Project n°: **516165**

ADELINE

Advanced air-**D**ata **E**quipment for air**LINE**rs

Specific Targeted Research Projects (STP)

Priority 4: Aeronautics and Space

Deliverable D37 : SUMMARY FINAL REPORT

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THALES AVIONICS

Revision (**00**)

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OO	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

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1. INTRODUCTION

1.1 Objectives

The main project targets are:

- to reduce present equipment costs by 50 % including purchasing and exploitation costs,
- to increase aircraft's safety by drastically reducing air data system failure.

The means to achieve these targets are to develop simpler, more reliable and safer equipments than that of the American systems, that dominate the market.

Then the objectives of ADELINE are:

- Identification of innovative air data system architectures.
- Development of innovative measuring concepts to acquire all information with only two different types of probes instead of three for competitors' solutions.
- Development of breakthrough technologies:
  - New probe material and associated nanomaterial coating in order to reduce abrasion and ice adherence.
  - Innovative self regulated anti-icing technology based on the use of positive temperature coefficient (PTC) ceramics.
  - New packaging technologies for MEMS pressure sensor to allow the integration of the sensor within the probe.
  - Development of a self-test for pressure sensor.

The duration of the project is 36 months.

1.2 Consortium

A consortium of eight partners with all the required skills has been established as follows: two SMEs, one industrial, three academic institutes and two research centres.

The ADELINE consortium composition is summarised in the next table. It consists of industrial partners, research establishments and universities.

Each partner contributes with its specific and distinct skills, tools and knowledge in the highly inter-disciplinary ADELINE project.

Two SMEs (ATCT and Castings Technology International) are part of the Adeline project with one industrial partner (Thales Avionics), three academic institutes (Technical University of Berlin, University of Aachen and Cranfield University) and two research centres (Météo France CNRM and VZLU).

A User Club have been established to involve the main aircraft manufacturers and the standardization authorities to have a feedback on the solutions proposed by the consortium. Today Airbus, Dassault Aviation and EUROCAE are members of the User Club.

List of Participants						
Partic. Role*	Partic. no.	Participant name	Participant short name	Country	Date enter project**	Date exit project**
CO	1	THALES AVIONICS	THAV	France	To	36
CR	2	ATCT	ATCT	Israel	To	36
CR	3	VYZKUMNY A ZKUSEBNI LETECKY USTAV A.S.	VZLU	Czech Republic	To	36
CR	4	CASTINGS TECHNOLOGY INTERNATIONAL	Cti	United Kingdom	To	36
CR	5	TECHNICAL UNIVERSITY BERLIN	TUB	Germany	To	36
CR	6	RWTH AACHEN UNIVERSITY	RWTH	Germany	To	36
CR	7	METEO FRANCE CENTRE NATIONAL DE RECHERCHES METEOROLOGIQUES	CNRM	France	To	36
CR	8	Cranfield University	CU	United Kingdom	To	36

*CO = Coordinator

CR = Contractor

** "To (start of project)" and "month 36 (end of project)"

1.3 Summarized description of work

The project is organised in five work packages to allow:

- the definition of the system architecture

- the development of innovative principles and technologies
- the development and the flight tests of two different functional mock-ups.

1.3.1 WP 1000 : Architecture analysis

The architecture analysis of existing air data systems is based on Thales Avionics and aircraft manufacturers expertise in this domain. The objective is to identify innovative architectures and to establish the specification of the new system.

This work package is composed of the following sub tasks :

WP 1100 : Existing architecture synthesis; it was completed by the deliverable D1

WP 1200 : Architecture optimisation analysis; it was completed by the deliverable D2

WP 1300 : New equipment specifications; it was completed by the deliverables D4 and D5

1.3.2 WP 2000 : Innovative concept identification

THAV together with the technological experts (TUB, RWTH, ATCT, Cti) identify the drawbacks of existing probes and define the innovative concepts. The technological bricks needed for the new concepts are identified by:

- TUB for the MEMS pressure sensor packaging
- Cti and RWTH for the new probe materials, coating and simulations
- ATCT for the new PTC self-Regulated de-icing technique

This work package is composed of the following sub tasks :

WP 2100 : Technology state of the art; it was completed by the deliverable D3

WP 2200 : Research of new measurement principles; it was completed by the deliverable D8

WP 2300 : Research of new material and coating; it was completed by the deliverables D9 and D10

WP 2400 : Research of new de-icing techniques; it was completed by the deliverable D11

WP 2500 : Research of new packaging for pressure sensor; it was completed by the deliverable D12

WP 2600 : Identification of bricks to be developed; it was completed by the deliverable D13

1.3.3 WP 3000 : Technical bricks development

THAV, TUB, ATCT, Cti and RWTH have developed the identified technological bricks. A first assembly of all the bricks led to preliminary mock-ups. VZLU and CU performed the mock-ups tests in dry and icing wind tunnel.

This work package was composed of the following sub tasks :

WP 3100 : Development and test of new principles; it was completed by the deliverables D16 and D17

WP 3200 : Development and test of new materials and coating; it was completed by the deliverables D18 and D19

WP 3300 : Development and test of new de-icing techniques; it was completed by the deliverable D20

WP 3400 : Development and test of new packaging for pressure sensors; it was completed by the deliverable D21

WP 3500 : Technical bricks assembly and evaluation; it was completed by the deliverables D24 and D25

1.3.4 WP 4000 : Functional mock-up

The manufacturing of functional mock-ups was carried out by Thales with the participation of TUB for the sensor packaging manufacturing, Cti for the casting parts manufacturing, RWTH for the coating deposition and ATCT for the heater manufacturing.

VZLU and CU tested the mock-ups in dry and icing wind tunnel. CNRM carried out the flight test.

This work package was composed of the following sub tasks :

WP 4100 : Functional mock-up development and fabrication; it was completed by the deliverables D26 and D29

WP 4200 : Functional mock-up ground Test; it was completed by the deliverables D30 and D31

WP 4300 : Functional mock-up flight tests; it was completed by the deliverables D34 and D35

1.3.5 WP 5000 : Management

THAV has managed the project. All partners have carried out the dissemination activities and the exploitation plans. Annual reviews with the EC have reported on the feasibility of the technical and economical objectives.

This work package was composed of the following sub tasks :

WP5100 : Consortium & WP management; it was completed by the deliverables D7, D14, D22, D23, D27, D28, D32, D37, and D38

WP 5200 : Dissemination & exploitation plans ; it was completed by the deliverables D6, D15, D33 and D36.

1.3.6 Project milestones

Milestone n°	MILESTONE	DATE (in months)
M1	Air data architecture choice	To+3
M2	New equipment specification	To+3
M3	Selection of technical bricks to be developed	To+8
M4	GO/NO GO decision of the first review meeting	To+12
M5	Validation of individual technological bricks	To+13
M6	First complete mock-up evaluation	To+22
M7	GO/NO GO decision of the second review meeting	To+24
M8	Functional mock-ups available for ground tests	To+24
M9	Functional mock-ups available for flight tests	To+27
M10	Environmental resistance of mock-up to allow flight tests	To+28
M11	Validation of the performances of functional mock-ups in flight conditions	To+36

Start date of the project : January 15th, 2005

2. SCIENTIFIC AND TECHNICAL DESCRIPTION OF THE RESULTS

The following chapters will describe the progress made all along the project, task after task.

2.1 WP 1000 : Architecture analysis

2.1.1 WP 1100 : Existing architecture synthesis

The air data system must sense and provide to the aircraft the following parameters : total pressure, static pressure, angle of attack, total temperature, on several channels (primary and secondary). The architectures depend on the aircraft type (1st or 2nd level), the buses format (ARINC 429 or 629, AFDX), and the type of probes used (discrete or multifunction probes).

Different typical architectures have been identified and described in the deliverable D1:

- 3 using discrete probes
  - 2 for 1st level aircraft
  - 1 for 2nd level aircraft
- 1 using multifunction probes

2.1.2 WP 1200 : Architecture optimization analysis

The analysis of the different architectures addressed the following aspects:

- Air data systems requirements (current and medium term trends)
- Specifications for the different parameters
- Electrical power supply characteristics
- Safety and reliability
- MTBF
- Maintainability
- Environments

The principal conclusions of the analysis relative to discrete architectures are that they are fully compliant with current requirements. But they present important drawbacks towards future trends:

- these architecture require the most pneumatic tubing from pressure probes to ADC. To fit with the future trend, it will require integration of ADMs in the probe bases

- the number of equipments (probes, ADM, PHC) and holes in the fuselage need to be lowered in the future, for reduction of weight; future trends lead to the development of probes including several functions
- the testability of probes and de-icing regulation

The principal conclusions of the analysis relative to MFP based architectures are:

- MFP-based architectures are fully compliant with current requirements
- MFP based architectures present less drawbacks towards future trends. Reduction of tubing and air data measurements digitalisation at the probe location is quite `intrinsic" to that architecture
- The main drawback is the difficulty to find a location on the aircraft fuselage that fits the aero-dynamical conditions to obtain accurate measurement of the different parameters

Whatever the architecture is, the testability of probes (sensors, heater monitoring, etc.) shall be intensified.

Details on existing Architecture Critical Analysis are given in the deliverable D2.

2.1.3 WP 1300 : New equipment specifications

Innovative architectures were defined and compared, based on several areas of improvement for probes:

- Digitalisation in the probe base to suppress extensive tubing
- Increasing testability of probes (sensors, heater monitoring, etc.)
- Self-regulation of anti-icing system to eliminate over heating risks
- Reducing de-icing power consumption
- AOA from pressure measurements may be forbidden for some applications (risk of blocking holes)
- Reduction of clogging risk for other probes (Pt, TAT)

The 2 most promising ADS architectures for the medium term were identified.

The first one is composed of three primary independent channels and a standby or equivalent. Each primary channel is composed of one probe grouping Pt and TAT, one AOA, two Ps (left and right). No tubing, digitalisation module located at the probe base.

The second one, maybe in a further integration, is composed of one probe grouping Pt, TAT and AOA, leaving the Ps separated in order to keep the possibility to measure the Ps on both side (left and right): one probe grouping Pt, TAT, and AOA, two Ps (left and right), digitalisation module at the probe base.

Details on Innovative Architecture Comparison are given in the deliverable D4.

The specifications for the new equipments were described as:

- Functional specifications, depending on the parameter to be measured (range, accuracy, de-icing capability)
- Environmental conditions, mainly based on norm RTCA DO-160

The complete specifications for the new equipments are detailed in the deliverable D5.

2.2 WP 2000 : Innovative concept identification

2.2.1 WP 2100 : Technology state of the art – Ways of improvement

The objective was to identify all existing technologies, through the recognition of the current state of the art.

The 3 existing probes concepts were identified :

- fixed probes : they have no moving parts; they can sense : the static pressure, the total pressure, the total and the static pressure (Pitot-static probes), the angle of attack (or angle of sideslip), computed from pressure measurements, the total temperature, the static temperature, or any combination of parameters; fixed multifunction probes, for example nose boom probes can sense the static pressure, the total pressure, the angle of attack and the angle of sideslip
- mobile probes : these probes comprise a moveable part (a vane for example) that aligns in the airflow; they can sense, depending on their location on the aircraft, the angle of attack or the angle of sideslip, or a combination of these two angles
- mobile multifunction probes : these probes comprise a moveable part that aligns in the airflow, and which is equipped with pressure ports; they can sense the local angle of attack, the static pressure, the total pressure, the total temperature

The technologies concerned by these classical probes are:

- materials used: pure Nickel, or Copper Beryllium, or Aluminium alloy for the structure of the probes; brazing alloys for joining of the pieces

- coaxial heating wire or PTC heaters for the de-icing
- brazing technology for the joining of the probes (blow torch)
- coating of the parts exposed to airflow (electro-deposition, passivation)
- New technologies can be used, instead of the current ones, if they allow improvements for the probes. For example new materials, non toxic, can be chosen instead of Copper-Beryllium. Preliminary specifications for new materials were established, and a selection of possible candidate materials was done.

After comparison of the properties of these candidate materials, only 4 were selected for further investigation : Aluminium A201, Aluminium 357, Low alloy steel BT1, Magnesium Electron 21.

New coatings and deposition processes are also researched, compatible with the support material, in order to strengthen it if necessary, with a correct thermal conductivity. A first list of candidates was defined, and the methods of evaluation were proposed.

New heating elements are researched, particularly with PTCs.

As the future probes will comprise their sensor in their base, particularly pressure sensors, it is also necessary to define packaging technologies compatible with the MEMs sensors: to isolate the sensor itself from the air coming from the outside of the aircraft, to define a method of detection and compensation of the long term drift of these sensors.

Complete details on the Technological state of the art synthesis are given in the deliverable D3.

2.2.2 WP 2200 : Research of new measurement principles

The objective of this WP was to research and identify new measurements principles, that could improve the performances of the existing ones.

Concerning the measurement of the total pressure, an alternative to the classical Pitot tube was proposed: the fluid stagnation point principle. This principle can also be used for the measurement of the total temperature in the same probe, using a new miniature sensing element.

Concerning the measurements of the static pressure, no innovative measurement principle was identified during the first phase of ADELINE project. Then classical flush static ports will be used.

Concerning the measurement of the angle of attack, the objective was to eliminate all the moving parts of the sensor, to reduce cost and to avoid corrosion or friction problems linked to ball bearings. Several possibilities were proposed as a first approach. The distribution of the temperature around a heated cylinder (convective AOA probe) was chosen for further investigation. The possibility of integration of an additional function, icing condition detection, was also considered.

