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REPORT ON FUSELAGE BURNTHROUGH RESEARCH ADDRESSING INSTALLATION ASPECTS

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REPORT ON FUSELAGE BURNTHROUGH RESEARCH ADDRESSING INSTALLATION ASPECTS

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1 BACKGROUND & INTRODUCTION

Past accidents have illustrated the threat that exists from external fuel pool fires penetrating into the passenger cabin following post crash rupture of the aircraft fuel tanks.

Research has shown that the aircraft's aluminium skin currently offers little opportunity for fire hardening, and hence the focus of the research work has been centred on extending the burnthrough resistance of the thermal acoustic insulation systems. Testing has indicated that modifying, or replacing, fibreglass insulation systems with other currently available materials, can achieve appreciable gains in burnthrough resistance. By using thermal acoustic insulation systems having the appropriate fire resistant properties, which are installed in a controlled and consistent manner, the onset of fire penetration into the passenger cabin can be significantly delayed thus improving occupant evacuation capability.

The accident to the Swiss Air MD11 has focused attention on the flammability characteristics of thermal acoustic liners. The FAA issued a Notice of Proposed Rulemaking (NPRM) in the autumn of 2000 addressing both the burnthrough and flammability characteristics of insulation materials.

The development work carried out on the Darchem Flare Burnthrough rig over the past seven years has demonstrated its capability of representing 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 proposed regulatory changes.

2 DEFINITION OF TERMS

Burnthrough: The penetration of an external fire into the aircraft via the aircraft fuselage skin.

Pool Fire: An extensive ground fire originating from fuel spillage from damaged aircraft fuel tanks.

Thermal Acoustic Insulation: Any materials that are used to thermally and/or acoustically insulate the interior of the aircraft that are installed onto the aircraft skin.

Overlap at Frames: The length of insulation material that abuts against fuselage frames as illustrated in Figure 1.

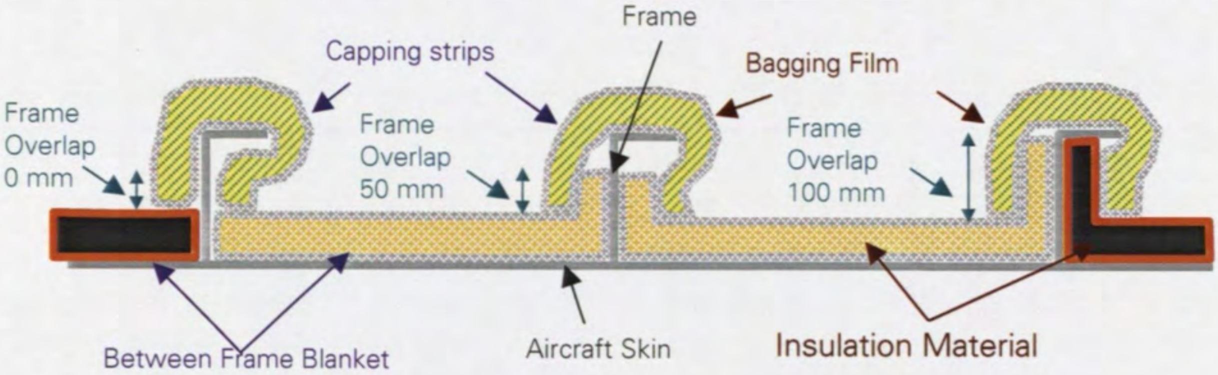


Figure 1 Fuselage Panel and Thermal Acoustic Insulation Basic Configuration

Overlapping of Insulation Bags: The length of insulation material that presents a double thickness of material against the aircraft skin for the purposes of joining two insulation bags. Figure 2 illustrates Overlapping of Insulation Bags.

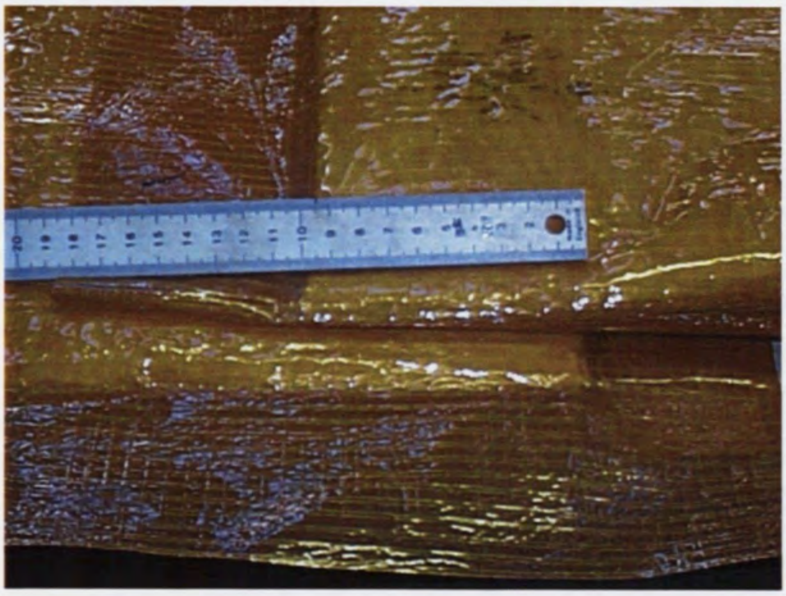


Figure 2 Illustration of Overlapping of Insulation Blankets

3 TEST METHODOLOGY

3.1 Description of Burnthrough Test Facility

Darchem Flare, funded by the CAA, has developed a burnthrough 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 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 resistant properties of fuselage materials.

3.1.1 *Burnthrough Facility*

The burnthrough facility, as shown in Figure 3, is a dedicated test furnace consisting of a mild steel frame and shell clad with 150 mm 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 250 mm above this aperture and sliding lid. When the furnace is 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.

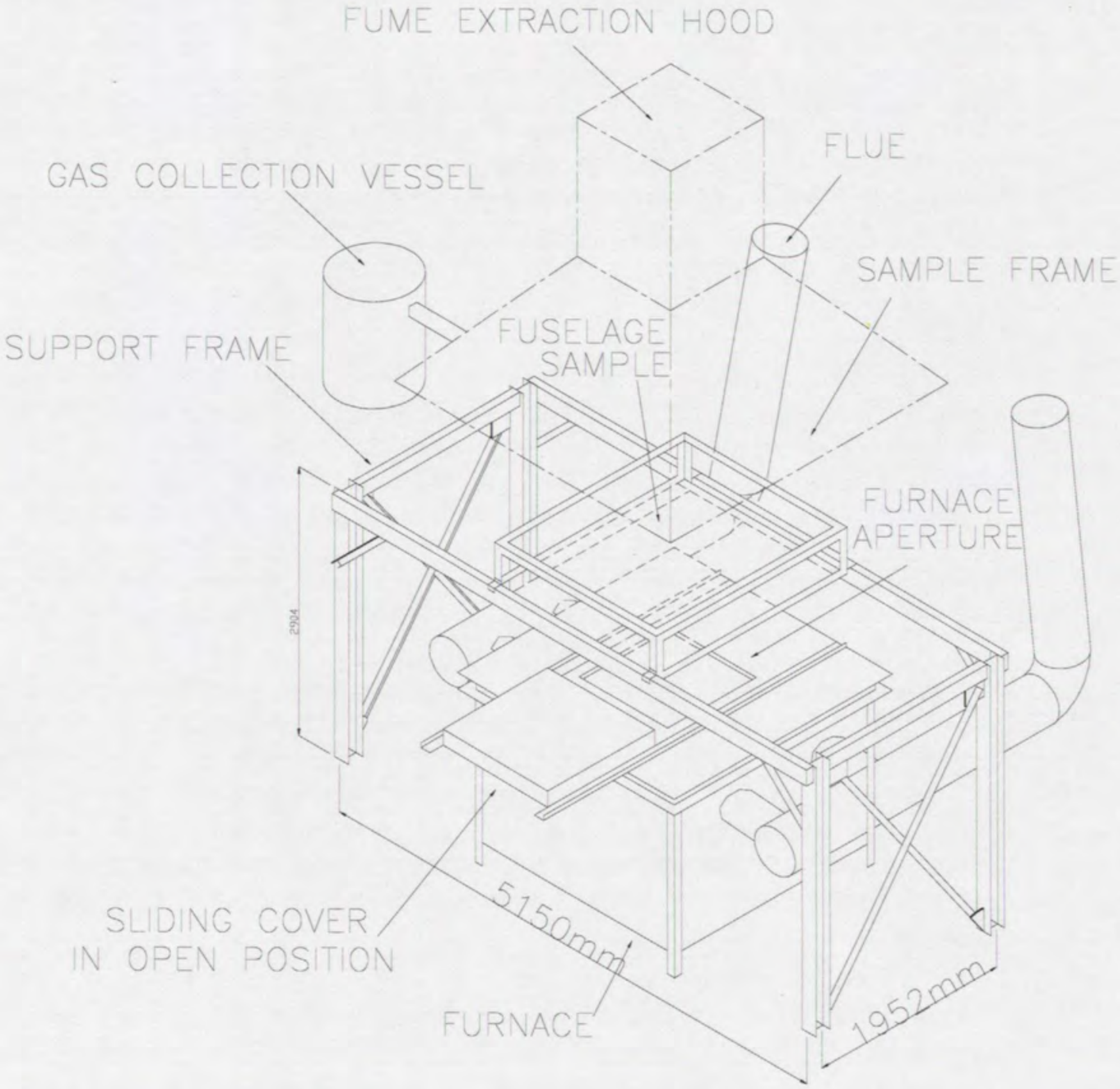


Figure 3 Medium Scale Burnthrough Facility

3.1.2 *Cold Sooting Facility*

The burnthrough facility described in Section 3.1.1 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 and thereby increasing the amount of radiant heat absorbed. 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, as shown in Figure 4, 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 wire 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 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.

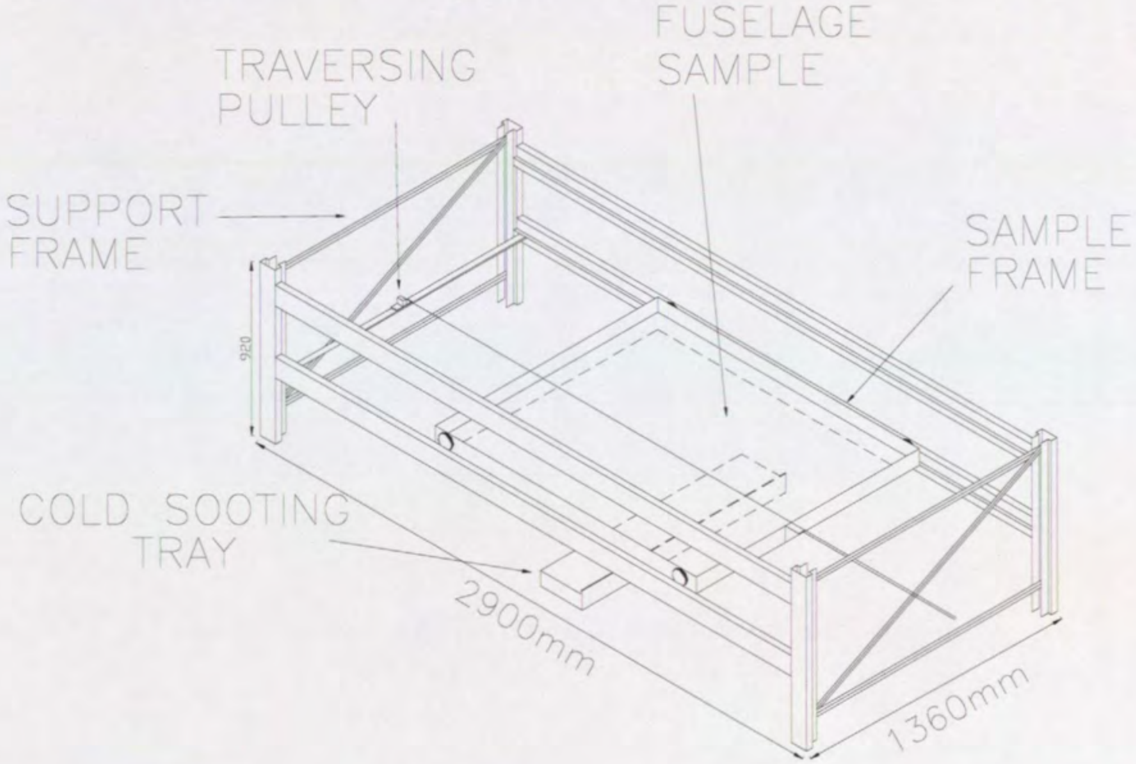


Figure 4 Cold Sooting Facility

3.2 Temperature, Heat Flux and Smoke 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 flame penetration, based on observation, was somewhat subjective. The original layout of thermocouple grid and heat flux measurement mounting platform utilised nine thermocouples and a single heat flux sensor. This was to enable temperature and heat flux measurements to be taken on the cold side of the test sample throughout the test. This original configuration was modified during the test programme to allow for the addition of another heat flux sensor. The revised configuration of the thermocouple grid and heat flux measurement sensors is shown in Figure 5.

The thermocouples used were metal-sheathed type k and were positioned at an approximate height of 100 mm from the hot face of the sample. The heat flux sensors used were manufactured by the Vatell Corporation, model number Thermogauge 1000-1A FAA, and were positioned at a distance of approximately 100 mm from the centre of the test panel on either side of the central frame, approximately 250 mm above the hot face of the panel.

