Summary Report on the Technical Tasks

LIGHTNING-Culham-TN(08)-05 Open

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1 INTRODUCTION

This Summary Report briefly outlines the status of the programme LIGHTNING which came to completion in January 2008. It describes the work carried out in the Technical tasks, some of the findings, and the milestones achieved.

2 TEST SAMPLES

The programme looked at areas where lightning protection has been found difficult to design in or to certificate on General Aviation aircraft because of the lack of available test data and guidelines.

The consortium identified and helped develop designs for lightning protection which were tested with high currents and/or high voltages.

- Identify, through testing supported by modelling, lightning protection solutions for lightweight composite structure. The programme has looked in particular at the use of different metallisations, and their effectiveness under different conditions [paint thickness, structural weight/strength, lightning threat level]. Methods have also been developed and tested for effectively bonding lightweight composite skins.

- Determine how effectively dielectric materials such as plexiglass and fibreglass can resist lightning swept stroke puncture or initial arc attachments.

- Identify installation methods to protect Avionics Systems and Power Bus, demonstrating them by testing of mock up systems.

The output of the programme is in the form of test reports, which themselves incorporate guidelines on implementing lightning protection.

These guidelines are also being put together in a stand-alone report which will assist European aircraft manufacturers in the design of lightning protected aircraft.

3 THE MAIN DELIVERABLES

The main completed deliverables of the programme are itemised below. Many of the manufacturer partners also developed and manufactured test samples which are not explicitly included as itemised deliverables.

Hex	External surface protection	1.1	Identify commercially available metallisations applicable for composite external surfaces. Provide justification for including or excluding them from initial test matrix. Output will be in the form of the initial test matrix and a chart giving merits/demerits of different generic protection approaches, which will both form part of D1.
UBW	Insulating Composites	1.2	Identify commercially available coatings or protection strips applicable for external surfaces of insulating skins. Provide justification for including or excluding them from insulating panel tests. Output will be in the form of an initial test plan, and a chart giving merits/demerits of different generic approaches, which will both form part of D1.
Isc	Lightweight Structural skins	1.3	Identify commercially available construction techniques for lightweight composites, including flat laminate, and foam or honeycomb sandwich panels. Provide justification for including or excluding them from test matrix. Output will be in the form of the initial test matrix and a chart giving merits/demerits of different generic structural approaches, which will both form part of D1.
Culham	Panel Manufacture	2.1	Manufacture panels of many different construction and protection techniques, according to the test matrix defined in Task 1. Several panels of each type will be provided. 48 test panels will be manufactured by month 6, 160 more by month 14.
AEL	Panel Characterisation	2.2	Characterise the mechanical properties of the manufactured test panels. This is to compare the different manufacturing methods, and to provide input data for predictive tools (WP4). 48 test panels will be characterised by month 7, 160 more by month 15.
Cul	Panel Tests & Measurement	3.1	Test effects of lightning attachments to composite structure as a function of a matrix of parameters. These include:Lightning test levels, panel construction (thickness, material etc), external lightning protection. Lightning effects will be quantified in terms of visible damage and also as monitored panel response (deformation or edge load) during the test. 48 initial test panels will be tested by month 8, Some parameters then studied in more detail 160 more panels quantified by month 15. Provide test report D9.
AEL	Aircraft Structure Validation	3.2	To demonstrate the extent to which test results obtained on flat panels are valid for assessing lightning damage to full scale aircraft structure. Representative control surface structure will be tested, and compared to results from identical panel tests. Also includes tests to some structural interfaces such as pitot or tip lights to composite skin. Compile test report D11 and section for Final Report (WP7.2)
AEL	Fibre Optic Strain Measurement Validation	3.3	To demonstrate effectiveness of fibre optic strain measurement systems, as a means of assessing unseen lightning damage. Provide Test Report D13 and section for Final Report (WP7.2)
IZM	Modelling Impulse Effects	4	To carry out modelling on dynamic response of the test panels to lightning and compare to test results Identify range and limits of modelling and simple analytical methods in predicting the impulsive effects of lightning attachments on lightweight panels. Provide report D12 and section for Final Report (WP7.2)
UBW	Windscreen Tests	5.1	To provide sufficient generic test data to support lightning certification of aircraft windscreens, for windscreens only (Month) and windscreens with heater mats (Month). Complete test report D2 and Section for Final Report(WP7.2).
UBW	Glass Airframe Tests	5.2	Glass airframe structure incorporating lightweight protection, especially the use of external high resistance techniques. Determine by test electrode geometry their limits of effectiveness. Write test report D8 and Section for Final Report(WP7.2)..

