EASA REGULATORY IMPACT ASSESSMENT

ENHANCED FUSELAGE BURNTHROUGH PROTECTION

JULY 2009

Issue 3

AMENDMENT RECORD

ISSUE NUMBER	DATE	REMARKS
1	April 2009	Initial Issue
2	June 2009	Incorporation of EASA comments
3	July 2009	Incorporation of EASA comments. Final Report

CONTENTS

ABBREVIATIONS

ADB	CSRTG Accident Database
AECMA	European Association of Aerospace Industries
AIA	Aerospace Industries of America
ATSB	Australian Transport Safety Bureau
CEAT	Centre d'Essais Aeronautique de Toulouse
CFRP	Carbon Fibre Reinforced Polymer
CIAIAC	Civil Aviation Accident and Incident Investigation Commission - Spain
CSRTG	Cabin Safety Research Technical Group
EASA	European Aviation Safety Agency
FAA	Federal Aviation Administration
NPA	Notice of Proposed Amendment
NPRM	Notice of Proposed Rulemaking
OPF	Oxidized Polyacrylonitrile Fibre
TAI	Thermal Acoustic Insulation
TC	Transport Canada
UK CAA	United Kingdom Civil Aviation Authority

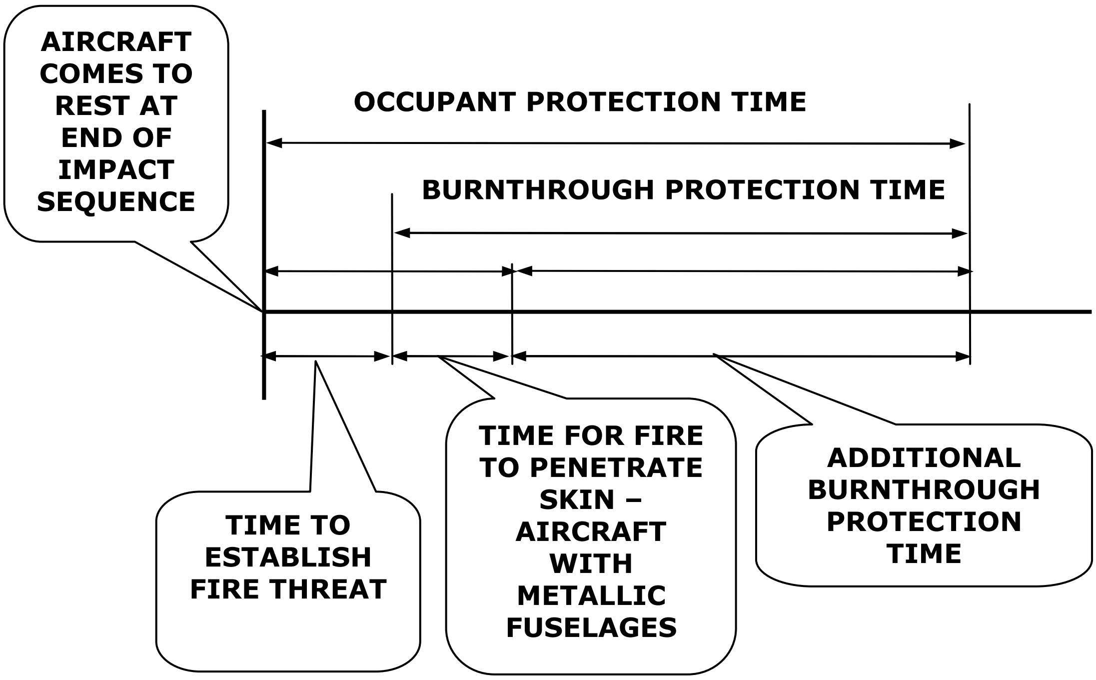
DEFINITION OF TERMS

Pool Fire *- An extensive ground fire originating from fuel spillage from damaged aeroplane fuel tanks*

Occupant Protection Time *is the time in the accident sequence, from the aircraft coming to rest, to the point at which occupants within the cabin cease to be protected from the fire penetrating into the fuselage[1].*

Burnthrough Protection Time *is the time from the onslaught of the fire onto the fuselage to its penetration into the cabin.*

Additional Burnthrough Protection Time *is the time from the fire penetrating the fuselage skin to its penetration into the cabin (applicable to metallic fuselages only).*



Burnthrough Test Time *is the time established for the material by the burnthrough flame penetration test requirements prescribed in the new Part VII added to Appendix F of CS-25.*

[1] For aircraft with metallic fuselages, the Occupant Protection Time is assumed to be five minutes. Four minutes being provided by the Thermal Acoustic Insulation and one minute from the aircraft coming to rest to the time that the fuselage skin is penetrated by the fire.

1 PURPOSE AND INTENDED EFFECT

1.1 ISSUE WHICH THE NPA IS INTENDED TO ADDRESS

The European Aviation Safety Agency amended CS-25, by the addition of 25.856(b), to require that Thermal Acoustic Insulation fitted to the lower half of the fuselage provides a fire barrier to protect the cabin from fire entry following a post impact pool fire. Whilst this regulatory action reflects that taken by the FAA in their Final Rule (Reference 2), EASA commissioned a study (Reference 3) to provide an updated review of the potential risks posed to occupant survival from ground pool fires and to identify regulatory means for mitigating these risks.

The use of Thermal Acoustic Insulation as a fire barrier does not provide complete protection and may not be the most cost beneficial means of achieving the safety intent. Furthermore, advances in technology (e.g. carbon composite fuselages) bring about further issues that may need to be considered in regulating for enhanced burnthrough protection of aircraft.

This Regulatory Impact Assessment (RIA) considers the feasibility of introducing a new CS-25 regulation to provide an objective rule for enhanced fuselage burnthrough resistance from pool fires and possibly the deletion of the existing requirements relating to burnthrough resistance being provided by Thermal Acoustic Insulation.

1.2 SCALE OF THE ISSUE

The conclusions reached in this RIA are based primarily on a study commissioned by EASA into Enhanced Fuselage Burnthrough Protection (Reference 3). Consideration of these options is significantly influenced by the limited potential that exists on aircraft with metallic fuselages to provide additional protection to occupants in pool fire accidents. A study carried out for the FAA (Reference 4) concluded that:

> *"Enhanced Fuselage Burnthrough Protection has been reassessed and the life saving benefit increased from that previously estimated. The number of lives saved per year is estimated to be approximately 12."*

This study was based on an analysis of fire related accidents that occurred over the period 1967 to 1996. The benefit derived was assessed taking into account the improvements that had been made to fire and evacuation related requirements that had been introduced into Part 25 at the time.

The rate of occurrence of pool fire accidents has reduced quite markedly since the time of the FAA study (Reference 4). RIA Table 1 shows the average rate of occurrence of known pool fire accidents to Western World Large Transport Aeroplanes over the periods 1967 to 1996 and 1997 to 2007. Since it is likely that there were pool fire accidents that were not identified in the studies described in Reference 3 and Reference 4 the actual accident rate for pool fire accidents is likely to exceed the values shown in RIA Table 1. However, the data indicate that the average accident rate has decreased significantly, perhaps by a factor in the region of three to four since the time of the FAA study. Although the average number of passengers per flight has increased steadily since the 1960's it would seem likely that the benefit has reduced by a factor in the region of 3 i.e. from 12 to approximately 4 lives saved per year.

RIA Table 1: Average Rate of Occurrence of Pool Fire Accidents to Western World Large Transport Aeroplanes[2]

POOL FIRE ACCIDENTS OVER THE PERIOD 1967 to 1996	POOL FIRE ACCIDENTS OVER THE PERIOD 1997 to 2007	NUMBER OF FLIGHTS OVER THE PERIOD 1967 to 1996	NUMBER OF FLIGHTS OVER THE PERIOD 1997 to 2007	AVERAGE POOL FIRE ACCIDENT RATE OVER THE PERIOD 1967 to 1996	AVERAGE POOL FIRE ACCIDENT RATE OVER THE PERIOD 1997 to 2007
72	14	389,160,000	288,060,000	1.9E-07	4.9E-08

4207 Final Report & Data/Accident & Fatality Rate

Perhaps one of the more significant issues that limit the benefit to be gained from enhanced burnthrough protection in pool fire accidents is the extent to which penetration of the fire into the cabin is by routes other than through the fuselage skin. Reference 3 concluded that:

> *"Fire entry into the cabin through fuselage breaks, ruptures, and opened doors constitutes a major threat to occupants in approximately three-quarters of pool fire accidents and this cannot be mitigated by enhanced fuselage burnthrough protection."*

Furthermore there is a limit to the life saving potential in accidents where the threat to the cabin is from fire penetration of the cabin. The regulatory change introduced in CS 25.856(b) is intended to provide an *Additional Burnthrough Protection Time* of four minutes. If fully effective this would provide an *Occupant Protection Time* in the region of five minutes. Protection beyond this is likely to yield minimal life saving potential. A study carried out for the UK CAA in 1998 (see Reference 5) into the likely benefit that might accrue from fire hardening of the entire fuselage, concluded that:

> *"The rate of improvement in benefit appears to vary exponentially with limited improvement beyond the four to eight minute additional protection point".*

As part of the EASA study (Reference 3), a Monte Carlo Model was developed to assess whether the assertion that five minutes of *Occupant Protection Time* is adequate. Occupant protection is required until the time that the evacuation process is complete or the fire-fighters have established control of the fire. The data used in the model was that contained in the FAA report Reference 6. These data were used to generate distributions of the following variables:

The time taken to initiate an evacuation[3]
The time taken to complete an evacuation[4]
The time for the fire-fighters to arrive[5]
The time for the fire-fighters to control the fire[6]

[2] Based on **known** pool fire accidents – the absolute values of accident rates are likely to exceed these rates.
[3] The 'Time to Initiate an Evacuation' was measured from the end of the impact sequence to the time that the evacuation started.
[4] Evacuation Completion Times were derived from the start of the evacuation to the time the last occupant exited the aircraft. The times relate to mobile occupants that were able to self-evacuate.
[5] The time to arrival of fire-fighters is measured from the time the aircraft stopped at the end of the impact sequence to the time that they were in a position to start fire-fighting activities
[6] The time for the fire-fighters to establish control is measured from their time of arrival to the time that they established control of the fire.

