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# INVESTIGATION INTO THE EFFECT OF CORROSION INHIBITING COMPOUNDS ON FUSELAGE BURNTHROUGH

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# INVESTIGATION INTO THE EFFECT OF CORROSION INHIBITING COMPOUNDS ON FUSELAGE BURNTHROUGH

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## Summary

The CAA, as part of its on-going programme to improve cabin safety, has initiated a study into looking at ways of improving the burnthrough resistance of aircraft fuselages. The intent is to be able to delay the ingress of fire and associated toxic gases into the cabin thus increasing survivability time.

As part of this study, Darchem Flare (formerly Faverdale Technology Centre) was asked to carry out research into determining whether the use of corrosion inhibiting compounds on the inside of aircraft fuselages impacted upon fuselage burnthrough.

After an initial phase of testwork, although several areas of interest emerged, it was reasoned that because of the limited test data no firm conclusions could be reached regarding the effect of using corrosion inhibiting compounds on fuselage burnthrough times. A further test phase was then carried out to compliment the initial investigation and collect enough data for conclusions to be reached.

The results from the initial investigation had suggested that the presence of corrosion inhibiting compounds inside an aircraft fuselage might have an effect on burnthrough time. The results from the recent series of tests suggest that this is unlikely. The burnthrough times for aluminium panels with or without corrosion inhibitors are similar.

The tests have shown that corrosion inhibiting compounds are such that they are capable of producing large quantities of smoke and even bursting into flames when heated indirectly.

## Contents

# 1 INTRODUCTION

Several accidents have occurred where external pool fires have entered into the cabin by burning through the fuselage. As a result the CAA initiated a study into looking at ways of improving the burnthrough resistance of aircraft fuselages with a view to delaying the ingress of fire and associated toxic gases into the cabin thus increasing survivability time.

Complementary to this study, and as a consequence of work already undertaken on behalf of the CAA, Darchem Flare was tasked to carry out research into determining whether the use of corrosion inhibiting compounds on the inside of aircraft fuselages impacted upon fuselage burnthrough.

Corrosion inhibiting compounds are usually hydrocarbon based water displacing compounds and as such tend to be highly flammable. Aircraft manufacturers and maintenance centres apply varying quantities of anti-corrosion compounds to the interior of the fuselage skin.

Previous testwork (Dodd[1]) has shown that when a section of fuselage is exposed to conditions representative of a post-crash fuel fire the presence of corrosion inhibiting compounds causes the unexposed cold face to flash with flames within a short period of time.

Such an effect could in turn lead to insulation bags or any dust and debris catching alight and propagating a fire before the exterior fire has actually penetrated the fuselage skin.

With this in mind and to gain a better understanding of the behaviour of corrosion inhibiting compounds in a fire situation, several programmes of testwork were devised.

## 2 MEDIUM SCALE FACILITY

### 2.1 Burnthrough Test Facility

Darchem Flare, funded by the CAA, have developed a testing method which has been referred to as 'medium scale'. This test facility replicates 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.

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 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.

