel-cost in certification testing. Hence, three challenges including high cost in fuel refinement, fuel-cost in certification testing, lack available testing condition and the acceptance criteria in recent standard are expected to be overcome.

With the development of this research project, CAAC and EASA will develop the certification of alternative fuels in compliance with airworthiness standards, and promote the formation of the Sino-EU alternative aviation fuel certification standards.

- Low fuel cost in certification process
- Low cost in biofuel refining
- Novel drop-in & non drop-in fuel certification process and management.

KGT2: Airframe Flight Physics

Noise reduction

1. Advanced experimental and numerical methodologies for analysing noise generation and propagation.
2. Innovative noise control/reduction technologies

3. Low-noise concepts and installation effects

Drag and CO2 reduction

1. Advanced simulation of high Reynolds number, realistic setting controlled flows on large/innovative HPC architectures.
2. Advanced turbulent models for modelling detached flows and laminar-turbulent transition.
3. Multidisciplinary optimization technology
4. Instability analysis and unsteadiness control in aircraft design.

KGT2-1: Airframe Flight Physics-Noise reduction

Computational methodologies and experimental technologies for effective analysis of aero-acoustic noise generation and propagation

For next-generation quieter aircraft design and making steps toward the realization of the ambitious goals set by ACARE Flightpath 2050, one of the essential aspects is to comprehensively understand and accurately address noise generation and radiation by means of experimental measurements and computational simulations. In spite of remarkable effort and progress made over the years, particularly, in EU framework programs, it is recognized that current experimental technologies and numerical methodologies are not sufficiently complying with the need of effective industrial use for accurate analysis of aircraft noise emission. For massive industrial applications in design process and for problem diagnosis and mitigation, reducing aircraft development time and costs has in many cases been attained at a price of reduced reliability and accuracy of solutions.

Comprehensive aero-acoustic analysis rests on an accurate exploration on near-field unsteady aerodynamic flow physics and far-field noise transmission. This requires a correlated setup, in either experimental measurements or numerical simulations, of systematic studies on turbulent aerodynamic flows (as noise-generating sources) and far-field noise propagation (in relation to aircraft noise emission and its impact on environment). A lack of reliable correlation between noise generation and propagation forms a significant source of inaccuracy in many current aero-acoustic measurements and simulations.

For accurate CFD/CAA (Computational Fluid Dynamics/Computational Aero-Acoustics) analysis, furthermore, the computational resources may become excessively demanding, or even prohibitive, for applications of industrial relevance to formulate aerodynamic noise generation in correlation with far-field noise propagation. High-Performance Computing (HPC) architectures, in conjunction with robust numerical algorithms and advanced flow-physics modelling approaches, have been emerging as large-scale computational methodologies exploitable to make steps forward for facilitating the use of CFD/CAA as potential industrial tools implemented in the process of developing quieter aircraft.

The proposed RTD topic, standing on the basis of emerging computational methods and experimental technologies that have shown promising capabilities (yet often in academic research), aims at new development and further improvement to enhance the TRL beyond the current state of the art on two primary aspects: *robust CFD/CAA methodologies* and *effective experimental technologies* for addressing industry-relevant aero-acoustic problems.

Aircraft noise-control technologies and integration strategies of control systems

Over almost two decades, the urgency to reduce the airframe and engine noise components has become increasingly pressing, and the most straightforward approach to obtain noise reduction without affecting the other key attributes in aircraft design has been to apply proven technologies and refine existing designs. But it has since become more obvious that the ambitious ACARE targets set for 2050 won't be reached with existing technologies. Given the noise generation mechanisms cannot be drastically reduced from further incremental refinement of the current designs, the step for a breakthrough change has to come from innovative approaches based on fundamental research and detailed investigations of novel concepts.

To achieve the ambitious goals set by Flightpath 2050, it is necessary to develop the most effective technologies for modifying the near-field noise generation mechanisms and leading to far-field noise reduction. This objective has sustained continuous efforts over the recent years, aiming at the development of innovative methods for the control of noise generation and propagation, giving birth to new innovative methodologies and technologies targeting airframe and engine noise reduction.

In spite of significant contributions made in a large amount of previous and ongoing effort on effective noise-control technologies, nonetheless, the gap remains large from current academic laboratory research to actual industrial deployment. Indeed, quantifying the benefits of a new design, noise control or abatement procedure in terms of decibels is a very challenging task. Two key factors are at least partly responsible for this difficulty. Firstly, the non-linearity of fluid dynamics makes it very complicated and effort-consuming to predict the transient behaviour of a flow field, especially for the very high Reynolds number at stake in aeronautics. Unfortunately, knowledge on the transient features of turbulence are an essential ingredient of the aero-acoustic prediction chain, because the mechanisms causing noise in the far-field result from subtle imbalances in amplitudes and phases between reciprocating motions in the medium. Secondly, the past efforts conducted to reduce the noise emitted by the various components of an airplane have resulted in a fair balance between their respective contributions integrated over a complete flight. Different components are clearly dominating the noise spectrum at take-off, and others are responsible for most annoyance during landing. In order to address in a timely and cost-effective way the problem of aircraft noise using noise-control technologies, it is essential to devise integration strategies aiming at developing and deploying best common denominator technologies, in terms of applicability to the different elements

By means of numerical simulations and/or experimental testing, the proposed RIA topic aims at development of emerging innovative noise-control concepts and, going beyond the proof of concepts reported in academic research, enhancing further the TRL with relevant validation of identified promising noise-reduction technologies, which are supported further by the development of integration strategies of control systems installed on different aircraft components.

Low-noise configurations and airframe-aeroengine installation supported by multidisciplinary optimization

Aviation has a significant impact on the environment and the EU citizens due to emissions (noises, pollutant matter and contrails) to which the population is exposed. On the other hand, aviation generates around 2% of EU GDP and accounts directly and indirectly for 3.7 million jobs. This has led to the implementation of a number of ambitious goals set by the sector at horizon 2050 in the Strategic Research and Innovation Agenda (SRIA) of the Advisory Council for Aviation Research and Innovation in Europe (ACARE). For noise emissions, the target to meet by the 2020 horizon is to reduce perceived external noise by 50%, while the new horizon defined for 2050 (described in the Flightpath 2050 document) is targeting a reduction by 65%. In support of this objective, it has been acknowledged that the technological objectives will not be reached through an evolutionary approach only. Breakthrough innovations are needed, i.e. new solutions which rely on a disruption with respect to current approaches.

In the process of developing future new aircraft concepts, obviously, the step must be progressed by a close coupling with research on innovative low-noise configurations of airframe components and power systems, as well as on low-noise aircraft installation. The proposed research and innovation actions target new low-noise technologies and concepts that are not currently used in aeronautics or that have not yet being put in combination in the aviation sector. By means of numerical simulations and experimental measurements, innovative low-noise high-lift configurations, landing-gear systems and airframe-aeroengine installation, in which multidisciplinary optimization will play a significant role in supporting the design of new low-noise concepts and will be undergone further development to improve its applicability for robust aero-acoustic design.

The proposed RIA topic aims at demonstrating the validity of the low-noise technologies and concepts resting on sound technical and scientific approaches. The aerodynamic and aero-acoustic performance should be jointly assessed quantitatively against the relevant criteria such as economic viability, time efficiency, potential to cope with evolutions of regulations, environmental friendliness and energy sustainability etc. The proposed topic will also assess at the end the potential of the low-noise technologies and concepts developed at further technology readiness levels and possible barriers that may prevent such developments.

KGT2-2: Airframe Flight Physics-DRAG AND CO2 reduction

Advanced simulation of high Reynolds number range, realistic setting controlled flows on large/innovative HPC architectures

Substantial resources have been invested over the years into Computational Fluid Dynamics (CFD), particularly in the development of efficient and robust numerical algorithms for solution of the governing equations, grid generation and adaptation, powerful post-processing tools, etc. Not surprisingly, these investments (many of them made in the framework of European programs) have resulted in a remarkable progress in CFD capabilities. This contributed significantly to improve the flow physics understanding, reduce aircraft development time and cost minimizing the reliance on wind-tunnel and flight tests. However, experience shows that industrial numerical simulation tools are presently suffering two main drawbacks that prevent their full industrial deployment for massive applications in design process: excessive long computational times for problems of industrial relevance, and reduced reliability and accuracy of the solutions at flight extremes. This includes the accurate simulation of turbulent drag reduction through the application of active/passive flow-control techniques to manipulate the drag produced by the flow structures in turbulent boundary layers.

