DESIGN AND DEVELOPMENT OF THE ECLIPSE AND DEMON DEMONSTRATOR UAVS

A. Yarf-Abbasi, A. Clarke, C. P. Lawson & J. P. Fielding
Department of Aerospace Engineering, School of Engineering, Cranfield University, Bedfordshire, MK43 0AL

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Abstract

The paper will initially describe the main requirements of the 5-year FLAVIIR integrated programme for UAV technology research and development. This programme is sponsored by BAE SYSTEMS and the UK EPSRC research council and started in June 2004, with contributions from 10 UK universities, led by Cranfield University.

FLAVIIR's aim is to develop technologies which will allow development of UAVs with low acquisition and operating cost characteristics. It is an important requirement that these technologies be integrated, and demonstrated at higher technology readiness levels than are usual in the University sector. One means of achieving this is to use a number of technology demonstrators, culminating in the sophisticated DEMON flying UAV demonstrator. A particularly challenging requirement is that the vehicle must demonstrate an entire flight cycle, without the use of conventional flying control surfaces.

The earlier ECLIPSE UAV will be described, as will its use in providing early test information, prior to the flights of the larger, but similarly shaped DEMON vehicle.

The paper will describe the technology integration process and the design and development of the DEMON vehicle.

Other technologies are to be flown in the DEMON, and lessons learnt from these, and other technologies will be proposed for full-size UAVs.

Nomenclature

UAV	=	unmanned air vehicle
UCAV	=	unmanned combat air vehicle
EPSRC	=	Engineering and Physical Sciences Research Council
CC	=	Circulation control
FTV	=	Fluidic thrust vectoring
CFC	=	Carbon Fibre Composite
ECU	=	Engine Control Unit
GPS	=	Global positioning System
MTOW	=	Maximum take off weight
APU	=	Auxiliary Power Unit

1 Introduction

Fielding and Smith (Ref. 1) give an introduction to the FLAVIIR Programme. The main objective of which is to develop technologies which would support the design of low cost (both to acquire and operate) flapless UAVs. Research includes fundamental aerodynamic research to provide control effectors without the use of conventional flaps, linked to developments in the areas of control systems, manufacturing engineering, structural design, electromagnetic behaviour of UAV structures, and design optimisation. The FLAVIIR programme includes significant demonstration of the new technologies, ranging from bench tests through model aircraft flights to sophisticated autonomous flying vehicles. These demonstrations provide data for the new technologies but also research into the integration process itself. A total of fourteen research groups at ten Universities have been involved in the five year programme, which has a total value of £6.5M ($13M). Two thirds of this funding comes from BAE Systems and one third from EPSRC. The 5-year programme started in June 2004.

This paper will concentrate on a description of the Cranfield University Eclipse and Demon demonstrator UAVs and gives an update on earlier work described in Yarf-Abbasi and Fielding (Ref. 2).

2 Eclipse and Demon Objectives

The demonstrator programme objectives include:-

- Provide demonstrators of higher technology readiness levels than from previous University projects, with values up to 5.
- To demonstrate interaction of several new technologies in a representative low-cost flying vehicle.
- To help integrate the activities of research groups at several Universities to produce synergies between them.
- To investigate in-flight effects of novel technologies
- To facilitate industrial exploitation of new technologies.

Flying demonstration inevitably involves risk, so it was decided to modify the previously-designed Cranfield Eclipse UAV to investigate critical design areas prior to the detailed design of the similarly-shaped but larger Demon aircraft.

3 The Eclipse UAV Development and Modification

To reduce the development, manufacturing and operating costs of the FLAVIIR programme flight demonstrator, it was decided to use an existing Unmanned Air Vehicle (UAV) planform to decrease the design effort. The studies led the way to use the Eclipse jet UAV as baseline platform for the development of the DEMON UAV demonstrator.

