Project Final Report

Grant Agreement Number: FP7 - 234009

Project acronym: KIAI

Project title: KNOWLEDGE FOR IGNITION, ACOUSTICS AND INSTABILITIES

Funding Scheme: Collaborative Project (Small or medium-scale focused research project)

Period covered From 01/05/2009 to 31/04/2013

Name, title and organisation of the scientific representative of the project's coordinator:

Doctor, Sebastien Roux, SNECMA

Tel: +33 1 60 59 71 69

E-mail: sebastien.roux@snecma.fr

Project website address: www.kiai-project.eu

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ABBREVIATIONS USED IN THIS DOCUMENT

Abbreviation / acronym	**Description**
ACARE	Advisory Council for Aeronautical Research in Europe
ADF-PCM	Approximated Diffusion Flame-Presumed Conditional Moments
AFR	Air-Fuel Ratio
AIAA	American Institute of Aeronautics and Astronautics
ANECOM	Aero Engine Design and Test Services. ANECOM is a sub-contractor used to provide support for the siren rig testing at DLR Cologne.
ASME	American Society of Mechanical Engineers
AVBP	CERFACS-IFPEN simulation code
BC	Boundary condition(s)
CAEP	Committee on Aviation Environmental Protection
CFD	Computational Fluid Dynamics
DNS	Direct Numerical Simulation
EIMG	Engine Industry Management Group
FDF	Flame Description Function
FP	Framework Programme
FTF	Flame Transfer Function
HP	High Pressure
ICAO	International Civil Aviation Organisation
ICAS	International Council of the Aeronautical Sciences
IMG4	Industrial Management Group of the industrial aeronautical sectors for airframe, engines, equipment and air traffic management
IPR	Intellectual Property Right
ISSIM	Integrated Stretch Spark-Ignition Model

LDA	Laser Doppler Anemometry
LDV	Laser Doppler Velocimetry
LES	Large Eddy Simulation
LoNoMe	Low NOx Methodology, a methodology adapted to low NOx combustor technologies
LOTAR	Liquid-fulled ONERA Thermo Acoustic Rig
MAVERIC	MAquette pour la Validation et l'Expérimentation sur le Refroidissement par Injection Contrôlée
MERCATO	Montage Expérimental de Recherche en Combustion Aerobie par Techniques Optiques
LPP	Lean Premixed Prevaporised
NOx	Nitrogen Oxides
OGV	Outlet Guide Vanes
PDPA	Phase Doppler Particle Analysis
PIV	Particle Image Velocimetry
PLIF	Planar Laser Induced Fluorescence
RANS	Reynolds-Averaged Navier Stokes equation
RQL	Rich burn Quick quench Lean burn
SME	Small and Medium Enterprise
SRA	Strategic Research Agenda
TP	Third Party
UHC	Un-burnt Hydro Carbon
ULN	Ultra Low NOx
URANS	Unsteady RANS

KIAI Consortium

The KIAI consortium gathers 18 organisations – academia, research institutes and SMEs – from 4 countries. Each of these partners has been carefully selected to bring particular expertise or facilities to the consortium. They share a common interest in advancing combustion research by developing innovative technologies, and collaborate in an integrated, synergistic approach leading to results that would not be achievable by any of the partners on its own.

The KIAI consortium is composed of the following organisations:

- SNECMA, SN
- Turbomeca, TM
- Rolls Royce Deutschland Ltd & Co KG, RRD
- Rolls-Royce plc, RRUK UK
- AVIO S.p.A, AVIO
- INSA de Rouen - UMR 6614, CORIA
- Centre National de la Recherche Scientifiques, CNRS
- Université de Pau et des Pays de l'Adour, UPPA
- Technische Universität München, TUM
- IFP Energies Nouvelles, IFPEN
- Office National d'Etudes et de Recherches Aerospatiales, ONERA
- Deutsches Zentrum für Luft und Raumfahrt e.V., DLR
- Loughborough University, LU
- Università degli Studi di Firenze, UNIFI
- Centre de Recherche et de Formation avancée en calcul scientifique, CERFACS
- ARTTIC, ART
- Microturbo, MT
- Karlsruhe Institute of Technology, KIT

Contact details:

Dr Sebastian Roux

SNECMA

Site de Villaroche, Rond-Point René Ravaud - Réau

Tel: +33 1 60 59 71 69

E-mail: Sebastian.roux@snecma.fr

KIAI public website: www.kiai-project.

1. Executive summary

Air traffic is expected to grow over the next 20 years annually by respectively 3-5% for passengers and 9-10% for freight (ACARE1 "average" scenario). This traffic growth will continue to negatively impact the environment with increased greenhouse effects (CO2 emissions) and degradation of local air quality (NOx but also soots, particulates and CO emissions as well as UHC).

The engine emissions issue is addressed by the evolution of the relevant international regulations (e.g. ICAO CAEP2 standards) and by ambitious technological objectives agreed by the European aeronautics industry described in "Vision 2020" of the 2nd version of the ACARE Strategic Research Agenda ("SRA2")2.

Availability of clean engines not only has a huge environmental impact, but has also become a vital stake for every manufacturer to maintain a position within world competition for sustainable growth of aviation transport. Developing combustion technologies for clean engines is consequently necessary to comply with the ambitious ACARE 2020 targets and future ICAO standards, to gain new markets and to remain competitive ahead of non-European manufacturers.

The European engine industry has been addressing engine emissions for many years in several very ambitious R&T projects, particularly in the EC framework programmes 5 and 6. Lean combustion technologies have proven in R&T projects (LOPOCOTEP, TLC, INTELLECT D.M, EEFAE, NEWAC and CLEAN) their high potential for achieving the overall NOx reduction targets and for reducing particulates. Nevertheless, the potential of low NOx technologies is facing the problem of managing new technologies that are fundamentally sensitive to unsteady behaviour like combustion instabilities, quenching,, ignition or engine re-light.

