SUPERSKYSENSE RESEARCH PROJECT:

HYDRAULIC FLUID HEALTH MONITORING AND RECONDITIONING SYSTEM

FINAL PUBLISHABLE EXECUTIVE SUMMARY

M42

Dissemination: CO. This document is classified as SuperSkySense CONFIDENTIAL

Project no	030863
Project acronym	SuperSkySense
Project title	Smart Maintenance of Aviation Hydraulic Fluid Using an On-Board Monitoring and Reconditioning System
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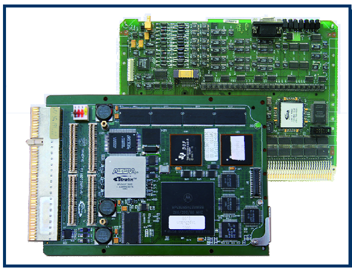
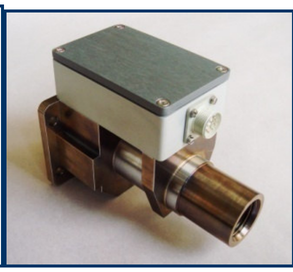
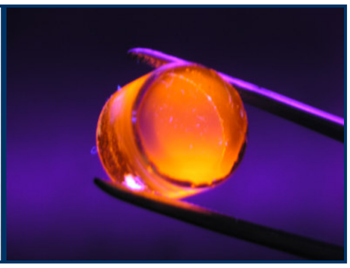
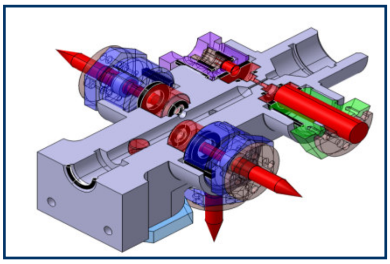
Period covered: 15/10/2006 – 14/05/2010 Date of preparation: 01/06/2010

Project Coordinator name: Gaby Chaib
Project Coordinator organisation name: INTERLAB IEC

SUPERSKYSENSE

Smart Maintenance of Aviation Hydraulic Fluid Using an On-board Monitoring and Reconditioning System



Project Mission: "Strengthening Competitiveness" and "Improving environmental impact" of the European aeronautical industry.

Project Objectives: To design, develop and validate an intelligent on-board multisensor system to monitor the critical parameters and assess the condition of aviation hydraulic fluid and to recondition it as demanded.

SuperSkySense has been financed by the European Commission, within the Sixth Framework Programme.

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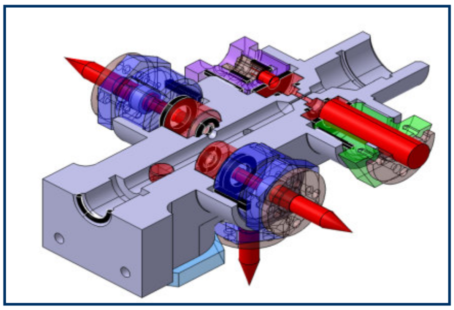
PROJECT OVERVIEW

The **SuperSkySense** project has been financed by the European Commission, within the Sixth Framework Program. This project proposes the development of an optimised maintenance concept for aviation hydraulic fluids based on an autonomous onboard system capable of monitoring fluid condition and restoring it when required, thereby increasing its lifetime and preventing possible damages to the aircraft caused by fluid degradation.



Aviation hydraulic fluids are hygroscopic and, as a result, their lifetime is highly unpredictable. The performance of the entire aircraft hydraulic system is affected by the condition of the hydraulic fluid and if degradation goes undetected, it may cause damages with serious consequences. These may be economic at best or catastrophic at worst.

At present, assessing the condition of the hydraulic fluid in an aircraft is laborious, time consuming and expensive. Therefore the fluid is typically tested less than once a year, with the risk of unscheduled maintenance if the fluid has exceeded its limits of usage. Consequential interruption of the airline service bears a significant economic cost.

The SuperSkySense project initially aimed to develop an optimized maintenance concept based on an autonomous onboard system capable of monitoring the fluid condition and restoring it when required. Regarding the onboard reconditioning system, after an exhaustive feasibility study, it was concluded that the tested absorbents and resulting solutions were too cumbersome for on-board integration but could be adequate for ground use.
Nevertheless, given the predictive capability of the monitoring system, it was assessed that fluid maintenance can be scheduled to coincide with regular service and maintenance operations, thus optimizing associated costs and avoiding service interruption, therefore preserving the main added-value of the projects initial objectives.

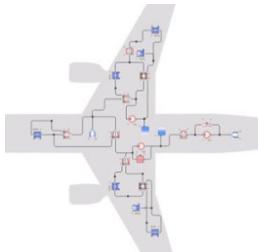
Fibre-optic luminescent and infrared sensors as well as other optical and electrochemical techniques have been developed for fluid monitoring. Similarly, different water separation and elimination techniques have been investigated and selected. The chosen approach yielded a balanced-risk strategy in which established techniques have been combined with cutting-edge research, the outcome of which resulted in concurrent individual deliverables of high intrinsic value, thereby enhancing the combined benefits expected from the project.

Merging multidisciplinary knowledge from multiple fields such as microelectronics, chemical fibre-optics, infrared, and aircraft hydraulics, experts across Europe have combined their expertise with the support of the European Commission to bring the SuperSkySense project to life. After 42 months of work and the participation of fourteen partners from six different countries, three prototypes of on-board hydraulic monitoring systems have been designed, manufactured and tested successfully. This document summarizes the activities and the results of this work.

SuperSkySense Research Project:
Hydraulic Fluid Health Monitoring and Reconditioning System
Publishable Executive Summary M42

1 . OBJECTIVES

> **To design, develop and validate an intelligent on-board multisensory system to monitor the critical parameters and assess the condition of aviation hydraulic fluid and to recondition it as demanded.**



Strategic

SUPERSKYSENSE aims to strengthen the competitiveness of the European civil aeronautics industry by offering ways of reducing substantially its associated maintenance costs, additionally providing improved safety, reliability and reduced environmental impact, by means of an optimised maintenance concept based on an on-board fluid monitoring and reconditioning system.

Technical

- To develop an optimised hydraulic fluid maintenance program to reduce cost, downtime and environmental impact, and to increase safety and reliability of aeronautical hydraulics.
- To design, develop and validate an on-board intelligent multisensory system to monitor the critical parameters and evaluate the condition of the aviation hydraulic fluid used in most civil aircraft (phosphate ester-based fluids).
- To design, develop and validate an on-board hydraulic fluid reconditioning system to stop fluid degradation and as such enhance the fluid's lifetime almost indefinitely.

Economical

The adoption of this system will significantly reduce aircraft operating costs linked to hydro-mechanical equipment in the short and long term, through reduction in consumption, maintenance and other direct operating costs.

Social

Part of the aforementioned savings will be consequently passed on to passengers. Furthermore, it aims to improve safety and reliability of the air transport system as a whole while contributing to the reduction of lost time, frustration and cost for European travellers.

Safety

SuperSkySense will provide and process critical information linked to vital airframe functions such as hydraulic actuators, allowing anticipating potential risks due to fluid degradation, thereby preventing malfunction. The reliability level of the overall hydraulic system and components will increase drastically

Environmental

By contributing to the reduction of harmful and aggressive fluid waste, this project leads to reducing pollutants originating from aeronautical hydraulics maintenance activities.

2 . THE CONSORTIUM

As mentioned previously this project leverages the experience of a multidisciplinary group of professionals, each specialized in their own complementary field, whether it is microelectronics, chemical fibre-optics, infra-red, aircraft hydraulics, mechanical engineering, aircraft MRO, end users, and much more.

The names of the companies and institutions constituting the SuperSkySense consortium are given below:

No.	Participant organisation name	Short name	Logo
1	INTERLAB Ingeniería Electrónica, S.A. (E) (Coordinador)	ILAB	INTERLAB INGENIERÍA ELECTRÓNICA
2	Airbus Operations SAS	A-F	AIRBUS
3	EADS Deutschland GmbH - EADS Innovation Works (D)	EADS-IW-D	EADS
4	Lufthansa Technik Budapest Kft (Hu)	LT	Lufthansa Technik Budapest
5	Loughborough University (UK)	UoL	
6	Instytut Lotnictwa (Pl)	IoA	IL
7	Compañía Española de Sistemas Aeronáuticos S.A (E)	CESA	CESA
8	SOFRANCE S.A. (F)	SOF	SAFRAN Sofrance
9	Universidad Complutense de Madrid (E)	UCM	UCM GsoLfa
10	EADS France – EADS Innovation Works (F)	EADS-IW-F	EADS
11	Fundación INASMET (E)	IAM	inasmet tecnalia
13	Centre de Transfert de Technologies Céramiques (F)	CTTC	CTTC
14	Groupe d'Etudes en Procédés de Separation (F)	GEPS	GEPS

3 . PROJECT STRUCTURE

Given the complexity of the project, it is divided in Work Packages (WP). Each work package is assigned a leader (WPL) to coordinate the task and communicate the deliverables to the project coordinator. The project´s structure is illustrated in the following diagram.