3.1 The Original Eclipse UAV Development

The original Eclipse UAV was designed and developed by the 3rd Intake of the BAE SYSTEMS/Cranfield Part-Time MSc in Aircraft Engineering and formed the group design project. The main features of the Eclipse vehicle are summarised as follows;

- The wing and fuselage were constructed from a single piece tip-to-tip structure consisting of a Styrofoam core skinned with carbon fibre. Two removable carbon-fibre panels form the closure for the top of the fuselage over the fuel tank bay and the engine bay, the latter incorporating the engine air intake into the panel. (Fig. 1)
- To accommodate the flight control system and mount the nose undercarriage, a removable tray and structural beam were made from carbon fibre and bolted to the fuselage two forward frames.
- A removable conical shell construction formed the nose fairing structure.

'Fig. 1. The original Eclipse UAV during manufacturing'

- All eight separate control surfaces along the trailing edge of the wing and tail fin structure were made from foam, skinned with carbon fibre.
- Both the nose and the main undercarriage legs were of the retractable conventional sliding oleo design. The spring and damping was achieved by using a standard telescopic damper unit. Both the main undercarriage legs contained a pneumatic braking system within the wheel rim.
- The Aircraft Systems were based around an XRAE avionics crate. It contains all the sensors required for sensing the aircraft's attitude, flight direction and location. The crate also includes a telemetry link to the ground station transmitting key flight parameters to allow system health monitoring and provide feedback to the operator. Furthermore the Control Surface Actuators are based on 'off the shelf' model aircraft equipment.
- A single AMT Olympus jet engine is used to power the vehicle. The engine produces maximum thrust of 190N at a fuel consumption of 400g/minute.

- The fuel system was designed using a reliable concept similar to a motorcycle fuel system. This design does, however, restrict the aircraft to positive 'g' maneuvers.

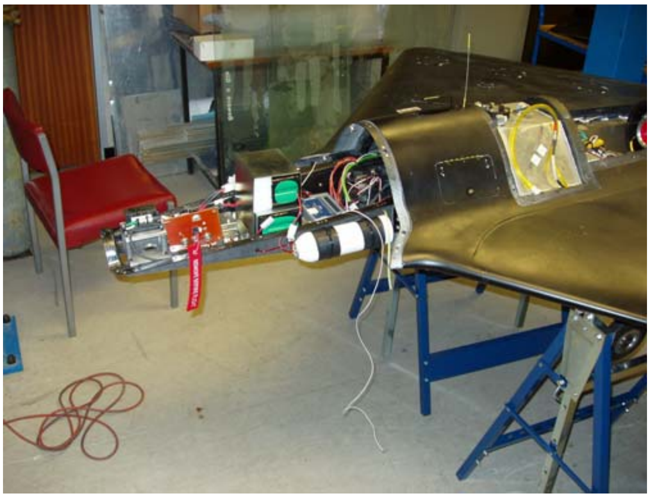
3.2 The Eclipse UAV Flight Preparation

To enable Eclipse UAV flights, it was necessary to prepare the vehicle airframe for flight and to obtain adequate clearance from the relevant authorities to fly at a designated site.

The modification of the Eclipse UAV was carried out in parallel with the design and developments of the DEMON UAV (See below).

The starting point for the Cranfield Aircraft Design Centre team was to assess the vehicle structure and systems to determine a sensible modification strategy. From inspection of the vehicle, various areas were identified for modification and replacements. The main sub-systems which were modified are as follows;

- As the XRAE avionics crate was heavy, as well as requiring substantial software development, it was thought to be not cost-effective to maintain the original system. As a result, a combination of the radio control Weatronic receiver system and the Futaba 14MZ transmitter were chosen as the flight control system (FCS). An advantage of this choice was that the system uses dual integrated receivers as well as having the capability of regulating the output power using duplex power supplies to the actuators and the telemetry system.
- The XRAE crate had provided the power distribution to all the actuators and telemetry systems. Having replacing the crate with the new FCS, the team needed to replace and modify some of the wiring and replace the main power source for the vehicle. Three independent battery packs were selected to provide the electric power for the vehicle. The first two were to power the Weatronic system, telemetry system and the all the actuators. The third battery pack was selected to power the ECU. Fig. 2. shows the new FCS installation.
- The Eagle Tree telemetry system was installed into the Eclipse UAV to provide the vehicle position during flight using the Global Positioning System (GPS). Furthermore by using Eagle Tree Dual A/D Expander, both the nIMU Nano Inertial Measurement Unit (to measure 3-axial acceleration and 3-axial rate of turn) and the Space Age Control air data probe (to measure the vehicle angle of attack, sideslip, and speed) were integrated into the vehicle. The pilot and the flight officer can view the transmitted data via laptops.