The sources of the long term drift of MEMs pressure sensors were analysed, and the ways of improvements were identified.

More details on the Research of new measurement principles are given in the deliverable D8.

2.2.3 WP 2300 : Research of new material and coating

The candidate materials previously identified were :

- Aluminium base alloys (A201, 354, 357),
- Copper base alloys (aluminium bronze AB2, brass SCB6),
- Iron base alloys (Low alloy steels BT1, Stainless steels 316, Precipitation hardening steels),
- Magnesium base alloys (WE54, Electron 21),
- Nickel base alloys: pure nickel
- Titanium base alloys (CP, Ti6Al4V, TiAl)

Their exact specifications were compared : recommended heat treatments, corrosion resistance, mechanical properties, operating temperature range, ductile to brittle transition, thermal conductivity, castability and casting processes.

After comparison of the properties of all these candidate, only 4 were selected for further investigation : Aluminium A201, Aluminium 357, Low alloy steel BT1, Magnesium Electron 21.

All the details of this analysis can be read in the deliverable D9.

The research of coatings for the substrate materials identified led to Physical Vapor Deposition (PVD) thin coatings, for their hardness and corrosion resistance.

Four different coatings were selected :

- TiN (titanium nitride)
- Al_2O_3 (single layer aluminum oxide)
- Me:C-H (single layer metal containing DLC)
- TiN / Al_2O_3 (multilayer)

The different combinations of coatings and base materials that are characterized are presented below.

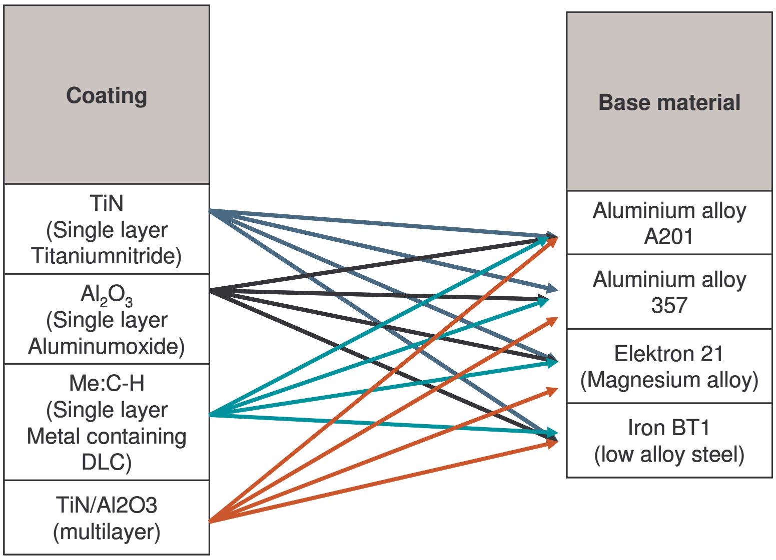


Figure 1 : Combination of PVD coatings and base materials to be characterized

PVD coatings are deposited in a high vacuum process. The whole procedure of creating the coatings is divided in several steps.

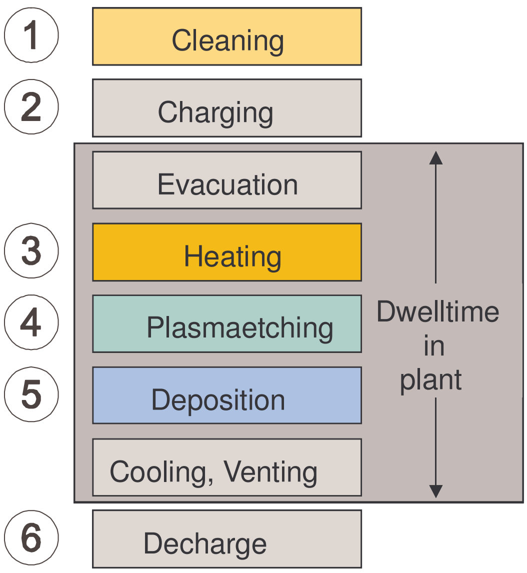


Figure 2 : Procedure of PVD coating

In order to deposit the different coatings with required chemical and structural composition a stable process window has to be developed for each coating, depending mainly on the following deposition parameters:

1. pressure,
2. target power (magnitude and type), voltage, current,
3. reactive gas share,
4. target-component distance,
5. deposition time

The samples for characterization of the different coatings are as shown below:

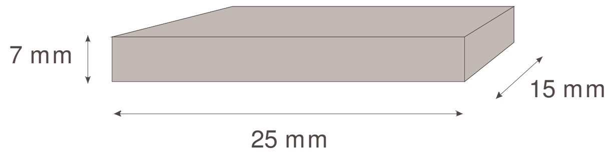


Figure 3 : Samples for characterization of coating and base materials

Based on the procedure described above, samples made of Aluminum Alloy 201, Aluminum Alloy 351, low alloy steel Iron BT1, Magnesium alloy Elektron 21 were coated with TiN, Me-DLC and Al_2O_3 respectively.

Magnesium alloy Elektron 21 turned out to be a difficult candidate for PVD-coating and was abandoned.

The evaluation of different properties of the coatings as well as of the coating-substrate compounds was performed experimentally and by FEM simulations.

The mechanical properties were measured by nano-indentation, which allows to measure hardness and elastic modulus of the thin film without the influence of the substrate material.

The characterization of adhesion behaviour was done using industrially accepted methods.

The first measurement method for adhesion measurements is the calo-test, using a steel ball with a radius of 10mm and diamond suspension usually with a grain size of 1µm as abrasive medium.

The second method to characterize the adhesion behaviour of the compound is the scratch test. In this test a scratch is created on the coated test body using a diamond penetrator with the shape of a Vickers diamond.

The characterization of coating structure was done using scanning electron microscopy (SEM). It allows to have a closer look at the structure of the coatings.

Other characterizations concerning chemical composition, wetting behaviour, thermal conductivity of base materials and of coatings, were also performed.

A key point to the optimization of substrate-coating systems is residual stress in the coating (influence on fracture and delamination of thin coatings). Residual stresses could be measured by a number of methods e.g. curvature, X-rays, ultrasonics. Curvature measurement was used here for the evaluation of residual stresses.

Analytical calculations of temperature distribution in a Pitot tube were made for 4 basic materials and 3 coatings to determine the impact of the coating.

Test of abrasion resistance of base materials coated by three different coatings was made using Sol-Gel-Korund grinding powder (CerpassXLT, grit size 36).

The performed research has shown so far that Aluminum alloys 201 and 357 and low alloy steel IronBT1 can be successfully coated with the different PVD-coatings TiN, Me-DLC and Al_2O_3.

The Magnesium alloy Elektron21 could not be coated with acceptable properties.

From coating point of view Aluminum alloys or low alloy steel should be used as base materials for further investigations. Based on their mechanical properties Me-DLC and TiN are the most promising coating candidates so far.

Complete details on this work can be read in the deliverable D10.

2.2.4 WP 2400 : Research of new de-icing techniques

The objective of this WP was to identify new possibilities for the de-icing and anti-icing of aerodynamic probes.

First the conditions of the existence of icing were remembered.

The current technologies for de-icing are the heating of the probes, either by means of a coaxial heating wire (generally for application in probes such as Pitot tubes), or using PTCs elements (when the surfaces to be heated are relatively flat, as for the vane of a AOA sensor).

The main interest of PTCs is their high resistance temperature coefficient, when the Curie point is reached. This allows an efficient temperature regulation.

The possibility of the use of PTCs for the heating of tubular shapes was explored.

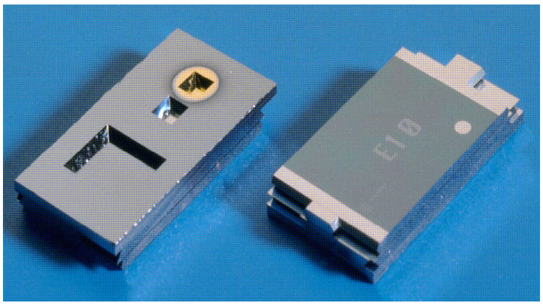
Numerical thermal analysis were made.

A first mock-up of this project was realized, for purpose evaluation.

More details on the new de-icing and anti-icing techniques are given in the deliverable D11.

2.2.5 WP 2500 : Research of new packaging for pressure sensors

The objective of this WP was to propose new packaging solutions for pressure sensors, e.g. the THALES sensor, in order to permit the installation directly in the probes, to avoid pneumatic tubing on the aircraft.



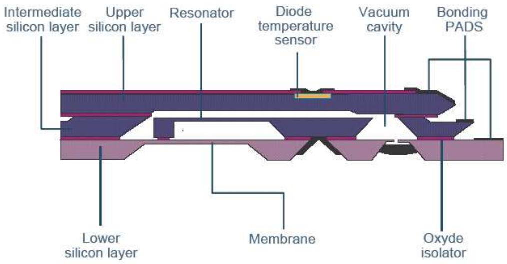


Figure 4 : THALES pressure sensor

Some very important parameters are to be considered for the packaging:

- tight against humidity and particle ingress, oil, kerosene, grease protection
- operating over a pressure range from 100....1400mbar
- operating over a temperature range from –40...100°C
- ultra low stress packaging for insuring
    - no change of resonant behaviour of the membrane of the sensor
    - low thermal hysteresis
    - low pressure hysteresis

Different packaging techniques were considered, regarding the electronic and the mechanical points of views.

For the electronic packaging concern, some improvements were proposed, that allow also to merge media duct and electronic interconnect.

The highly stress sensitive pressure sensor is to be mounted to the substrate by a low modulus adhesive at its outer (bond pad) extreme side.

Concerning the media duct and separation method, from the current state of the art, several types of pressure sensor packages have been identified and classified.

The critical analysis of these technologies was made and led to the following conclusion that quite none of the classified principles will allow the sensor to perform under the required conditions to the required performance level. New concepts need to be developed to provide the required characteristics, especially in term of hermetic capsulation, hysteresis free pressure duct, and high range of operation under pressure and thermal load.

More details on the sensor packaging techniques are given in the deliverable D12 .

2.2.6 WP 2600 : Identification of bricks to be developed

As a result of the previous Work Packages, several techniques were identified for further developments.

2.2.6.1 Fluid stagnation point total pressure and temperature probe

Numerical simulation have been made in order to optimize the design.

The first technical brick is the validation of the numerical model, using comparison between numerical simulations and experimental results. The simulations addresses the aerodynamic and the thermal behaviour of the probe.

A mock-up was manufactured with rapid prototyping facilities, and tested in wind tunnel to determine if the probe is compliant with the requirement in terms of performance.

The principle of the fluidic pressure probe is compatible with the integration of a total temperature measurement. One brick to be developed is the selection of the sensitive element to reduce the size and the cost of such element.

2.2.6.2 Materials and coating

A selection of four couple substrate/coating was done:

- A201 with Al2O3
- A201 with MeDLC
- A357 with Al203
- Iron BT1 with MeDLC

The technical brick is to determine the best couple substrate/coating. Four samples have been tested in real conditions on the SAFIRE ATR42 aircraft during campaign in West Africa in 2006. The sample's analyses will help to determine the coating's influence and to determine the best couple.

Laboratory tests will be done to complete the selection, to determine the resistance to corrosion, erosion resistance, droplet impact, wetting behaviour, thermal shock resistance … and to compare it to standard material used nowadays.

2.2.6.3 Anti-icing and de-icing technique

The PTC technology appears compliant with the requirement in term of heat flux according to numerical simulation performed on COSMOS, with aluminium alloy. The base material appears important if the PTC heaters are used.

Different solutions for the heating of a tube shape were proposed. The technical bricks to be developed consist in the heating of a tube shape using:

- Linear sticks
- Shaped PTC
- Circular slices

Another technical brick is to develop solution for installation of PTC on a flat surface (application to flat static pressure probe or probe base).

Using heating wires, different trials have to be performed to cast the heating element in a tube shape. The interest of such a solution is that it will guaranty a good thermal contact between the heater and the structure, without assembly by torch brazing. Two types of processes are studied according to the material:

- Plaster moulding for aluminium alloy
- Investment casting for steel

2.2.6.4 New angle of attack principle using convective solutions

After a critical analysis, from the different solutions proposed for an AOA sensor without moving parts, the principle of a convective AOA probe was chosen for further developments.

Two solutions appeared possible:

- First solution : the central part of a bar is heated. Temperature sensors are disposed at the surface of the bar. The temperature distribution measured by the sensors is function of the AOA.

- Second solution: heaters are disposed at the surface of the bar; the temperatures and the electrical powers consumed by the heaters are function of the AOA.