A detailed description of the project´s structure and objectives can be consulted in a document entitled the Description of Work, or DoW for short, which serves internally as a business plan and road map, as well as, officially, a contract between the consortium and the European Commission (EC).

The project coordinator is responsible of communicating with the EC on behalf of the consortium; this role has been entrusted to INTERLAB for the duration of the project.

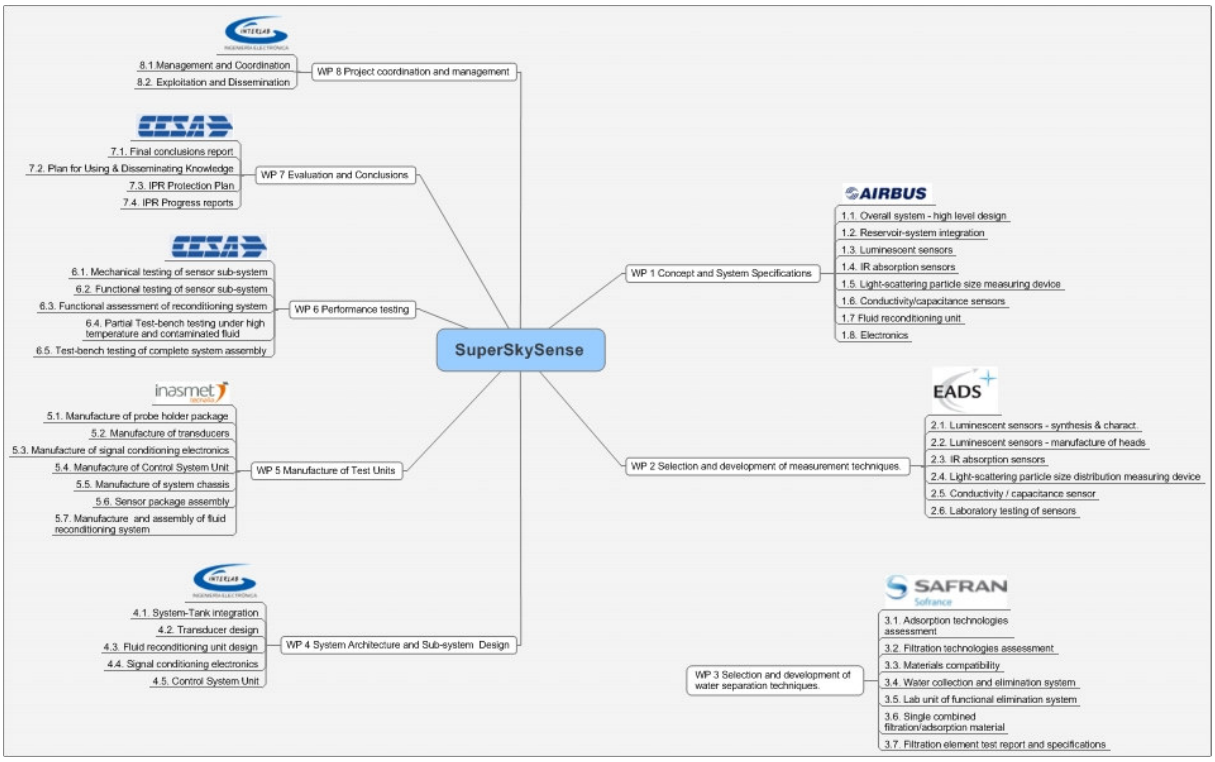


Figure 1 - SuperSkySense project breakdown structure

4 . PROJECT PROGRESS

The project started officially on October 15th 2006 and the final meeting took place on April 15th 2010, 42 months later. The time has come to review the initial list of objectives to assess the achievements of the SuperSkySense venture. To do so we will recap each work package in order up-to the "Evaluation and Conclusion" which constitute the WP7.

WP1 - Concept and system specifications

Work package 1 - *Concept and system specifications* – consists in defining a global system concept, providing a set of specifications for the online monitoring and water removal subsystems, providing specifications for mechanical and electrical interfaces of the airplane infrastructure. This work-package was carried out by AIR-BUS, in close co-operation with CESA, specialised designer and manufacturer of aircraft hydraulic systems and with the Corporate Research Centres of EADS Innovation Works in France and in Germany. This preliminary work was completed in the first period of this project and was the building stone to all the future developments to come. It was essential to the work packages related with subsystem designs such as WP2, 3 and 4.
The main tangible outputs of this work package are (D.1.1.) the "*Full system specifications report containing specifications of individual sub-systems*" and (D.1.2.) the "*Test plan*". Both deliverables required updates and adjustments later-on in the project but had their main definitions set at this stage.

No major difficulties have been encountered in this period, with the exception of the inability of defining a clear test plan for the chlorine / chloride content assessment. Exceeding the framework of the available theory at hand, the consortium was unable to predict the behaviour of the tests beforehand, whether through infrared based measurement or fibre-chemical based measurements; a trial and error approach was deemed required.

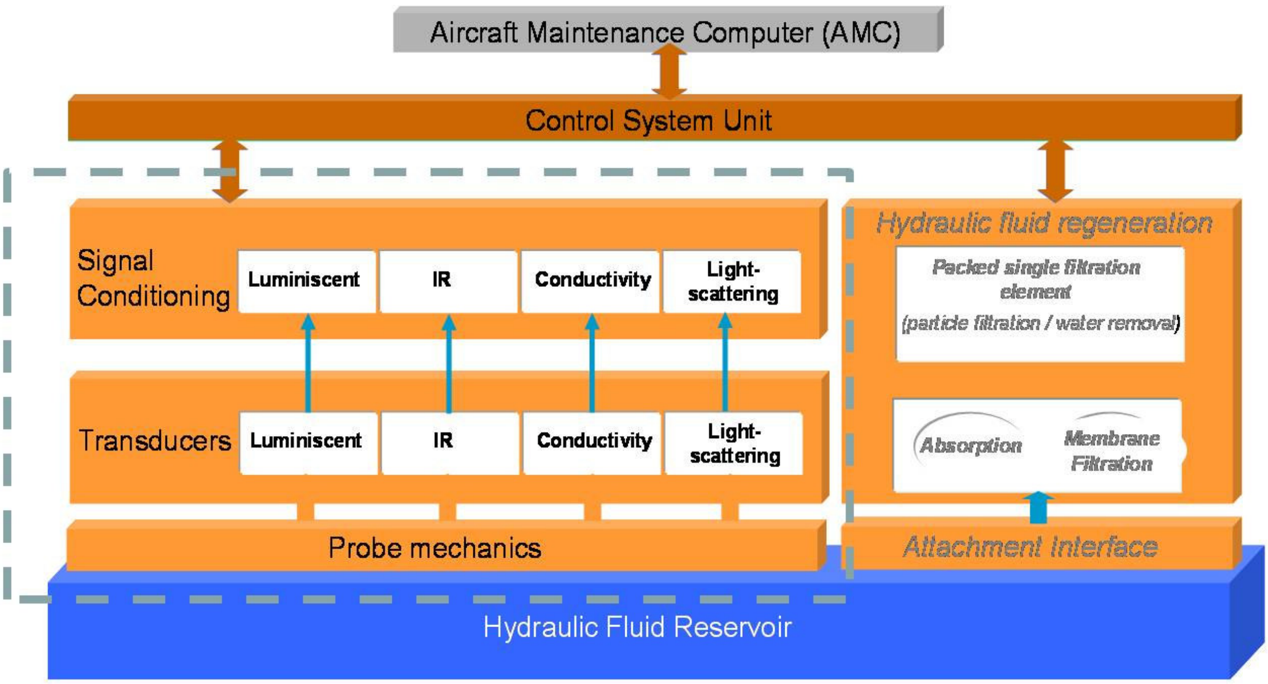


Figure 2 - SuperSkySense system block diagram

WP2 - Selection and Development of Measurement Techniques

Work package 2 - *Selection and Development of Measurement Techniques* – consists in exploring various alternatives for measuring relevant parameters of aeronautical hydraulic fluid. By *relevancy*, we mean that the measurements allow a direct or indirect evaluation of the quality or level of deterioration of the fluid. The parameters which were initially considered are humidity, acidity, chlorine, dissolved oxygen – as an indirect measure of dissolved air – particles, electrical conductivity and capacitance.

A variety of different techniques have been explored, including luminescent sensing, infrared spectroscopy, light-barrier based optical particle counting and conductivity/capacitance based, to measure the aforementioned parameters of the hydraulic fluid.

The selected measurement techniques within this WP have then been manufactured in test units within WP5 and performance tested within WP6.

What is being measured?

