PROJECT PERIODIC REPORT

Grant Agreement number: 255881

Project acronym: ACOC-TH

Project title: Thermal instrumentation, tests and modeling of engine surface coolers in representative aerodynamic conditions

Funding Scheme: Clean Sky Joint Technology Initiative

Date of latest version of Annex I against which the assessment will be made:

Periodic report: First
Period covered: **from** 01/01/2010 **to** 30/06/2011

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

Prof. Guillermo Paniagua
von Karman Institute for Fluid Dynamics

Tel: +32 2 359 96 29

Fax: +32 2 359 96 00

E-mail: paniagua@vki.ac.be

1. Publishable summary

Summary description of project context and objectives

The recent technological developments in the aeronautical domain and the continuous search for more efficient engine architectures demand a parallel investigation on advanced oil cooling strategies. The usual cold sources like the inlet air stream and the fuel circuit are approaching their limits as new engine designs are exploited. The higher level of complexity on the mechanical systems requires an adequate thermal management of the systems. The heat removal by the aircraft structure will be limited by the use of composite materials with lower operational temperature and thermal conductivity properties. Furthermore, the limitation on the maximum fuel temperature decreases the viability of the fuel tank as a cold source.

The present work is included in the research frame of novel engine cooling strategy. It has the objective to quantify the thermal performance of an Air Cooled Oil Cooler (ACOC) heat exchanger assembled on the inner wall of the secondary duct of a turbofan. The goal of such design is to use the available surface as a heat exchanger between the air and the oil. In order to increase the thermal performance, the wet area is increased by adding longitudinal fins, reaching the required heat dissipation power. Such a design implies a strong compromise between the aerodynamic penalties, (introduced by the increased drag) and the thermal performance of the heat exchanger.

The developed research presents an innovative aero-thermal study by testing the new heat exchanger concept in a 3D shaped transonic wind tunnel capable of reproducing the flow condition within the bypass of an engine. Innovative data processing approaches, based on inverse heat conduction methods (IHCM), were developed and employed during the course of this work.

Work performed during the first reporting period of the project

During the first reporting period (01/01/2010 to 30/06/2011) of the project the following work was performed:

- Design of the optical access for the transonic stream tube wind tunnel facility in order to perform the measurement campaign with optical measurement for advanced heat transfer analysis such as inverse heat conduction methods for full characterisation of ACOC.
- Development of the IHCM methodology.
- Design, manufacturing and building of the Surface ACOC facility.

Project partners

von Karman Institute for Fluid Dynamics (Dr. Guillermo Paniagua)
Université Libre de Bruxelles (Dr. Patrick Hendrick)

Summary of progress made

Development of an inverse heat conduction method

Inverse problems are mathematically classified as ill-posed whereas standard heat transfer problems are considered as well-posed. The solution of a well posed problem must satisfy the condition of existence, uniqueness and stability with respected to the input data. The existence of a solution of an inverse heat transfer problem is assured by physical reasoning and its uniqueness can only be proved for some special cases. The difficulty in an inverse problem is the fact that the solution is very sensitive to random errors in the measured input data, thus requiring special techniques to ensure the stability of the calculation. Common approaches to solve the inverse heat transfer problem rely on the minimization of an objective function that involves the squared residuals in a similar way to optimization techniques.

The present research addresses the solution of an inverse heat transfer problem using exclusively minimization techniques. The goal of this method is the estimation of a transient unknown heat flux based on the temperature measurements performed on an opposite wall by means of infrared thermography. The primary requirements of the method is that it should be robust to noisy data inputs and capable of solving the full 3D heat transfer problem.

The implemented IHCM was based on an iterative Alifanov procedure. Conjugate gradient methods with the adjoint problem were used as a minimization technique. The coupling of the inverse heat conduction solver with a commercial finite element program (COMSOL MULTIPHYSICS) provided the possibility to solve a generalized transient 3D IHCP.

For validation purpose, numerical and experimental methodologies were developed to test the solver for a variety of situations. This process revealed to be of vital importance to understand the sensitivity of the method to different parameters that typically govern the heat transfer process. The validation was obtained by imposing a known heat flux on a surface of the numerical domain. Afterwards, the resulting temperatures were used as an input to the IHCM. Finally the estimated heat flux was compared with the exact one and the errors quantified. Heat fluxes with strong temporal and spatial discontinuities revealed to be more difficult to estimate. The influence of noisy measurements was attained by adding artificial noise on the input temperatures. The study revealed the capability of the developed methodology to recover the adiabatic heat transfer coefficient and the adiabatic wall temperature with an average uncertainty below 20%.