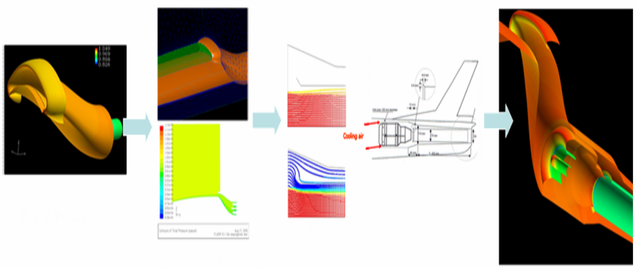


'Fig. 2. The Eclipse UAV new FCS and battery packs'

- The majority of the fuel system pipes needed replacement as they were found to be brittle and decayed.
- The engine and exhaust system was found to be mis-aligned. The main engine mounting was modified and two alternative exhaust pipes with different outer nozzle areas were made to check the power losses due to nozzle geometry. In parallel with the experimental testing, intensive study of the Eclipse UAV propulsion system was carried out using simulation. The simulation model was developed for the steady-state and maximum shaft-speed under standard ambient conditions using the Cranfield "TURBOMATCH" gas turbine performance simulation program. This was done to simulate the uninstalled AMT Olympus (190N) engine as well as evaluate the effect of the intake and the exhaust individually on the AMT Olympus 190N. Finally the full

simulation of the integrated propulsion system of the Eclipse UAV was carried out. (Fig. 3.)

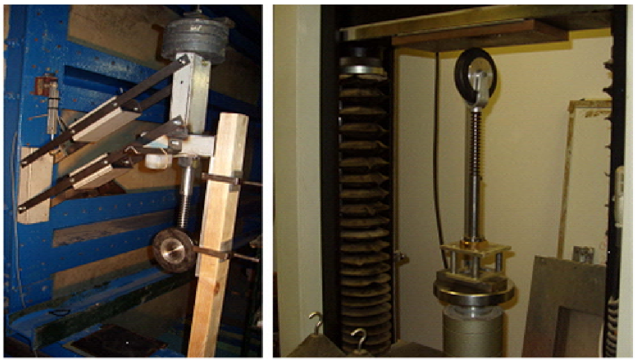
- After carrying out the modifications, the vehicle was installed in a special rig and the installed propulsion system was tested. Apart from evaluating the propulsion system, the thrust output using different exhaust nozzle geometries and the effect of the intake on thrust were analysed and the data were compared with the simulation results. (Fig. 4.)



'Fig. 3: The Eclipse UAV propulsion system evaluation process'

'Fig. 4. The Eclipse UAV propulsion system test'

- The drop test for the original main undercarriage showed it was not adequate for the vehicle. Therefore the main and nose undercarriage were modified to include the vehicle overall mass increase and eliminate issues which were highlighted during the undercarriage drop tests. (Fig. 5.)



'Fig. 5. The Eclipse UAV Main and nose Undercharge tests'

- The vehicle pneumatic power system was modified to supply only the brake system.
- Ballast was installed in the nose section of the aircraft (see Fig. 2.) to give the vehicle the capability to fly with different static margins. The pilot has used a Flight simulator and established the best static margin for the Eclipse UAV first flight.
- The Eclipse was painted to give visual clues of the aircraft orientation to the pilots.