The results of the model suggested that:

> *"On the assumption that an average time for establishing the fire threat and penetrating the skin of a metallic aircraft is approximately one minute, an additional burnthrough protection time of 4 minutes is likely to provide adequate occupant protection for the majority of pool fire threats".*

Hence, the opportunity that exists for improving the safety of occupants beyond that afforded by CS 25.856(b) is limited. Therefore, any improvements that are made to safety levels related to enhanced fuselage burnthrough protection must be shown to be cost beneficial. The current rule imposes an economic burden on the industry since it requires the installation of more expensive and heavier Thermal Acoustic Insulation.

Furthermore, the current rule relates to the burnthrough characteristics of Thermal Acoustic Insulation, which is not required to be fitted to aircraft.

Cost and weight estimates for providing burnthrough protection from Thermal Acoustic Insulation are varied. Typically it might be expected that for a single deck twin aisle aircraft the material cost would amount to approximately US $43,000 and the incremental weight increase perhaps greater than 200 lb (see Appendix 2).

It may therefore be concluded that whilst there is potential life saving benefit to be derived from improving the burnthrough characteristics of aircraft fuselages, for this improvement to be cost beneficial the costs incurred would need to be modest.

Hence, a more objective rule might provide a more cost beneficial solution to the issue and allow the industry flexibility in taking advantage of changes in technology to meet the overall safety objectives. This view has been expressed by the industry and is reflected in the comment from the AIA (Reference 7) in their response to the FAA NPRM 00-09 (Reference 8), "Improved Flammability Standards for Thermal/Acoustic Insulation Materials Used in Transport Category Airplanes":

> *"Regarding the proposal for resistance to burnthrough, the AIA believes the FAA approach of mandating a design solution for a fire barrier through regulatory action is inappropriate. A more appropriate approach would be to require that the fuselage design in the affected areas incorporate a fire barrier, and leave the actual design to industry. The FAA could address specific solutions through Advisory Circulars. The AIA recommends the FAA withdraw this part of the proposal and reissue it as a proposed fuselage design requirement."*

1.3 BRIEF STATEMENT OF THE OBJECTIVES OF THE NPA

The objectives of the proposed NPA are to ensure that the requirements contained in CS-25 afford an adequate level of protection for occupants in post-impact pool fire accidents commensurate with the costs incurred. The intention is to provide the aircraft manufacturer with greater flexibility as to the manner in which this goal is achieved.

2 OPTIONS

2.1 CONSIDERATION OF FIRE PATHS

The EASA study (Reference 3) assessed the potential fire paths into the cabin from a post impact pool fire. The following summarises the findings of the study, in relation to fire entry paths, which have formed the basis for the options considered in this Regulatory Impact Assessment.

In 1996, the UK CAA commissioned a burnthrough assessment study (Reference 9) into the most likely paths fire would use to penetrate the passenger cabin during a post-crash fire. This study, conducted by Faverdale Technology Centre Ltd, used a combination of past accident reviews, surveys of existing aircraft and a visit to the International Fire Training Centre at Teesside Airport to study an aircraft subjected to pool fires. This study identified a number of typical fire paths, which are represented in Figure 1 below.

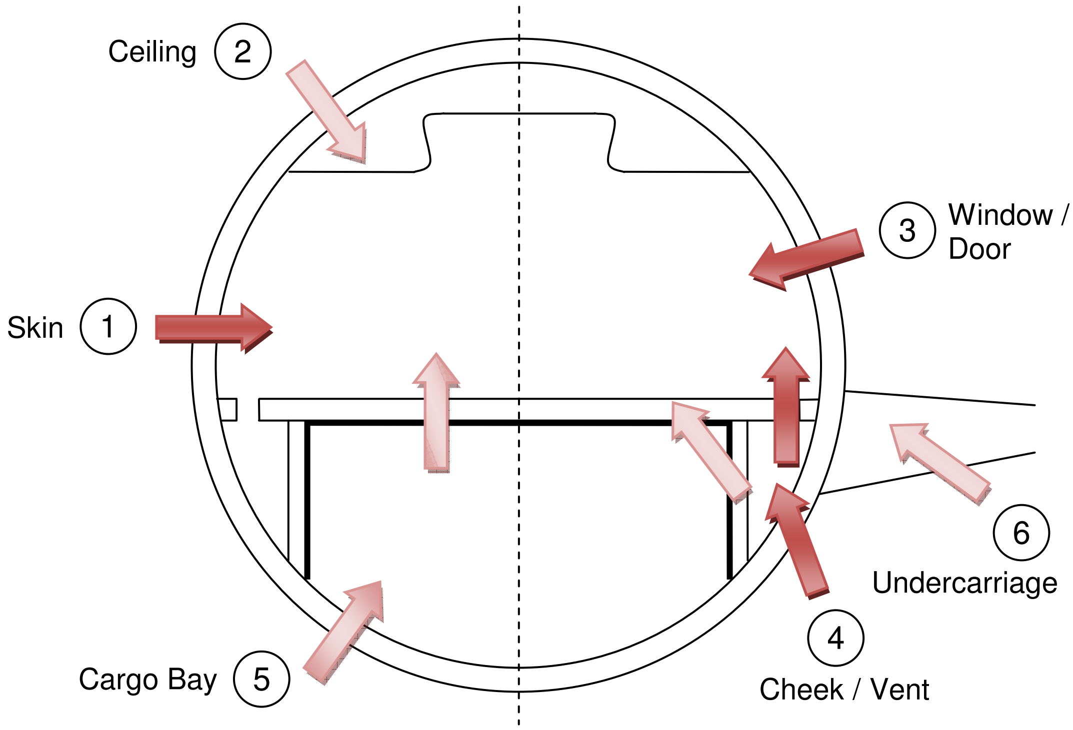


Figure 1: Typical Fire Paths into the Passenger Cabin

The fire path indicated by (1) in Figure 1 represents a direct burnthrough in the side of the passenger cabin. The CAA study indicated that the fire would need to penetrate the fuselage skin, insulation system and cabin sidewall panel. In fire path (2), the fire penetrates the upper fuselage skin, insulation system and then ceiling panels or overhead stowage bins. In these areas, smoke is likely to penetrate into the cabin before fire due to the gaps between the cabin interior panels.

Fire path (3) involves fire penetrating into the cabin through either cabin windows or through passenger doors. Penetration of the fire through the cabin window panes results in immediate access to occupied areas (in contrast with the fuselage skin where the fire has to also penetrate the insulation system and interior panels). Window seals may also emit smoke when exposed to fire. The study also identified the cabin doors as possible fire paths. The report states that the fuselage door should be capable of offering at least as much protection as the fuselage; consisting of skin, insulation system and some form of substantial interior panel. The seals around doors also present a possible fire entry route if the materials used for the seals are not fire resistant.

Fire paths through the lower fuselage (4) include burnthrough of the fuselage skin and then the insulation bags into the cheek area. The cheek area can often span a significant length of the fuselage (normally only stopped by wing box/main landing gear stowage), allowing fire to spread down the length of the fuselage and follow any path available into the passenger cabin. Once in the cheek area, the primary paths for fire to enter the cabin are either through the main cargo compartment or through the return air grills in the dado panel. For new Part 25 aircraft carrying passengers only, a class C compartment (see CS 25.857) would be used for the main cargo compartment, which consists of sidewall and ceiling cargo liners tested to CS-25 Annex F Part III (see CS 25.855). This presents a significant fire barrier and therefore the immediate threat to the cabin will be through the return air grills. Fire path (5) through the lower fuselage into the cargo compartment would require penetration of the fuselage skin, insulation bags and then the cargo compartment floor and liner. Unlike the sidewall and ceiling liners, the floor liner of a class C cargo compartment needs only meet the less stringent CS-25 Annex F Part I test, however the fire would still need to penetrate the ceiling liner, cabin floor and its covering before entering the passenger compartment. Additionally, full-scale fire testing conducted by the FAA (Reference 10) indicated that the aircraft is less vulnerable to path (5) when the gear is collapsed; however, the exposed cheek area (path 4) is a likely area for flame penetration with gear in either position.

The final fire path (6) identified in the CAA study was through the main landing gear bay. With the landing gear extended, fire may enter the bay and have direct access to the pressure floor. To enter the cabin, the fire would need to burnthrough the pressure floor, insulation system and then cabin floor. The extent of opening into the landing gear bay is dependent on the aircraft design; some aircraft may have the doors open and others may be partially or fully closed when the landing gear is extended. A similar situation would exist for the nose gear bay.

