Discipline or report series[#10] Technology/CASE	**Date**[#40] 15 November 2015
Document number JTT116/0034	**Issue** 01
Title[#15] **Summary and Completion Report for the Clean Sky CASE Project**	

Summary[#60]

This report summarises the work undertaken on the CASE programme.

This document has been written in accordance with:
AP-EP-1 Control of Documents.

Approval signature(s) Greg Wells

Author[#20] Claire Stevens Technology Manager	**Approved by** Greg Wells	**Approver Signature**
Author[#20]		

Additional keywords[#90]	**Retention category** A

Circulation

Greg.Wells@aeroenginecontrols.com;

Contents

Change History

Issue	Author	Date	Comment
1	Claire Stevens	16 November 2015	First issue

Definitions

Term/Acronym	Definition
AEC	Aero Engine Controls
WP	Work Package
ORFS	Oxford RF
M-E	Micro Epsilon
Bath	Bath University
FMU	Fuel Metering Unit
Morgan	Morgan Technical Ceramics
Newcastle	Newcastle University
LVDTs	Linear Variable Differential Transformers

Referenced Documents

Reference	Title
JTT116/0003	Test plan for evaluating a Piezo Acoustic Sensor dated 10 May 2011
JTT116/0004	Clean Sky CASE Initial Technology Review
JTT116/0005	Piezo Acoustic Test results dated 6 June 2013
JTT116/0008	AEC release of Clean Sky CASE deliverable D4.2.1 dated 28 June 2012
TT116/0009	Clean Sky CASE Interim / Final Technologies Review
JTT116/0021	Contaminated Fuel test Procedure dated 20 September 2013
JT116	Justified Concept Recommendations (ORFS)
TR13001	Technical Report – Mass Flow dated 19th April 2013
TR0094	Morgan Proof of Concept design and test report dated 9 Februay 2011
MB04	Recommended Concept document dated 11 July 2012
MB06	Test report dated 8 October 2012
MB011	Test report dated 26 September 2013
T128905	Eddy Current Sensor Preliminary Specification Definition dated 23rd June 2011.
ZG05213	Coil Geometry Definition dated 30 August 2011
TG06104	FMEA risk management report DATED 11 December 2011
L199835	Packing slip Eddy Current Sensor dated 4 July 2013
L151092	Packing slip Eddy Current Sensor dated 30 July 2013

1 Introduction

In order to meet the challenges of the SAGE3 engine configurations in terms of robustness, environmental capability, size, functionality, performance, and reliability, all at reasonable cost, new technology sensors and effectors will be required.

Aero Engine Controls (AEC) has identified several new technologies that offer the potential to provide the necessary benefits to next generation fuel systems sensors and effectors, and also plans to broaden its activities searching for new technology opportunities. This programme is planned to develop these technologies (with specialist partners where they have the required technologies and skills) and evaluate the sensor and effector systems by bench and systems rigs demonstrators.