Dia	Shielded System Cable Harness	6.2	Provide & test D4,a protected cable loom installation, to determine the transient levels induced on it as a function of of various shielding and bonding approaches. Write test report.
Extra	Power Bus Protection System	6.3	Prepare and test D5, a mock up of a generic power generation, battery and power bus installation for a composite aircraft. Determine the transient levels induced on the power bus in the event of a strike to the nose of the aircraft. Assess different installation and bonding methods to minimise such transient levels and produce test report.
AEL	Management	7.1	To ensure that the Lightning project and consortium is run efficiently, to cost and time and producing the maximum benefit for the efforts expended. To ensure that there is adequate communication within and outside the team. To ensure compliance with the EU requirements for FP6 STREP projects.
Cul	Final Reporting	7.2	To provide validated methods for protecting composite light aircraft from the effects of lightning. It will include Structural, Avionics (harnesses and power bus) and Fuel Systems.The document D14 will include test data and general guidelines on lightning effects to help manufacturers in lightning protection of future aircraft developments.

4 Achievements of the Programme Tasks

The activities on the various tasks are now summarised.

Task 1 was to review the available lightning protection methodologies for both glass and carbon composite structure, as well as reviewing the available methods of manufacture. From this phase a consensus was formed for types of structure which would be used for in a test programme for comparing the various lightning protection techniques.

The matrix for these test samples is given below, and all these were made and tested.

Test Panels Matrix 1: Comparison of different Lightning Protection Materials

		Protection	Solid Laminate Woven	Sandwich foam (see note 1)
Wet Lay-up	Extra/Diamond	Cramer CCC459	2	4
	Extra/Diamond	Ni-Cu Weave	2	2
	Extra/Diamond	Phos Bronze	2	2
	Extra/Diamond	Al Expanded Foil	2	2
	Extra/Diamond	Cu Expanded Foil x2?	2	2
	Extra/Diamond	Bronze Mesh (90gsm)	2	2
	Extra/Diamond	AluMesh	2	2
	Extra/Diamond	Nickel ???	0	0

Samples painted by Aviation Enterprises

		Protection	Solid Laminate Woven	Sandwich foam (see note 1)
Prepre	Hexcel	Nickel/CFC	2	2
	Hexcel	Alu/Glass	2	2
	Hexcel	Ni/Cu Weave*	2	2

* (or any protection used by other partners)
Samples painted by Aviation Enterprises

		Protection	Solid Laminate Woven	Sandwich foam (see note 1)
Prepreg	Aviation Ent	Cramer CCC459	2	6 (Note 5)
	Aviation Ent	Ni-Cu Weave	2	2
	Aviation Ent	Phos Bronze	2	2
	Aviation Ent	Al Expand	2	2
	Aviation Ent	Cu Expanded Foil x2?	2	2
	Aviation Ent	Bronze Mesh (90gsm)	2	2
	Aviation Ent	AluMesh	2	2
	Aviation Ent	Nickel ???	0	0

Samples painted by Aviation Enterprises

		Protection	Solid Laminate UniD	Sandwich Nomex (see note 2)
Prepreg	Airbus Spain	Al Expanded Foil	2	2
	Airbus Spain	Cu Expanded Foil x2?	2	2
	Airbus Spain	Bronze Mesh (90gsm)	3	4 (note 4)
	Airbus Spain	Bronze Mesh (380gsm)	3	3
	Airbus Spain	AluMesh	2	2

Samples painted by Airbus Spain

Note 1 **Sandwich lay-up (see also note 2 [Airbus Spain] & note 3 [Aviation Ent.])**

Weave;459 or Hexcel	Cu Exp Foil/Bronze	Alu Exp Foil /Alumesh
cramer 452 x1	cramer 452 x 2	glass scrim
Airex foam 5mm	Airex foam 5mm	cramer 452 x 2
cramer 452 x1	cramer 452 x1	Airex foam 5mm
		cramer 452 x1

Note 2 Airbus Spain will use 5mm Nomex, and their standard UniD and woven fabric (~200gsm).[see Table above]
Note 3 Aviation Ent. will use closest equivalent to the Cramer 452 material, otherwise as Note 1
200gsm is the target for the woven fabric.
Note 4 Additional Samples are to investigate paint thickness effects
Note 5 4 of the sandwich panels for preliminary tests
(available before other Matrix 1 samples)

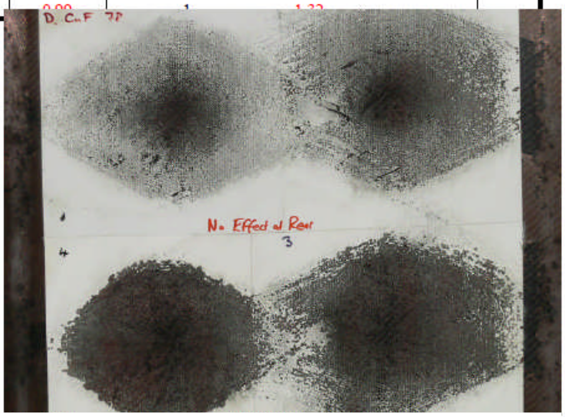
This was the main initial deliverable, with input from all parties. Subsequently, following testing of this first batch of panels and internal review of the results, a further programme was drawn up to look at the more interesting aspects from the first phase; in particular paint thickness effects and also skin bonding techniques. So this matrix was simply a starting point rather than a definition of the programme.