An additional fire path (7) in the lower fuselage relates to the cargo compartment door, as illustrated in Figure 2.

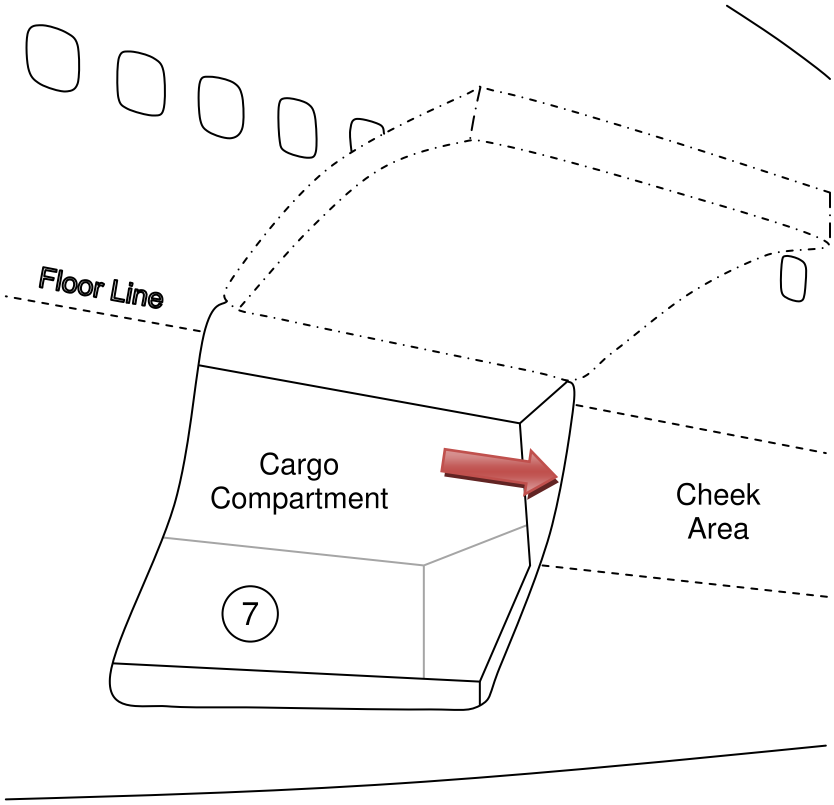


Figure 2: Potential Fire Entry Path through the Cargo Door into the Cheek

If fire burns through the cargo door skin, it can either penetrate the interior skin of the door and enter the cargo compartment, or penetrate the door sidewall or top panel and enter the cheek area. Fire entering the cargo compartment is covered by fire path (5), however, if the cargo access door does not have a cargo liner tested to Annex F Part III, fire could enter the cheek area.

To prevent the fire entering the cheek area through the cargo access door, it must be ensured that either the door itself, or the side wall and top panel around the door are protected from burnthrough. A similar situation also exists for other access doors in the lower fuselage, such as for equipment bays.

In summary, the fire path of least resistance to the passenger cabin from the upper fuselage is likely to be through the skin (path 1) or a cabin window (path 3). Through the lower fuselage, burnthrough into the cheek area can provide direct entry into the passenger cabin through the return air grills. These are indicated in Figure 1 by the darker arrows. When considering the entire aircraft length, there are additional lower fuselage fire paths in areas without the cargo compartment, which would present a similar fire path as the cheek areas. The FAA testing (Reference 10) indicated that the aircraft is more vulnerable with the gear extended, due to the larger surface area exposed to the fire. This configuration exposes additional paths through the main and nose landing gear bays which may be open. Additionally, the empennage crawlthrough is generally only partially insulated and can provide a direct path through the skin.

Experience indicates that a fire with the ferocity of a typical ground pool fire will use any path available to it to penetrate the structure. While the FAA Rule 25.856(b) provides improved protection for the lower fuselage where insulation is present, it provides no improvement to the situation in the upper fuselage. Where gaps are present in the lower fuselage insulation system, fire may penetrate into the aircraft. The most likely fire paths described above for the lower fuselage indicate that protection of the cheek area should be paramount. By ensuring no gaps are present in the insulation system for the cheek area, and protecting against fire entering the cheek area from under the cargo compartment, this may improve the overall fire resistance of the lower fuselage.

While this review indicated the quickest fire paths likely to be present in an aircraft subjected to a ground pool fire, it did not assess the relative fire / smoke threat posed by each path. As part of the EASA study (Reference 3), a mathematical model was constructed in an attempt to quantify the relative threat presented to occupants from each of the primary fire threats. However, it was not possible to obtain meaningful results from the model due to the lack of precise accident data concerning the times for the threats to occupants occurring and the progress of the evacuation.

In summary the EASA study (Reference 3) concluded:

> *"There are many potential fire paths that exist through to the cabin from a pool fire. It is likely that the quickest fire paths present in an aircraft subjected to a ground pool fire are the cheek area in the lower fuselage, the upper fuselage skin, and windows. However, no conclusions can be reached regarding the relative threat posed by each of the potential fire paths."*

On this basis the regulatory options considered in this RIA are primarily directed toward optimisation of the threats from the following areas:

- Cabin windows
- Upper fuselage
- Lower fuselage

2.2 ALTERNATE MEANS OF BURNTHROUGH PROTECTION

As part of the EASA study (Reference 3) consideration was given to the potential that existed for means other than by Thermal Acoustic Insulation to protect the cabin from fire penetration from pool fires. Intumescent coatings, if applied to the exterior surface of an aluminium-alloy fuselage skin, could potentially provide protection against burnthrough from a pool fire. These coatings are designed to swell significantly when exposed to fire, thereby providing a layer of insulation that delays the temperature rise and subsequent destruction of the substrate material.

Intumescent coatings are used extensively in building structures and on aircraft engine firewalls. Several manufacturers of this type of coating have explored their potential for use as an external fuselage burnthrough barrier. One manufacturer has demonstrated the excellent burnthrough performance of an intumescent coating in conjunction with the FAA, utilising a full-scale fuselage. The performance of the coating was observed by a number of aircraft manufacturers and a number of distinct advantages and disadvantages are apparent:

Advantages

- Complete and continuous coverage of the fuselage skin with no discontinuities
- No requirement for complex internal fire protection barriers
- Potential weight savings

Disadvantages

- Unproven durability against environmental degradation (UV, contamination etc)
- Unproven durability from in service wear and tear
- Inferior surface finish may result in aerodynamic issues
- Removal of the coating in accidents involving scraping of the fuselage

One manufacturer noted that to provide adequate durability against environmental degradation the intumescent coating would require to be protected with an additional coating, seriously degrading the fire protection properties. It was also noted that intumescent coatings with a very smooth finish do exist, but they need to be applied as a powder coating requiring oven curing at 150 deg C. This is likely to be impractical for a complete aircraft fuselage.

It is likely that the primary disadvantage is the lack of ability of an external fire barrier to withstand damage in an accident. The vast majority of accidents resulting in a ground pool fire involve a ground slide with the landing gear separated or retracted. Whilst any damaged area of the coating may be protected from fire by the ground, this cannot be guaranteed and would be virtually impossible to demonstrate. The only ground pool fire accidents where an external intumescent coating would be totally effective are those where the aircraft remains on its undercarriage and the fuselage has not suffered scraping. The EASA study (Reference 3) found that in 88 pool fire accidents where fire had entered the cabin, the aircraft remained on its landing gear and had no ruptures in only 4 %.

It may therefore be concluded that whilst intumescent coatings are unlikely to prove feasible as the primary means of providing fuselage burnthrough protection they may assist in the protection of the cabin by coating internal features such as the underside of the cabin floor or areas such as those illustrated by fire path 7 in Figure 2.

2.3 THE OPTIONS IDENTIFIED

Three regulatory options are considered in this Regulatory Impact Assessment:

1. **Do Nothing**
   - The "Do nothing" option means to make no improvements to CS-25 in relation to improved burnthrough protection. CS 25.856(b) "Thermal /acoustic insulation materials" introduced by NPA 2008-13 (Reference 1) requires thermal acoustic insulation materials to meet the flame penetration test requirements prescribed in the new Part VII added to Appendix F of CS-25. This option would mean that CS-25 remains unchanged from the standard introduced by NPA 2008-13.

   - Aircraft with non-metallic structures would continue to be addressed by an Equivalent Level of Safety finding.

2. **Amend CS-25 to provide a <u>partially</u> objective rule** to provide protection to occupants in pool fire accidents.
   - For aircraft with metallic fuselages, compliance may be demonstrated with the CS-25 amendment introduced by NPA 2008-13, which gives partial protection to the lower fuselage by the use of suitably selected and installed Thermal Acoustic Insulation. Additionally, windows should provide four minutes of burnthrough protection and the lower fuselage is redefined to encompass the side of the aircraft up to the top of the cabin windows. Applicants would also need to identify all of the fire paths into the cabin from <u>the lower fuselage</u> and demonstrate that all practicable measures had been adopted to minimise the threat to occupants.