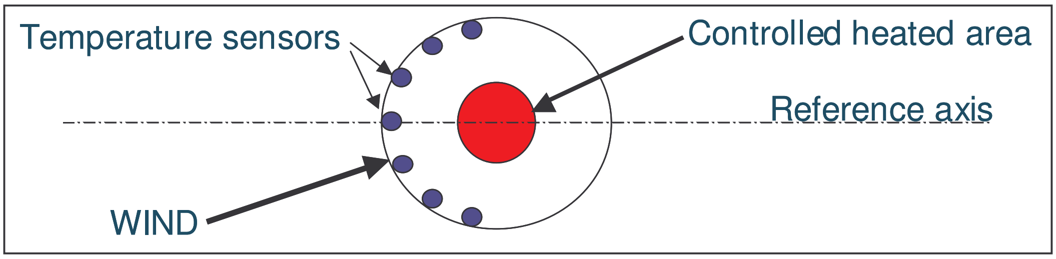


Figure 5: schematic of the first convective solution

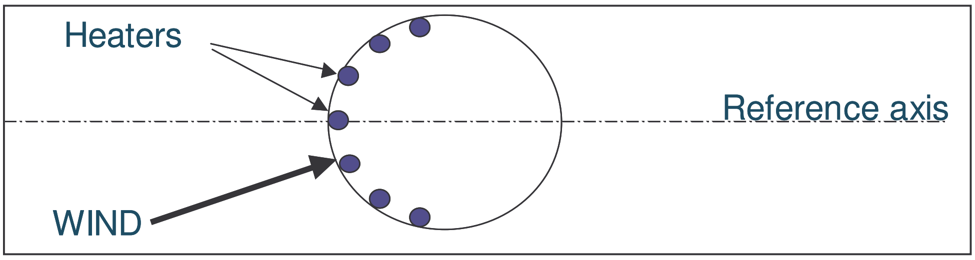


Figure 6 : schematic of the second convective solution

According to both solutions presented, different technical bricks have to be developed.

The first solution uses temperature sensors disposed at the surface of the bar. The technical brick is to determine the elements used as temperature sensor: PTC, thermocouple, thin film deposition or thick film deposition.

The second solution uses heaters disposed at the surface of the bar. The technical brick is to determine the elements used as heaters: PTC, thin film deposition, heating wires, flex-circuits or thick film deposition.

Several critical points need to be checked by numerical simulation or/and experimentations: for example the dynamic behaviour, the functioning in particular environmental condition (functioning in damp condition, effect of droplet on the measurement…).

More details on the selection of the technical bricks are given in the deliverable D13 .

2.3 WP 3000 : Technical bricks development

2.3.1 WP 3100 : Development and test of the new principles

The new principles of measurements are the fluid stagnation point probe and the convective AOA probe.

2.3.1.1 Fluid stagnation point probe simulations and mock-up test

The validation of the numerical model was done by comparing the results of simulation to experimental measurements on the first mock-up. Different viscous models, grids and conditions have been studied. The results of this comparison allow using the numerical simulation to develop the new probe concept.

The simulations were made with numerous parameters, that have been tested to improve the design: geometrical parameters (diameters, lengths), and different internal configurations (number of fin exit, fin's gap, orientation).

An example of numerical simulation is shown below, at Mach = 0.9.

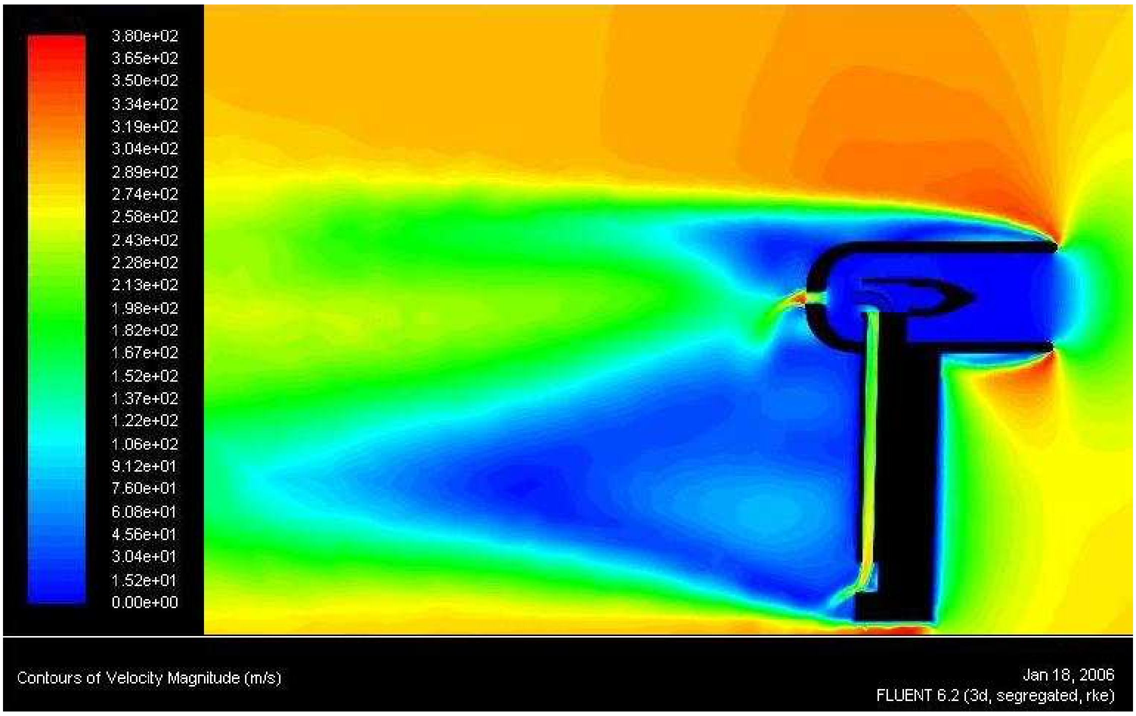


Figure 7 : Numerical simulation at Mach 0.9

The simulations show that the principle is valid at high speed: stagnation area is still present and located at the same places that at low speed. Furthermore no shock waves are observed.

The key parameters have been optimized with numerical simulations, and tested in wind tunnel at VZLU with an adjustable mock-up manufactured in collaboration between CTI and THALES.

Figure 8 : Pictures of the Transonic Wind tunnel at VZLU

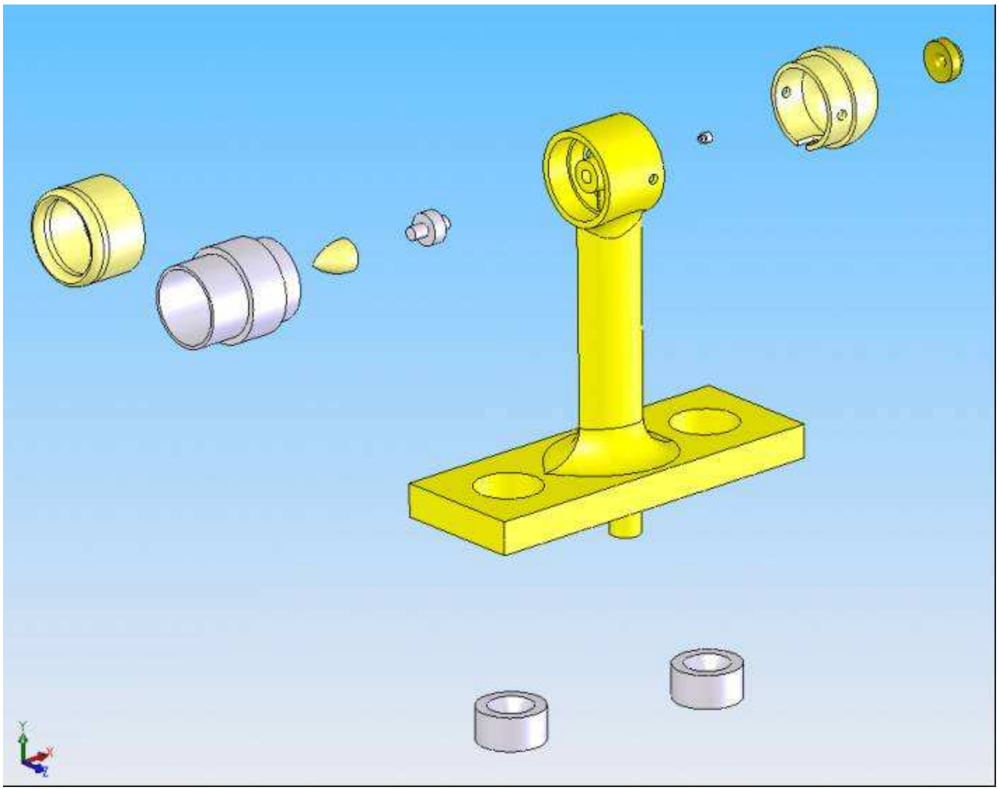


Figure 9 : representation of the adjustable probe

More details on the fluid stagnation point probe simulations and mock-up test are given in the deliverable D16 .

2.3.1.2 Second principle simulations and mock-up test (Convective AOA)

The 2 solutions identified previously have been tested.

2.3.1.2.1 First convective concept mock-ups tests

The principle consists in the heating the central part of a cylinder, and to measure the temperature at several points at its surface exposed to the airflow.

The sensing of the temperatures at the surface of the cylinder was done using 2 different solutions :

- use of electrical wires as temperature sensors; these wires were made of Balco (iron and nickel alloy); they were fitted into grooves at the surface of the bar
- use of Inconel or nickel tracks deposited on a Kapton flex circuit glued on the cylinder

The wind tunnel tests of these mock-ups consisted in measuring the temperature of the different sensors, for different orientations of the cylinder.

The conclusion of these tests was that the temperature sensors (wires or flex) used were not well adapted for this application. The variations of the AOA are detected, but the measurements are not enough accurate for computing the AOA. Later in the project, small thermocouples were used to sense the temperatures, but the results were not improved significantly.

2.3.1.2.2 Second convective concept mock-ups tests

The principle consists in the heating of the cylinder by means of heaters installed at its surface; for each heater, the relation between the electrical power consumed and its temperature depends on the AOA.

Three different versions of heaters were implemented : heating wires in grooves at the surface, inconel flex heaters and nickel flex heaters glued at the surface of the cylinder.

These mock-ups were tested in wind tunnel.

As a conclusion of the tests with this second convective concept mock-ups, it appeared that the determination of the AOA seems possible using this principle, but presents some difficulties. It must be also noted that the influence of humidity or liquid water droplets in the airflow was not taken in account.

2.3.1.2.3 Numerical simulations

Numerical simulations of the concept of convective AOA was also made, using FLUENT, FLOWTHERM and COSMOS.

The conclusions of the simulations and tests of the second principle mock-ups show that the principle of an AOA probe using the phenomena of convection is usable.

The two concepts of convective probe are possible.

However it seems that the operation of this principles will be difficult to obtain.

Details on the convective AOA simulations and mock-up test are given in the deliverable D17 .

2.3.2 WP 3200 : Developments and test of new materials and coatings

2.3.2.1 Development and test of new materials

3 alloys were chosen: aluminium alloys A201 and A357, and an iron alloy HY100.

The different casting techniques have been compared; sand casting is considered unlikely to be utilised since the dimensional tolerances, surface finish and moulding constraints are likely to impose too many restrictions. Investment casting techniques would therefore be utilised in the production of test pieces.

For the initial test pieces produced plaster moulding was used for the aluminium samples and investment shell for the steel samples. The prepared moulds can be seen in the following figure.

Figure 10 : Plaster mould for aluminium (left) and shell moulds for steel (right)

Samples were manufactured by Cti and transmitted to RWTH for further testing.

Aluminium 201 Sample
ASTM B686-03: A201

Steel Sample
(MIL-S-23008D(SH): HY100)

Figure 11 : Cast components

Specific samples for in flight-testing by SAFIRE were also manufactured.

These samples were composed of a base to attach them to the aircraft and a stalk that would protrude into the airflow. Wax replicas were produced using wax printing and the samples were manufactured using investment shell moulding. These were then cast in each alloy; ASTM B686-03: A201, ASTM B686-03: A357.0 & MIL-S-23008D(SH): HY100. Examples of the as-cast test pieces can be seen below.

Steel Flight Sample Aluminium Flight Sample

Figure 12 : as-cast samples for flight-testing

Four samples were sent to RWTH for coating. A small area at the tip was however left un-coated to determine the effect on the base material if the coating is removed during operation. Once coated these were mounted onto the Meteo France research aircraft for exposure.

The samples were mounted during a campaign in West Africa. The flight campaign consisted of approx 200hours of flight time.

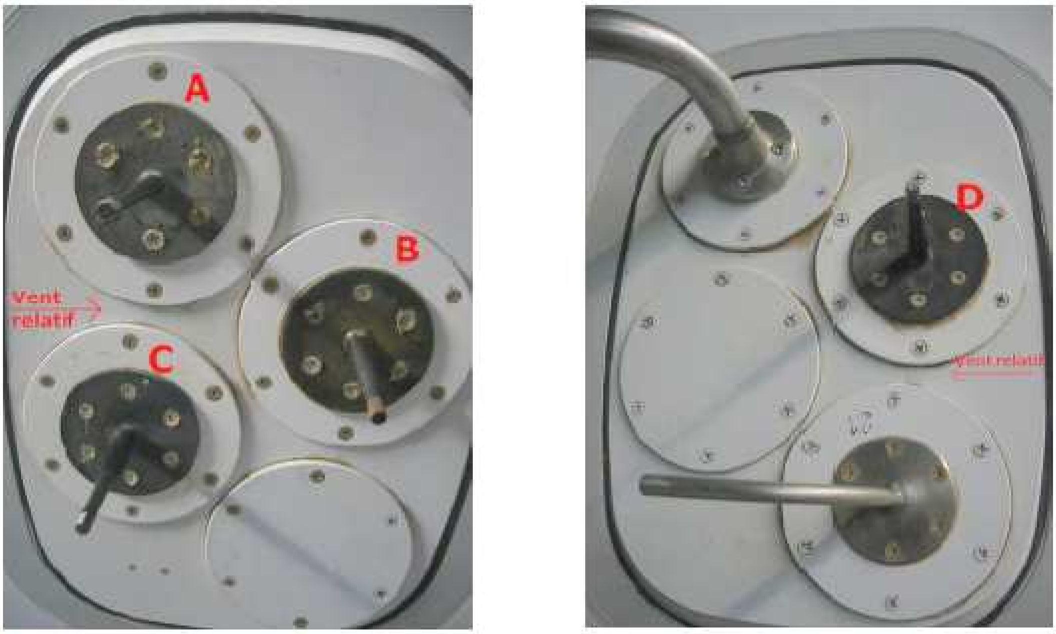


Figure 13 : Samples on the aircraft

Samples of cast-in heating elements were manufactured, for a first evaluation of the process.

