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INTERIM REPORT ON FUSELAGE BURNTHROUGH RESEARCH TESTWORK ADDRESSING INSTALLATION ASPECTS

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Contents

1 INTRODUCTION

Following the accident to the Boeing 737 at Manchester airport in 1985 the Civil Aviation Authority (CAA) and Federal Aviation Administration (FAA) embarked upon a joint research project. The aim of the investigation was to look at ways of improving the burnthrough resistance of aircraft fuselages with a view to delaying the ingress of fire into the cabin, thus increasing survivability time. This study into burnthrough resistance forms part of the CAA's and FAA's on going programme to improve cabin safety.

The aircraft's aluminium skin offers little opportunity for fire hardening, and hence the focus of the work has been centred on extending the burnthrough resistance of the thermal acoustic insulation systems. Testing has indicated that appreciable gains in burnthrough resistance can be achieved by either modifying or replacing the current fibre glass insulation systems with other currently available materials.

More recently the accident to the Swiss Air MD11 has focused attention on the flammability characteristics of thermal acoustic liners. It is the intent of the FAA to issue a Notice of Proposed Rulemaking (NPRM) in the autumn of 1999 addressing both the burnthrough and flammability characteristics of insulation materials.

The development work carried out on the Darchem Flare Burnthrough rig over the past six years has demonstrated its capability of representing accurately ground pool fires. The test work required to support the NPRM is being conducted jointly by the FAA and the CAA; the FAA concentrating on the development of a materials test and the CAA, using the Darchem Flare facility, investigating the criticality of the installation aspects of thermal acoustic liners.

This document reports on the work carried out to date by Darchem Flare in support of the NPRM and addresses the issues that require resolution in the near term.

As part of the NPRM process the FAA are carrying out a Cost Benefit Analysis. The findings of this work to date suggest that retrospective changes to thermal acoustic liners may not be shown to be cost beneficial primarily because of the high labour costs associated with the replacement of liners. For this reason some limited testing has also been carried out by Darchem Flare to assess the potential for gaining the necessary burnthrough protection without replacing the existing insulation materials.

2 OBJECTIVES

The Darchem Flare work carried out in support of the NPRM is in three phases. The objectives of each of these phases are as follows:

2.1 Phase 1 – Overlap

To determine the effect on burnthrough penetration times of varying the degree of overlap between the thermal acoustic liners located within the aircraft frame bays.

2.2 Phase 2 – Fixing Methods

To determine the effect on burnthrough penetration times of method of attachment of thermal acoustic liners located within the aircraft frame bays.

2.3 Phase 3 – Retrofit Options

To investigate the potential of retrofit solutions, to provide acceptable burnthrough penetration protection, which do not involve replacement of existing thermal acoustic liner systems.

3 METHOD

3.1 Description of Burnthrough Test Facility

Darchem Flare, funded by the CAA, have developed a test method which has been referred to as 'medium scale'. This test facility simulates the full-scale conditions of a post crash fuel pool fire. The conditions are replicated in a controlled and repeatable manner using a dedicated gas fired test unit. The facility allows for relatively quick and inexpensive testing of current and proposed fuselage materials and systems. The facility can also be used as a screening tool for full scale testwork.

The results from the many medium scale tests conducted to date have correlated well with full scale testwork and the nature of the medium scale test method allows for systematic investigation of such parameters as insulation fixing methods in addition to the more obvious fire resistance properties of fuselage materials.

Burnthrough Facility

The burnthrough facility is a dedicated test furnace consisting of a mild steel frame and shell clad with 150mm thick ceramic fibre insulation. Its internal dimensions are 2m x 2m x 1.5m high. The furnace is powered by four 300 kW propane burners which fire tangentially to ensure that energy is transferred efficiently to the furnace wall. The floor of the furnace is brick-lined to provide the required heat energy, both convective and radiative, in the correct proportions. The air and propane gas supplies are driven to the furnace by a fan and a pressurised gas supply, respectively.

The roof of the furnace incorporates a manually operated sliding lid which when rolled back reveals a 1 metre square aperture on the top of the furnace. The sliding lid section has a plug type sealing action onto a 25mm ceramic fibre gasket to ensure that no hot gases leak out during the furnace warm up period. The test piece is held in a frame 250mm above this aperture and sliding lid. When the furnace has heated up to temperature and soaked, the insulated lid is rolled back, allowing instantaneous thermal assault to the test sample for the duration of the test. The results show that this method of storing energy and then releasing it provides repeatable test conditions.

Smoke and Toxic Gas Measurement

The facility is also capable of monitoring smoke production. A light source and photoelectric cell are positioned opposite one another above the test sample. The amount of light detected by the cell is represented as a voltage. The voltage is directly proportional to the light intensity. The amount of smoke released is then indicated by the percentage reduction in light transmission. Full details of the facility and its commissioning are contained in CAA Paper 94002. A diagram of the facility is shown in Figure 1.

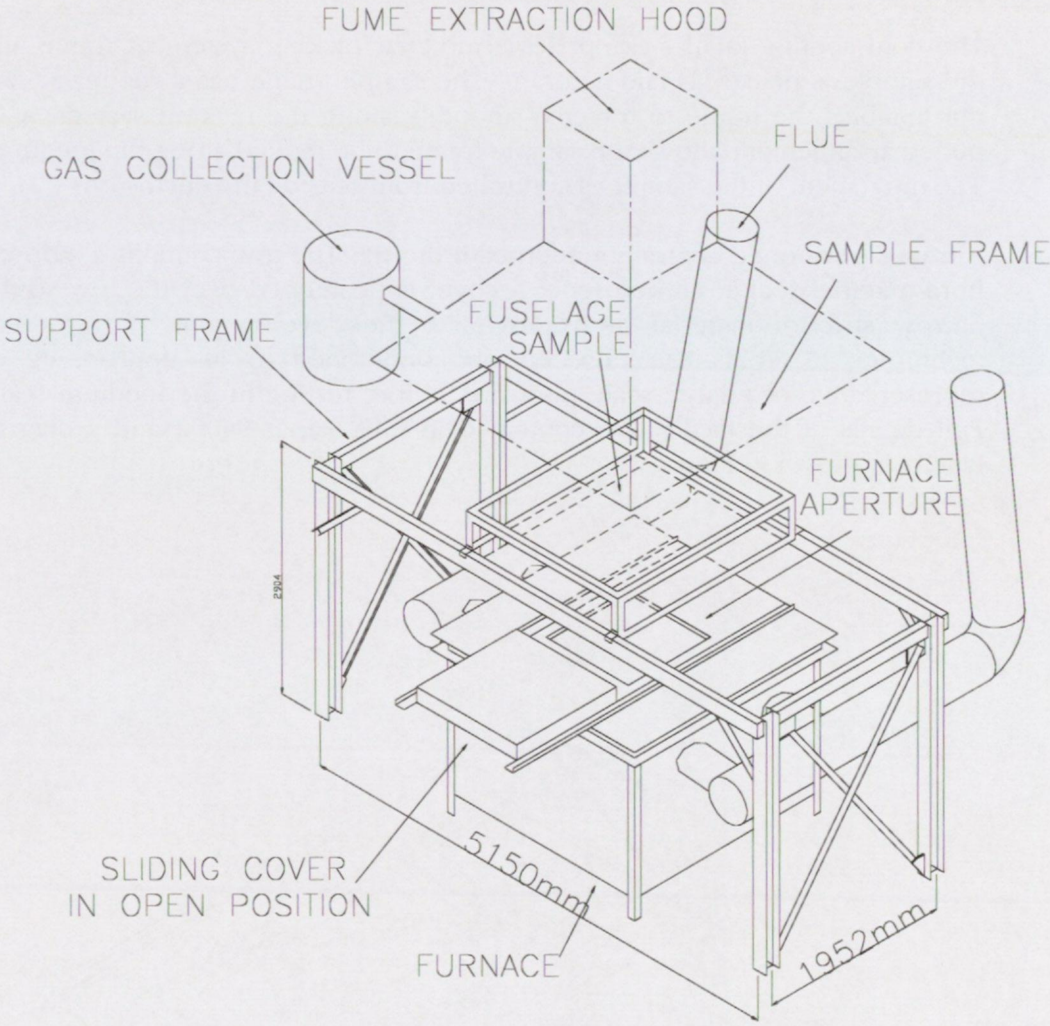


Figure 1 Medium Scale Burnthrough Facility

Cold Sooting Facility

The burnthrough facility described above is a gas-fired facility and as such burns with a relatively clean flame. In a real pool fire the presence of soot particles plays an important role in the burnthrough process, by altering the surface emissivity of the fuselage skin and thereby increasing the amount of radiant heat absorbed. So in an attempt to replicate the conditions of a post crash fuel pool fire as closely as possible a method was devised to allow samples for burnthrough testing to be conditioned with soot. In order not to affect the burnthrough test itself a method had to be devised which was sufficiently gentle not to heat damage the sample. A 'cold sooting' procedure was devised.

The cold sooting facility comprises a modular racking system. A frame, into which the sample is placed, is laid across it. The sample frame has a runner at each corner that enables the frame to traverse smoothly along the racking system. A cable and pulley arrangement allows the sample frame to be moved along the length of the rig. The movement of the sample is controlled from outside the enclosure.

A tray is positioned centrally underneath the rig. The tray contains a strip of ceramic fibre material soaked in kerosene. A cover is positioned over the tray so that only a narrow strip of material protrudes. With the development of this cold sooting technique, materials can now be pre-conditioned to an appropriate emissivity representative of a large scale pool fire, before testing in the medium scale facility. Full details of the facility are contained in CAA Paper 94002 and a diagram of the facility is shown in Figure 2.

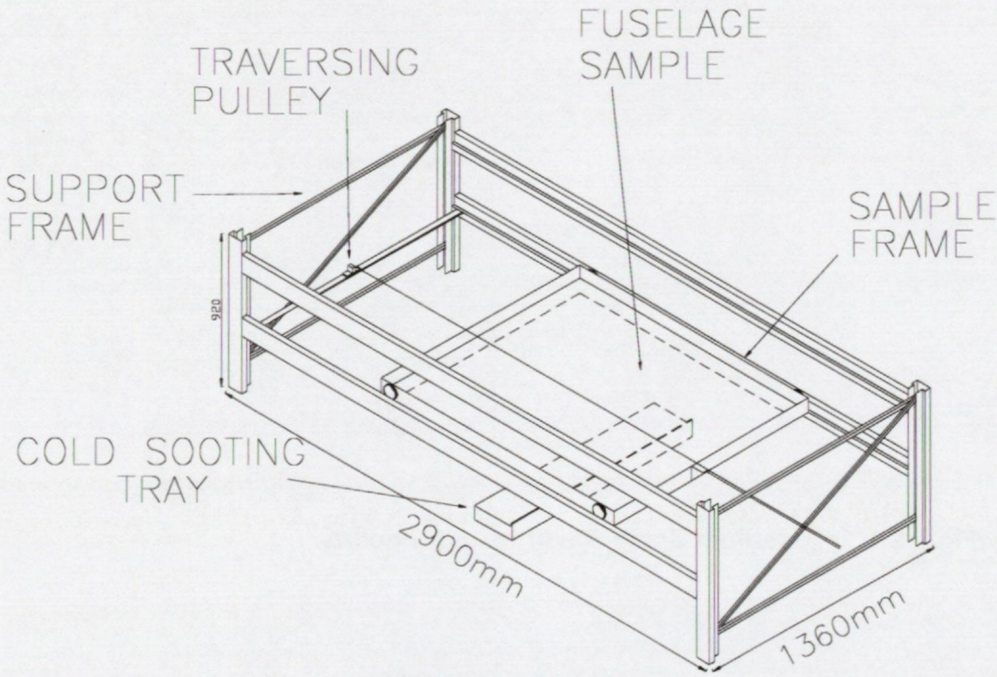


Figure 2 Cold Sooting Facility

3.2 **Temperature and Heat Flux Measurement**

From the work carried out by both Darchem Flare and the FAA Technical Center in Atlantic City it became apparent that the determination of when burnthrough occurred, based on observation, was somewhat subjective. To supplement the information already recorded an additional thermocouple grid and heat flux meter mounting platform were constructed and positioned above the test furnace. This was to enable temperature and heat flux measurements to be taken on the cold side of the test sample throughout the test. The layout of the thermocouple grid and the position of the heat flux meter are shown in Figure 3. The thermocouples used, nine in all, were metal sheathed type k and were positioned at an approximate height of 100mm from the hot face of the sample. The heat flux meter used was manufactured by the Vatell Corporation, model number Thermogauge 1000-1A FAA, and was positioned in the centre of the test panel 250mm from its hot face.

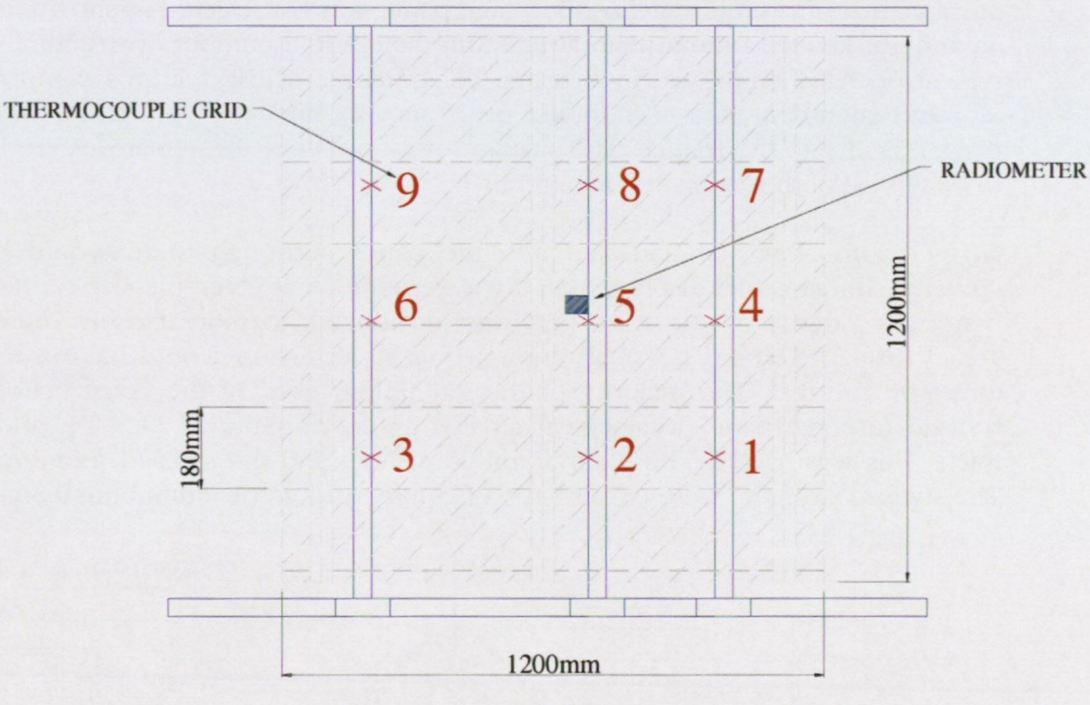


Figure 3 Thermocouple Grid and Heat Flux Meter Position

3.3 **Test Panel Configuration**

The basic configuration of each test sample was made up of two components, a stylised fuselage panel and a thermal acoustic insulation system, as described below. For the testing in Phase 3 additional materials were also employed.