### 2.2 Smoke 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.

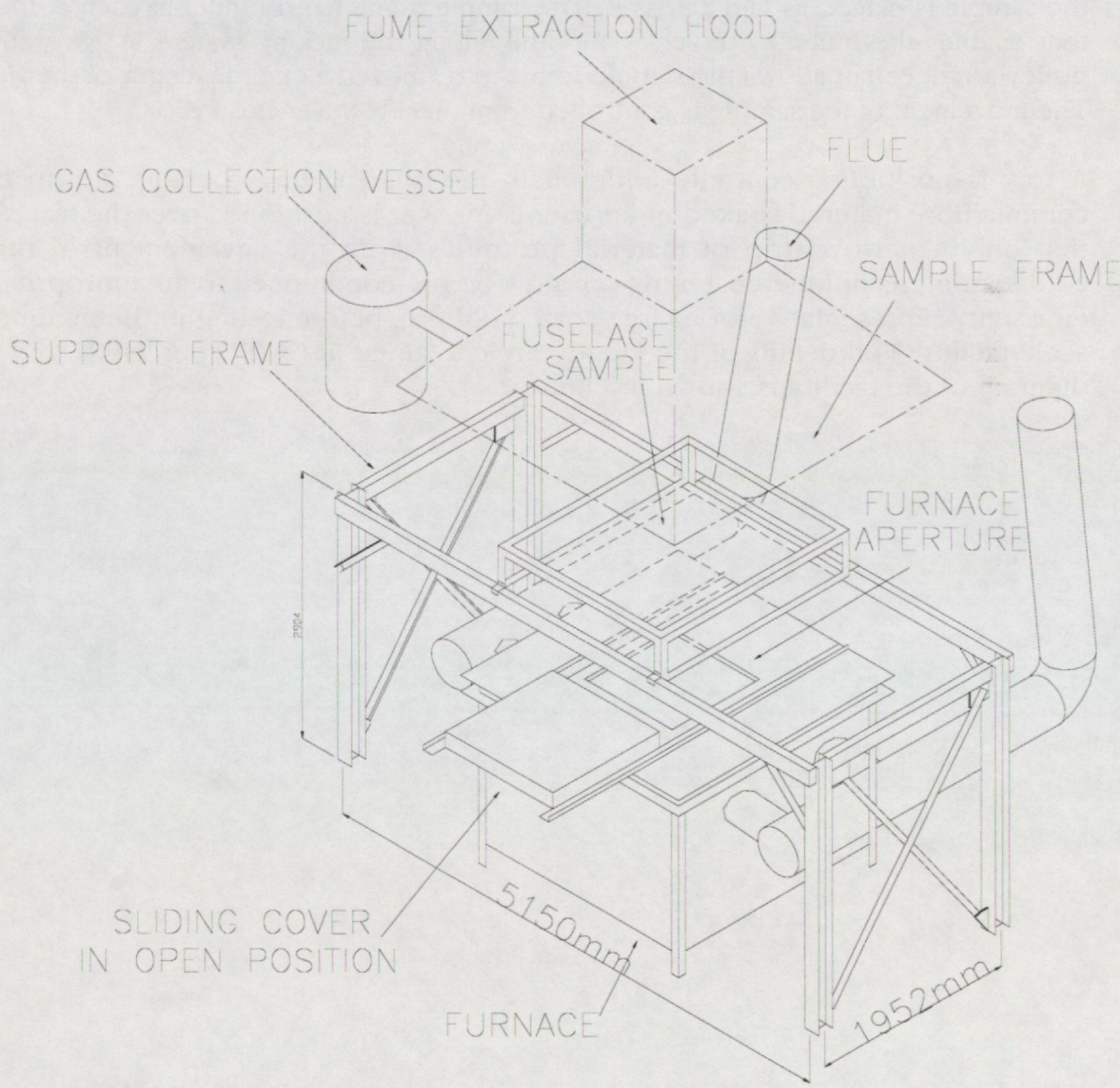


**Figure 1 Medium Scale Burnthrough Facility**

## 2.3 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 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 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 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.

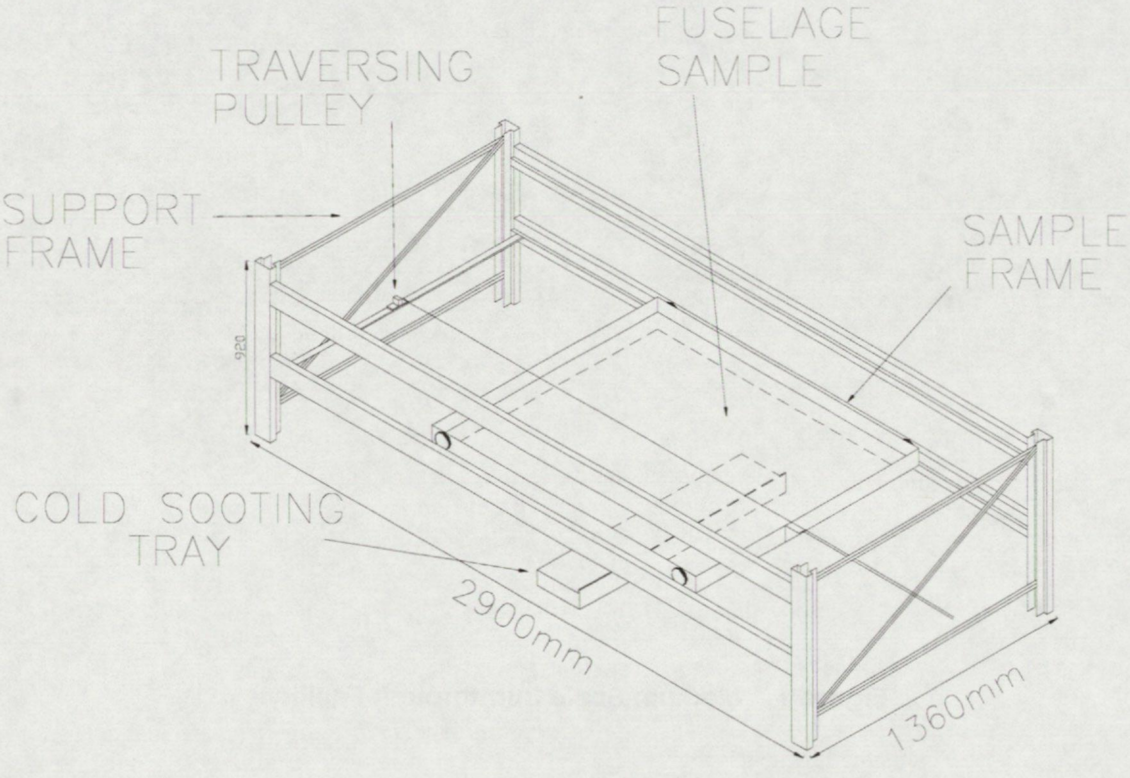


**Figure 2 Cold Sooting Facility**

## 3 TEST SET UP

### 3.1 Test Data Set A

In this initial phase of testwork a total of six burnthrough tests were conducted as summarised in Table 1. Three Corrosion Inhibiting Compounds were tested each being manufactured by different companies. The corrosion inhibiting compounds chosen were representative of the majority of those in use by the aerospace industry. For the purposes of this report the corrosion inhibiting compounds are not given their actual names but are referred to as Alpha, Beta and Gamma. The corrosion inhibitors Alpha and Gamma were spray applied from aerosol cans. The Beta corrosion inhibitor was brush applied. All the corrosion inhibiting compounds were applied in accordance with the manufacturer's instructions.