- **Acidity**
- **Moisture**
- **Particles**
- **Oxygen**
- **Electrical properties: Electrical conductivity and capacitance**

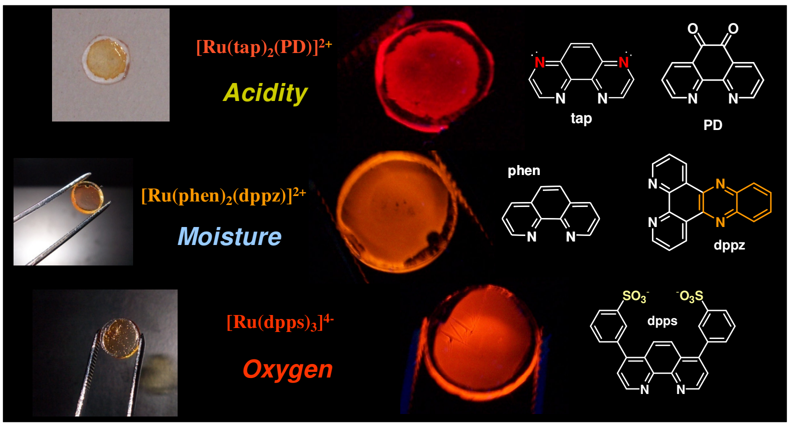
WP2 Sensing Technology: Optical sensor, Luminescent

Objective: Design and characterization of luminescent indicator dyes for specific determination of acidity, moisture and oxygen in hydraulic fluids.

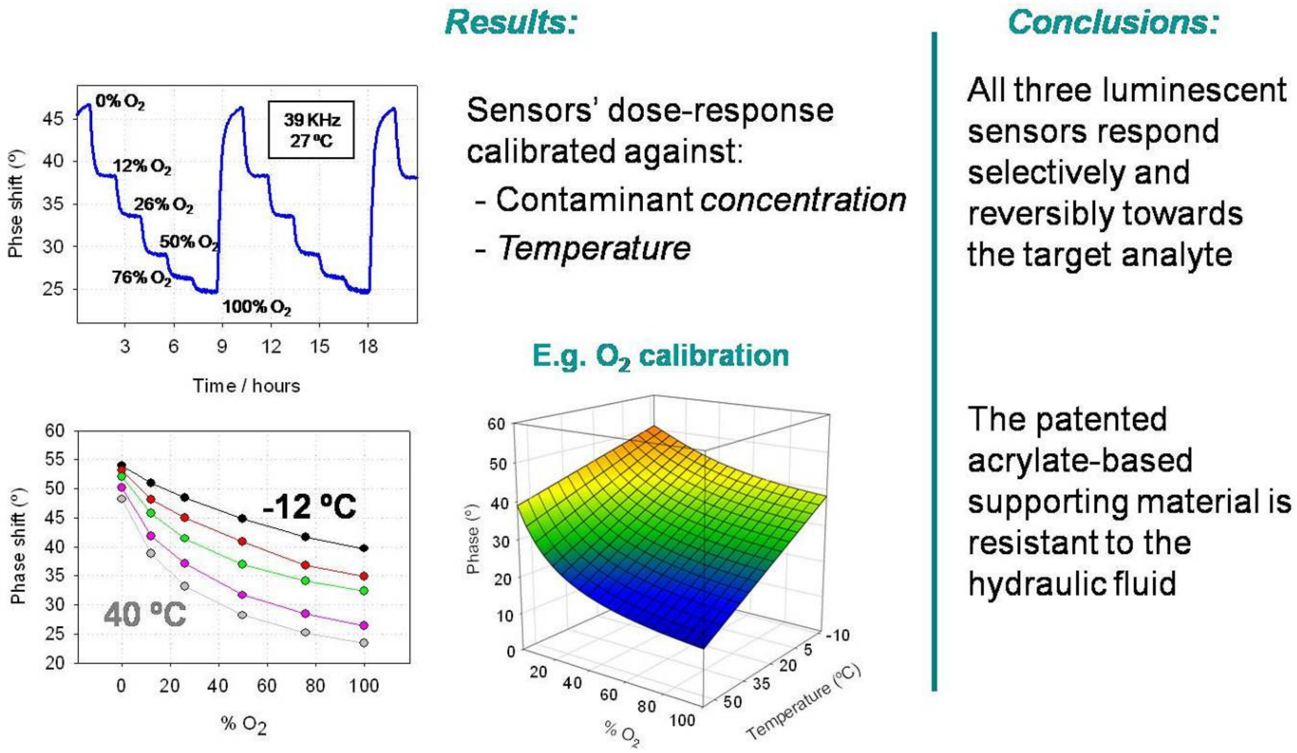
Achievements: The sensitivity levels of the developed luminescent sensors for moisture, acidity and oxygen have demonstrated to be accurate within the required range**.**

Sensing Technology: Optical sensor, Luminescent

Parameters: Acidity, moisture and oxygen



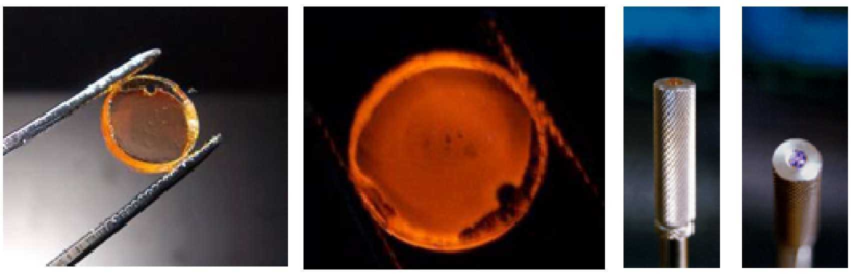
WP 2 - Figure 1 - Luminescent indicator dyes prepared at UCM



Key breakthrough: Robust thin indicator layers chemically bonded to optical windows.

Using the luminescent indicator dyes, doped polymer materials have been prepared and optimized by the **UCM** Laboratory of Applied Photochemistry for each chemical parameter. The dye concentration has been optimized for adequate signal when interrogated with laboratory bench scale optoelectronic unit provided by **INTERLAB**. The sensing principle is based on the change of the luminescent signal in the presence of the target contaminant.

The polymer films are based on heavily cross-linked acrylate monomers covalently attached to functionalized glass windows (to avoid dissolution into the hydraulic fluid). Testing has ensured no leaching of the indicator dye to the hydraulic fluid and temperature resistance in the –15 to 110 ºC range.



WP 2 - Figure 2 - Orange-luminescent sensor films developed at UCM to monitor chemical species in hydraulic fluids. The polymer film (20–30 µm) is chemically attached to a 9-mm glass disk. The stimuli-sensitive window is then mounted inside a stainless steel encasing.

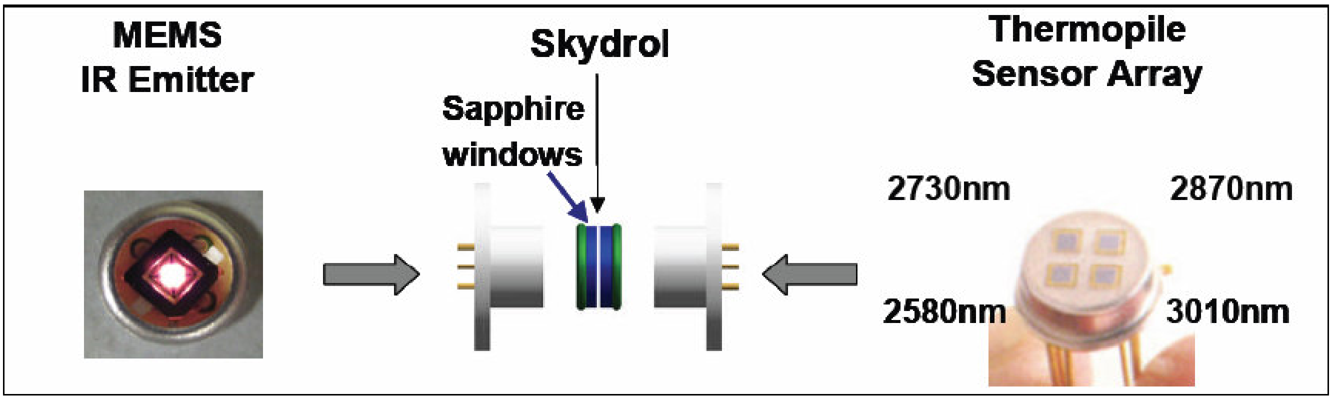
WP2 Sensing Technology: IR-Based Chemical Sensor

Objective: Design and characterization of alternative approaches to measure the critical parameters such as Acidity and Moisture.

Achievements: Successfully testing Laboratory prototype for water content (0-1.5%) and acidity (0-1mgKOH/g).

Sensing Technology: Optical sensor, Infrared absorption

Parameters: Acidity and moisture



WP 2 - Figure 3 - IR-based chemical sensors developed by EADS-IW-D.

The IR chemical sensors suggested by EADS-IW-D are used for measuring two parameters: water concentration and acidity of the hydraulic fluid. Both parameters can be monitored by assessing changes in the IR transmission of the fluids. Water addition to phosphate ester hydraulic fluids results in an increased IR absorption at around 3500cm-1 (or 2870nm). The absorption is roughly symmetrical around this central line. But as soon as the fluid gets contaminated with acid, the symmetry disappears.