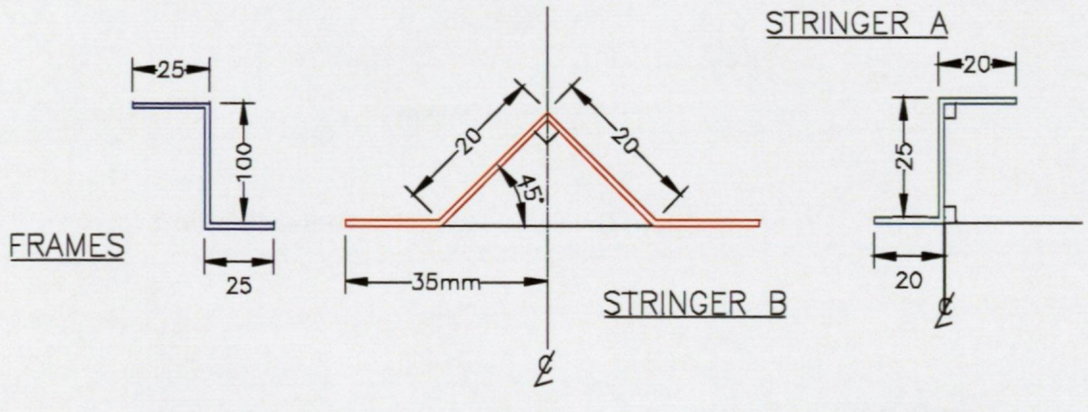
The Stylised Fuselage Panel

Early fuselage burnthrough research testwork was primarily concerned with the flame resistance characteristics of insulation and bagging film materials. Many medium scale burnthrough tests were conducted using plain aluminium panels and insulation blankets. The results from these tests provided a very good indication of the burnthrough characteristics of different insulation blanket materials. However if the potential of promising materials is to be realised, in terms of improved burnthrough resistance of an aircraft, then attention must also be focused on the attachment methods and installation aspects of insulation system design.

With this in mind the CAA commissioned Darchem Flare to develop a stylised aluminium skin and fuselage frame. With the development of this stylised fuselage panel it is possible to test representative sizes of insulation blankets and also the method by which they are attached to one another and to the fuselage skin.

From studies of aircraft fuselages and as a result of discussions with the CAA and airframe manufacturers a stylised fuselage panel was constructed as shown in Figures 4a and 4b. Riveted onto a plain aluminium panel are a number of structural features typical of those employed in fuselage construction. These features comprise three airframe members and a number of z section and top hat stringers running perpendicular to the frames. The size and positioning of these features are intended to be typical of those used on an aircraft.

No curvature was manufactured into the panel. Although there would be some curvature on an actual fuselage skin it was reasoned that given the size of the stylised panel any degree of curvature that was introduced, to more closely represent an actual fuselage, would be small enough that its omission would have a negligible effect on the test. The majority of the aluminium used in the construction of the stylised fuselage panel was typical aircraft grade aluminium, 2024-T3, and 1.6mm thick. This was used in the plain aluminium sheet and the stylised frame members. The stylised stringers were constructed of commercial grade aluminium 0.8mm thick.



All Dimensions in mm

Figure 4a Frame and Stringer Arrangement for Stylised Fuselage Panel

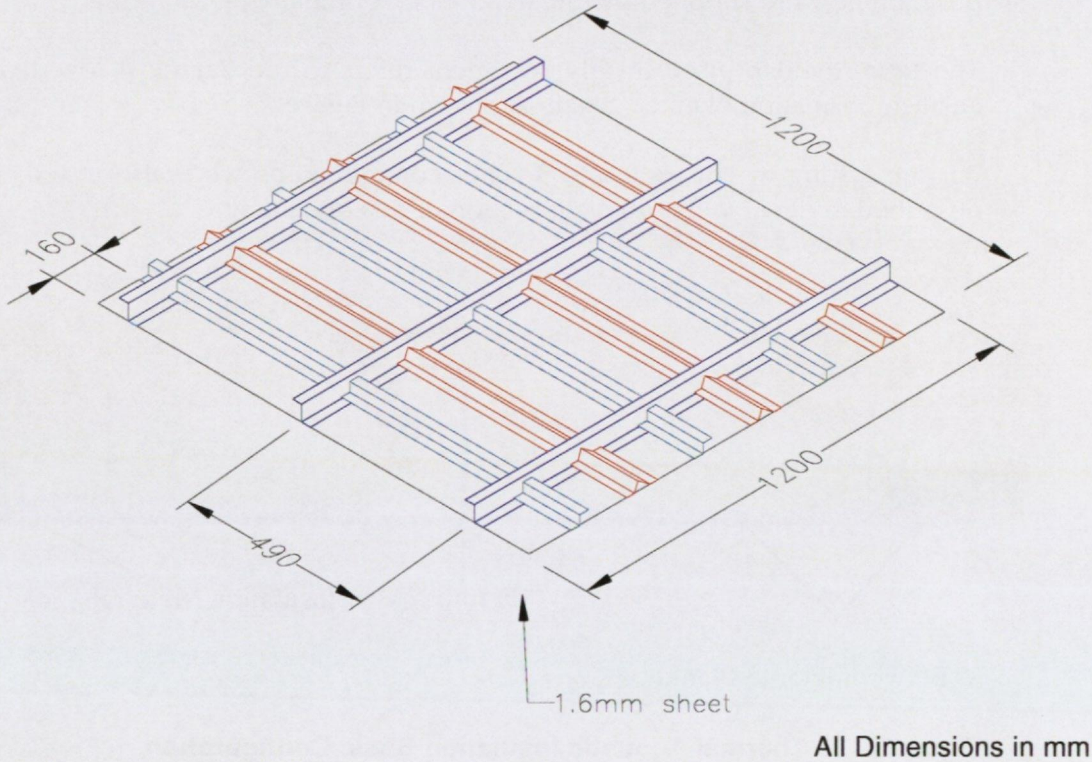


Figure 4b Isometric View of Stylised Fuselage Panel

Thermal Acoustic Insulation System

The basic thermal acoustic insulation configuration is shown in Figure 5 and comprises four between-frame blankets of two sizes, which cover the majority of the sample and three cap strips, which cover the frames.

Two types of insulation material were used, Microlite AA and Orcobloc. Microlite AA is a fibre glass material which is currently used on the majority of transport category aircraft. Orcobloc is an Orcon product designation for insulation batting made from Curlon fibres. Curlon is comprised of heat treated oxidised polyacrylonitrile fibre and is similar in appearance to fibre glass but black in colour.

For most of the tests the Microlite AA used was 50.8mm thick with a density of 6.7 kg/m^3 for between frame blankets and 25.4mm thick with a density of 9.6 kg/m^3 for the cap strips. All the Orcobloc tested had a density of 6.7 kg/m^3. Two thickness' were used 50.8mm for the between frame blankets and 25.4mm for the cap strips.

All the insulation materials tested were sealed in water resistant polymer bags manufactured by the Orcon Corporation. The coverings used were Orcofilm AN-18R, which is a metallized polyvinyl fluoride film, reinforced on one side with polyester yarns and Orcofilm KN-80 Kapton which is a polyimide film, reinforced on one side with nylon yarns.

For some of the tests in Phase 3 an additional barrier was used. The additional barrier used was Nextel, which is a thin fire resistant ceramic fibre developed by the 3M Company.

The majority of the aircraft fixing components used in Phases 2 and 3 of the test programme were supplied by the Monadnock Company of California.

The term 'overlap' used in this document refers to the degree of overlap between adjacent insulation blankets, again as shown in Figure 5.

For the testing in Phases 2 and 3 other configurations were also tested. These are described in detail in the relevant section of this document.

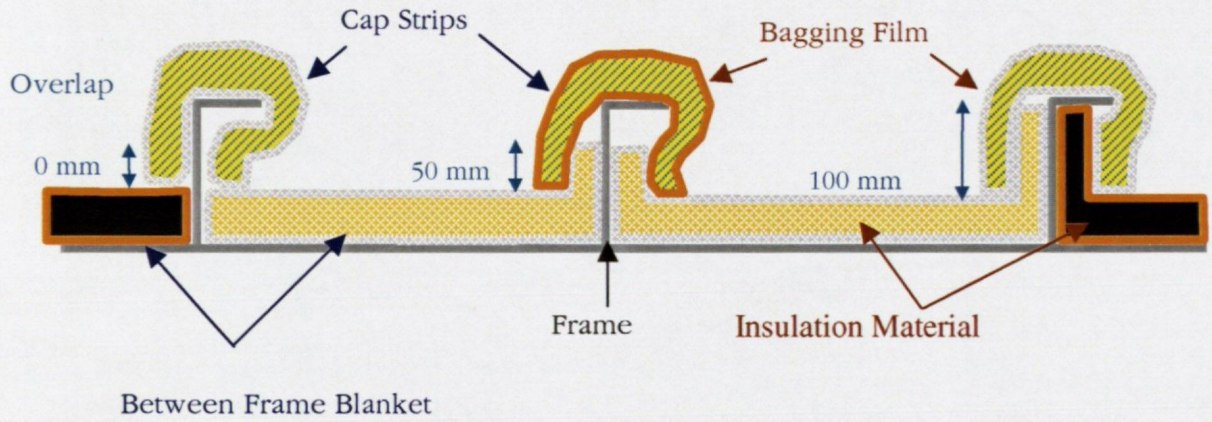


Figure 5 Thermal Acoustic Insulation Basic Configuration

4 TEST RESULTS

4.1 Phase 1 – Overlap

The results from Phase 1 of the burnthrough test programme are presented in Table 1. Three burnthrough times are referred to. The *aluminium burnthrough time* refers to the burnthrough time for the stylised aluminium fuselage panel only. The *system burnthrough time* is the time to flame penetration of the system (aluminium panel and insulation) and the *insulation burnthrough time* is the difference between the two.

For tests A1–A7 the system burnthrough times quoted correspond to <u>substantial</u> flame penetration of the test sample. For tests A7a, A8, A9 and A9a reference should be made to the observations made in Tables 3 and 4. For this phase the thermocouple grid and heat flux meter were in position only for the following tests, A7a, A8, and A9a.

Sketches of the test configurations and where applicable, graphical heat flux and temperature grid profiles, are shown in Figures 6 to 20. For the sketches of the test configurations the following key applies:

- **Microlite AA Insulation (0.60)**
- **Microlite AA Insulation (0.42)**
- **Orcobloc Insulation (0.42)**
- **AN-18R Bagging Film**
- **KN-80 Bagging Film**

For all Phase 1 tests the insulation blankets were attached to the stylised fuselage panel and to each other using steel insulation fixing pins positioned every 175mm (7") along each frame as indicated on Figure 6 below.

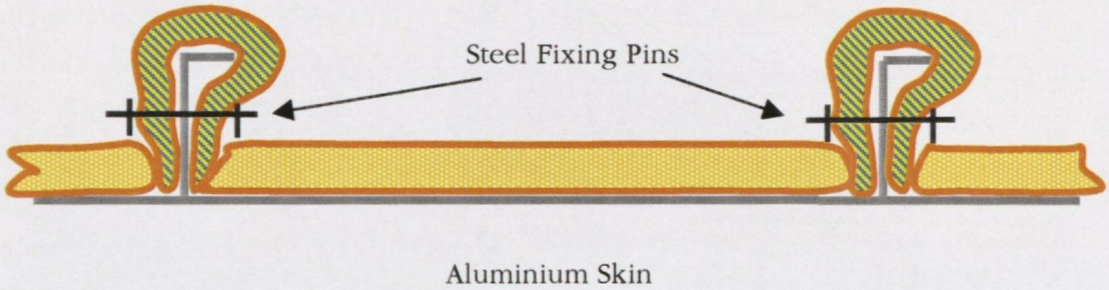


Figure 6 Test A1 Microlite AA in KN-80 (0mm Overlap)

Table 1 Phase 1 Test Results

Test No	Insulation Material	Bagging Film	Overlap	Density		Thickness		Burnthrough Time			Area of Failure (Flame Penetration)
				Frame	Cap Strip	Frame	Cap Strip	Aluminium	Insulation	System	
			mm	kg/m3		mm	mm	secs	secs	secs	
A1	Microlite AA	KN-80	0	6.7	9.6	50.8	25.4	49	45	**94**	In Region of Frame
A2	Microlite AA	KN-80	50	6.7	9.6	50.8	25.4	43	44	**87**	Between Frames
A3	Microlite AA	KN-80	100	6.7	9.6	50.8	25.4	46	38	**84**	Between Frames
A4	Microlite AA	AN-18R	0	6.7	9.6	50.8	25.4	53	25	**78**	Along line of frame
A5	Microlite AA	AN-18R	50	6.7	9.6	50.8	25.4	46	35	**81**	Between Frames
A6	Microlite AA	AN-18R	100	6.7	9.6	50.8	25.4	43	30	**73**	Between Frames
A7	Orcobloc	KN-80	0	6.7	6.7	50.8	25.4	48	78	**126**	Along line of frame
A7a	Orcobloc	KN-80	0	6.7	6.7	50.8	25.4	49	80	**129**	Along line of frame
A8	Orcobloc	KN-80	50	6.7	6.7	50.8	25.4	41	94	**135**	Around Part of Perimeter
A9	Orcobloc	KN-80	100	6.7	6.7	50.8	25.4	49	221	**270**	Around Part of Perimeter
A9a	Orcobloc	KN-80	100	6.7	6.7	50.8	25.4	45	525	**570**	Between Frames

Figure 7 Test A2 Microlite AA in KN-80 (50mm Overlap)

Figure 8 Test A3 Microlite AA in KN-80 (100mm Overlap)

Figure 9 Test A4 Microlite AA in AN-18R (0mm Overlap)

Figure 10 Test A5 Microlite AA in AN-18R (50mm Overlap)

Figure 11 Test A6 Microlite AA in AN-18R (100mm Overlap)

Tests A7 and A7a

For tests A7 and A7a a sketch of the test sample configuration is provided in Figure 12. Observations on the failure mechanism are provided in Table 2.

Table 2 Observations on Tests A7 & A7a

Test	Observations
A7	126 seconds: substantial flame penetration along line of frame
A7a	129 seconds: initial flame penetration along line of outer frames 180 seconds: flame penetration along line of centre frame 270 seconds: increasing Test Panel Collapse

Figure 12 Tests A7 & A7a Orcobloc in KN-80 (0mm Overlap)

Test A8

For test A8 a sketch of the test sample configuration is provided in Figure 13. Observations on the failure mechanism are provided in Table 3.