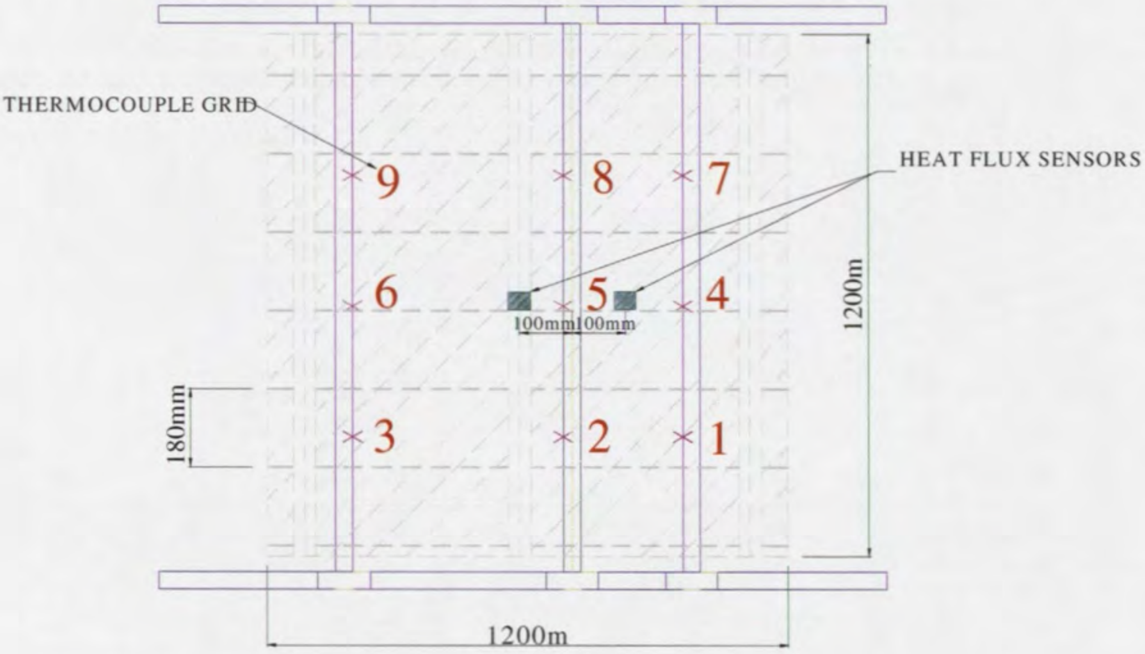


Figure 5 Thermocouple Grid and Heat Flux Meter Position

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.

3.3 Test Panel Configuration

The basic configuration of each test sample was comprised primarily of two components, either a stylised fuselage panel or an actual fuselage panel, and a thermal acoustic insulation system.

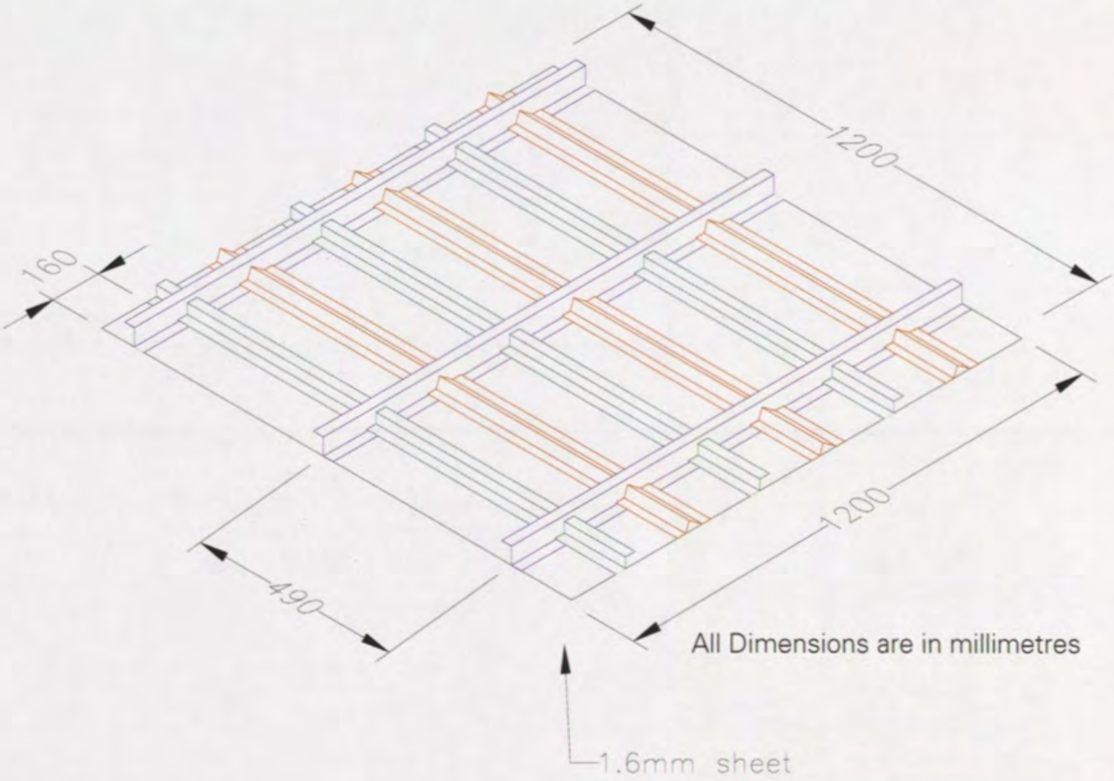
3.3.1 *The History of the Stylised Fuselage Panel*

Early fuselage burnthrough research 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 material burnthrough characteristics. However, if the potential of promising materials was to be realised, in terms of improved burnthrough resistance, then it was evident that 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. The development of this stylised fuselage panel made it possible to carry out repeatable tests on representative sizes of insulation blankets, as well as the method by which insulation blankets 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 Figure 6, Figure 7, Figure 8 and Figure 9. Riveted onto a plain aluminium panel are a number of structural features typical of those employed in fuselage construction. These features comprise three frame 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 considered that given the size of the stylised panel any degree of curvature that was introduced, to represent more closely 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 1.6 mm thick. This was used in the plain aluminium sheet and the stylised frame members. The stylised stringers were constructed of commercial grade aluminium 0.8 mm thick.



All Dimensions are in millimetres

Figure 6 Isometric View of Stylised Fuselage Panel

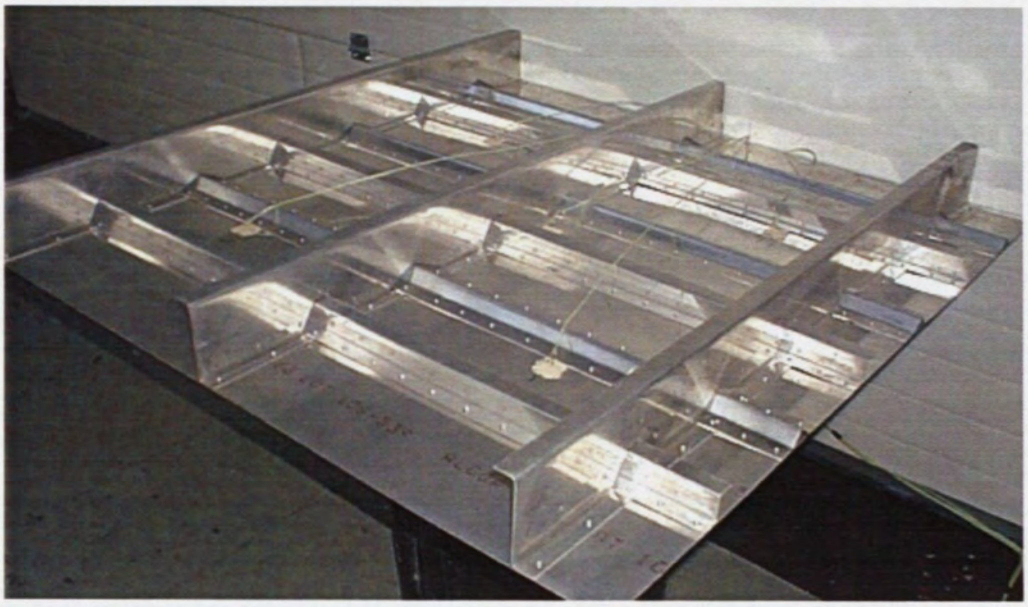
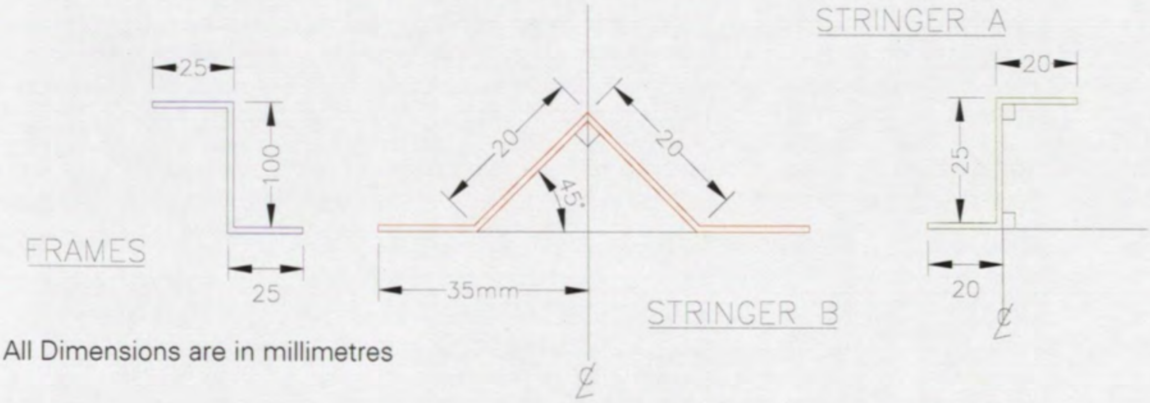


Figure 7 View of Stylised Fuselage Panel



All Dimensions are in millimetres

Figure 8 Frame and Stringer Arrangement for Stylised Fuselage Panel

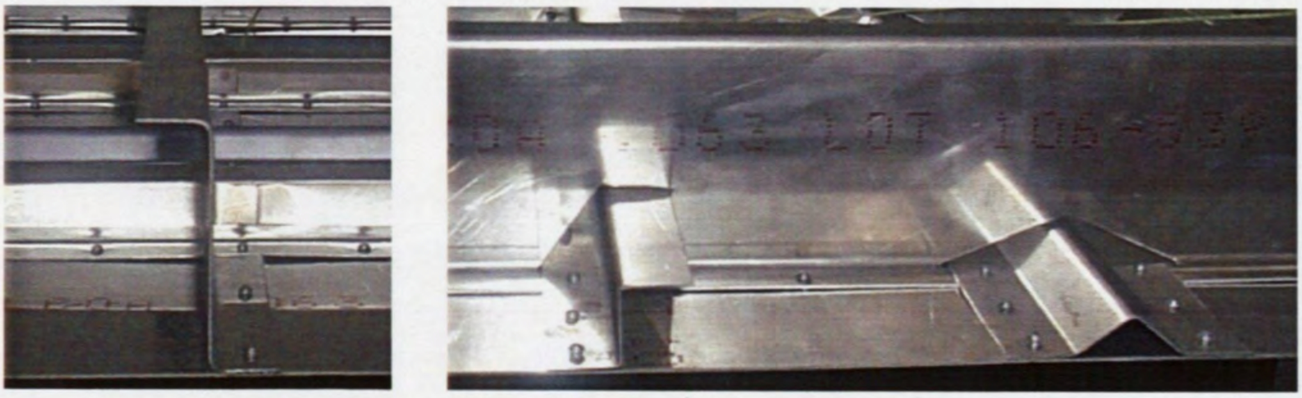


Figure 9 Frame and Stringer Arrangement for Stylised Fuselage Panel

3.3.2 *Actual Aircraft Panel*

Using the stylised fuselage panel for a number of tests enabled all of the aluminium test panels to be identical in configuration. This is one of the major advantages in using a stylised panel for comparative test work. Such a consistent configuration of test panel would have been harder to achieve using actual aircraft fuselage panels.

However, following completion of the research work, carried out to establish the important aspects of thermal acoustic liner installation, the final tests were carried out on actual aircraft panels. This philosophy was adopted to ensure that the test conditions were as representative as possible of the burnthrough protection that might be afforded from an actual aircraft installation. For some of the tests carried out, actual aircraft panels proved to present a more severe challenge to the installation than stylised panels. This aspect is discussed in greater detail in Section 4.

The aircraft panels used for the burnthrough tests were taken from cut-outs from an in-service aircraft that had undergone conversion to a freight aircraft. In an attempt to ensure consistency for each test all of the panels used were thoroughly cleaned before use and where possible the panels were chosen so that the configurations of frames and stringers were similar to the configuration of the stylised panel and each other. A typical aircraft panel is shown in Figure 10 and Figure 11.

Figure 10 View of Actual Aircraft Panel

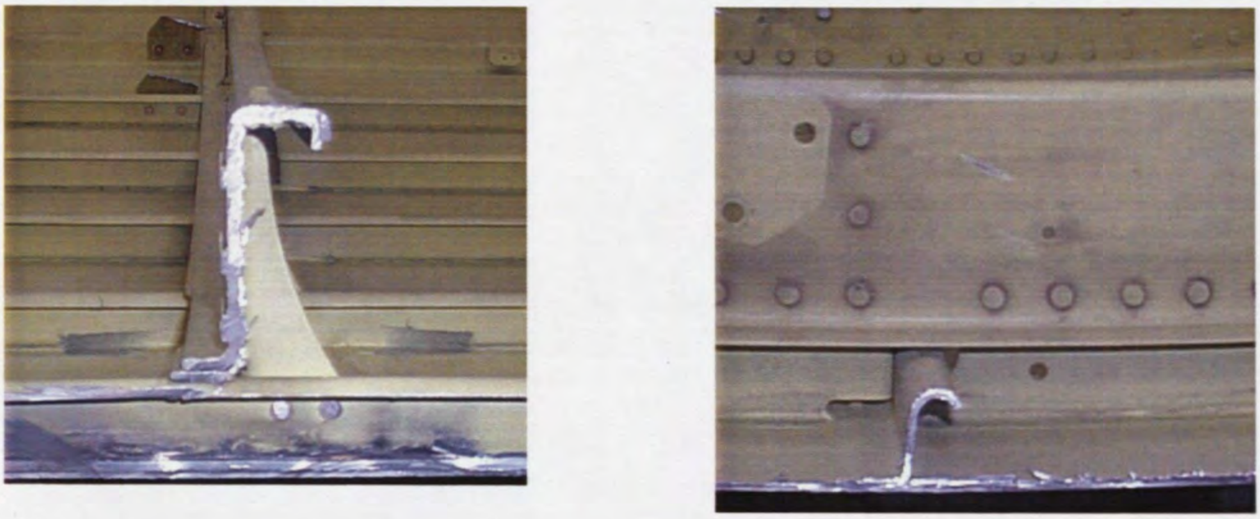


Figure 11 Frame and Stringer Details on Actual Aircraft panel

3.3.3 *Thermal Acoustic Insulation System*

Since the prime purpose of the research study was to determine the installation aspects that are critical to burnthrough times the materials used for the thermal acoustic insulation systems were standardised.