The fuselage samples were taken from an actual passenger aircraft and were the sections cut out on conversion to a freighter aircraft. The sections of fuselage tested were almost identical in configuration, in terms of the positioning of frames and stringers, and were all from an area of the fuselage just below cabin floor level.

Before the fuselage samples were prepared for testing both sides of the fuselage were thoroughly scrubbed and cleaned with an organic solvent to remove any dirt or any corrosion inhibitor already present. The exteriors of the fuselage samples were preconditioned to the appropriate surface emissivity in the manner described previously.

The insulation used was glass fibre, 76.2mm thick and with a density of 9.6 $kg/m^3$ and the bagging material was a polyvinyl fluoride film reinforced with polyester yarn, both chosen because of their widespread use.

For the tests involving insulation the insulation was held in place using insulation fixing pins made of mild steel. Holes were made in the frames and each pin went through the two insulation blankets adjacent to the frame. This arrangement was held in position using metallic push fit washers. The insulation blankets were weighed down around the edges of the panel with several large weights ensuring the insulation blankets remained in position. The perimeter of the panel was not sealed so that any smoke or flames originating from the back face of the panel were able to escape.

For all the tests thermocouples were placed on the cold face of the fuselage panel (i.e. the face away from the heat source). For tests involving insulation, thermocouples were also placed on the cold face of the insulation.

**Table 1 Summary of Test Data Set A**

| Test No. | Configuration | Corrosion Inhibitor | Insulation Material | Insulation Thickness (mm) | Insulation Density (kg/m³) | Bagging Film Material | Comments |
|---|---|---|---|---|---|---|---|
| CI 2 | Fuselage | None | None | NA | NA | NA | – |
| CI 3 | Fuselage | Gamma | None | NA | NA | NA | – |
| CI 5 | Fuselage | Beta | None | NA | NA | NA | – |
| CI 7 | Fuselage | Alpha | None | NA | NA | NA | – |
| CI 8 | Fuselage + Insulation | None | Microlite AA | 76.2 | 9.6 | PVF | Insulation weighted down around edge |
| CI 1 | Fuselage + Insulation | Beta | Microlite AA | 76.2 | 9.6 | PVF | Insulation weighted down around edge |

## 3.2 Test Data Set B

In this further phase of testing a total of seven burnthrough tests were conducted. It was the intention to build on and compliment the tests carried out in the initial investigation. The tests conducted are summarised in Table 2.

For this series of tests rather than use actual sections of aircraft fuselage as in the initial test phase, stylised fuselage panels were used. Stylised Fuselage Panels are prefabricated specifically for test work and are intended to give a consistent representation of a typical section of aircraft fuselage. Stylised panels were used to ensure that each fuselage panel was identical in configuration and was completely clean before use. The stylised panel had been developed to test representative sizes of insulation blankets and methods of attachment. The features on the stylised panel make it more representative of an actual aircraft fuselage than a plain sheet of aluminium.

The exterior of the stylised fuselage panels were preconditioned to obtain the requisite level of emissivity using the cold sooting procedure previously described. The corrosion inhibiting compounds used were the same as those used in the initial investigation and applied in a similar manner.

The insulation and bagging film material used were also the same as those used in the initial investigation with the exception of the insulation used in test B. In test B (stylised fuselage + insulation) the density of the insulation material was $6.7 kg/m^3$. The difference in density of insulation used was entirely due to material availability.

As in the initial test phase for the tests involving insulation, the insulation was held in place using insulation fixing pins made of mild steel. In test 2 (stylised fuselage + insulation + beta), the insulation blankets were weighed down around the edges of the panel. The perimeter of the panel was not sealed so that any smoke or flames originating from the back face of the panel were able to escape. In an actual aircraft insulation system it is probable that if the insulation is fitted correctly any flames or smoke produced between the skin and insulation would not be able to escape therefore in an attempt to replicate this situation in test B (stylised fuselage + insulation), and test 5 (stylised fuselage + insulation + beta), the perimeter of the panel was sealed using aluminium tape.

For all the tests thermocouples were placed on the cold face of the stylised panel. For tests involving insulation, thermocouples were also placed on the cold side of the insulation, that is, the side of the insulation not in contact with the stylised aluminium panel.

**Table 2 Summary of Test Data Set B**

| Test No. | Configuration | Corrosion Inhibitor | Insulation Material | Insulation Thickness (mm) | Insulation Density ($kg/m^3$) | Bagging Film Material | Comments |
|---|---|---|---|---|---|---|---|
| A | Stylised Fuselage | None | None | NA | NA | NA | – |
| B | Stylised Fuselage + Insulation | None | Microlite AA | 76.2 | 6.7 | PVF | Test sample sealed around perimeter using aluminium tape |
| 1 | Stylised Fuselage | Beta | None | NA | NA | NA | – |
| 2 | Stylised Fuselage + Insulation | Beta | Microlite AA | 76.2 | 9.6 | PVF | Insulation weighted down around edge |
| 3 | Stylised Fuselage | Alpha | None | NA | NA | NA | – |
| 4 | Stylised Fuselage | Gamma | None | NA | NA | NA | Insulation weighted down around edge |
| 5 | Stylised Fuselage + Insulation | Beta | Microlite AA | 76.2 | 9.6 | PVF | Test sample sealed around perimeter using aluminium tape |

## 4 RESULTS AND DISCUSSION

The results from the burnthrough tests are summarised in Tables 3 and 4. Plots of average cold face temperatures are shown in Appendix 1, Figures 1, 2, 4 and 5. Plots of smoke obscuration are shown in Appendix 1 Figures 3, 6 and 7. In all the tests the burnthrough times were recorded as the time at which flame penetration through the system occurred.