Table 3 Observations on Test A8

Test	Observations
A8	135 secs: Slight failure at point along perimeter 405 secs: Flame penetration of insulation between frames

Figure 13 Test A8 Orcobloc in KN-80 (50mm Overlap)

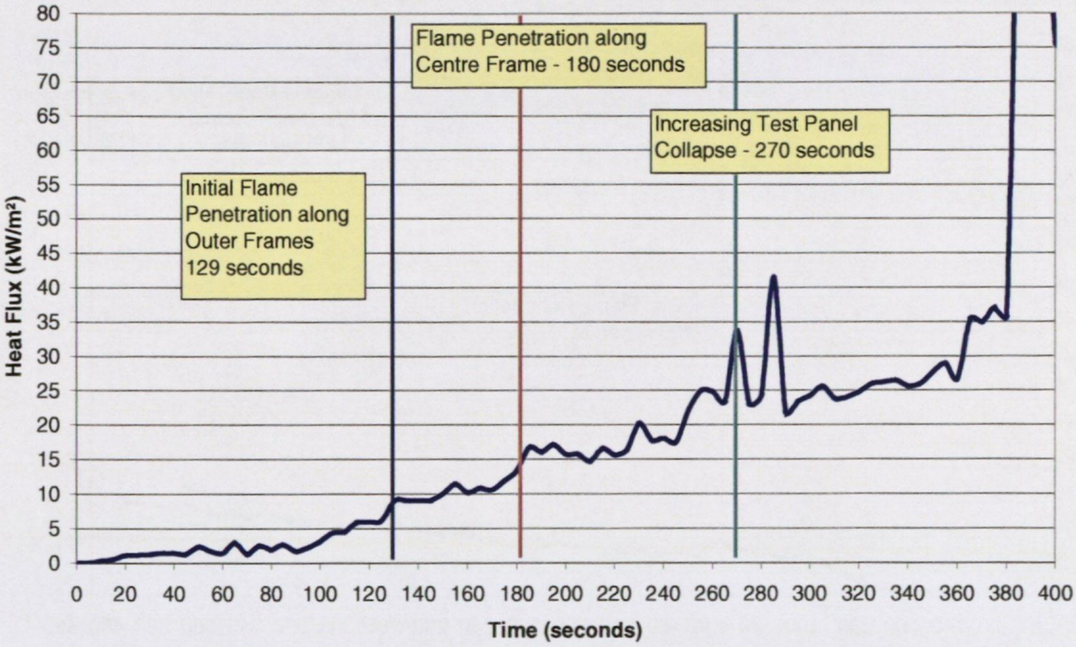


Figure 14 Heat Flux Profile for Test A7a

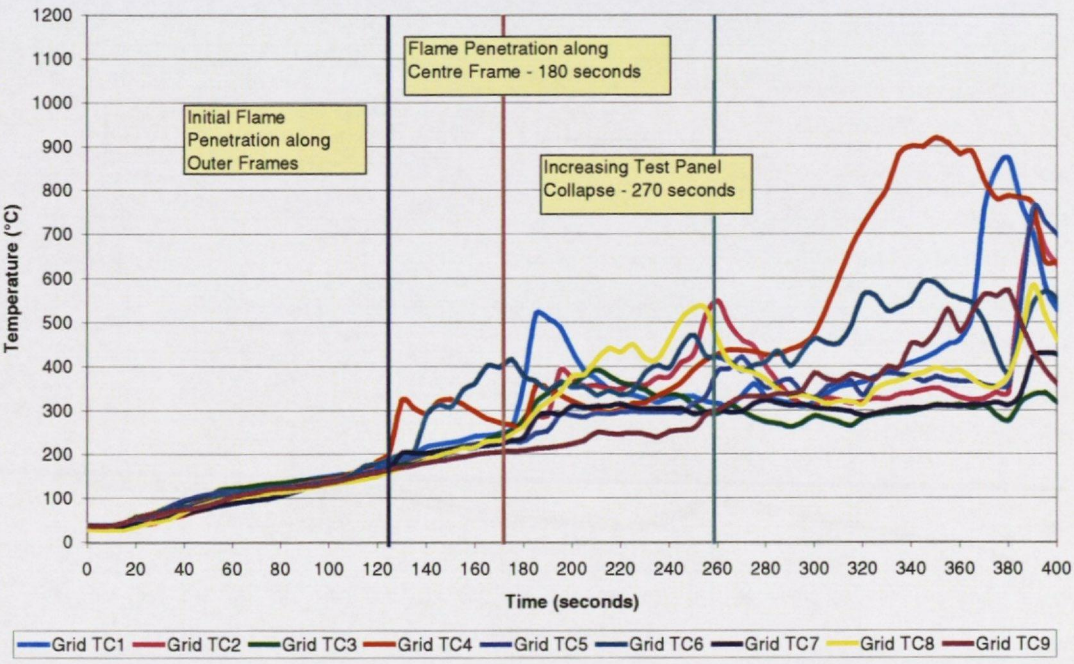


Figure 15 Thermocouple Grid Profile for Test A7a

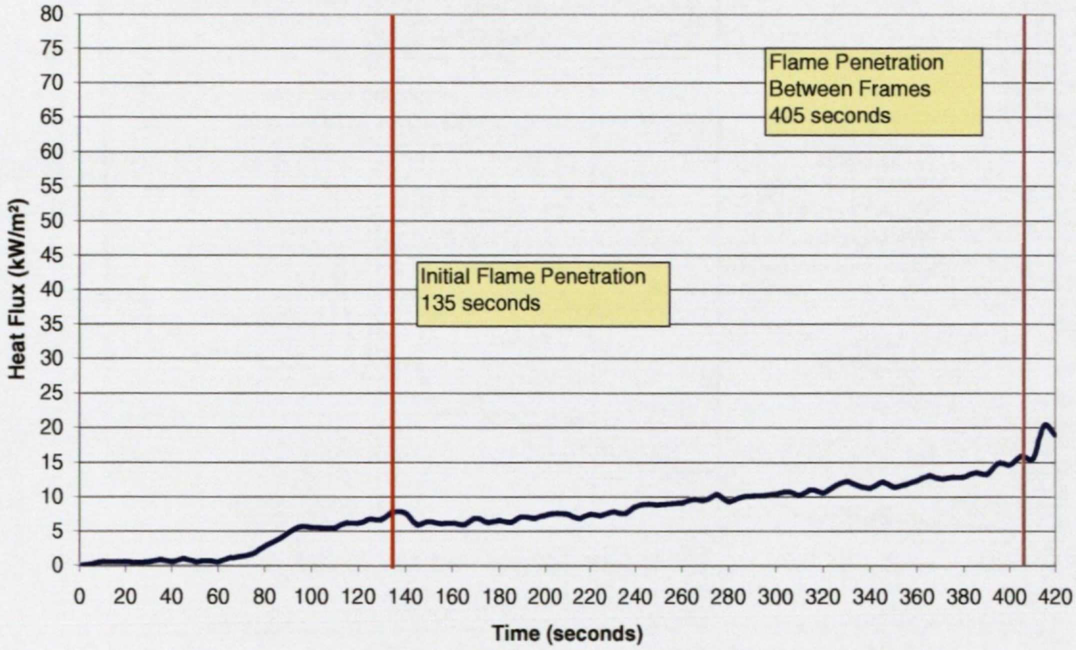


Figure 16 Heat Flux Profile for Test A8

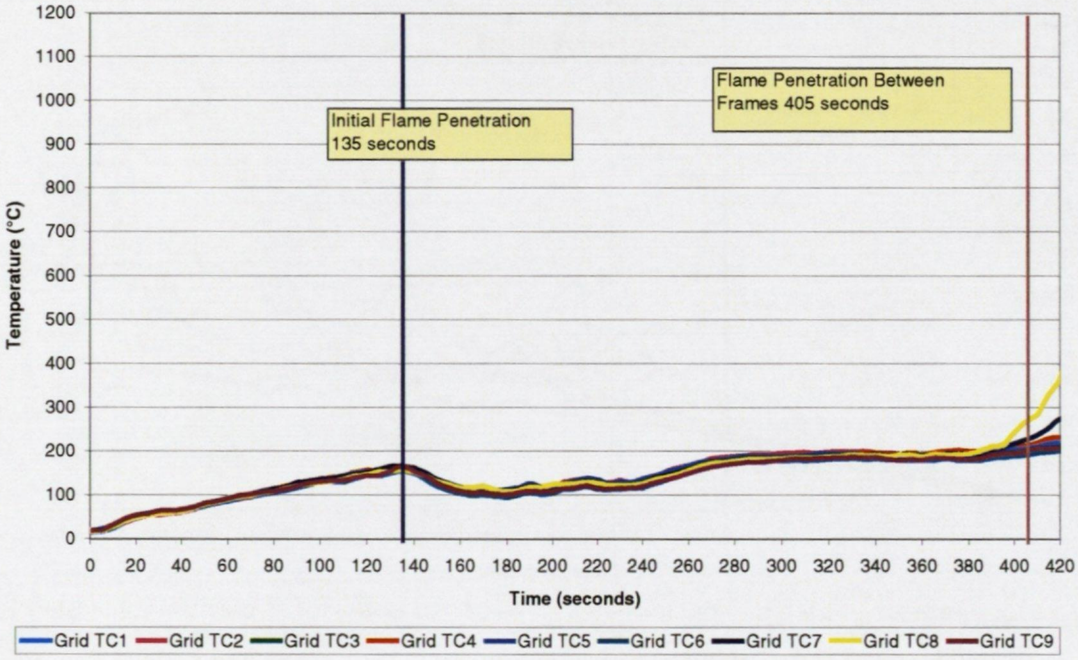


Figure 17 Thermocouple Grid Profile for Test A8

Tests A9 and A9a

For tests A9 and A9a a sketch of the test sample configuration is provided in Figure 18. Observations on the failure mechanism are provided in Table 4.

Table 4 Observations on Tests A9 & A9a

Test	Observations
A9	270 secs: Slight failure at point along perimeter 330 secs: Increasing flame penetration along line of frames 410 secs: Test panel collapse
A9a	570 secs: Initial flame penetration 615 secs: Test Panel Collapse

Figure 18 Tests A9 & A9a Orcobloc in KN-80 (100mm Overlap)

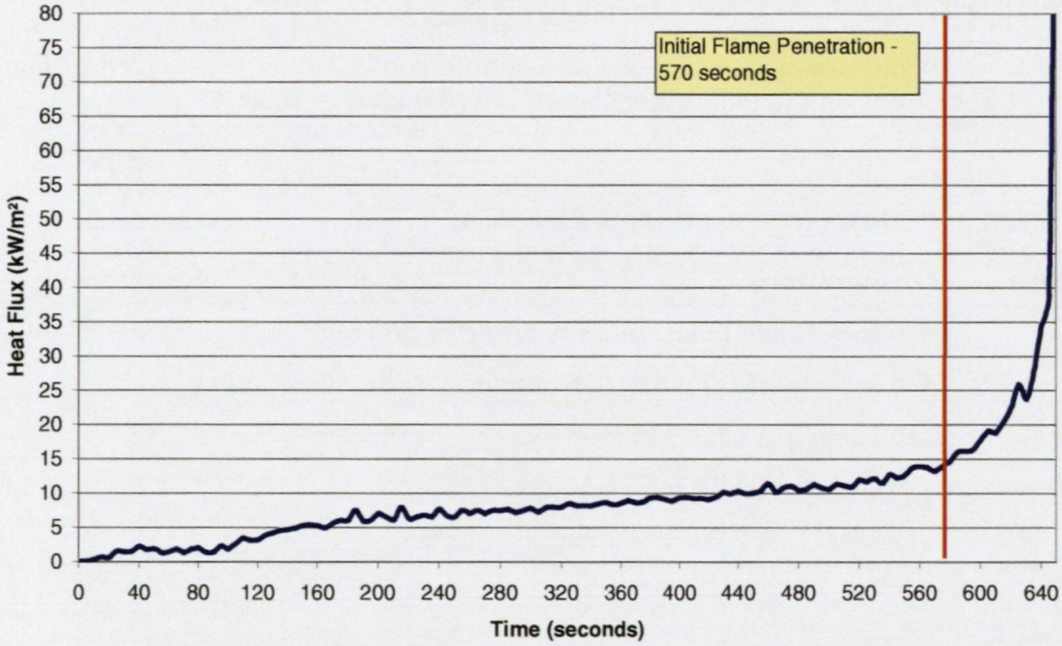


Figure 19 Heat Flux Profile for Test A9a

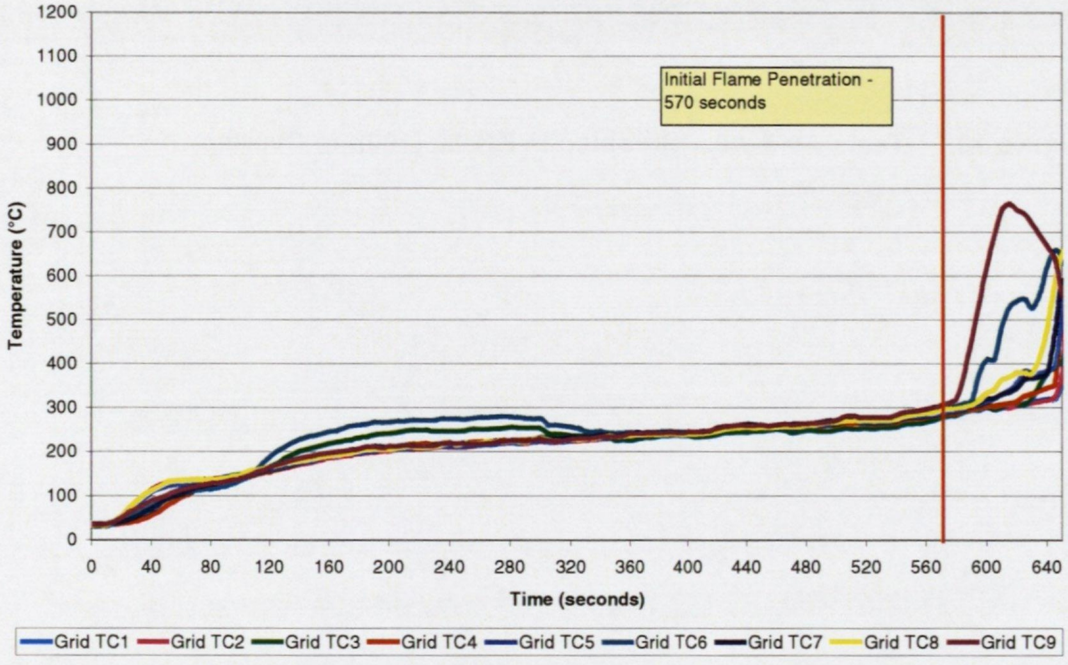


Figure 20 Thermocouple Grid Profile for Test A9a

4.2 **Phase 2 – Fixing Methods**

The results from Phase 2 of the burnthrough test programme are presented in Table 5. The definitions of burnthrough time are as described in Section 4.1.