Adaptation of the wind tunnel

The initial wind tunnel walls were adapted to support a round Germanium window of 80 mm of diameter and 10 mm thickness. The adaptation of the test section allows the optical access at two different locations, on the lateral and top wall. However, due to the complex geometry, optical access on one complete fin was not possible. Since the surface boundary condition on the optically inaccessible parts of the domain were not known, the 3D heat transfer process over one fin was retrieved using the developed IHCM.

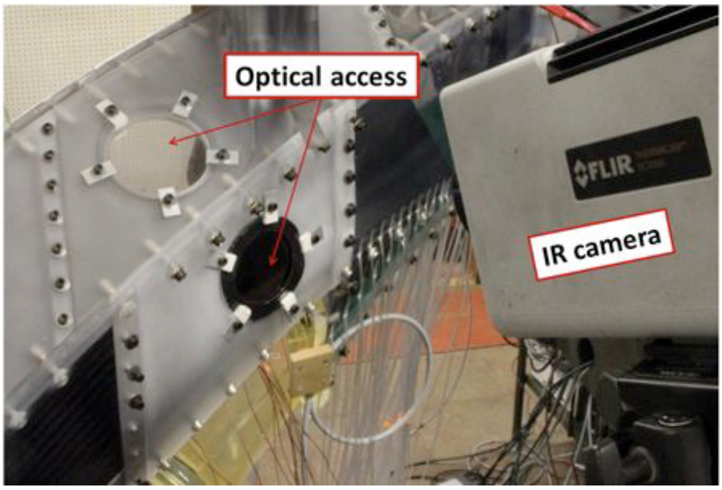

Fig. 1: Wind tunnel modification to allow IR optical access (Germanium window)

Design and manufacturing of surface ACOC test setup

In task 1.1, ULB worked on the definition of test environment, geometry and working conditions with discussions with the VKI and experts in this field, among others turbofan engine manufacturers.

In task 1.2, ULB worked on the Manufacturing, instrumentation and set-up of the test installation on the oil side of the ACOC.

The design and optimization of SACOC (Surface ACOC) must respond to a compromise between the thermal performance and the aerodynamic performance on the air side, and minimum pressure losses on the oil side to avoid too low oil pressure resulting in cavitation. Also, its installation must take into account the air flow direction and the engine geometry. An experimental investigation of the thermal part was done in the frame of this project. The objectives were to test air-oil heat exchanges in realistic conditions with SACOC breadboards connected with a real oil side.

The test bench used in this project is dedicated to aero-thermal comparisons of different SACOC technologies identified as suitable for aero-engine applications.

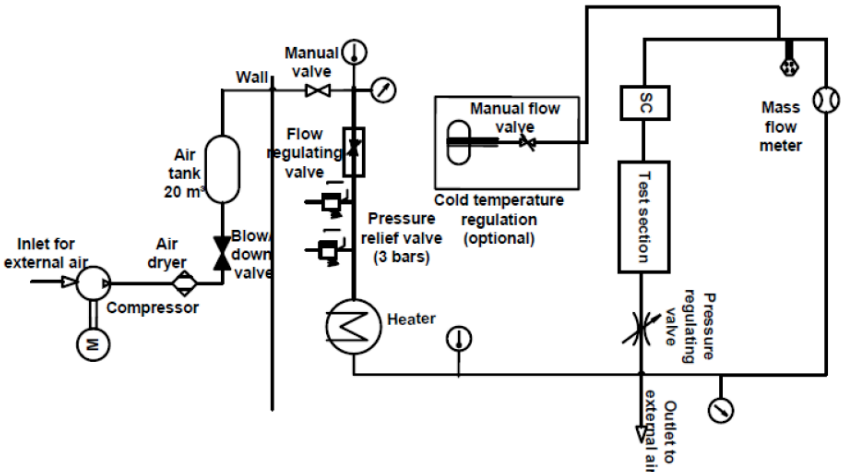

Fig. 2 : SACOC test bench air side

Air is stored at a pressure reaching 40 bar using a compressor. As the output flow is generally low for high pressures, and as the required cooling air velocity reaches high values (from 30 m/s to 210 m/s) the air flow is generated thanks to a "blow down" system. It consists on opening manually a high pressure valve, establishing then the air flow thanks to the difference of pressure between the air tank and the rest of the facility. The airflow is regulated with a valve, which progressively opens when the tank pressure decreases (and so does the velocity). The maximum mass flow measured with the latter is 1360 g/s. After settling the air flow, a 92 kW heater associated to a PID regulator allows to reach a static temperature of 340 K (corresponding to the engine take-off working conditions). The test section is preceded by a settling chamber to ensure the air flow is axial, and to drastically reduce the turbulence level.