Although at this stage of the test programme a number of different configurations have been tested, the thermal acoustic insulation configuration used as the baseline is shown in Figure 12. This configuration comprises four between-frame blankets of two sizes, which cover the majority of the sample and three capping strips, which cover the frames.

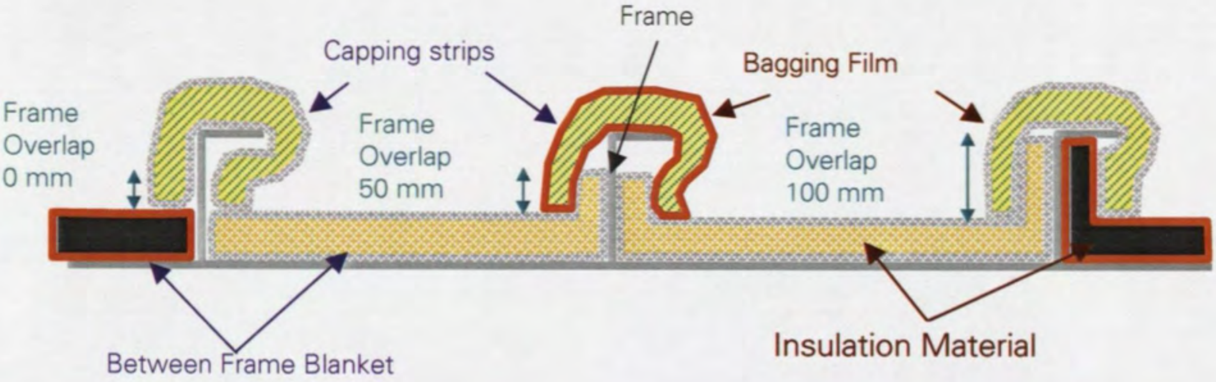


Figure 12 Thermal Acoustic Insulation Basic Configuration

The types of insulation materials and bagging films used for the programme are summarised below in Table 1 and Table 2.

Table 1 Insulation Materials

Microlite AA	
Description	Microlite AA is a fibreglass material, which is currently used on the majority of transport category aircraft.
Typical Densities	6.7 kg/m^3 for between frame blankets 9.6 kg/m^3 for the capping strips
Nominal Thickness	50.8 mm for between frame blankets 25.4 mm for capping strips
Orcobloc	
Description	Orcobloc is an Orcon product designation for insulation batting made using Curlon fibres. Curlon is comprised of heat-treated oxidised polyacrylonitrile fibre and is similar in appearance to fibreglass but black in colour.
Typical Densities	6.7 kg/m^3 for between frame blankets 9.6 kg/m^3 for the capping strips
Nominal Thickness	50.8 mm for between frame blankets 25.4 mm for capping strips

All the insulation materials tested were sealed in water-resistant polymer bags as described below.

Table 2 Bagging Film

Bagging Film	
Orcofilm AN-18R	A metallized polyvinyl fluoride based film, reinforced on one side with polyester yarns.
Orcofilm KN-80	A polyimide based film, reinforced on one side with nylon yarns.
Insulfab 330	A metallized polyvinyl fluoride based film manufactured using a proprietary adhesive bonding fabric.

3.4 Fixing Methods

To represent the configurations present in an actual aircraft a number of standard fixing components were used. These were of three main types:

3.4.1 *Through Frame Fixing Pins*

Through frame fixing pins are an insulation system attachment method by which a single or two-piece metallic or plastic component is located through the aircraft fuselage frame. The insulation system is pushed on to the pin and held in place using a washer. This method of installation results in the insulation material being pierced in the region of the pin. Typical through frame fixing pins are shown in Figure 13 and Figure 14.

Figure 13 Plastic Through Frame Fixing Component and Washer

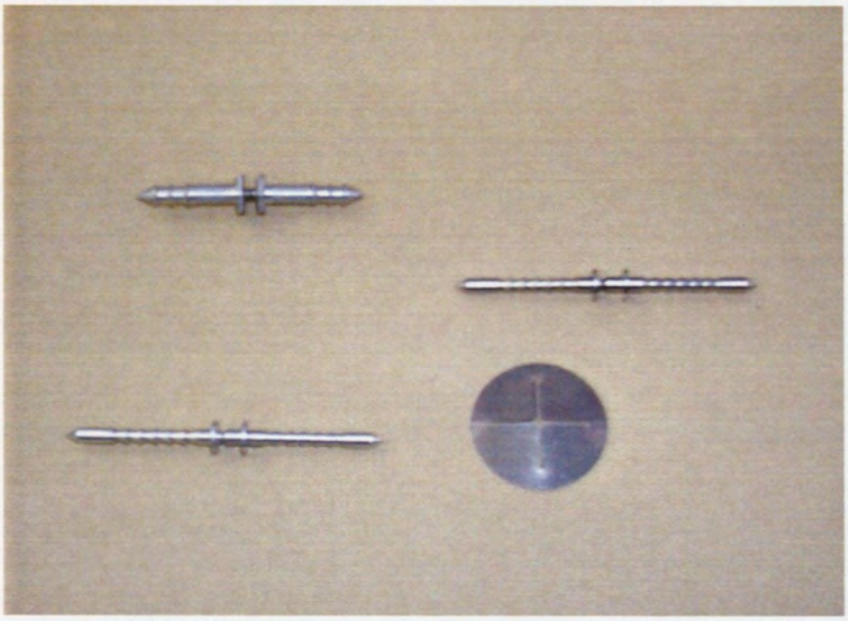


Figure 14 Metallic Through Frame Fixing Component and Washer

3.4.2 *Over Frame Clips*

Over frame fixing clips are an attachment method by which a spring metallic or plastic component is located over the aircraft frame and mechanically holds the capping strip and the between frame blanket together at the frame. Typical over frame fixing clips are shown in Figure 15.

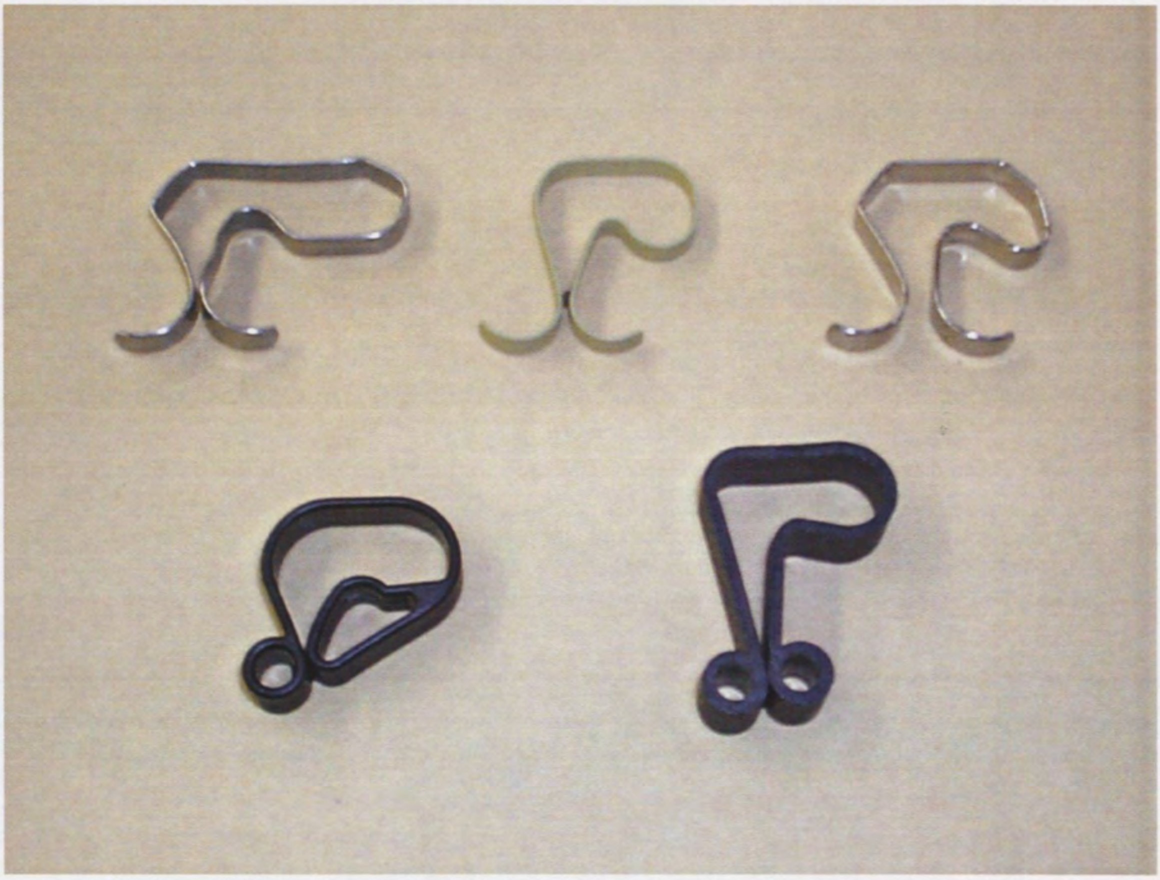


Figure 15 Metallic & Plastic Over Frame Clips

3.4.3 *Stringer Fixings*

Stringer fixings are similar to through frame pins in that the insulation system is pushed onto the pin and held in place using a washer. This method of installation results in the insulation material being pierced in the region of the pin. The fixings themselves are located on the stringers, typically by means of a clip attached to the fixing pin.

A typical stringer pin as located on the fuselage stringer, and with insulation installed, is shown in Figure 16 and Figure 17.

Figure 16 Stringer Pin/Clip Attachments to Stringer

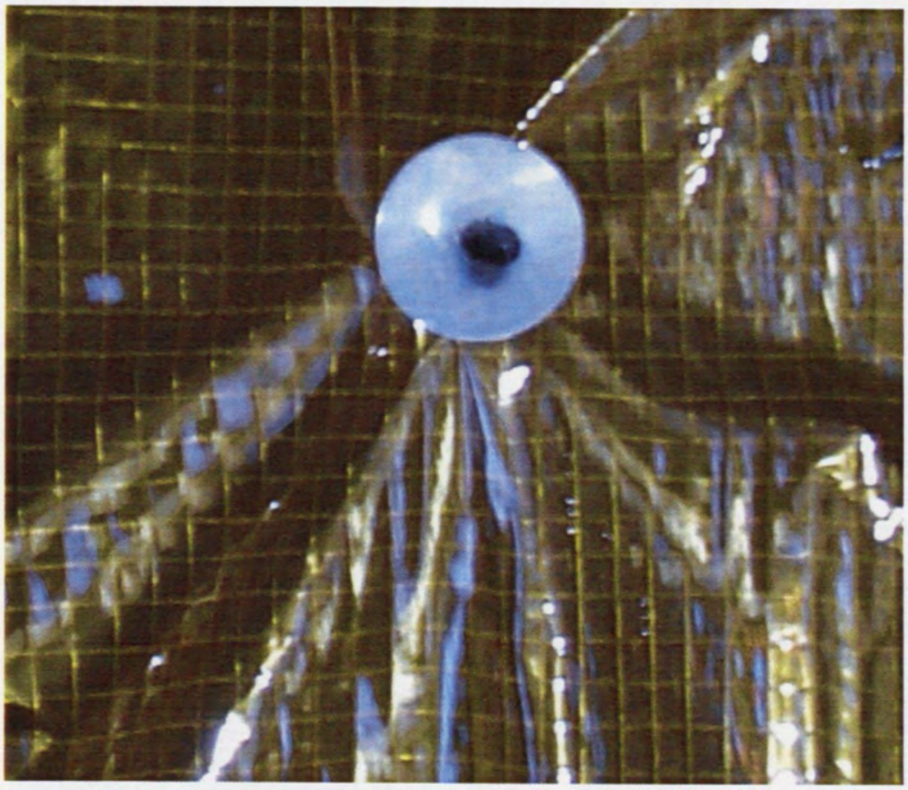


Figure 17 Stringer Pin/Clip with Insulation Installed

3.5 Burnthrough Criteria

Visual determination of burnthrough time is by its nature subjective. From the many tests carried out during this research programme it became evident that this subjectivity would lead to large variations in the assessed burnthrough time. 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.

The test programme showed that where flame penetration was sudden and widespread across the panel, thermocouples would indicate rapid increases in temperature. However it was also found that in many instances the recorded temperatures across the cold surface could vary quite considerably, often due to localised small flames breaking out on the specimen.

It was therefore considered that heat flux might be a better failure criterion than temperature. The FAA decision to use heat flux on their small-scale rig, to define the failure point, meant that there would also be commonality between the two rigs in terms of the means of determining burnthrough times.

Many tests were carried out using different materials and installation characteristics where heat flux measurements were recorded throughout the test. Based on these results the failure point was taken as corresponding to a heat flux measurement of 20 kW/m^2 for the following reasons:

(i) Where flame penetration was sudden and widespread, visual flame penetration, rapid temperature increase and a heat flux reading in the region of 20 kW/m^2 all occurred during a small time interval.

(ii) Figure 18 and Figure 19 illustrate the heat flux histories for seven tests. The target burnthrough time of at least 240 seconds is shown on both figures. It may be seen that tests A7a, B3, B4 and B8 did not meet the target burnthrough times (irrespective of the heat flux failure criterion). Tests A8, A9a and B9 were considered to have met the 240-second target burnthrough time for the insulation material. It may be seen that for all three of these successful tests, that the heat flux readings tend to rise rapidly in the range 15 to 20 kW/m^2. The choice of 20 kW/m^2 as the failure criterion therefore has the advantage that small variations in the heat flux reading produce small changes in the derived burnthrough time. At lower heat flux levels small variations in the recorded values could result in larger variations in the derived burnthrough time.

The level of 20 kW/m^2 is also at a similar level to that used by the FAA as the failure criterion on their small-scale test rig (2.0 Btu/ft^2 sec – approximately 22 kW/m^2).

All of the testing carried out into the installation characteristics of thermal acoustic liners, on the Darchem rig, utilised either a stylised panel or an actual aircraft panel. The time to burnthrough the entire system (panel and thermal acoustic liner) was measured on all tests using the burnthrough criteria described above. The target burnthrough time for the total system was taken as five minutes, and since the time to burn through a panel is typically one minute, the target time for burnthrough of the insulation material was taken as four minutes. This is compatible with the burnthrough acceptance time for materials used by the FAA on their small-scale rig.