With the exception of test B9 the system burnthrough times quoted correspond to substantial flame penetration of the test sample. For all the tests additional observations are provided in Tables 6-8. For all of the Phase 2 tests the thermocouple grid and heat flux meter were in position.

Sketches of the test configurations and graphical heat flux and temperature grid profiles are shown in Figures 21 to 31. Appendix A contains photographs of the fixing components used. For the sketches of the test configurations the following key applies:

■ **Orcobloc Insulation (0.42)**

■ **KN-80 Bagging Film**

Table 5 Phase 2 Test Results

Test No	Insulation Material	Bagging Film	Gap/ Overlap	Density		Thickness		Burnthrough Time			Area of Failure
				Frame	Cap Strip	Frame	Cap Strip	Aluminium	Insulation	System	
			mm	kg/m3		mm	mm	secs	secs	secs	
B3	Ocrobloc	KN-80	100	6.7	6.7	50.8	25.4	42	100	**142**	Along line of frame
B4	Ocrobloc	KN-80	100	6.7	6.7	50.8	25.4	40	83	**123**	Around part of perimeter
B8	Ocrobloc	KN-80	100	6.7	6.7	50.8	25.4	41	NA	**99**	Along line of tape joint
B9	Ocrobloc	KN-80	100	7	6.7	50.8	25.4	41	199	**240**	Along line of frame

Tests B3 & B4

For tests B3 and B4 a sketch of the test sample configuration is provided in Figure 21. Observations on the mechanism of failure are provided in Table 6.

For tests B3 and B4 the configuration of the test sample was identical to that of test A9 from Phase 1. The only difference was that instead of the steel fixing pins used in Phase 1 to attach the insulation system to the frame, actual aircraft componets were used. For test B3 these components were positioned every 175mm (7") along each frame as in Phase 1 and for test B4 the components were positioned every 350mm (14"). In both tests although the same method of attachment was employed two different aircraft components were used. Frame 1 used entirely Fixing Component A, Frame 3 used entirely Fixing Component B and Frame 2 used a mixture of the two.

Table 6 Observations on Tests B3 & B4

Test	Observations
B3	142 secs: Initial and substantial flame penetration
B4	123 secs: Slight failure at point along perimeter 163 secs: Significant flame penetration

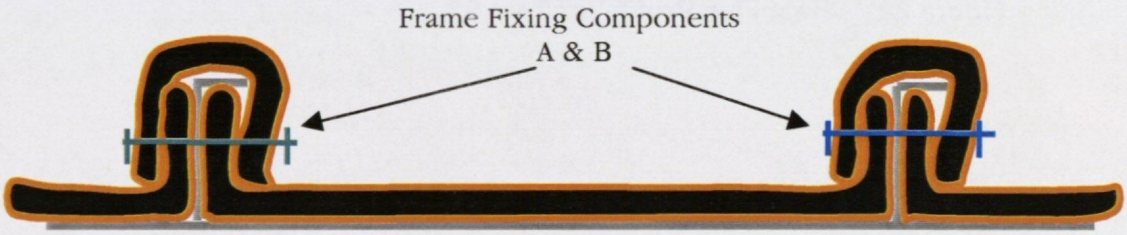


Figure 21 Tests B3 & B4 Orcobloc in KN-80 (100mm Overlap)

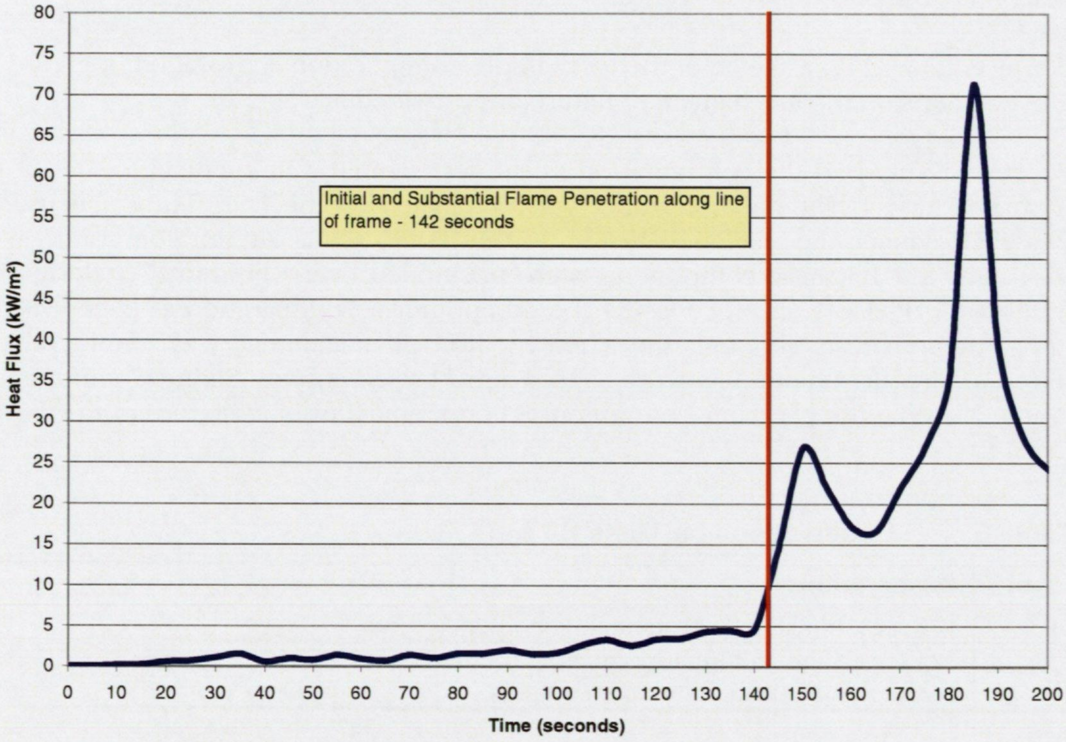


Figure 22 **Heat Flux Profile for Test B3**

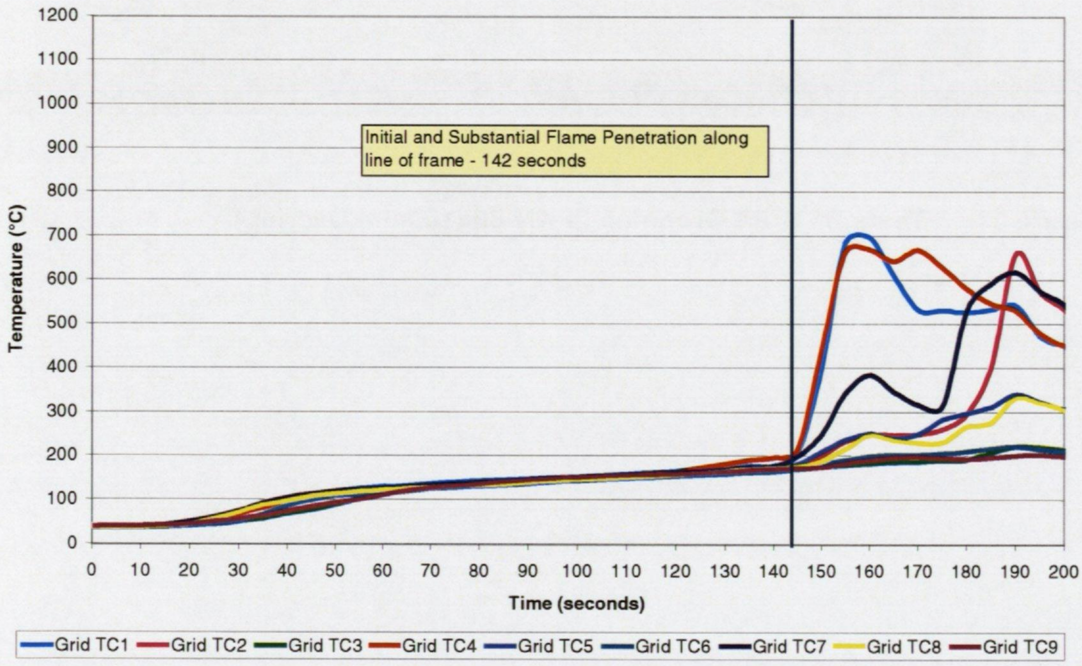


Figure 23 **Thermocouple Grid Profile for Test B3**

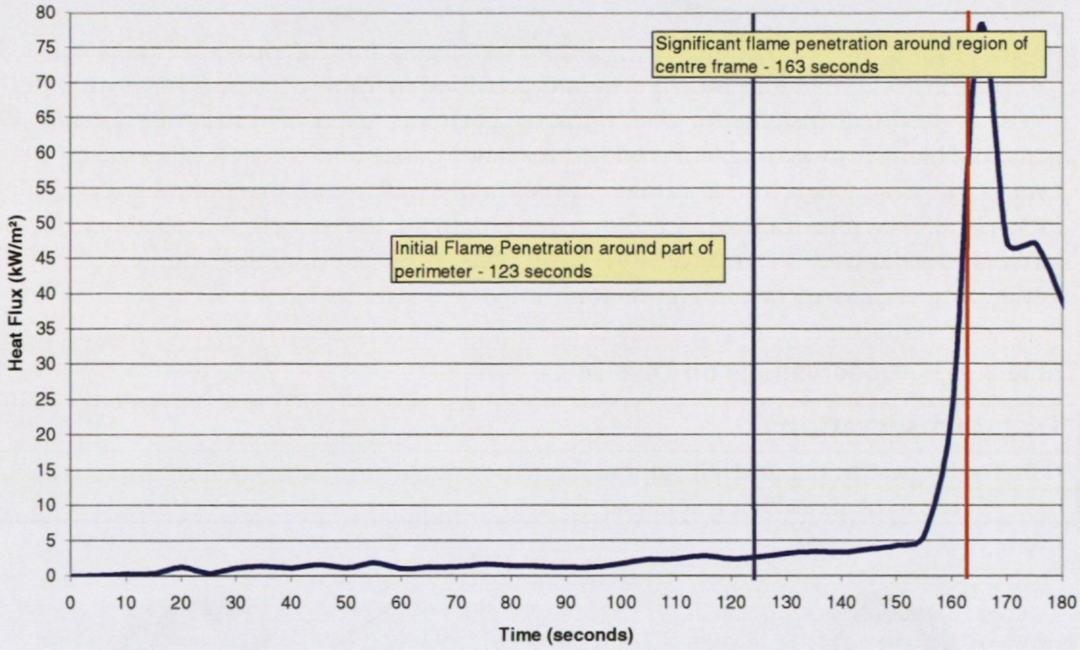


Figure 24 Heat Flux Profile for Test B4

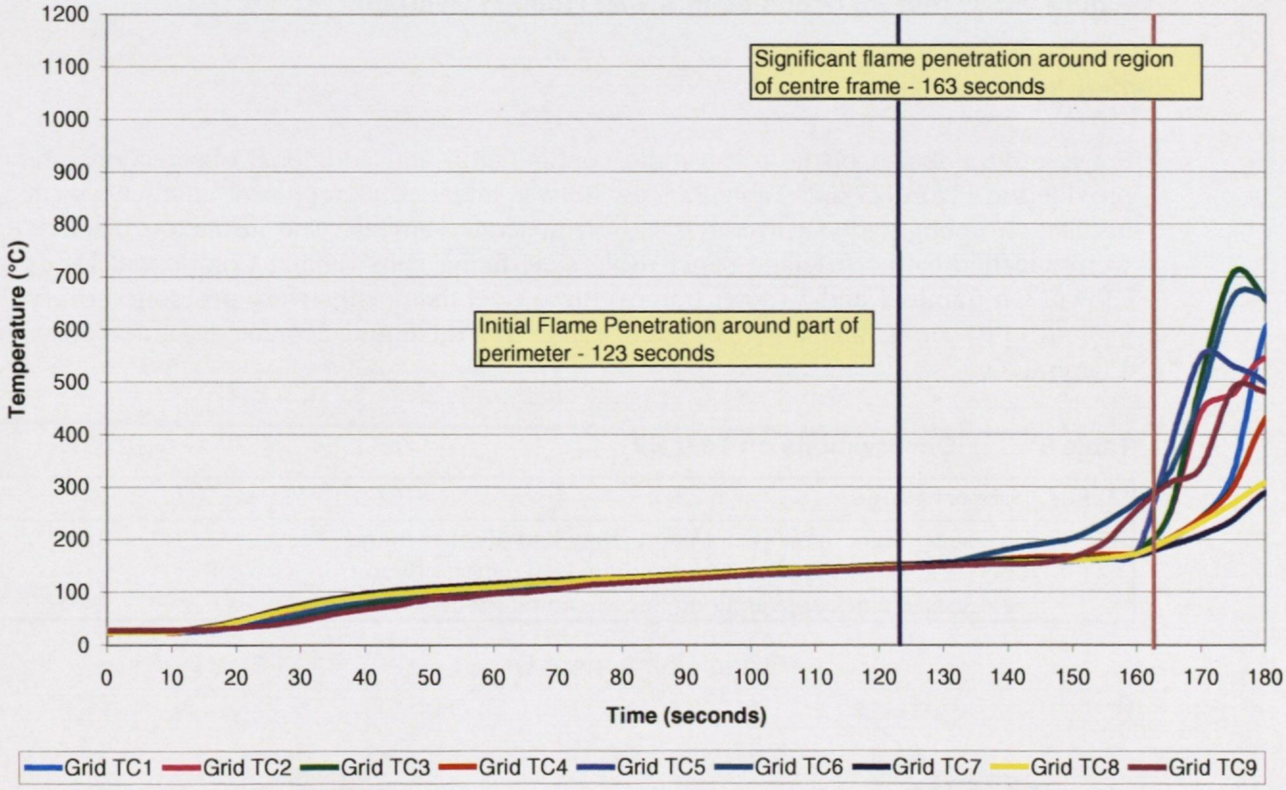


Figure 25 Thermocouple Grid Profile for Test B4

Test B8

For test B8 a sketch of the test sample configuration is provided in Figure 26. Observations on the failure mechanism are provided in Table 7. Test B8 was intended to represent a typical installation configuration currently used on in-service aircraft. The insulation blankets were attached to the fuselage panel and to each other using Fixing Component C attached to the stringers as shown. These were positioned every 350mm (14"), parallel to the frames and along the length of the panel. Where the insulation blankets overlapped a strip of PVF tape was positioned along the length of the overlapping area as shown in Figure 26.