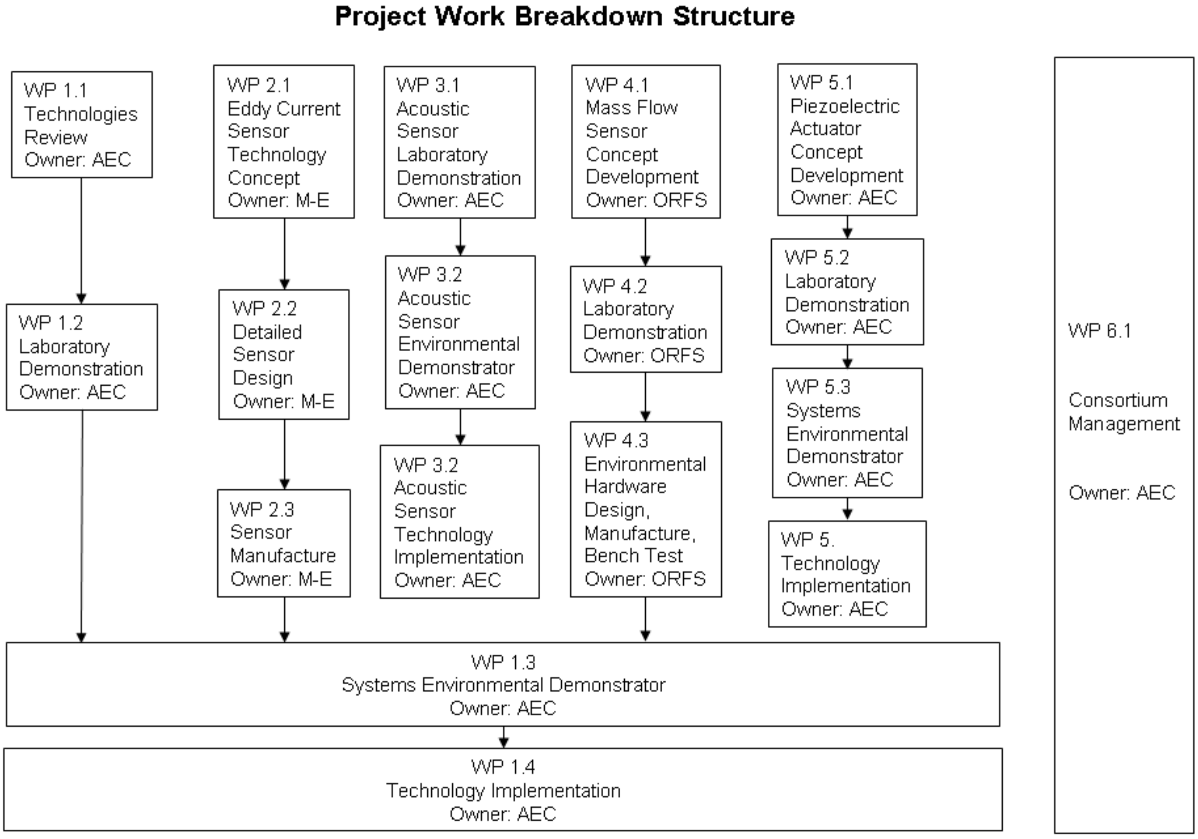
It should be appreciated that for sensor systems in particular, but also for effectors, the overall performance of the system is largely dependent on the performance of the electronics required to condition the sensor signals. AEC is a world leader in the supply of engine mounted electronics and is well positioned to work with specialist sensor suppliers to assess and evaluate electronic and overall systems performance levels that can realistically be achieved on engine. In addition to this, AEC can also realistically assess the weight, installation, reliability, and cost implications of the electronics and harnessing for all systems, in addition to the raw sensor attributes and limitations.

Several of the new technologies identified so far by AEC are considered to be in competition with each other, and are to be developed independently, or with different supplier partners. Although the competing supplier partners are aware of each other, no partners will have access to confidential data from the other suppliers. To this end the proposal below is split in each section along the lines of the different technologies to be developed and evaluated, with partners only having visibility of their own technologies

The work package descriptions of “JTI-CS-2010-4-SAGE-03-004” and the work carried out in response to the Description of Work is summarised in this report. The work was apportioned between AEC and the other partners in the CASE consortium as follows;

AEC	-	Management
		Acoustic Sensor WP3
		Piezoelectric Actuator WP5
Micro Epsilon	-	Eddy Current Sensor WP2
Oxford RF	-	Mass Flow Sensor WP4

2 Work Package Descriptions and Work Undertaken



2.1 Work Package 1 – Technologies Review

2.1.1 Initial Technologies Review

The Initial Technologies Review confirmed the initial selection of piezo acoustic displacement transducer, eddy current position transducer, piezo acoustic mass flow meter, and piezo pump effector as devices to demonstrate in CASE.

Document TT116-0004 refers.

2.1.2 Interim and Final Technologies Review

The Interim and Final Technologies review confirmed the initial selection of piezo acoustic displacement transducer, eddy current position transducer, and the piezo acoustic mass flow meter for demonstration in the CASE project. A thorough assessment of alternative implementations of piezo technology for effectors resulted in down selection of a piezo electric ring bender servovalve replacement. This device is considered to have the potential to be developed to provide a low cost, low weight, high reliability replacement to current generation servovalves used for FMU control.

Document TT116-0009 refers.

2.2 Work Package 2 – Laboratory Demonstration

2.2.1 Piezoelectric Actuator – AEC

Laboratory demonstration tests were completed at Bath.
Report MB06 dated 6 October 2012 refers.

2.2.2 Acoustic Sensor – AEC

Laboratory demonstration tests were completed at Morgan. Report TR0094 dated 9 February 2011 refers.

2.3 Work Package 3 - Systems Environmental Demonstrator

AEC tested individual component technologies such as piezo, mass flow sensor. The intent was to complete the environmental test as a block test but it was decided that this was not be worthwhile above the components test.