Task 2 is the major task of manufacturing the samples based initially on the above matrix. This was quickly completed (AEL, Dia, Extra, Hexcel, Airbus E). As noted in task 1 an iterative process then began in which further panels were manufactured (most by AEL) and tested (CUL).

The first batch of panels were all characterised by AEL prior to test in order to compare their mechanical properties. However initial test and modelling results showed unexpected dynamic behaviour of the panels under the shock loading of the lightning attachment. This could not be understood from the simple static characterisation data. Subsequently more rigorous stress-strain characterisations of the panels were performed on the two main panel types (sandwich and monolithic). These were compared with static load modelling of the same panels and gave a good correlation for the non-linearities observed (IZM).

Table of Characterisation Data

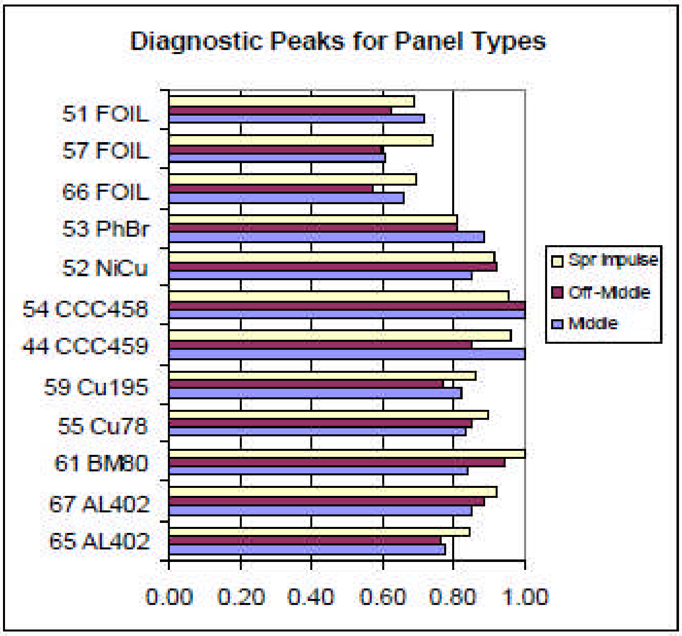
LIGHTNING TEST PANEL CODES AND CHARACTERISATION RESULTS	Iss 2	6.6.06							
		MONOLITHIC PANELS				SANDWICH PANELS			
		Solid panel Test Load		0.9 kgs		Sandwich Panel test load..		9.4 kgs	
		Zero deflection		0.1 mm		Zero deflection		0.16 mm	
AEL	Ident Prefix	Net	mm Deflection		mm Deflection	Net	mm Deflection		mm Deflecti
Paint - light primer plus		1 coat		2 coats		1 coat		2 coats	
Al Expanded Foil 78gsm	AEL	5	0.91	6	1.11	11	1.2	12	1.19
Cu Expanded Foil 78gsm		7	0.81	8	0.99	13	1.19	14	1.24
Cu Expanded Foil 195gsm		9	0.75	10	0.99	15	1.19	16	1.14
Bronze Mesh (80gsm)		3	1.04	4	1.15	17	1.26	18	1.29
AluMesh 402 (90gsm)		1	0.8	2	0.9	19	1.16	20	1.14
EXTRA	EA	ALL ONE COAT OF PAINT (Light primer)				ALL ONE COAT OF PAINT (Light primer)			
Cramer CCC459		EA1-CCC459	1.96	EA2-CCC459	1.66	EA19-CCC459	1.35	EA20-CCC459	1.65
Cramer CCC458-1		EA3-CCC458	1.48	EA4-CCC458	1.3	EA21-CCC458	1.61	EA22-CCC458	1.67
Ni-Cu Weave		EA5-HNC9104	1.44	EA6-HNC9104	1.48	EA23-HNC9104	1.46	EA24-HNC9104	1.58
Phos Bronze		EA7-HBR9106	1.5	EA8-HBR9106	1.35	EA25-HBR9106	1.29	EA26-HBR9106	1.56
Al Expanded Foil 78gsm		EA13-DAF0078	0.97	EA14-DAF0078	0.93	EA31-DAF0078	1.45	EA32-DAF0078	1.68
Cu Expanded Foil 78gsm		EA15-DCF0078	1.93	EA16-DCF0078	1.46	EA33-DCF0078	1.35	EA34-DCF0078	1.39
Cu Expanded Foil 195gsm		EA17-DCF0195	1.18	EA18-DCF0195	1.21	EA35-DCF0195	1.36	EA36-DCF0195	1.54
DIAMOND	DIA					ALL ONE COAT OF PAINT (Light primer)			
Cramer CCC459		S1	0.92	S2	1.00				
Cramer CCC458-1		S3	NO SAMPLE	S4	NO SAMPLE				
Ni-Cu Weave		S5	0.93	S6	0.94	2	1.33		
Phos Bronze		S7	1.18	S8	1.15	7	1.26		
Al Expanded Foil 78gsm		S9	0.98	S10	[illegible]	[illegible]	[illegible]		[illegible]