Table 7 Observations on Test B8

Test	Observations
B8	99 secs: Initial and substantial flame penetration 162 secs: Test Panel Collapse

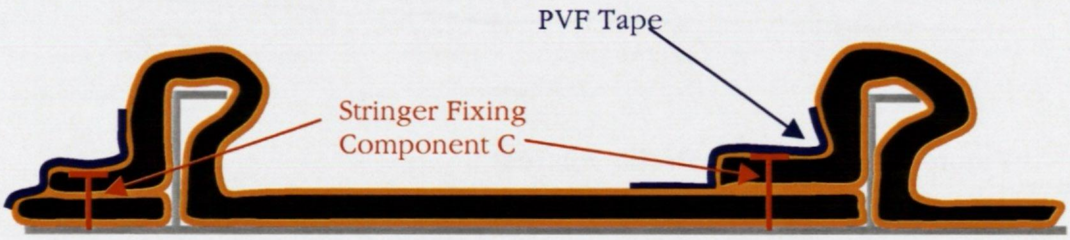


Figure 26 Test B8 Orcobloc in KN-80 (100mm Overlap)

Tests B9

For test B9 a sketch of the test sample configuration and additional observations are provided in Figure 27 and Table 8. Test B8 was intended to represent another typical installation configuration currently used on in-service aircraft. The insulation blankets were attached to the fuselage panel using steel fixing clips (Fixing Component D) as shown. On frames 1 and 3 (outer frames) these steel fixing clips were positioned every 350mm (14") along the length of each frame and on frame 2 (central frame) every 175mm (7").

Table 8 Observations on Test B9

Test	Observations
B9	240 secs: Slight flame penetration along line of outer frame 295 secs: Flames appear between frames in region of frame 403 secs: Flames appear along line of central frame

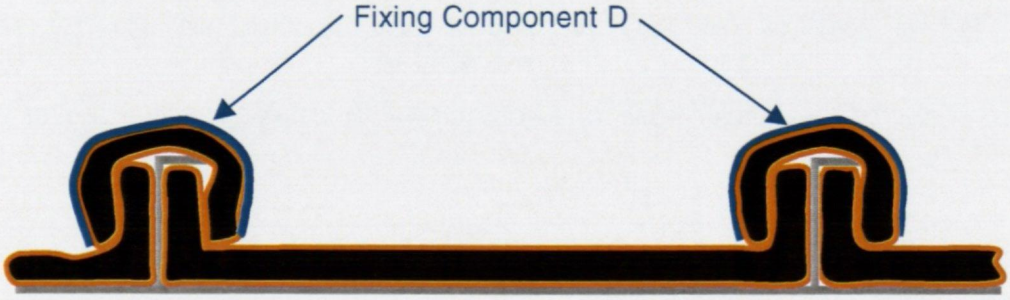


Figure 27 Test B9 Orcobloc in KN–80 (100mm Overlap)

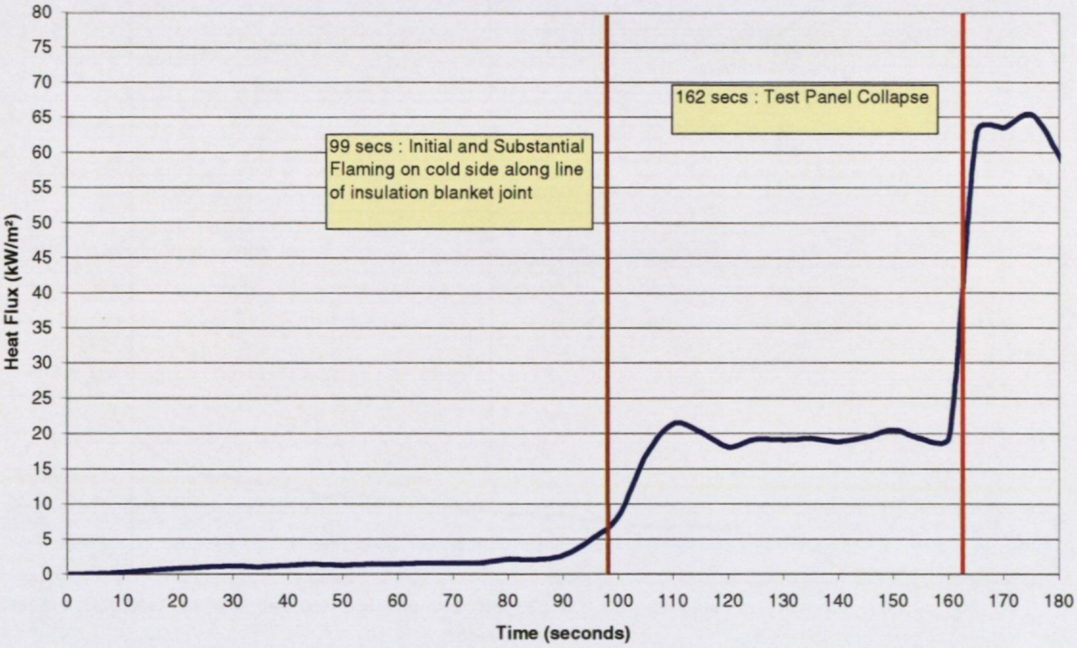


Figure 28 Heat Flux Profile for Test B8

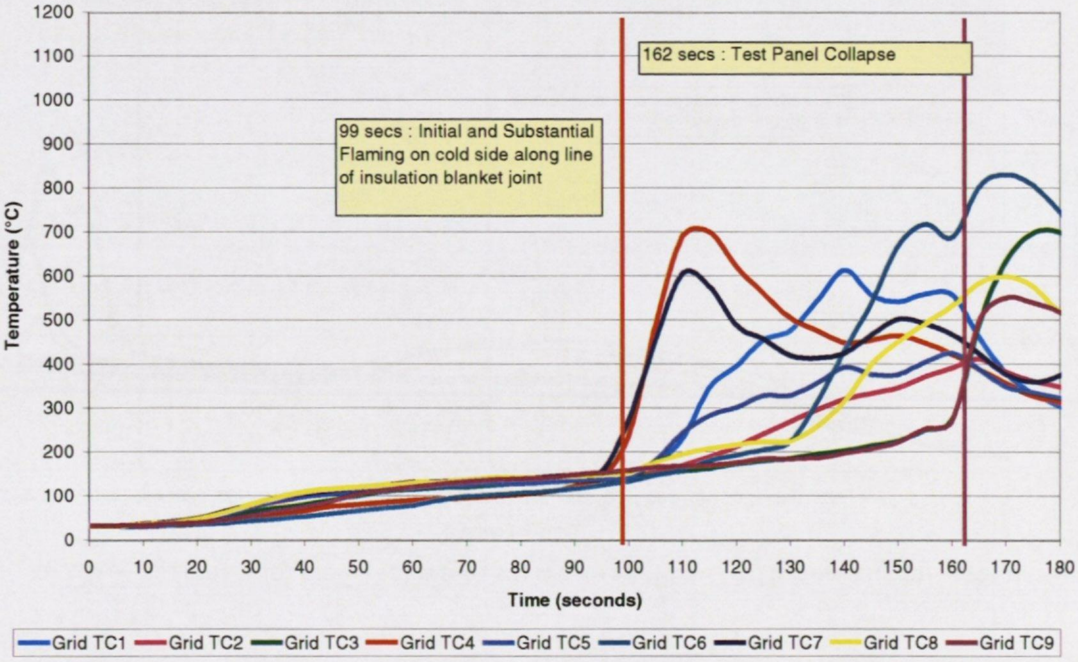


Figure 29 Thermocouple Grid Profile for Test B8

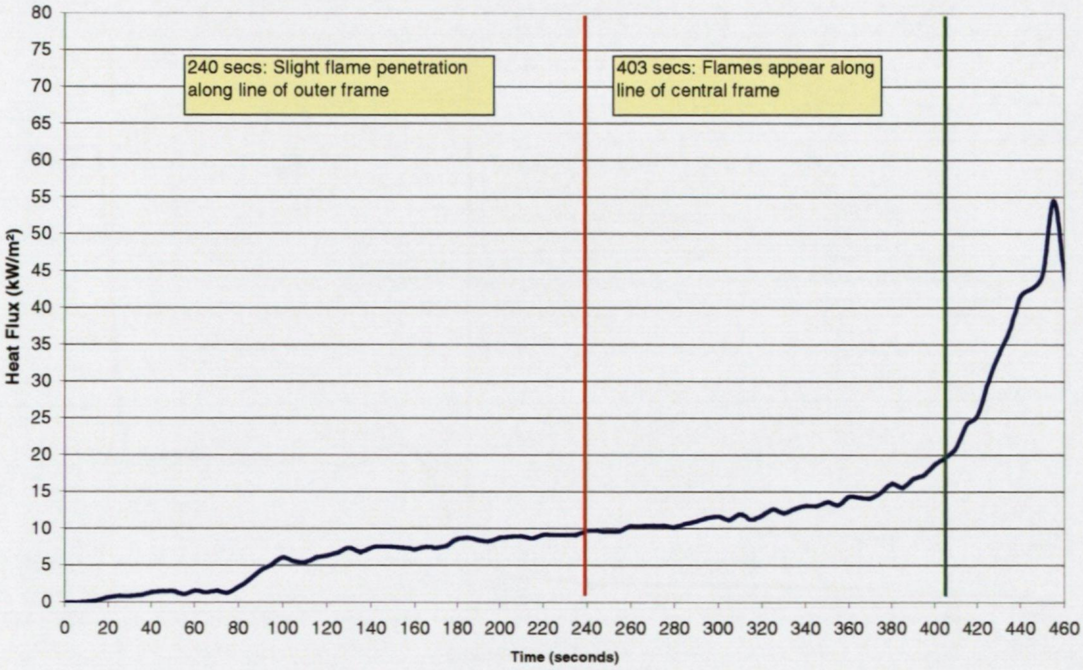


Figure 30 Heat Flux Profile for Test B9

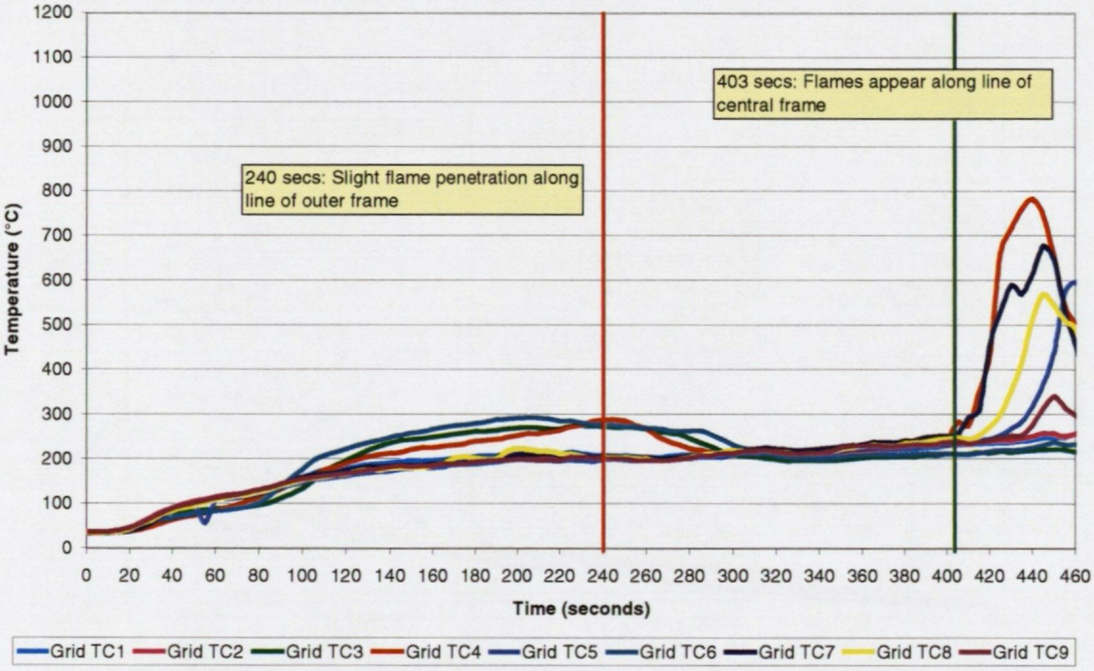


Figure 31 Thermocouple Grid Profile for Test B9

4.3 **Phase 3 – Retrofit Options**

The results from Phase 3 of the burnthrough test programme are presented in Table 9. The definition of burnthrough times are as described in Section 4.1.

For all of the Phase 3 tests the thermocouple grid and heat flux meter were in position.

Sketches of the test configurations and graphical heat flux and temperature grid profiles are shown in Figures 32 to 43. For the sketches of the test configurations the following key applies:

- **Microlite AA Insulation (0.60)**
- **Microlite AA Insulation (0.42)**
- **Orcobloc Insulation (0.42)**
- **Nextel encapsulated in KN-80 Bagging Film**
- **Nextel encapsulated in KN-80 Bagging Film**
- **AN-18R Bagging Film**
- **KN-80 Bagging Film**
- **Nextel**
- **Nextel**

Table 9 Phase 3 Test Results

Test No.	Insulation Material	Bagging Film	Gap/ Overlap	Additional Barrier	Density		Thickness		Burnthrough Time			Area of Failure
					Frame	Cap Strip	Frame	Cap Strip	Aluminium	Insulation	System	
			mm		kg/m3		mm	mm	secs	secs	secs	
C1	Microlite AA	AN-18R	0	Nextel	6.7	9.6	50.8	25.4	40	*	*	*See Section 4.3 and Table 10
C2	Microlite AA	AN-18R	0	Nextel & KN-80	9.6	9.6	50.8	25.4	42	*	*	*See Section 4.3 and Table 10
C3	Microlite AA	AN-18R	0	Nextel in KN-80	6.7	9.6	50.8	25.4	38	**	**	**See Section 4.3 and Table 11
C4	Microlite AA	AN-18R	0	Nextel in KN-80	6.7	9.6	50.8	25.4	42	**	**	**See Section 4.3 and Table 11

Test C1 & C2

For tests C1 and C2 sketches of the test sample configurations are provided in Figures 32 and 33. Observations of the mechanism of failure are provided in Table 10.

Table 10 Observations on Test C1

Test	Observations
C1	66 secs: Bagging film material starts to shrink away 81 secs: Insulation material starts to be consumed 112 secs: Slight flame appearance intermittently along centre frame
C2	253 secs: Slight flaming on cold side

In test C1 the stylised fuselage panel was lined with Nextel ceramic fibre as shown. The Nextel was positioned between the frames and extended up the side of each frame. An additional Nextel 'cap strip' was then positioned over the frame so that an overlap existed between each Nextel piece. Typically the overlap for frame 2 (centre frame) was 80mm and for frames 1 and 3 (outer frames) 30mm. The basic insulation configuration of Microlite AA and AN18R bagging film, was then installed on top of the Nextel layer using steel fixing pins.