For the time being, the European engine industry does not have at its disposal methodologies adapted to predict behaviour of low NOx combustors. Consequently and in order to be able to set up the development of low NOx technologies, KIAI will deliver unstationary CFD tools which will allow a deep comprehension of unsteady phenomena.

The main objective of the KIAI project is to provide reliable methodologies to predict the stability of industrial low NOx combustors, as well as their ignition process from spark to annular combustion.

When used at an early stage in the conception cycle of low NOx combustors, KIAI CFD methodologies will play a key role and considerably accelerate the delivery process of lean combustion technology with a proven capability to reach 80% NOx emission reduction required for introduction into service before 2020 with the necessary reliability, safety and economical viability.

As already demonstrated by past and ongoing studies and European projects low NOx technologies lead to crucial unsteady phenomena that are neither controlled nor predictable at the moment.

The scientific objectives of KIAI are directly linked to providing a better understanding and prediction of these unsteady phenomena by:

- predicting the coupling between the acoustics and the flame
- determining the acoustic boundary conditions of multiperforated plates surrounding the combustion chamber
- accounting for non-premixed spray flows in the combustion process.
- exploring aerodynamic unsteadiness in strutted pre-diffusers adapted to high mass flow injectors and develop a liquid film break-up model for an injector
- evaluating the ability for LES to help to make the final decision between two similar geometries in the design process of low NOx combustors

The main expected outputs of KIAI derived from the scientific objectives are:

- Acoustic tools able to provide stability maps of the combustors including the influence of the flame
- An acoustic description of multi-perforated plates widely encountered in combustion chambers
- A tabulated chemical description of non-premixed spray combustion
- A liquid film break up model
- An estimation of the reliability of LES with respect to its capacity to account for small technological variations of geometry for both isothermal and reactive flows

2. Project objectives and achievements per Work Package

The table hereafter gives us the main objectives and achievments of theKIAI project :

Sub - Project (please select)	Objectives	Achievements
SP2 Prediction method for thermoacoustics	Predict frequencies and amplitudes of combustion instabilities using network solver.	1. Implement measured and CFD predicted FTF into low order model of combustor. 2. Predict frequency, stability, modeshape and amplitudes for azimuthal modes in the FANN geometry with 2 different lean fuel injectors using low order model of combustor with measured FTFs.
	Predict the flame transfer function of a lean fuel injector using a 'numerical siren' rig CFD method	Predicted FTFs for lean fuel injectors within CIPCF siren rig (T2.4.1) from uRANS simulations of 2 phase reacting flows with 2 difference lean fuel injectors implicitly defined in the mesh and with broadband forcing.
	Validate the instability modes of a high pressure FANN combustor rig tests	Measured FTFs for 2 lean fuel injectors from OH* and CH* chemiluminence and unsteady pressure measurements.
		Measured instability characteristics for 2 lean fuel injectors for a range of operating conditions in a high TRL FANN rig.
	Predcit the Flame Transfer Function (FTF) of lean fuel injector systems using CFD (RANS/URANS for RRUK and LES for CERFACS) and investigate the spray flame behavior	Both CFD techniques were used to chracterize the spray flame dynamics and the flame transfer functions of UCAM and ONERA experiments. In terms of results, LES is confirmed to be a powerful tool for FTF evalautions. In parallel RANS/URANS provided acess to new features underlying the potential link between entropy spot generation and acoutics thereby affecting the FTF.
	Evaluation and assessment of the thermo acoustic numerical tool ability to predict experimantl stability maps of real burners	Confrontation of a reduced model and RANS approach on a high pressure rig as well as a full 3D Helmholtz sover coupled to LES for an atmospheric rig.
	Experimental data base for CFD simulations + improvement of the knowledge on the role of the liquid phase on the thermo acoustic coupling	Design and manufacturing of the LOTAR experiment, caracterisation of the boundary conditions (acoustic + two phase flow), Phase averaged processing on droplet size and velocity measurement, on PLIF measurements (kerosene and OH),

Sub - Project	Objectives	Achievements
		Flame transfert function measurements.
SP3 Multiperforated plates issue in industrial combustors	Study with LES the acoustic and thermal behaviour of an effusion-cooling plate submitted to an acoustic pulsation	Understanding of the aerothermal phenomena responsible for the modification of cooling efficiency of an effusion-cooling plate submitted to an acoustic pulsation.
	Perform an acoustic analysis with a Helmholtz solver of a TM combustion chamber with and without an acoustic model for the effusion-cooling plates. Evaluate the performances of the model.	The acoustic behaviour (acoustic pressure field, mode frequency, mode stability) is greatly impacted by the Howe model as expected (i.e. acoustic energy dissipation by the model).
	Assessing the predictive capabilty of LES simulations.Reproducing experimentally a generic acosutically forced wall flow with injection through the wall	An LES methodology has been developped and successfully tested. A comprehensive database has been produced on the UPPA test facility MAVERIC
	Implementation and validation of multi-perforated plate liner models for thermo-acoustics computations	Model implementation in a direct and eigen value acoustic solver along with their validation against experiment and LES results
SP4 Ignition and re-ignition	Study ignition in a TM combustor with LES and compare two different models for LES of an ignition sequence in a TM combustor	Both models have shown their potential to simulate an ignition sequence of a TM combustor. The flame behaviour during an ignition sequence strongly depends on the combustion model
	Fundamental experimental investigation of high altitude ignition as a function of flow conditions	experiments carred-out varying AFR,
	Experimental investigation of high altitude ignition for a tubular combustor with a realistic nozzle geometry	flow regimes and ignition positions fully investigated
	Experimental investigation of high altitude ignition for a tubular combustor on a real Injection System of an Ultra Low Emissions Combustor	pressure effect on relight altitude ignition largely investigated
	Provide knowledge on ignition (successful or failed) for one injector	Done
	Evaluate the key mechanisms for flame kernel propagation form ignition to the fuel injector (One injector configuration)	Done
	Characterise the propagation around phenomena in a multiple injectors configuration	Done