   - For aircraft with non-metallic fuselages five minutes of *Occupant Protection Time* is required. The *Burnthrough Test Time* for the upper fuselage and windows should be four minutes and the lower fuselage five minutes. The lower fuselage is redefined to encompass the side of the aircraft up to the top of the cabin windows. Applicants would also need to identify all of the fire paths into the cabin from <u>both the upper and lower fuselage</u> and demonstrate that all practicable measures had been adopted to minimise the threat to occupants. This will entail:

     - ❖ the deletion of CS 25.856(b)
     - ❖ Amendments to Appendix F to CS-25 and the guidance material to accommodate other materials or components that may need to be tested (e.g. non-metallic fuselages, cabin windows)
     - ❖ guidance relating to the more general nature of the advisory material (e.g. the changes to the definition of the lower fuselage, the protection provided by the cabin windows and guidance on acceptable means of compliance for carrying out the Fire Path Risk Assessment)
     - ❖ the introduction of a new CS-25 requirement:

       CS 25.xxx Fuselage burnthrough fire protection
       "For aeroplanes with a passenger seating configuration of 20 seats or more, means must be provided to minimise the risk to occupants from the effects of fire penetration into the cabin following a post-impact ground pool fire. All practicable measures must be taken to

protect the occupants from fire and smoke for a minimum of five minutes. (See AMC 25.xxx)"

3. **Amend CS-25 to provide a <u>totally</u> objective rule** to provide protection to occupants in pool fire accidents.

   - For all aircraft five minutes of *Occupant Protection Time* is required. The *Burnthrough Test Time* for the upper fuselage and windows should be four minutes and the lower fuselage five minutes. The lower fuselage is redefined to encompass the side of the aircraft up to the top of the cabin windows. This will entail:

     - ❖ the deletion of CS 25.856(b)
     - ❖ Amendments to Appendix F to CS-25 and the guidance material to accommodate other materials or components that may need to be tested (e.g. non-metallic fuselages, cabin windows)
     - ❖ guidance relating to the more general nature of the advisory material (e.g. the changes to the definition of the lower fuselage and the protection provided by the cabin windows)
     - ❖ the introduction of a new CS-25 requirement:

     CS 25.xxx Fuselage burnthrough fire protection
     "For aeroplanes with a passenger seating configuration of 20 seats or more, means must be provided to protect occupants from the effects of fire penetration into the cabin following a post-impact ground pool fire. All practicable measures must be taken to protect the occupants from fire and smoke for a minimum of five minutes. (See AMC 25.xxx)"

A more detailed evaluation of the practical implications of these options is given in Section 4.1.1 for aircraft with metallic fuselages and Section 4.2.1 for aircraft with non-metallic fuselages.

2.4 THE PREFERRED OPTION SELECTED

After due consideration the Agency believes that **Option 2 - Amend CS-25 to provide a <u>partially</u> objective rule to provide protection to occupants in pool fire accidents** is to be preferred.

However further research is required to determine the feasibility of:

1) **enhancing the burnthrough protection afforded by cabin windows and**
2) **extending the enhanced burnthrough protection for the lower fuselage of aircraft with metallic structures to the top of the window line**

prior to these aspects being included in this option.

The final definition of Option 2 can only be confirmed after the cabin window research has been completed and the costs and potential benefits fully assessed, or following a decision not to carry out the research. The burnthrough protection requirement for the upper fuselage is likely to be influenced by the level achievable for the cabin windows.

3 SECTORS CONCERNED

The proposed regulatory change is to CS-25 and hence the aircraft affected will be those for which the application for a type certificate is made after the regulatory change considered in this RIA. All newly designed CS-25 aircraft, with twenty or more seats, will need to comply. The primary cost of the regulatory change will be borne by the aircraft manufacturer. These costs will result from any increases that may be incurred in material costs, design and testing. Aircraft operators will also be affected should any of the design solutions result in weight increases. There will be a marginal cost to EASA in their oversight of the manufacturer in showing compliance with the regulatory change.

4 IMPACTS

All of the identified impacts are evaluated for aircraft with metallic fuselages and aircraft with non-metallic fuselages based on the regulatory options proposed in Section 2.3. The primary areas for consideration for enhanced fuselage burnthrough protection are

- Cabin windows
- Upper fuselage
- Lower fuselage

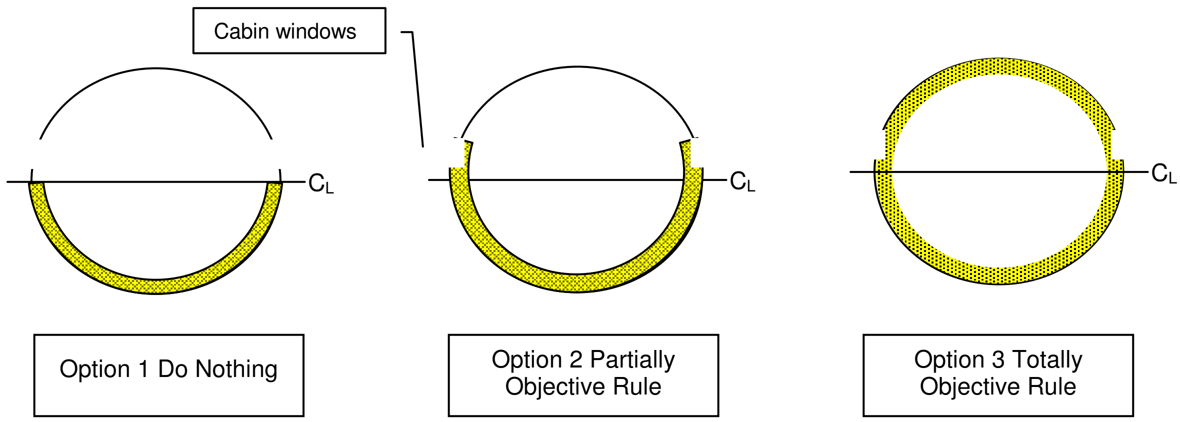
Each of these areas is considered separately in relation to regulatory change against the following impacts:

- Safety
- Economic
- Environmental
- Social
- Other aviation requirements outside of EASA scope
- Foreign comparable regulatory requirements

Equity and fairness issues are also addressed for each of the regulatory options.

4.1 AIRCRAFT WITH METALLIC FUSELAGES

4.1.1 Explanation of Options



Option 1 - Do Nothing means to make no improvements to CS-25 in relation to improved burnthrough protection. CS 25.856(b) "Thermal /acoustic insulation materials" introduced by NPA 2008-13 requires Thermal Acoustic Insulation materials to meet the flame penetration test requirements prescribed in the new Part VII added to Appendix F of CS-25. The protection to the cabin from fuselage burnthrough is limited to those areas where Thermal Acoustic Insulation is installed. Fire penetration of the cabin can occur through the cabin windows, through the upper fuselage and through gaps and discontinuities. The manufacturer is limited in the means by which the safety objectives are met in that the means of compliance is restricted to the protection being afforded by Thermal Acoustic Insulation – other means may be found acceptable by the Authority but only via an Equivalent Level of Safety application.

Option 2 - Partially Objective Rule This option allows the manufacturer to determine the manner in which fuselage protection is afforded and is not limited to protection from Thermal Acoustic Insulation. The lower fuselage is redefined to encompass the side of the aircraft up to the top of the cabin windows. The *Burnthrough Test Time* for the lower fuselage is 5 minutes and the cabin windows 4 minutes. No protection time is defined for the upper fuselage. An acceptable means of compliance would be by showing compliance with CS 25.856(b) – albeit with the improved level of protection afforded by the cabin windows, the redefinition of the lower fuselage and areas identified in the Fire Path Risk Assessment. Advisory Material will provide guidance on the methodology to be adopted for carrying out the Fire Path Risk Assessment on <u>the lower fuselage</u> and examples of what might constitute acceptable levels of risk.

Option 3 - Totally Objective Rule This option allows the manufacturer to determine the manner in which fuselage protection is afforded and is not limited to protection from Thermal Acoustic Insulation. The lower fuselage is redefined to encompass the side of the aircraft up to the top of the cabin windows. The *Burnthrough Test Time* for the lower fuselage is 5 minutes and the cabin windows and upper fuselage should afford 4 minutes of protection. Compliance with these times may be established using the flame penetration test requirements prescribed in the new Part VII added to Appendix F of CS-25. This option requires total protection of the fuselage and does not allow discontinuities in the protection to the cabin.

4.1.2 Cabin Windows

An essential element of Options 2 and 3 are the provision of four minutes of *Burnthrough Protection Time* for the cabin windows. All impacts of this particular issue are considered in this section.

4.1.2.1 Safety

Cabin windows provide a potential route for external fire to penetrate directly into the occupied area of the cabin. Full-scale tests carried out in References 10 and 11 and medium scale tests carried out in Reference 12 show that fire can penetrate cabin windows in well under five minutes. In some accidents, occupants reported seeing flames entering through cabin windows.

Cabin windows are typically manufactured from several acrylic panes. The outer pane is the thickest and is required to carry the cyclic cabin pressure loads. It also provides an acoustic barrier. On some aircraft, the thickness may vary along the fuselage length to meet particular acoustic needs. The middle pane is much thinner and is designed to carry the cabin pressure load in the event of failure of the outer pane. The innermost non-structural pane is also thin and acts as a protective barrier to prevent damage to the structural panes. The outer and middle structural panes are normally made from stretched acrylic, which has improved strength properties compared with as-cast acrylic. The thin inner pane is likely to be manufactured from as-cast acrylic.

On the majority of aircraft, cabin windows are located in the upper half of the fuselage.

Test and accident evidence on cabin window fire penetration times and the failure mechanisms involved are evaluated in Section 4.1.2.1.1 and Section 4.1.2.1.2 respectively of this RIA. The source data is taken from the EASA study Reference 3.