If current simulation capabilities, including LES and RANS/LES models, can be made to work with drag reduction techniques (passive/active flow control), the simulation of full aircraft at high Re would certainly reveal many indirect effects of reducing drag locally and which can be very useful for aircraft design process.

Research in flow control needs to be done subject to more complex conditions: realistic geometries, strong curvature, adverse pressure gradient, free-stream turbulence, etc that characterizes the practical aircraft setting. The efforts should be made to substantially up the Reynolds number range of problems to be addressed. This would mean to go increasingly for extremely high-quality LES and possibly LES-RANS. The latter requires very careful discrimination and much judgment on the penalties incurred. With any shift towards more complex conditions and LES model, the use of high-order methods is ever more important.

Realistic actuators and sensors that provide the prospect of realistic boundary conditions that feed into the simulation tools are of high importance. Simulators need to understand what actuators are realistic in a practical setting (frequency, density of actuators, size, reliability….). Important part of the computational research needs then be devoted to how these actuators can be represented realistically in a computational setting. A proper and accurate set of experimental data necessary for the validation process is also of vital importance.

New numerical methods and new hardware architectures are emerging as possible solutions of these problems: High order methods in complex geometries could be the solution to obtain the desired accuracy. At the same time, the capabilities of leading-edge emerging HPC architectures are still not fully exploited by simulation tools for large aeronautical problems. These do not take advantage of the immense new capabilities of new hardware architectures, such as streaming processors or many-core platforms. Likewise, current high order methods are mainly limited to academic environment, it is necessary to mature their application in complex geometries and high Reynolds problems.

In order to tackle these problems. We propose to go beyond the state of the art in the following main research lines: 1) Advanced techniques for efficient implementation of solvers on heterogeneous and highly parallel High-Performance Computing (HPC) architectures. 2) Innovative and efficient numerical algorithms for large scale computing in aeronautics, based on advanced parallel architectures. In particular High-order methods in complex geometries and high Reynolds numbers.

Advanced turbulent models for Computational Fluid Dynamics

Computational Fluid Dynamics (CFD) techniques have become essential in the aircraft design loop and are regularly used by most industrial aircraft manufacturers. Namely, these numerical techniques are used to define aircraft aerodynamic surfaces and provide valuable information to the structural and loads departments enabling a cost efficient aircraft design with reduced fuel consumption. Furthermore, the use of CFD is saving time and resources, limiting the number of costly wind tunnel experiments and flight tests. In some occasions, numerical simulations are the only available tool to evaluate extreme aircraft conditions and performance such as stalled conditions, shock boundary layer interaction or buffet. Although CFD techniques have been shown to be mature enough for benign design flow conditions, the accuracy of the numerical solutions near the design envelope limits, or when new aircraft configurations are considered, are still limited.

Two key elements are identified as the main bottlenecks for the full acceptance of CFD results by industry near the limits of the design envelope.

- Firstly, **turbulence modelling** has seen major enhancements during the last decades but its accuracy remains limited for **detached flows**.

- Secondly, **laminar-turbulent transition** modelling is one of the major bottlenecks for CFD and essential to accurately compute aircraft performance and loads.

Detached flows and turbulence modelling

The following future activities are suggested to address future needs in the accurate simulation of complex aerodynamic flows:

- **Further development of improved RANS approaches**, focussing on reliable separation prediction for complex 3D flows and correct prediction of turbulence levels in the early separated shear layer (responsible for errors in reattachment prediction). RANS will remain the only affordable approach in high-Re boundary layers for decades to come – also in the framework of hybrid RANS-LES methods, the accuracy of which can be limited by RANS errors.
- **Industrialisation of hybrid RANS-LES models**, which consists of several aspects:
    - Consolidation of the latest state of the art improved methods
    - Further improvement of Grey Area behaviour without loss of generality and robustness
    - “Smarter” models requiring less user input and decisions:
        - More “flexible” zonal/embedded approaches
        - Automatic detection of RANS and LES regions
        - Automatic and adaptive meshing for hybrid RANS-LES methods
    - Addressing the expertise gap between the developer and user communities via clear best practice guidelines, method applicability recommendations and training events
- **Development and implementation of models for flow control devices**, in order to capture the effects of e.g. vortex generators, synthetic jets, plasma actuators, turbulent screens, riblets in a cost-effective manner. Extension of RANS models to include such effects will enable the assessment of such advanced concepts at aircraft level as well as opening the door to efficient (adjoint) optimisation of flow control device parameters and placement.

Additionally to improvements in cruise flight drag, significant benefits can also be expected from a better knowledge and modelling of boundary layer flow during transient phases of flight. High-lift configurations need reliable predictions of boundary layers with regions of strong adverse pressure gradient which are close to separation and sometimes even locally separated. Separation limits the maximum lift that a wing can generate at low speeds, and thus limits the achievable speed reduction required to ensure safe take-off and landing conditions. Prediction of separation is highly sensitive to simulation tool deficiencies and quickly becomes unreliable rendering aerodynamic optimization and drag reduction efforts futile.

Laminar-turbulent transition

The physical mechanisms by which a laminar flow transitions to a turbulent regime are relatively well understood. In boundary layer cases, transition can be (in most scenarios) explained by modal linear instability, which considers spatial linear growth of Tollmien–Schlichting (TS) waves. However, in some cases a temporal transient growth of perturbation (i.e. non modal instability) can explain some “bypassed transition” mechanism to turbulence. Other physical mechanisms for transition are 3D cross-flow transition, or purely inviscid instabilities which can be explained by inflection points in the velocity gradients. Techniques to compute modal and non-modal instability analysis are varied. One of the most widespread methods (and accepted in industry) is the e^N method, which accounts for the TS type of transition. However, there is a lack of generalised models that are able to predict laminar-turbulent transition. Namely, CFD methods to predict transition do not in general incorporate the linear instability knowledge (neither modal nor non-modal). It is therefore necessary to unify the linear stability information, and incorporate this into mature CFD techniques, to create new models that can explain transition to turbulence for a variety of flow scenarios such as in the presence of adverse pressure gradients, bubbles or detached flows.

In summary, most advanced Computational Fluid Dynamics tools are able to accurately predict the vast majority of flow problems if the appropriate computational model (e.g. geometrical simplifications, turbulence model) and enough resolution (e.g. mesh of sufficient refinement and quality or increased formal order of the method) are selected for simulation. Computational inaccuracies may be categorised as modelling errors (e.g. separated flows and transition to turbulence) or purely numerical errors. To mitigate these two types of errors requires better models and higher resolution.

Consequently, more reliable and accurate models, such as turbulence models for detached flows and models to predict laminar-turbulent transition are required which will ensure a significant widening of applicability of CFD solvers, particularly in off-design and maximum load situations.

Multidisciplinary optimization technology for innovative aircraft configurations including local flow control applications

The improvement of the optimization process in the aerodynamic design of aircraft configurations is becoming of key factor to reduce development and operational costs and decrease the time-to-market for new aircrafts. Indeed, despite the increased computational power, the greater sophistication and perfection of physical and computational models and an ever more automated industrialization process, it is undeniable that the timescale for realization of new aircraft (from paper to the market) has not substantially reduced. In this framework, innovative optimization techniques can play a major role, as effective and intelligent exploration of the space of all possible configurations is an essential requirement to reach the goal of time-to-market decrease in aerospace industry.