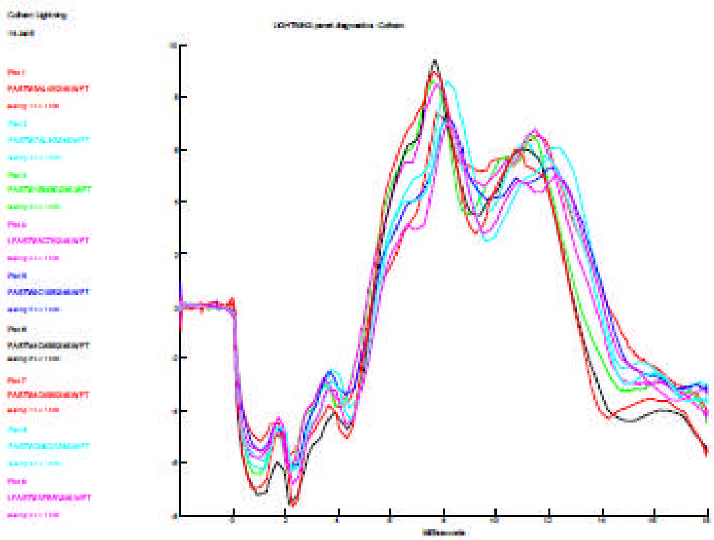
One of the manufactured panels, shown here after multiple tests.

Task 3 is the lightning testing and measurement of the panels, which was carried out in several phases throughout the programme. Results presented show that the impulse imparted to the panel during lightning tests is not strongly dependent on the lightning protection used, but can be strongly affected by external layers such as thick paint. For thick paint samples the lightweight metallisations performed better than the heavier ones; although they had larger areas of superficial damage. This is an interesting result; it suggests that the actual protection used is less significant than the thickness of the paint above it. This work was presented at the 1997 ICOLSE conference in Paris.

Comparison of recorded peak impules and panel deflections for the various protection types. (Normalised to 1)



Recorded panel deflections during lightning tests, for different protections



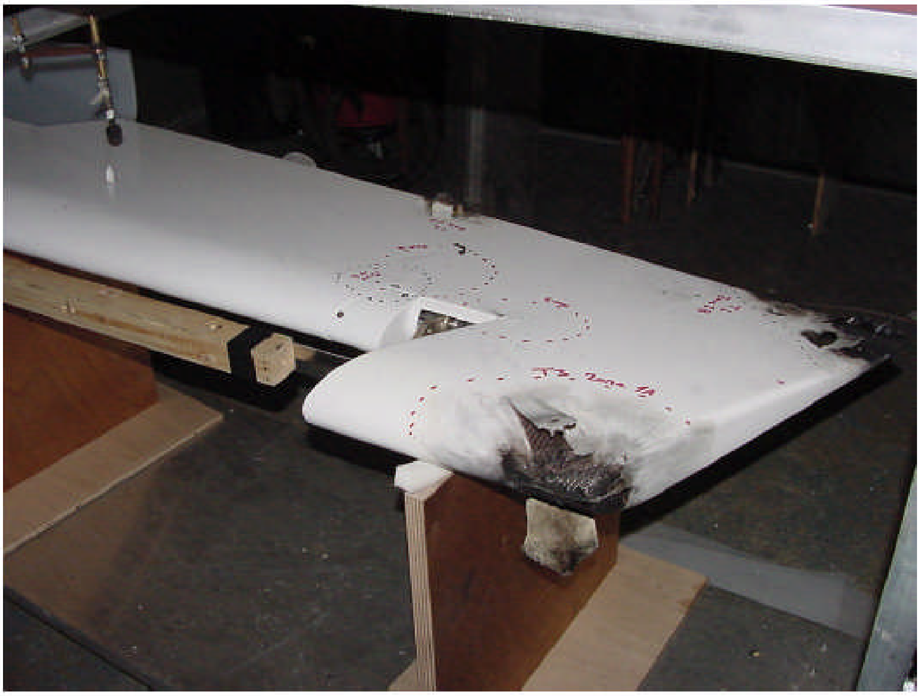
Further work in task 3 was then to look at larger samples such as rudders and winglets, and see whether the damage occurring during lightning tests is consistent with that which occurs on simpler flat panel samples. These comparison tests were done with Cramer 459 and/or copper expanded foil protection, on flat panel, full rudder and winglet samples manufactured by Grob (Germany) and Evektor (CzechRepublic). None of these large samples punctured, and surface damage was consistent between the samples. The biggest concern was that full scale samples might exhibit different failure mechanisms such as major trailing edge splits, but this did not happen.