**Fuselage only**

In Test Data Set A the burnthrough times, shown in Table 3, for the three fuselage sections coated with corrosion inhibitors CI3 (gamma), CI5 (beta), and CI7 (alpha), were similar, burnthrough occurred after 46–48 seconds. The section without any corrosion inhibitor CI2 (fuselage only) burnt through after 60 seconds. At the time it was postulated that this difference in burnthrough times for these four almost identical sections of fuselage could be due to the presence of corrosion inhibitor.

In Test Data Set B the burnthrough times, shown in Table 4, for the three stylised fuselage panels treated with corrosion inhibitors Tests 1 (beta), 3 (alpha) and 4 (gamma) were similar, burnthrough occurred after 35–37 seconds. The panel without any corrosion inhibitor Test A (stylised fuselage only) burnt through after 30 seconds.

From the results from Test Data Set B where aluminium panels with and without corrosion inhibitors display similar burnthrough times, it appears that the presence of corrosion inhibiting compounds on an aircraft fuselage do not have a significant effect on the burnthrough time of the aluminium skin.

In tests CI3, CI5 and CI7 (Data Set A) smoke appeared on the back face after only 5–7 seconds from the start of the test and then flames after a further 19–21 seconds. In test CI2 smoke didn't start to appear until 12 seconds into the test and then flames after a further 23 seconds. This suggested that in the absence of other variables the presence of corrosion inhibitors on a fuselage skin caused it to emit smoke and for flames to appear on the cold face earlier.

The appearance of smoke and flames on the fuselage panel without corrosion inhibitor, in Test Data Set A, appeared contradictory. This could be due to either corrosion inhibiting compounds, or other flammable compounds, remaining on the fuselage panel following cleaning. This uncertainty regarding the cleanliness of actual fuselage panels led to a series of tests being conducted using stylised fuselage panels (Test Data Set B).

In tests 1,3 and 4 (Data Set B) smoke appeared on the back face after only 9–10 seconds from the start of the test. In test 1 (beta) flames then appeared after a further 6 seconds. In tests 3 (alpha) and 4 (gamma) no flames appeared at all prior to burnthrough. In the tests without corrosion inhibitor no levels of smoke or flames were observed.

The results from both data sets demonstrate that the nature and composition of corrosion inhibiting compounds are such that they are capable of producing large quantities of smoke and in some instances flames prior to the occurrence of burnthrough. In these tests, it appears that sufficient heat is being conducted through the aluminium before burnthrough to cause the corrosion inhibitors to vaporise and as a result produce smoke and potentially flash over.

**Fuselage and Insulation**

In Test Data Set A, for the tests with fuselage and insulation, CI8 (no inhibitor) and CI1 (beta), smoke appeared after 18 and 10 seconds respectively. As before the fuselage section with corrosion inhibitor produced smoke sooner than the one without. Flames then developed 12 seconds later for CI8 and 21 seconds later for CI1. The time to flame appearance for the two sections was similar, 30 and 31 seconds respectively.

The results from Test Data Set A display a lack of consistency. As described previously for tests CI8 and CI1 there was almost no difference in the time to flame appearance for the two tests although corrosion inhibitor was present in test CI1. In test CI2 in which no inhibitor was used more smoke was produced than in test CI7 in which inhibitor was used. In an attempt to explain this it is worth noting that all the fuselage sections tested had some form of sealant running along the lengths of the stringers and frames which no doubt contributed to the quantity of smoke produced. In addition, although every effort was made to thoroughly clean the fuselage section it is possible that substances remained which also contributed to the smoke and flames.

For Test Data Set B the result from test B correlates with previous testwork on the burnthrough of stylised fuselage panels and fibre glass insulation.

The results from tests 2 and 5 involving stylised panels plus a corrosion inhibitor (beta) and insulation require closer attention. As stated previously in an attempt to replicate a typical aircraft configuration the method of installation attachment evolved throughout the test programme. This has probably resulted in wider range of issues for discussion but does not impact upon the overall conclusions of this document.

Cap strips (insulation material fixed over the frames) were used in test 5 but not in test 2. Also in test 5 the perimeter of the panel was sealed using aluminium tape, the insulation bags were also attached to one another using aluminium tape to form a cohesive system, this was not the case in test 2. In test 2 the insulation bags were weighted down around the perimeter of the panel with large metal weights. The two test samples started to emit smoke after approximately the same time from the start of the test, however in test 2 almost immediately flames were produced as well. This may well have been due to the method of installation of the insulation blankets. In test 5 the insulation formed more of a cohesive system and as such any flaming occurring on the back face of the stylised panel may not have been visible.

Given the data it is unclear whether or not the presence of the corrosion inhibiting compounds in tests 2 and 5 had any effect on the burnthrough time of the system. It is clear though that their presence significantly increases the amount of smoke generated when the system is subjected to fire testing as well as providing the possibility for a fire to develop inside the aircraft before penetration by an external fire has occurred.

**Smoke Generation**

The average reduction in light intensity as shown in Tables 3 and 4 provides an indication of the quantity of smoke released during the test.

For Test Data Set A almost all the tests produced sufficient smoke to reduce the light intensity by 15–30%.