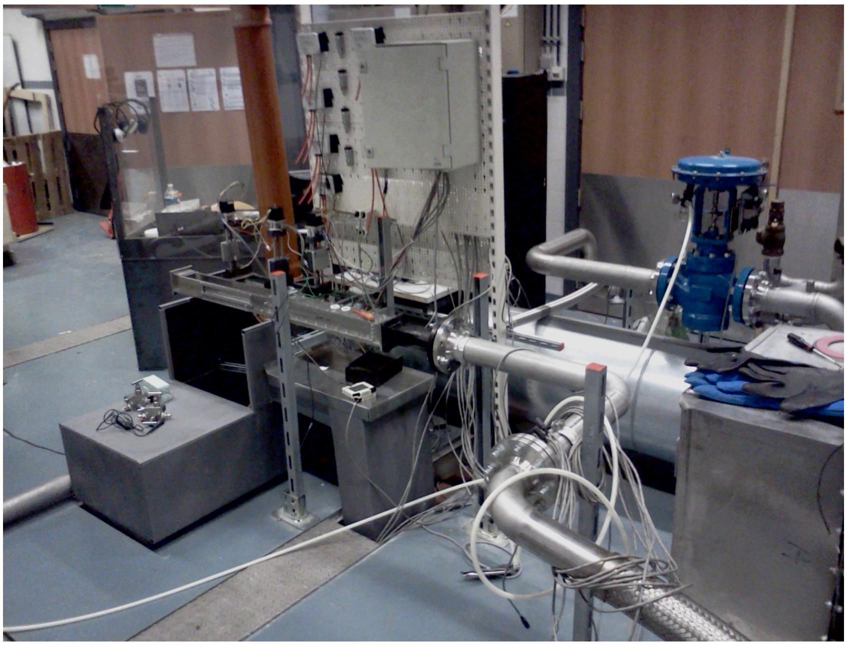

Fig. 3 : The air circuit of the SACOC test facility

Several pressure and temperature sensors were added to provide a monitoring of the test bench, and a software protection. A pressure relief valve is placed before the regulation flow valve for safety reasons. Also a security thermostat and kill switches define the hardware protection of the air circuit.
The air circuit is completed by a realistic oil circuit. The oil employed must naturally respect the standard MIL-PRF-23699F, as the one used in real aero-engines.

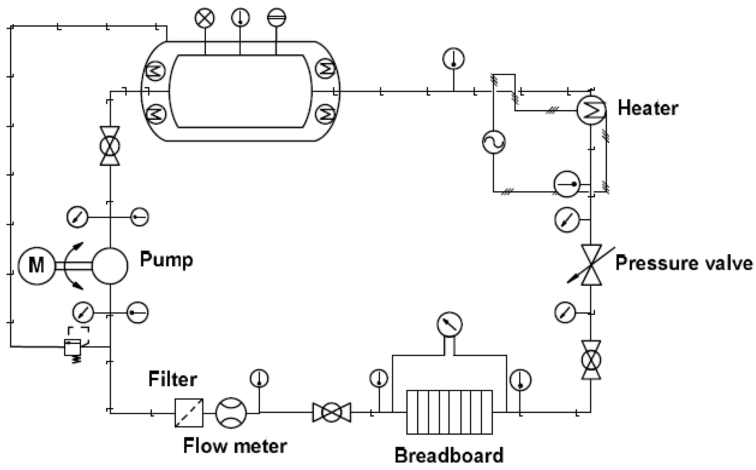

Fig. 4 : SACOC test facility oil circuit

The oil tank is divided into two compartments: an external tank (145 liters), with the role to maintain the temperature constant in the whole circuit, and an internal tank (70 liters), containing the oil flowing through the breadboard and the whole circuit.
An electric pump is placed after the tank. It generates the oil flow by controlling its rotation speed with a precision of 0.1% of the maximum rotation speed (corresponding to a flow of 1800 l/h). The flow is measured by a flow meter, which is actually a small free turbine with an electronics compensating for the changes in viscosity and in temperature.
Although it will not be used for the tests, the circuit is provided with a regulation valve placed after the breadboard. The oil pressure can reach up to 6 bar as in modern aero-engines. Finally, a 9 kW heater is situated between the breadboard and the oil tank to compensate the heat losses resulting from the cooling in the SACOC. The test bench can regulate an oil temperature from 20°C to 170°C.