The expected increase of air traffic for the next fifteen years has established several environmental targets for the next generation of aircraft: 50% reduction in carbon dioxide emissions, fuel consumption, perceived noise and development time, as well as 80% reduction in emissions of nitrogen oxides. The achievement of these targets makes necessary to explore other unconventional/innovative configurations. In this search for optimized innovative configurations one also can add to this design optimization processes the possibilities of taking on board flow control devices early in the design stages. The typical application of flow control devices are presently used with the purpose of mitigating some undesired effect, namely drag or flow detachment. That means that flow control is generally a patch that is applied on and already designed aircraft, thus, hampering the exploitation of its full potential, that could only be achieved after a complete integration of the flow control into the aerodynamic design process.

However, in practical optimization problems, in which hundreds of design variables are considered, the use of current RANS industrial solvers is unfeasible because of their high computational cost. Alternative mathematical tools are necessary in this context; different techniques as surrogate modeling, control theory together with code optimization and proper parallelization methods can decrease the cost of the optimization aerodynamic design process.

Other contribution is related to the consideration of the design process as a global optimization problem; in this regard, the use of evolutionary algorithms (EAs), due to their ability to obtain global optima, in combination with metamodels to substitute expensive CFD simulations, makes possible to perform a preliminary exploration of the design space at a relative low cost.

There are several examples of aerodynamic optimization using an Evolutionary Programming algorithm hybridized with a Support Vector regression algorithm (SVMr) as a metamodel. Specific issues as precision, dataset training size, geometry parameterization sensitivity and design of experiments techniques are still an issue and the potential of the proposed approach to achieve innovative shapes that would not be achieved with traditional methods is very attractive.

We may then faced with the question of how to be sure we have found out the maximum potential of the outcome of the preliminary designs - if results aren't as good as hoped, there will be doubts such as "did we put the actuators in the wrong place?. Should the amplitude/frequency be adjusted? Very quickly, even considering mono-disciplinary optimisation, we have a very large parameter space. Adjoint optimisation of flow control systems therefore becomes a very attractive prospect: Sensitivities can be computed for thousands of parameters for the same computational expense as one parameter, making it possible to consider delegating actuator placement and configuration to an optimisation process. Work in this direction is developed by Uni-Kaiserslautern and have successfully computed the adjoint sensitivities for synthetic jet AFC to a full complexity high-lift / fuselage configuration.

Another crucial point is the introduction of robust or reliability based optimization techniques in the design loop. Indeed, industrial optimization processes must take account of the stochastic nature of the system and processes to design or re-design and consider the variability of some of the parameters that describe them. Thus it is necessary to characterize the system that is being studied from various points of view related to the treatment of uncertainty. In particular, it is necessary to consider the sensitivity of the system to the uncertain parameters and assess its reliability. Then, having established the ability to characterize the system from this point of view, it is necessary to build an optimization loop that can improve its reliability or that is capable of providing a robust optimum, or that could withstand acceptably random perturbations of design parameters or operating conditions.

Integration of Local flow control for cruise drag reduction in future transport Aircraft

Latest research in flow control has shown important benefits in both cruise and low speed configuration by avoiding flow detachment, reattaching the flow, re-laminarizing the boundary layer, etc.

The typical application of flow control devices is on an already designed geometry, with the purpose of mitigating some undesired effect, namely drag or flow detachment. That means that flow control is generally a patch that is applied on and already designed aircraft, thus, hampering the exploitation of its full potential, that could only be achieved after a complete integration of the flow control into the aerodynamic design process.

First steps of flow control applications integrated into the design process are currently ongoing with the application of hybrid laminar flow control on the wing leading edge; thus requiring a small redesign of the airfoil profile for already manufactured wings. But a big step is still required in the design process in order to take onboard the possibilities of the flow control devices from the early design stages, and not as a mitigation action.

Universities and research centers have made a huge effort to develop new flow control devices with progressively less and less power consumption and an increasing accuracy in their simulation models. Nevertheless, there is still a breach that needs to be traversed: we need to learn how to capitalize on the full potential of the wide range of available flow control devices, and this exploitation does not yield from an isolated optimization but from the complete integration of the system.

The expertise in flow control devices is currently spread among academia, research centers and industry. Each of us masters a different flow control device, the typical aerodynamic design process or even the preliminary design process involving all the disciplines. Thus we have a quite comprehensive toolbox of flow control techniques, from which some of them have already been successfully applied for solving a specific problem (eg. boundary layer suction to extend laminar regime on the wing). Nevertheless, the range of applicability and the potential benefit of many other devices remain still relatively unknown. It is widely accepted that we could better design the aero shapes if we introduce the flow control techniques in the early stages (eg. increased efficiency leading to smaller surfaces, less interference drag...)

The process of the technology readiness level evolution demands some specific steps before the possible industrialization: from a concept proof stage we need to develop pilot cases. Those pilot cases should be attractive and representative enough. The application of the already developed knowledge on a real problem will give us the opportunity to attain higher maturity levels. "*We do not know how to use a hammer only after reading its user manual, but after hitting some nails"*.

The path to such an ambitious activity is surrounded by traps that might attract the attention and divert our efforts. Thus a clear scope management will be required to keep the focus of the activity within the area of biggest interest, namely the application of the different flow control techniques for solving a specific problem.

Any multidisciplinary optimization that couples aerodynamic forces with the structure, although extremely interesting, cannot be considered within this activity by two main reasons: firstly, aero-structural coupling technology is already relatively mature and it is being applied by the industry, universities and research organizations, and secondly, this wider scope would weaken the focus of the activity on the integration of the flow control devices into the aerodynamic design. The first step in the process is to couple two bricks: aerodynamic design and flow control devices, before thinking about a higher complexity application with other disciplines involved.

KGT3: Environmental friendly materials and structures

1. Environmentally friendly materials
2. Functional integration
3. Structural Health Monitoring

KGT3: Environmental friendly materials and structures

Research topics related to materials

Current aircraft designs are already a result of the transition from metal structures towards lightweight composite structures mainly made from carbon fiber composites (CFRP). While these materials allow a lighter construction and therefore improve the ratio of aircraft weight to passenger/cargo weight there are several challenges regarding the environmental impact of these materials:

- The production of CFRP materials requires a lot of energy, which reduced the benefit of saving energy during its lifetime. Therefore alternative material sourced like bio-sourced materials should be investigated.
- The production process of composite structures still features a large amount of manual work. There is still a large potential to improve and automate all manufacturing steps in order to make them more efficient and reduce the required energy.
- Composite materials are difficult to recycle because they may lose their superior properties during the recycling process. Considering the amount of energy put into the production and manufacturing of these materials the recycling techniques should be improved in order to created secondary materials with a minimized loss in performance.

The following research topics have been identified as to most promising ones in the context of environmentally friendly materials and production.

Bio-sourced fibers

Much of the energy required for producing conventional composite materials is put into the production of the fibers. This includes both the production process and the origin of the raw materials, since they are mainly based on fossil resources. Bio-sourced fibers can be an alternative, but require specific research and development to reach competitive performance levels and production processes suitable for an industrial use.

With respect to bio-sourced fibers the following aspects are foremost important for future research:

- Fatigue behavior and durability – Bio-sourced fibers cannot be tailored to mechanical performance to the same degree as conventional fibers. They have a different structure (often hollow) and show a much higher spread in parameters due to their natural origin. Since this has a direct impact on the mechanical performance of the material the fatigue behavior and durability should be investigated. This also includes the development of numerical simulations that take into account the special properties of these materials.
- Cost-effective and environmentally friendly production of long-fiber semi-finished products with adapted properties – While conventional fibers can be produced in a continuous process the length of natural fibers is limited. For an industrial application however it is essential to provide semi-finished materials with a long-fiber character and defined properties. Future research should first focus on the general feasibility of producing such materials and later on developing suitable production processes for larger scales.

In addition to the aspects mentioned here future research activities should also be built on the developments and findings of the EU project Eco-Compass.

Bio-sourced resins and additives

Although the matrix material of fiber composites holds the fibers in place and distributes the loads to the fibers its mechanical performance is not always as critical as that of the fibers. Therefore a feasible solution for improving the environmental footprint of composite materials may be replacing conventional petrol-based matrix materials with bio-sourced materials while maintaining the high mechanical performance using conventional fibers.