In order to implement the above principle, four IR wavelengths were selected; 2870nm for water concentration, 2730nm and 3010nm for acidity or the symmetry around centre line and last but not least, 2580nm as a reference channel which is independent of any chemical contamination.

WP2 Sensing Technology: Optical Sensor

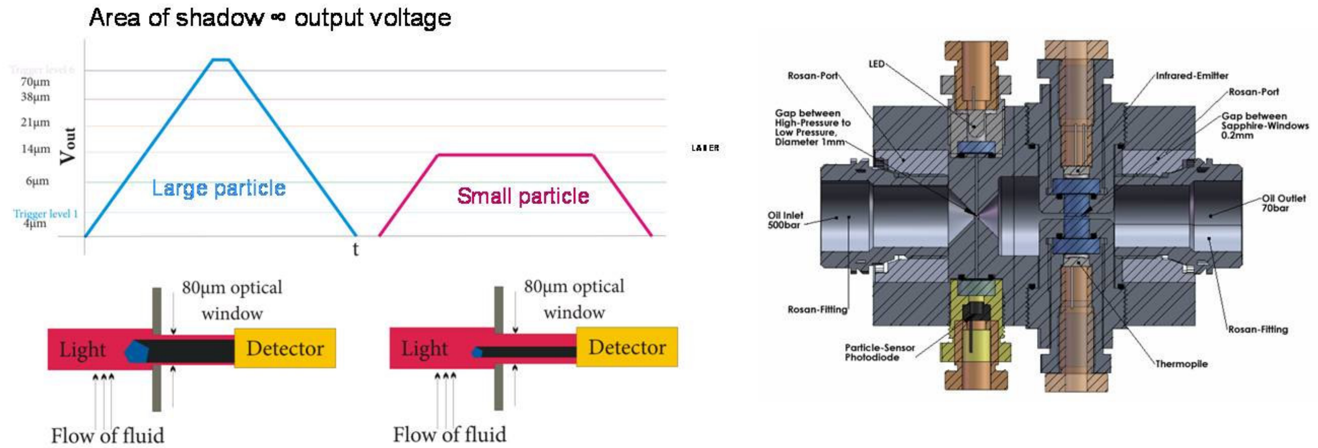
Objective: Design and characterization of an optical particle counter sensor.

Achievements: Prototype of particle counter sensor successfully tested and calibrated.

The optical sensor allows determining the level of particle contamination based on particle size.

Sensing Technology: Optical sensor.

Parameters: Particulate Matter Contamination



WP 2 - Figure 4 - Particle sensors developed by EADS-IW-D.

The schematics shown on the left reveals the measurement principle proposed by **EADS-IW-D**. A light barrier system consisting of a laser diode and a Si-photodiode at the receiver end forms the basis of the particle sensor.

The mechanical structure, on the right-hand side, illustrates the setup made for particle measurement. The main challenge here was the precise alignment required to insure proper measurement, this issue has revealed itself only during the integration and testing phases. It required some mechanical rework but the issue was finally resolved.

WP2 Sensing Technology: Electrical Sensor

Objective: Design of electrical sensors for the measurement of the hydraulic fluid conductivity and capacitance characteristics.

Achievements: Design, manufacturing and calibration of a standalone sensor of capacitance and electrical conductivity.

Sensing Technology: Electrical Sensors

Parameters: Conductivity and capacitance

WP 2 - Figure 5 - Conductivity and capacitance sensors developed by IoA.

Two electrical parameters of the hydraulic fluids: dielectric constant and conductivity are measured by this sensor. The electrical capacitance and conductivity transducer (CCS) design of the **Institute of Aviation, Warsaw,** Poland (**IoA**) uses a single cylindrical probe for measuring both electrical properties. The probe consists of two coaxial cylinders immersed in the hydraulic fluid. In the case of a conductivity measurement the cylinders represent contacting electrodes and for the capacitance measurement constant equipotential surfaces defining the measuring capacitor.

WP3 - Selection and development of water separation techniques

Work package 3 – *Selection and development of water separation techniques* – This work package aimed to study different water separation technologies in relation to their efficiency in removing water from phosphate-ester based hydraulic fluid. The main objective was to test and select a set of water separation techniques and materials that may subsequently be assembled to produce a simple passive reconditioning element.

Extensive testing of different technological alternatives has been performed based on membrane filtration and adsorption using various types of materials and configurations.

Adsorbents Used

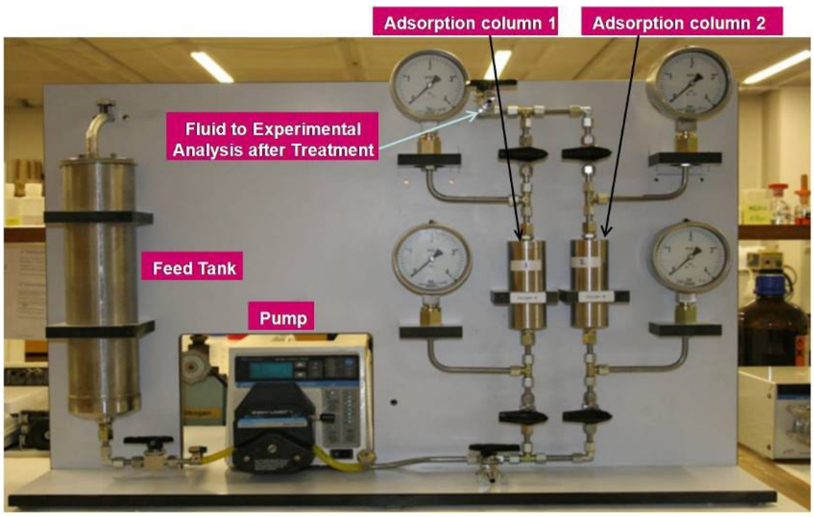
- Activated Alumina
- Molecular Sieves
- Drierite
- Silica Gel
- Magnesium Oxide
- Boiling Stones
- Florisil

Hydraulic Fluids Tested

- SKYDROL 500 B-4
- SKYDROL LD-4
- HYJET IV- A^{plus}
- HYJET V

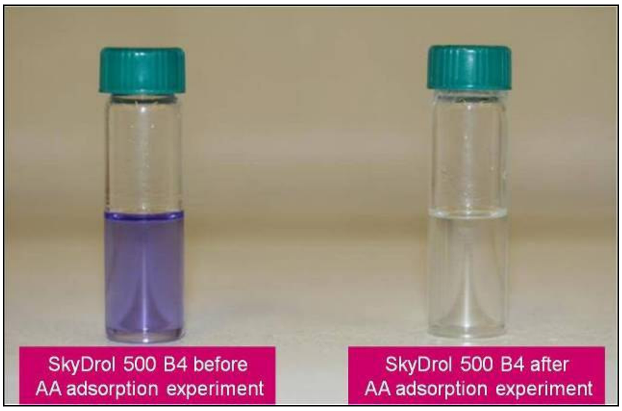
It was concluded that none of the tested absorbents were adequate for an on-board reconditioning system given that the studied technologies gave way to alternatives which were too cumbersome for onboard integration.
It was observed that hydrophilic membranes do not allow water extraction because they are also esterophilic; while ultrafiltration membranes had limited results since they reject completely free water but only partially dissolved water.

In spite of the lack of positive results, some of the technologies developed in the frame of this project will be possibly used in the future. The know-how developed by **CTTC** and **SOFRANCE** on ceramic foams may allow in the future the use of more adequate (narrow band or selective) adsorbents. Current progress in nanotechnologies is carefully considered. Other applications requiring important exchange surfaces (air treatment for example) are also examined.



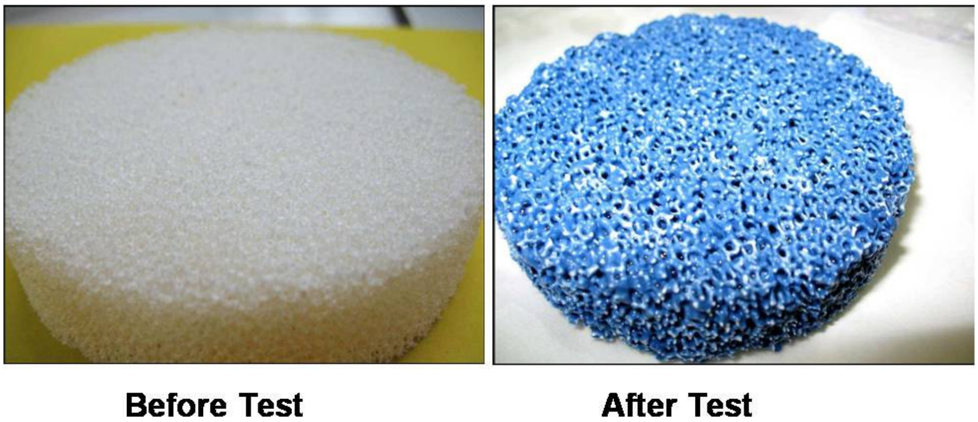
WP3 - Figure 1 - Image of the water separation experimental rig.