Sub - Project	Objectives	Achievements
	Fundamental experimental investigation of high altitude ignition as a function of thermodynamic conditions (p,T), mixture quantity (F) and flow conditions (mean velocity, turbulent intensity); Experimental investigation of high altitude ignition for a tubular combustor with a realistic nozzle geometry	Design and manufacture of an altitude relight rig; Fundamental experimental investigation of high altitude ignition as a function of thermodynamic conditions, mixture quantity and flow conditions; Distinction between flame kernel generation and flame kernel propagation phenomena; Experimental investigation of high altitude ignition for a tubular combustor with a realistic nozzle geometry
	Experimental data base for CFD simulation on APU ignition at high altitude conditions	Design and manufacturing of the setup, PIV measurements, ignition probability
	Validate LES on two technological discriminating configurations for reactive flow Predict the ignition of a multi-burner configuration with LES	- LES has been validated on two discriminating conditions - LES predicted the multi-burner ignition for 3 different configurations
SP5 Unsteady aero-dynamics in injection	Develop capability to model unsteady flow	Improved capability to model transient flows: developed capabilty to apply transient boundary conditions
	Develop capability to predict primary break-up	Primary break-up model for Jet in Cross Flow has been developed and implemented in corporate CFD code
	1- Design/construct a fully annular experimental test facility representative of combustor/compressor interface of medium thrust engine 2- Apply traditional pneumatic probes, but also time-resolved hot wire probes and commision non-intrusive 2-component PIV measurement technique into fully annular facility 3- Produce a database of unsteady flow characteristics in engine representative pre-diffusers 4- Improve understanding of importance of unsteady pre-diffuser flows via analysis of the experimental data 5- Provide experimental data for boundary condition specification and for solution validation of CFD predictions.	All objectives were achieved.
	Perform detailed measurement on a liquid film break-up, investigate pressure effects and the transients in liquid film break-up	Large data base for the validation of liquid film breakup models created. Simplified model for predicting the Sauter mean diameter available. Correlations for breakup times, Sauter mean diameter and droplet velocities derived.

Sub - Project	Objectives	Achievements
	Experimental data base for CFD simulation on influence of injector geometry on flow instabilities	Averadge velocity measurement from PIV + spectral analysis on velocity and pressure signals on ten injectors
	Validate the capacity of LES to distinguish two flows discriminated by a technological detail for an industrial injector system	LES has been able to quantitatively make the distinction between two flows discriminated by a technological detail of a realistic industrial injection system

3. Main projects results

3.1 Summary table of KIAI Achievements

Sub - Project (please select)	**Main results (comparison of situation before / after KIAI to highlight the progress made)**	
	BEFORE	**AFTER**
SP2 Prediction method for thermoacoustics	Predicted FTF directly from FANN measurements by matching frequencies. Therefore unable to predict the occurrence of instability prior to FANN rig tests.	With measured and CFD predicted FTFs are able to predict instability during the preliminary design phase.
	No predictive capability for FTF	Now can predict FTF from CFD simulations (uRANS incompressible).
	No measured FTFs for the lean fuel injectors with 2 phase flow available	Measured FTFs now measured to TRL 3-4.
	No measured FTFs for the lean fuel injectors with 2 phase flow available	Measured FTFs are now validated against FANN rig tests to TRL 5.
	Validation of FTF CFD estimations for purely gaseous flames	Preliminary assess of CFD strategy for CFD evalautions of FTF of spray flames.
	Validation obtained for few points issued by atmospheric test rig operating on gaseous fuels.	Validation at high pressure and atmospheric spray flames for given operating conditions.
	No detailed experiments on two phase flow flame submitted to thermoacoustic instabilities(Boundary conditions for acoustics and	Data base on a well controlled experiments, analysis of the spray and flame behaviour during the pulsating cycle, measurement of the flame

Sub - Project (please select)	Main results (comparison of situation before / after KIAI to highlight the progress made)	
	BEFORE	**AFTER**
	two phase flow ; spray response, Flame transfert function)	transfert function
SP3 Multiperforated plates issue in industrial combustors	Lack of knowledge on the acoustic and thermal behaviour of an effusion-cooling plate submitted to an acoustic pulsation. No simulation method to handle this question	Numerical methodology validated and applied to the problem of the acoustic and thermal behaviour of an effusion-cooling plate submitted to an acoustic pulsation.
	Lack of knowledge on the effectivenes of acoustic models for effusion-cooling plates in combustor simulations	acoustic models for effusion-cooling plates in combustor simulations used in TM combustor acoustic simulations
	UPPA could study experimentally confined turbulent flows without forcing with standart PIV. TM could perfom LES of wall flows without acoustic forcing.	The experimental capability of UPPA concerning the study of confined flows has been considerably improved: acoustic forcing on MAVERIC rig, phase locked PIV. A comprehensive experimental database has been built-up and delivered. TM has now at its disposal a methodology to study by LES wall flows with acoustic forcing.
	Eigen value solver of the acoustic Helmholtz equation.	Direct and eigne value solver of the acoustic Helmholtz equation with dedeicated multi-perforated liner models - validation against experiments and LES predictions (fully resolved or modeled liner perforations).
SP4 Ignition and re-ignition	Lack of simulation tool to	2 types of tools to predict

Sub - Project (please select)	Main results (comparison of situation before / after KIAI to highlight the progress made)	
	BEFORE	**AFTER**
	predict ignition in a combustor	ignition: ignition criterion and unsteady reactive simulations
	old literature (late 70's,Lefebvre e co.)	dependency of kernel generation e kernel propagation by turbulence intensity and flow velocity
	lack of experimetnal result on the turbulence effect	the flame kernel is characterize by igniter type (spark area,spark frequency, spark duration) and ignition position inside combustor chamber
	Only atmospheric pressure experiments.	LBO curve carried-out up to 0.3 bar
	Start from scratch	Design of a new burner (KIAI burner) where ignition studies have been performed for premixed and non-premixed flows and two different swirl numbers
	Start from scratch	Probability maps obtained simultaneously with the ignition scenario for different locations of the spark. Data set avalaible for a direct comparison for LES (-WP4.6)
	Start from scratch	Design of multiple injector to study propagation around phenomena. Identification of three different modes of propagation according the spacing between the injectors. Data set avalaible for a direct