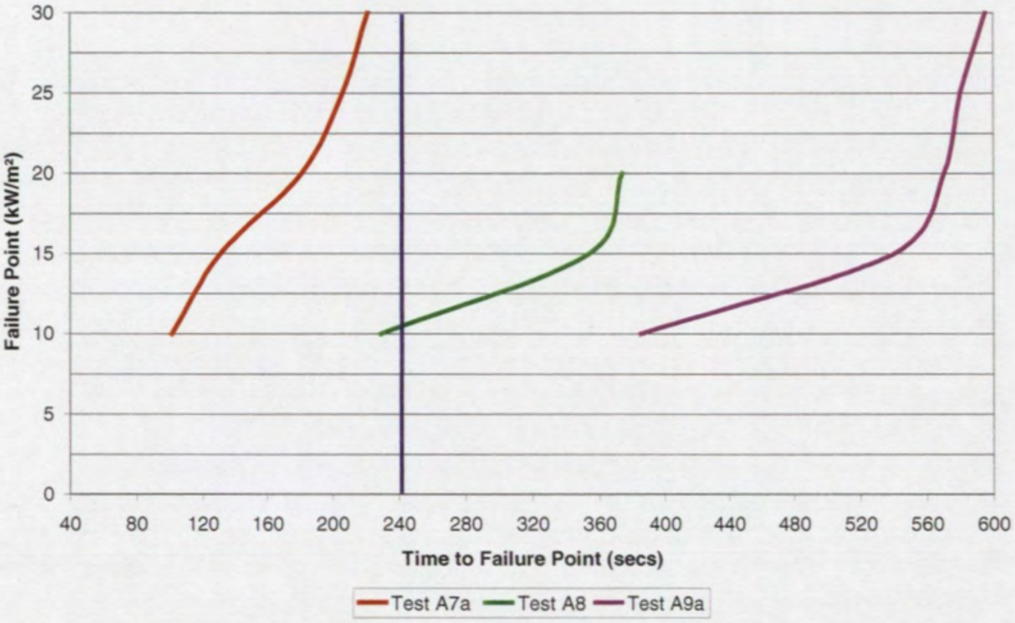


Figure 18 Phase 1 Failure Point Analysis

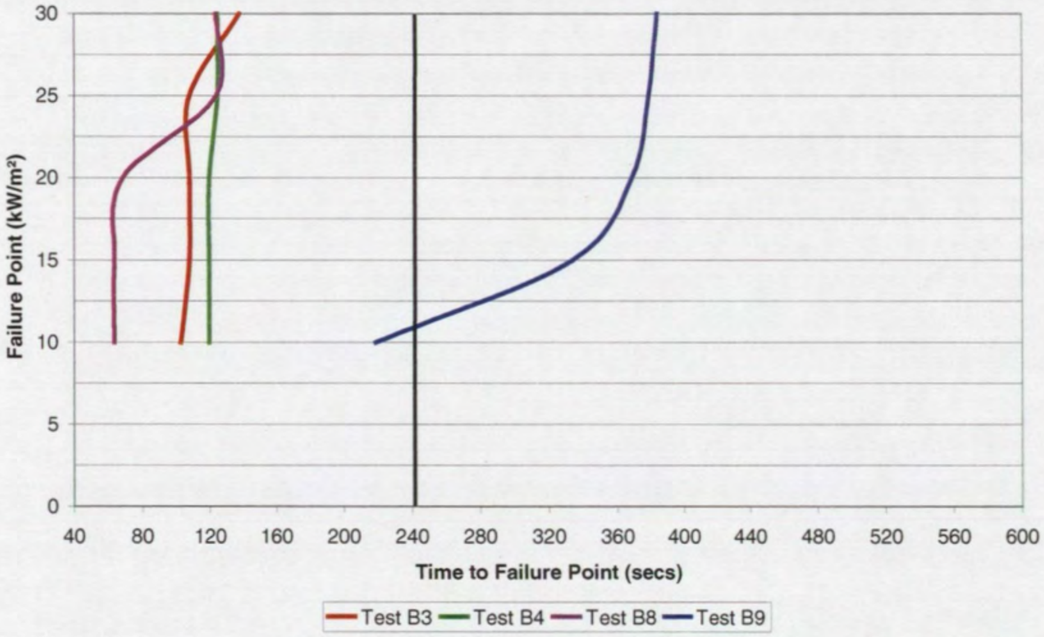


Figure 19 Phase 2 Failure Point Analysis

4 INSTALLATION TESTING OF THERMAL ACOUSTIC LINERS

4.1 Thermal Acoustic Liner Material

Since the testing, during this phase of the programme, was aimed at determining the critical installation aspects of thermal acoustic liners, it was necessary that each of the tests be conducted using materials having similar characteristics. It was also necessary to ensure that failures were due to weaknesses in the installation and not in the materials. Testing conducted in this burnthrough research programme and that carried out by the FAA has identified several materials that have adequate burnthrough resistance. A combination of Orcobloc insulation material and Orcofilm KN-80 bagging film are such materials and were used as the standard for the tests described in this report.

4.2 Test Panels, Protective Coatings & Corrosion Inhibitors

As described in Section 3.3.1 the earlier installation tests were carried out using "stylised panels", constructed to produce a common standard and hence improve consistency in testing. Using the stylised panel a minimum acceptable standard of installation characteristics was derived. However, it was considered expedient to verify this standard on an actual aircraft panel. Whilst almost all of the minimum standards derived from the stylised panel testing were confirmed using the actual aircraft panel, the overlapping of insulation bags, previously defined, was found to be inadequate. The reasons for the difference in results between the stylised panel and the actual aircraft panel were difficult to understand. The most obvious difference was that the stylised panel was constructed from unprotected aluminium whereas the aircraft panel had protective coatings normally found on aircraft structure. It was postulated that the reason for the premature failure of the actual aircraft panel might be the generation of gases from these protective coatings.

An earlier series of tests had investigated the effects of corrosion inhibitors on burnthrough times using both stylised panels and actual panels. This work was carried out prior to the installation aspects of thermal acoustic liners being investigated. The conclusions of this study were that the burnthrough resistance of the **panels** was not significantly affected by the presence of corrosion inhibitors but that they tended to produce large quantities of smoke. In some cases, following generation of these gases, combustion occurred on the cold face prior to penetration of the fuselage, resulting in significant flaming.

If the postulation that the premature failures encountered with the aircraft panels was associated with the generation of gases from the protective coatings and their subsequent combustion, it was thought that this situation might be further exacerbated by the presence of corrosion inhibitors.

However, the aircraft panel also tends to be more structurally robust than the stylised panel and hence may produce longer burnthrough times on those installations that are more resilient.

Whilst the stylised panel testing had been invaluable in determining the critical aspects of the installation, the final confirmatory stage of the testing, on the installation aspects, was conducted using what was likely to be the more severe conditions i.e. using an aircraft panel to which a corrosion inhibitor had been applied.

4.3 Overlap at Frames

4.3.1 *General Discussion on Test Results*

Any gaps in the insulation material, close to the fuselage skin, provide a possible penetration route for the fire to enter the cabin. Testing has illustrated that it is necessary for insulation bags to be installed at frames such that they overlap the frame.

Tests A7a, A8 and A9a illustrate the pronounced effect that bag overlap can have on burnthrough times. All three tests were carried out using the stylised fuselage panel. The insulation system used was Orcobloc encapsulated in Orcofilm KN-80 and was attached to the frame using steel fixing pins and washers.

The results from these three tests are shown in Figure 20. Each value shown on the graph represents the time taken to reach a heat flux level of 20 kW/m2.

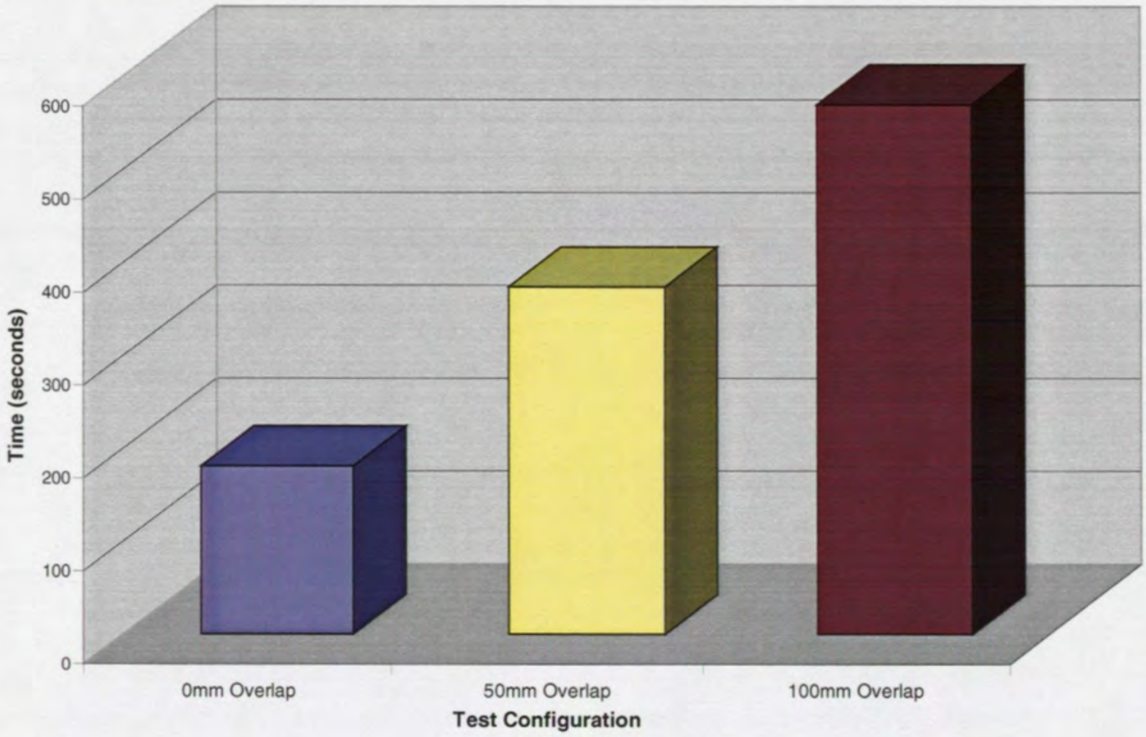


Figure 20 Burnthrough Times with varying Frame Overlap

Earlier testing using insulation materials with inadequate fire resistance characteristics had demonstrated that overlap at frames did not significantly affect burnthrough times. The results obtained from this series of tests utilising stylised fuselage panels, were confirmed by tests on actual fuselage panels.

4.3.2 *Discussion & Conclusions*

The research work conducted on overlap at frames indicates that for insulation systems utilising insulation materials with superior fire resistance characteristics then burnthrough protection improves with increasing frame overlap. For insulation systems utilising insulation materials with inadequate fire resistance characteristics then overlap has little or no effect on the burnthrough time of the system.

All testing was carried out on panels having frames that were 100 mm deep and the best protection was afforded by overlaps of 100 mm. It is therefore likely that the best protection would be afforded on frames, of different sizes, when protected over their entire depth.

4.4 **Overlapping of Insulation Bags**

4.4.1 *General Discussion on Test Results*

As previously described any gaps in the insulation bags will present a route by which fire may penetrate into the aircraft. Early testing on stylised panels demonstrated that an insulation bag overlap of 100 mm produced acceptable burnthrough times. However, for the majority of the configurations tested to date, using actual aircraft panels, overlaps of this magnitude have produced times that are lower than the target of four minutes for fire penetration of the insulation material. The reasons suggested for bag overlap installations on actual aircraft panels producing lower burnthrough times than the stylised panels are discussed in Section 4.2.

Test D6-14 was conducted using an actual aircraft panel with corrosion inhibiting compounds applied. The insulation system used for Test D6-14 was again Orcobloc insulation encapsulated in Orcofilm KN-80 bagging film. A variation of the typical insulation configuration was used and a frame overlap of 100mm. The insulation system was attached to the aircraft panel using steel over frame clips positioned every 260 mm along the frame.

Testing was normally carried out with the blankets between the two main frame bays being made of a single insulation blanket. However, for this test two blankets were used to investigate the integrity of the bag overlap. The insulation blankets were overlapped by 150 mm and were fastened together using double-sided adhesive tape across the entire width of the area of overlap. In addition PVF tape was used beyond the area of overlap to attach the blankets together as shown in Figure 21 and Figure 22. Fire resistant stringers pins were also attached to the aircraft panel in the region of the bag overlap at a spacing of 150 mm apart. The insulation blankets were then pushed onto these stringer pins and held in position using fire resistant washers as shown in Figure 21. The areas of bag overlap for the two frame bays were offset as shown in Figure 23 in an attempt to improve the integrity of the insulation system to fire penetration.