The objective was to determine whether the heating element wires could be successfully cast into the test piece. A schematic of the test piece with the inset wire can be seen below.

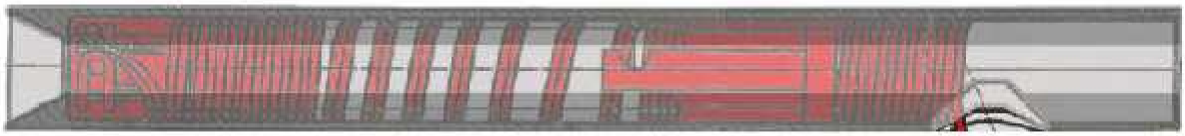


Figure 14 : test piece with the inset wire

As a conclusion for this work on new materials and casting techniques, the mock-ups produced have demonstrated the castability of the selected alloys. In addition development conducted enabled the casting-in of the heating element wires. Both the investment shell and plaster moulding techniques were equally effective.

More details on the casting mock-up and test are given in the deliverable D18.

2.3.2.2 Development and test of new coatings

The objective was to carry on with the evaluation and test of the new coatings.

Abrasion tests have been performed on tubes with the Me-DLC coating, with 3 preliminary different preparations of the coatings : sand-blasted, grinded and polished.

Figure 15 : Aspect of the tube before test (sb=sand-blasted, g=grinded, p=polished)

A visual inspection of the tube has shown no mechanical damage of the coating. After the test the tubes were examined using optical 3D-Topographie measurement system UBM and the surface analysis software, in order to quantify the abrasion.

The following figure shows an example of this analysis.

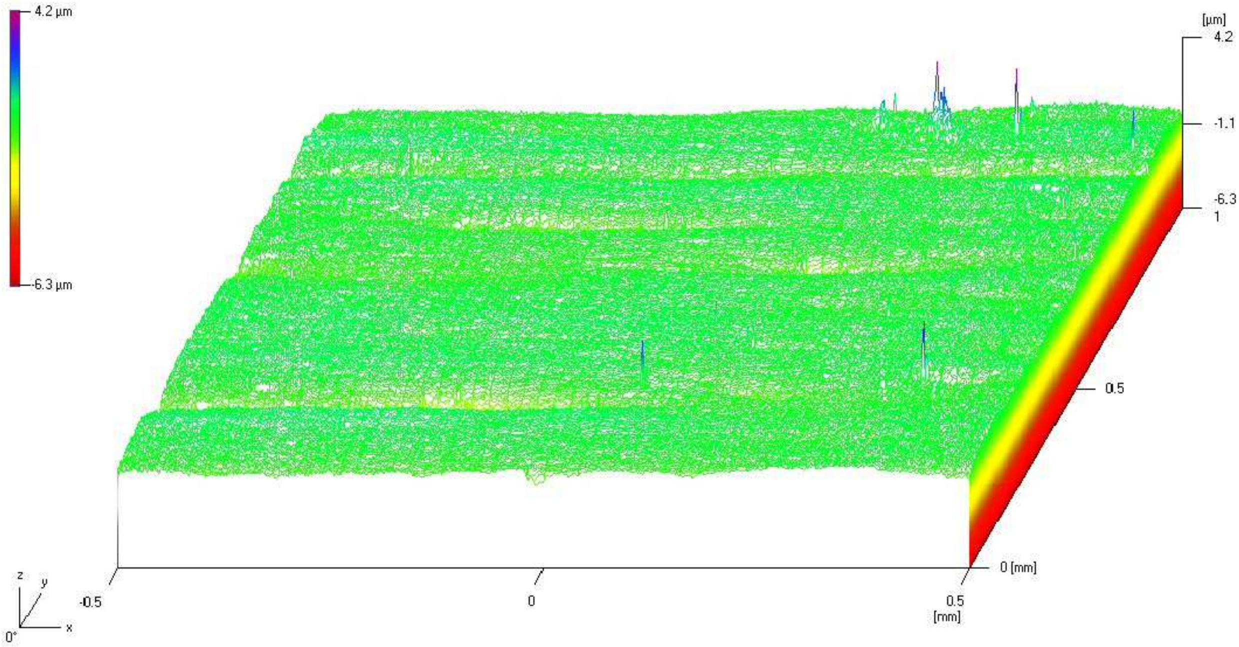


Figure 16 : Polished surface after grinding test

Erosion resistance test was performed to categorise the surface behaviour of candidate coating systems and determine how enduring these coatings are likely to prove in service.

The coatings are being subjected to impingement by water droplets in two separate experiments: splash imaging and damage threshold tests.

The Cranfield Droplet Impact tower was used to impact the test surfaces with 500 micron droplets at 50 m/s and images have been collected of the of the resulting splash cloud. The size and speed of droplets in the splash zone is related to the degree of wetting of the surface during droplet impact conditions.

The types of impact event used to sort the observations are given as "Dry" for a fine mist of splashed water, "Drop" for large, slow moving splashed water, "Layer" for the appearance of a coronet, typical of impact into a thin uniform water layer and "Unclear" for the rest.

Some images of splash are presented below.

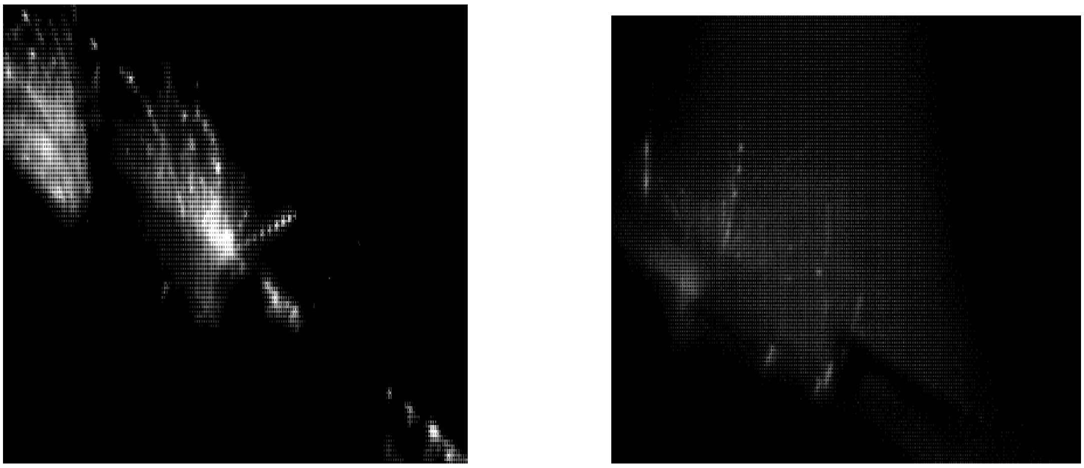


Figure 17 : Example image of splash

A high ratio "Dry/Drop" suggests that the surface tends to clear itself of water rapidly under the aerodynamic shear forces. The TiN surface appears to do this. A low ratio suggests water is building up on the surface and is being dislodged more by the influence of subsequent of droplets. The DLC coating appears to be like this. The Al_2O_3 appears to be intermediate in its dynamic wetability.

Damage threshold tests were performed using the Cambridge University MIJA (multiple impact jet apparatus) to strike the test surfaces with a 500 micron jet of water at progressively increasing speeds until mechanical damage can be seen in the coating or the underlying material.

Results of these tests will be presented later.

The surface energies of coatings was determined by drop shape analysis and contact angle measurements using a Krüss DSA 10 video contact angle measuring device.

Only the surface energies of the coatings were investigated, to see if they are more polar or more disperse.

In TiN the disperse share is smaller than the polar share. In contrast to TiN Me-DLC coating has a lower total surface energy. The polar share in Me-DLC is lower than the disperse share. Similar properties were determined for Al_2O_3. The disperse share is again higher than the polar share.

The performed research has shown so far that Aluminum alloys 201 and 351 and low alloy steel IronBT1 can be successfully coated with the different PVD-coatings TiN, Me-DLC and Al_2O_3.

From coating point of view Aluminum alloys or low alloy steel should be used as base materials for further investigations. Based on their mechanical properties Me-DLC and TiN are the most promising coating candidates so far.

In order to optimize the overall properties of the compounds surfaces of the base materials have to be prepared with a lower roughness as it was done here. That would require a surface treatment after casting process prior to coating process.

More details on this WP are presented in the deliverable D19.

2.3.3 WP 3300 : Development and test of new de-icing techniques

This WP had for objective to develop and test the PTC heating technology used inside a static port, with the following design goals:

- Using low temp PTC (0, 40, 60 °C) as to eliminate over heat on ground
- Using the specified central area, for the heater and designing the heat flow to the peripheral non heated surface
- Using the minimal inrush current possible
- Using minimal weight possible
- Keeping the flatness requirements of the outer surface while clamping the PTC

The value of 19 w/in^2 was adopted to ensure de-icing to eliminate all fear from constructions restraints.

According to the standards, the de-icing test demands that the surface, covered by a 3 mm thick layer of clear ice (hand sprayed and accumulated) around the freezing point, should be clear of ice within 4 min from the heater starting time.

The first thermal analysis and tests were made on a small port

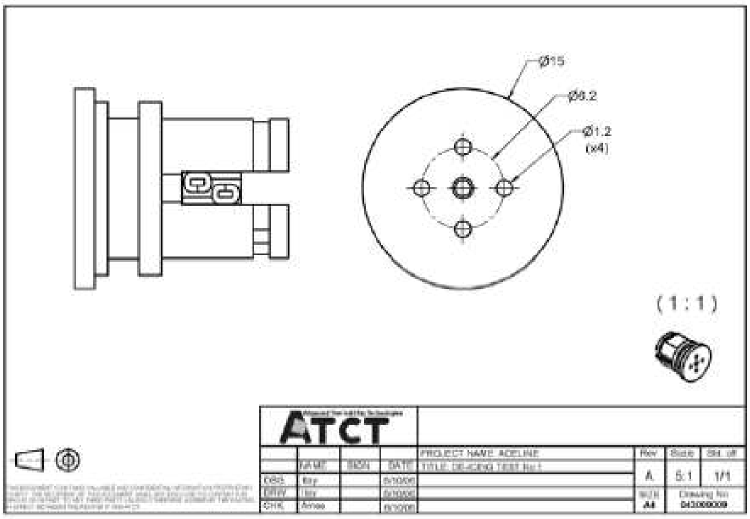


Figure 18 : First mock-up for thermal analysis and tests

The thermal analysis with 19 w/in^2 require some 9 watts permanent power, and as to achieve anti -icing conditions (at least > +10 °C as a minimum) it needs more than 11 watts as shown below in the next figure.

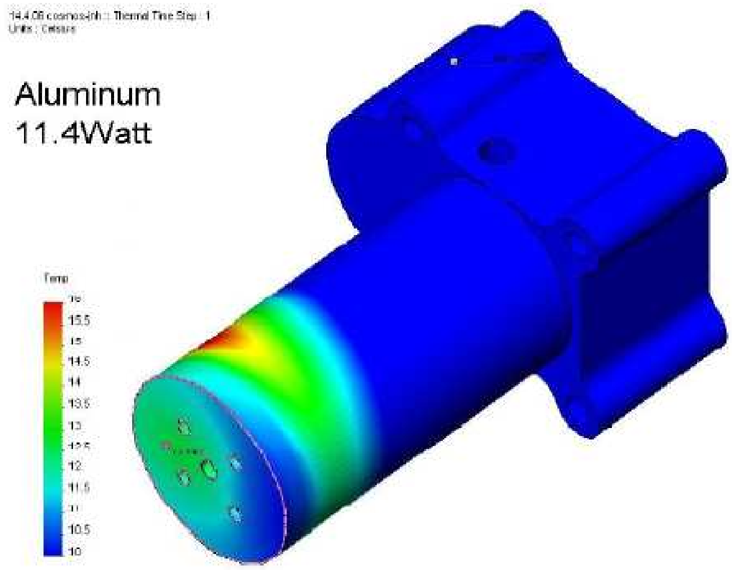


Figure 19 : Thermal analysis

Figure 20 : De-icing test of the first mock-up

A second mock-up of small port has been tested. The heater is surrounding the air passage and rely for heat transfer on the "trunk" –the pneumatic outlet (dia is 20 mm) two units of 120C PTC heaters were used.

The change in the design impacts the time for de-icing, as ice departed almost 4 min from starting time while average power is almost twice. This due to much larger parasitic mass to be heated and loosing heat surfaces, and mainly due to the sizing of the ice around the plate and melting (anti icing) instead of departing.