One of the large scale structural test items (full rudder) having lightning protection for several different lightning zones.

Tests were to Zones 1A, 1B, 2 and here with the electrode locate for a Zone 2A test.

Dotted lines near the upper hinge indicate minor effects a the cocured bonding strips.

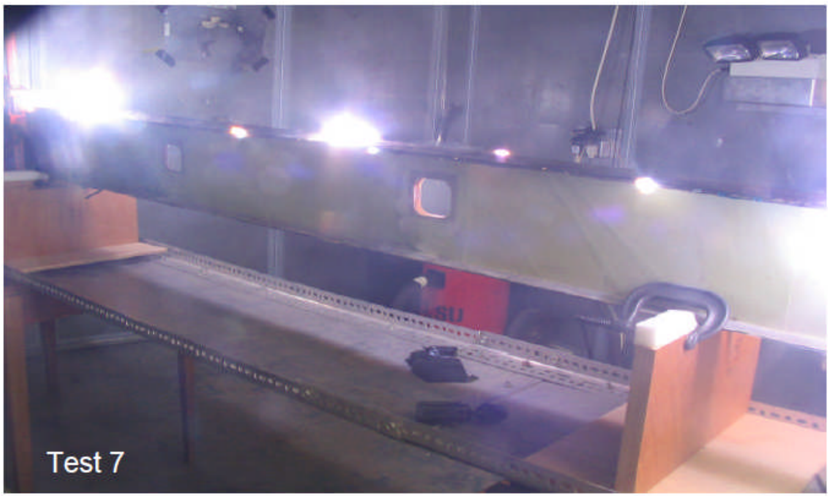
Damage is superficial



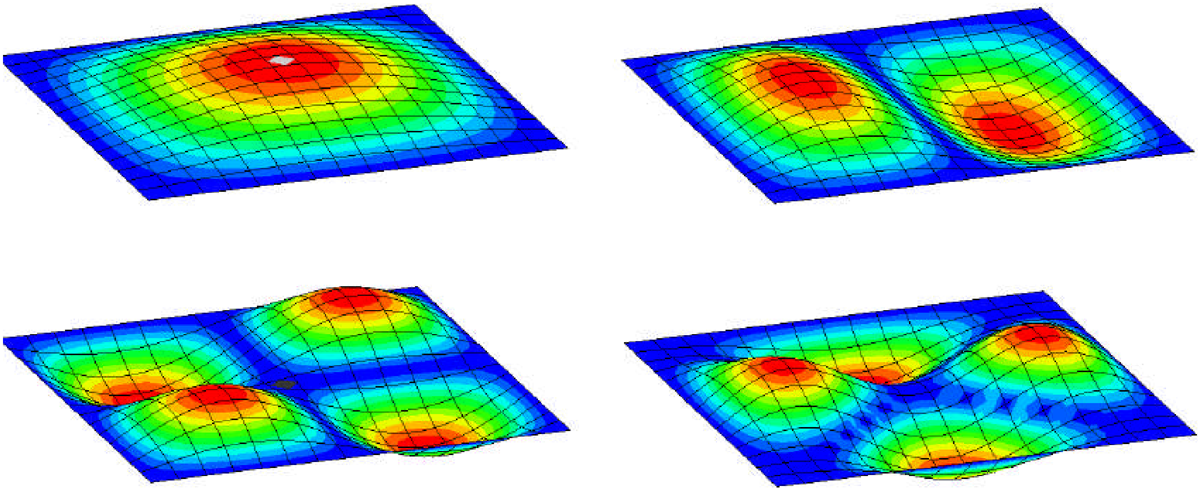
Other small representative samples devised and tested included fuel filler caps mounted in composite skins, lightning bonding strips, bearings and a vent outlet installation.

A full scale wing spar sample was manufactured by AEL which incorporated a fibre optic strain gauge. Lightning currents were conducted along the spar at increasing levels, with the wing spar strain under load monitored after each test. At high current levels these strain measurements indicated spar degradation; the degradation in strength appeared to be caused by local interply delaminations.