Research and innovation efforts, during upcoming years, should be focused on obtaining 100% bio-based polymeric matrices that could meet the high requirements of aeronautical industry, encompassing resins , fillers and curing agents.

As second step, greener synthetic routes should be explored in order to reduce the carbon footprint of the associated processes, together with energy consumption decrease and minimization of reaction byproducts.

Besides, bio-mimetic self-healing thermoset composite will probably undergo the highest growth within the different materials used when it comes to aircrafts, providing the ability of self-repairing small damages caused by impacts or erosion. Thereby, the lifespan of aircrafts will be greatly increased, maintenance costs will be reduced. Additionally, indirect environmental impact is expected since the energy consumption and gas emission associated to part manufacturing will be reduce as a result of their durability thereof.

Nevertheless, there is a bigger challenge to be achieved in order to guarantee eco-sustainability of aeronautical industry; composites recycling after aircrafts end-of-life, where polymer matrices composition will play a key role in future. Chemical recycling technologies, comprising depolymerization and purification processes to obtain recycled raw materials and recycled long fibers should be seriously investigated during next years.

As in bio-sourced fibers case, future research activities should also be built on the developments and findings of the EU project Eco-Compass.

Thermoplastic composites

Thermoplastics composites have the advantage over thermoset materials of higher impact resistance. They also offer the possibility of employing fast forming processes, such as press forming. The combination of these types of processing with automation of the manufacturing process offers the possibility to improve the overall manufacturing process.

There is a long way to be toured in terms of eco-friendliness in thermoplastic composites, however, developments carried out in EU project Eco-Compass regarding fibers and bio-sources could represent a considerable shortcut to achieve the thermoplastic target of 100% bio-based materials. Nevertheless, high performance demanded in current aeronautical thermoplastic composites, such as PEEK or PPS based ones, represents a real challenge to be achieved by bio-based materials that use to be based in polyester backbones that cannot accomplish mandatory requirements, such as high maximum service temperatures.

Besides its bio-based character, fire resistance should be enhanced, by means of replacing halogen based flame retardants by intrinsic covalently linked halogen-free additives. New fire resistant thermoplastics should impart desired properties without penalizing mechanical and thermal properties.

Fiber reinforced thermoplastics present several advantages in respect with thermosets. Thermoplastic matrices offer the ability to be reprocessed by thermal transformation conventional processes, such as injection molding or thermoforming, avoiding the current thermoset composite recycling technologies that consist of difficult and high energy consumption chemical methodologies. Notwithstanding, a previous conditioning milling steps has to be done to obtain short fiber reinforced thermoplastics that can be midway between high performance and engineering polymer, and hence, can be used as raw materials to obtain non-structural high added value parts of aircrafts.

Chemical surface treatment

In contrast to conventional fibers bio-sourced fibers often do not have the same non-mechanical properties. They are not as fire-resistant, pick up moisture more easily and may need fungus protection. Due to the natural variations of the fibers they may also need a surface preparation to assure proper and even bonding to the matrix material. It is therefore essential to develop suitable surface treatments to handle these properties. The key aspects to consider here are the environmental compliance of the chemical agents and processes involved and their impact on the materials properties, e.g. additional weight due to required additives.

Low-cost and automated manufacturing

Current processes involved in manufacturing complex composite parts still involve a large amount of manual work. Processes like fibre placement have already been developed to industrial application, but are often limited to simple geometries and specific raw materials (pre-impregnated fibers). In order to automate the remaining manual tasks, technologies like robot-based pick-and-place systems, which can also handle dry fibers and complex geometries should be developed to a stage where they can contribute to reducing costs and improving the quality of smaller series.

Other approaches for improving manufacturing processes should focus on using simpler manufacturing methods, like oven curing or automated resin infusion. With a focus on saving energy during production and avoiding scrap parts process monitoring and control is a very promising field of research. Using monitoring methods, such as ultrasonic cure monitoring, the manufacturing process can be adapted to what is actually happening with the part to be produced. This approach can replace the current practice of running processes that are longer than necessary (and therefore consume more energy) to avoid scrap parts.

Life-cycle assessment on innovative composite materials

Since the main purpose of using bio-sourced materials instead of conventional materials is the improvement of the environmental impact, a proper life-cycle analysis should always be part of the research activities described above.

This of course requires verified models for quantifying energy consumption, CO_x-output etc. during the production and lifetime of these materials. A complete life-cycle assessment should therefore be developed for the most promising materials and the processes involved in their production.

Research topics related to functional integration

Alternative materials to currently used composites may be much more environmentally friendly during the initial production process and have a better environmental footprint during their lifetime. However, bringing these materials into future aircraft may not be successful if only mechanical properties are considered, since the development of modern composite materials is highly focused on superior mechanical performance. A promising approach to let alternative materials compete with these conventional materials is the integration of additional functionality and the enhancement of inherent properties of these materials. The aim of this approach is to not only replace current materials, but to have an alternative material with integrated functionality that can replace a conventional material and additional external measures and systems, which provide the functionality in a conventional way. The functional integration may include:

- Tailored thermal and electrical conductivity (e.g. as a replacement for additional insulation)
- Energy storage integration (replacing external batteries)
- Enhanced damping properties (replacing measures for acoustic insulation and simplifying mechanical compliance)

The following research topics have been identified as the most promising ones in the context of functional integration.

Energy storage

A great advantage of composite materials is their flexible lay-up in which additional functionality can be integrated easily. Especially as soon as electrical systems replace hydraulic or pneumatic systems the demand for electrical power storage systems also grows. Due to the fact that common storage systems, such as batteries, are very heavy and rather bulky, a constructive solution would be their integration in or their combination with structural components, such as the frame or unloaded parts, such as attachments.

There are several areas of interest for the research in the fields of structural energy storage:

- Structural Integration of available systems into a composite with sufficient electrical conductivity and the ability of replacement and repair;
- Development of semi-finished storage systems with a comparable high energy density and/or power density for better structural integration;
- Improvement of composite materials for their multifunctional use as components of an energy storage device;
- The integration process and design has to be evaluated in terms of lightweight construction considerations.
- The structural energy storage system should be as fault-tolerant as possible in terms of cash-issues. Furthermore safety-issues such as toxicity, flammability and environmental compatibility have to be taken into account.

Research topics related to Structural Health Monitoring

Independent of the materials being used it is essential to assure a proper mechanical function of aerospace structures during their entire lifetime. In this context there are two aspects, which can greatly reduce the efficiency of the materials during design and operation

- The spectrum of the mechanical loads which is to be expected during given operating conditions is understood rather well. However there are many uncertainties that must be considered (e.g. manufacturing tolerances). These uncertainties lead to large safety factors and may make a structure much heavier that it actually needs to be.
- The current aircraft operation and design is based on strictly scheduled maintenance plans. Since an in-depth inspection leads a grounding of the aircraft and therefore reduces availability, inspection intervals are increasingly extended. This in turn requires a structure with an undetected damage to last until the next inspection interval, making it much heavier that actually necessary.

These issues can be addressed by introducing a structural health monitoring (SHM). This continuous monitoring is already common practice for systems like engines and electrical circuitry, but is practically completely absent for structures. The goals of introducing structural health monitoring are

- Finding damages as early as possible in order to take appropriate actions while the damage is small. This should allow for a simple repair instead of replacing large parts after undetected damage growth.
- Detecting severe impacts and their location during operation on the ground and in flight, for which composite airframe structures are much more vulnerable. This allows for early and complete detection of possible damaging impacts that may otherwise remain undetected.
- Extending the life-time of existing structures by monitoring critical areas as an economically more efficient solution than conventional inspection at short intervals.
- Reducing structural weight by increasing the capabilities of detecting damages between scheduled inspections and therefore being able to reduce unnecessarily high safety factors.
- Demand-driven maintenance instead of strictly scheduled maintenance in order to make the aircraft and fleet operation more efficient.

The following research topics have been identified as the most promising ones in the context of structural health monitoring:

SHM using Lamb waves

In contrast to other SHM methods like fiber-optic sensing or comparative vacuum measurements the use of Lamb waves, which can be thought of as integrated ultrasound inspection, allows a monitoring of the area around the sensors and not just at the sensor location. This potentially allows the coverage of large areas with a relatively small number of sensors.