A full size static port mock-up was then designed. After several iterations, the final design is as follows.

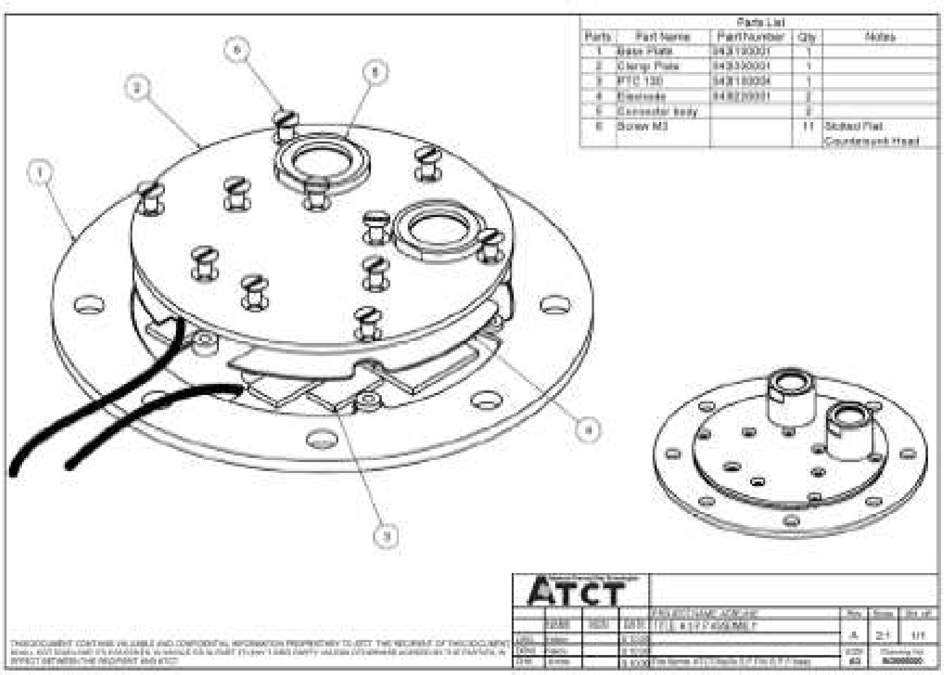


Figure 21 : Final design

The tests results were found satisfactory.

Thermal analysis and estimation of time constant were also performed in this configuration.

More details on this WP are detailed in the deliverable D20.

2.3.4 WP 3400 : Development and test of new packaging for pressure sensors

The objective was to design a packaging method for the silicon pressure sensor from THALES.

Two main points were to be investigated:

- Packaging of the bare silicon pressure sensor
- Functionality of the liquid cork principle

Focus of the sensor packaging development was to realize a reliable interconnection of the sensor with minimized mechanical and thermo-mechanical stresses to sensor. As a base substrate an FR4 material was used. A schematic of the assembly and a photograph are shown below.

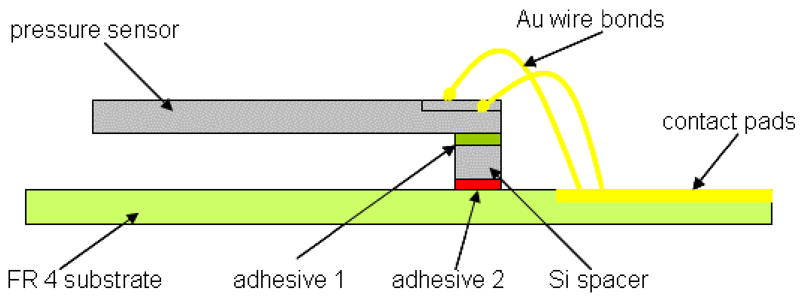


Figure 22 : Schematic sketch of the pressure sensor assembly

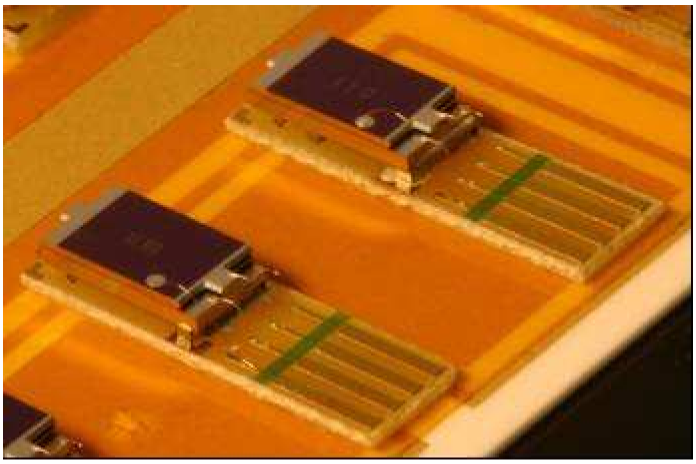


Figure 23 : Pressure sensors assembled

These sensors were tested from –40 °C to +85 °C, and from 100 hPa to 1400 hPa with good results.

For the connection of the sensor to the spiral duct the sensor was glued into an aluminium housing with a cavity. The spiral duct was realized by milling in transparent PMMA plates. The liquid cork was inserted into the spiral. Final step was the mounting of the complete assembly to the aluminium housing and sealing of the connection between spiral and housing with a silicone adhesive.

The next steps will be to optimize the assembly process and to validate it with reliability testing and optimization of liquid cork principle.

The following figure shows the assembly of the pressure sensor.

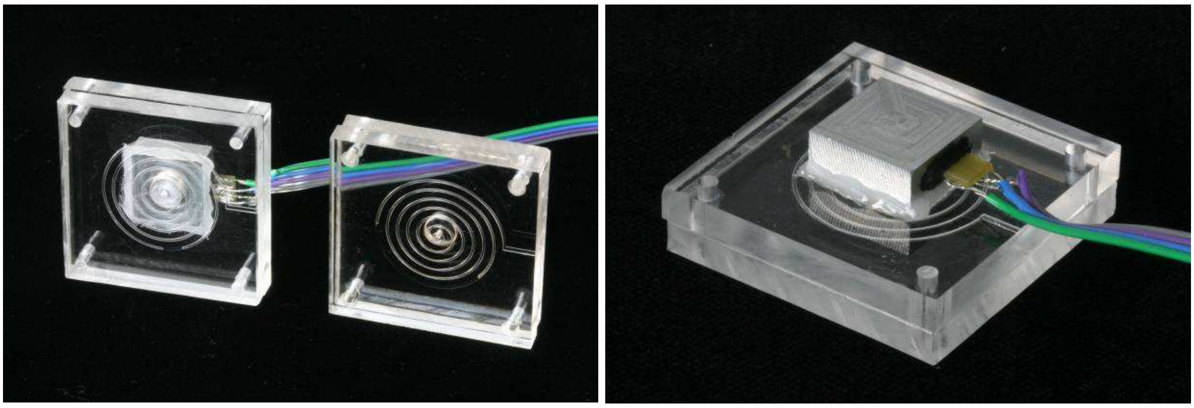


Figure 24 : Pressure sensor with spiral duct and liquid cork

Concerning the sensor, another point had to be examined, the detection of the long term drift, for compensation purpose. An important root cause of drift is the increase of the reference pressure (nominal vacuum 0 hPa). Basically, the method consist in measuring the Q-Factor of the resonator, that is sensitive to the increase of internal pressure.

Then the method consists in modelling a parameter representative of the Q-Factor and to monitor the modelling error (representative of the drift).

The method has been checked against robustness (repetitively, influence of the environment). The conclusion of the performed measurements are that the measurement is repeatable.

More details on the WP3400 are in the deliverable D21.

2.3.5 WP 3500 : Technical bricks assembly and evaluation

This objective of this WP was to assembly the different technological bricks in 2 mock-ups.

2.3.5.1 First complete mock-up

The optimized aerodynamic design of the mock-up was established using test in the dry wind tunnel at VZLU.

From this design a first mock-up was manufactured, comprising 3 different heaters in order to determine the best power repartition of power between the heater of the principal tube, that of the internal part and that of the mast.

This mock-up was tested at VZLU (dry wind tunnel) and showed quite the same results as the adjustable probe previously tested. It was also tested in an icing wind tunnel for the determination of its behaviour under different conditions. For these tests the mock-up was equipped with a set of thermocouples to know the temperature repartition, and to be used for the calibration of the thermal numerical simulations with FLUENT.

Figure 25 : First tests in icing wind tunnel of the first heated mock-up

The results of these tests were used for the validation of CFD using FLUENT.

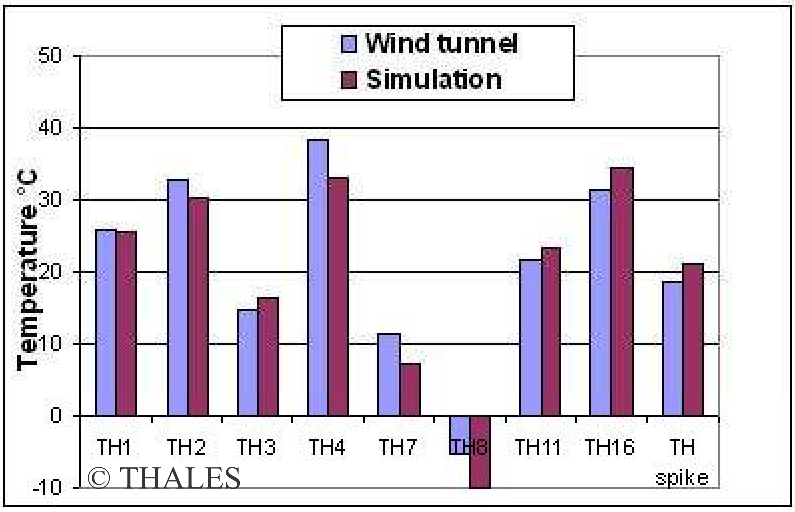


Figure 26: Comparison between simulation and wind tunnel test

Concerning the measurement of the total temperature, miniaturized temperature sensors were identified and tested. Different packaging were proposed by TUB, after mechanical and thermal analysis, to ensure that the sensor will resist to the internal airflow, and will be thermally isolated from the structure.

The following figure shows one example of sensor for test.

Figure 27 : Rectangular Sensor Holder, left tip with probe, right complete holder

The second principle mock-up was manufactured . This last version of the second principle was realized using thin thermocouples; this mock-up was not a complete mock-up and has been used to define which convective solution will be developed, if this principle of convective AOA is proven feasible.

Samples of the selected couples material and coating were manufactured for in flight testing (see § 2.3.2.1 above).

The couples tested were HY100/MeDLC, A357/Al_2O_3, A201/ Al_2O_3, A201/MeDLC. The tip of the samples were coated only on one half of the perimeter, thus allowing comparison between coated and uncoated surface.

The examinations performed on these samples, after around 200h flight in Africa, by Cti and RWTH, were SEM (scanning electron microscope) on the tip of the sample, Microscopic examination of a polished cross section, and EDS analysis.

The conclusions were that Me-DLC and Al_2O_3 coatings deposited in a PVD (Physical Vapor Deposition) process are protecting the substrates sufficiently against abrasion and corrosion. The survey of the surfaces and the analysis of the element composition in the SEM confirmed the existence of the coating. The coatings themselves were not damaged despite the severe test conditions.

Based on the results so far and based on technological aspects, the application of Me-DLC on the probes is recommended.

The 2 material mock-ups for flight test will be made of A357 and coatings Me-DLC and Al_2O_3.

The following figures show typical pictures of these examinations for the couple HY100/MeDLC.

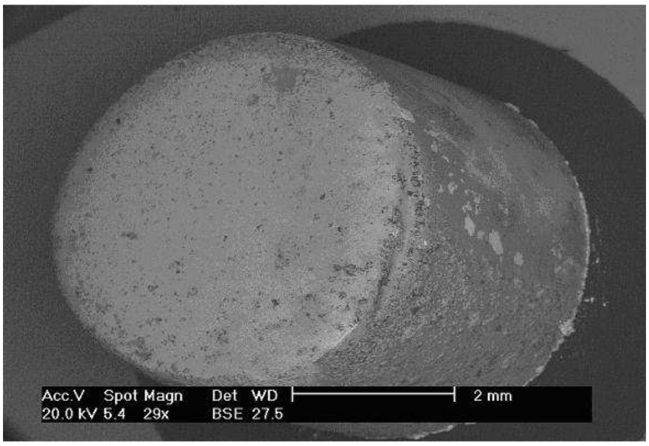


Figure 28 : General view of the sample (left) and view of the tip (right)

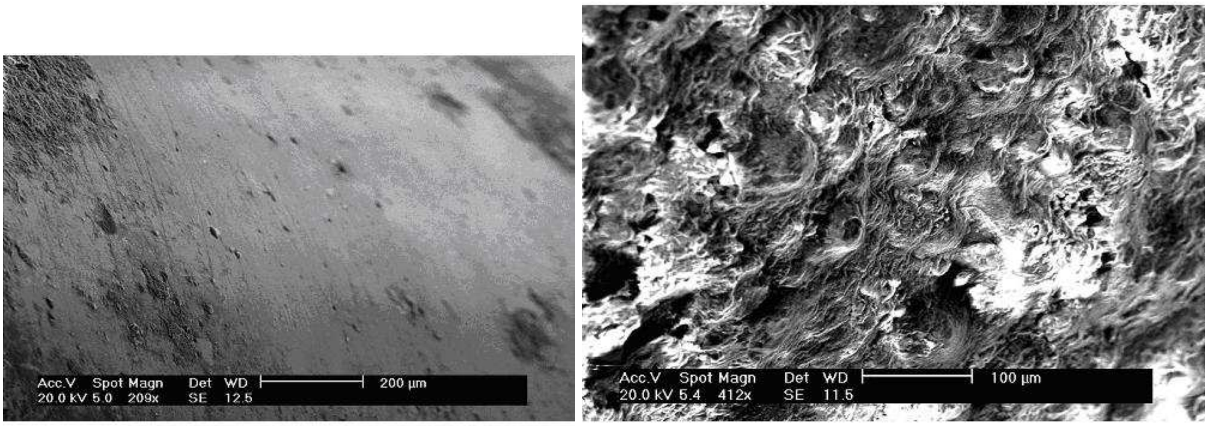


Figure 29 : SEM views of the coated surface (left) and uncoated surface (right)

It appears very clearly that the coating protects well the substrate HY100.