Sub - Project (please select)	Main results (comparison of situation before / after KIAI to highlight the progress made)	
	BEFORE	**AFTER**
		comparison for LES.
	Data Base of Minimum Ignition Energies of Kerosene Sprays.	Probability curves of ignition instead of Minimum Ignition Energies; Test rig for investigation of ignition in subatmospheric conditions on laboratory scale; Possibility of differentiation between ignition failure modes - no flame kernel or flame kernel quenching;
	No results available on combustor based on swirling combustion principle	Data base for LES validations
	No realistic LES of a multiple burner ignition	LES of a 5-burners ignition showing good quantitative match with experiments. Methodology available for future conception.
SP5 Unsteady aero-dynamics in injection	No model in incorporate turbulence inflow conditions for LES	a model for turbulent inflow conditions can be applied for LES
	No models were availbale to predict the primary break-up of liquid kerosen injector	Break-up model for kerosene jets is available

Sub - Project (please select)	Main results (comparison of situation before / after KIAI to highlight the progress made)	
	BEFORE	**AFTER**
	No dedicated test facility available for the unsteady aerodynamic assessment of engine representative OGV and pre-diffusers in modern, low emission lean burn combustors. Consequently understanding of the unsteady flow at the compressor-combustor interface was limited. Equclose to incipient separtion conditionsally, the accuracy of CFD predictions for conditions close to maximum static pressure rise in the pre-diffuser, which is known to be close to incipient separation conditions	(1) A dedicated test facility now exists at Loughborough University and has been successfully used to characterise the unsteady aerodynamics in the OGV and pre-diffuser of both clean and strutted systems. (2) A database of experimental data is available for boundary conditions and solution validation for CFD simulations. (3) RRD began preliminary use of thre data during KIAI, which will eventually lead to improved design methods. (4)Information was provided for the first time of the highly unsteady nature of one-sided pre-diffusers
	Primary breakup process of a liquid film barely understood. Dominating parameters not fully identified and details on the breakup process unknown. No database for the validation of numerical tools to predict/simulate primary breakup available.	High speed observations on the film disintegration process at various operating conditions and atomizers designs revealed an identical disintegration process. Improved understanding of the atomization process gained. Key parameters that influence the atomization quality identified. Transferability of results derived from simplified 2D atomizers to industrial atomizer designs demonstrated.

Sub - Project (please select)	Main results (comparison of situation before / after KIAI to highlight the progress made)	
	BEFORE	**AFTER**
		Large database for the validation of numerical simulations of the liquid film breakup process available.
	No such data base available	Data base for LES validation permitting to see its ability to capture the influence of geometrical details on flow or acoustic unsteadinesses.
	No evaluation of the LES to account for technologinal geometrical details for real injection systems	Validation of the ability for the LES to quantitatively account for technologinal geometrical details for real injection systems

4. Potential Impact

4.1 Dissemination and exploitation of knowledge

4.1.1 Dissemination of knowledge

List of publications

(SEE § 5.1.1)

Joined Workshop with the KIAI project

The aim of the co-organized KIAI/TECC-AE workshop was to :

- Present the objectives and results obtained within the EU projects KIAI and TECC-AE
- Receive feedback from the Workshop participants that allow further cooperation or deeper studies before the end of both projects
- Present an overview of the EU projects FIRST, LEMCOTEC (specific research on Lean Combustion for ultra-high OPR engines) and IMPACT-AE
- Demonstrate links between the concerned programs and to foster further cooperation within the international combustion community
- Discuss further research needs related to Europe´s Vision for Aviation ("Flightpath to 2050")

More details can be found on the public website of the workshop :

http://www.eurtd.com/kiai-tecc/workshop/index.php

4.1.2 Exploitation of knowledge

KIAI will directly impact development costs by providing answers to important questions raised by developers and compiled hereafter.

How to anticipate issues intrinsically linked to low NOx technology for the concept to be developed?

Identification, quantification and solution of the main unsteady related phenomena in the combustor : combustion instabilities light and re-light issues.

How to take right decisions during the first iterations of the conception phase with controllable consequences over all the remaining development?

Increasing the application field of existing methodologies by extending them to unsteady flows. Design methodologies must cover all the aspects in order to get rapid and robust conception avoiding the discovery of problems at the later stage of the process or in production or at worse in service.

How to reduce the number and the duration of the design iterations and the number of tests to speed up the whole design process?

Increase CFD robustness by application and validation on complex situations.

By controlling the risks of new technology designs, KIAI will contribute to technologies leading to further reductions in specific fuel consumption through enabling the environmentally acceptable use of higher bypass ratio and overall pressure ratio cycles. This will have a positive effect on operational costs. Besides, acquisition and maintenance costs are indirectly impacted by KIAI. In a general way**, KIAI will secure the innovative developments emerging from technologically orientated projects** like TECC-AE (FP7- 211843). The conditions for this methodological maturity are obviously the success of this proposal first at the evaluation process in order to be funded and along project lifetime.