2.4 Work Package 4 - Technology implementation

The technologies are being considered for possible applications on the next engine platforms and / or further technology development programmes, for example, piezo devices are being considered for a servo valve replacement as part of a UK specific funded activity.

2.5 Work Package 5 - Eddy Current Sensor Definition

The Eddy Current sensor was proposed as a replacement for LVDTs used in current FMUs. Eddy current sensors can offer significant size, weight, measurement accuracy, speed and reliability benefits compared to current LVDT technology.

The preliminary specification definition concept for the Eddy Current Sensor is documented within document T128905 dated 23rd June 2011.

2.1 Work Package 6 - Eddy Current Sensor Definition System Detailed Design

The Eddy current sensor coil geometry was completed in August 2011 (document ZG05213 dated 30th August 2011 refers) and the FMEA risk management report was created on 11th December 2011, document TG06104 refers.

2.2 Work Package 7 - Eddy Current Sensor Manufacture

ME delivered 2 off sensors to AEC in July 2013 for testing Packing slips L149835 and L151092 refer.

2.3 Work Package 8 - Acoustic Sensor; Laboratory Scale Definition System Demonstration

AEC worked with both Morgan and Newcastle to carry out proof of concept testing both in the laboratory and on an AEC test rig. The first generation sensor design consisted of two separate active elements in two separate housings, one of which had to be fitted at each end of a valve in order to measure the valve position.

Manufacture and population of the units was subcontracted to Morgan and delivered to AEC for testing. A test plan, reference JT116-0003 detailing how the sensor would be tested using the BR725 FMU and was issued on 10 May 2011.

The testing on the AEC test rig utilised the first generation sensor design and was limited to a range of temperatures around room temperature. The testing of the first generation sensor design identified issues with the method of mechanical attachment of the active sensor element, the piezo-ceramic, with the sensor housing and highlighted the critical nature of the method of mechanical attachment to the overall performance of the sensor.

Production of the test report was delayed due to resource issues and were reported in document JT116-0005 dated 5th October 2012.

2.1 Work Package 9 - Acoustic Sensor; Systems Environmental Demonstrators

The need for a second generation of sensor design was driven by AEC with the need to optimise the sensor packaging to make the sensor more compact and able to be fitted in a variety of different engine control applications. The second generation sensor combined the two previous active elements into a single housing that was only required to be fitted at one end of a fuel control valve in order to measure the valve position. Attempts to optimise the materials used to attach the piezo-ceramic material to the housing for use in an aero-engine environment over the complete range of conditions were not successful and it became clear that a new generation of sensor and further work would be required in order to provide a suitable sensor. However, AEC decided to carry on with a limited test programme using the second generation sensor design. Test procedure JT116-0021 “Contaminated Fuel Test” dated 20 September 2013 refers.

Unfortunately, due to the technical problems and delays in getting the test equipment and the test rig commissioned, the test programme was cancelled and the project was put on hold.

2.2 Work Package 10 - Acoustic Sensor; Implementation

See comments in 2.4

2.3 Work Package 11 – Mass Flow Sensor; Concept Development

Oxford RF Sensors were selected to develop a fuel mass flow measurement system using high frequency ultrasonic techniques as part of the CASE Project. The target was to take the first steps toward developing a device capable of deriving the mass flow rate of fuel from a measurement of two parameters:

i. The effective per unit mass velocity of fuel (and thus the volumetric flow rate through a pipe of known cross section).
ii. The density of the fuel.

The proposal was that the two measurement tasks would first be addressed individually, with a view to subsequent integration into a single piece of hardware and accompanying electronics, and that the project would be carried out in 3 stages:

1. Concept development - extrapolating from other uses of ultrasonic acoustic techniques to establishing the optimum size, frequencies and overall sensor dimensions.
2. Laboratory demonstration - building proof-of-concept demonstrators for evaluation over limited environmental conditions.
3. Delivery of demonstrator unit to AEC for full systems environmental rig testing.

The concept work was completed and presented to AEC. The Report "Justified concept Recommendations" outlines the concepts proposed by ORFS.

2.4 Work Package 12 – Mass Flow Sensor; Laboratory Demonstration

ORFS presented a subsequent laboratory demonstration to AEC on 29th March 2012. Albeit at a low TRL level, the sensor systems presented by ORFS was considered to have the potential to be developed to aerospace engine fuel mass flow sensors. The report, reference JTT116/0008 dated 28th June 2012 refers.