Detailed results on these analysis are given in the deliverable D24.

2.3.5.2 2nd principle mock-up of new AOA concept

As announced in § 2.3.1.2 above, a new mock-up of the first convective principle (with a central heater) was made using thin thermocouples for the temperature measurements at the periphery of the cylinder.

The tests in wind tunnel of this mock-up were performed.

The simulations realized on this concept were compared with the experimentations and show the same tendency. The maximum temperature evolution on the first concept is before the flow separation of the boundary layer.

But all these results are not significantly better than that obtained previously.

it appeared that a convective mock-up for in flight tests could not be envisaged.

For that reason it was decided to install on the aircraft a static port heated with PTCs as second functional mock-up, instead of AOA.

Detailed results on these tests are given in the deliverable D25.

2.4 WP 4000 : functional mock-up

2.4.1 WP 4100 : Mock-ups development and fabrication

2.4.1.1 Total pressure and temperature probe

The aerodynamic design is that of the adjustable probe, for best results. The base plate of the probe is designed to fit with the aircraft interface. Six screws and an o-ring will be used to assemble the probe on the aircraft. An electronic box is screwed at the base plate of the probe, in order to control the heater. The electrical connectors are screwed on the box. One pneumatic interface is used to connect the total pressure probe.

Regarding the temperature function, tests were performed using 4 different assemblies of thermal sensors and 2 probes for their installation: a classical temperature probe and the new total pressure and temperature probe defined in ADELINE. Tests were performed on all combinations of sensors (4) and probes (2). The data recorded are the temperature of the wind tunnel and the temperature (in fact its resistance) given by the sensor in test. The tests consist in recording the data with and without airspeed, with and without heating.

Two conclusions were deduced from these tests :

- For all sensors, the influence of heating is more important when they are installed in the new total pressure probe than in the classical temperature probe;
- When they are installed in the classical temperature probe, the best sensor (the less sensitive to heating) is the classical sensor.

This means that:

- The convection of the airflow around the sensor is better in the classical temperature probe; for the new total pressure probe results can be improved by increasing the thermal exchanges between the airflow and the sensor, perhaps changing the position of the sensor inside the probe
- The installation of the new sensors must be improved, with a better thermal insulation of the sensor from the structure for example, the installation of a thermal shield around the sensor, perhaps with the elimination of the boundary layer inside the probe

New sensors with thermal shield were manufactured by TUB for the functional mock-up.

The following figure shows the functional mock-up for in-flight tests.

Figure 30 : Functional mock-up for flight tests

As it was not possible at this stage of the project to develop a mock-up with cast-in pieces around the heating wire, this mock-up was manufactured using a cast-in piece of brass for the mast and the tube, allowing brazing of the heater. Internal pieces were made of machined pieces. All the assembly was brazed. A specific treatment coating was defined by RWTH for this mock-up.

2.4.1.2 Material probes

Two dummy probes were manufactured for in flight testing of the new materials and coatings (A357 with an Me-DLC coating and A357 with a hard anodize).

These probes are not heated nor operative. The following figure shows one dummy probe.

Figure 31 : Material probe

2.4.1.3 Functional heated static pressure probe

A new concept of the inner heater was used. It consists of silicone prepared pre-cut sheet, instead of the conventional insulation material that ATCT used, which is a peripheral moulded glue; the benefit of this method is the reduction of the outer thickness needed for insulation (electrical) and humidity seal from approx. 1.5 mm to less than 1 mm.

The heater PTCs disks are positioned to achieve a good dispersion of heat flux from one side.

Special care was taken in defining the coating of the electrode and the static port base and top plate.

Several tests were done with two types of coatings; the first is hard anodize with absorption of Teflon (TUFRAM); this coat although highly resistive had some drawbacks; then the chosen coating was the regular hard anodize with the demand of coating up to the max available thickness.

The following figure shows the functional heated static port.

Figure 32 : mock-up of the heated static port

More details on the WP 4100 can be found in the deliverables D26 and D29.

2.4.2 WP 4200 : Functional mock-up ground Test

2.4.2.1 Lifetime estimation

The objective of this part of the WP4200 was to use FEM to enable the prediction of the life duration, without coating and with coating.

The external parts of the probes are exposed to abrasive and erosive conditions, fatigue as well as to the environmental conditions. The FEM calculations were made to estimate influence of the erodent on the coating and the substrate materials. Also comparison between PVD coating Me-DLC and natural Al_2O_3 scale is made. In addition the impact test was conducted to assess quality of the PVD coating.

Erosion is an abrasive wear process. This process depends on many factors, the most important being the size of the particles. The Probabilistic Design Simulation (PDS, tool within ANSYS finite element software) is based on Monte-Carlo probabilistic method, which will generate input parameters in specified range according to user defined statistical distribution, to simulate for example the range of size of the particles. The stress analysis of the probe under impacting particles is limited to the case of perpendicular impacts. Also the impact which is a dynamic event will be considered as a quasi static process.

The FEM model for the simulation is shown below. For simplification a 2D axial symmetric model is used. The substrate and the coating were modelled with Plane183 finite elements and the particle with Plane 82 finite elements. The mesh is refined in the area of contact to catch the high stress gradients developed there.

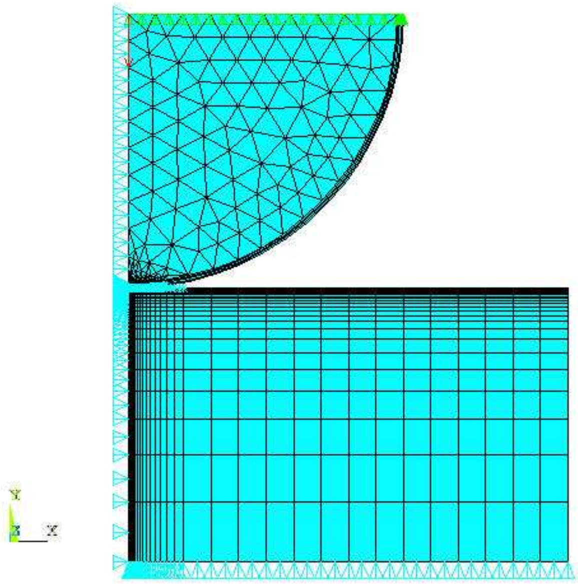


Figure 33 : Finite element model of the contact

The stress analysis show that Impact of particles is a fatigue/erosive process, starting with plastic deformation of the substrate material, cracks nucleation and growth, and ends with film fracture.

In the case of hard PVD coating on the soft substrate (Me-DLC on A357) the fracture will appear on the round of the concave created by the load. Because of low plastic strain of the A357 substrate there is limited support for the coating.

Then it is suggested to provide hard PVD coatings on the hard substrates.

From the PDS analysis it appears that the impacting force is more important than the particle size. There is also a linear correlation between the impact force and the stress in the coating.

An example of the stress distribution in the coating/substrate system is shown below.

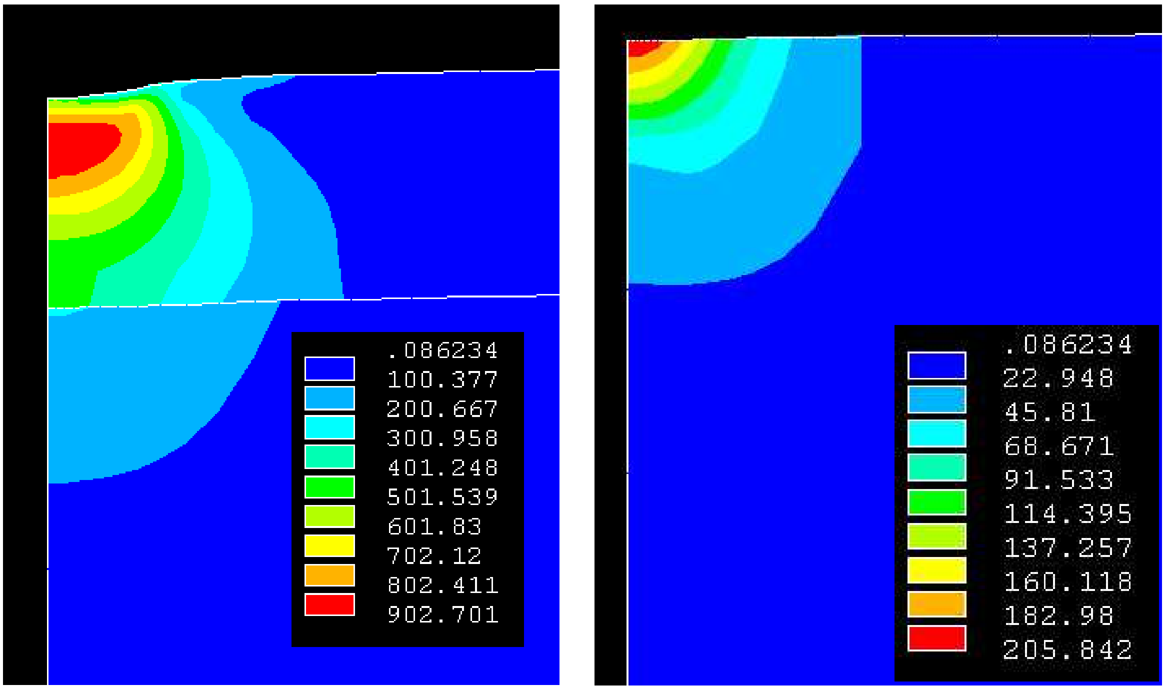


Figure 34 : Equivalent stress in the coating/substrate system (left), substrate (right)

The static analysis is not in position to correctly simulate the erosion process. So simulations have been made with dynamic transient analysis software.

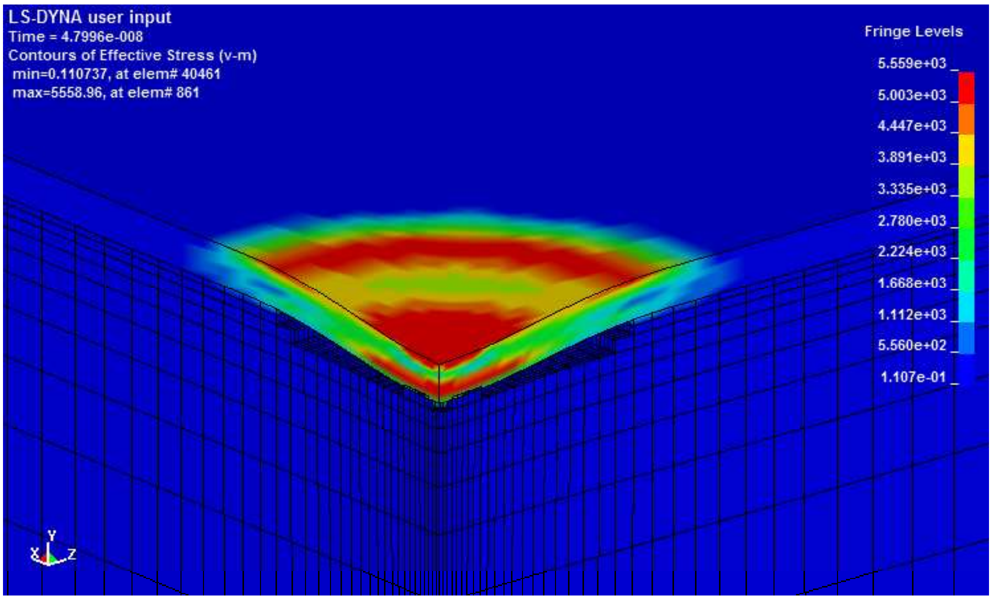


Figure 35 : Equivalent stress in the Me-DLC coating with particle velocity 250 m/s

The results of all these calculations are summarized as follows:

- Me-DLC coating protects the A357 substrate
- Me-DLC could fail only because of accumulated damage in A357 substrate
- Al_2O_3 scale on the A357 substrate in no protection against erosion

In order to get a better knowledge of the combination coating/substrate impact tests have been conducted.

The conclusions of this work are that at forces much higher than expected in service and after 3 Mio. impacts there is no complete damage of the thin coating. The coating is only partially separated from the substrate. So the area covered with the coating is still protected against erosive wear.

All the details on the lifetime estimation can be found in the deliverable D30.

2.4.2.2 Ground tests of the mock-ups

As described in the WP4100, § 2.4.1 above, 4 functional mock-ups were manufactured (2 total pressure and temperature probes TOPFLOW and 2 heated static ports) and 2 dummy probes for test of materials and coatings.