The figure bellow provides an overview of the influence of KIAI on the steps that will be needed to manage work programme impacts:

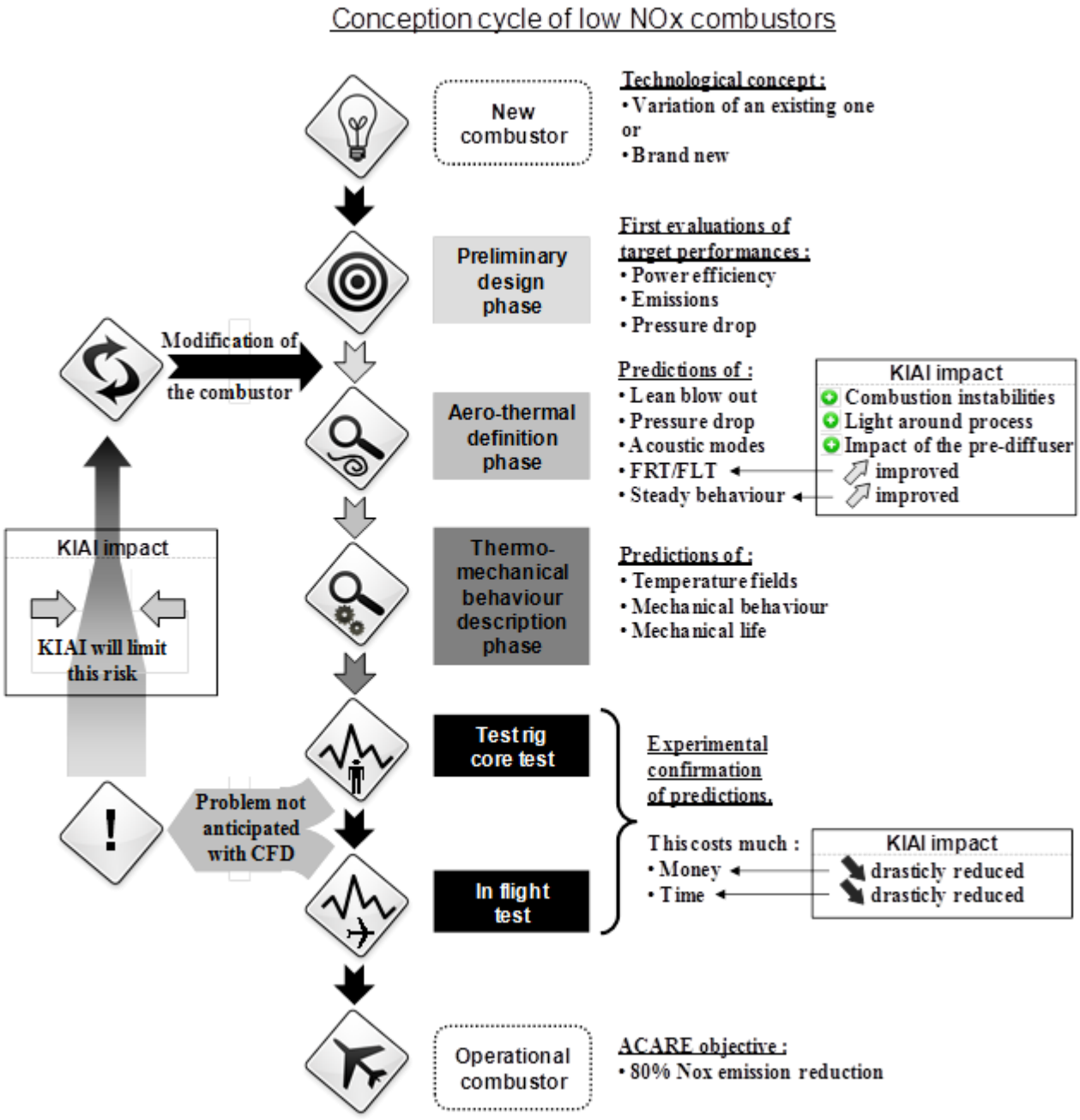

Figure 1 : Impact of KIAI on the conception cycle of low NOX combustors aiming at reducing NOX emission by 80%

4.2 Socio-economic impact and societal implications of the project

KIAI will address the objective of the transport aeronautics work programme to “ensure more environmentally friendly air transport focussing on the greening of the aircraft performance”. In relation to the AREA 7.1.1.1 Green Aircraft in which the proposal is submitted, KIAI will make a significant contribution to accelerate the entry into service of technologies aiming at reducing NOX

emissions by 80% in landing and take-off and down to 5 g/kg of fuel burnt in cruise. The pressing ICAO standards give consistency to KIAI as a way to speed up the development of low NOx technologies.

In the frame of the evolution of the CAEP standards and societal requirements towards cleaner technologies, KIAI output is also a key element in strengthening the competitiveness of the European engine industry. Compliance with more stringent future international environmental regulations and / or local policies and necessity to meet public expectation concerning environmental issues, are essential challenges for the global aviation. The development of low-emission combustor technology is therefore a pre-requisite for European engine aircraft manufacturers and especially for the partners of the project to guarantee their competitiveness in the world-wide market, not only in the short term but also in the long term. **KIAI will have a major impact on short and long term engine manufacturer competitiveness as it will contribute to accelerate the availability of lean technologies.**

5. Use and dissemination of foreground

5.1 Section A (public)

5.1.1 List of all scientific (peer reviewed) publications (A1)

No	Title	Main author	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Year of publication	Relevant pages	Permanent identifiers (if available)	Is/Will open access provided to this publication?
1	Describing function analysis in a multiple flame combustor	F. Boudy, D. Durox, T. Schuller, S. Candel (CNRS)	Proceedings of the ASME Turbo Expo 2010,	GT2010-22372	ASME		2010	11		NO
2	Nonlinear mode triggering in a multiple flame combustor	F. Boudy, D. Durox, T. Schuller, S. Candel (CNRS)	Proceedings of the Combustion Institute	33	Elsevier		2010	8	doi:10.1016/j.proci.2010.05.079	NO