2.5 Work Package 13 – Mass Flow Sensor; Systems Environmental Demonstrator

A low pressure proof-of-concept sensor capable of measuring volumetric flow rate (i) was demonstrated, operating with water as a test fluid. A density measurement module was also shown to be operating with some success at fixed temperature. However, it was agreed that this latter component of the mass flow measurement technology required substantial further development before it was appropriate to progress it to stage (3).

It was suggested that the volumetric flow rate sensor might be re-engineered for compatibility with the AEC test rig and that this might be tested in July 2013 in conjunction with a commercially available (but impractically large for real aerospace applications) density sensor. However, it was judged that a more appropriate route would be to conclude the project at the end of phase 2 and close the project.

ORFS submitted a draft closure report to AEC reference: TR13001 dated 19 April 2013.

2.6 Work Package 14 – Preliminary Actuator Concept Development

As described in the proposal a significant part of this activity is sub-contract to the University of Bath with whom AEC has a longstanding working relationship. An initial delay in the start of the project was due to the problems associated with appointment of a full time researcher.

The process started with a literature review which formed the first stage of the project and resulted in the issue of the Concepts overview document. This report looked at possible configurations of piezoceramic actuators and different valve types. There was then a down selection process which was defined as stage 2 and culminated in the production of the detailed concept report.

After discarding obvious non-starters, the detailed concept report described 5 concepts in more detail including an approximate sizing for each.

During the selection phase Bath and AEC jointly identified and assessed critical parameters (see appendix for scoring spread sheet and five concepts) for each of the five concepts.

The selection criteria with the largest weighting were:

- Failure mode
- Size
- Reliability

- Manufacturability/Complexity
  There were some concerns and associated problems with all piezo concepts such as Encapsulation or protection from degradation of the piezoceramic by water. However, it was decided that these issues were not insurmountable and so could be addressed at a later stage in the project.

Report "Piezo Concepts for Fuel Metering, Recommended Concept document" reference; MB04 dated 7 July 2012 refers.

2.7 Work Package 15 – Laboratory Scale System Demonstration

Noliac's ring bender (model number CMBR07) was selected for testing. During the selection phase of this project, this concept attained a higher score compared other piezoceramic structures.

Laboratory demonstrator tests were completed and report MB06 dated 10 August 2012 refers.

Further work was required to investigate alternative clamping design options of the piezoelectric ring bender. This work was carried out during 2013 and report MB011 dated September 2013 refers.

2.8 Work Package 16 – Systems Environmental Demonstrators

During 2014 the prototype still had several issues that needed fixing and the temperature testing was planned but not completed by June 2014. To date this project is still ongoing and as such environmental testing was not completed under the Clean Sky CASE project.

2.9 Work Package 17 – Technology Implementation

The technologies are being considered for possible applications on the next engine platforms and / or further technology development programmes, for example, piezo devices are being considered for a servo valve replacement as part of a UK specific funded activity.

2.10 Work Package 18 – Consortium Management

The major activities of Consortium Management have been the successful synchronisation of the activities of the partners (ME and ORFS) and the predominant sub-contractors the Universities of Bath and Leeds, and Morgan Technical Ceramics based in Southampton.

The consortium is working as planned, and no changes to the consortium have been considered necessary.

Regular scheduled project meetings/communications structure:

a) Weekly telephone conversations and emails with partners and Morgan Technical Ceramics.
b) Reviews with the Clean Sky Assessor, David I. Jones, have been held regularly, usually face to face at the AEC site in Birmingham but occasionally via telecom. At these meetings the status of each work package and the deliverables have been discussed.
c) Monthly Programme Reviews have been held in Birmingham where the progress against plan and investment status are reviewed with the Research and Technology Director.

There is no project website.

The initial interface Schedule referenced document JT116/007 dated 22 May 2012 refers.

2.10.1.1 Appendix

Morgan Documents

TR0094 ISSUE 1.pdf

Bath University Documents

MB04 Recommended Concept
MB06 test report
MB011 Test report

ORFS Documents

TR13001
Justified Concept Recommendations

ME Documents

ZG05213
T128905
TG06104
packing slip L149835
packing slip L151092

AEC documents

JTT116-0003 (Issue 1).doc
JTT116-004 Deliverable Initial Technologies Review.doc
JTT116-0005 (Issue 1).doc
JTT116-0008
JTT116-009 Deliverable Interim & Final technologies Review.doc
JTT116-0021 Contaminated Fuel Test Procedure
JTT116/0007