4.1.2.1.1 Test Evidence – Window Penetration

Test data on the resistance of cabin windows to external fire penetration is limited. However, two test programmes conducted by the FAA and one test programme carried out for the UK CAA provide some data on cabin window fire penetration. The results of theses tests are summarized and discussed below.

In 1984, the FAA conducted a number of full-scale pool fire tests using a DC 10 fuselage section to compare the fire penetration resistance of a standard all-acrylic window assembly with that of a window assembly incorporating an experimental thermally improved fail-safe pane. The programme included four tests with both types of window assembly mounted side by side in a fuselage panel (Reference 11). Fire penetration times extracted from the test report are shown in RIA Table 2.

RIA Table 2: Window Fire Penetration Times - FAA 1984 Tests

Test Number	Fire Penetration Time - All Acrylic Window (Minutes: seconds)	Fire Penetration Time - Window with Thermally Improved Fail Safe Pane (Minutes: seconds)	Improvement (Minutes: seconds)
1	3:09	3:45	0:36
2	3:04	3:29	0:25
3	3:08	4:07	0:59
4	3:45	5:08	1:23

The results of the 1984 FAA tests show that the standard acrylic window assemblies tested allowed fire to penetrate in times ranging from 3 minutes 4 seconds to 3 minutes 45 seconds. Clearly, these data only apply to one particular design of window assembly and fire penetration times for other aircraft types may vary.

In 1988 and 1989, the FAA carried out 6 full scale pool fire tests incorporating acrylic cabin windows using DC 8 and CV 880 fuselages (Reference 10). Unfortunately, the window penetration times were generally not stated; the only data available being that windows had been penetrated by the end of the test. The data extracted from the test report is shown analysed in Appendix 1 and summarised in RIA Table 3.

RIA Table 3: Window Fire Penetration Details - FAA 1988/1989 Tests

Test Number	Fuselage Section	Fire Duration (Minutes: seconds)	Penetration Through Windows	Penetration Time-Visual through seals (Minutes: seconds)	Comment
1	Aft	1:46	No	-	
2	Forward	3:45	No	-	
3	Centre	6:07	Yes	2:29	Penetration around window seal
4	Aft	5:20	Yes	Less than 5:20	
5	Forward	4:03	Yes	Less than 4:03	
6	Centre	3:35	Yes	Less than 3:35	

The data in RIA Table 3 shows that in Test 6, windows had been penetrated by fire within 3 minutes and 35 seconds. Unfortunately, the data available from these tests does not provide exact penetration times. However, it does provide evidence that windows can be susceptible to fire penetration in three to five minutes. It also shows that window seals are susceptible to fire penetration, as in Test 3 this occurred after 2 minutes 29 seconds.

There is no evidence within Reference 10 to suggest that windows had been penetrated in extremely short times. Overall, this limited data is to some extent consistent with the findings of the 1984 FAA window tests. In 1995, tests were carried out on fuselage panels by Faverdale Technology Centre on behalf of the UK CAA, using a medium scale test rig (Reference 12). A small number of the test panels incorporated cabin windows taken from a BAe 146. During the tests windows dropped out after 39 seconds. The failure mechanism was described as "The window seal burns, the aluminium around the window distorts and the window melts and drops out".

4.1.2.1.2 Accident Evidence – Window Penetration

Eighty-eight ground pool fire accidents were reviewed in this study. For four of these accidents, there are specific accounts of fire, smoke or heat entering the cabin through melted windows. Evidence describing the degree of deterioration to the cabin environment and estimates for the time taken for window fire penetration are shown as follows:

<u>Manchester B737-200, 1985 (ADB Ref 19850822A) - Aborted Take-off following Uncontained Engine Failure - 55 Cabin Fire Fatalities, 137 Occupants</u>

> *"The flames were seen to cause some 'cracking and melting' of the windows, with some associated smoke in the aft cabin before the aircraft stopped.*
>
> *Another passenger from 6B, after seeing foam being sprayed over the fire on the left side of the aircraft, tried to move into the aisle but it was jammed with people and it was difficult to move. On turning he saw flames shooting in through the side windows and up through the floor area. The flames were several feet in length and continual.*
>
> *It is estimated that the windows resisted penetration by the fire for at least 40 to 50 seconds after the aircraft stopped. However, visible signs of damage to the outer panels, including cracking and apparent melting, were evident much earlier."*

An assessment of data for the Manchester B737-200 accident indicates that the windows burned through between 55 and 95 seconds from the fire commencing. This range of times has been derived by assuming the fire onslaught commenced either very soon after the engine disc ruptured the fuel tank or when the passengers on the left side started moving forward as a result of the fire outside (45 and 15 seconds prior to the aircraft stopping respectively). The accident report concluded that the windows were penetrated at least 40 to 50 seconds after the aircraft stopped.

Calgary B737-200, 1984 (ADB Ref 19840322A) - Aborted Take-off following Uncontained Engine Failure - 0 Cabin Fire Fatalities, 119 Occupants

> *"Shortly after the evacuation commenced, fire melted windows along the left side of the aircraft. When the windows melted through, heat and smoke entered the aircraft, and the cabin environment quickly deteriorated. Substantial quantities of smoke also entered through the right over-wing exit and right rear service door. Conditions within the aircraft cabin were significantly worse in the aft section. Heat was felt as the windows melted through. Those passengers who had been seated beside the windows nearest the fire experienced some singeing of hair and clothing. Aft of seat row 8, flame damage had occurred to the interior of the passenger cabin. Windows had melted or burned away and the fuselage liners and seat upholstery were heavily damaged by fire entering through the window openings."*

An assessment of data for the Calgary B737 accident indicates that the windows burned through in around 2 to 3 minutes. This is derived from the fact that the windows were penetrated soon after the evacuation commenced. The evacuation commenced 1 minute and 55 seconds after the engine disc failed and ruptured the fuel tank. The fire commenced soon after the fuel tank was ruptured.

Kuala Lumpur A300, 1983 (ADB Ref 19831218A) - Impacted Trees and Ground during Approach - 0 Cabin Fire Fatalities, 247 Occupants

> *"The evacuation of all passengers and crew took approximately 5 minutes. The Captain was the last to leave and when he was at the mid-cabin section he noticed visible smoke in the Aft Cabin. The propagation of the external fire into the cabin via the rear RH fuselage and cabin windows probably took 6 to 9 minutes and cabin flashover throughout the cabin was probably completed in 10 minutes."*
>
> *"The propagation of the fire was also retarded because of the intense tropical rain and fuel was being dispersed by the floodwater."*

The accident data for the Kuala Lumpur A300 states that fire propagation through the cabin windows probably took 6 to 9 minutes. These burnthrough times appear very high compared with other accidents and are possibly due to the effect of the tropical rain and floodwater.

Los Angeles DC 10, 1978 (ADB Ref 19780301A) - Overrun following Aborted Take-off - 0 Cabin Fire Fatalities, 200 Occupants

The structural integrity of the cabin was not compromised, since the entire fuselage remained intact and the fire remained outside the fuselage. Some smoke penetrated the cabin area but did not hinder successful evacuation. The only seats sustaining thermal damage were 18A, 18B, 24A and 24B, and the flight attendant's seat at L3. This damage was probably caused by radiant heat entering the cabin through the L3 exit and through the cabin windows when they melted. Most of the windows between L3 and L4 were melted and burned. Little or no evidence of fire penetration was noted at these open windows.

An assessment of data for the Los Angeles DC 10 accident suggests that although the windows were melted within 6 minutes they had withstood the fire onslaught for much of that time. This time is based on the fire duration of around 6 minutes, which is derived from the fact that the second wave of fire fighting vehicles arrived 4 minutes after the accident and the fire was extinguished 2 minutes after they arrived.)

4.1.2.1.3 Consideration of Options

Option 1 does not provide protection to the fire threat via cabin windows. A *Burnthrough Protection Time* of 5 minutes would seem attainable based on the accident and test data analysed in this RIA. However, adoption of this Option could result in fire penetration via cabin windows occurring in less than one minute; as experienced in the 1985 Manchester accident to the Boeing 737.

Options 2 & 3 provide a *Burnthrough Protection Time* of 5 minutes by requiring windows that have been shown to meet a *Burnthrough Test Time* of 4 minutes. Protection times beyond this are not likely to have any significant life saving potential as discussed in Section 1.2 of this Regulatory Impact Assessment. It is evident from the accident experience that fire penetration of cabin windows can provide a real threat to occupants. However, it has not been found possible to quantify the magnitude of this threat. Hence the life saving potential of providing enhanced protection of the cabin windows cannot be quantified.

4.1.2.2 Economic

Testing and accident experience suggest that there is quite a large variation in the time that cabin windows can withstand the threat from pool fires. It might be expected that the reasons for this variation are due to differences in both the fire threat and the window design. However, it would appear likely that some existing window designs might be capable of providing *Burnthrough Protection Times* from typical pool fires in the region of three to four minutes, as indicated by FAA test evidence (refer to RIA Table 2). The design characteristics required to provide resilience to a fire threat are unknown. Assessments of the cost involved in providing windows with a fire penetration characteristic are not available. However if existing designs provide three to four minutes of protection it would suggest that any costs involved could be minimal.

It is considered that research should be conducted in order to achieve an improved understanding of the burnthrough characteristics of cabin windows of varying designs.

