DEVELOPMENT OF THE DEMON TECHNOLOGY DEMONSTRATOR UAV

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Keywords: *UAV, Demonstrator, Flight, Advanced Technologies*

Abstract

This paper will describe the design and development of the DEMON flying Demonstrator UAV.

The vehicle will be used to DEMONstrate a number of technologies of the FLAVIIR Integrated Programme. These include fluidic thrust vectoring developed by Manchester University, circulation control devices from Manchester and Cranfield Universities and advanced flight control algorithms from Leicester University and Imperial College.

Cranfield University designed and built the DEMON aircraft with contributions from BAE SYSTEMS and other partners.

The paper will summarise the design and construction processes, and describe the component, system and pre-flight tests. It will then summarise the first flight test campaign and outline the second flight test programme plans.

This programme has yielded considerable knowledge about the development and integration of novel technologies into a challenging, representative aircraft. It has also DEMONstrated the collaborative efforts of a number of research teams from several partner Universities and BAE SYSTEMS.

Notation

AMT	AMT Company, producer of the Olympus and Titan engines
APU	Auxiliary power unit
CAA	Civil Aviation Authority
CC	Circulation control
CCD	Circulation control device
CFC	Carbon fibre composite
CG	Aircraft centre of gravity
CNC	Computer numerically controlled
ECU	Engine control unit
EPSRC	Engineering and Physical Sciences Research Council

1 Introduction

1.1 Aims

Fielding and Smith (Ref. 1) gave a brief description to the multi-University research project that was funded by BAE SYSTEMS and the British Research Council, EPSRC.

The overall aim was to investigate (to moderate TRL levels) technologies that could bring improvements to the performance and costs of UAVs.

It was realised that these technologies could have individual merit, but that integrated together could have synergistic benefits. It was also realised that while such technologies might appear to be attractive during theoretical, computational, or bench-test phases, they may be unworkable in realistic operating environments. It was, therefore, decided that the FLAVIIR programme needed significant integration and demonstration activities led by Cranfield University. A number of demonstrations were performed, which cumulated in flight tests of a representative UAV Demonstrator vehicle, which incorporated as many FLAVIIR technologies as possible.

To support these aims, the demonstration requirements (ref. 2) included the needs to:

(a) demonstrate technologies in a realistic airborne environment;
(b) integrate the technologies into a working flying vehicle;
(c) demonstrate technology readiness levels higher than normal University programmes, preferably up to 4 or 5;
(d) to provide means for industrial exploitation;
(e) provide research about the integration process.

1.2 Vehicle Requirements (Ref. 2)

1.2.1 Flight Performance

The vehicle will demonstrate a full flight cycle from take-off to landing without the use of conventional flight control surfaces.

The aircraft will operate from airfields with manoeuvres that will ensure that the aircraft altitude will not exceed 400ft and distance from the pilot of more than 500m.

Initial manoeuvres will demonstrate the capability of performing racetrack or figure of eight manoeuvres. Subsequent flights will demonstrate completely autonomous flight.

1.2.2 Airworthiness Requirements

The aircraft will be safe to operate and will be demonstrated to comply with reference [3] 'over 20kg' category. Where appropriate, the vehicle will be designed to EASA-VLA requirements.

1.2.3 Costs and Timescales

The vehicle will be designed, manufactured and flown within the original budget of the FLAVIIR Programme, and performs flight tests in the fifth year of the programme.

2 Eclipse and DEMON, Conceptual and Preliminary Design

2.1 Concept Choice

The above requirements meant that the design team decided to use as much as possible of the effort and results of previous Cranfield UAV designs.

Ref. [4] describes the aircraft that were considered, and the early development process for the ECLIPSE vehicle (Fig.1).

Fig. 1 The Eclipse Vehicle Performing Taxi Trials

It was decided to use as much as possible of the ECLIPSE design and configuration and to integrate FLAVIIR technologies, in particular, the fluidic thrust vectoring (FTV) system being developed by Manchester University and fluidic circulation control devices (CCD) being developed by Manchester and Cranfield Universities.

2.2 Modifications to the Eclipse configuration to produce the DEMON Design

The Eclipse uses four trailing-edge devices per wing and wind tunnel tests and analysis showed that adequate role control could be provided by replacing the inboard aileron with a CCD in each wing.

Fig. 2. shows that the ailerons were effective up to an aircraft incidence of 15°, but it was decided to limit incidences to below 12° for initial flight tests.

Fig. 3. shows the longitudinal characteristics to be good, as confirmed by wind tunnel tests at 10, 50 and 100% scales.