No	Title	Main author	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Year of publication	Relevant pages	Permanent identifiers (if available)	Is/Will open access provided to this publication?
3	LES investigation of the flow through an effusion-cooled aeronautical combustor model	E. Motheau T. Lederlin P. Bruel	ETMM8	June 2010	ERCO-FTAC	Marseille, France	2010	6		YES
4	Pre-filming primary atomization: Experiments and modeling and Spray Systems	E. Motheau T. Lederlin (TM) P. Bruel (UPPA/CNRS)	Flow Turbulence and Combustion	Vol. 88 – No. 1	Springer		2012	169-189		NO
5	LES investigation of the flow through an effusion-cooled aeronautical combustor model	S.Gepperth (KIT-ITS)	European conference on Liquid Atomization	23rd	ILASS	Brno, Czech Republic	2010			NO
6	Assessment of numerical tools for the evaluation of the acoustic impedance of multi-perforated plates	C. Bianchini (UNIFI)	Proceedings of ASME Turbo Expo	GT2011-46303; June 6-11, 2011	ASME	Vancouver, Canada	2011	10		NO

No	Title	Main author	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Year of publication	Relevant pages	Permanent identifiers (if available)	Is/Will open access provided to this publication?
7	Numerical and experimental investigation on the acoustic behaviour of multi-perforated liners in aero-engines	F. Simonetti (UNIFI)	University of Florence PhD Thesis		University of Florence					NO
8	EXPERIMENTAL DETERMINATION OF FLAME TRANSFER FUNCTION USING RANDOM VELOCITY PERTURBATIONS	Alexis Cuquel, Daniel Durox, Thierry Schuller (CNRS/ECAM)	Proceedings of the ASME Turbo Expo 2011	GT2011-45881	ASME	Vancouver, Canada	2011			
9	Unsteady simulation of liquid jet atomization in cross-flow at gas turbine conditions	G. Eckel, M. Rachner, P. Le Clercq, M. Di Domenico, and M. Aigner (DLR)	ILASS – Europe 2011 24th European Conference on Liquid Atomization and Spray System	September 2011		Estoril, Portugal,	2011			

No	Title	Main author	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Year of publication	Relevant pages	Permanent identifiers (if available)	Is/Will open access provided to this publication?
10	A test facility for assessing simulations of jets in cross flow configurations	P. Bruel (UPPA/CNRS) J.L. Florenciano (UPPA / TM) T. Kousksou (UPPA) T.Lederlin (TM)	9th International ERCOFTAC Symposium on Engineering Turbulence Modelling and Measurements	06-08/06/2012		Thessaloniki, Greece	2012		hal-00768340	YES
11	Experimental investigation on effusion liner geometries for aero-engine combustors: Evaluation of global acoustic parameters	A. Andreini (UNIFI)	Proceedings of ASME Turbo Expo	GT2012-69853; June 11-15, 2012	ASME	Copenhagen, Denmark	2012	12		NO
12	LES for the evaluation of acoustic damping of effusion plates	C. Bianchini (UNIFI)	Proceedings of ASME Turbo Expo	GT2012-68792; June 11-15, 2012	ASME	Copenhagen, Denmark	2012	12		NO

No	Title	Main author	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Year of publication	Relevant pages	Permanent identifiers (if available)	Is/Will open access provided to this publication?
13	Impact of flame base dynamics on the nonlinear frequency response of conical flames	Alexis Cuquel (CNRS/ECAM)	Comptes Rendus de Mécanique	Accepted for publication	Elsevier		2012			
14	Unstable limit cycles featuring frequency heterodyning and nonlinear describing function analysis	Frédéric Boudy (CNRS/ECAM)	Comptes Rendus de Mécanique	Accepted for publication	Elsevier		2012			
15	NONLINEAR FLAME DESCRIBING FUNCTION ANALYSIS OF UNSTABLE LIMIT CYCLES FEATURING CHAOTIC STATES IN PREMIXED COMBUSTORS	Frédéric Boudy (CNRS/ECAM)	Proceedings of ASME Turbo Expo 2012	GT2012-68998 June 11-15, 2012	ASME	Copenhagen, Denmark	2012			NO
16	EFFECTS OF THE MEAN FLOW FIELD ON THE THERMO-ACOUSTIC STABILITY OF AERO-ENGINE	Jannis Gikadi Thomas Sattelmayer (TUM)	Proceedings of GT2012 ASME Turbo Expo 2012: Power for	GT2012-69612 June 11-15, 2013	ASME	Copenhagen, Denmark	2012			NO

No	Title	Main author	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Year of publication	Relevant pages	Permanent identifiers (if available)	Is/Will open access provided to this publication?
	COMBUSTION CHAMBERS		Land, Sea, and Ai							
17	Linearized Navier-Stokes and Euler equations for the determination of the acoustic scattering behaviour of an area expansion	Jannis Gikadi Thomas Sattelmayer (TUM)	18th AIAA/CEAS Aeroacoustics Conference (33rd AIAA Aeroacoustics Conference)	04 June 2012 - 06 June 2012	AIAA	Colorado Springs, CO	2012		DOI 10.2514/6.2012-2292	
19	Modeling the chemical structure of spray flames using tabulated chemistry method	B. Franzelli B. Fiorina N. Darabiha (CNRS/EM2C)	CLASS 2012, 12th Triennial International Conference on Liquid Atomization and Spray Systems	2-6 September 2012		Heidelberg, Germany	2012			
20	A MULTI-REGIME FLAMELET METHOD FOR PREMIXED AND NON-PREMIXED	B. Franzelli B. Fiorina N. Darabiha	XXIII ICTAM,	9–24 August 2012,		Beijing, China	2012			