4.1.2.3 Environmental

It is likely that any environmental impacts associated with enhancing the burnthrough protection of cabin windows afforded by this proposed regulatory action will be minimal. However, consideration will need to be given to any environmental impacts associated with the use of any alternate materials. This should include issues associated with the choice of materials, the manufacturing process, and the performance of the materials in post impact pool fires. Should there be any weight increases associated with any changes made to enhance the burnthrough protection of cabin windows these will result in an increased fuel burn. However any weight increases are likely to be small and the impact on the environment will be minimal.

4.1.2.4 Social

There are no social impacts associated with enhancing the *Burnthrough Protection Time* of cabin windows.

4.1.2.5 Other Aviation Requirements Outside EASA Scope

There are no aviation requirements outside EASA scope associated with enhancing the *Burnthrough Protection Time* of cabin windows.

4.1.2.6 Conclusions

Accident evidence shows that the fire penetration of some current design acrylic windows is possible in as little as 1 minute. Fire penetration of windows has been cited as a major reason for rapid deterioration of the cabin environment in several accident reports.

Cabin window fire penetration resistance is likely to be influenced by thickness, installation details, and material properties. Little research appears to have been conducted into the fire penetration resistance of cabin windows, and further research may be beneficial. Cabin windows are likely to be able to prevent fire penetration for at least 4 minutes if the design is optimised, but there could be weight penalties. There is undoubtedly a threat from fire penetration of cabin windows although quantification of the life saving benefit from improving their fire penetration characteristics has proven to be difficult.

On this basis it would seem that provided it can be confirmed that the economic impact of requiring windows that are qualified to a *Burnthrough Test Time* of 4 minutes is confirmed as being small, then the safety improvements to cabin windows afforded by Options 2 and 3 would seem to be cost beneficial. **Further research is required in order to make this determination.**

4.1.3 Upper Fuselage

With the aircraft in its normal orientation, either on or off its undercarriage, there is little doubt as to the risk posed to the lower fuselage from the ground fire plume. The CS 25.856 (b) rule, employing thermal acoustic insulation as a flame penetration barrier within the lower half of the fuselage, aims to address this risk.

However, the risk to the upper fuselage is less clear. CS 25.856(b) does not require protection for the upper fuselage.

It would be reasonable to assume that the upper fuselage is shielded to some degree against a ground fire by the lower fuselage and therefore may be at less risk of burnthrough. Nevertheless, on some occasions the fire plume may present a significant risk to the upper fuselage, including instances when it is blown against the upper fuselage by wind. However, in this situation the heat flux may be significantly different from that normally experienced by the lower fuselage.

Additionally, the risk of burnthrough to the upper fuselage is increased if the fuselage becomes inverted during the accident. In this situation, the burnthrough risk to the upper skin would be similar to the risk normally posed to the lower skin.

In order to evaluate the burnthrough risk to the upper fuselage, evidence has been sought from full-scale fuselage tests and accident data.

4.1.3.1 Safety

4.1.3.1.1 Evidence from Full-Scale Fuselage Tests

The FAA carried out 6 full-scale fuselage burnthrough tests during 1988 and 1989 (Reference 10) utilising large burning kerosene pools located at ground level. These tests are extremely important regarding the issues considered in this RIA because the pool fires were extinguished before the fuselage had completely burned out, preserving vital data on the extent of skin burnthrough. This information is seldom preserved in most real pool fire accidents.

All six tests were conducted with the fuselage in the normal orientation. Tests 1, 2 and 3 had the landing gear retracted with the fuselage resting on its belly and Tests 4, 5 and 6 had the fuselage supported on its landing gear.

A detailed examination of the test records given in Reference 10 was carried out to determine the likelihood of upper fuselage burnthrough and where possible determine upper fuselage burnthrough times. Two sources of data were available within Reference 10 as follows:-

Firstly, the narrative provided an account of the fire damage suffered by the fuselage and the fire duration for each test. This provided times within which burnthrough of the upper half of the fuselage had occurred, but not the absolute minimum burnthrough times.

Secondly, thermocouples located on the test fuselages were used to monitor the skin temperatures. These enabled burnthrough times at these locations to be determined. Again, this data may not have provided the minimum burnthrough times for each test since the thermocouples may not have been located where burnthrough occurred the earliest.

Data extracted from the results of the FAA Full Scale Tests are detailed in RIA Table 4 and RIA Table 5. The following observations are made:-

a) In five of the six tests, Tests 1, 2, 4, 5 and 6, the upper fuselage skin burned through within 5 minutes or less. In Test 5, the upper fuselage skin burned through in as little as 1 minute and forty seconds.

b) In one test, Test 3, the upper skin burned through within around 6 minutes.

RIA Table 4: Upper Fuselage Burnthrough Details - FAA Full Scale Tests

Test Number	Fuselage Section	Fire Duration (Minutes : Seconds)	Extent of Upper Fuselage Burnthrough
1	Aft	1:46	Above the rear starboard door
2	Forward	3:15	Centre of top of fuselage
3	Centre	6:07	Level with the cabin overhead section
4	Aft	5:20	Up to the window level
5	Forward	4:03	Centre of top of fuselage
6	Centre	3:35	Top of fuselage

RIA Table 5: Upper Fuselage Burnthrough Times at Thermocouples (Location: Just Below Windows)

Test Number	Fuselage Section	Figure in FAA Test Report	Actual Burnthrough Time at Thermocouple Location (Minutes: Seconds)
1	Aft	-	Not Available
2	Forward	-	Not Available
3	Centre	-	Not Available
4	Aft	D-11	4:10
5	Forward	E-8	1:40
6	Centre	F-3 and F-5	2:00 and 2:50

It should be noted that all times given above are from the time the fire had spread fully across the surface of the fuel pool i.e. they equate to a *Burnthrough Protection Time*.

The fact that in five out of six full-scale tests skin burnthrough occurred in the upper half of the fuselage within five minutes, clearly demonstrates the vulnerability of the upper fuselage skin to burnthrough.

However, it is evident from the test results that upper fuselage burnthrough may not be as extensive or severe as in the lower fuselage. Nonetheless, burnthrough did occur during these fully representative tests and even a small area of burnthrough might allow sufficient smoke or fire to enter the cabin and impede evacuation.

This evidence from the FAA full scale fuselage burnthrough tests suggests that protection of only the lower half of the fuselage, as required by CS 25.856(b), may not provide the level of flame penetration resistance and improvement to occupant survivability intended. Additional evidence was sought from actual aircraft accidents.

4.1.3.1.2 Evidence from Aircraft Accidents

Invariably, once a fire has penetrated the cabin from outside, an extensive fire takes hold within the cabin, which then burns through the upper fuselage from inside. This destroys any physical evidence of burnthrough of the upper fuselage caused by the external fire.

Of all the 88 burnthrough accidents, reviewed in the EASA study (Reference 3), adequate information on burnthrough damage to the upper fuselage was available in only one. This was the only accident where the fire was extinguished sufficiently quickly to preserve the external fire damage. In addition, the time taken to extinguish the fire was recorded and excellent photographic records were available showing the extent of exterior damage and the fire entry position through the cabin interior panels. This accident occurred in 1994 to a DC-9 aircraft at Vigo Airport in Spain.

The following resume is extracted from a translation of the accident report (Reference 13):-

DC-9-32, Vigo, Spain, March 21st 1994

"This accident occurred at Vigo Airport, Spain on March 21st 1994 and involved a McDonnell Douglas DC 9-32 aircraft. The aircraft was too low on approach. The main undercarriage contacted approach lights and upward sloping ground just ahead of the runway, detaching the main undercarriage legs and part of the right hand wing fuel tank. Leaking fuel ignited and the fire followed the aircraft to where it stopped just to the side of the runway. When the aircraft stopped, the fire passed to the left side and affected practically the whole of the exterior of the plane, causing heavy damage.

Figure 3: Burnthrough Accident: DC-9-32, Vigo, Spain, March 21st 1994

When the aircraft entered the runway, a nearby vehicle notified an emergency on frequency 121.5 MHz. Immediately the Control Tower alerted the Fire Service which left with all its appliances. Approximately one minute after the alarm was raised the Fire Service appliances arrived at the aircraft and began to work on the left wing to protect the evacuation. 30 seconds later, the fire on that side was extinguished and they moved to work on the right wing, with the fire being extinguished one minute later.

No sooner had the aircraft stopped; the crew ordered and directed its evacuation, as well as distancing the passengers from the area affected by the fire. The evacuation passed off in an orderly manner.

In the evacuation the two front doors and the two emergency exits located over the left wing were used. The forward overwing emergency exit was opened and on causing smoke to enter the cabin an unsuccessful attempt was made to close it.

Once the fire was extinguished, barely two minutes after their arrival at the aircraft, some members of the Fire Service equipped with oxygen cylinders and mask entered the aircraft's cabin, checking that it had been totally evacuated.

Of the 110 passengers and 6 crew, all evacuated with no fatalities."

Analysis of the accident data shows that the duration of the main fire was around three minutes. It started when the aircraft came to rest and ceased when it was extinguished on the starboard side. All of the fire damage is considered to have occurred in the three-minute period after the aircraft stopped as any flames present during the ground slide would have trailed behind the aircraft.

The extent of fire damage to the exterior of the starboard rear fuselage is shown in Figure 4 and Figure 5. The intense fire burned through the lower fuselage skin revealing the thermal acoustic insulation. Two of the fuselage frames were burned through. The upper half of the fuselage was burned through around and above the cabin windows. However, the extent of burnthrough of the upper fuselage is significantly less than through the lower fuselage.