The aircraft was flown successfully at a static margin of 3-4%.

The DEMON FTV system required a two-dimensional nozzle and so the rear fuselage was re-shaped to accommodate this. It was realised that a secondary air supply would be needed to provide relatively high pressure air for the

CCDs and a number of options were investigated. It was decided to use an additional small gas turbine to drive a compressor to provide air at the correct flow rates and pressures for the wing-mounted CC devices. This small turbine is referred to as an auxiliary power united (APU).

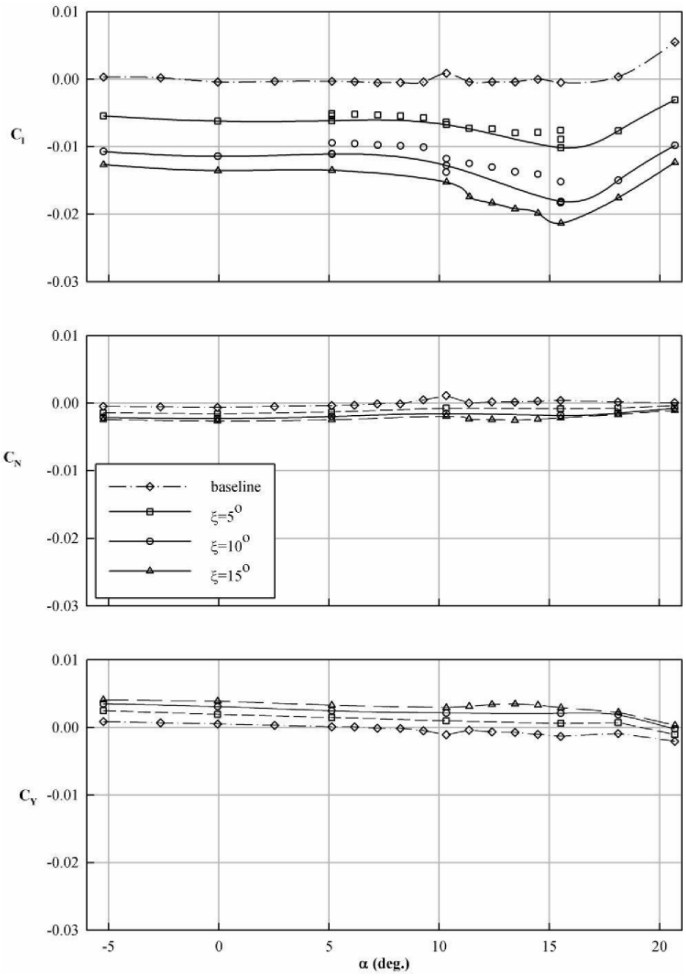


Fig. 2 Inboard Aileron Control Characteristics of the 50% Scale Full-Span Model

As the DEMON design progressed, it was realised that an increase in size would be beneficial, relative to Eclipse. The advanced technology systems required considerable space in the DEMON airframe, so it was decided to implement a 15 per cent linear increase in size of the airframe, keeping the Eclipse configuration to retain the proven aerodynamic data. This gave a significant increase in internal volume and thus gave payload flexibility.