Using a network of sensors distributed across the structure the propagation of guided acoustic waves (particularly Lamb waves) is evaluated. The presence of damage will lead to reflections of the waves and conversions between different wave modes. This can be detected as a change in the sensor signals.

Due to the measurement principle the time delay of the signal change with respect to the excitation of the wave is known at each sensor. Using different techniques like triangulation or reconstruction methods known from conventional ultrasonic testing the location of the damage can be determined. While this has been shown successfully for simple structures one common problem is, that the methods are often not applicable to complex structures. This is mainly due to variations in mechanical properties, which are directly linked to the way the waves propagate. In complex structures the stiffness may be different at each location and in each direction.

Therefore a major focus of future research related to SHM using lamb waves should be the improvement of suitable methods for determining damage locations in complex structures. This should not only be achieved by using a very dense sensor network and ignoring much of what is known about the structure, but by actually considering the properties of the structure and their impact on the wave propagation.

Another important aspect that is worth being focused on in future research initiatives is the generation of reference signals. As described above, signal changes are being detected and evaluated. This requires that suitable reference data is available. Since the wave propagation is influenced by many environmental aspects like temperature, humidity and structural loading, reference signals are required for all these conditions. It is not possible to determine all these signals by measurement. Therefore effective simulation methods should be developed in order to generate reference signals based on the given conditions of an aircraft.

SHM using fiber optic Bragg Gratings

Optical fibers containing a (potentially large) number of strain sensing Bragg Gratings offer a number of appealing advantages for application in aircraft structures, such as light weight, tolerance for harsh environments, long term stability, completely passive operation and no interference with other signals. The optical fibres can be embedded in the (composite) structure or surface mounted. The latter has the big advantage that a sensor can be installed at any time during manufacturing and operational life and that a broken sensor can be replaced.

Besides measuring the local strain, these sensors can also measure the temperature or even the pressure. Apart from damage detection the same or part of the sensor network can be applied for load monitoring and impact detection. This allows for a multiple purpose sensor network.

The current application of damage detection by means of FBGs lies in skin/stringer debonds and cracks in metallic joints. Another highly interesting application is the monitoring of composite repairs, which can circumvent the current problems related to the bond quality and durability of secondary bonding by monitoring the repair for disbands. This may save weight and also remove the need for so-called “chicken rivets”.

The new generation of data acquisition systems, developed within Europe, to read out the FBGs are based on optical chip designs and are very small and efficient. The sample rates are high enough for lower frequency (20 kHz) damage detection, but need to be further improved for impact detection (100 kHz) and Lamb wave detection (MHz). In the latter case FBG sensors can be combined with Lamb wave sensors described in the previous section.

SHM Technology

This rather general aspect covers the entire technological portfolio, which is required for a continuous monitoring of structures.

Many different methods and physical concepts for structural health monitoring are available. The research activities addressed here should therefore focus on answering the question of which methods are most suitable for monitoring a given structure within a defined framework, including the sensitivity to different damages and damage locations. This information is especially important for aircraft designers in order to give them an early indication on what improvement can be expected from SHM and how they can consider SHM in an early design stage.

General research aspects, which are relevant for using SHM systems and still needs to be addressed for all sensing technologies are the correlation of acquired signals to damage severity, which is important for whether and when more detailed inspection is required and the in-flight operation of SHM systems, where SHM signals have to be reliably separated from flight load influences.

Advanced sensor technology

The sensors being used for structural health monitoring can vary from simple and cheap piezo-ceramic discs to grouped and pre-packaged multi-sensor elements or autonomous sensor modules with on-board energy harvesting, data acquisition and communication.

In this context future research activities related to sensor technology should focus on the following aspects:

- How much functionality should be integrated into a single sensing element? – The aim of this research is to find an optimum compromise between a centrally organized network, where all functions are concentrated in a single device and a totally decentralized network where all functionality is concentrated in the sensing elements.
- Multi-physical sensing – Often more than one physical information is needed. This could be for example omnidirectional strain, multi-axial strain, temperature, acceleration or humidity. Instead of gathering all this information with independent systems it makes more sense to use a single sensor for multiple sensing purposes where possible or to group different sensors for reducing wiring and weight. A single multi-physical sensor may be heavier and more expensive than a conventional sensor, but could determine information that otherwise could only be obtained with multiple simple sensors. Wave modes of Lamb waves are a good example for this, because a single multi-axial (including out-of-plane) sensor might allow the separation of different wave modes, which would otherwise require at least three simple sensors. Another aspect that is worth being addressed here are sensors with a varying directivity.
- SHM method synergies – In order to monitor a complex structure more than one SHM method may be required. In order to maintain an overall small number of sensors synergies between different SHM methods should be investigated. E.g. for a combination of SHM using Lamb waves and fiber optic strain sensing the fiber optic sensors may also be used for detecting the Lamb waves.

Structural integration of sensors

A very challenging and critical aspect for adding an SHM system to a structure is the proper integration or application of the sensors and the required wiring. The SHM system may not in any way reduce the structural performance. It must be robust enough to theoretically last longer than the structure itself. This requires that the sensing elements themselves are sufficiently robust and that the entire system is properly protected against environmental influences, including mechanical loading, humidity etc.

A reliable structural integration does not just relate to how the sensors are embedded in or attached to the structure, but also how the installation process is integrated into the overall manufacturing process. The state of the art regarding sensor integration has recently been demonstrated by the DLR in the EU project SARISTU where several hundred sensors were successfully integrated into a door-surrounding structure.

For future research activities the sensor installation should be automated as much as possible and the wiring of large sensor networks should be reduced in order to save weight while maintaining a good signal quality and an efficient operation of the sensor network.

Sensor network layout

So far there are no rules and regulations for how to layout a sensor network in order to reliably monitor a structure. However, the way the sensors are distributed may greatly influence the performance of a sensor network. An optimized sensor network would be capable of completely and reliably monitoring a defined area with a small number of sensors.

The challenge is not only to use a small number of sensors, but also to avoid blind spots in the network and assure that all areas of a structure are covered by a defined number of sensors. This also requires taking account of manufacturing limitations and structural restrictions for sensor installation.

The positioning of virtual sensors in a numeric representation of the structure can help to predict sensor signals based on measured wave propagation (e.g. high-resolution laser vibrometry) or simulation data taking into account specific sensor properties. Using such a virtual representation of a sensor network, the layout can be optimized to meet a required structural coverage and probability of damage detection. The proposed research activities in this context include the simulation of Lamb wave propagation in complex structures and optimization algorithms for sensor networks.

Application of SHM technology in aviation

Currently, certification of SHM technology for existing (aging) aircraft is challenging. Moreover, the current new aircraft design process does not account for benefits that SHM techniques can have. One reason for this is because, unlike a non-destructive inspection (NDI), SHM has difficulty to prove its performance in terms of probability of detection. The implementation of the SHM technologies to the existing and new aircrafts strongly depends on their performance (e.g. probability of detection) under various damage location and size in a cost effective way.

Determination of the POD (reliability) for an SHM sensor system is very important for successful application in aircraft structures, but is much more demanding than for traditional NDI methods where this can be deduced from various test details representative of the structure to be inspected, containing damages of various sizes sufficiently mimicking operational conditions. These have to be inspected by several inspectors yielding the final data set. In case of a SHM system the same principle can be applied. However, the human factor is no longer present. Missed cracks are only due to the capability of the system in finding a damage of a certain size at a certain location. A damage located away from a sensor will in general be harder to detect than a nearby damage. An SHM system consists of a network of sensors and signal processing capability designed for a specific structure. To determine the detection capability experimentally, a representative part of the structure now has to be manufactured instead of a representative detail in case of NDI system. Experimental validation of the detection capability of a SHM system is therefore very expensive. On the other hand in the absence of the uncertain human factor, which is hard to model, the detectability can to a large extent be computed. Such a probabilistic model assisted approach, in which the damage detection is simulated together with the uncertainties (e.g. signal noise), can alleviate the costs significantly and only requires a limited amount of experimental data for validation of the numerical analyses.