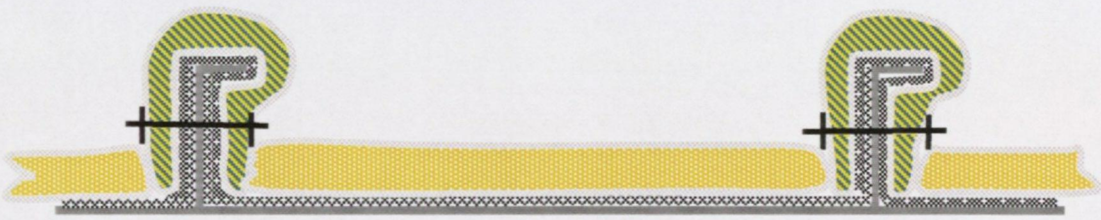


Figure 32 Test C1

In test C2 the basic insulation configuration was used with additional barriers. Each of the between frame blankets were made up of Microlite AA encased in AN-18R with a layer of Nextel on the hot side. The entire arrangement was then encapsulated in KN-80 film. For this test the between frame insulation blanket had a density of 9.6 kg/m^3 as shown. The Nextel and KN-80 covering extended up the side of each frame. For frames 1 and 3 (outer frames) the basic cap strips were then attached to the frames using steel fixing pins. For frame 2 (central frame) the same arrangement used for the between frame blankets was employed on the cap strip, so that the Nextel and KN-80 layers overlapped. Again steel fixing pins were used to install the insulation.

Figure 33 Test C2

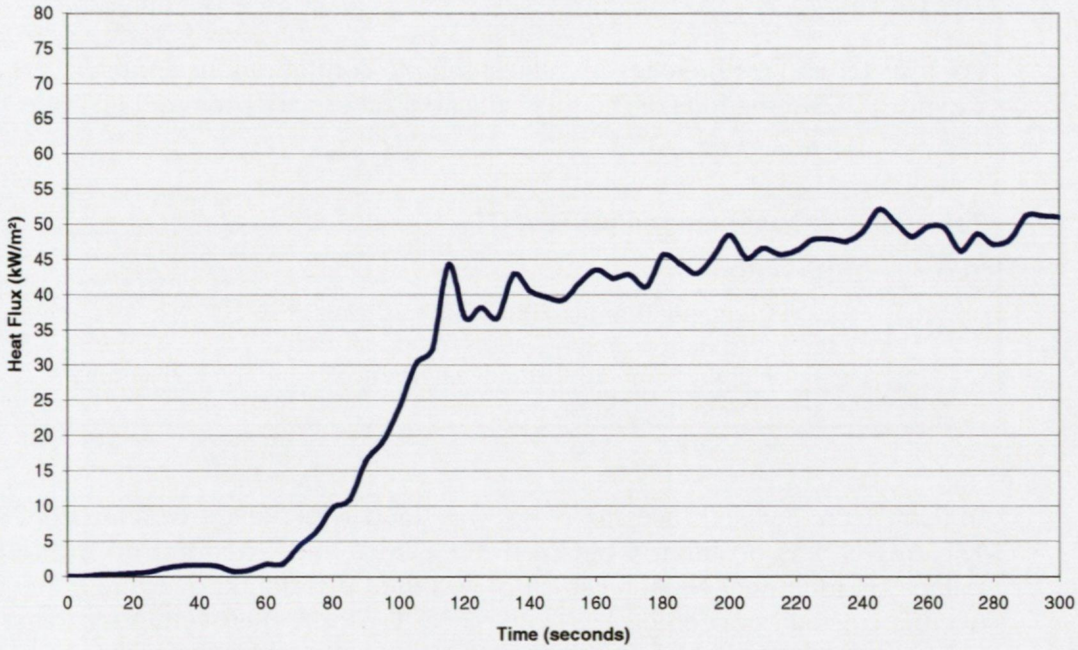


Figure 34 Heat Flux Profile for Test C1

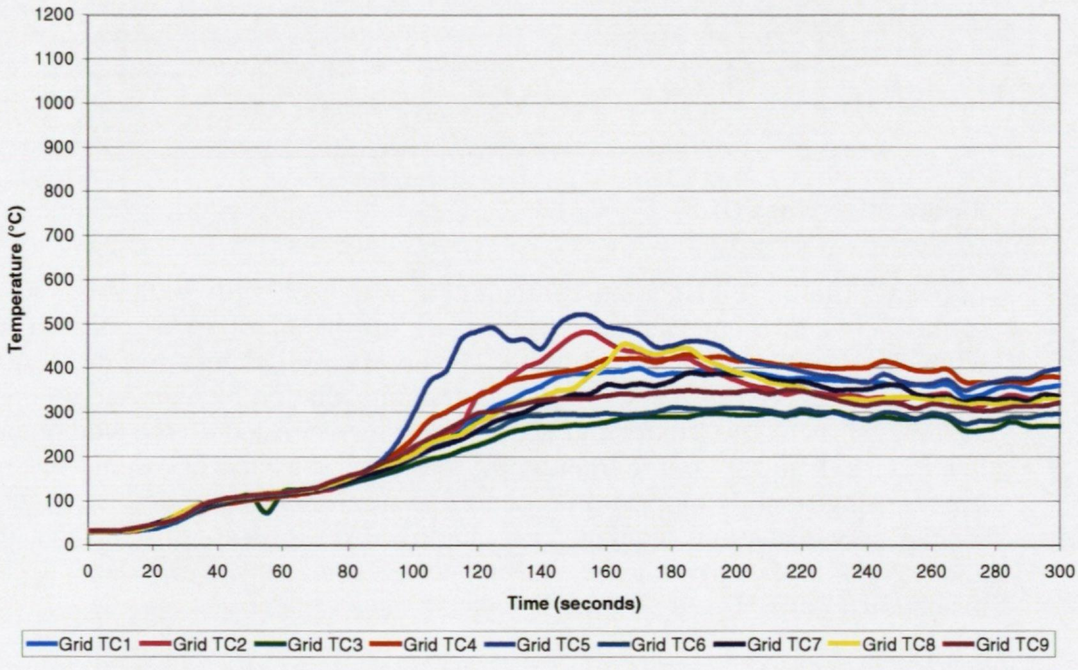


Figure 35 Thermocouple Grid Profile for Test C1

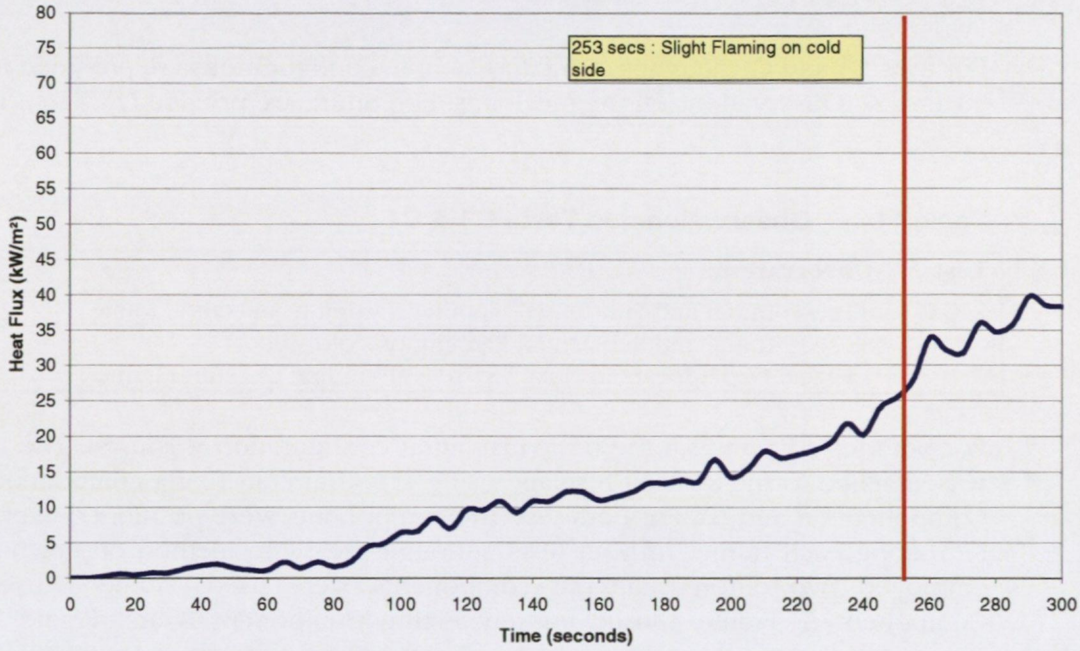


Figure 36 Heat Flux Profile for Test C2

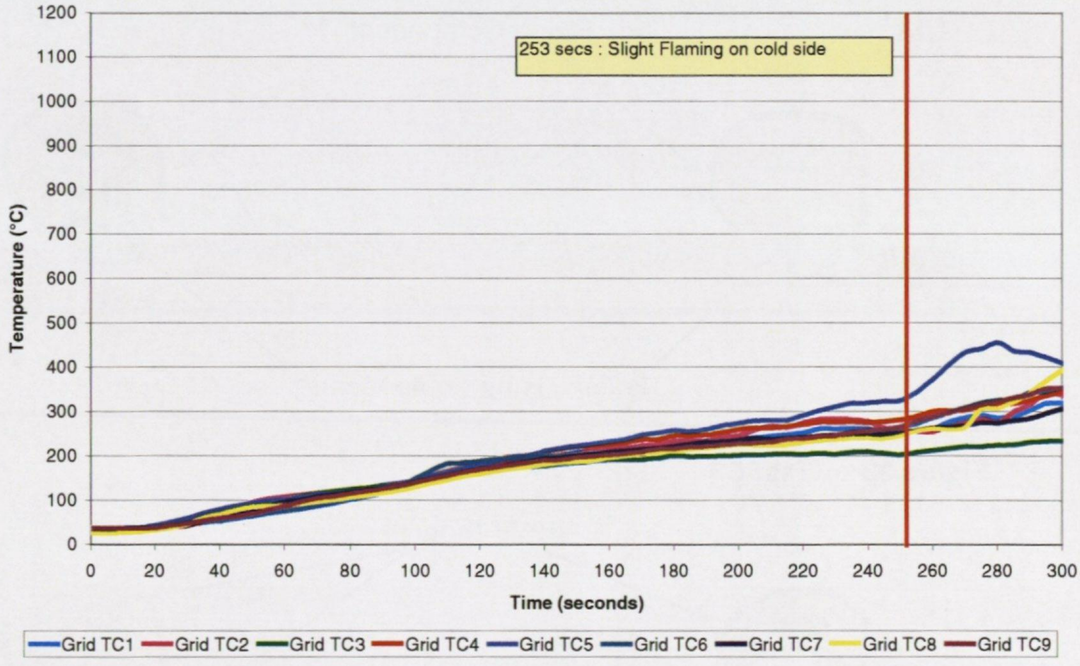


Figure 37 Thermocouple Grid Profile for Test C2

Test C3 & C4

For tests C3 and C4 sketches of the test sample configurations are provided in Figures 38 and 39. Observations on the mechanism of failure are provided in Table 11.

Table 11 Observations on Tests C3 & C4

Test	Observations
C3	80 secs: Initial and Substantial Flaming starting from central frame
C4	88 secs: Initial and Substantial Flaming on cold side 135 sec: Gap appears in Nextel system along line of central frame

For both tests C3 and C4 the basic insulation configuration was used. The insulation was attached to the stylised fuselage using actual aircraft fixing components (Fixing Components A and B). For both tests the components were positioned every 175mm (7") along each frame. In both tests although the same method of attachment was employed two different aircraft components were used. Frame 1 used Fixing Component A, Frame 3 used entirely Fixing Component B and Frame 2 used a mixture of the two. An additional barrier was then positioned on top of this basic insulation configuration. The additional barrier comprised Nextel encapsulated in KN-80. This was then installed so each section of Nextel/KN-80 overlapped. For test C3 this additional barrier was held in position using steel fixing clips, Fixing Component D as shown and for test C4 lengths of PVF tape were used.