No	Title	Main author	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Year of publication	Relevant pages	Permanent identifiers (if available)	Is/Will open access provided to this publication?
	COMBUSTION IN SPRAY FLAMES	(CNRS/EM2C)								
21	A tabulated chemistry method for spray combustion	B. Franzelli B. Fiorina N. Darabiha (CNRS/EM2C)	Proceedings of the Combustion Institute, Volume 34	24 July 2012	Elsevier		2013	1659–1666	http://dx.doi.org/10.1016/j.proci.2012.06.013	NO
22	Compressible and low Mach number LES of a swirl experimental burner	D. Barré et al. (CORIA/CERFACS)	Comptes Rendus Mécanique Volume 341, Issues 1–2	January 2013	Elsevier			277–287	http://dx.doi.org/10.1016/j.crme.2012.11.010	NO
23	Laser-induced spark ignition of premixed confined swirled flames	Bruno Renou (CORIA)	Combustion Science and Technology Volume 185, Issue 3, 2013		Taylor and Francis		2013		DOI: 10.1080/00102202.2012.725791	NO

No	Title	Main author	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Year of publication	Relevant pages	Permanent identifiers (if available)	Is/Will open access provided to this publication?
24	EXPERIMENTAL AND THEORETICAL INVESTIGATION OF THERMAL EFFECTIVENESS IN MULTI-PERFORATED PLATES FOR COMBUSTOR LINER EFFUSION COOLING	A. Andreini (UNIFI)	Proceedings of ASME Turbo Expo 2013	June 3-7, 2013	ASME	San Antonio, Texas, USA	2013			NO
25	FORCED AND SELF-EXCITED INSTABILITIES FROM LEAN PREMIXED, LIQUID-FUELLED AEROENGINE INJECTORS AT HIGH PRESSURES AND TEMPERATURES	Simone Hochgreb (RRUK - Cambridge)	Proceedings of ASME Turbo Expo 2013	June 3-7, 2014	ASME	San Antonio, Texas, USA	2013			NO
26	Analysis and comparison of primary droplet characteristics in the near field of a prefilming airblast atomizer	S.Gepperth (KIT-ITS)	Proceedings of ASME Turbo Expo 2013	GT2013-94033	ASME	San Antonio, Texas, USA	2013			No

No	Title	Main author	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Year of publication	Relevant pages	Permanent identifiers (if available)	Is/Will open access provided to this publication?
27	NUMERICAL INVESTIGATION OF THE PLANE-WAVE REFLECTION COEFFICIENT OF AN EXHAUST PIPE AT ELEVATED TEMPERATURES USING LINEARIZED NAVIER-STOKES EQUATIONS	Jannis Gikadi Thomas Sattelmayer (TUM)	Proceedings of ASME Turbo Expo 2013	GT2013-94843	ASME	San Antonio, Texas, USA	2013			NO
28	PREDICTION OF THE ACOUSTIC LOSSES OF A SWIRL ATOMIZER NOZZLE UNDER NON-REACTIVE CONDITIONS	Jannis Gikadi Thomas Sattelmayer (TUM)	Proceedings of ASME Turbo Expo 2013	GT2013-95449	ASME	San Antonio, Texas, USA	2013			NO
29	PREDICTION OF THE NONLINEAR DYNAMICS OF A MULTIPLE FLAME COMBUSTOR BY COUPLING THE DESCRIBING FUNCTION METHODOLOGY WITH A	Alexis Cuquel (CNRS/ECAM)	Proceedings of ASME Turbo Expo 2013	GT2013-95659	ASME	San Antonio, Texas, USA	2013			NO

No	Title	Main author	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Year of publication	Relevant pages	Permanent identifiers (if available)	Is/Will open access provided to this publication?
	HELMHOLTZ SOLVER									
30	Thermoacoustic Analysis of a Full Annular Aero-engine Lean Combustor with Multi-perforated Liners	A. Andreini (UNIFI)	19th AIAA/CEAS Aeroacoustics Conference		ARC	Berlin, Germany	May 27-29, 2013		DOI: 10.2514/6.2013-2099	NO
32	Experimental Study of the Unsteady Aerodynamics the Compressor-Combustor Interface of a Lean Burn Combustion System	A. D. Walker (Loughborough University)	49th AIAA/ASME/SAE/ ASEE Joint Propulsion Conference	Accepted for publication - July 15-17 2013	AIAA	San Jose, CA, USA	2013			NO
33	Spark Ignition of Flowing Kerosene Jet-A1–Air Mixtures at High Altitude Relight Conditions	M.Majcherczyk (KIT EBI)	Proceedings of the European Combustion Meeting 2013	Accepted for publication		Lund, Sweden	2013			
34	Semi-Empirical Primary Atomization Models for	G. Eckel P. Le Clercq	8th International Conference on			Jeju, Korea	2013		ICMF2013-437	NO

No	Title	Main author	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Year of publication	Relevant pages	Permanent identifiers (if available)	Is/Will open access provided to this publication?
	Transient Lagrangian Spray Simulation	(DLR)	Multiphase Flow (ICMF)							
35	Liquid-Fuel Behavior Experimentally Investigated during Thermo-Acoustic Instability Cycles in Aeronautical Injector	Julien M.Apeloig Pierre Gajan (ONERA)								

5.1.2 List of all dissemination activities (A2)

Below are presented other dissemination activities carried out during the project duration (conferences, workshops, web sites, flyers, thesis, posters, etc.).

No	Type of activities	Main leader	Title	Date	Place	Type of audience	Size of audience	Countries addressed
1	Conference	TM and UPPA	8th International ERCOFTAC Symposium on Engineering Turbulence Modelling and Measurements	09-11/06/2010	Marseille, France	Scientific community (higher education, Research)	30-40	
2	Conference	CERFACS	5th European Conference on Computational Fluid Dynamics, ECCOMAS CFD 2010,	16/06/2010	Lisbon, Portugal	Scientific community (higher education, Research)	100	
3	presentations	SN	S. Roux presented the KIAI project at the last TIMECOP meeting.	11 décembre 2010	Paris, France	Scientific community (higher education, Research)		
4	exhibitions		ASME Turbo Expo 2010: Power for Land, Sea and Air	14-18/06/2010	Glasgow, UK	Scientific community (higher education, Research)	50	