3.3 The Eclipse UAV Taxi Trials

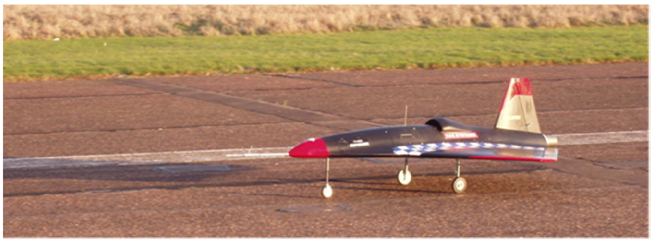
Following the completion of the necessary modifications and testing of the Eclipse UAV sub-systems in isolation, the next step was to carry out the taxi trials for the vehicle, aiming to check all its systems prior to first flight.

Two major taxi trials have been carried out at Cranfield Airfield. The first trial (March 2007) focused on the integrated systems shakedown within the vehicle. The second taxi trial (Fig. 6, November 2007) focused on the fast taxi trials. During taxi trials all necessary procedures and safety issues were taken into account.

In both taxi trials the following major steps were carried out

- Pre-starting vehicle check list
- Trailing edge device actuation test
- Landing gear and brake systems test
- Propulsion system test
- Testing the steering system by visual inspection
- Transmitter range test with and without the engine operating
- Telemetry system range test
- Fail safe system test

- Shaking down of all systems

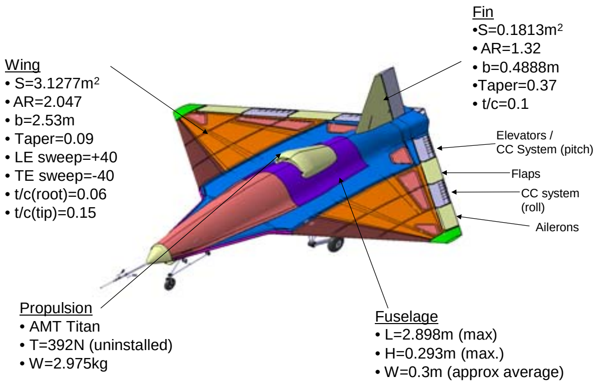


‘Fig. 6. The Eclipse UAV fast taxi trail at Cranfield Airfield’

The first taxi trial accomplished all its objectives without any issues. The second taxi trial highlighted two aspects which needed to be revised. The first was the sudden drop in thrust while carrying out the fast taxi trials. The second issue was the locking of the main wheels when the brakes were applied. The first issue was resolved immediately as it was found out that the fuel pipes needed rerouting and shortening. The second issue was considered to be more substantial and required complete redesign of the main and nose undercarriage, rather than modifying the current system. This was considered to be more cost-effective as the DEMON UAV size had increased and a complete new undercarriage was to be designed for that vehicle.
A third taxi trial will be scheduled as soon as the new undercarriage is manufactured.

4 DEMON 115 Design Development

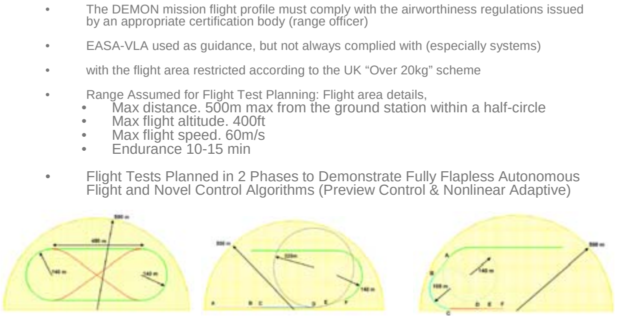
Ref. 2 describes the way in which the DEMON 115 was designed as a 115% geometrically scaled version of the original Eclipse vehicle (Fig. 7). As the vehicle design progressed from detail design more information became available. Table 1 shows the current project plan for the aircraft development.
The requirement for the demonstration of flapless flight was found to be extremely difficult on approach and landing. The fluidic thrust vectoring (FTV) system was shown to be suitable for take-off and cruise but lacked sufficient pitch authority at the reduced throttle settings required for approach.