High level conduction test to instrumented wing spar. Here arcing is occurring between external skin plies and the spar caps



Task 4 is modelling of the impulse effects (IZM). The measured impulses and panel deflections during the lightning tests were modelled to see if the nature of the shock effect from lightning can be better understood, and its effects modelled. A comprehensive presentation was initially given at the Madrid meeting. The panel response eigenmodes were well represented, but the predicted deflections were too high.



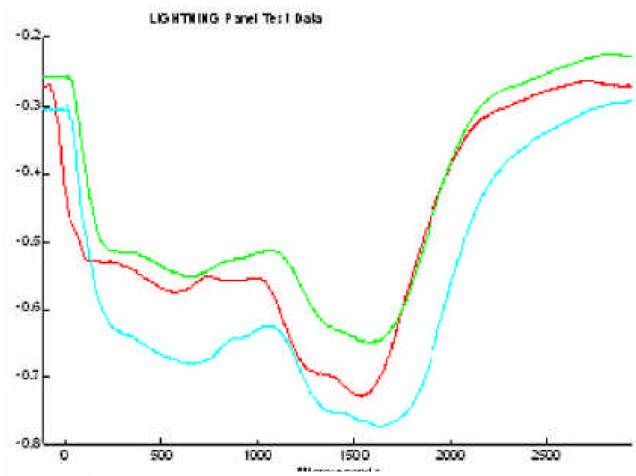
IZM modelling of the panel, depicting possible Eigenmodes

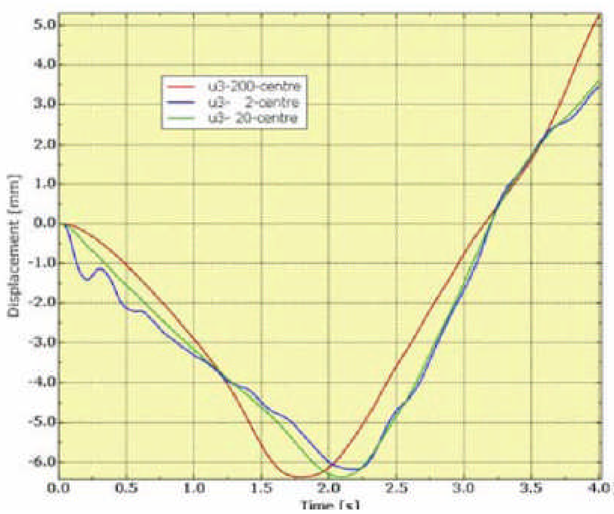
Subsequently the model was checked by comparing the predicted panel deflections under central static loading with the equivalent measurements made during panel characterisation tests.

The modelling of the static deflections gave good results.

One of the observations made on panel deflections during the lightning tests was that mechanical deflections are surprisingly fast, and so the model was modified to apply the shock impulse over a more realistic (ie shorter) time duration of <1ms or so. There was then good agreement with the oscillatory modes set up in the panel. (see Figure below)

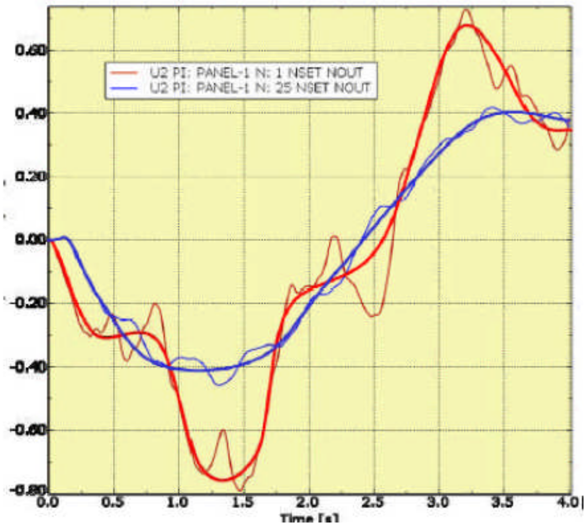
It appeared in the measurements as if the acoustic shock dominates the effects on the panel, but that the more damaging effect for puncture is a very local and faster effect linked to surface explosion. This latter effect appears to be strengthened by thicker paint layers.





From IZM report [LI 0801]

Measured time-deflection data (above).
Original modelling of scenario (above right).
Subsequent modelling (right) with 50us impulse gave good correlation as described in text below.



Task 5 (UBW) studies lightning effects on insulating surfaces such as windscreens and fibreglass unprotected structure. Comprehensive experimental work was carried out in which surface flashover characteristics are compared with the puncture characteristics, and looking at additional parameters such as time to flashover/breakdown.