5	conferences		33th International Symposium on Combustion	01-06/08/2010	Beijing, China	Scientific community (higher education, Research)	100	
6	conferences	KIAI Coordinator (S. Roux), TM (T. Lederlin) and UPPA (P. Bruel)	6th European Aeronautics Days	29/03-03/04/2011	Madrid, Spain	Industry	30	
7	posters	CORIA	5th European Combustion Meeting	28/06- 01/07/2011	Cardiff, UK	Scientific community (higher education, Research)		
8	conferences	CNRS, TUM, UNIFI	ASME Turbo Expo 2011	6-10/06/2011	Vancouver / Canada	-select-		
9	conferences	CNRS, CERFACS	7th Mediterranean Combustion Symposium	11-15/09/2011	Sardinia / Italy	-select-		
10	workshops	CORIA, CERFACS, UPPA, SN, ONERA	Workshop APAM	15 novembre 2011	Toulouse, France	Industry	20	

11	conferences	Talk: Bruel, P., Florenciano, J.-L., Kousksou, T., Lederlin, T. TM, UPPA	International symposium ERCOFTAC (ETMM9)	06- 08.06.2012	Thelassoniki, Greece	-select-	40	
12	conferences	TUM	18th AIAA/CEAS Aeroacoustic Conference	04-06/06/12	Antlers Hilton, Colorado Springs	Scientific community (higher education, Research)	50	
13	exhibitions	TUM, UNIFI	ASME Turbo Expo 2012	11-15/06/12	Copenhagen, Denmark	Scientific community (higher education, Research)	150	
14	exhibitions	KIT	ECM 2013	June 2013	LUND ,Sweden	Scientific community (higher education, Research)	100	
15	conferences	CORIA	ASME Turbo Expo 2013	3-7/06/13	San Antonio, US	Scientific community (higher education, Research)	150	
16	conferences	CORIA and CERFACS	ASME Turbo Expo 2013	3-7/06/13	San Antonio, US	Scientific community (higher education, Research)	150	
17	conferences	TUM	18th AIAA/CEAS Aeroacoustic Conference	04-06/06/12	Antlers Hilton, Colorado Springs	Scientific community (higher education, Research)	50	

18	conferences	TUM	ASME Turbo Expo 2012	11-15/06/12	Copenhagen, Denmark	Industry	150	
19	conferences	TUM	ASME Turbo Expo 2013	03-07/06/13	San Antonio, USA	Industry	100	
20	conferences	LU	49th AIAA/ASME/SAE/ASEE Joint Propulsion Conference	15-17 July 2013	San Jose, USA	Scientific community (higher education, Research)	50-100	various
21	workshops	ARTICC - UNIFI	KIAI-TECC Public Workshop	17-18/9/2012	Florence, Italy	-select-	100	
22	Others	KIT-ITS	various lectures and workshops	2009-Today	KIT, ITS	Civil Society	20-50	

5.2 Section B (confidential or public)

5.2.1 Part B1 – List of applications for patents, trademarks, registered designs, etc.

List of applications for patents, trademarks, registered designs, etc.					
Type of Exploitable Foreground	**Confidential**	**Foreseen embargo date** **dd/mm/yyyy**	**Application reference(s) (e.g. EP123456)**	**Subject or title of application**	**Applicant (s) (as on the application)**

5.2.2 Part B2 – Exploitable foreground

Type of Exploitation Foreground	Description of exploitation foreground	Confidential	Foreseen embargo date dd/mm/yyyy	Exploitation products or measures	Sector of application	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary (s) involved

6. Report on societal implications

The complete societal report is available online.

The table bellow summarize the list of PHD working on the project.

Partners	Name	Title
TM	Juan-Luis FLORENCIANO MERINO	Etude de la réponse d'un écoulement avec transfert pariétal de masse à un forçage acoustique
CORIA	Frenillot	Etude phénoménologique des processus d"allumage et de stabilisation dans les chambres de combustion turbulente swirlées.
CORIA	Cordier	Etude de l'allumage dans les chambres de combustion aéronautiques, par des approches expérimentales et numériques
UPPA	Juan Luis FLORENCIANO	ÉTUDE DE LA RÉPONSE D'UN ÉCOULEMENT AVEC TRANSFERT PARIÉTAL DE MASSE À UN FORÇAGE ACOUSTIQUE
TUM	Jannis Gikadi	Prediction of Acoustic Modes in Combustors with Complex Impedances, Flames and Multidimensional Flow Fields
DLR	Georg Eckel	Ph.D. Thesis titel is not yet final. The field is Numerical simulation of turbulent reacting multiphase flows.
UNIFI	Cosimo Bianchini	Phd Title in 2011
UNIFI	Francesco Simonetti	Phd Title in 2011
UNIFI	Giulio Lenzi	PhD Title in 2012
UNIFI	Alessio Picchi	PhD Titlle planned for 2014
UNIFI	Andrea Giusti	PhD Titlle planned for 2014
CERFACS	A. Gahni	Two-phase Flow Large Eddy Simulation for Flame Transfer Function EvaluationandStability map predictions
CERFACS	D. Barré	Large Eddy Simuation of ignition sequences: from first kernel to light-around processes
CERFACS	M. Falese	Mesh adaptation for Large Eddy Simualtion of Industrial Flows: bifurcating flows and LES quality
KIT EBI	Michal Majcherczyk	Experimental investigation of liquid fuels ignition process in subatmospheric conditions
KIT-ITS	S. Gepperth	Experimental investigation on the liquid film disintegration process in prefilming airblast atomizers at elevated pressure
ONERA	J. Apeloig	Experimental investigation of the spray implication in thermo-acoustic instabilities occurring in liquid-fuelled turbo-engines
SN	Barré	Simulation numérique de l'allumage des chambres de combustion aéronautiques annulaires
SN	Eyssartier	ETUDE DU COUPLAGE ENTRE INSTABILITES HYDRODYNAMIQUES ET OSCILLATIONS DE COMBUSTION