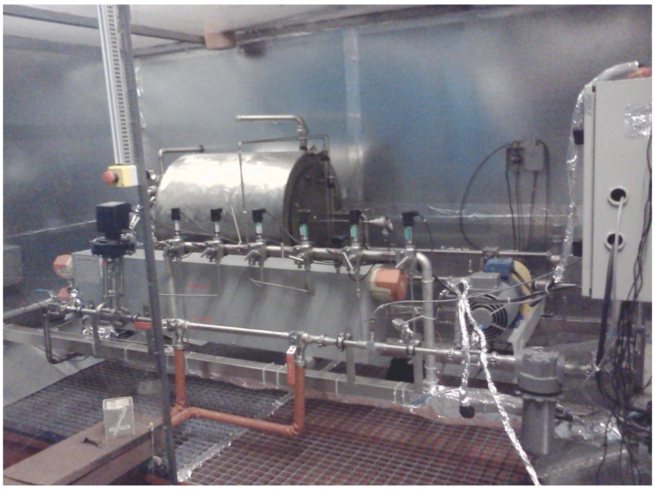

Fig. 5 : The SACOC facility oil circuit

With this test facility, different breadboards have been tested during the period 2 of this project in order to characterize mainly the oil side of the SACOC.

Highlights

The modifications in the test rig were designed for the optical measurements. The methodology for IHCM was developed. SACOC test rig was designed and manufactured.

Effective resources usage

Rep.. Period 1	**Entity: VKI**		
Cost type	**Work package**	**Explanation**	**Cost**
Personnel	1	Prof. Paniagua (0.41PM)	€ 3,541.15
		RTD/Innovation personnel	Total (€) 3,541.15
Subcontracting			
		RTD/Innovation subcontracting	Total (€) 0.00
Indirect	N/A	N/A	€ 2,670.78
		RTD/Innovation	Total (€) 6,211.93

Rep. Period 1	**Entity: ULB**		
Cost type	**Work package**	**Explanation**	**Cost**
Personnel	1	Preparation work of the ACOC test facility done on ULB funds	€ 0.00
		RTD/Innovation personnel	Total (€) 0.00
Subcontracting	---	---	€ 0.00
		RTD/Innovation Subcontracting	Total (€) 0.00
Direct cost	1.2	Manufacturing, instrumentation and set-up of the test installation on the ACOC oil side	€ 20,219.79
Indirect costs	N/A	N/A	€ 4,043.96
		RTD/Innovation	Total (€) 24,263.75

2. Deliverables and milestones tables

Deliverables

D1.1-12 Intermediate report. Description of the test environment, geometry of the ACOC and working conditions (oil flow and air flow)

3. Financial statement

FP7 - Grant Agreement - Annex V - Article 171 of the Treaty

Form C - Financial Statement (to be filled in by each beneficiary)

Project nr.	255881	Funding scheme	Article 171 of the Treaty
Project Acronym	ACOC-TH		
Period from	01/01/2010	Is this an adjustment to a previous statement?	No
To	30/06/2011		
Legal Name	VON KARMAN INSTITUTE FOR FLUID DYNAMICS	Participant Identity Code	999698006
Organisation short Name	VKI	Beneficiary nr.	1
Funding % for RTD activities (A)	75.00	If flat rate for indirect costs, specify %	N/A (Actual Indirect Costs)

1. Declaration of eligible costs/lump sum/flat rate/scale of unit (in €)

	Type of Activity				
	RTD (A)	Demonstration (B)	Management (C)	Other (D)	Total (A+B+C+D)
Personnel costs	3,541.15	0.00	0.00	0.00	3,541.15
Subcontracting	0.00	0.00	0.00	0.00	0.00
Other direct costs	0.00	0.00	0.00	0.00	0.00
Indirect costs	2,670.78	0.00	0.00	0.00	2,670.78
Total	6,211.93	0.00	0.00	0.00	6,211.93
Maximum JU contribution	4,658.95	0.00	0.00	0.00	4,658.95
Requested JU contribution					4,658.95

2. Declaration of receipts

Did you receive any financial transfers or contributions in kind, free of charge from third parties or did the project generate any income which could be considered a receipt according to Art.II.17 of the grant agreement? No

If yes, please mention the amount (in €)

3. Declaration of interest yielded by the pre-financing *(to be completed only by the coordinator)*

Did the pre-financing you received generate any interest until 31/12/2012 according to Art.II.19? No

If yes, please mention the amount (in €)

4. Certificate on the methodology

Do you declare average personnel costs according to Art.II.14.1? No

Is there a certificate on the methodology provided by an independent auditor and accepted by the Commission according to Art.II.4.4? No