In addition, most adsorbent solutions tested had the undesirable side effect of removing some essential components of the hydraulic fluid.



WP3 - Figure 2 - Undesirable water separation effects.

The ceramic foams produced by **CTTC** did not adsorb the dissolved water as expected but instead it absorbed part of phosphoric ester color additives as can be seen in the following figure (WP3 - Figure 3).



WP3 - Figure 3 - Ceramic foam undesirable water separation effects.

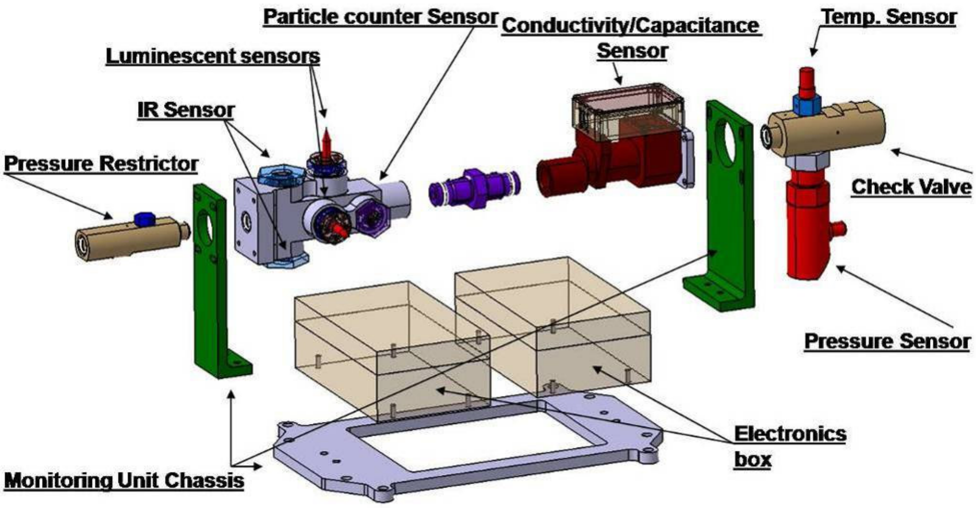
Nevertheless, two additional feasibility studies have been performed in the last period of the project by **GEPS** to investigate other innovative ideas for hydraulic fluid dewatering, particle and gas removals. Both studies showed promising results and their results are available to the public under demand. These two techniques are:

- Coupling membrane filtration and evaporation on the filtrate side
- Filtration by vacuum made by a Venturi apparatus

Although an actual on-board reconditioning system was not successfully developed - an eventuality which had been taken into consideration in the initial Description of Work given the ambitious nature of the objective- it is believed, by the member of the consortium, that invaluable insight has been obtained regarding the behaviour of hydraulic fluids and their constituents, thereby paving the way for future developments in ground-based systems, far less demanding in terms of weight, or to future attempts to develop an on-board system, within the scope of future projects.

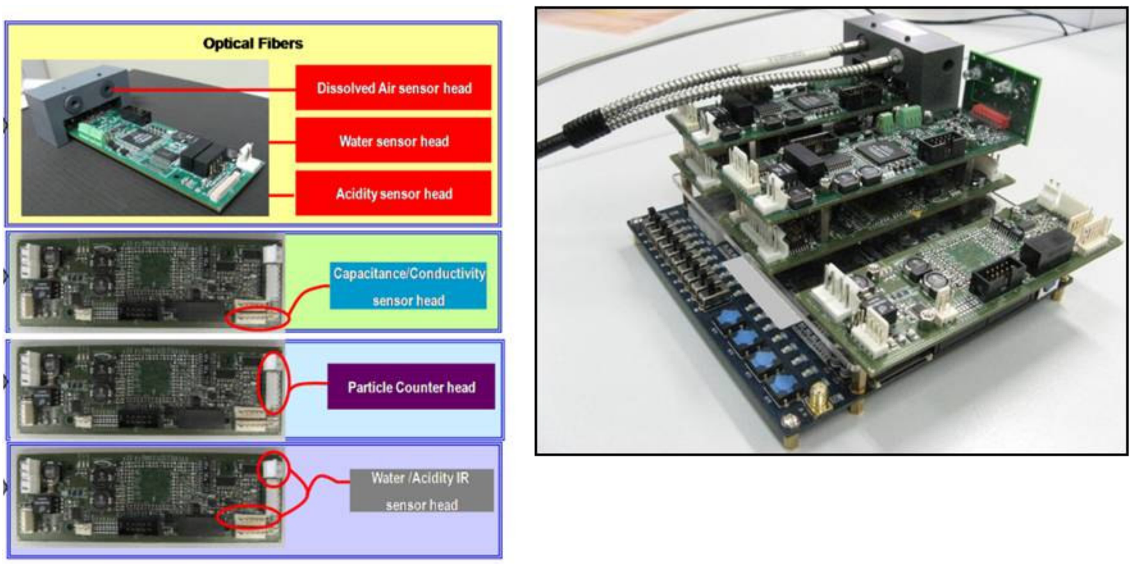
WP4 - System Architecture and Sub-system design

Work package 4 – *System Architecture and Sub-system design* – This is quite straightforward and can be summarized with visual aids such as drawings since the main objective of this WP is to generate the detailed plans and schematics of the full system, ready for manufacturing. As can be expected this work package is followed by the manufacture of the test units which can be summarised by pictures.



WP4 - Figure 1 - Integration diagram of all the sensors in the test rig.

The preceding diagram (WP4 - Figure 1) shows the mechanical design of the manifold prepared by **INASMET** and which houses the sensors. The following figures (WP4 - Figure 2) illustrates the sensor electronics, This modular approach allows to measure six parameters, using four different technologies through the same signal conditioning module within a single multisensory system. Modules are independent and can be further developed and installed as a stand-alone or combined set of hardware.



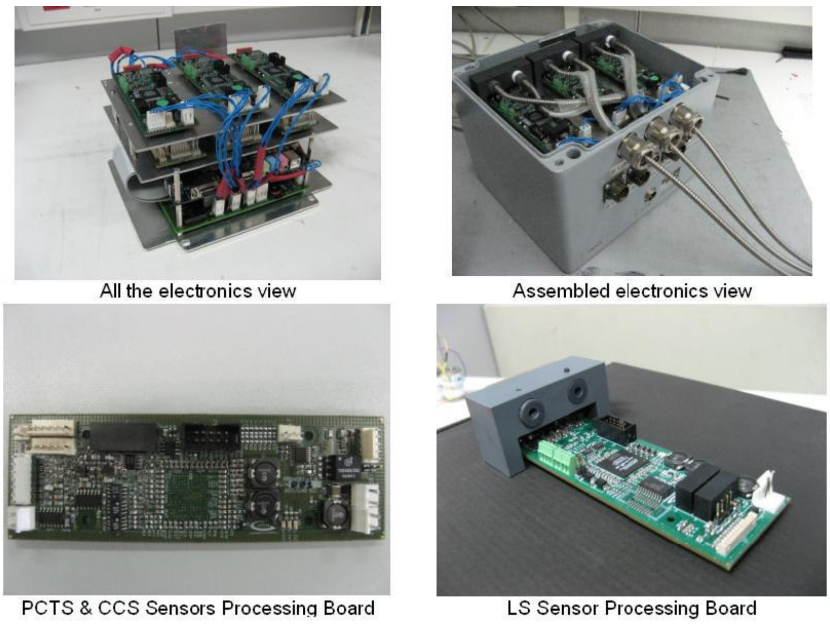
WP4 - Figure 2 - SSK Sensor electronics

WP5 - Manufacture of test units

Work package 5 – *Manufacture of test units* – Based on the aforementioned design diagrams and detailed plans, three test units have been manufactured and made ready for testing.

WP5 - Figure 1 - Three test units manufactured and ready for testing.

The **Control System Unit (CSU)** gathers the data from the sensors and that provides the connections to the test bench. The **power supply** and **protection boards** are considered as part of the CSU.

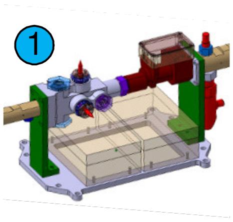


WP5 - Figure 2 - Control System Unit and electronic boards developed by INTERLAB

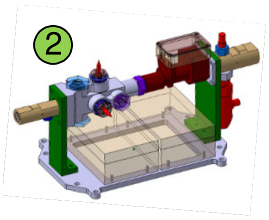
WP6 - Testing

Work package 6 – *Testing* – This work package is critical to assess the level of achievement of the project. Nevertheless it is important to underline that the test plans set forth greatly exceed the actual frame of the projects objectives. By this we mean to say that the goal of the project is not to build an actual on-board monitoring system for hydraulic fluid which is certifiable in all aspect of airworthiness, but rather to demonstrate that the functionalities of the sensors are reliable in realistic working conditions.