Figure 4: Vigo DC-9-32 Skin Burnthrough of Lower and Upper Fuselage

Figure 5: Vigo DC-9-32 External Fire Damage Starboard Side

The cabin interior suffered minimal damage considering the intensity of the fire - see Figure 6. The interior fire damage would have been worse had the fire not been extinguished so rapidly.

Figure 6: Vigo DC-9-32 Minimal Fire Damage to Cabin Interior

The starboard Type III overwing exit, opened during the evacuation, allowed fire to enter the cabin and locally scorch the interior materials - see Figure 7.

Figure 7: Vigo DC-9-32 Scorching Near Starboard Overwing Emergency Exit

Figure 8 shows fire damage to the interior cabin materials above the level of the cabin windows. The Spanish accident investigation authority CIAIAC has confirmed the internal fire damage was caused by the external burnthrough above the windows and not from fire entering the Type III Overwing Exit opened during the evacuation.

Figure 8: Vigo DC-9-32 Localized Fire Damage Due to Upper Fuselage Burnthrough

It is evident that in this accident the fire burned through the upper fuselage skin, burned some of the cabin lining materials, and penetrated the cabin in significantly less than 5 minutes.

This evidence supports the conclusions gained from the review of the FAA Full Scale Fuselage Burnthrough Tests, confirming that a ground pool fire has the potential to burn through the upper fuselage in less than five minutes given the necessary conditions, namely, a large enough fire which may be exacerbated by wind blowing the flame plume on to the upper skin. Furthermore, it demonstrates that even with a relatively small area of burnthrough in the upper skin, the cabin interior materials can be exposed to enough heat to allow fire penetration into the cabin.

4.1.3.1.3 Fuselage Orientation

If a fuselage were to become inverted during an accident, the burnthrough risk to the upper fuselage would be similar to the risk for the lower fuselage had the fuselage remained upright.

The requirement to harden the upper fuselage against burnthrough was not included in CS 25.856(b), thus not addressing the risk of burnthrough to an inverted fuselage. Quantification of this residual risk was therefore an important objective within this study.

Accidents with fuselage breaks are likely to negate some or all of the burnthrough protection installed. Therefore, in order to assess correctly the risk posed by inverted fuselages it is appropriate to consider only accidents that did not involve fuselage breaks.

As shown in Figure 9, for pool fire accidents where the fuselage remains substantially intact as a result of the impact, 6% involve an inverted fuselage.

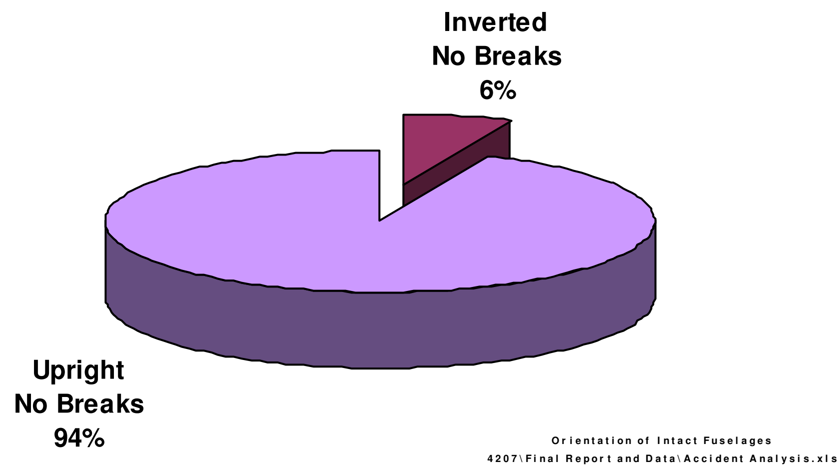


Figure 9: Proportion of Inverted Fuselages in Ground Pool Fire Accidents Not Involving Fuselage Breaks

4.1.3.1.4 Consideration of Options

The EASA study (Reference 3) concluded:

> *"Although evidence available at this time does not provide a typical or minimum time for upper fuselage burnthrough it appears that it occurs later than lower fuselage burnthrough. In full-scale tests, upper skin burnthrough occurred in as little as 1 minute 40 seconds. Accident evidence shows that upper fuselage burnthrough can occur in less than 3 minutes. The extent of flame impingement on the upper fuselage would depend on the fire location, any shielding effects from the lower fuselage, and any wind effects on the fire plume.*
>
> *A number of accidents have resulted in the fuselage becoming inverted and remaining intact. In this scenario, the vulnerability of the upper fuselage to burnthrough is no different to the lower fuselage in normal circumstances."*

Based on these conclusions it appears that there is a not insignificant risk of fire entry into the cabin via the upper fuselage, in that fire penetration can occur in less than 2 minutes from the time that the fire threat is established.

It is also evident that the threat to the upper fuselage is for the most part not as severe as the threat to the lower fuselage. It would therefore seem unrealistic to consider a regulatory option that requires 5 minutes of *Burnthrough Test Time* for the upper fuselage. However, it would be a positive safety advantage to provide an *Occupant Protection Time* of 5 minutes for the upper fuselage and due to the reduced threat to the upper fuselage it is likely that this may be achieved by requiring a *Burnthrough Test Time* of 4 minutes.

Option 1 and Option 2 do not require any protection for the upper fuselage of aircraft with metallic fuselages, which means that fire penetration of the cabin can occur in less than 2 minutes from the time that the fire threat is established. This could be the primary route for fire entry into the cabin other than through fuselage breaks or opened exits. The minimal protection afforded by the upper fuselage is of particular significance in pool fire accidents in which there are no fuselage breaks and the fuselage is inverted. It is assessed that for pool fire accidents where the fuselage remains substantially intact as a result of the impact, 6% involve an inverted fuselage. Furthermore in accidents where the fuselage is inverted the required *Occupant Protection Time* is likely to be longer due to the level of disruption in the cabin.

Option 3 would require complete protection for the upper fuselage. This would amount to providing a *Burnthrough Test Time* of 4 minutes over the entire upper fuselage.

4.1.3.2 Economic

Option 1 and Option 2: Do not require any enhancements to the upper fuselage for aircraft with metallic fuselages hence there are no economic impacts.

Option 3: The largest cost associated with this option is likely to be associated with the fire hardening of the upper fuselage to provide a *Burnthrough Test Time* of 4 minutes. It is feasible that this might be achieved by the installation of burnthrough enhanced Thermal Acoustic Insulation especially since gaps and discontinuities are much less prevalent in the upper fuselage than in the lower fuselage. Based on the assessments made in Appendix 2 the material cost associated with providing burnthrough compliant Thermal Acoustic Insulation for the upper fuselage might be expected to be:

$19,300 for a single deck single aisle aircraft and

$43,300 for a single deck twin aisle aircraft

Whilst this proposed regulatory change is only applicable to future aircraft it is reasonable to consider the cost impacts on a world fleet of aircraft composed of a similar number of single aisle and twin aisle aircraft that exist today. It is assessed that the world fleet currently[7] comprises of approximately 4,000 twin aisle aircraft and 16,000 single aisle aircraft. Using the material cost assessments alone of $19,300 for a single deck single aisle aircraft and $43,300 for a single deck twin aisle aircraft this would amount to over $480,000,000 for the world fleet. If these costs were amortised over say a fifteen year period they would amount to over $32,000,000 per annum. It must be emphasised that all of these costs are to a rough order of magnitude but they provide an indication of the scale of the economic impact.

It is likely that there will also be a significant weight increase as a result of this option. Estimates made by AIM Aviation (Reference 14) on the FAA NPRM (Reference 8) include the following statement:

> *"This construction would add in excess of 205 pounds to a typical single deck, twin aisle aircraft. Other likely successful approaches would add up to 600 pounds to the same aircraft."*

This will result in an increase in operating cost due to increased fuel burn which will have an economic impact on the operator. Typically it might be expected that the cost resulting from additional fuel burn is in the region of $30 per pound per year which would amount to a minimum increase in costs of $6,000 per year. Once again considering the world fleet comprised of 4,000 twin aisle aircraft and 16,000 single aisle aircraft this would amount to $120,000,000 per annum.

Therefore the cost attributable to the use of burnthrough resistant material would be in excess of $32,000,000 plus $120,000,000 equals $152,000,000 per annum.

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[7] It is recognised that this proposed regulatory action is not applicable to the current world fleet and that many future aircraft designs may not have metallic structures. However, the assumptions concerning the world fleet composition of single and twin aisle aircraft indicate the order of magnitude of the economic impact. The Cost Benefit considerations discussed in Section 4.1.3.6 rely only on the relative numbers of single and twin aisle aircraft and the conclusions reached are not dependent on the total number of aircraft in service – the cost benefit ratio is unaffected by total fleet size.

4.1.3.3 Environmental
The Fire Path Risk Assessment required in Options 2 and 3 may result in the need to introduce new materials. As part of this assessment consideration will need to be given to any environmental issues associated with the materials used, their manufacturing process, and their performance in post impact pool fires. Since Option 3 results in a significant weight increase it will have the most significant impact, of the three options, on the environment due to the increased fuel burn.

4.1.3.4 Social
There are no social impacts associated with enhancing the burnthrough protection of the upper fuselage.

4.1.3.5 Other Aviation Requirements Outside EASA Scope
There are no aviation requirements outside EASA scope associated with enhancing the *Burnthrough Protection Time* of the upper fuselage.