Figure 21 Details of Insulation Bag Overlap Showing PVF Tape and Stringer Pins

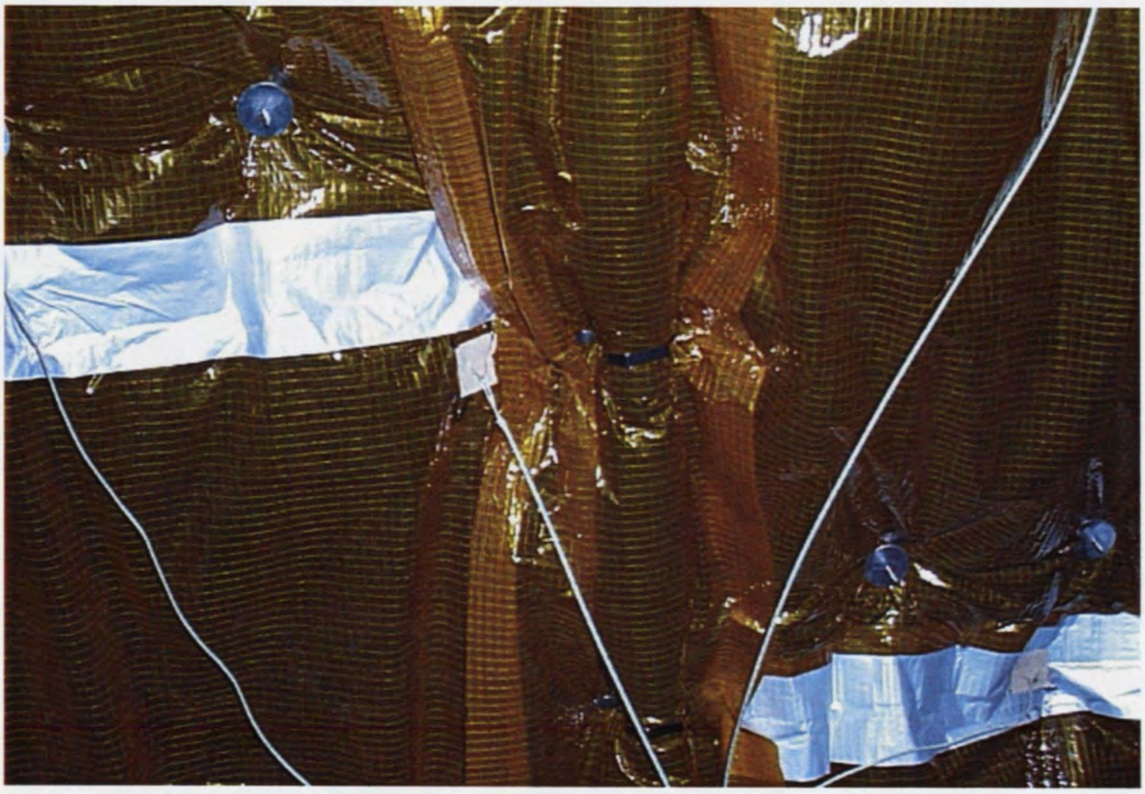


Figure 22 Details of Insulation Bag Overlap

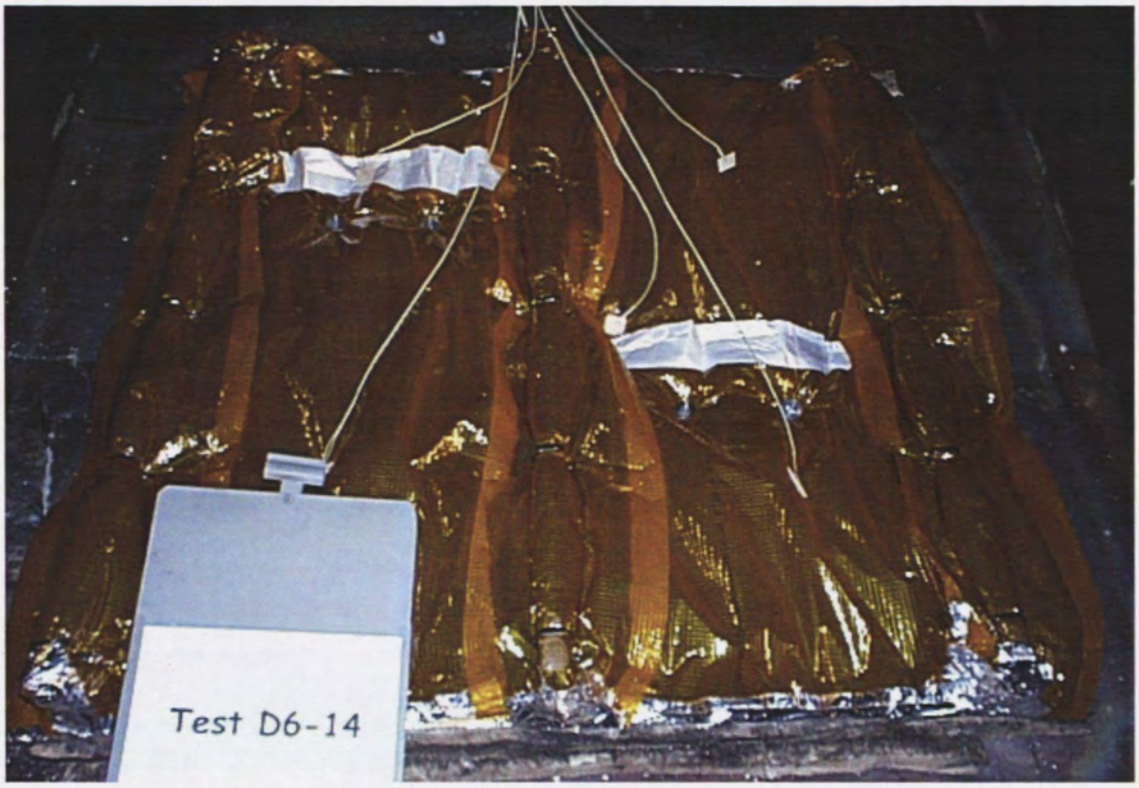


Figure 23 Test D6-14 Before Test

The results of the test are shown in Figure 24. The time taken to reach a heat flux level of 20 kW/m2 was approximately 745 seconds.

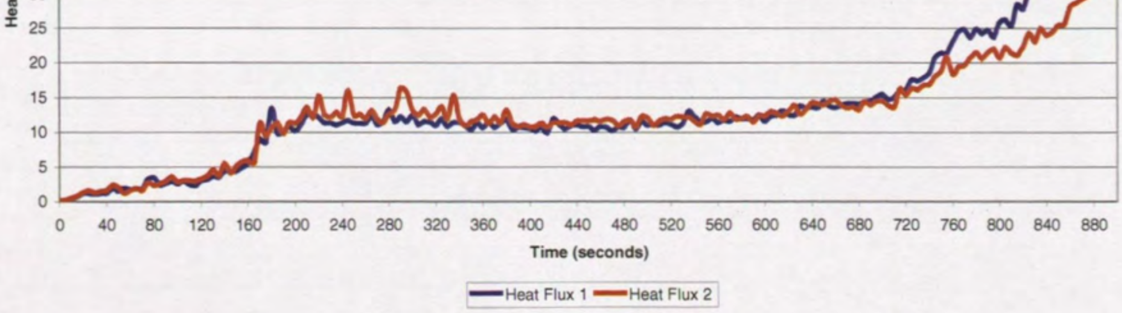


Figure 24 Heat Flux Profile for Test D6-14

4.4.2 *Discussion & Conclusions*

As stated earlier in this section any gaps in the insulation bags will present a route by which fire may penetrate into the aircraft. The presence of overlapping blankets in the frame bays introduces another possible route for fire penetration of the insulation system. It appears that this area of weakness is significant. From the tests conducted on aircraft panels, to define the installation characteristics required to attain acceptable burnthrough times, on configurations involving bag overlap, only the configuration with 150mm of bag overlap has produced satisfactory results.

4.5 **Capping Strips**

4.5.1 *General Discussion on Test Results*

A test was conducted on an insulation system with no capping strip present to determine the necessity for this aspect of the installation. The results of the test, D6-4, are shown in Figure 25.

This test was carried out using an actual aircraft panel that had been treated with corrosion inhibitors. The insulation bags were attached to the frame using aluminium through frame pins positioned at 50 mm up the frame and at a pitch of 350 mm. The insulation blankets extended up the frame a distance of 50 mm. The test resulted in rapid burnthrough with the 20 kW/m² level of heat flux being achieved in approximately 65 seconds from the start of the test.

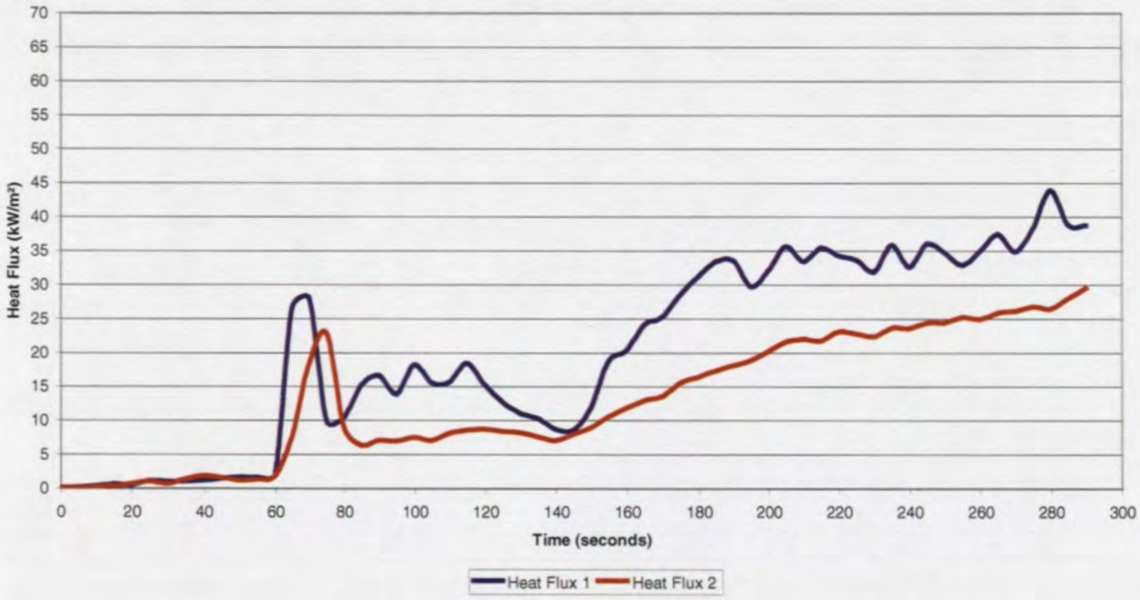


Figure 25 Heat Flux Profile for Test D6-4

A similarly configured test was then carried out with the addition of capping strips, test D6-5. The capping strips were made of fibreglass batting encapsulated in a PVF based bagging film. As with test D6-4 the insulation bags were attached to the frame using aluminium through frame pins positioned at 50 mm up the frame and at a pitch of 350 mm. The overlap at the frame was 100 mm. The heat flux profile for test D6-5 is shown in Figure 26.

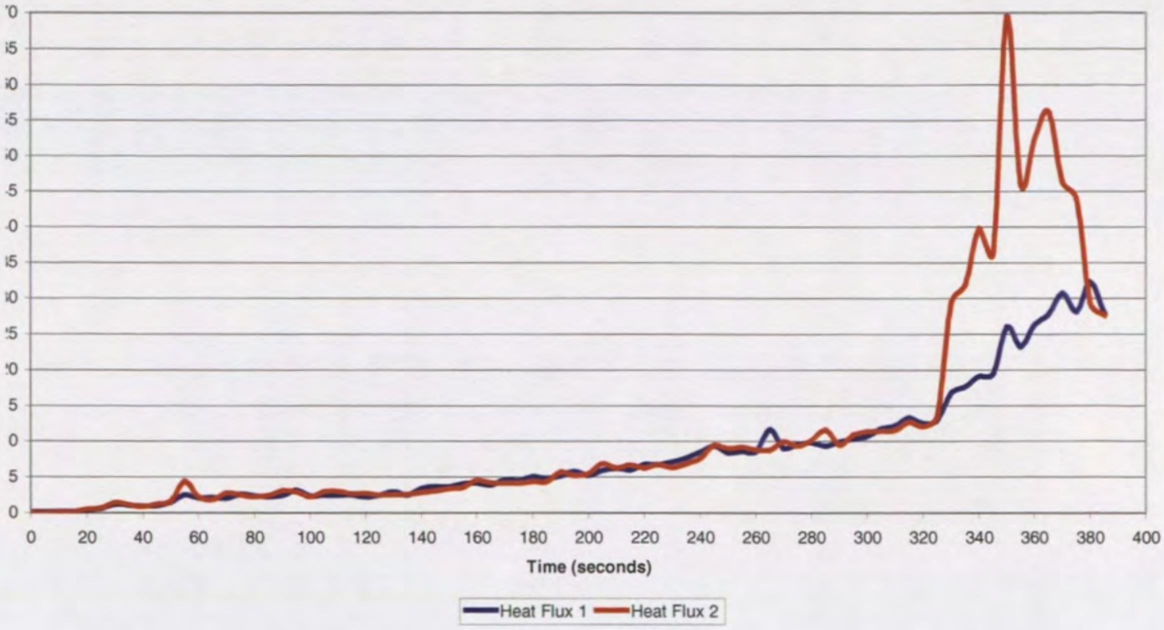


Figure 26 Heat Flux Profile for Test D6-5

The test resulted in a heat flux level of 20 kW/m² being achieved after approximately 330 seconds from the start of the test.

4.5.2 *Discussion & Conclusions*

These results indicate that for an insulation system to act as an effective barrier to flame penetration the aircraft frame must be covered in some way with insulation material.

Test D6-5 was carried out using capping strips made of fibreglass batting encapsulated in a PVF based bagging film. Tests D6-7 and D6-8, which are described later in this document, were carried out using capping strips made of Orcobloc encapsulated in Orcofilm KN-80, which has previously shown to display superior levels of burnthrough resistance. (see Figure 37 and Figure 38)

These tests demonstrate that the burnthrough protection provided by the configurations in Tests D6-7 and D6-8 are significantly better than the protection afforded in Test D6-5. However Test D6-5, using capping strips made of fibre glass batting encapsulated in a PVF film, exhibited adequate burnthrough protection.

4.6 **Discontinuities**

4.6.1 *General Discussion on Test Results*

Terminal blocks, pipe fixings or any other feature attached to the aircraft structure in close proximity to the aircraft skin present a possible fire penetration route unless protected by the thermal acoustic liner.

The configuration used in Test D3-1 was intended to simulate a hydraulic pipe clamp block attached to an airacraft panel in order to assess the effects of such a feature on burnthrough resistance. A 150mm long by 25mm square mm long block of aluminium was attached to the centre of the central frame on a stylised panel. In order to accommodate the clamp block a cut out was made in the capping strip.

Lengths of PVF tape were then applied around the edge of the cut out to position the capping strip tightly against the simulated clamp block. Figure 27 and Figure 28 show the arrangement as described. The heat flux profile of the test is presented in Figure 29.

The configuration tested did not result in significant heat flux levels being achieved on the cold side until well in excess of 300 seconds.