For Test Data Set B, in the tests involving a stylised panel and corrosion inhibitor only sufficient smoke was produced so as to reduce the light intensity by approximately 10–20%. For tests 5 and 2, involving a stylised panel plus insulation and corrosion inhibitor (beta) the reduction in light intensity was between 37 and 48% respectively. This compares to a reduction of only 7.7% for test B involving a stylised panel and insulation only.

When considering the data a number of factors should be taken into account. The values given for the reduction in light intensity refer to a 120 second period from the start of the test, except for tests CI 3 (gamma) and CI 7 (alpha) where the values refer to the first 90 seconds, and as such do not take into account any smoke produced after 120 seconds. In representing the smoke production as a reduction in light intensity across the test enclosure it is possible that where significant quantities of flames are produced the light provided by the flames interferes with the results.

A profile of light intensity against test duration for all the tests is shown in Figures 3 and 7.

**Table 3 Summary of Test Data Set A**

| Test No. | Configuration | Corrosion Inhibitor | Time to smoke emission (sec) | Time to flame appearance (sec) | Time to burnthrough (sec) | Average Reduction in Light Intensity |
|---|---|---|---|---|---|---|
| CI 2 | Fuselage | None | 12 | 35 | 60 | 18.4 |
| CI 3 | Fuselage | Gamma | 5 | 26 | 46 | 31.5 |
| CI 5 | Fuselage | Beta | 7 | 26 | 48 | 25.8 |
| CI 7 | Fuselage | Alpha | 7 | 26 | 46 | 14.3 |
| CI 8 | Fuselage + Insulation | None | 18 | 30 | 54 | 23.9 |
| CI 1 | Fuselage + Insulation | Beta | 10 | 31 | 50 | 31.1 |

**Table 4 Summary of Test Data Set B**

| Test No. | Configuration | Corrosion Inhibitor | Time to smoke emission (sec) | Time to flame appearance (sec) | Time to burnthrough (sec) | Average Reduction in Light Intensity |
|---|---|---|---|---|---|---|
| A | Stylised Fuselage | None | – | – | 30 | 0.8 |
| B | Stylised Fuselage + Insulation | None | – | – | 60 | 7.7 |
| 1 | Stylised Fuselage | Beta | 10 | 16 | 36 | 9.3 |
| 2 | Stylised Fuselage + Insulation | Beta | 18 | 18 | 100 | 48.1 |
| 3 | Stylised Fuselage | Alpha | 10 | – | 37 | 10.7 |
| 4 | Stylised Fuselage | Gamma | 9 | – | 35 | 18.7 |
| 5 | Stylised Fuselage + Insulation | Beta | 20 | – | 69 | 37.7 |

## 5 CONCLUSIONS

The results from the initial phase of testing had suggested that the presence of corrosion inhibiting compounds on an aircraft fuselage may have an effect on the burnthrough time of the aluminium skin. However, subsequent testing has shown that corrosion inhibitors are likely to have an insignificant effect on burnthrough times. Aluminium panels with and without corrosion inhibitors display similar burnthrough times for the aluminium skin.

The nature and composition of corrosion inhibiting compounds are such that they are capable of producing large quantities of smoke and in some instances causing flames to appear on the cold face prior to burnthrough.

## 6 REFERENCE

1. '*Burnthrough Resistance of Fuselages: Further Investigation*'

Darren C Dodd, C R Jenkins, M A Snell (1995)