The metrological tests were done only for the total pressure probes TOPFLOW, because they are not applicable for the other probes. Safety Of Flight (SOF) tests were done for all mock-ups before installation on the aircraft.

This § describes only the tests not yet detailed in the above chapters.

2.4.2.2.1 Metrological tests of TOPFLOW

These last mock-ups were tested in the dry wind tunnel at VZLU. The results obtained were satisfying, and similar to that of the adjustable probe.

They were also tested in the icing wind tunnel at CRANFIELD UNIVERSIY, that has been modified in order to allow icing conditions closer to that required in terms of temperature, airspeed and LWC. The modification consists in the design, manufacturing and installation of a new working section, smaller than the first (section area is 33% of the original full section).

The wind tunnel was first characterized to evaluate the stability and pressure fluctuations, without and with water.

The test conditions were modified from the planned ones, to be adapted to the possibilities of the wind tunnel.

These tests (32 runs) were satisfying.

The following figures show a general view of the installation, and of the control room.

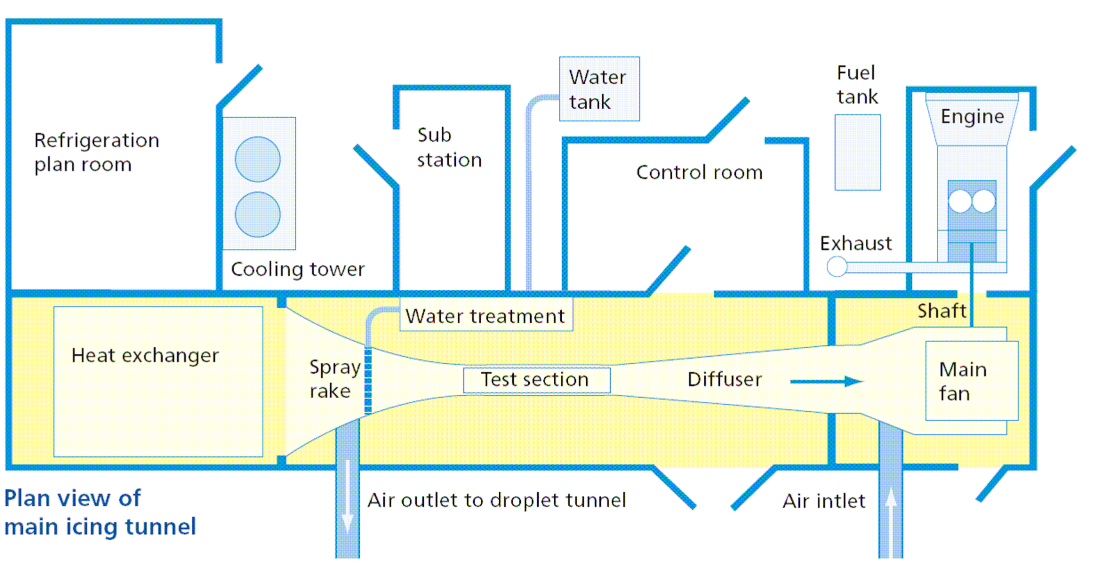


Figure 36 : General view of the wind tunnel at Cranfield University

Figure 37: Control room

The test conditions were modified from the planned ones, to be adapted to the possibilities of the wind tunnel.

2.4.2.2.2 Safety Of Flight tests of the TOPFLOW probe

The principal tests were:

- ON/OFF cycling at room temperature
- Low temperature (extreme low temperature exposure and operation at –55°C)
- High temperature (extreme high temperature exposure at 85°C and operation at 70°C)
- Vibration (pre-test resonance search, endurance test, final resonance test search), 3 axes

The checks before and after each test were visual inspection, insulation resistance, power consumption.

All tests were satisfying.

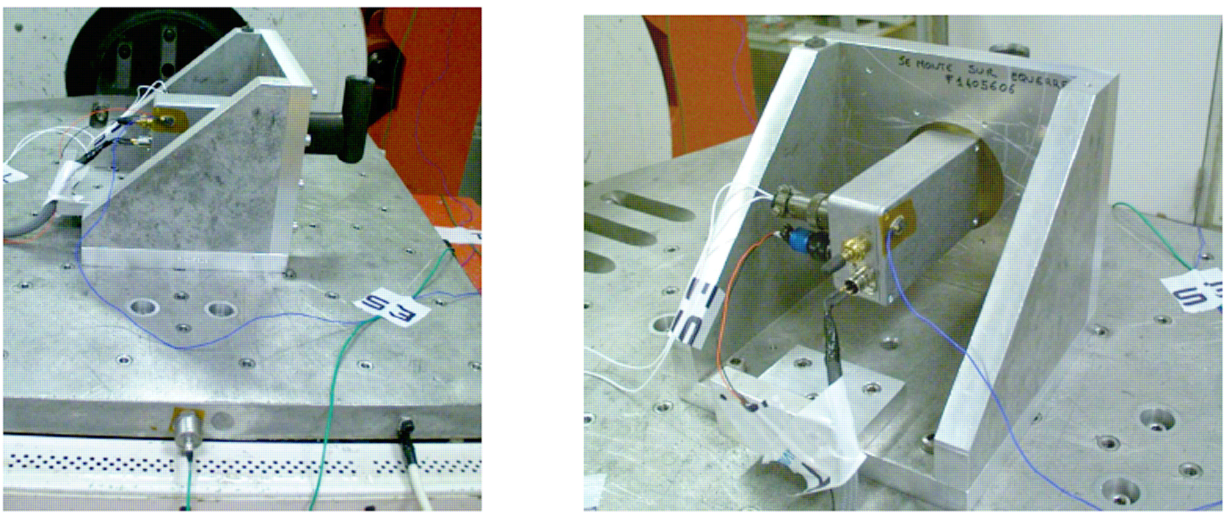


Figure 38 : TOPFLOW probe, Z axis vibration test

2.4.2.2.3 Safety Of Flight tests of the Static pressure port

The following tests were done

ATP	Test Description	RESULT
	DIELECTRIC WITHSTANDING TEST (500 V, I < 5 mA) CRITERIA: Fail / ok	OK
1.1	ENDURANCE FUNCTIONING: 100 on-off cycles CRITERIA: Fail / ok	OK
1.2	BONDING TEST CRITERIA: R < 2.7 milliohm	1.1.1.1.1.1.1.1.1 0.7 mΩ
1.3	INSULATION RESISTANCE TEST CRITERIA: 500 VDC, R > 30 MΩ	5 GΩ
1.4	HEATER RESISTANCE TEST Criteria: Room Temperature R = 2 Ω ± 50%	2.2 Ω
1.5	INRUSH CURRENT TEST Criteria: I inr. ≤ 25 A, Applied Voltage 18 ÷32 V	21 A / 32 V during 1 sec
1.6	HEATER OPERATION TEST Steady State Current Value (without air flow) Reference	3.3 A / 18 V & amb. temp. – 50 °C 1.9 A / 32 V & amb. temp. – 50 °C
1.7	OVER VOLTAGE : CRITERIA: Fail / ok	OK
1.8	**NTC / RTD (temp sensor x 2) functioning**	
1.8.1	NTC N1 resistance room temperature reference	1.947 KΩ & amb. temp + 24.5 °C
1.8.2	NTC N2 resistance room temperature reference	1.965 KΩ & amb. temp + 24.5 °C
1.8.3	NTC N1 resistance after 20 min heater operation, reference	0.71 KΩ & amb. temp. – 50 °C
1.8.4	NTC N2 resistance after 20 min heater operation, reference	0.69 KΩ & amb. temp. – 50 °C
1.9	POWER SUPPLY = operation at 18 and 32 VDC (without air flow)	59 W & amb. temp. – 50 °C
1.10	Weight (5 m cables)	500 gr
3.1	**MECHANICAL TESTS**	
3.1.1	STORAGE TEMP = - 50 °C (24 hours at each) STORAGE TEMP = + 80 °C (24 hours at each)	OK OK
3.1.2	FUNCTIONAL SHOCK 1 shock per axis acc. MIL-STD-810F method 516.5 procedure I (20 g for 11 m sec saw tooth)	OK
3.1.3	ENDURANCE VIBRATION = 45 minutes per each axis according MIL-STD-810F Method 514.5 cat 12 figure 514.5C-8	OK
3.1.4	HUMIDITY = 4 days test acc MIL-STD-810F method 507.4modified. Changing between 23C 94% RH to 35C 20% RH	Not perform

Figure 39 : Static port SOF tests (2)

The complete ground tests report of the mock-ups is given in the deliverable D31.

2.4.3 WP 4300 : Functional mock-up flight tests

The functional mock-ups have been installed on the ATR42 aircraft, by SAFIRE.

1 or 2 TOPFLOW were mounted, depending on the flights, and one Static Port.

The flight tests with these mock-ups were performed between October 16th 2007 and March 1st 2008. There was 21 flights, representing a total of 61.3 hours. The recorded data of all these flights were transmitted by SAFIRE to THALES for exploitation.

The flight tests report constitutes the deliverable D34; it gives details on the basic installation of the aircraft, the principal data regarding the installation of the probes, and summarizes the events occurred during the flights.

The exploitation of the flight tests is given in the deliverable D35.

The principal conclusions of this exploitation are given in the following paragraphs.

2.4.3.1 Static port behaviour

The static port was installed on the aircraft connected to an electronic box, allowing the conversion into signal voltages, compatible with the recorder, of the voltage and the current of the power supply. The temperature from a thermocouple positioned on the probe, inside the aircraft, was also recorded, as well as the Static Air Temperature and the Total Air Temperature of the airflow.

The Static port was installed on the same window as the material probes, see below.

Figure 40 : DETAIL OF THE WINDOW FOR THE STATIC PORT AND THE MATERIAL PROBES

The data from the static port were recorded and examined for the 6 first flights.

From all these data, it appears that the heater of the static port operates correctly.

The evolution of the power consumed is in good relationship with the evolution of the temperatures (increases when the temperatures TAT or SAT decreases).

The temperature of the thermocouple remains relatively constant; this indicates that thermal regulation of the PTC heater is efficient. The regulation temperature is around 60 °C.

The power consumption is around 100 Watts, depending essentially on the external conditions of temperature. There is no correlation between the power consumed and the Liquid Water Content in the airflow. This can be explained by the fact that the static port is far away from the nose of the aircraft; then it is protected against the impact of water droplets.

An typical example of the recorded data is shown below (flight N° as0751).

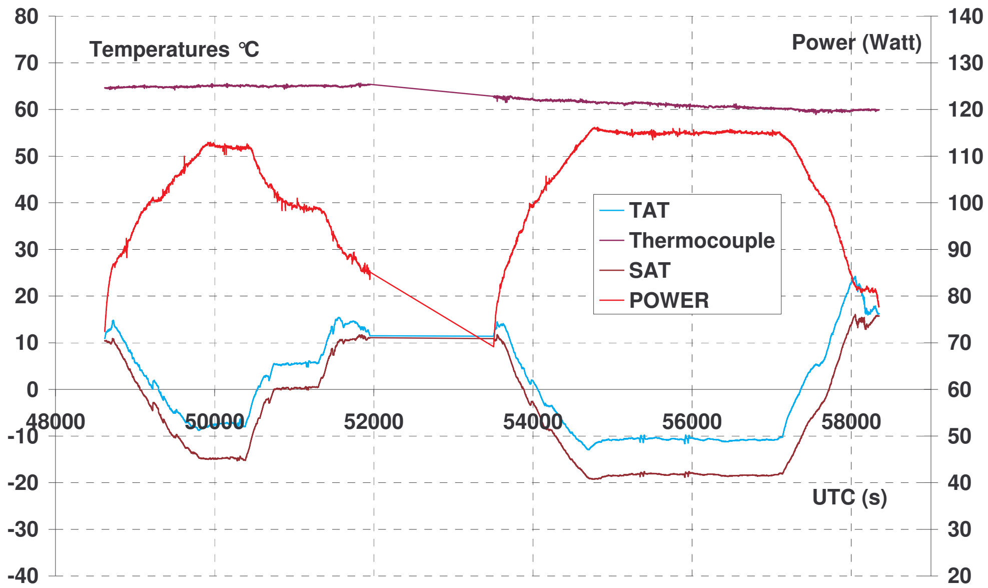


Figure 41 : FLIGHT N° as0751, TEMPERATURES AND ELECTRICAL POWER

2.4.3.2 TOPFLOW probe behaviour

2.4.3.2.1 Total pressure

The TOPFLOW probe has been tested in 3 different locations on the aircraft.