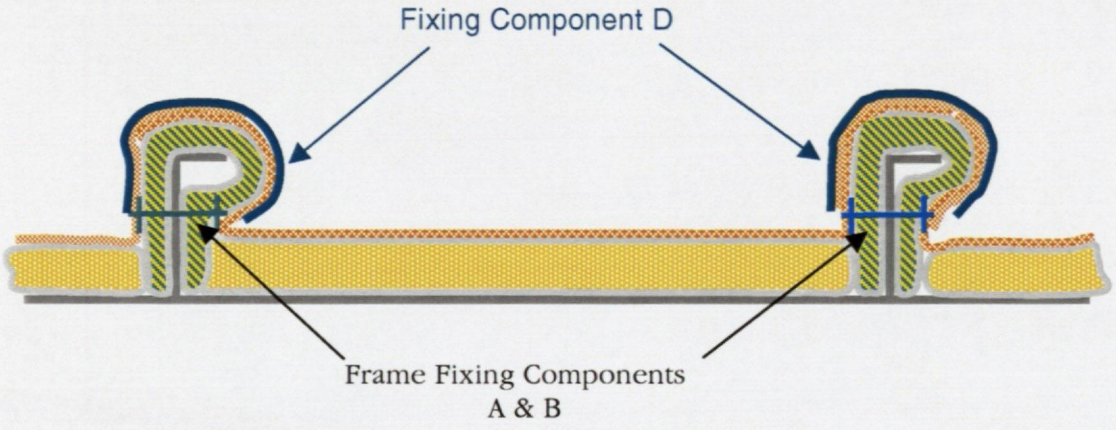


Figure 38 Test C3

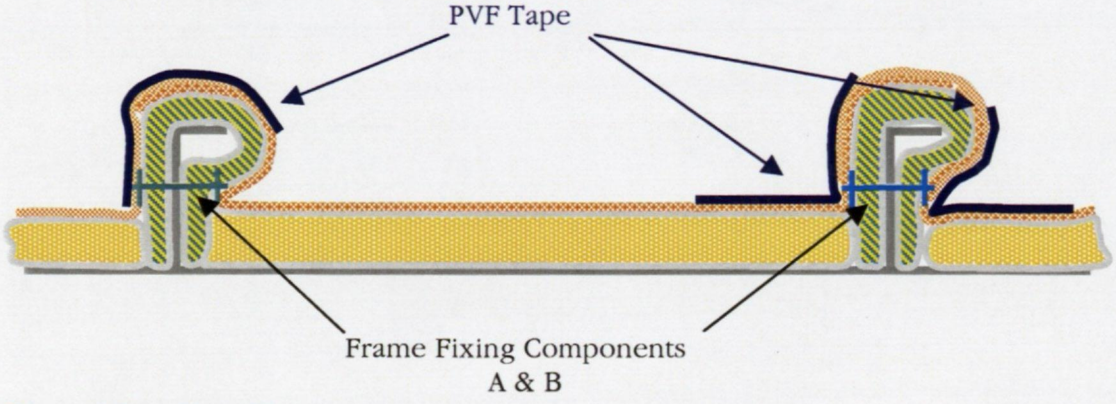


Figure 39 Test C4

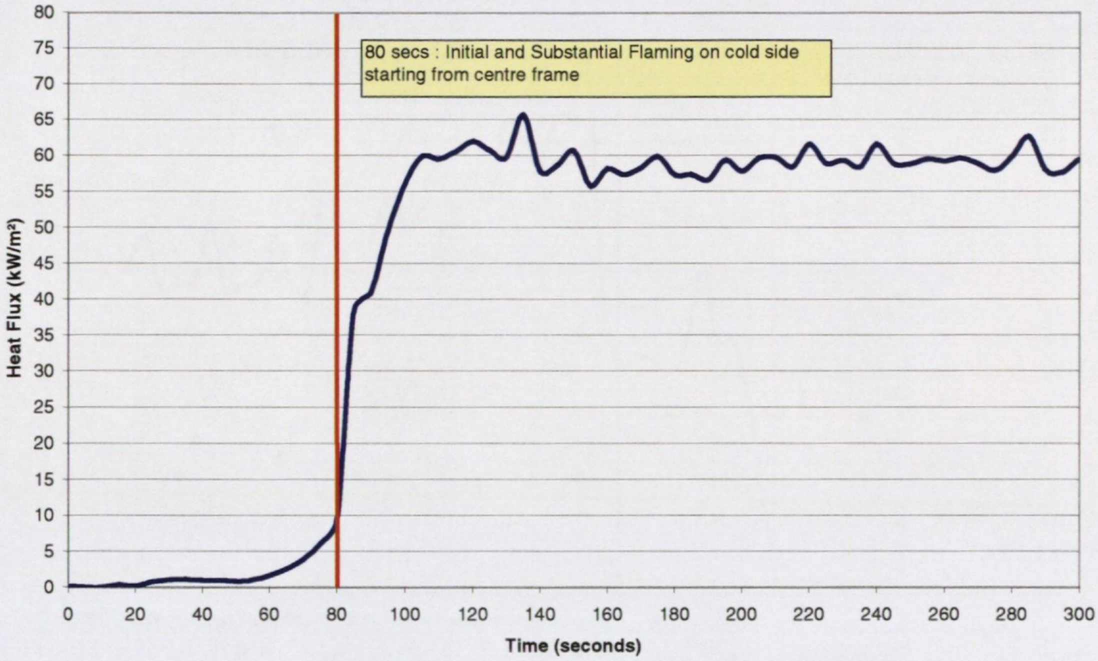


Figure 40 Heat Flux Profile for Test C3

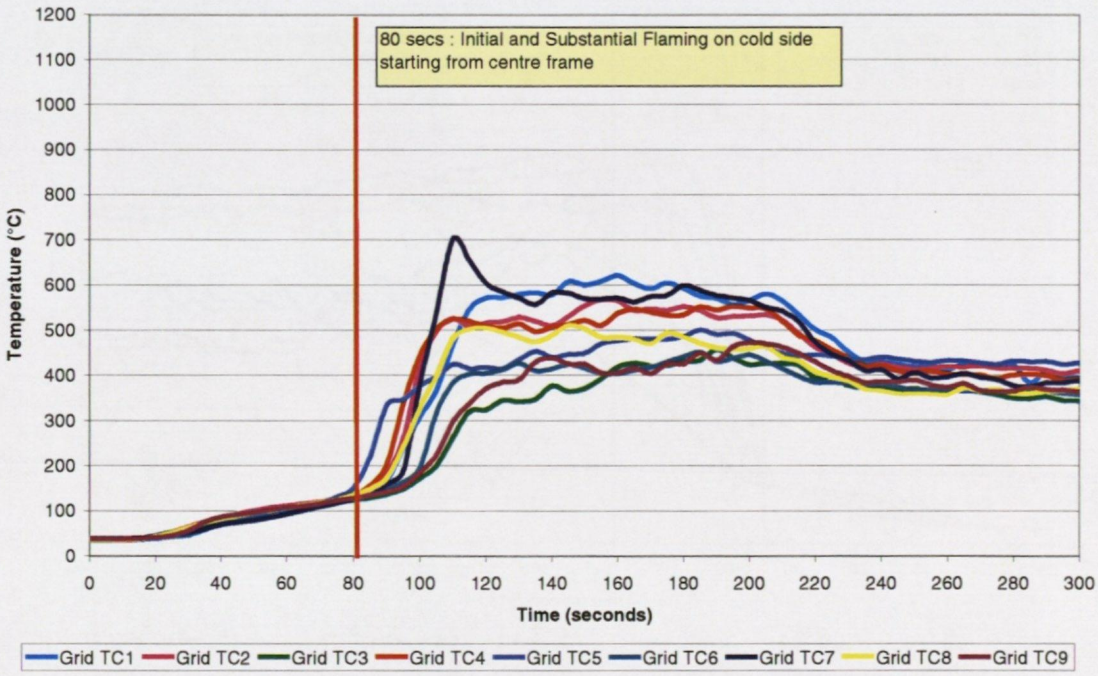


Figure 41 Thermocouple Grid Profile for Test C3

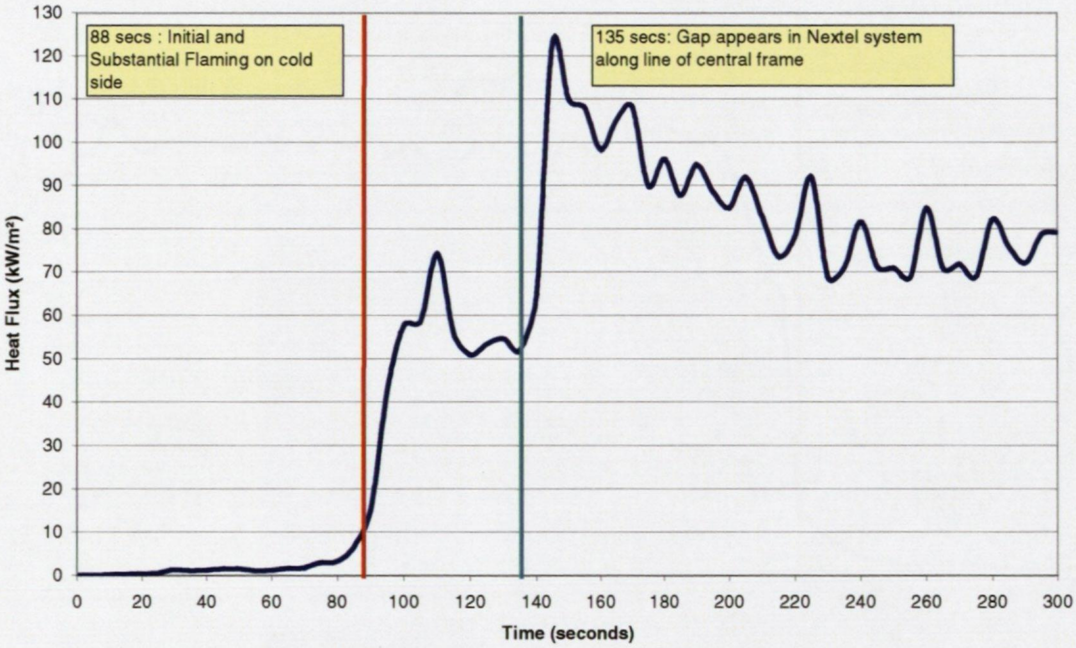


Figure 42 Heat Flux Profile for Test C4

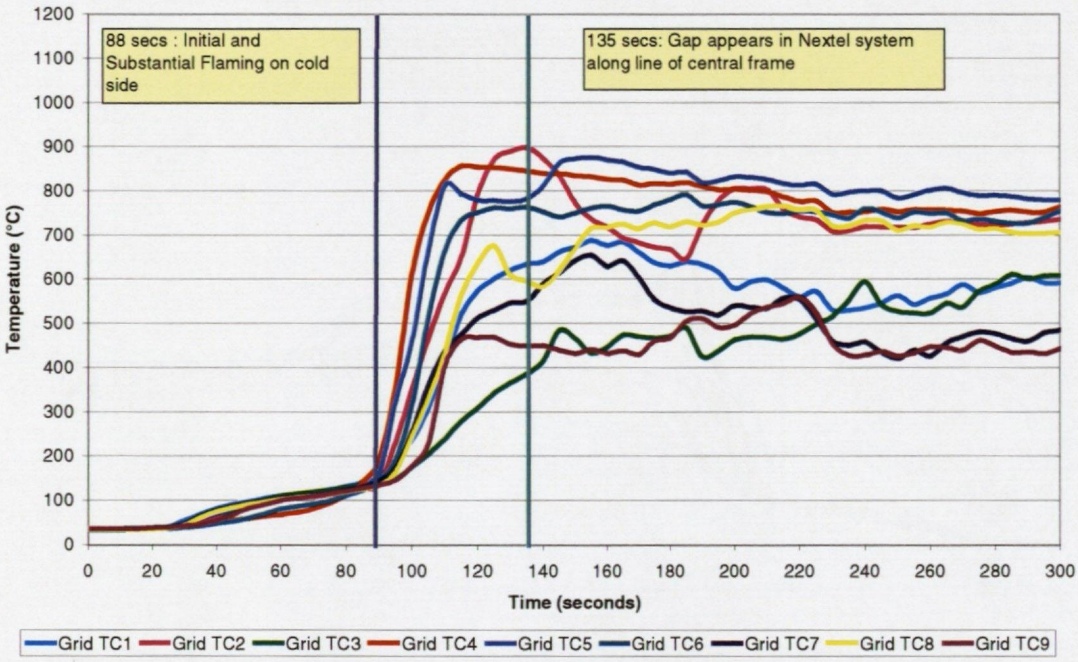


Figure 43 Thermocouple Grid Profile for Test C4

5 DISCUSSION

5.1 Phase 1 – Overlap

For tests A1 to A6 the system burnthrough times quoted in Table 1 correspond to substantial flame penetration of the test sample. For all the tests the system burnthrough times were less than 95 seconds. For tests A1 to A3 involving Microlite AA encapsulated in AN-18R and tests A4 to A6 involving Microlite AA encapsulated in KN-80 no discernible relationship is apparent between the degree of overlap and burnthrough time. Although for tests A1 and A4 where no overlap was present the initial area of failure was in the region of the frames, this contrasts to tests A2, A3, A5 and A6 where the initial area of failure was between the frames. An explanation of the lack of a relationship between overlap and system burnthrough time for these tests is that the material performance is poor so that material failure is occurring almost at the same time as system failure and the two are indistinguishable.

For test A7 involving Orcobloc and KN-80 with no overlap, the system burnthrough time of 126 seconds, corresponded to substantial flame penetration of the test sample. For test A7a again involving Orcobloc and KN-80 with no overlap, the system burnthrough time of 129 seconds, corresponded to initial flame penetration of the test sample along one of the outer frames. Flame penetration along the centre frame occurred after an additional 51 seconds. However even though no overlap was present the burnthrough times for the system for both tests were at least 30 seconds greater than in tests A1 to A6.

For tests A8 (50mm overlap) and A9 and A9a (100mm overlap) involving Orcobloc and KN-80 the system burnthrough times do not correspond to substantial flame penetration of the sample. For tests A8 and A9 the burnthrough times quoted correspond to a slight failure at a point along the perimeter of the sample which occurred after 135 and 270 seconds respectively. For both tests substantial flame penetration of the test sample did not occur until approximately 400 seconds into the test. For test A9a initial flame penetration occurred after 570 seconds with complete failure not occurring until approximately 615 seconds. The results from these tests raise the issue of appropriate burnthrough failure criteria. Burnthrough times determined by visual observation are by their nature subjective and for some test configurations do not provide enough information about the performance of the system. Burnthrough failure criteria are discussed in Section 5.4.

An important note for all the tests conducted in Phase 1 is that the insulation blankets were attached to the fuselage frame and to each other using steel fixing pins. The method of attachment was typical of actual aircraft fastening methods but the materials of construction were not. In using steel fixing pins the test programme was designed to eliminate the fixing components as variables and focus on investigating the relationship between burnthrough time and overlap.

5.2 Phase 2 – Fixing Methods

For all tests in Phase 2 the insulation material/bagging film combination was Orcobloc/KN80 with 100mm of overlap. This installation was found to be the most effective, with steel fixing pins, and thus any degradation in performance of the actual aircraft components, used in this phase, would be readily identified.

For tests B3 and B4 significant flame penetration of the test sample occurred after 142 and 163 seconds respectively. In Phase 1 for tests A9 and A9a, which were identical in terms of insulation materials used and configuration, significant flame penetration occurred after approximately 400 and 570 seconds respectively. The only difference between tests A9 and A9a, and B3 was that in test A9 steel fixing pins were used and in test B3 actual aircraft fixing components were used.

For tests B3 and B4 the pitch at which the fixing components were positioned was different, however for these tests there appeared to be no relationship between the pitch of these fixing components and the burnthrough time of the system. In test A9 post-test all of the steel fixing pins were intact, in tests B3 and B4 none of the fixing components were intact.

Test B8 was a representation of a typical aircraft installation. Substantial flame penetration of the system occurred after only 99 seconds.

Test B9 was identical to tests A9, A9a, B3 and B4 in terms of insulation materials used and configuration, and for this test significant flame penetration occurred after approximately 400 seconds. In this test steel fixing clips were used to attach the insulation blankets to the fuselage frame rather than through-frame fixing pins. On the outer frames the steel clips were positioned on a 14" pitch and on the central frame the clips were positioned every 7". The initial area of failure for this test was along the line of one of the outer frames suggesting that 14" is perhaps too long a pitch to secure the insulation effectively in position.

5.3 Phase 3 – Retrofit Options

As stated previously in this document the objective of Phase 3 was to investigate the potential of retrofit solutions to provide acceptable burnthrough penetration protection which do not involve replacement of existing thermal acoustic liner systems.

Tests C1 and C2 focused on providing a solution using existing insulation materials and bagging film that could be introduced onto an aircraft in the new build stage or during a major maintenance check. The exact details of each sample are provided in a previous section of this document. In both tests although slight flaming appeared on the cold side of the sample no actual flame penetration through the sample occurred for the duration of the test. Therefore using visual burnthrough as the failure criteria both tests resisted flame penetration for at least 240 seconds. However the heat flux and temperature grid profiles for both tests indicate that although no flame penetration occurred sufficient heat was transferred through the sample to result in significant heat flux and temperature levels on the cold face.

Tests C3 and C4 focused on providing a solution which could be installed on top of existing insulation systems with no need for current insulation systems to be removed. Again the exact details of each sample are provided in a previous section of this document. In test C3 substantial flaming occurred on the cold side after approximately 80 seconds resulting in elevated heat flux and temperature profiles on the cold side although no obvious flame penetration occurred. In test C4 substantial flaming occurred on the cold side after approximately 88 seconds resulting in elevated heat flux and temperature profiles on the cold side and after 135 seconds an obvious gap appeared in the Nextel/KN-80 system resulting in an even higher heat flux profile.