CAA Paper 95003: Civil Aviation Authority London

## APPENDIX 1 GRAPHS

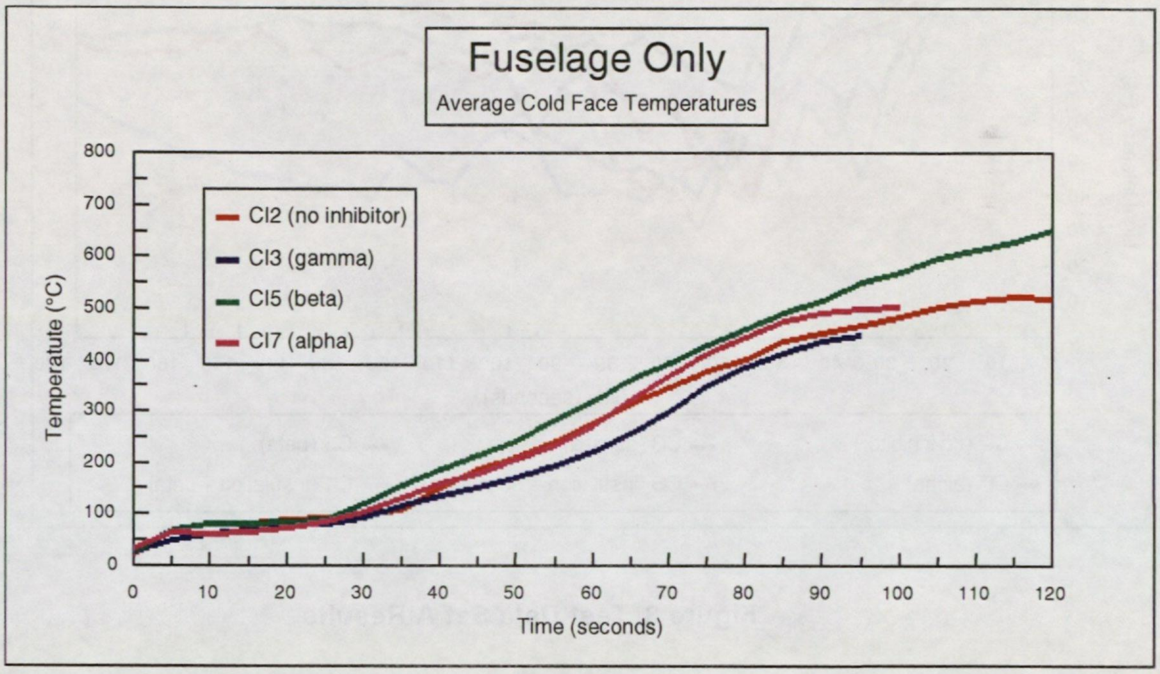


**Figure 1 Test Data Set A Fuselage Panel Results**

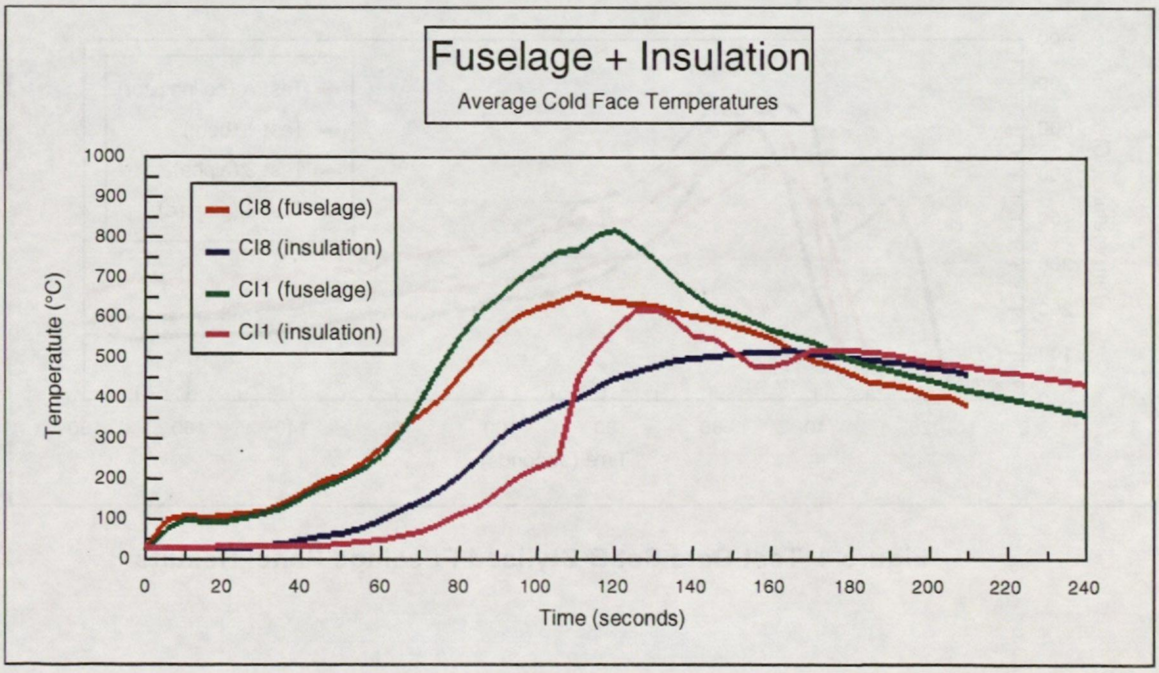


**Figure 2 Test Data Set A Fuselage Panel + Insulation