For the windscreen plexiglass (1mm) the samples could easily hold off 70kV, but at higher voltages the arc simply tracked around the edge of the 1m square sample. Puncture was eventually achieved by immersing the sample in oil. When the windscreen incorporates heater mats these appeared to act as stress-raisers and breakdowns occurred at significantly lower levels. Breakdowns were also shown to be possible at points where windscreen or canopy cracks had been repaired; these regions are shown to be dielectrically much weaker. High current tests were also carried out to representative windscreens to see if the shock from the arc could cause damage.

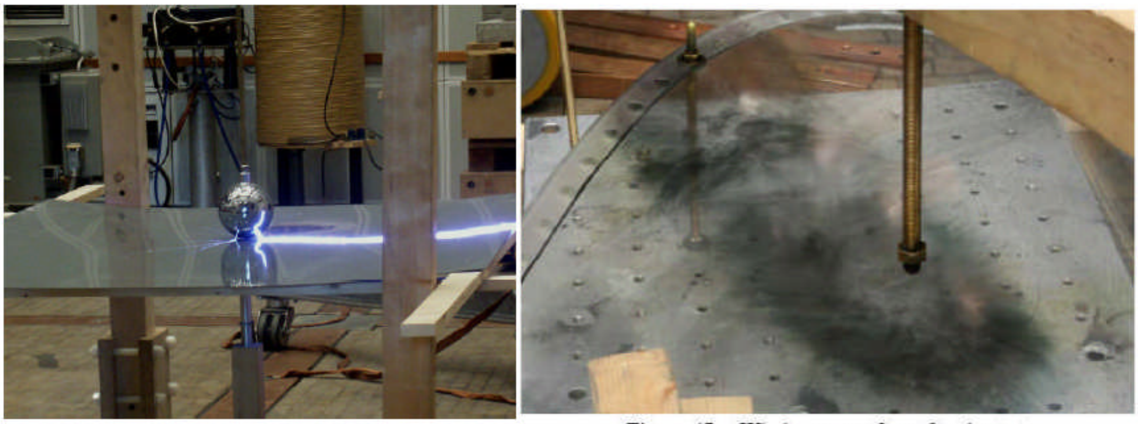
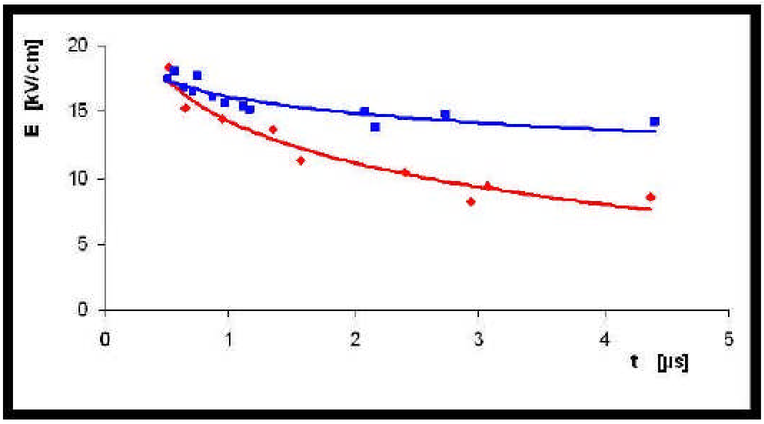


Figure 47: Windscreen surface after the tests

Testing of plexiglas sample showing HV flashover around edges (left). At right is a high current test to a windscreen sample, no shock damage from the arc occurred..

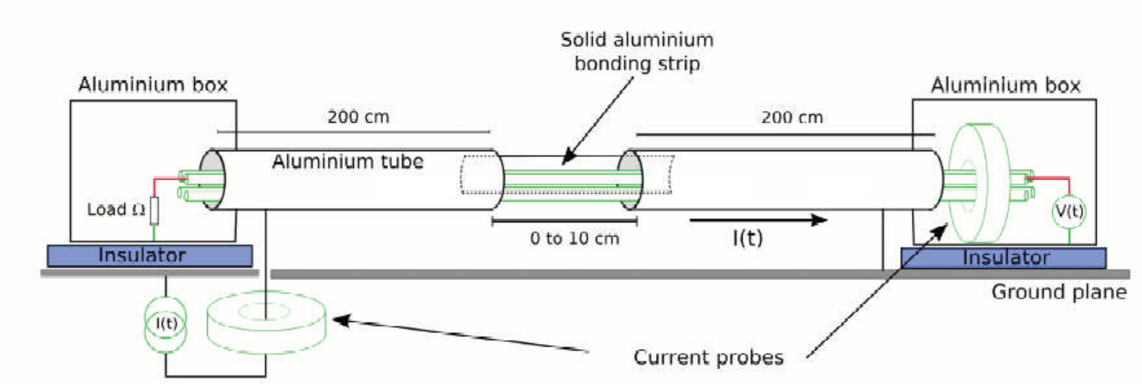
The surface field discharge strength is shown below for positive and negative polarity