Having said that, let's review what has been done in the testing phase of the SuperSkySense Initiative. As mentioned earlier three identical monitoring prototypes have been manufactured, each destined to a different set of test.

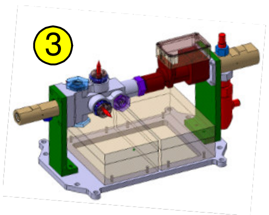


Unit1 – Vibration Tests – IoA
One unit was taken in charge by the Institute of Aviation, **IoA**, who was responsible of performing **vibration tests**, among which are i) sinusoidal vibrations, ii) repeated half sinusoidal, ii) mechanical shocks.



Unit 2 – Endurance & Fatigue Tests – CESA
A second unit was sent to **CESA** for **endurance and fatigue tests** as well as a limited set of functional tests under operational conditions (that is, sensors subjected to pressure and wetted by hydraulic fluid).

Unit 3 – Functional Tests - Airbus



The third and last unit was entrusted to **Airbus** France for the most significant of all tests, the **functional testing** of the sensor subsystem which was done on the fully integrated Esther test bench in the impressive Toulouse facilities. These results were monitored closely by all partners directly or indirectly involved in the development of the sensors, their electronics or their mechanical housing. The hydraulic fluid under test was also sampled for conventional laboratory test, for comparison.

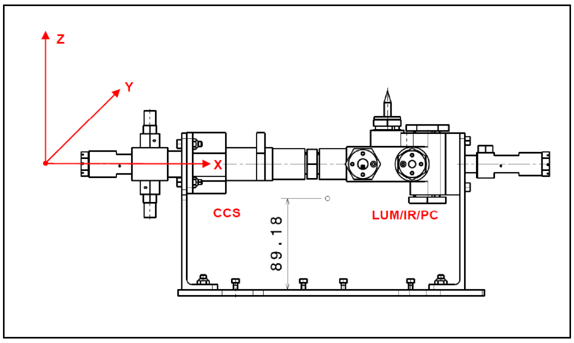
WP6 –UNIT 1 – Vibration Tests – IoA

The purpose of the SSK random vibration tests was to verify that all sensors, their electronic boxes and manifold, creating together the SSK Monitoring Unit, were able to withstand random vibration levels within specified tolerance without any structural failure or damages of any external or internal components. The actual goal was to make sure the design was safe to undergo functional tests in Airbus Esther test bench without any risk of damaging it. Additionally, it was decided to push the tests as much as possible, up-to airworthiness level if possible. Although we did not expect to reach such levels, it was deemed interesting to see just how robust the design really was. “Shake it till it brakes” was the modo for this testing phase.

To mimic real working conditions during the vibration tests the manifold was filled with hydraulic fluid. This allowed verifying the manifold´s leakproof property during and after the tests. The functionality of the sensors was not tested in this context.

Vibration test setup:

The equipment under test for each vibration level was installed so the input vibratory motion was parallel to one of its three major orthogonal axes shown below.



WP6 - Figure 1 - Three orthogonal axes X, Y, Z of SuperSkySense Monitoring Unit manifold

For each axis of reference an accelerometer was attached to the equipment mounting frame to record the equipment's vibration response in the corresponding axis of vibration.

The vibration tests were divided in the following two parts:
1. Ten minute random vibration tests in 5 increasing levels for each axis.
2. Three hour random vibration test according to EUROCAE ED14/ R.T.C.A D0160 complied with robust vibration test applicable for equipment installed in fixed wing aircraft with turbojet or turbofan engines.

WP6 - Figure 2 – Vibration test setup

Summary of vibration test

The design was deemed sufficiently robust to withstand possible vibrations during functional tests and therefore does not present any relevant risk to the Esther test bench.

Furthermore, it was noted that when pushing the tests to the extreme nearly all the sensors and their parts, in particular the luminescent sensors and the conductivity and capacitance sensor successfully withstand the tests. Only the infrared and particle counter sensor’s electronics were damaged after prolonged vibration.

WP6 – UNIT 2 – Endurance & Fatigue Tests – cesa

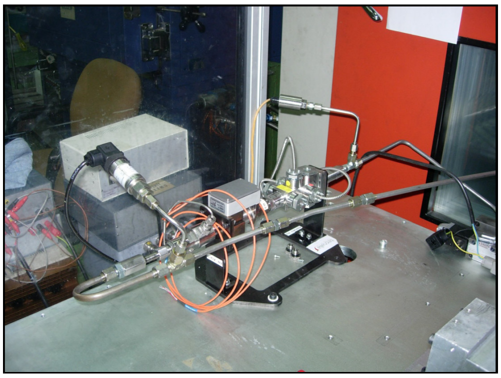
Test Sequence

- Product Acceptance Test (PAT)
- 100% of Endurance Test (5.000 cycles).
- Product Acceptance Test after Endurance test and before fatigue Test.
- 100% of Fatigue Test (55.000 cycles).
- Product Acceptance Test after fatigue test.

Summary of endurance test results

Five thousand (5,000) pressure cycles and electronic cycles were performed on the unit. At regular intervals of one thousand (1,000) cycles, a check of the Control System Unit was performed to validate that the system was behaving as expected. Details of the exact test variables are available within the corresponding work package report. Nevertheless, in order to give an idea of the range of application, the following is an extract for one of the test readings: After 2.98 sec, a pressure of 209 bars was applied in the inlet port of the SSK and a flow less than 0.6 l/min passed through it during 2.32 sec. The pressure in the outlet port of SSK was of 1 bar. With the unit pressurized under these conditions a check of the Control System Unit was performed and the results were as expected.

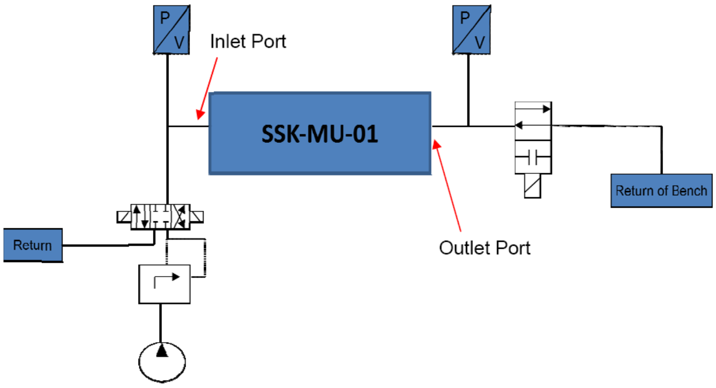
Before and after the endurance test a product acceptance test, except the proof pressure check, was performed. No problem and no leakage were detected and all results were within tolerance. Therefore the unit has passed **successfully** the endurance test and its design is deemed fit to be integrated in Airbus Esther test bench for functional tests.



WP6 - Figure 3 - Unit 2 – Endurance test setup

Summary of fatigue test results

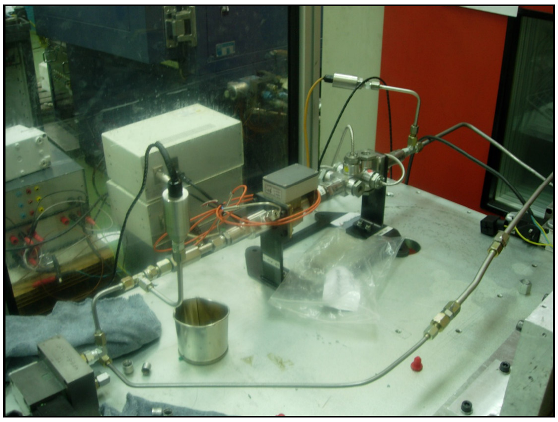
Fifty five thousand (55,000) cycles of pressure of 0 to 87.5 to 0 bars were performed.



WP6 - Figure 4 - Unit 2 – Hydraulic scheme to Fatigue Test

Unlike the previous test, some issues related to leakage have manifested themselves due to the degradation of O-rings which were incompatible with hydraulic fluid. One leak could not be fixed without jeopardizing the functionality of the Conductivity and Capacitance Sensor Unit. These degraded elements had to be replaced in order for the tests to continue.

After the fatigue test, a product acceptance test was performed, except for the part of the PAT corresponding to Conductivity and Capacitance Sensor Unit. The results of the test were within tolerance and no further leakage or problems were detected. The results were similar to the results of the initial PAT and therefore the design was deemed to have passed sufficiently the fatigue test in order to undergo tests in the Esther test bench. The reason for this assessment is the following: the Esther test bench is not expected to work at high pressure and therefore the risk of leakage should be minimal. Furthermore, IoA the partner responsible for the CCS sensor with the support of INASMET, the architect of the manifold, have prepared a plugging mechanism to intervene in case a leakage was to occur. This contingency plan aimed to mitigate any risk of jeopardizing the functional test or, although highly improbable, damaging the Airbus test bench.