Figure 27 Simulated Clamp Block on Fuselage Frame

Figure 28 Simulated Clamp Block with Insulation Installed

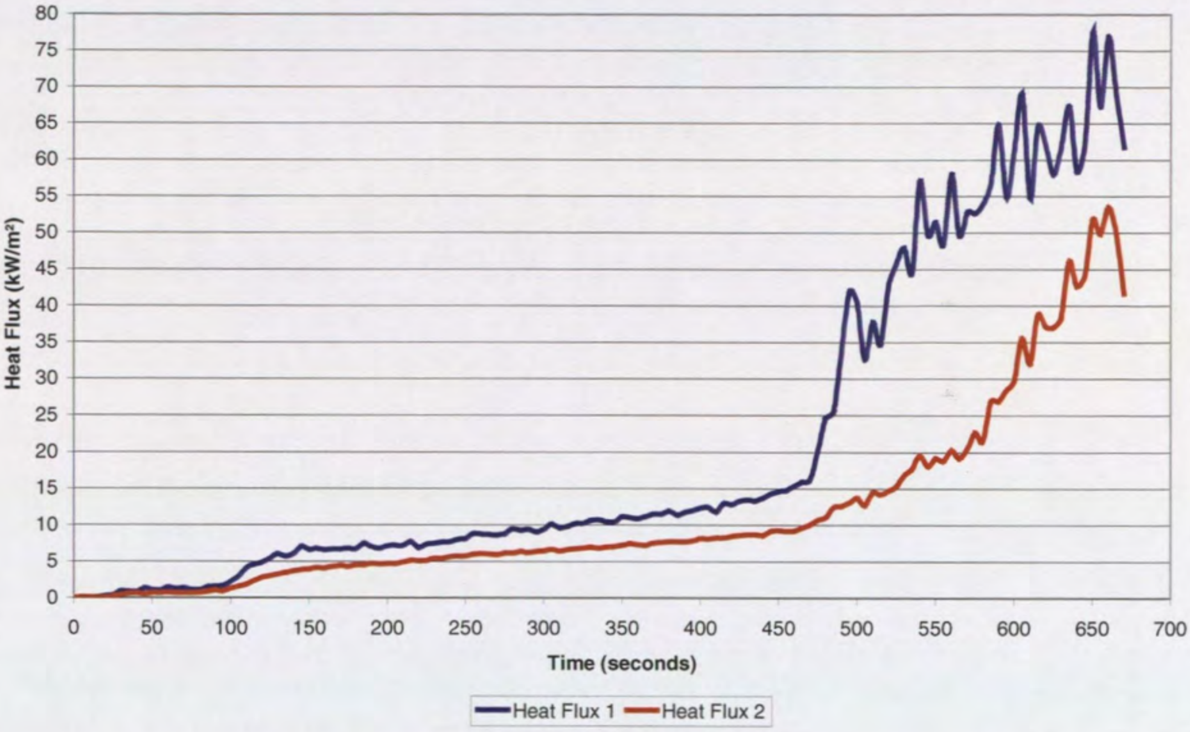


Figure 29 Heat Flux Profile for Test D3-1

4.6.2 *Discussion & Conclusions*

Test D3-1 demonstrates that it is possible to have breaks in the capping strip and not render the insulation system more vulnerable to flame penetration provided the insulation materials are configured so as not to provide flame penetration routes. This was achieved in this test, by using PVF tape to secure the capping strip tightly against the simulated clamp block. An earlier test D6-4 showed that capping strips were necessary for the integrity of the test panel to be maintained. So although isolated breaks in the capping strip do not seem to pose a problem, if adequately sealed, a continuous break of some length may well weaken the integrity of the system.

5 TESTING OF FIXINGS

As described in Section 3.4, actual aircraft fixing components were used during the final stages of testing to replicate a typical aircraft installation. The fixings used are described as through frame, over frame and stringer. A number of tests were conducted on each fixing type to determine their suitability for insulation systems where improved burnthrough resistance was to be achieved.

5.1 Through Frame Fixings

5.1.1 *General Discussion on Test Results*

As described in Section 3.4.1 through frame fixing pins are attachment methods utilising a two-piece component, which is located through the aircraft fuselage frame. The insulation system is pushed on to the pin and held in place using a washer. This method of installation results in the insulation material being pierced in the region of the pin.

In the early stages of the research work, when the through frame method of installation attachment was used, the material of construction of the pins and washers was steel. This was done to eliminate the fixing component being a potential reason for failure. Using such steel components resulted in considerable burnthrough times being achieved when insulation systems, made of materials with superior burnthrough resistance, were used.

Subsequently a number of tests were carried out to determine the effect that these through frame fixing pins could have on burnthrough time for an insulation system installed onto a stylised fuselage panel. The focus of the tests was on determining the importance of pitch of the fixing pins, their location on the aircraft frame and their material of construction.

The insulation system used for the tests was again Orcobloc insulation encapsulated in Orcofilm KN-80 bagging film. In Section 4.3 the importance of frame overlap was discussed. For the tests described in this Section of the report 100 mm of frame overlap was used since this resulted in improved burnthrough results in comparison with smaller overlaps. A number of steel and aluminium through frame fixings were used for these tests with pitches along the frame of approximately 170 mm, 260 mm, and 350 mm. The vertical location of the through frame fixings in relation to the skin of the panel was also varied with values of 25 mm and 50 mm being selected. Figure 30 shows one of the through frame fixings as located on the test panel.

Figure 30 Aluminium Through Frame Pin positioned 50 mm up the Frame

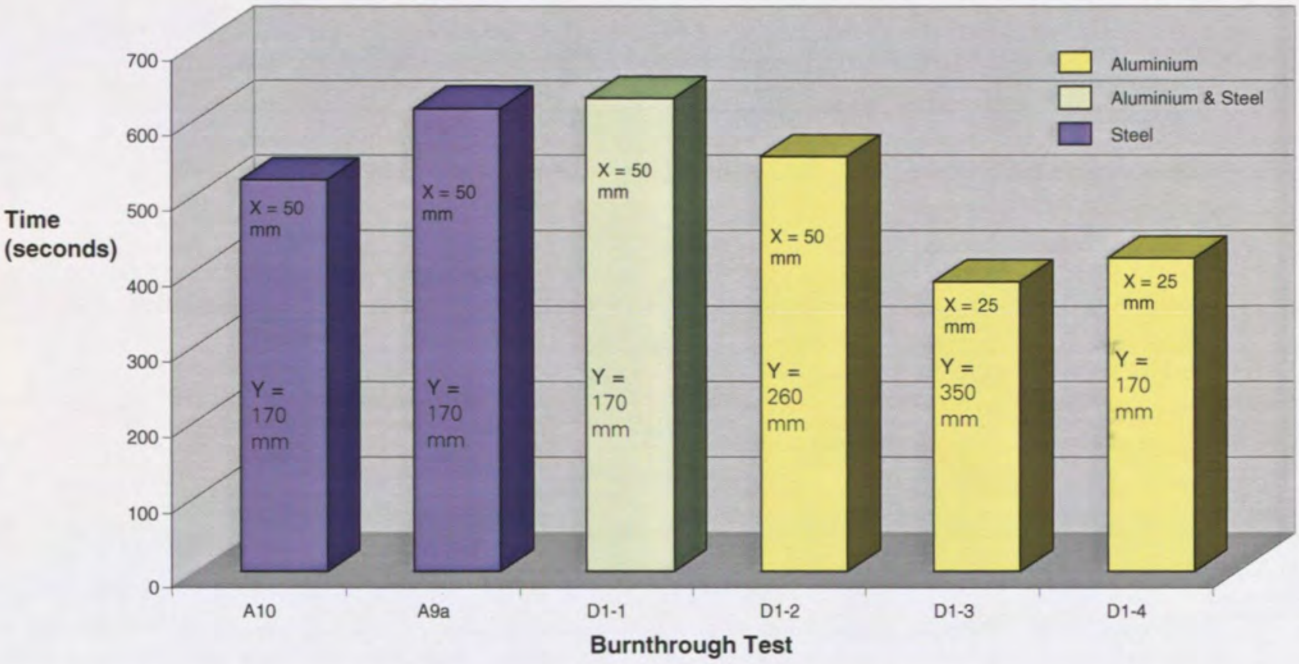


Figure 31 Time to Reach Failure Point of 20 kW/m² for Tests using Through Frame Fixing Pins & Washers

NB: Y = Pitch of through frame fixing along the frame
X = Vertical location of through frame fixing in relation to the skin of the panel

The results of the testing directed at through frame fixings, presented in Figure 31, relate to the complete system and hence include the burnthrough time for the aluminium stylised fuselage panel. The Figure shows the time taken for a heat flux level of 20 kW/m² to be reached i.e. the burnthrough failure criterion. The system failure times are in the approximate range 380-600 seconds. All results are in excess of the 300-second complete system failure criterion.

Although the results are not shown a number of tests were also carried out using plastic through frame pins. The results of these tests were varied such that no conclusions could be drawn.

5.1.2 *Discussion & Conclusions*

Several points emerge from the research work related to through frame fixings. The through frame fixing pins and washers used were either aluminium or steel and therefore by definition were all deemed to be at least fire resistant. Both materials yielded satisfactory results for through frame fixings.

Test D1-3, which was configured with the aluminium through frame pins 25 mm up the frame and on a pitch of 350 mm exceeded the burnthrough time targeted. However, the tests producing the greatest burnthrough times were those where the through frame pins were located at least 50 mm up the frame. This is to be expected; the further away from the fire source the pins are located the more likely they are to remain intact for longer.

Test D1-4 produced marginally better results than test D1-3. The only difference in the test configurations being that the pitch of the fixings in test D1-4 was 170 mm compared to 350 mm for D1-3. Tests D1-1 and D1-2 also show an increase in burnthrough time with decreasing pitch. These tests indicate that decreasing the pitch of the fixings produces a slightly more burnthrough resistant insulation configuration.

Penetration of thermal acoustic liners by fixings should be avoided wherever possible since they result in a possible fire entry point. Fixings that do not penetrate the liners, such as over-frame fixings are therefore more likely to provide consistently good burnthrough protection. Fixings that provide good mechanical retention of thermal acoustic liners are also more likely to provide good burnthrough protection. As might be expected, testing has also shown that improvements in burnthrough protection are achieved when through frame fixings are placed furthest away from the fuselage skin.

5.2 Over Frame Fixings

5.2.1 *General Discussion on Test Results*

As described in Section 3.4.2 over frame fixings are an attachment method by which a spring metallic or plastic component is located over the aircraft frame. They mechanically hold the capping strip and the between frame blanket together at the frame. These fixings do not penetrate the frame or insulation system.

A number of tests were carried out to determine the effect that these over frame fixing clips could have on burnthrough time for an insulation system installed onto a stylised fuselage panel. The focus of the initial tests was on determining the importance of pitch of the fixing clips and their material of construction. The insulation system used for the tests was again Orcobloc insulation encapsulated in Orcofilm KN-80 bagging film.

In Section 4.3 the importance of frame overlap was discussed and for each of these tests the frame overlap was 100 mm. Steel and plastic clips were used and pitches of approximately 170 mm, 260 mm, 350 mm and 530 mm. Details of the typical construction of these samples are shown in Figure 32 and Figure 33. The condition of one of the plastic over frame fixings after a test is also shown in Figure 34. A summary of the results of these tests is shown in Figure 35.

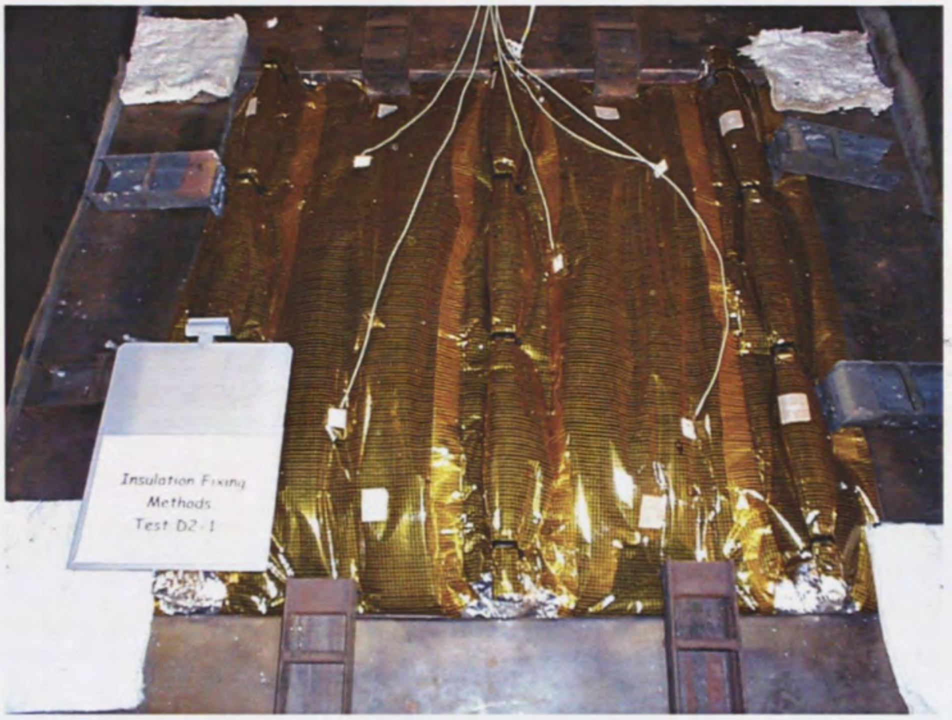


Figure 32 Test D2-1 Plastic Over Frame Clips on a 14" pitch

Figure 33 Test D2-1 Close up of Plastic Clip

Figure 34 Test D2-3 Close up of Plastic Over Frame Clips after Testing

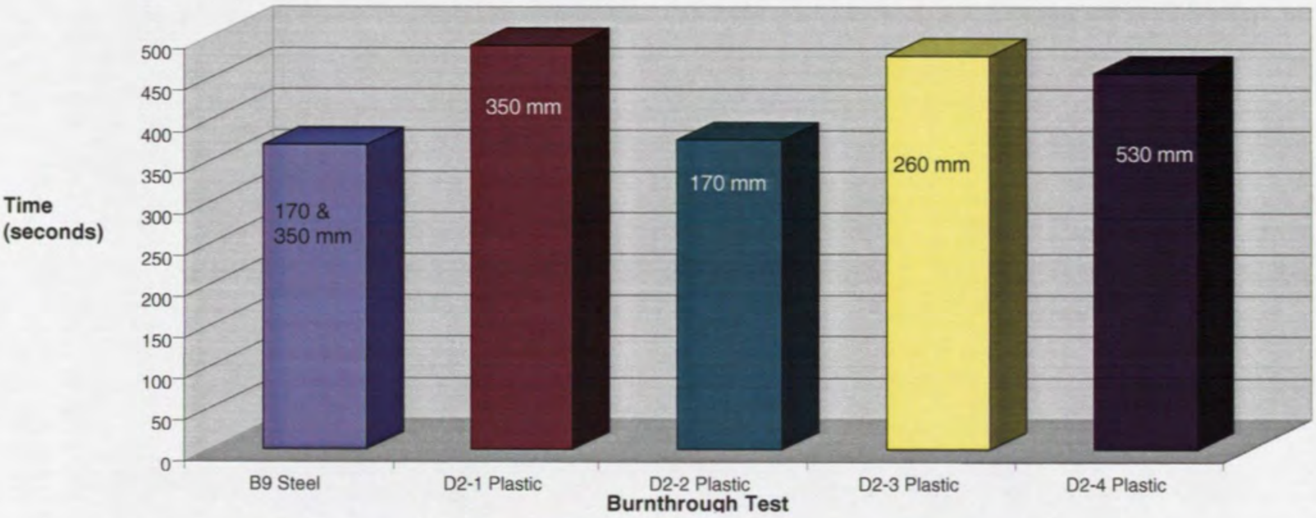


Figure 35 Time to Reach Failure Point of 20 kW/m² for tests involving over frame clips

NB: The values at the top of each column indicate the pitch of the fixings along the frame

It should be noted that the values presented in Figure 35 are for the insulation material only (i.e. the additional protection time afforded by the stylised panel is not included). As can be seen from Figure 35, which indicates the time taken for a heat flux level of 20 kW/m² to be reached, all the failure times are in excess of 350 seconds for the insulation material. This value is consistently in excess of the 240-second failure criterion for the insulation material. The testing on the stylised fuselage panel also indicates no trend or pattern in relation to the pitch of the over frame fixing or its material of construction over the range of pitches tested.