Results**

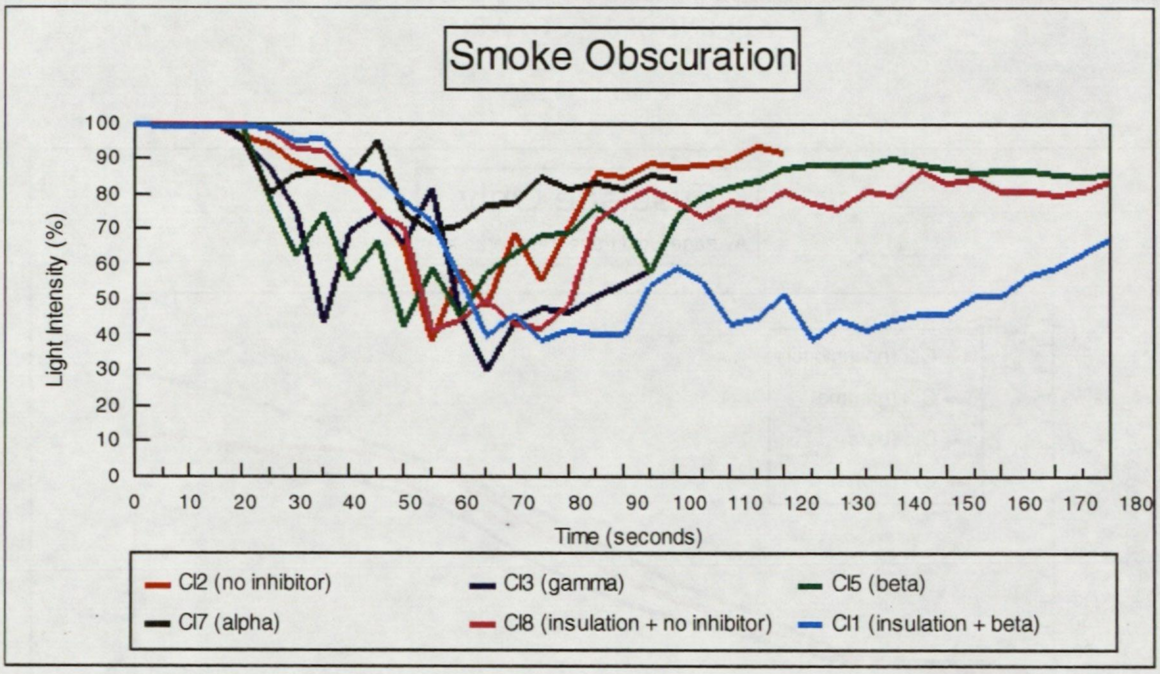


**Figure 3 Test Data Set A Results**

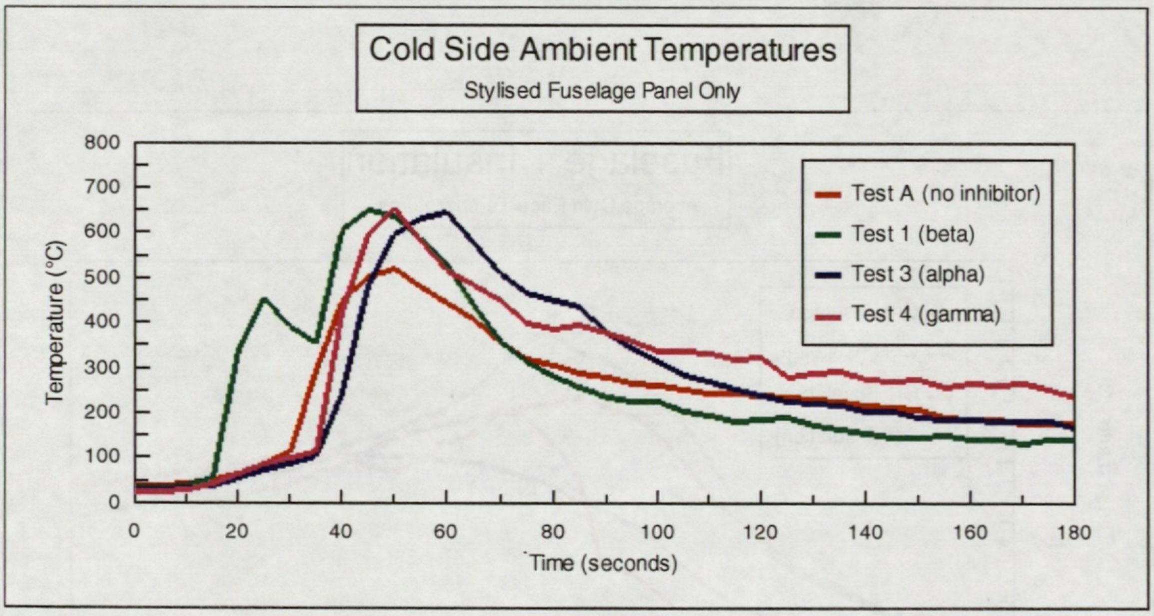


**Figure 4 Test Data Set B Stylised Fuselage Panel Results**

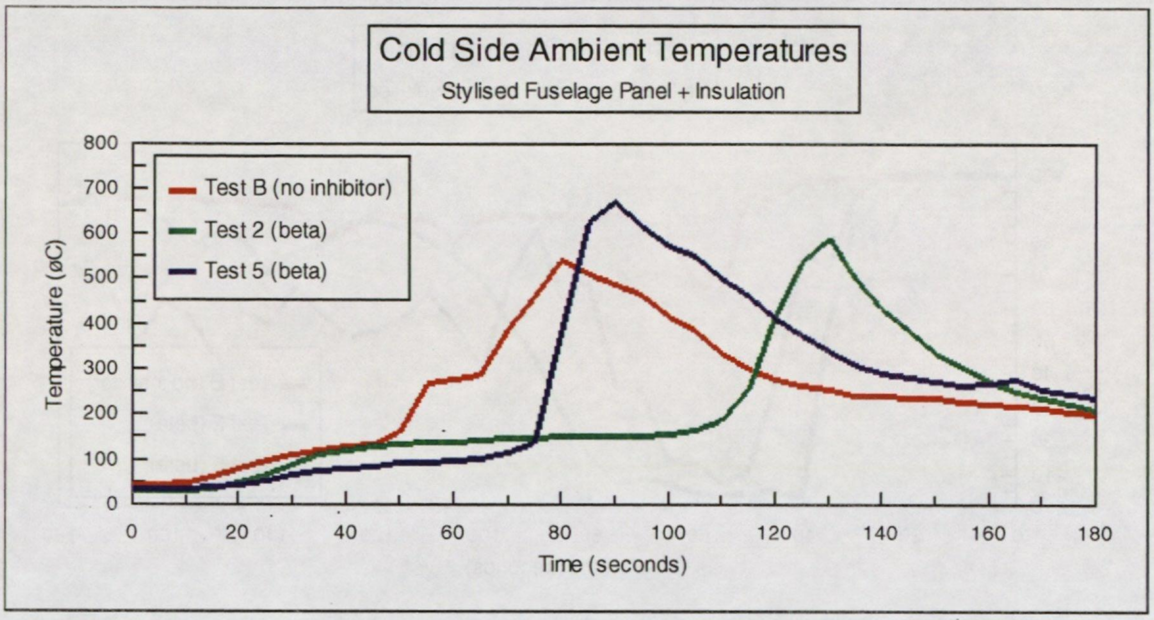