The fibreglass samples were surprisingly poor dielectrics, presumably because of the voids and cavities naturally present in the material. Typically 6kV was required to breakdown the 1mm samples, which is not appreciably greater than that required to breakdown air. Interestingly the dielectric strength was much higher in oil, presumably because voids and cavities were filled with the high strength dielectric. Tests were carried out to a full size glass vertical tail to demonstrate the effectiveness of aluminium lightning strips in capturing the attachments. High current tests were also performed on such strips to determine their current carrying capability, which is limited by magnetic forces rather than heating effects.

Task 6 was to improve lightning protection for avionic systems and the electrical power bus.

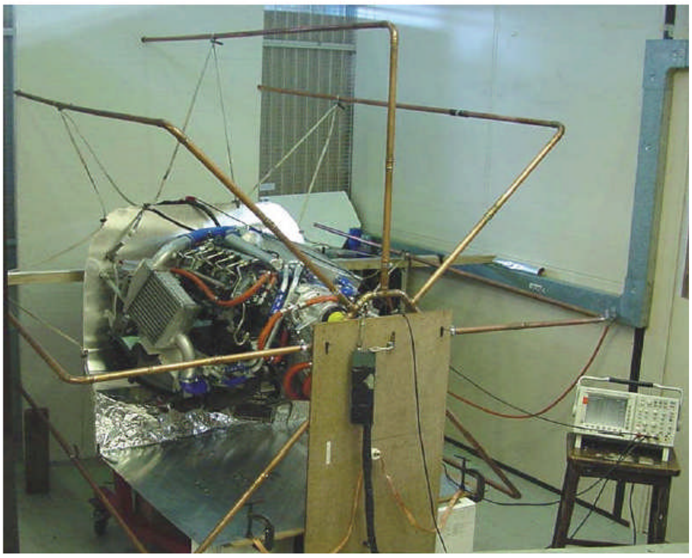
Two main test beds were proposed; the Avionics Protection test bed (6.2) was provided mainly by Diamond. Induced voltages and currents were measured on cable installations inside sections of thin-walled aluminium tube, and the voltages related to simple parameters such as tube DC resistance and current.



Since this work, the use of tubes has been questioned because of inspection difficulties and so some modelling work has been carried out to look at the use of U-channels as an alternative.

The Power System test bed (6.3) was initially delayed because of difficulties in sourcing an engine and firewall installation. A full engine was later provided by Diamond, and tested to determine typical harness currents and alternator currents in order to identify suppression requirements on the power bus.

Engine test bed in its return conductor cage. Tests were carried out to compare use of ground plane and concentric cage as return path.



Some additional tests were carried out to show how GDTs can be used as 28V power bus transient suppression without the problems of follow-on currents.

Task 7 was project management. Project Coordination activities were carried out by AEL, and the Technical Coordination by Culham. The geographical proximity of these partners (45km) has made “coordination of the coordination” straightforward as meetings are easy to arrange.

This document represents the Summary Report summarising the technical activities. A second summary note will be issued putting together the guidelines from the programme, this is essentially completed as a draft (June 08), but it is an open document and its issue is being held until some details have been clarified.

General Technical Benefits
It is useful to look back at the programme and see what immediate benefits will be provided to manufacturers of light aircraft. [The impulse measurement work and corresponding modelling has also elicited interest from large aircraft manufacturers.]

- Test data on panels provides a valuable starting point for design of lightning protected structures. This includes not only appropriate metallisations and their expected performance, but also effective bonding techniques to such metallised skins which retain smoothness of aerodynamic surfaces. The data also indicate acceptable use, and limits of use, of glass fibre and large windscreens/canopies.
- Avionics test bed results and simple analytical techniques can be read across to aircraft installations to help identify protection levels for avionics equipment. This is based on use of interbonded aluminium tubes or U-channel raceways, with mixed bundles of shielded/unshielded wires. Tests show that high currents (typically 10kA) can be expected onto battery/power bus from alternator cables, and it is necessary to protect the power bus from transients of this level. Protection from these effects is discussed.
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Goals not Achieved
The experimental work on the avionics test bed ran slowly due mainly to shortage of skilled personnel, and the programme was not as detailed or instructive as had been hoped.

It was not possible to source thermoplastic panels for comparison in the test programme, and this funding allocation was not used.

The thick monolithic samples were tested too late for Airbus-Es to be able to carry out non-destructive testing on them within the programme, and this funding allocation was not used.