Condition-based maintenance

The life cycle of a component or system is comprised globally of the following phases:

1. design, production and installation
2. implementation and operation usage
3. degradation as a result of usage
4. recovery, repair and maintenance

The original equipment manufacturer sets the maintenance schedule based on estimates of intended usage and assumptions about future process parameters. To guarantee the safe operation, a conservative approach is applied and heavy usage and severe degradation is assumed in the design phase. As a result, in general, the actual usage is lighter than assumed and the design life may be considered conservative. On the other hand, new (unknown) usage scenarios and degradation processes may not have been taken into account, which may lead to non-conservatism in the design.

The existing aircraft sensors and the sensors of the SHM system provide information on the health of the aircraft structure. Condition Based Maintenance requires knowledge about the momentary and future condition of a component or system. This knowledge then serves as the input to optimize maintenance and asset management procedures, such as the adjustment of maintenance schedules, maintenance techniques, logistical processes, design, inventory management or operational usage. The economic consequences of these efforts are taken into consideration to determine the return of investment of actions taken. Another important aspect for CBM is the (local, domain specific) regulations and certification- and safety requirements.

KGT4: CNS/ATM for greener air transport

1. Greener Flight Trajectory Operations
2. Collaborative Network Management

Greener Flight Trajectory Operations

"Moving from Airspace to Trajectory Based Operations" entails the systematic and continuous sharing of aircraft 4 D Trajectories between various participants in the ATM process all through the flight phases from flight planning through flight execution to ensure that all partners have a common and continuously updated view of a flight and have access to the most up to date data available to perform their respective tasks. It enables the dynamic adjustment of ATM assets like airborne/ground capabilities as well as airspace characteristics to balance predicted demand with unpredicted distortions to the business/mission trajectories kept to a minimum. Whenever possible, the necessary strategic and tactical interventions are considered all through the flight phases seeing the trajectory from an en-route to en-route in order to capture anything from gate to gate trajectory level as well as at the partners capability levels, taking into consideration the wider impact on the air and ground part of the trajectories concerned as well as for the airports and for the overall Network performance.

This is based on the operational and technology scope definition of the trajectory based operations concept and trajectory management framework, its content, performance and access across all flight phases and associated concept and technology developments. The SESAR Trajectory Management Framework (TMF) based on the Trajectory based operations concept specifies the structure needed to achieve the safe and efficient creation, amendment and distribution of the Reference Business/Mission Trajectory (RBT/RMT) including the RBT/RMT information content & quality, the Actors involved, and the Services associated with trajectory information (e.g. creation, proposed revision and update processes).

Justification / Need for collaboration

The ICAO TBO and SWIM ConOps are reaching maturity as well as relevant SESAR solutions. In addition related SESAR 2020 Very Large scale Demonstrations are planned for execution in the H2020 timeframe. However, it is foreseen that intercontinental inbound flights will not be capable of supporting TBO and therefore significantly impact the performance of the Single European Sky network. In addition, the air traffic management system of the intercontinental destination may not be able to fully support the European TBO based flight requirements. Therewith it will impact the operational performance of that flight. This will thus affect the ability of the airline to meet the Single Sky environmental and cost related goals.

The SESAR 2020 programme does not support projects with both European and Chinese partners. It confirms however the relevance and benefits of having take place such intercontinental flight studies and validations projects, since they will provide essential insights into the impact of such intercontinental flights to the Single European Sky performance goals. In addition it will also bring necessary insights in requirement for the intercontinental partners to support TBO flights in their region.

Expected impact

Submitted projects are to study and evaluate in the context of TBO, especially for the increasing number of Europe-China flights, as many of the underneath topics as possible.

- The needed Operational and Technical Capability levels for the Air Traffic Management system in intercontinental region with the view to a full harmonisation and seamless interoperability throughout the network in terms of operational procedures and technology standards.
- Identify and validate (bring down to numbers) the impact on emissions, noise, fuel burn of TBO based ATM flights by none-TBO ATM systems (both on the ground as airborne).
- Identify key enabling technologies (MCMF GNSS, LDACS, SatCom …) that need synchronized deployment and synergetic collaboration, and the related requirements on compatibility, capacity, interoperability, and standards development. This can

potentially be done in close collaboration with the SESAR Very Large scale Demonstration projects.

- Identify additional areas of optimisation of the available ATM capabilities and capacity, and validate their operational and environmental business and performance benefits (both for ground based and airborne systems).
- Identify areas of improvement in SWIM ground-ground and air-ground information, weather and flight plan data sharing (both for ground based and airborne systems).

Abbreviations:

AMAN	Arrival Manager
ATM	Air Traffic Management
GNSS	Global Navigation Satellite System
LDACS	L-band Digital Aeronautical Communication System
MCMF	Multi-Constellation Multi-Frequency
TBO	Trajectory Based Operations
RBT / RMT	Reference Business/Mission Trajectory
SESAR	Single European Sky ATM Research
SWIM	System Wide Information Management
TMF	Trajectory Management Framework

Collaborative Network Management

The transition towards Trajectory Based Operations requires the sharing of information both during the process of planning and execution of all combined flight operations. This requires all involved parties and stakeholders, including aircraft operator, ground handler, airports, ANSPs and network management to have continuous access to the latest information in relation to the execution and decision making around flights.

Improved network-wide flight planning systems are needed to support the planning and execution of Business Trajectory (BT)/Mission Trajectories (MT). This allows the involved stakeholder to act better based on shared relevant data, during normal operations as well as under non-nominal conditions such as adverse weather or contingencies.

In addition, for a more seamless and efficient execution of the 4D executed flight trajectory with optimum climb and descent profiles, air traffic management needs to be able to plan and manage the flow of traffic with high accuracy and no delays. To achieve the required more strategic arrival management of inbound flights, increased planning horizons of Arrival Management Systems (AMAN) are needed, which use accurate flight trajectory predictions.

Based on the predicted commercial traffic demand and planned operational air traffic known in the network, better coordination should be achieved between civil and military users for flexible allocation and use of airspace.

Justification / Need for collaboration

Whereas SESAR focuses on optimising overall network operation in Europe, the challenge also exists to extend this concept to intercontinental operations. In particular for flight operations with China, there is already a need identified for more flexible airspace access, improved air traffic flow management and collaborative decision. There is a clear need to align Chinese networked operations developments with those in the EU and US.

The SESAR2020 programme presently does not plan any collaboration projects between partners from Europe and China to demonstrate and evaluate collaborative network management in support of trajectory based intercontinental operations. Both in China and Europe, the introduction of advanced communication, navigation and surveillance technology, globally connected aircraft operators and ground based partners will allow improved sharing of flight data and aircraft status information between aircraft and ground infrastructure, including inflight updates of the most optimum trajectory.

On the ground, the operation at the busy airports in EU and CN will benefit from closer networked information sharing between airlines, airport, ATC and other service providers. The information sharing optimises airport movements, decision making and turnaround process, and also for long range intercontinental operations.

In essence, collaborative network management will provide the necessary enabling technology towards optimised long range trajectory based operations between CN and EU.

Expected impact

Joint studies and research projects on collaborative network management between Europe and China will provide benefits on both sides.

- Coordination between China and Europe in the development of the collaborative network management processes will ensure alignment of regional concepts;
- Increased flight efficiency through user preferred routing and trajectory optimisation will be a priority, since reducing fuel consumption will provide benefits in emissions and air quality;
- More dense air traffic and complex arrival flows can be handled more efficiently by increased time horizons in the arrival management processes for 4D trajectory operations;
- Inflight updates of the most optimum flight trajectory, taking into account latest weather forecasts and earlier planning of the arrival sequence;
- Airspace access may be obtained more efficiently by flexible allocation based on civil and military needs shared over the network;
- Airport processes and aircraft turnaround will be more efficient by a better collaborative decision making process, enabled by networked sharing of latest data;
- Sudden disturbances in the network in/between China and Europe can be handled more efficiently by collaborative decision making based on shared data.