Name of the auditor		Cost of the certificate (in €), if charged under this project	

5. Certificate on the financial statements

Is there a certificate on the financial statements provided by an independent auditor attached to this financial statement according to Art.II.4.4? Yes

Name of the auditor	Monika Lenaerts - BVBA Robrechts Lenaerts Bedrijfsrevisoren - Réviseurs d'Entreprises	Cost of the certificate (in €)	0.00

6. Beneficiary's declaration on their honour

We declare on our honour that:

- the costs declared above are directly related to the resources used to attain the objectives of the project and fall within the definition of eligible costs specified in Articles II.14 and II.15 of the grant agreement, and, if relevant, Annex III and article 7 (special clauses) of the grant agreement;
- the receipts declared above are the only financial transfers or contributions in kind, free of charge, from third parties and the only income generated by the project which could be considered as receipts according to Art.II.17 of the grant agreement;
- the interest declared above is the only interest yielded by the pre-financing until 31/12/2012 which falls within the definition of Art.II.19 of the grant agreement;
- there is full supporting documentation to justify the information hereby declared. It will be made available at the request of the Joint Undertaking and in the event of an audit by the Joint Undertaking and/or by the Court of Auditors and/or their authorised representatives.

Beneficiary's Stamp	Name of the Person(s) Authorised to sign this Financial Statement
	Dominick HEMERYCK
	Date & hand signature
	17/07/2013

FP7 - Grant Agreement - Annex V - Article 171 of the Treaty

Form C - Financial Statement (to be filled in by each beneficiary)

Project nr.	255881	Funding scheme	Article 171 of the Treaty
Project Acronym	ACOC-TH		
Period from	01/01/2010	Is this an adjustment to a previous statement?	No
To	30/06/2011		
Legal Name	UNIVERSITE LIBRE DE BRUXELLES	Participant Identity Code	999986290
Organisation short Name	ULB	Beneficiary nr.	2
Funding % for RTD activities (A)	75.00	If flat rate for indirect costs, specify %	20.00

1. Declaration of eligible costs/lump sum/flat rate/scale of unit (in €)

	Type of Activity				
	RTD (A)	Demonstration (B)	Management (C)	Other (D)	Total (A+B+C+D)
Personnel costs	0.00	0.00	0.00	0.00	0.00
Subcontracting	0.00	0.00	0.00	0.00	0.00
Other direct costs	20,219.79	0.00	0.00	0.00	20,219.79
Indirect costs	4,043.96	0.00	0.00	0.00	4,043.96
Total	24,263.75	0.00	0.00	0.00	24,263.75
Maximum JU contribution	18,197.81	0.00	0.00	0.00	18,197.81
Requested JU contribution					18,197.81

2. Declaration of receipts

Did you receive any financial transfers or contributions in kind, free of charge from third parties or did the project generate any income which could be considered a receipt according to Art.II.17 of the grant agreement?	No
If yes, please mention the amount (in €)	

3. Declaration of interest yielded by the pre-financing *(to be completed only by the coordinator)*

Did the pre-financing you received generate any interest until 31/12/2012 according to Art.II.19?	No
If yes, please mention the amount (in €)	

4. Certificate on the methodology

Do you declare average personnel costs according to Art.II.14.1?			No
Is there a certificate on the methodology provided by an independent auditor and accepted by the Commission according to Art.II.4.4?			No
Name of the auditor		Cost of the certificate (in €), if charged under this project	

5. Certificate on the financial statements

Is there a certificate on the financial statements provided by an independent auditor attached to this financial statement according to Art.II.4.4?			No
Name of the auditor		Cost of the certificate (in €)	

6. Beneficiary's declaration on their honour

We declare on our honour that:

- the costs declared above are directly related to the resources used to attain the objectives of the project and fall within the definition of eligible costs specified in Articles II.14 and II.15 of the grant agreement, and, if relevant, Annex III and article 7 (special clauses) of the grant agreement;
- the receipts declared above are the only financial transfers or contributions in kind, free of charge, from third parties and the only income generated by the project which could be considered as receipts according to Art.II.17 of the grant agreement;
- the interest declared above is the only interest yielded by the pre-financing until 31/12/2012 which falls within the definition of Art.II.19 of the grant agreement;
- there is full supporting documentation to justify the information hereby declared. It will be made available at the request of the Joint Undertaking and in the event of an audit by the Joint Undertaking and/or by the Court of Auditors and/or their authorised representatives.

Beneficiary's Stamp	Name of the Person(s) Authorised to sign this Financial Statement
	Françoise Magerman
	Date & hand signature
	18/03/2013