WP6 - Figure 5 - Unit 2 Fatigue tests setup

WP6 – UNIT 3 – Functional Tests – airbus

The overall goal here was to measure the hydraulic fluid properties, which translates in assessing the levels of achievement of the SuperSkySense project.

The specific purpose of these tests was to observe the sensors behavior given different water contents and cleanliness classes of the bench fluid, under two different temperature conditions.

The test was performed on AIRBUS ESTHER 3000 PSI hydraulic test bench. This test bench is hydraulically representative of an aircraft in a condensed way, with a set of aircraft equipment (i.e. actuators). The SSK manifold was fitted between high and low pressure lines (see WP6 - Figure 6). Module was put under pressure for first time the 7th of January 2010.

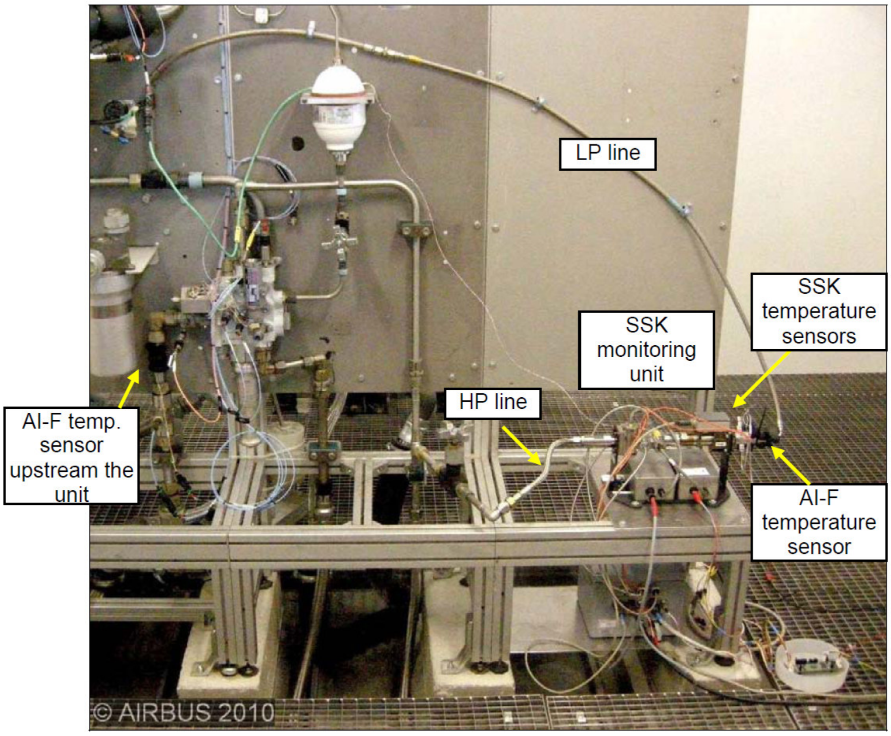
The SSK monitoring unit allowed calculating the following parameters:

- Water content
- Dissolved gas
- Acidity
- Particle content (cleanliness class)
- Electrical properties: electrical conductivity and capacitance

The ESTHER test bench:

Specific software was developed for the test supervision by a computer. This control and display unit allows setting the endurance test, the flight cycle, to control and supervise test and safety parameters, the activation of the MOOG servo-controller, the automatic leakages measurement and the data files management.

A hydraulic restrictor was designed to set a constant flow (~0.6 l/min) through the unit.



WP6 - Figure 6 - SSK Monitoring unit integration area within Airbus Esther test bench.

The system includes temperature control and monitoring capabilities with minimum acquisition accuracy of +/-1 °C.

Functional test specific conditions (contamination of the fluid during SSK test):

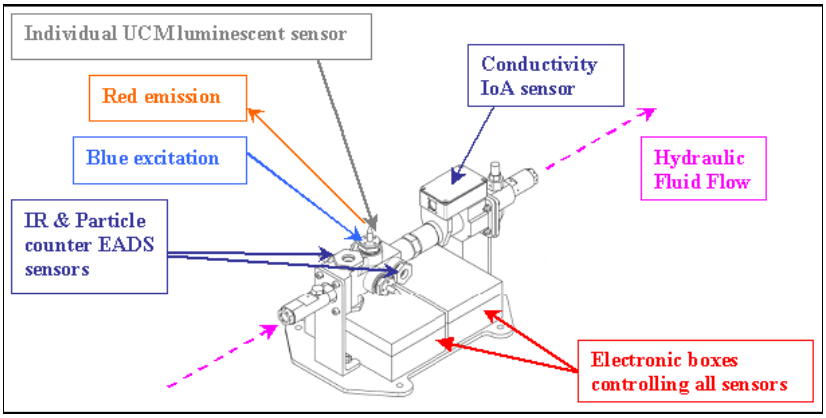
The hydraulic fluid in ESTHER circuit for the SSK test was contaminated with water and dust with introduction in LP filter bowl, in accordance with the NSA307110 specification. This contamination was made in order to validate measurements of water content and cleanliness class by probes used within the tested equipment.

During SSK test:

Tests were performed at two different temperatures: 41°C and 56°C (measured at SSK unit outlet).

Fluid samples were taken periodically, prior to any new contamination or relevant changes applied to the hydraulic fluid under test, and for every change of temperature. This was done using the AC sampling valve on the HP manifold. These samples were sent to be tested by conventional laboratory methods in order to contrast the performance of the SSK monitoring unit against the present state-of-the-art.

- Water contamination: Initial phase.
- Water and dust: Dust is slowly added to the fluid.
- Additional dust contamination: Dust level is gradually increased.



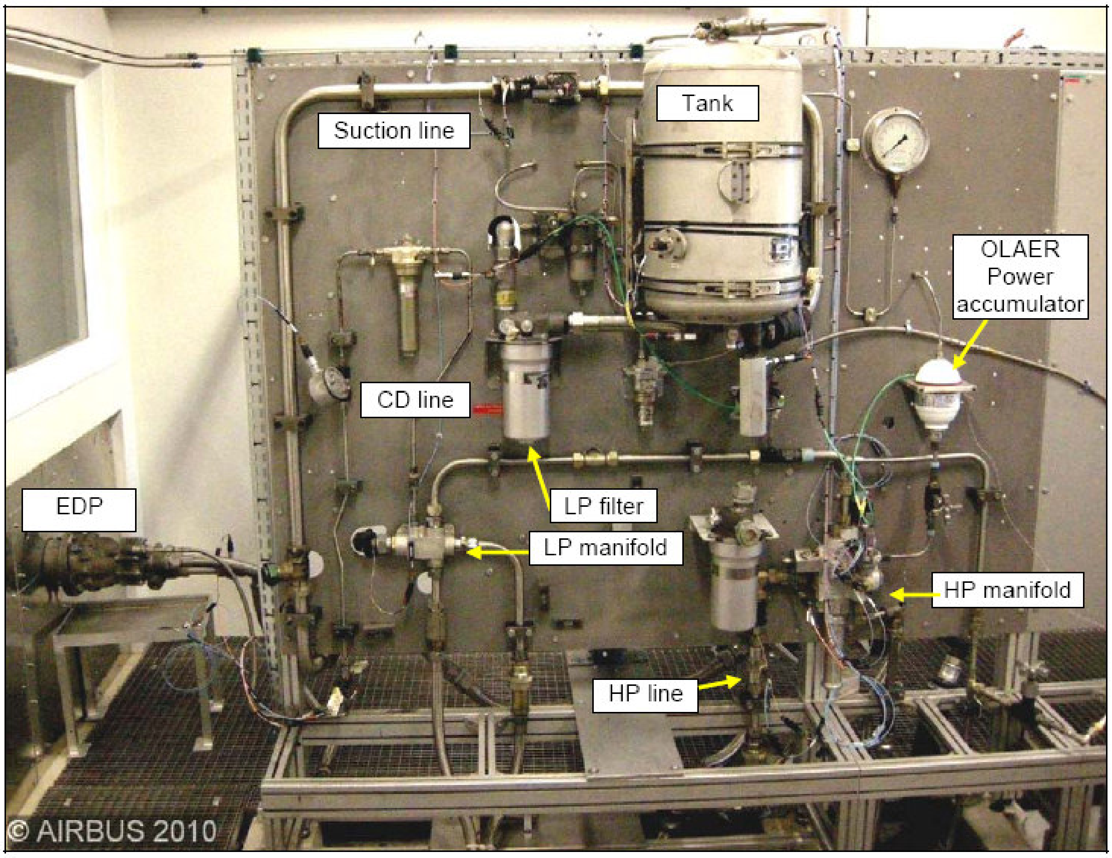
WP6 - Figure 7 - Functional test in Esther test bench

Summary of functional test results

Objective	Status	Observations
Water content EADS IW-D	Success	The water sensor covered the required detection range 0-1.5% Water sensor results from the Esther test bench matched laboratory results.
Water content UCM	Success	The water sensor covered the required detection range 0-1.5% Water sensor results from the Esther test bench matched laboratory results.
Oxygen UCM	Success	The measured results are coherent with the operational procedures at Airbus test bench. *No comparative measurements were possible in-situ due to current lack of alternative sensors.* This is explained by the fact that the oxygen content can only be monitored in-situ as it would change during transport of samples due to contact with ambient oxygen.
Acidity sensor	Partial	Lab results were demonstrated with the same fiber optical chemical sensors as the