Using the stylised panel a minimum acceptable standard of installation characteristics could be derived. However, it was considered expedient to verify this minimum acceptable standard on an actual aircraft panel. Section 4.2 discussed the effect that corrosion inhibitors, and the protective coatings applied to aircraft structures, may have on burnthrough time of a fuselage and insulation system. Therefore two tests, D6-7 and D6-8, were conducted on an actual aircraft panel using over frame fixings as the method of insulation system attachment. For test D6-8 corrosion inhibiting compounds were also applied to the actual aircraft panel as indicated in Figure 36.

Figure 36 Test D6-8 Fuselage Panel Coated with Corrosion Inhibitors

The two tests were conducted using Orcobloc insulation batting encapsulated in Orcofilm KN-80 bagging film and the overlap of insulation at the frame with the capping strip was 100 mm. The heat flux profiles are shown in Figure 37 and Figure 38.

For both tests the burnthrough time of the system was again well in excess of the failure criterion of 300 seconds. Test D6-8 did not fail until approximately 900 seconds. The burnthrough times for the actual fuselage panel tests are higher than those for the equivalent tests using the stylised fuselage panel.

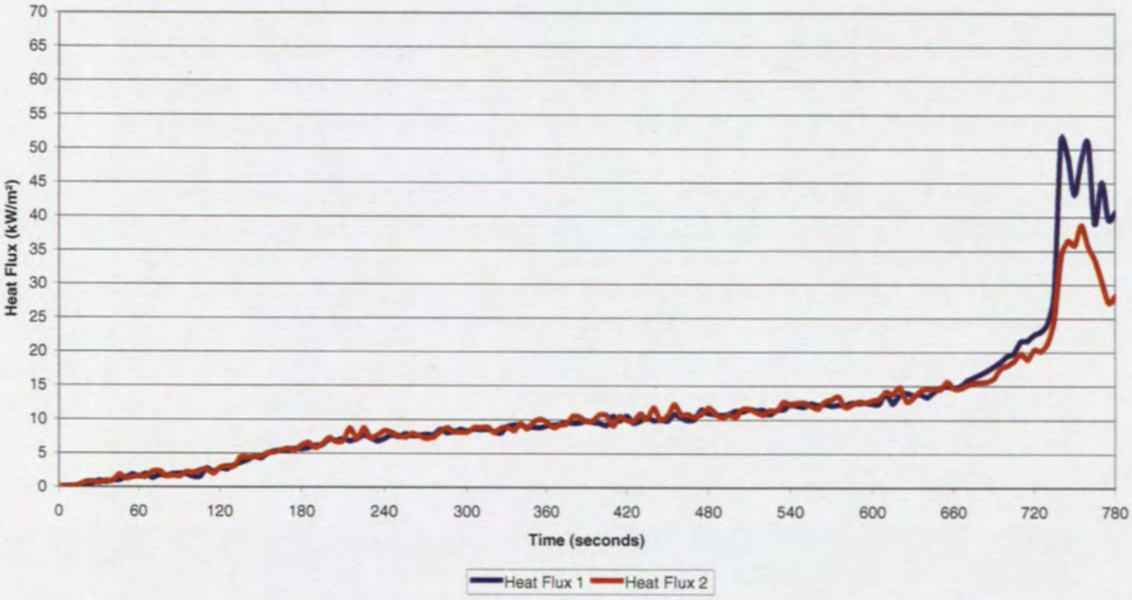


Figure 37 Heat Flux Profile for Test D6-7

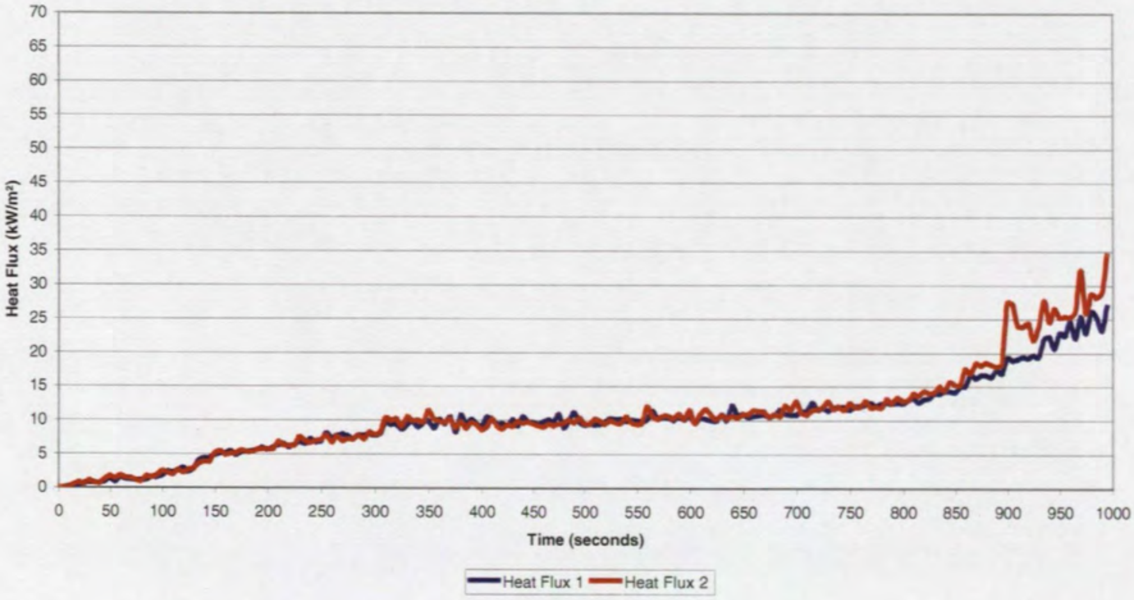


Figure 38 Heat Flux Profile for Test D6-8

5.2.2 *Discussion & Conclusions*

For the series of tests involving stylised fuselage panels all failure times for the insulation system were in the range of approximately 350-450 seconds. This range of values is well in excess of the 240-second failure criterion. The data from this series of tests did not indicate any relationship between the burnthrough time of the insulation system and the pitch, or material, of the over frame fixings. With regards to the choice of material being plastic or steel, from the test results it could not be determined which was the best material to use. However in general terms fire resistant materials would always be preferred.

The above results indicate that fixings that do not penetrate the frame but provide attachment for the insulation bags by clipping them over the top of the frame are capable of preventing fire penetration at the joints. The material of such clips and their pitch should be such as to provide good retention of the thermal acoustic liners.

The effectiveness of this method of insulation system attachment is no doubt in part due to the location of the over frame clips. Being on top of the aircraft frame they are further away from the fire source and are to an extent protected by the insulation system.

For the two tests described previously using over frame fixings, on actual fuselage panels the burnthrough time of the system was well in excess of the failure criterion, with one not failing until approximately 900 seconds. The increase in burnthrough times for the actual fuselage panel test compared to the stylised fuselage panel series of tests can in part be attributed to the fact that the aircraft panel tends to be more structurally robust. As a result aircraft panels tend to produce longer burnthrough times on those installations that are more resilient. Although on marginal installations the presence of the protective coatings and corrosion inhibitors accelerate the time to burnthrough.

Tests D6-7 and D6-8 provide a very good indication of the levels of improved burnthrough resistance attainable by using existing methods of insulation system attachment on materials displaying superior burnthrough resistance.

5.3 Stringer Fixings

5.3.1 *General Discussion*

Stringer fixings, as described in section 3.4.3, are similar to through frame pins in that the insulation system is pushed on to the pin and held in place using a washer. The fixings themselves are located on the stringers typically by means of a clip attached to the fixing pin.

One of the first tests conducted in the current burnthrough programme investigating insulation installation aspects was representative of a typical aircraft configuration. A sketch of the test sample configuration is shown in Figure 39 and photographs showing the installation are provided in Figure 40 and Figure 41. The insulation blankets were attached to the stylised fuselage panel and to each other using **plastic** stringer fixings as shown. These were positioned every 350 mm, parallel to the frames and along the length of the panel. The insulation blankets were overlapped by 100 mm and along this overlap a strip of PVF tape was positioned along the length of the blankets.

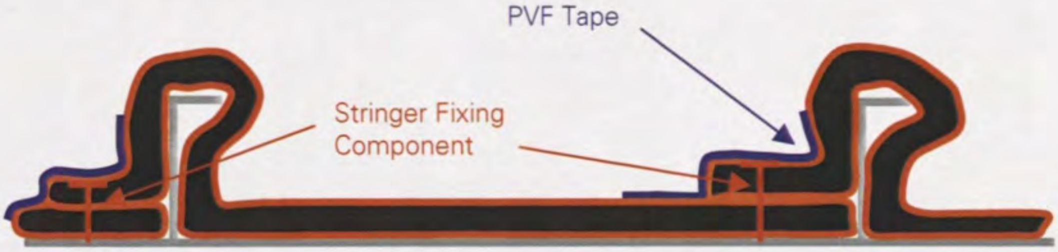


Figure 39 Test B8 Orcobloc in KN-80 (100 mm Overlap)

This test resulted in a rapid burnthrough with the 20 kW/m² level of heat flux being achieved in approximately 110 seconds as shown in Figure 42. This result indicated that this method of attaching an insulation system to the aircraft fuselage was not capable of providing significant burnthrough protection even by using insulation materials that have been shown to be burnthrough resistant.

Figure 40 Test B8 Pre-Test

Figure 41 Test B8 Close Up of Stringer Pin and PVF Tape Configuration

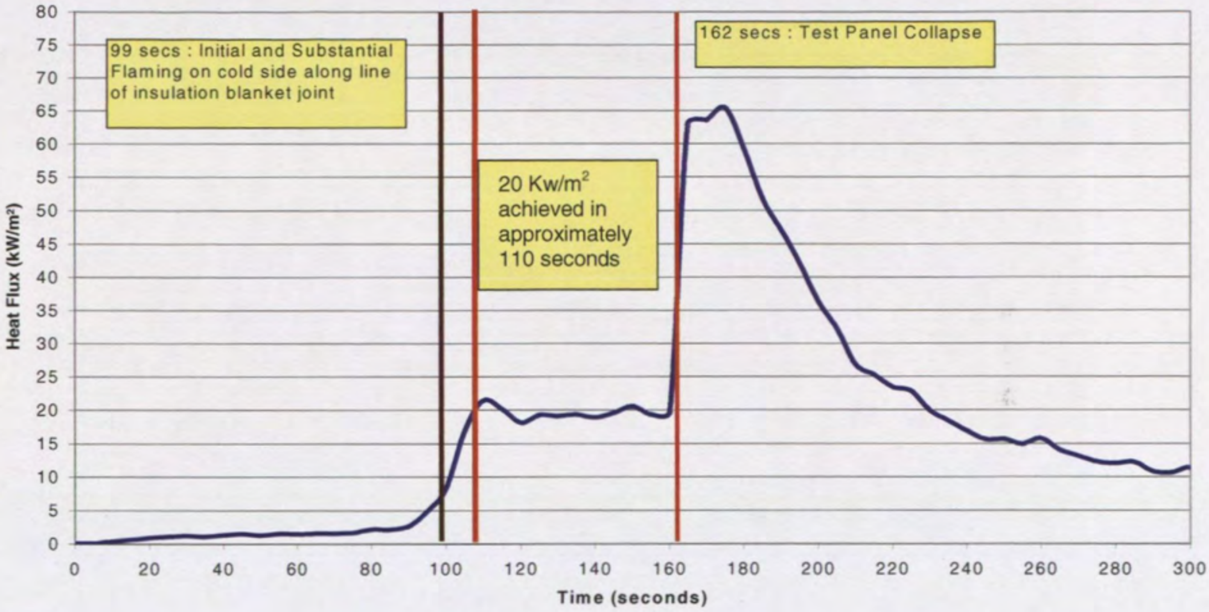


Figure 42 Heat Flux Profile for Test B8

In test B8 the combination of plastic stringer fixing pins and PVF tape was found to be unacceptable. Test D5-1 was conducted using a stylised fuselage panel and the Orcobloc insulation material and Orcofilm KN-80 bagging film combination. The insulation bags were attached to the frame using steel over frame clips, positioned over the frame at a pitch of approximately 250 mm. The frame blanket extended a distance of 100 mm up the frame. In one of the frame bays a number of aluminium stringer pins were riveted on to the stringer sections as shown in Figure 43. The insulation was pushed onto these stringer pins and then held in place using aluminium washers as shown in Figure 44.