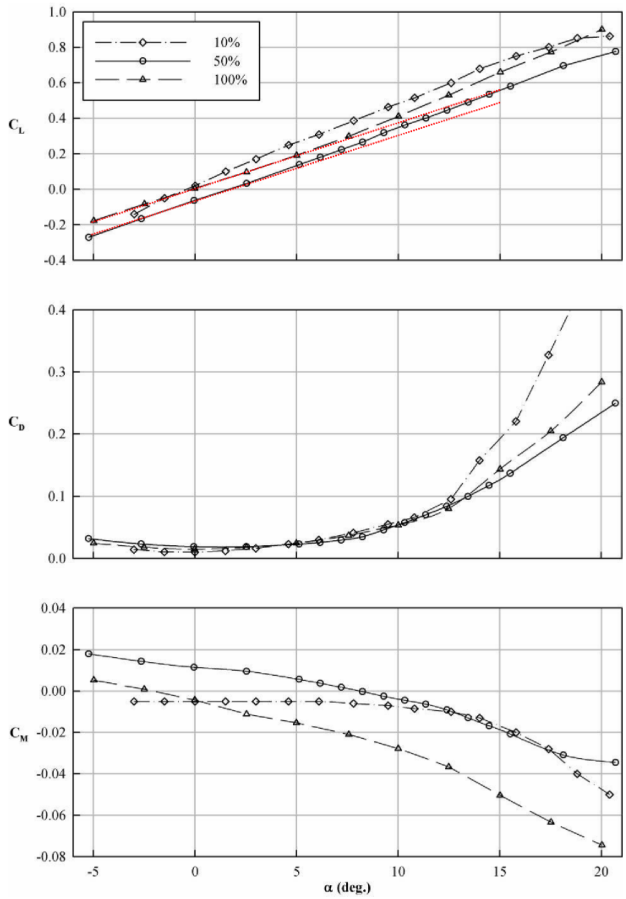


Fig. 3 Static Longitudinal Aerodynamic Characteristics of the FLAVIIR Demonstration Vehicle (DEMON)

2.3 Parallel development work on the Eclipse Vehicle

The Eclipse was an existing aircraft, which was used for risk-mitigation exercises to inform the preliminary and detail design of the new, larger DEMON vehicle.

Several modifications were made to the original Eclipse aircraft as described in Ref. 5 and summarised below:-

The major modification to the Eclipse was the replacement of the previous flight control system by a Weatronic/FUTABA radio-controlled flight control system and an Eagle Tree telemetry system.

Some wiring and fuel line were replaced. Nose and main landing gear units were modified. Ballast was installed in the aircraft's nose to allow variations in aircraft stability to be explored.

It was originally intended to perform flight tests of the aircraft, but this was not possible, due to cost and timescale issues.

However, the aircraft was successfully modified and performed low-speed and mid-speed taxi trials, which provided much useful information and experience. This included shake-down trials of all systems, to prove their integration. It highlighted minor deficiencies of the fuel system which were remedied in the DEMON aircraft. The braking and landing gear systems were inadequate, and this experience led to the significant improvements that were incorporated in the DEMON landing gear. This was also necessary because the larger DEMON was almost twice as heavy as the Eclipse.

3 Detail design and manufacture of the DEMON

3.1 Detail Design Process

As the vehicle design progressed to detail design, more information became available, and helped to progress the vehicle design.

The requirement for the demonstration of flapless flight was found to be extremely challenging for approach and landing. The FTV system was shown to be adequate for take-off and cruise but had insufficient pitch authority at the lower throttle settings required for approach and landing.

It was decided to provide a source of secondary air flow in addition to the engine bleed source to be used for the FTV system. This may be also used to power additional, inboard, circulation-controlled pitch devices, as well as the outer CC devices. The secondary air supply is provided by a small APU, driving an air compressor, as mentioned above.

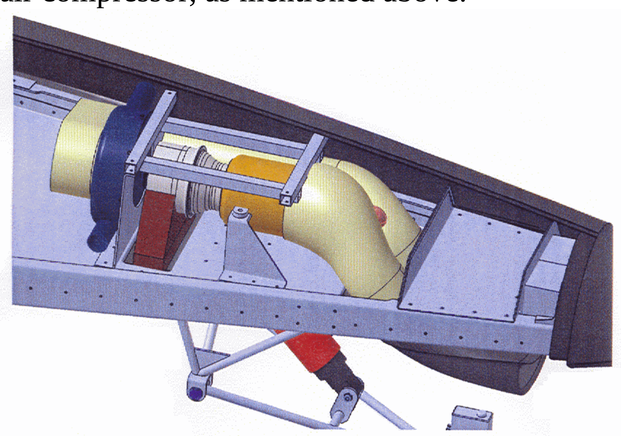


Fig. 4 APU/Compressor Installation

Fig. 4. shows a CAD image of the APU and compressor mounted in the aircraft's payload bay.

These improvements led to weight growth which was aggravated by the aft centre of gravity tendency of rear fuselage-mounted engine. It had been decided to provide the aircraft with a small static margin and, thus nose ballast was required, thus further aggravating weight growth.

This was mitigated by careful repositioning of heavier components forward of the Aircrafts C.G, the selection of a light FCS and attention to detail weight savings.

It was decided to replace the Olympus engine with the slightly larger Titan engine, with an uninstalled thrust of 390 N. This gives suitable thrust margins for the aircraft, but with a small increase in engine mass and fuel consumption.

The mass, centre of gravity, and performance stabilised and allowed the aircraft to fly the required experimental flights at all-up masses of 80 kg.

3.2 Vehicle Manufacture

Ref. 2 gives detail of the construction and assembly of the vehicle, but a brief description follows. The majority of the airframe was manufactured from carbon-fibre composite by Cranfield's School of Applied Sciences.