UCM	success	ones used in the prototypes, nevertheless, once the electronics was miniaturized and integrated in the final prototypes, a significant loss of the signal sensitivity was observed. To make sure that the issue was limited to the optoelectronics, small changes were made to it (e.g. changing the led for a better one) which improved the acidity measurements by amplifying drastically the signal (4x). This serves to show that, although the prototype in itself failed to cover the required range (0-2 A.I.), a new set of prototypes with improved optoelectronic components would work. Therefore, the proof of concept still stands and is defendable with tangible data.
Acidity sensor EADS IW-D	Partial success	The main problem is that the sensitivity was limited and would saturate below the threshold. It saturated at A.I. =1 while it should be able to reach A.I. = 2. On the other hand, this sensor responded very well to the functional tests. Since these tests were made in realistic working conditions, the acidity sensors indicated very low acidity of the tested fluid which was coherent with the laboratory results. Further laboratory experiments revealed the extension of the detection range by reducing the optical absorption path.
Particle Count EADS IW-D	Partial success	Can detect particles from 4-70µm. Concentration was measure using the test bench defined flow of (~0.6 l/min). Why a partial success then? • Although the particle count worked perfectly in a controlled laboratory, it was not possible to replicate conclusively in the realistic ESTHER test bench. It was concluded that particle sedimentation and mobilisation, which are concurrent with actuator activity, compromised the flow of particle in front of the sensor window. The particles would need to be "shaken-off" in order to be properly visible to the sensor. • Lack of precision due to imprecise flow measurement: Initially it was believed that the flow could be measure precisely with the same sensor. This proved to be wrong. The solution to this problem would have been, and still is simple for future attempts, by integrating an external flow sensor we can assure a precise measurement of the flow and therefore a precise measurement of the concentration.
Electrical Conductivity IoA	Success	Very satisfying measurement results: • Good Tº compensation • Water addition influence consistent with previous tests • Small offset error (below 7% FS) between CCS sensor results and samples laboratory analysis. The conductivity sensor covered the required detection range 0.1-1.5µS/cm and results from the Esther test bench matched laboratory results.
Electrical Capacitance IoA	Inconclusive	Does not provide useful data as capacitance measurements vary greatly for a wide range of variables. Capacitance measuring method should be analyzed and improved (significant capacitance fluctuations). Although the hydraulic fluid capacitance is almost linearly dependant on the water content the capacitance sensor does not provide useful data as capacitance measurements also vary greatly for different types of hydraulic fluid and their mixtures. There are multiple brand and mixtures of hydraulic fluids on the market, which are often blended arbitrarily. It is impossible to know the exact composition unless an exhaustive

		analysis is made. Nevertheless, it is believe that valuable insight has been gain regarding monitoring electrical properties of the hydraulic fluid, and this observation should be kept in mind for future studies.
Reconditioning System	Inconclusive	Although it is deemed non viable for onboard use at this point, GEPS presented new studies with promising results regarding innovative ideas: - Membrane filtration and evaporation. - Vacuum made by a Venturi apparatus.



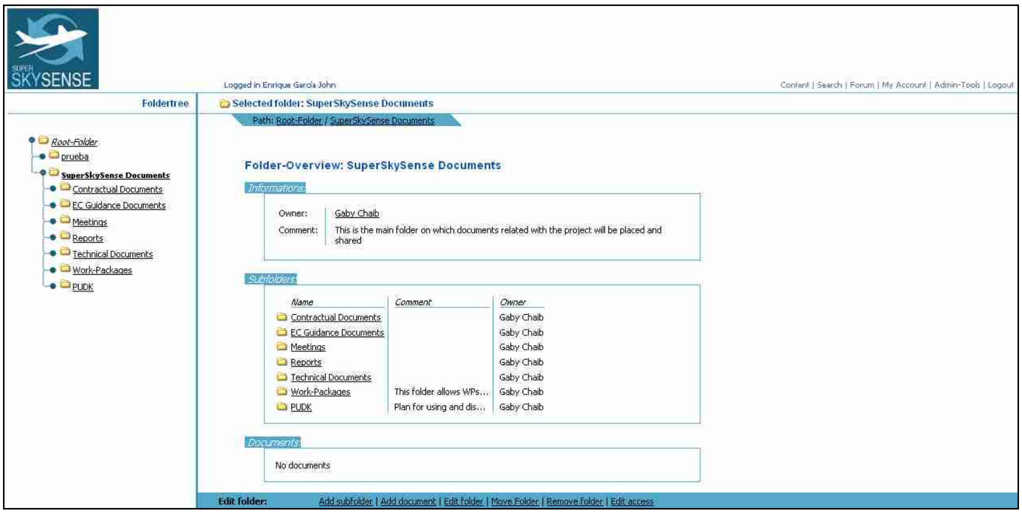
WP6 - Figure 8 - Airbus Esther test bench

5 . PROJECT WEB SITE – WWW.SUPERSKYSENSE.EU

A public web site was created for the project SUPERSKYSENSE. It has a public area with a basic structure, which introduces the project, its objectives and the consortium. It also has a private area for the consortium. It serves as working area and document repository for the project partners, each of which has an individual user name and password.

Web Figure 1 - SuperSkySense public web site

Both the public and private areas have been growing throughout the project. An operational document management system is provided within the web, including an internal messaging system and threaded mail functionality.



Web Figure 2 - SuperSkySense private web area

FUTURE STEPS - DISSEMINATION AND EXPLOITATION OF RESULTS

AIRBUS - COMMENTS BY DR. VOLVER BAUMBACH

Many airlines are looking to monitor the state of the phosphate ester hydraulic fluid in a more practical way. Today, aircraft maintenance procedures require frequent fluid sampling to insure fluid performance is within tolerance; it is recommended that a sampling of all available hydraulic systems be made on average every second C-check, according to the AMM. Once the aircraft is placed in the maintenance shop the fluid sample is taken and sent to a laboratory for analysis. Usually it takes from three to seven days to receive the results. By the time the operator receives the sample results and realizes that one, or more, of the parameters is out of permisible limits the aircraft is usually already back in service. Such a situation imposes corrective actions to be taken to replace fully or partially the contaminated hydraulic fluid. This can imply aircraft down time, a situation which bares significant expenses.

With respect to the SSK objectives, the development of an on-board hydraulic fluid monitoring system was suggested. An optimum solution would be to place all necessary parameter requested in the AMM on such a monitor. In other words, the following parameter set would be necessary to replace a full laboratory test:

- **Particle contamination**
- **Conductivity**
- **Density**
- **Viscosity**
- **Chlorine**
- **Moisture**
- **Acidity**

From in-service experience, with respect to the airbus portfolio, it is evident that **particle contamination**, **water content** and **acidity** are the most critical parameters.

Although a major step towards fluid monitoring has been achieved within the frame of the SSK project, not all the parameters have been covered to fully replace the coventional method. Furthermore, the particle counting is still not sufficiently mature to pass all the qualification tests to get a hydraulic component ready for on-board applications. This is basically due to its very complex nature of the physics beyond the measurement method. Bearing this in mind, two sensors remain for reliable monitoring of critical hydraulic fluid parameters, which are acidity and moisture. These two parameters basically account for, together with elevated temperatures, the residual life time of the fluid. In new aircraft hydraulic architectures, fluid temperatures are monitored much more precisely than on previous airplanes, therefore these sensor technologies could clearly become beneficial to support fluid health assessment procedures. A potential solution is described in the referenced literetature at the end of this section [1].

Ground service laboratory unit:
An alternative approach also presents great interest to the airlines. This intermediate step would be a ground service laboratory unit which would allow the measurement of relevant parameter as a replacement to the conventional sample laboratory analysis. The major advantage here is that such equipment would not be exposed to the same stringent qualification tests and certification requirements of on-board equipment. Given that hydraulic fluid sampling is not needed by continuous means this approach remains adequate while adding significant values to the operators. Valuable time can be saved and if a corrective action can be taken while the aircraft is on the ground instead of waiting for the laboratory results, significant expenses can be saved too.

Coordinator note regarding ground service laboratory unit comercial exploitation:
This comercial exploitation of the SuperSkySense project is presently being investigated wih some private partners already implicated in ground hydraulic auxiliary instrumentaion under non disclosure agreements.

References

[1] R. M. Behr, V. Baumbach, Model Based Aerospace Hydraulic Fluid Lifetime Prognostics, R3ASC Conference, Toulouse, (2010).

SUPERSKYSENSE

Smart Maintenance of Aviation Hydraulic Fluid Using an On-board Monitoring and Reconditioning System

Project Coordinador:
Gaby Chaib
Interlab IEC

www.superskysense.eu