The results from Phase 3 are such that if visual flame penetration was the only method for determining failure of an insulation system then three out of four passes would have been achieved assuming 240 seconds as the pass criterion. If however another measure of system failure was applied such as time to a given heat flux level, for example 20kW/m^2, then all four tests would have failed.

5.4 Burnthrough Criteria

For a number of the tests described in this document the issue of burnthrough failure criteria has been an important one. Visual determination of burnthrough time is by its nature subjective. While visual burnthrough time is an important parameter to record it would perhaps be inappropriate for it to be used in isolation when considering an actual specification for burnthrough performance. A more appropriate failure criterion may involve time to reach a given heat flux or temperature level on the cold side of the test sample. This could then be used in conjunction with visual determination of burnthrough time to provide acceptable burnthrough failure criteria for such a burnthrough performance specification.

Table 12 presents heat flux data for the tests where the heat flux meter was in position. Three failure points were selected, 10, 15 and 20 kW/m^2 to study the implication of adopting various failure criteria. The values presented in the table below under the heading 'time to failure point' represent the time taken to reach the specified heat flux value from the point at which the aluminium fuselage panel failed. The visual time refers to the observed burnthrough time of the insulation system, again from the point at which the aluminium panel failed, where two values are presented two distinct events were observed. Using a value of 240 seconds as a pass criterion the figures in red are above this value.

Using a value of 10kW/m^2 as the failure point seems to be inappropriate. The values of 15 and 20 kW/m^2 however seem to represent a reasonable level of heat flux that could be used to define the burnthrough resistance of a system. For most of the tests the point at which these levels of heat flux are reached corresponds to substantial failure of the system. One of the test results that stands out is test C1 where a pass for the system would be obtained if visual burnthrough time was the only parameter used to determine burnthrough time. If however heat flux was used as the failure criterion then failure of the system would occur in less than 60 seconds.

Table 12 Phases 1, 2 and 3 Test Results Failure Point Analysis

Test	Time to Failure Point (sec)			Visual Time(s)
	10 kW/m^2	15 kW/m^2	20 kW/m^2	
A7a	101	131	181	80/221
A8	229	354	374	94/364
A9a	385	540	570	525
B3	103	108	108	100
B4	120	120	120	83/123
B8	64	64	69	58/121
B9	219	334	369	199/359
C1	40	50	55	NA
C2	130	195	235	211
C3	47	47	47	42
C4	48	48	53	46/93

6 CONCLUSIONS

6.1 Phase 1 – Overlap

The test programme indicates that for insulation systems where the fire resistance characteristics of the insulation materials are inferior then overlap has little or no effect on the burnthrough time of the system. For such systems burnthrough times determined by visual observation provide a reasonably good indication of the point at which failure of the system occurs.

For insulation systems employing insulation materials with superior fire resistance characteristics overlap is important and for such systems the time for substantial flame penetration to occur can be in excess of 240 seconds.

Overlaps in the region of 100 mm would appear to be adequate to realise the full potential of the burnthrough characteristics of the superior insulation materials.

Burnthrough times determined by visual observation for these systems do not provide a good enough indication of the point at which failure of the system occurs.

Overlaps of less than 100 mm (e.g. 50 mm) may provide an adequate level of burnthrough protection but this will require further testing that is based on failure criteria determined by the heat flux meter.

6.2 Phase 2 – Fixing Methods

The poor performance of insulation systems using materials that have demonstrated superior fire resistance characteristics in other tests highlights the importance of fixing methods and components in maintaining the integrity of a given insulation system. No tests have been conducted where plastic fasteners have survived, to realise the full potential of the insulation materials. To achieve high levels of burnthrough resistance it would appear that metallic fasteners, or fasteners having the fire resistant properties of metals, are required.

6.3 Phase 3 – Retrofit Options

Further testing is to be carried out on possible retrofit options. The tests carried out to date have not resulted in the determination of any satisfactory solutions.

6.4 Burnthrough Criteria

The results of the complex insulation configurations tested in Phase 3 highlight the importance of determining acceptable objective burnthrough failure criteria when trying to bring about improvements to the burnthrough performance of current and future insulation systems.

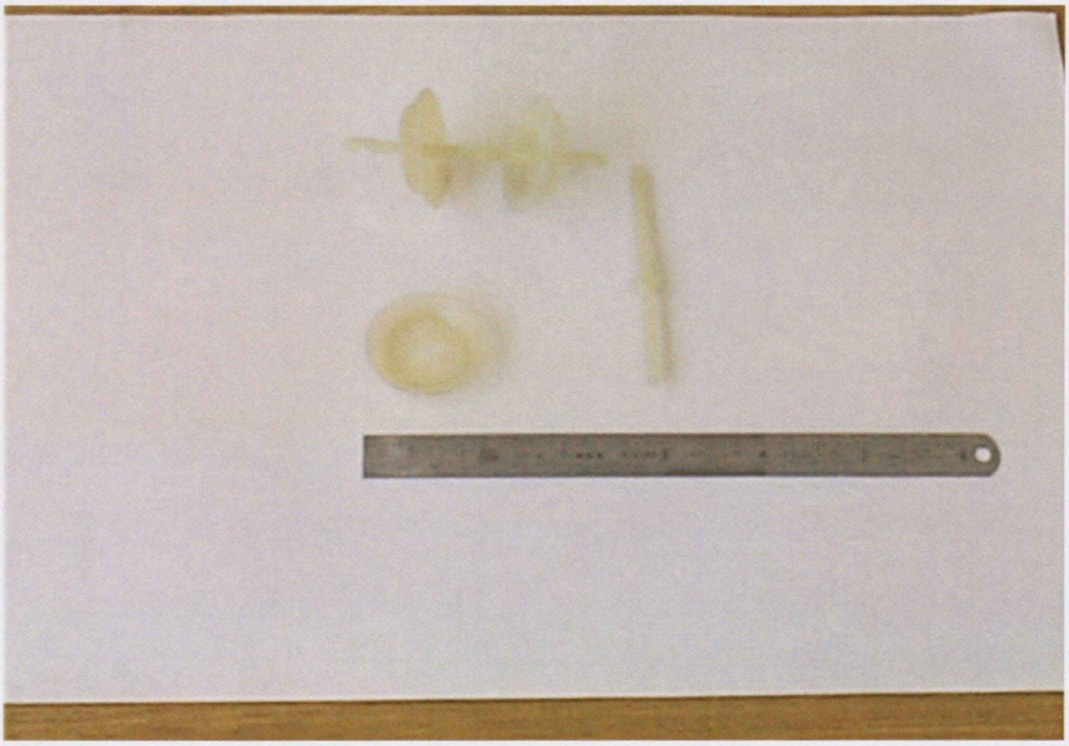
In developing a burnthrough performance specification, the use of visual observation to determine the failure of the system is not sufficient.

For such a specification to bring about meaningful improvements in the burnthrough performance of insulation systems then other factors need to be considered, such as heat flux.

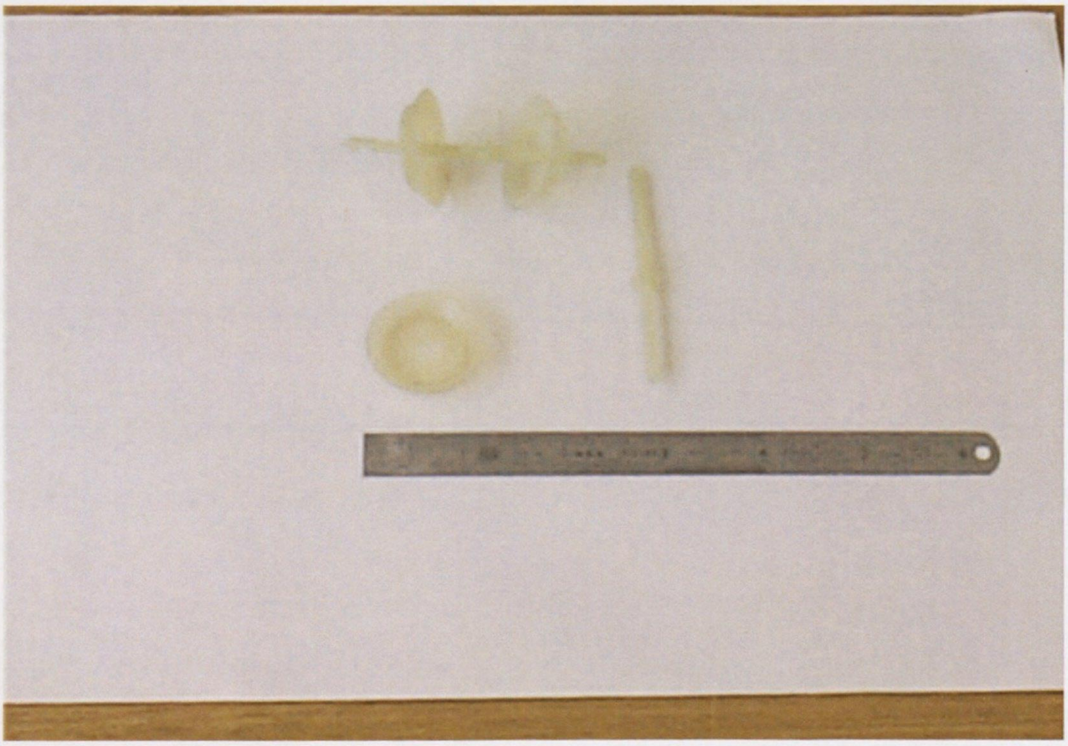
From the tests to date a value of approximately **20 kW/m^2** seems to correspond to substantial flame penetration in the majority of test samples and as such may well be an appropriate failure criterion.

Further tests are to be carried out to determine whether this level of heat flux represents a suitable failure criterion.

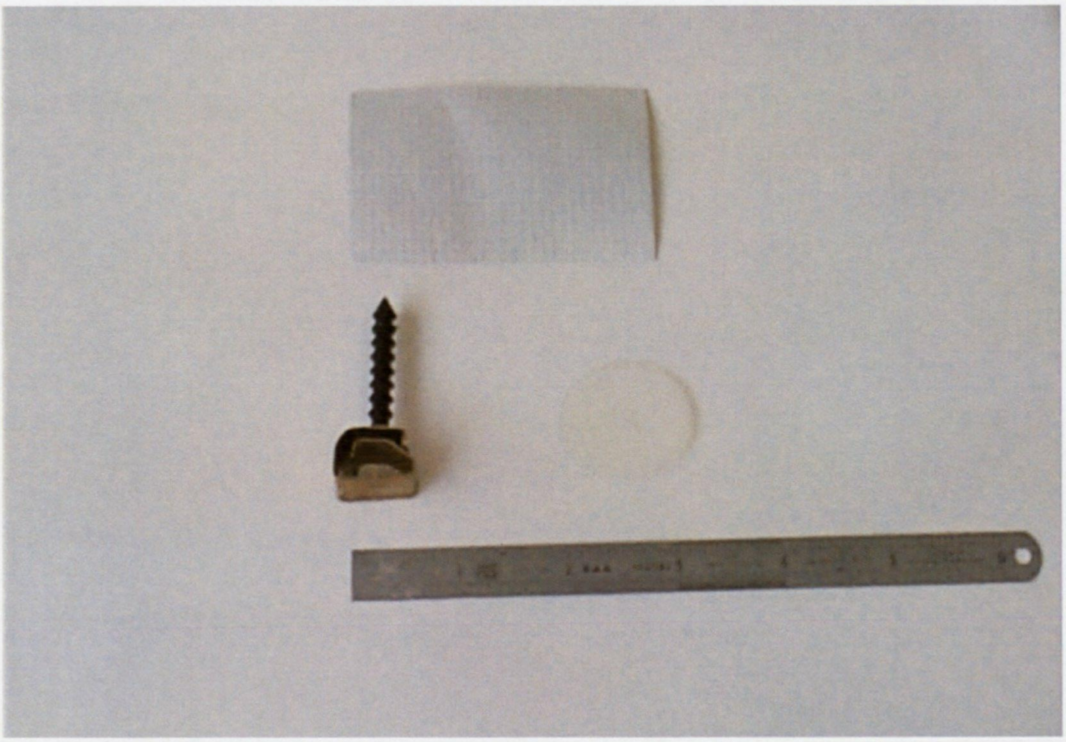
Appendix A Fixing Components



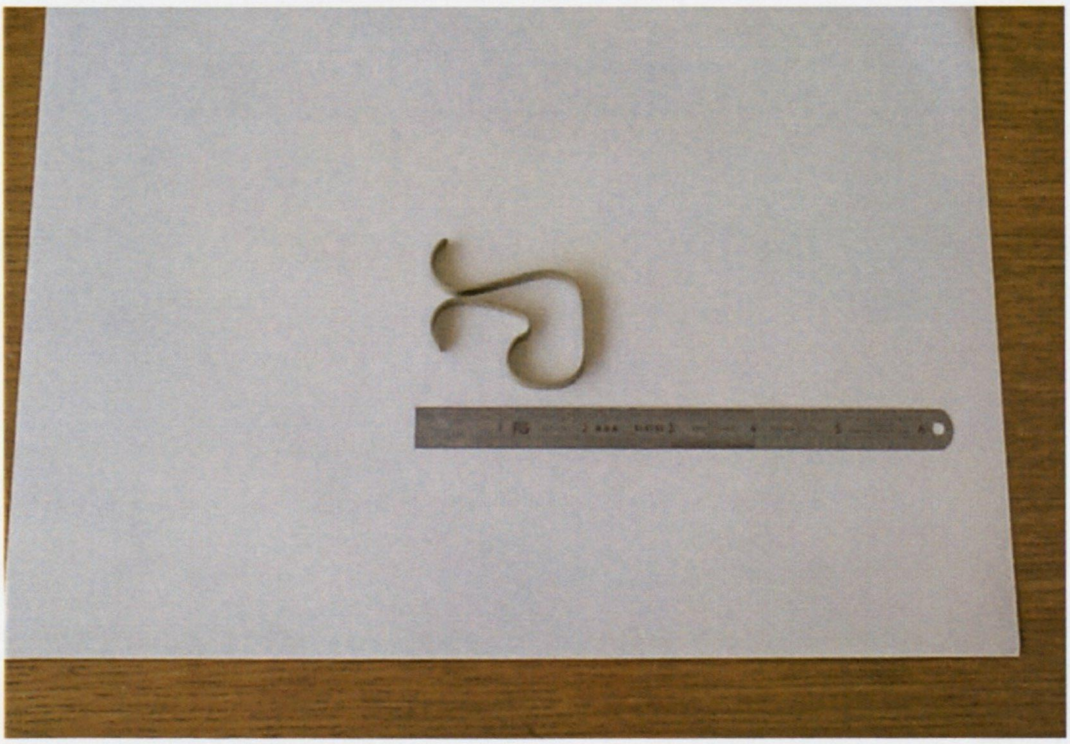
Fixing Component A



Fixing Component B



Fixing Component C plus Tape



Fixing Component D