The most effective carbon fibre composite (CFC) reinforcement materials for light weight, thin, but highly curved structures are a combination of materials. Bi-axial woven fabric, which can easily drape to conform to complex double curvature surfaces without wrinkling, and unidirectional tape added to woven fabric in single curvature areas requiring maximum stiffness. For DEMON, the complete structure used biaxial fabric with strips of unidirectional tape laminated between fabric layers in all of the spar flanges.

For a single airframe, mould tool cost was a major part of the overall manufacturing cost, especially with very light structure. Low-cost tooling and assembly rigs were designed and used. Fig. 5. shows the partially-completed airframe.

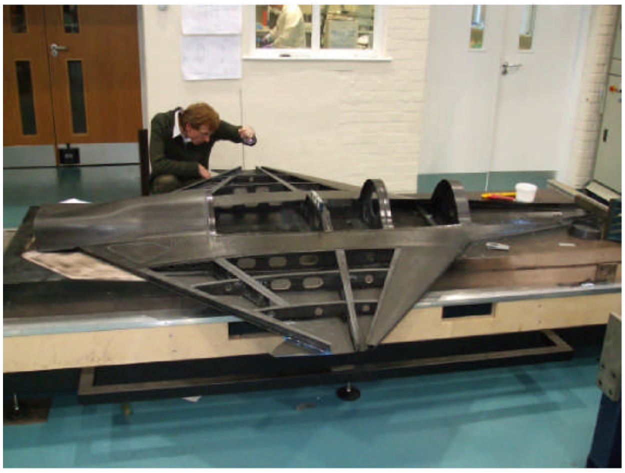


Fig. 5 Bonding of Composite Structures

The payload bay floor was constructed from aluminium alloy and provides locations for the nose landing gear APU, batteries, and ballast.

The aircraft secondary power is provided by batteries fitted in the nose of the aircraft, to minimise ballast requirements.

4 Aircraft Description

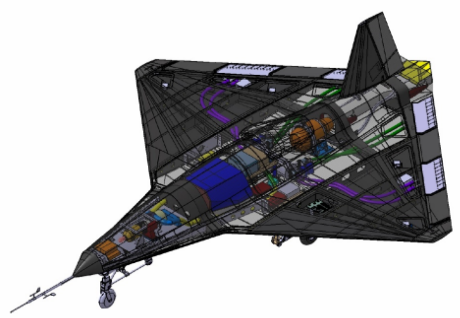


Fig. 6 DEMON UAV CAD Model

Fig. 6. shows a recent CAD model of the aircraft internal layout. Of particular note are the FTV and CC devices that are being developed by Manchester University. The APU and compressor system have been designed and constructed by WREN turbines and the flight control system by Bluebear Systems Research. Advanced flight control algorithms have been developed by Leicester University and Imperial College. The aircraft design, integration, alternative CC devices, and airframe manufacture were performed by Cranfield University.

Table 1 gives the aircraft's leading particulars in terms of dimensions, masses and performance.

DIMENSIONS	
OVERALL LENGTH	**2.88M**
HEIGHT	**0.92M**
WING SPAN	**2.53M**
ASPECT RATIO	**2.05**
GROSS WING AREA	**3.13**
MASSES	
NORMAL TAKE-OFF MASS	**80KG**
MAX. LANDING MASS	**80KG**
MAX. FUEL CAPACITY	**15L**
POWERPLANT	
MODEL	**AMT TITAN**
SEA LEVEL STATIC THRUST	**392N**
PERFORMANCE	
MAX. SPEED	**65m/sec.**
TAKE OFF DISTANCE	**450M**
LANDING DISTANCE	**440M**
STRUCTURAL LIMITATIONS	$\begin{cases}+4.2g \\ -1.5g\end{cases}$

Table 1 DEMON Aircraft Leading Particulars

The airframe structure has been described in paragraph 3 above and the main system items are shown in Fig. 7. Fig. 8. (2 images) shows the assembly and system integration in the payload and avionics bay.