‘Fig. 7. DEMON 115 Geometry’

It was decided to provide a source of secondary air flow, additional to the engine bleed source used for the FTV system. It will be used to power additional, inboard, circulation-controlled pitch devices, as well as the outer cc devices. The secondary air supply system is provided by a small auxiliary power unit (APU), driving an air compressor.
These changes and general maturing of the design led to weight growth, as in most aircraft development programmes. This trend was aggravated by the aft centre of gravity tendency of rear fuselage-mounted engines and a thrust vectoring system. It was decided to provide the aircraft with a positive static margin and therefore nose ballast was required, thus aggravating weight growth.
This tendency was mitigated by careful re-positioning of heavy components towards the nose of the aircraft and selection of a lighter flight control system (FCS) and attention to detail weight saving.
The aircraft was still some 5kg overweight and concerns were expressed about the installed thrust of the AMT Olympus engine. The uninstalled thrust is 230N, but there would be significant reductions due to the s-duct intake and two-dimensional thrust vectoring nozzle. It was therefore, decided to replace the Olympus with the slightly larger TITAN engine with an uninstalled thrust of 390N. This will give suitable thrust margins for the aircraft, but at a small engine mass increase and increase in fuel consumption.

The mass, centre of gravity, and performance have stabilised and will allow the aircraft to fly useful experimental flights, including that shown in Fig. 8.



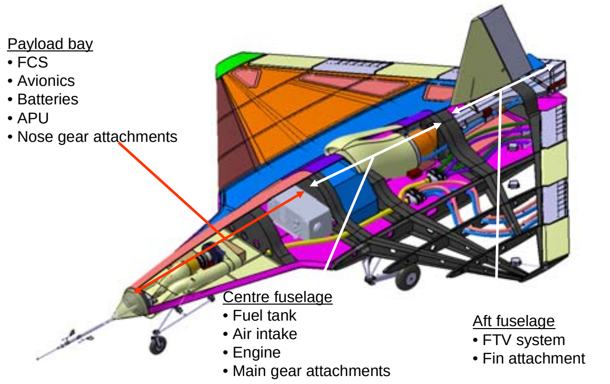
'Fig. 8. Mission Requirements

The aircraft was subjected to a Critical Design Review in December and component manufacture commenced in April 2008.

5 DEMON 115 Description

5.1 General Description

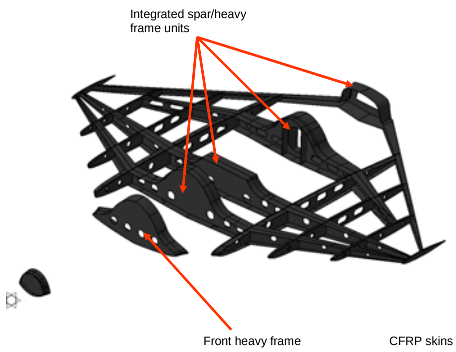
Fig. 7 shows the general configuration. Fig. 9 shows a CAD model of the aircraft internal layout. Of particular note are the FTV and CC devices that are being developed by Manchester University and built by the Apprentice School of BAE SYSTEMS. The APU and compressor system have been designed and constructed by WREN turbines and the flight control system by Bluebear Systems Research. Advanced flight control algorithms from Leicester University and Imperial College will be installed in the FCS and flight-tested. The aircraft design, integration and alternative CC devices and airframe manufacture are being performed by Cranfield University.



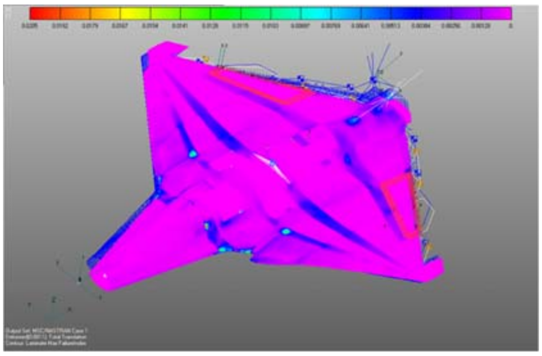
'Fig. 9. Internal Layout'

5.2 Structures

The major structural components are shown in Fig. 10 and are being constructed from advanced composite materials. They have been designed with the aid of finite element analysis (Fig. 11). Some composite components have already been manufactured. The forward fuselage payload bay floor will be constructed from aluminium alloy and will provide locations for the nose landing gear APU, batteries and ballast.