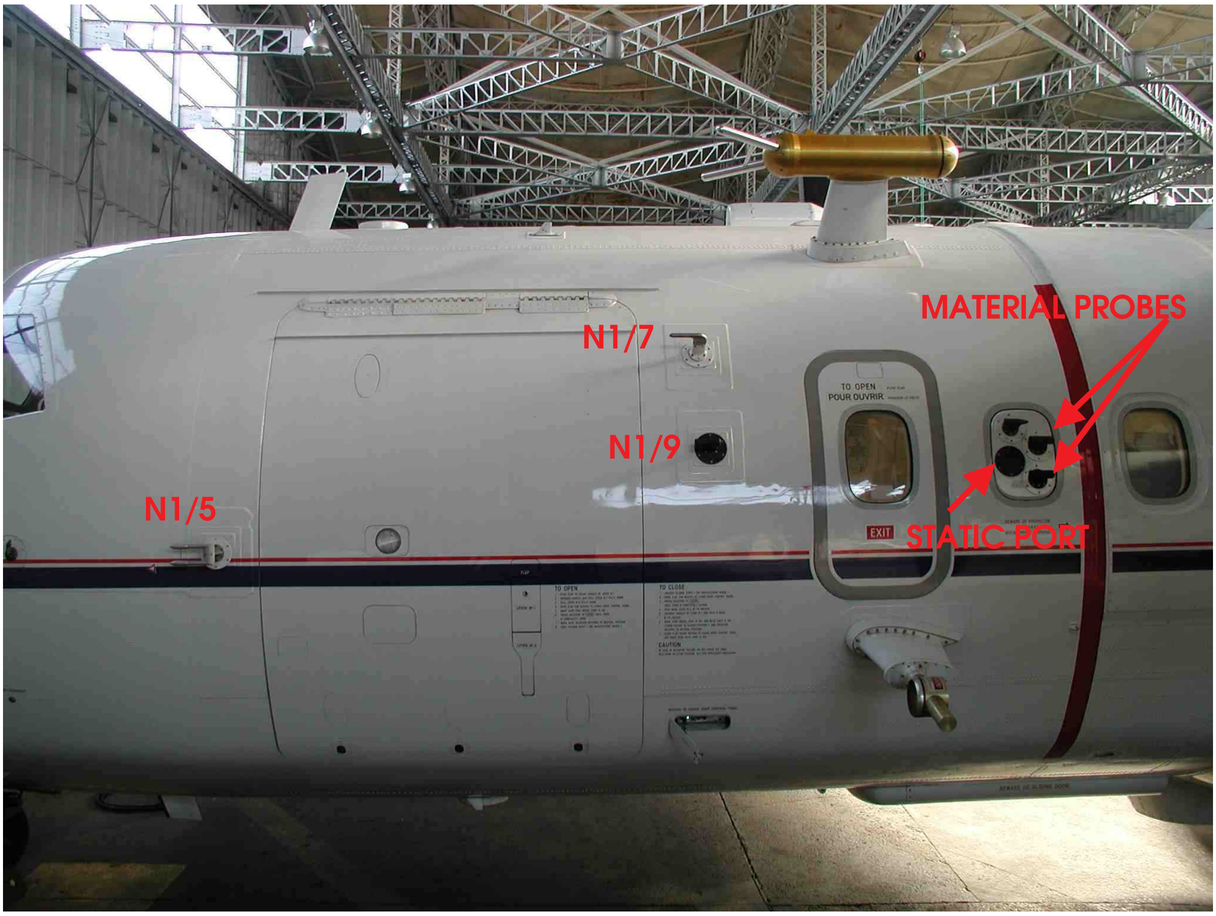


Figure 42 : LEFT SIDE OF THE AIRCRAFT

On the left side it has been installed at positions N1/7 and N1/9, and on the right side of the aircraft at the position N1/6 symmetrical of N1/5 left.

For all these positions the probe was relatively far away from the nose of the aircraft compared to the position of the Pitot of the basic installation. It is well known that the total pressure can be influenced by the boundary layer of the aircraft and by the wakes of other equipments located upstream. Then these positions are not as good as desirable, but there was not any possible position more convenient.

The data from TOPFLOW were compared to that of the aircraft installation, and of a Pitot from KOLLSMAN.

It appeared from the first flights that the measurement of the total pressure was disturbed and influenced at given values of the angle of attack. The fine analysis of the recorded data has shown that this was linked to the wakes of the AOA vane when the probe was mounted at N1/6, right side, or to that of the King probe (position N1/5) and of an edge corner when is was in positions N1/7 and N1/9. However it has been found that the measurements of the total pressure from TOPFLOW were good in a significant range of AOA, when TOPFLOW is mounted in position N1/9, with the King probe of N1/5 removed. In this configuration the results are even better than that of a classical Pitot (KOLLSMAN) mounted in N1/9.

As an illustration of the results, the following graphs show, for 2 flight tests, the pressure coefficients of the probes (first graph) and the angle of attack AOA and the liquid water content LWC (second graph) versus time.

The pressure coefficient called KPTX is defined as follow:

KPTX = (PTREF – PTX) / QC with :

PTREF = total pressure of the aircraft (from the reference installation probes)

PTX = is the total pressure of the probe installed at the position X (X = 7 for N1/ 7 and so on)

QC is the dynamic pressure of the aircraft (from the reference installation probes)= $1/2 * \rho * V^2$

Note : the value of KPTX is always positive (or just equal to zero if the probe is as good as the reference probe).

The angle of attack AOA and the liquid water content LWC are presented for the same flights.

The data shown below are relative to the flight tests n° as0817. This flight has been selected because of the meteorological conditions, with rain or icing, as indicated by the crew.

It is clear from these graphs that the better probe is that of position N1/9 (Topflow), and it is better than the KOLLSMAN Pitot at N1/7 or the second TOPFLOW at N1/6. It has been verified that the 2 TOPFLOW probes have identical aerodynamic performance, then the influence of the position on aircraft is proven.

The graphs of AOA and LWC show that these parameters have quite no influence on the TOPFLOW positioned at N1/9.

Figure 43 : Flight test n° as817- Pressure coefficients of TOPFLOW N1/9, N1/6, and Pitot N1/7

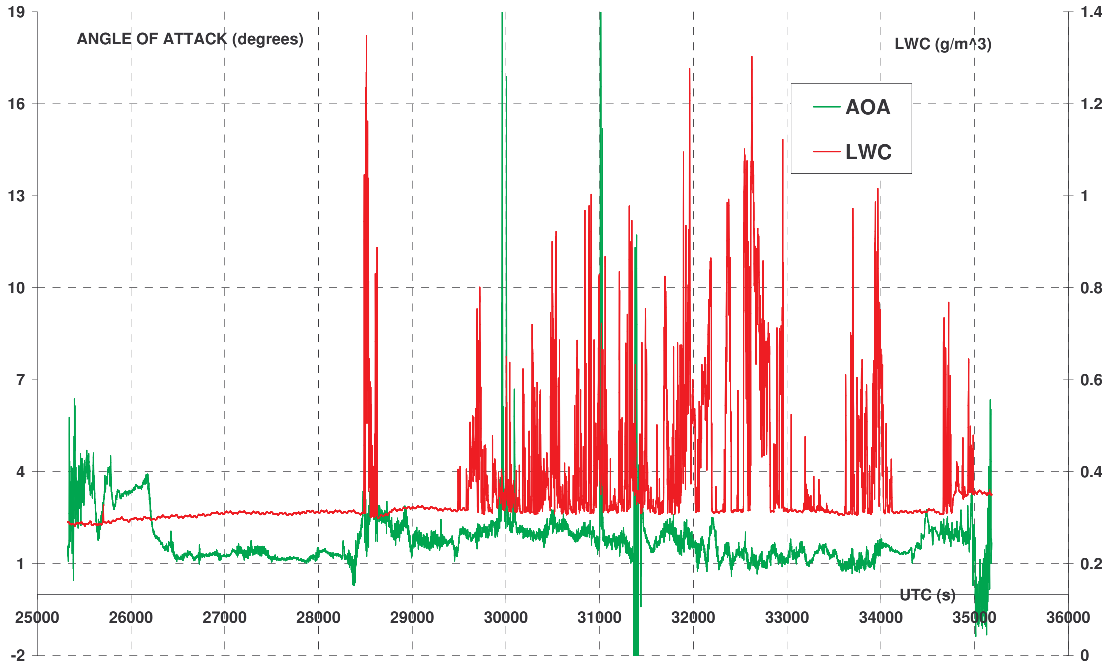


Figure 44 : Flight test n° as817- AOA and LWC

2.4.3.2.2 Total temperature

The total temperature from the TOPFLOW probe has been recorded and compared to that from a ROSEMOUNT TAT probe.

These records show clearly that when the heating of TOPFLOW is ON, the total temperature from TOPFLOW is too high, compared with that of the Rosemount TAT (not heated).

If the heater is OFF, the temperature of TOPFLOW becomes close to that of the Rosemount probe.

The records show also that there is a time constant of around 2 minutes for the establishment of the temperature after a commutation ON or OFF of the heater.

This means that the airflow around the temperature sensor in TOPFLOW is too much heated, and then that the internal design of the probe must be improved.

These results are not very surprising, as they were observed before, during the tests in wind tunnel. The optimization of the design of the probe TOPFLOW during the program ADELINE was made only for the total pressure measurement. Concerning the total temperature measurement, the first objective was to validate the use of new miniaturized temperature sensors in a probe. This objective has been reached.

2.4.3.3 Material probes

These probes have been installed on the aircraft before the functional probes; they have totalized 103.8 flight hours.

The 2 material probes show no signs of degradation after the flight test campaign.

The complete exploitation of the flight tests is given in the deliverable D35.

2.5 WP 5000 : Management

2.5.1 WP5100 : Consortium & WP management

The management of the project was performed by THALES.

The principal steps of the project have been the following:

- The kick-off meeting was held in Toulouse (France) the 25th of February 2005.
- The first six months of the ADELINE program has been very productive. The objective of this sixth month period was to kick-off the program, to analyze existing aircraft air data system architectures, to propose and compare innovative architectures, to establish the technological state of the art of all technical area involved in probes development and to specify requirements for innovative probes development. These goals have been

achieved. The demanded deliverables have also been produced by the consortium (D1, D2, D3,D4 and D5).These deliverables are available on ADELINE web site http://www.adeline-aero.org/. The ADELINE secured web site constitute the deliverable D6 of the project.

- A first technical progress meeting was held in Sheffield (United Kingdom) the 7th of April 2005 to kick-off WP2000.
- A second technical progress meeting was held in Vendôme (France) the 23rd of June 2005 for THALES to present results on architectures analysis to the consortium and for RWTH to presents the technological state of the art for all ADELINE research area. Trials on materials and coating have been decided during this meeting. THALES, ATCT and TUB have presented some idea to commence the research on pressure sensor packaging, new probe concepts and de-icing techniques. The Adeline-web site has been presented by TUB.
- A meeting with AIRBUS, an ADELINE user club member, has been held in Toulouse (France) the 3rd of May. We have presented the first ADELINE conclusions on aircraft air data system architectures to AIRBUS and we have got constructive remarks from it. AIRBUS has contributed a lot to D1 production.
- A third technical progress meeting was held in Berlin (Deutschland) the 14th and 15th September 2005. During this meeting, THALES (INT) has presented several new probe measurement concepts to the consortium : the fluidic total pressure probe, three new concepts to measure the analog of attack using ultrasound, strain gages, and convection, and proposal to use new MEMS sensing elements to measure temperature in total air temperature probes. The deliverables new measurement principles research report (D8), candidate materials selection report (D9), candidate coatings selection report (D10), de-icing and anti-icing techniques research report (D11), sensor packaging theoretical study report (D12), critical analysis and selection of technical bricks report (D13), 12-months activity & management report (D14), preliminary plan for using and disseminating knowledge (D15) have been edited and made available on ADELINE web site http://www.adeline-aero.org/.
- THALES AVIONICS (Vendôme) met Cti in November 2005 to discuss the development of fluidic pressure probe resin mocks-up for wind tunnel testing in January 2006.
- THALES AVIONICS (Vendôme) met VZLU in December 206 to check the performance of the VZLU wind tunnel facility using a standard Pitot tube whose performances are perfectly known. The measured performance was excellent.
- THALES AVIONICS partners (Valence & Vendôme) met beginning of January 2006 to assess the progresses of the project and prepare the annual review.
- The first annual review was held on February 16th 2006 in Valence, after technical meetings with the partners. The objectives were to present the main achievements of the

consortium at the end of the first year : technical achievements, deliverables, meetings, the work plan for the next 3 months, the project progress in term of cost statements.

- EC gives the authorization to continue.
- A technical progress meeting was held in Aachen (Germany) the 16th of June 2006 to kick-off WP3500 "Technical bricks assembly" and to plan activities between June and October 2006.
- A side meeting take place in TOULOUSE (Météo France premises), the 21st of September 2006, to discuss flight test plan and flight test setup.
- A technical progress meeting was organized in Cranfield (UK) the 12th of October 2006 to decide the final design of the functional probes to be tested in 2007.
- The second annual review was held in Prague (Czech Republic) the 23th of February 2007. The commission and the partners have welcomed the results of the second year activities. During this meeting, the European Commission has given the authorization to continue the project. A 2 months late was already presented in the previous 6th month report.
- A technical meeting was held in TOULOUSE (SAFIRE) on July 2nd 2007 to discuss of the flight test campaign.
- Two other technical meetings were held in TOULOUSE (SAFIRE) to check the installation of the probes on the aircraft, and in CRANFIELD to test the probes in the icing wind tunnel.
- The flight test campaign began on October 16th 2007 and ended on March 1st 2008.
- A technical meeting was held in SHEFFIELD (Cti) on December 4th 2007.
- The final meeting is held on March 26th 2008

All details relative to the WP 5100 are given in the deliverables D7- D14- D22- D23- D27- D28- D32- D37- and D38

2.5.2 WP 5200 : Dissemination & exploitation plans

This WP consisted in the Deliverables

- D6: creation of the ADELINE web site
- D15: Preliminary plan for using and disseminating knowledge
- D33: Requirements for new air data integrated systems
- D36: Final plan for using and disseminating knowledge