Chinese and European airlines will benefit from the above items both on intercontinental and regional flights. In particular the evaluation of possibilities for collaborative network management for the benefit of intercontinental flights between the regional air traffic networks in China and Europe will provide valuable feedback in the development of the mutual ATM networks, systems and services.

7. IMPACT

The partners in the GRAIN2 project were selected to ensure transnationality and the maximum complementarily of skills towards the successful achievement of the project objectives. More specifically, the consortium groups partners from nine different EU countries Spain, United Kingdom, Germany, France, Belgium, Sweden, The Netherlands, Italy, Czech Republic and China. All partners were firmly committed to carry out the different project activities.
The scope and dimension in the GRAIN2 project is such that none of the partners could have undertaken a similar project only by themselves. Indeed, by participating in a consortium of this kind the industrial partners have benefitted from the expertise and resources from the different partner groups. Thus, the aeronautic industries has benefitted of the scientific knowledge and skills of the RTD organizations and universities. The RTD partners, in turn, have taken profit from the experience and practical know-how of the aeronautic industries in Europe and China. By participating in the GRAIN2 project the project partners have expanded their field of RTD activities in Europe and China, therefore helping to the advance of science in both regions by means of collecting and disseminating state of the art scientific and technical information in the field of multi-physics simulation and validation.

The following outputs have been generated in the GRAIN2 project.

Strategic outputs
The general strategic objectives of the project are three fold: 1) to identify areas of mutual RTD interest; 2) to develop concepts of collaboration in those Key Green Technological areas between the European and Chinese partners; 3) prepare specific RTD activities that are mature for joint proposal for FP7 and for HORIZON 2020.
These three aspects have been successfully achieved along the project lifespan, as demonstrated in the final deliverables, progress reports and mainly on the veents, where the technical discussions have expanded the objectives to more precise technical discussions and shares.

Scientific and technical outputs.
a) An identification of emerging RTD research topics coming from the different KGTs.
b) A state of the art document for each of the Key Green Technological area.
c) A web-based GRAIN Communication System for storage and dissemination of the collected data relevant to computational methods and experimental tests for multidisciplinary applications in aeronautics.
d) Definition of future joint RTD work on critical Key Green Technological areas.

Above outputs have been disseminated and exploited both internally and externally by the project partners.
External exploitation addresses mainly two target groups: the aeronautics industry and the scientific community. The dissemination actions includes the planned kick-off workshop and final workshops in Europe, the Course in China as well as presentations of the GRAIN2 outputs at specialized industrial meetings (such as the Aeronautic Days organized by the EC).
China-Europe Workshop: this event has gathered during three days (3) most of the Chinese aeronautical community on Integrated Computational and Experimental Multi-physics for new Challenges in Aeronautics. Audience gathered scientists, technologists and decision maker managers from Europe and P.R. of China involved in aeronautics. The format of the conference including invited lectures and a general Round Table has provided at a glance a first information on the areas of possible win-win cooperation and with a clear picture of the level of expertise of contributors in the themes of the Workshop very similar to GRAIN2 ones.
Course: this event has deployed State of the Art lectures delivered by international experts including China on topics of major interest to GRAIN2 for future collaboration on multi-physics applications in the next Framework Programme HORIZON 2020. The time schedule of the Short Course allowed detailed presentations of lecturers intertwined with long break discussions between them and the audience. A two hours final Round table with academy, industrial and governmental institutions discussed the impact of Key Green Technological applications on research and industry environments connecting cultures and technologies.
Forum: The greener Horizons Forum has featured keynote speakers from academy, industry and government who shared their perspectives on the new global challenges of eco-efficiency, impact of civil and military aircraft emissions, debates on future greener opportunities to develop new environmentally friendly biofuels, and emerging modelling and large scale computational greener trends targeting a low level of emission, drag, noise and carbon neutral materials research, and programs. The Open Greener Horizon Forum also featured panel discussions in which leaders from industry, government, and academia addressed current issues and trends in R&D aerospace technology to establish an efficiency standard for the design of new greener aircraft.
The individual exploitation plans of the different partner groups participating in the project are as follows: Research centers and universities in Europe and China has used the experience shared in the GRAIN2 project for development and validation of new mathematical and numerical methods concepts and software applicable to the solution of multidisciplinary problems in aeronautics as well as for new experimental methods and tests for validation

purposes. The industrial companies, in the other hand, have also used the outputs of the GRAIN2 project as an essential ingredient for defining validation of multidisciplinary projects as well as for every day design of aircrafts. For all partners, the mutual knowledge of the RTD activities in Europe and China acquired during the GRAIN2 CSA is of interest for defining future joint RTD projects and actions with participation of European and Chinese organizations.
Turnover in the aeronautics sector exceeded €85 billions in 2004 and its balance of trade surplus –the difference between the products it sells to the world and the equivalent that are imported– was €28 billions. Increasing these figures in a form compatible with the new imperative of "More Affordable, Safer, Cleaner and Quieter" aircrafts can only be achieved by combining increasing RTD investment in undertanding the complexity of all multi-physics aspects involved in the design, manufacturing and operation of an aircraft.
The enhanced design of aircrafts structures and components accounting for the multidisciplinary couplings will invariably lead to better, safer and more competitive European aircrafts. A reduction in the design and production cycle leading to a reduced time-to-market is also expected. This naturally leads to the improved competitiveness of European aerospace industry currently under severe concurrence with respect to USA aeronautics technology, and indeed the increased competitiveness leads to an overall economic growth.
The outputs from the GRAIN2 CSA contributes to achieve above objectives in a number of ways. The different discussions in the GRAIN2 events are an indispensable source of information for both current design engineering and as reference for future RTD work towards the development of multidisciplinary design tools in aeronautics and aerospace industry. The data quality assessment methodology and the guidelines produced in the project have a similar value as a reference for improved design and also for establishing standard and rules for the efficient use of computational methods in multidisciplinary applications.

8. CONCLUSIONS

GRAIN2 has been a successful project. As its predecessor project GRAIN, and the former AeroChina and AeroChina2 projects, GRAIN2 provided the opportunity to the researcher to contact their counterpart on China and deeply discuss about topics of common interest.
During the entire project, the teams have worked together, with a continuous interaction through mail and teleconference. The technical discussions and the outcomes have matured progressively in each meeting, and several research topics have been already defined.

Several partners teamed up for the preparation of the proposals which were submitted in the last H2020 Transport call. This work ended up on the preparation of 4 proposals, competing with two additional ones in the same call. Finally, thanks to the good work done by the consortiums, the 4 proposals by the GRAIN2 partners were the ones selected by the EC and MIIT officers. The 4 projects were launched just after the final meeting of the GRAIN2 project, in an event jointly organized with all the coordinators of each project.

From the point of view of the management, the difficulties to mobilize such a large group of people have been solved from the experience of the GRAIN project. The KGT leaders are more active and pro-active than in the past. Anyway, the organization of the events has always been difficult due to the required approval of the decisions by the high level people in China.

Another issue to be improve is the motivation of external people to participate on the GRAIN2 events. This is mainly due to two factors. The first one is the delay on the final decision about the program of the events, and the second one is travel cost associated to the travel to or from China, or Europe.