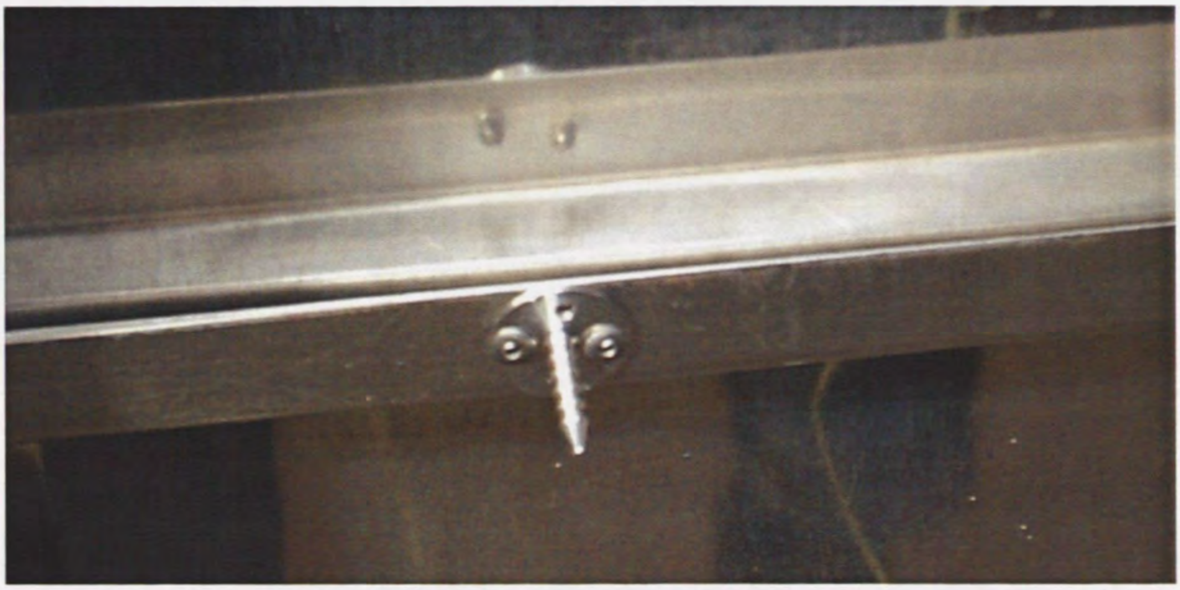


Figure 43 Test D5-1 Close Up of Aluminium Stringer Pin attached to Stringer

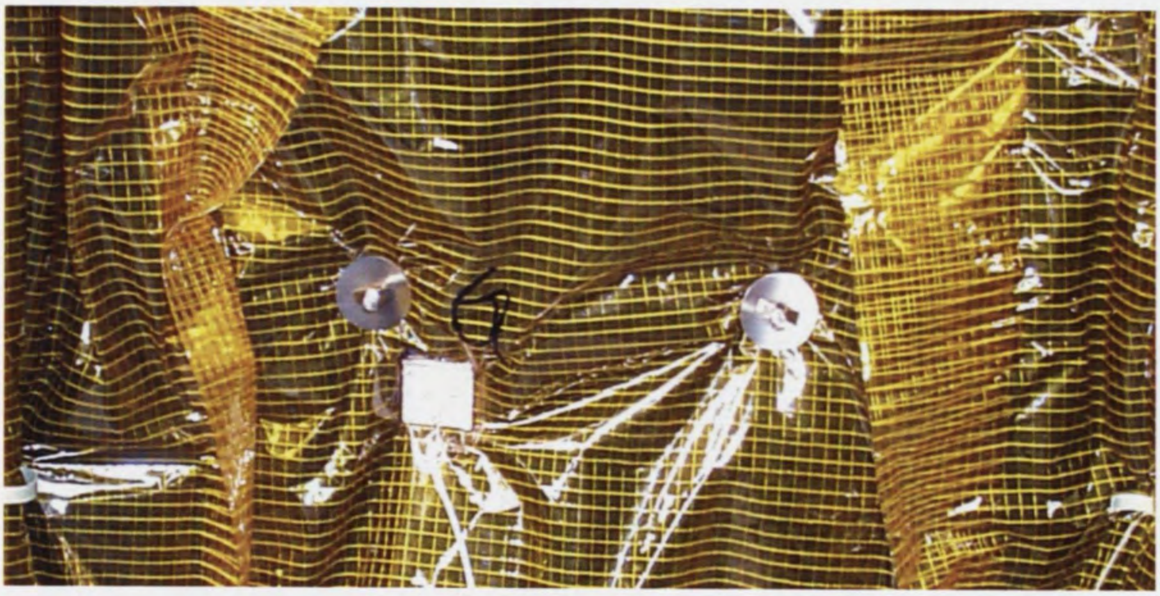


Figure 44 **Test D5-1 Close Up of Aluminium Stringer Pins& Washers as Installed on Stylised Panel**

The test resulted in the failure heat flux of 20 kW/m² being achieved after approximately 475 seconds with no appreciable difference between the frame bay containing the stringer fixing clips and the one without any. Results of the test are shown in Figure 45.

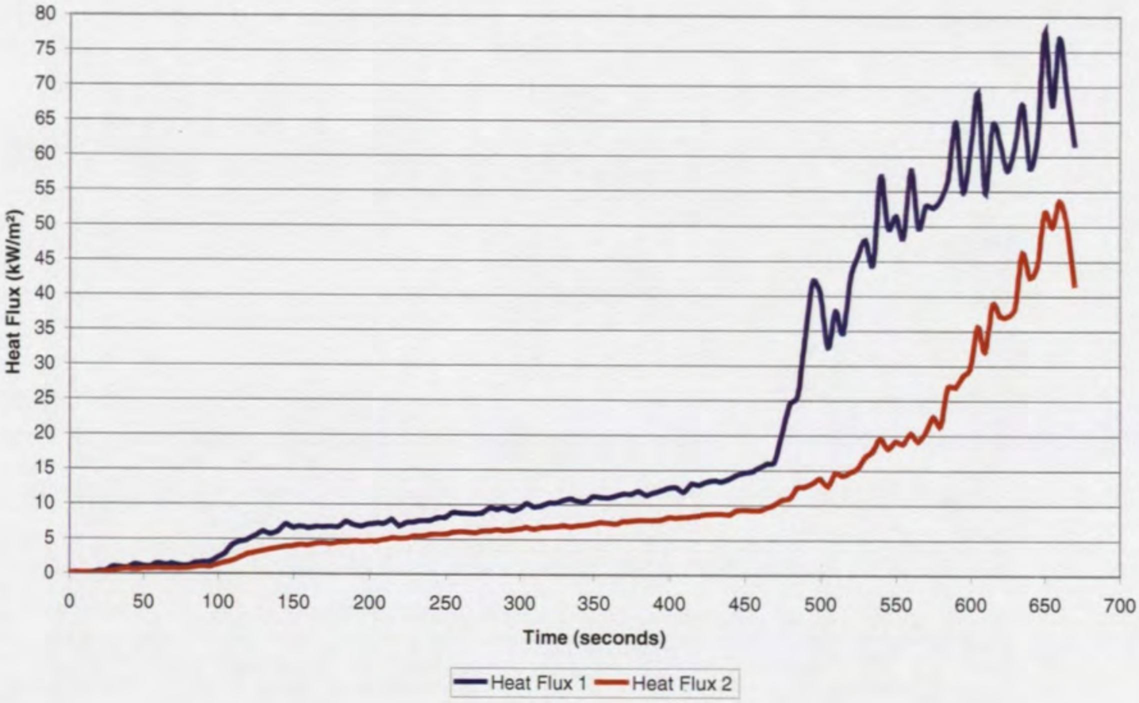


Figure 45 Heat Flux Profile for Test D5-1

5.3.2 *Discussion & Conclusions*

A limited number of tests were conducted on insulation systems utilising stringer fixings. From the research to date, two main conclusions emerge:

Systems that rely on plastic stringer fixings and insulation fixing tape, for insulation blanket attachment do not seem capable of producing adequate levels of burnthrough protection. This applies even if an insulation material displaying superior burnthrough resistance is used, as demonstrated by Test B8. It is considered that one of the main reasons for this is that airframe stringers are more likely to perish before the aircraft frame and therefore any attachment system which relies on the presence of airframe stringers alone is likely to be weaker than one which employs frame fixings.

For test D5-1 stringer fixings made out of fire resistant material were utilised in addition to frame fixing components. In this test, the insulation system configuration provided burnthrough protection for approximately 475 seconds. For this particular test only one of the frame bays contained stringer fixings and no differences in burnthrough time were noted between them. Test D5-1 indicates that for systems that utilise stringer fixings made out of fire resistant material, in addition to suitable frame fixing components, high levels of burnthrough protection can be achieved.

6 SUMMARY OF CONCLUSIONS

The body of testing, as referenced in this document, has shown consistently that any gaps in the insulation material, close to the fuselage skin, will result in rapid flame penetration into the cabin. It is therefore essential that the thermal acoustic liner installation is such that it restricts the passage of gases and subsequent flame penetration through to the cold side of the insulation bag.

The presence of protective coatings and corrosion inhibitors on the aircraft structure appears to have an adverse effect on the capability of an installation to achieve the levels of protection suggested by the testing carried out on stylised panels. The areas of the installation that seem to be particularly vulnerable are at the insulation bag overlap.

Overlap at Frames

The research work conducted on overlap at frames indicates that for insulation systems utilising insulation materials with superior fire resistance characteristics then burnthrough protection improves with increasing frame overlap. For insulation systems utilising insulation materials with inadequate fire resistance characteristics then overlap has little or no effect on the burnthrough time of the system.

All testing was carried out on panels having frames that were 100 mm deep and the best protection was afforded by overlaps of 100 mm. It is therefore likely that the best protection would be afforded on frames, of different sizes, when protected over their entire depth.

Overlapping of Insulation Bags

The presence of overlapping blankets in the frame bays introduces a possible route for fire penetration of the insulation system. It appears that this area of weakness is significant. From the tests conducted on aircraft panels, to define the installation characteristics required to attain acceptable burnthrough times, on configurations involving bag overlap, only the configuration with 150mm of bag overlap, secured with suitable tape, has produced satisfactory results.

Capping Strips

These results indicate that for an insulation system to act as an effective barrier to flame penetration the aircraft frame must be covered in some way with insulation material.

Test D6-5 was carried out using capping strips made of fibreglass batting encapsulated in a PVF based bagging film. Tests D6-7 and D6-8, as described earlier in this document, were carried out using capping strips made of Orcobloc encapsulated in Orcofilm KN-80, which has previously shown to display superior levels of burnthrough resistance. (see Figure 37 and Figure 38)

These tests demonstrate that the burnthrough protection provided by the configurations in Tests D6-7 and D6-8 are significantly better than the protection afforded in Test D6-5. However Test D6-5, using capping strips made of fibre glass batting encapsulated in a PVF film, exhibited adequate burnthrough protection.

Discontinuities

The testing demonstrates that it is possible to have breaks in the capping strip and not render the insulation system more vulnerable to flame penetration provided the insulation materials are configured so as not to provide flame penetration routes. This may be achieved by using PVF tape to secure the capping strip to discontinuities. An earlier test D6-4 showed that capping strips were necessary for the integrity of the test panel to be maintained. So although isolated breaks in the capping strip do not seem to pose a problem, if adequately sealed, a continuous break of some length may well weaken the integrity of the system.

Through Frame Fixings

The through frame fixing pins and washers used were either aluminium or steel and therefore by definition were all deemed to be at least fire resistant. Both materials yielded satisfactory results for through frame fixings. For tests utilising plastic pins and washers the test results were inconclusive.

Test D1-3, which was configured with the aluminium through frame pins 25 mm up the frame and on a pitch of 350 mm exceeded the burnthrough time targeted. However, the tests producing the greatest burnthrough times were those where the through frame pins were located at least 50 mm up the frame. This is to be expected; the further away from the fire source the pins are located the more likely they are to remain intact for longer.

Test D1-4 produced marginally better results than test D1-3. The only difference in the test configurations being that the pitch of the fixings in test D1-4 was 170 mm compared to 350 mm for D1-3. Tests D1-1 and D1-2 also show an increase in burnthrough time with decreasing pitch. These tests indicate that decreasing the pitch of the fixings produces a slightly more burnthrough resistant insulation configuration.

Penetration of thermal acoustic liners by fixings should be avoided wherever possible since they result in a possible fire entry point. Fixings that do not penetrate the liners, such as over-frame fixings are therefore more likely to provide consistently good burnthrough protection. Fixings that provide good mechanical retention of thermal acoustic liners are also more likely to provide good burnthrough protection. As might be expected, testing has also shown that improvements in burnthrough protection are achieved when through frame fixings are placed furthest away from the fuselage skin.

Stringer Fixings

Systems that rely on plastic stringer fixings and insulation fixing tape, for insulation blanket attachment do not seem capable of producing adequate levels of burnthrough protection. This applies even if an insulation material displaying superior burnthrough resistance is used, as demonstrated by Test B8. It is considered that one of the main reasons for this is that airframe stringers are more likely to perish before the aircraft frame and therefore any attachment system which relies on the presence of airframe stringers alone is likely to be weaker than one which employs frame fixings.

For test D5-1 stringer fixings made out of fire resistant material were utilised in addition to frame fixing components. In this test, the insulation system configuration provided burnthrough protection for approximately 475 seconds. For this particular test only one of the frame bays contained stringer fixings and no differences in burnthrough time were noted between them. Test D5-1 indicates that for systems that utilise stringer fixings made out of fire resistant material, in addition to suitable frame fixing components, high levels of burnthrough protection can be achieved.

Over Frame Fixings

For the series of tests involving stylised fuselage panels all failure times for the insulation system were in the range of approximately 350-450 seconds. This range of values is well in excess of the 240-second failure criterion. The data from this series of tests indicated no relationship between the burnthrough time of the insulation system and the pitch, or material, of the over frame fixings. With regards to the choice of material being plastic or steel, from the test results it could not be determined which was the best material to use. However in general terms fire resistant materials would always be preferred.

The above results indicate that fixings that do not penetrate the frame but provide attachment for the insulation bags by clipping them over the top of the frame are capable of preventing fire penetration at the joints. The material of such clips and their pitch should be such as to provide good retention of the thermal acoustic liners.

The effectiveness of this method of insulation system attachment is no doubt in part due to the location of the over frame clips. Being on top of the aircraft frame they are further away from the fire source and are to an extent protected by the insulation system.

For the two tests using over frame fixings, on actual fuselage panels the burnthrough time of the system was well in excess of the failure criterion, with one not failing until approximately 900 seconds. The increase in burnthrough times for the actual fuselage panel test compared to the stylised fuselage panel series of tests can in part be attributed to the fact that the aircraft panel tends to be more structurally robust. As a result aircraft panels tend to produce longer burnthrough times on those installations that are more resilient. Although on marginal installations the presence of the protective coatings and corrosion inhibitors appear to have accelerated the time to burnthrough.

These two tests provide a very good indication of the levels of improved burnthrough resistance attainable by using existing methods of insulation system attachment on materials displaying superior burnthrough resistance.

Final Conclusion

The extensive testing carried out under this research programme has shown that extended periods of protection (up to 900 seconds) may be achieved when burnthrough resistant materials are installed. However, the attainment of these high levels of protection is totally dependent on the characteristics of the installation.