'Fig. 10. Main Structural Components'



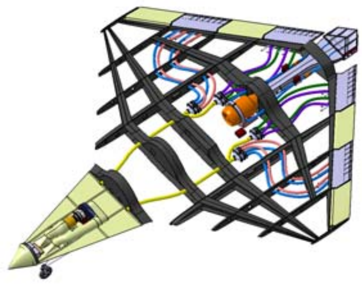
'Fig. 11. Finite Element Analysis'

The Eclipse trials showed the need for rugged long stroke landing gears (Fig. 12). The landing gears use as much commercial off-the-shelf (COTS) items as possible. These include model aircraft wheels and tyres and mountain-bike brakes, shock-absorbers and cables. Test rigs have demonstrated the successful operation of the braking system.

'Fig. 12. Main Landing Gear'

5.3 Pneumatic system

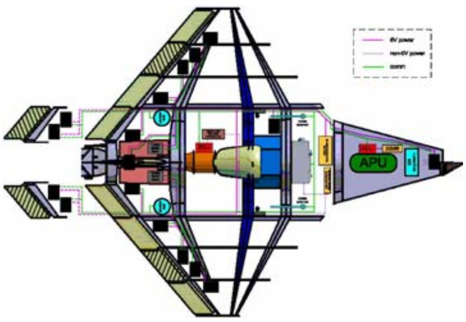
Fig. 13 shows the arrangement of the pipe system between the APU and the inboard and outboard CCV devices. It also shows the installation of the TITAN engine, bleed plenum and FTV system. The APU/Compressor assembly has been successfully tested.



'Fig. 13. Pneumatic System'

5.4 Electrical and other systems

The aircraft secondary power is provided by a number of batteries fitted in the nose of the aircraft to minimise ballast requirements. Fig. 14 shows the location of the electrical components which includes a large number of actuators.



'Fig. 14. Electrical System'

Detailed design has been completed for the fuel system which feeds both the main powerplant and the APU. The flight control system is to be integrated in the centre fuselage. The flight data nose boom from the Eclipse will be incorporated in the nose, as part of the air data system.

6 Future Development

It is hoped that the new DEMON landing gear will be tested at representative masses on the

ECLIPSE during high speed taxi trials at Cranfield. Several component and sub-system test rigs have been constructed and used, whilst a more extensive system integration rig is being designed. The programme of table 1 shows the structural design and manufacturing programme. This and much system integration and testing will lead to first flight for the aircraft in December 2008 with regular flight control algorithms, and more tests with the advanced algorithms during 2009.

MILESTONE	DATE	ACTIVITY
1	26th April 2008	Finalise Design and Manufacture Tooling
2	2nd June 2008	Manufacture Components
3	23rd June	Assemble Lower Skin and Major Structure
4	14th July 2008	Install Fixed Systems
5	21st July 2008	Assemble Upper Skin and Panels

‘Table 1. DEMON 115 – Detail Structural Design and Manufacturing Milestones

7 Conclusions

- The Eclipse UAV taxi trials have been valuable activities. They have evaluated sub-systems to be used in to the DEMON Vehicle as well as highlighting issues with some of the sub-systems design. As a result they have contributed to de-risking the overall FLAVIIR program.
- The current status of the DEMON 115 is that detail design is almost complete and has converged to a vehicle with suitable mass and performance.
- Many sub-system rigs and test facilities have been made and used.
- The first structural components, engine and APU/Compressor have been produced and are being tested.
- There is confidence that the aircraft will be able to fly shortly and meet the objectives set for it.

8 References

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[2] Yarf-Abbasi, A and Fielding, J. P. “Design Integration of the Eclispe and Demon Demonstrator UAVs. AIAA 2007-7725. 7th AIAA Aviation Technology, Integration and Operations Conference (ATIO), 18-20 September 2007, Belfast, UK.

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