**Figure 5 Test Data Set B Stylised Fuselage + Insulation Results**

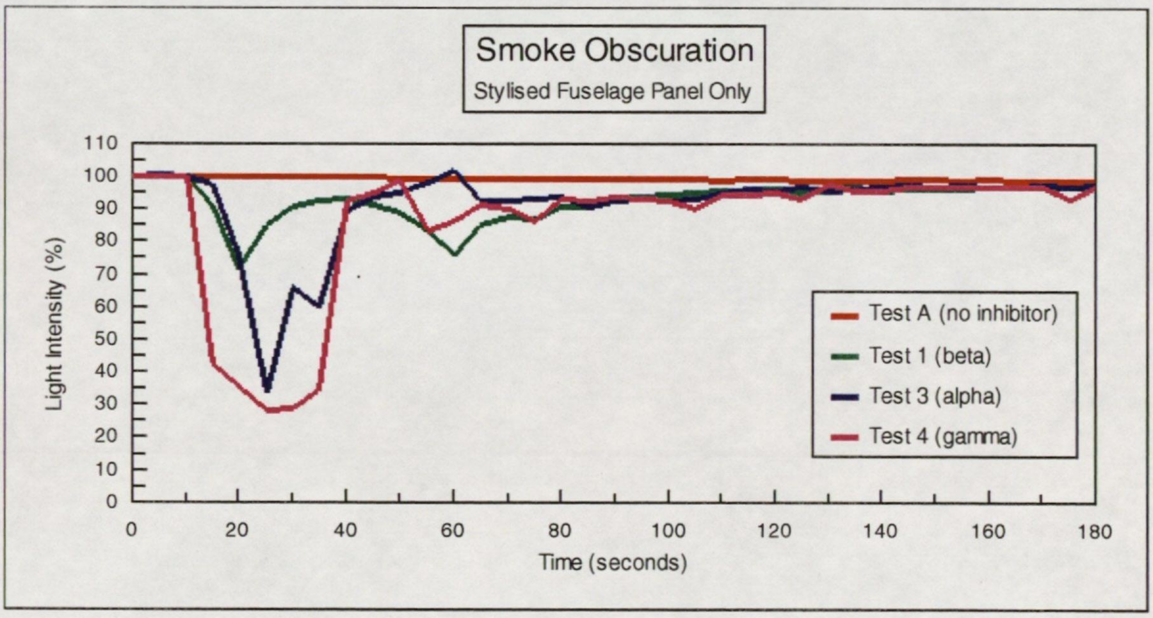


**Figure 6 Test Data Set B Stylised Fuselage Results**

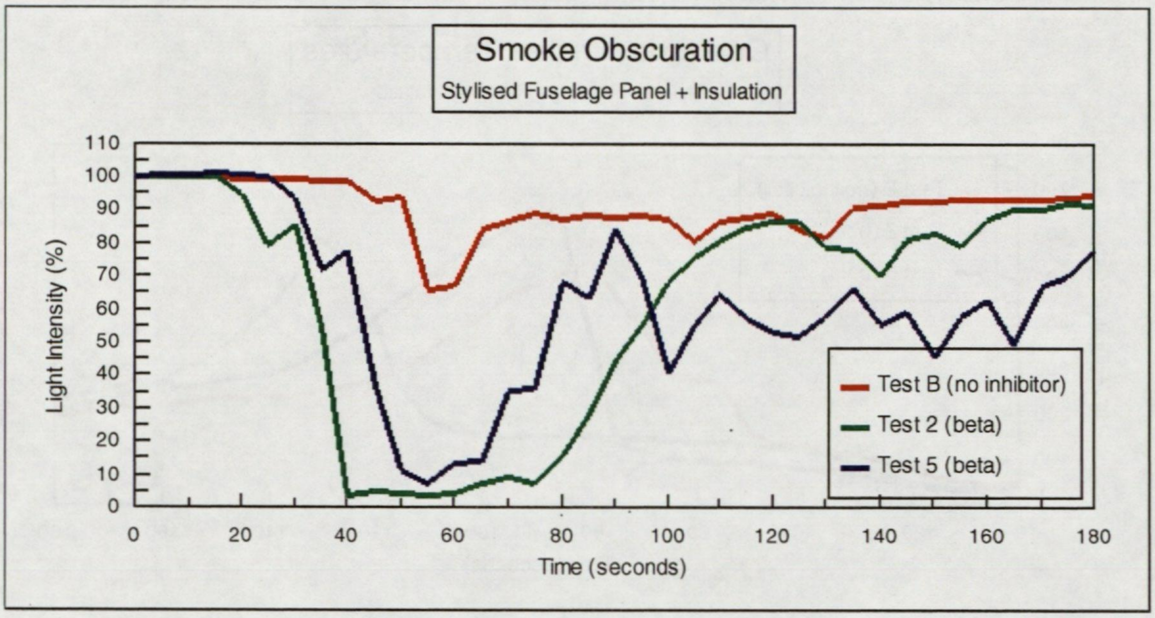


**Figure 7 Test Data Set B Stylised Fuselage + Insulation Results**