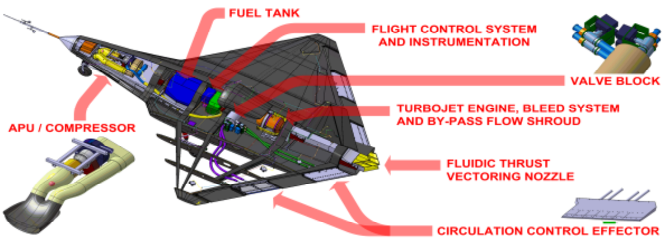
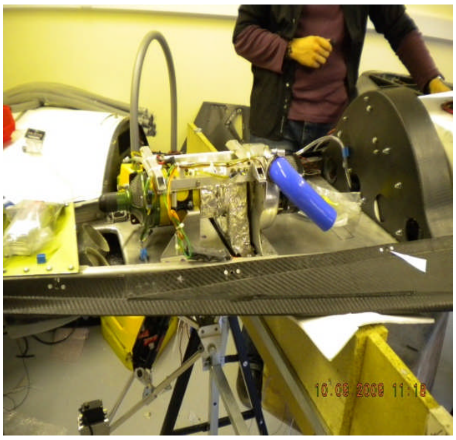


Figure 7 Main System Items



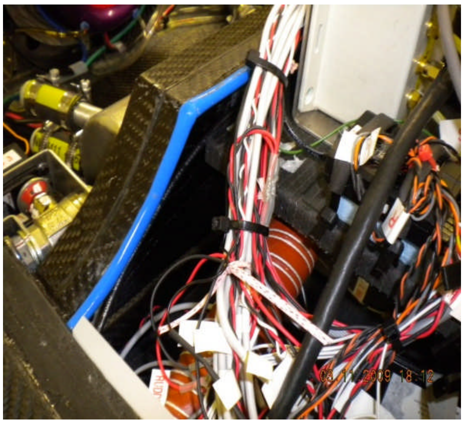


Figure 8 Final Assembly and Systems Integration Spring/Summer 2009

5 Ground and Flight Testing

Extensive component and system test rigs were built and used. Trials of the propulsion rig showed promising results, as did those for the APU/Compressor rig. The landing-gears were examined using the drop-test rig.

A pneumatic system rig was developed and successfully used to examine the installed performance of the APU/Compressor and the Manchester and Cranfield CCDs.

Fig. 9 DEMON Ground Testing Installed Thrust - September

Fig. 9. shows the installed powerplant tests, where thrust was measured using a load cell.

Finite-element models were used to predict wing deflections due to half-limit loads, which were verified by structural tests.

Numerous low and medium-speed taxi trials were held at Cranfield airport, where all the systems were demonstrated.

A Cranfield University flight test crew supported by BAE SYSTEMS transported the aircraft to the West Freugh test range in Scotland. This followed extensive discussions and document submissions to the CAA who supplied an exemption to allow test flights for the aircraft. This covered many issues, the main one being the determination of a safety boundary and robust cut-down system.

The team performed many low, medium and high speed taxi trails, but were hampered by appalling wind and rain conditions (Fig. 10.).

Fig. 10 DEMON at Flight Test sight

Their persistence was rewarded by an extremely successful first flight just before dusk (Fig. 11.) the 30th November 2009. The test pilot commented:

"I would hope that DEMON will fly again as she has so much to offer, being a very stable and well balanced platform with bags of performance".

Fig. 11 DEMON's First Flight

The aircraft was fitted with the Manchester University CCDs and advanced flight control systems.

The poor weather and range time limits prevented flights to demonstrate the advanced technologies, but a second flight test campaign is planned for the summer of 2010.

6 Conclusions

1. The Eclipse UAV taxi trails were valuable activities, which evaluated sub-systems that were used in the DEMON vehicle, as well as showing necessary improvements for the new aircraft.
2. The DEMON vehicle is complete and has led to a vehicle with mass and performance capable of meeting, or exceeding requirements.
3. Many sub-system rigs and test facilities were designed and successful testing was performed. The engine and APU/compressor have been acquired and successfully tested.
4. The airframe manufacture is complete and met mass and CG targets. Structural testing validated finite element predictions.
5. The FCS partnership has been demonstrated between 3 universities and the manufacturer.
6. Safety cases and operational procedures were produced which satisfied Airworthiness Authorities.
7. Excellent relationships were developed with BAE SYSTEMS and partner Universities.
8. A successful series of ground taxi and flight tests have been performed.
9. Demonstration of some FLAVIIR technologies will be performed in the second flight test campaign.
10. The DEMON is an aircraft that has considerable flexibility in it's configuration which will allow it to be used beyond the FLAVIIR programme.

7 Achnowledgements

The authors acknowledge the technical and financial support for the project from BAE SYSTEMS and the EPSRC (grant number GR/S71552/01). They would also like to acknowledge the significant contributions made by many people, including: BAE SYSTEMS, Cranfield University, CAA, FLAVIIR Partner-Universities and component suppliers.

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