9. CONTACT DATA

9.1 European partners contact data

NAME	E-MAIL	PHONE	MOBILE PHONE
Jacques Periaux	jperiaux@gmail.com		
Gabriel Bugeda	bugeda@cimne.upc.edu	+34 93 401 6494	
Sònia Sagristà	ssagrista@cimne.upc.edu		+86 13761635705
Jordi Pons-Prats	jpons@cimne.upc.edu	+34 93 413 4189	
Daniel Redondo	daniel.redondo@airbus.com	+34 916 243 560	
Dale King	dale.king@airbus.com	+44 (0)117 9363926	
Pedro E. Fernández	Pedro.E.Fernandez@airbus.com		
Frederic Eychenne	frederic.eychenne@airbus.com		
Torsten Bardewyck	torsten.bardewyck@airbus.com		
David Young	dave.young@eurocontrol.int	+33 169 88 7655	+32 499 94 2347
Sander Roosendaal	sander.roosendaal@honeywell.com	+420 (532) 115 539	+420 (724) 978 962
Joeri de Ruytter	Joeri.DeRuytter@Honeywell.com	+32 2 403 01 02	+32 497 48 87 04
Pierre Vialettes	pierre.VIALETTES@eads.net	+86 13501116187	
Jordi Saniger	Jordi.Saniger-Pare@eads.net		
Charles Hirsch	charles.hirsch@numeca.be	+32 2 642 28 00	+32 475 84 02 82
Raphael Van Liefferinge	raphael.van.liefferinge@numeca.be		
Piergiorgio Ferrante	piergiorgio.ferrante@numeca.be		
Maksim Danilov	maksim.danilov@dlr.de		
Markus Kleineberg	markus.kleineberg@dlr.de		
Micheal Schnell	Michael.schnell@dlr.de		
Florian Raddatz	Florian.Raddatz@dlr.de		
Norbert Kroll	norbert.kroll@dlr.de		
Luc de Nijs	luc.de.nijs@nlr.nl	+31 88 511 3737	
Marcelo Muller	Marcelo.Muller@nlr.nl	+31 88 511 4792	
Arjen Vollebregt	arjen.vollebregt@nlr.nl		
Eijkman, Marja	Marja.Eijkman@nlr.nl		
Bart Klein Obbink	Bart.Klein.Obbink@nlr.nl		
Paul Eijssen	Paul.Eijssen@nlr.nl		
Toan Nguyen	toan.nguyen@inria.fr	+33 476 615 240	
Frank Thiele	frank.thiele@cfd-berlin.com	+49 30 8090 7893	
Charles Mockett	charles.mockett@cfd-berlin.com	+49 30 5900 83 320	
Domenico Quagliarella	d.quagliarella@cira.it	3,90824E+11	
Marcello Amato	m.amato@cira.it	3,90824E+11	
Herman Deconinck	deconinck@vki.ac.be	323599618	
Tony Arts	arts@vki.ac.be	3223599605	
Christophe Schram	christophe.schram@vki.ac.be		
Tom Verstraete	tom.verstraete@vki.ac.be		
Shia-Hui Peng	shpeng@kth.se, peng@foi.se		
Sture Holmberg	sture.holmberg@kth.se		
Ahmad Bilal	abilal@leitat.org	+34 93 788 23 00	
Dirk Saseta	dsaseta@leitat.org	+34 93 788 23 00	
Markus Kremers	m.kremers@airborne.nl		
Anders Brodsjo	a.brodsjo@airborne.nl		
T. Ahmed	t.ahmed@airborne.nl		
Robbert Bakker	r.bakker@airborne.nl	+316 15881977	
Ning Qin	n.qin@sheffield.ac.uk	+44 (0)114 2227718	
Kostas Kontis	K.Kontis@manchester.ac.uk	+44 141 3304337	
Xiang Zhang	xiang.zhang@cranfield.ac.uk	+44 1234754621	
Ian Poll	ian.i.a.poll@cranfield.ac.uk		
Xavier Prats	xavier.prats@upc.edu	+34 93 413 4125	
Eusebio Valero	eusebio.valero@upm.es	+34 913 366 326	
Adel Abbas	adel.abbas@upm.es		+34 646475670
Nicolas Gauger	gauger@mathcces.rwth-aachen.de	+49 2418098672	
Hossein Zare-Betash	Hossein.Zare-behtash@glasgow.ac.uk	+44 141 3306204	
PLANTE Patrick	patrick.plante@thalesgroup.com		
BARBARESCO Frederic	frederic.barbaresco@thalesgroup.com		
MONLOUIS Laurence	laurence.monlouis@thalesgroup.com		
ADRIAN Odile	odile.adrian@thalesgroup.com		
JUGE Philippe	philippe.juge@thalesgroup.com		
FERRIER Jean-Marie	jean-marie.ferrier@thalesgroup.com		
Paolo Luchini	luchini@unisa.it		
Georg Eitelberg	georg.eitelberg@dnw.aero		
AKA	aka@esi-group.com		
Ingrid Lepot	ingrid.lepot@cenaero.be		
Spiros Pantelakis	pantelak@mech.upatras.gr		
Franco Bernelli	franco.bernelli@polimi.it		
Kaspar	kaspar@vzlu.cz		
Uwe Hessler	uwe.hessler@rolls-royce.com		
Chris Ovenden	Chris.Ovenden@ge.com		
Dietrich Knoerzer	dietrich.knoerzer@ec.europa.eu		

9.2 Chinese partners contact data

Name	Affiliation	Mobile Phone	E-MAIL
SUN Jian	CAE	13911807612	sunj@cae.ac.cn
ZHENG Yao	ZJU	13958128019	yao.zheng@zju.edu.cn
LI Jibao	ACAE	15800576676	Li9403@hotmail.com
DING Shuiting	BUAA	13501004073	dst@buaa.edu.cn
LI Cunbiao	PKU	13521759989	cblee@mech.pku.edu.cn
ZHOU Jinsong	ZJU	13957163019	zhoujs@zju.edu.cn
XU Huasheng	GTE	13880579519	hshxu2004@sina.com
FENG Zhenping	XJTU	13609197980	zpfeng@mail.xjtu.edu.cn
ZHAO Ning	NUAA	13813937575	zhaoam@nuaa.edu.cn
CHEN Yingchun	COMMAC	18019191988	chenyingchun@comac.cc
DUAN Zhuoyi	FAI	13772195221	dzy0927@126.com
GAO Zhenghong	NPU	13992867549	zgao@nwpu.edu.cn
FU Song	THU	13501107229	fs-dem@tsinghua.edu.cn
LI Li	ACTRI	15991781061	westlili@163.com
LIU Guozheng	ARI	13936406898	avic_caria_627@sina.com
HUANG Wenchao	ASRI	13389260092	va-623@163.com
SUN Xiaofeng	BUAA	13601027404	sunxf@buaa.edu.cn
LI Xiaodong	BUAA	13691353269	lixd@buaa.edu.cn
LIU Bilong	IACAS	13683371062	liubl@mail.ioa.ac.cn
YI Xiaosu	BIAM	13910759012	yi_xiaosu@sina.cn
LIU Qing	CQU	13896058388	qingliu@cqu.edu.cn
ZHU Jin	NIMTE	15958276797	jzhu@nimte.ac.cn
LIU Weiping	COMAC	13651756212	liuweiping@comac.cc
NIU Wensheng	ACTRI	13891898283	nwsheng@avic.com
SUN Xiasheng	ASRI	13319208623	Sunxs623@hotmail.com
XIAO Yingchun	ASRI	13669232661	Xiaoyc623@163.com
MA Xiaojun	COMAC	15000220623	maxiaojun@comac.cc
QIU jinhao	NUAA	13776669810	qiu@nuaa.edu.cn
ZHANG Jun	BUAA	13501388080	buaazhangjun@vip.sina.com
ZENG Xiaoping	CQU	13330278999	zxp@cqu.edu.cn
BAI Jie	CAUC	18622105688	caucbaijie@sina.com
WANG Guoqing	CARERI	13761527666	Wang_guoqing@careri.com
LIU Sheng	HUST	13871251668	Victor_liu63@126.com
LIU Wenxue	ACTRI	13892813122	wenxueL99@126.com
FENG Tao	JIUZHOU	18909010254	persuing@163.com
LU Shilu	CAE	13701000273	luosl@cae.ac.cn
SUN Jian	CAE	13911807612	sunj@cae.ac.cn
SUN Jian	CAE	13911807612	sunj@cae.ac.cn
ZHENG Yao	ZJU	13958128019	yao.zheng@zju.edu.cn
LI Li	ACTRI	15991781061	westlili@163.com
SUN Jian	CAE	13911807612	sunj@cae.ac.cn
ZHENG Yao	ZJU	13958128019	yao.zheng@zju.edu.cn
LI Li	ACTRI	15991781061	westlili@163.com