4.1.3.6 Conclusions

Option 1 and Option 2: These options have no safety or economic impacts.
.
Option 3: This option provides an improved level of safety. However, the economic impact is likely to be prohibitive. The costs of designing and manufacturing the upper fuselage of aircraft to the safety levels proposed in this option, based on material costs and additional fuel burn alone, is likely to amount to over $152,000,000 per annum on a world fleet basis. The FAA current value of life is $5,800,000. Hence for this safety improvement to be cost beneficial there would need to be a resultant life saving potential of almost 26 lives per year. Section 1.2 of this Regulatory Impact Assessment suggests that the current benefit to the world fleet, resulting from the improvements contained in CS 25.856(b), amounts to approximately 4 lives per year. Enhanced protection of the upper fuselage to the extent proposed by this option is only likely to yield a small fraction of this benefit and hence cannot be considered to be cost beneficial. Even if it were assumed that all of these lives might be saved by enhancing the burnthrough protection of the upper fuselage the cost benefit ratio would still be unacceptably high at 26 ÷ 4 = 6.5.

4.1.4 Lower Fuselage

4.1.4.1 Safety

When a ground pool fuel fire is situated beneath or near to an aircraft fuselage, fire plume impingement on the lower fuselage is inevitable. The fundamental risk of fuselage skin burnthrough is well understood. The most common fuselage skin material, aluminium alloy, melts at around 600 deg C (1100 deg F) and consequently provides little resistance to penetration by a fuel fire having a plume temperature of up to around 1100 deg C (2000 deg F). The burnthrough time for an aluminium alloy fuselage skin is well known and documented. It takes only 15 to 60 seconds for the skin to melt depending on its thickness and the intensity of the pool fire. Thermal acoustic insulation located inside the fuselage skin and lining panels may add to the overall fuselage burnthrough time.

Based on the EASA study (Reference 3) fire entered the cabin in 96% of the 88 ground pool fire accidents reviewed. In 45% of these accidents, fuselage burnthrough was assessed to be the primary, or a major contributor, to cabin smoke or fire entry. In the remainder of accidents, fire immediately entered the cabin through fuselage breaks, ruptures, or opened doors and therefore fuselage burnthrough, which may have occurred subsequently, was considered to be of secondary importance.

4.1.4.1.1 Lower Fuselage Skin

Full Scale Fuselage Burnthrough Tests conducted by the FAA in 1988/1989 (Reference 10) utilising DC-8 and Convair 880 fuselage sections demonstrated that the fuselage could be burned through within around 40 to 50 seconds (see RIA Table 6) even with thermal acoustic insulation installed, albeit insulation not compliant with the latest CS 25.856(b).

RIA Table 6: Lower Fuselage Burnthrough Details - FAA Full Scale Tests

Test Number	Fuselage Section	Entry Time Minutes : Seconds	Major Smoke/Fire Entry Route Into Cabin
1	Aft	0:44	Burnthrough of lower skin. Smoke penetrated through the cabin floor grills.
2	Forward	0:41	As above
3	Centre	0:15	As above
4	Aft	0:46	Burnthrough of lower skin. Smoke penetrated through the cabin floor.
5	Forward	Unclear from test report	Smoke entered via electronics bay then crew access tunnel.
6	Centre	0:40	Burnthrough of lower skin. Smoke penetrated through the cabin floor.

(Note: in RIA Table 6, the times shown are from the point at which the fire had fully spread across the pool of fuel. The times were established by analysing the test results given in Reference 10 as shown in Appendix 1.

In a typical aircraft, the lower half of the fuselage encompasses all of the under floor area and some of the cabin space above floor level. As described in section 2.1, once burnthrough of the lower fuselage skin has occurred in the cheek area below floor level, fire or smoke is able to enter the occupied cabin relatively unrestricted via the air return grills. This would present an immediate threat to the survivability of evacuating occupants. This is supported by evidence from the FAA 1988/1989 tests (see RIA Table 6) and a number of accident reports. In contrast, burnthrough of the fuselage skin above the floor level may present a lower risk if the cabin lining panels are capable of providing additional protection. This would be dependent on their fire resistance properties and whether joints between the panels are capable of resisting the passage of smoke and fire. Unless the lining panels and their installation were specifically designed to resist fire penetration it is most unlikely that they would offer any significant protection.

4.1.4.1.2 Equipment & Cargo Bays

Rapid smoke entry via the avionics bay was reported during one of the FAA 1988/1989 (Reference 10) full scale tests and the bay was described as un-insulated. Avionics and other heat generating bays requiring the dissipation of heat may logically have no insulation on the inside of the fuselage skin. Clearly un-insulated areas such as these, where the only fire barrier is the fuselage skin, are extremely vulnerable to rapid burnthrough.

Cargo Bays are likely to provide a less significant route for fire penetration into the cabin. As reflected in the FAA tests (Reference 10) analysed in Appendix 1:

> *"Penetration into the cargo compartment was through the aft bulkhead separating the cargo compartment from the crawlthrough area. The cabin floor was initially penetrated by flames above the crawlthrough area in 1 minute 43 seconds and the cargo compartment in 2 minutes 14 seconds. The cargo compartment appeared to provide some protection to the cabin against a pool fire of this type".*

4.1.4.1.3 Attachment Means, Gaps & Discontinuities

Significant aspects of the installation are the means used for attaching the Thermal Acoustic Insulation to the aircraft structure and the protective treatments likely to be present on the aircraft skin, stringers and frames. This is summarised in the following conclusions contained in the Darchem Flare report prepared for the UK CAA (Reference 15):

> *"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.*

CS 25.856(b) allows gaps to remain in the insulation that might introduce potential fire paths. These discontinuities in the protection include slots, holes, pass-throughs, structural joins and other openings. The FAA has conducted tests to determine an acceptable level of discontinuities to ensure safety (Reference 16). The FAA Advisory Circular, which is used as guidance material to CS 25.856(b) (Reference 17), includes the following note regarding discontinuities:

> *"Certain discontinuities are unavoidable: for example, where essential systems must go from the outboard to the inboard side of the insulation material, and such systems cannot practically be constructed of fire-resistant material themselves. Since the regulation does not mandate installation of thermal/acoustic insulation, such discontinuities cannot be prohibited, although their occurrences should be minimized. Such discontinuities need not be considered in the test samples. The rule, however, does require consideration of the installation design methodology, so discontinuities in the insulation would not be acceptable if they are caused by the installation design methodology".*

Although the Advisory Circular (Reference 17) addresses the need to minimise discontinuities it provides limited guidance relating to unacceptable discontinuities.

Another significant aspect revealed from the Darchem Flare testing (Reference 15) was that the presence of protective coatings and corrosion inhibitors could compromise the level of protection from pool fires afforded by Thermal Acoustic Insulation.

> "*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.*"

This issue is not accommodated by the FAA test method for Thermal Acoustic Insulation.

Door seals can also present a fire path into the cabin; the EASA study (Reference 3) concludes:

> *Extremely rapid smoke entry past door seals occurred during some of the FAA 1988/1989 full scale tests, although the quantity of smoke was relatively small and the risk was minimal compared with the major entry routes. Smoke entry past door seals could occur where small gaps between the door seal and the surround exist or because the seal is damaged by the fire. Seal material could be optimised to maximize burn resistance.*

4.1.4.1.4 Fuselage Skin – adjacent to cabin windows

Although, in some aircraft the cabin windows may be located, or partially located, in the lower half of the fuselage, in most aircraft they are located in the upper half. The fire penetration risks presented by cabin windows have been assessed separately in Section 4.1.2. However they require to be considered further in relation to the burnthrough protection afforded by the lower fuselage. There would seem little point in hardening cabin windows without providing a similar level of protection to their supporting structure. It is therefore considered necessary to consider, in this Regulatory Impact Assessment, the implications of providing protection to the lower fuselage extended to the top of the window line. Conversely little benefit will be achieved by extending the protection to the top of the window line if it is shown that it is not practical to install cabin windows with a *Burnthrough Test Time* of 4 minutes.

4.1.4.1.5 Fuselage Skin Abrasion

Many ground pool fire accidents involve a ground slide with the landing gear separated from the aircraft or with the landing gear retracted. In these accidents, it is very likely that the underside of the fuselage will suffer significant abrasion, particularly if the ground slide occurs on a hard surface such as runway paving. This is significant, because fuselages could potentially be protected against burnthrough by the application of an external fire resistant layer e.g. intumescent paint. Clearly, external fire protection could be damaged during an accident impact sequence rendering it ineffective.

4.1.4.1.6 Consideration of Options

The EASA study (Reference 3) concluded:

> *"Lower skin burnthrough is possible in 15 – 60 seconds, depending on skin thickness. Air return grills provide an easy path for smoke and fire to penetrate the cabin following burnthrough of the lower skin."*
>
> *"In areas of the fuselage having a cargo bay, the presence of liners will still allow fire to reach the air return grills, but may prevent the fire from accessing the cabin floor."*
>
> *"Equipment bays might have un-insulated fuselage skin, and if so, would not benefit from the additional fire penetration resistance afforded by insulation. Fire burnthrough into equipment bays gives the fire direct access to the fuselage floor or air return grills. "*

Option 1 addresses the threat to the lower fuselage by providing burnthrough resistant Thermal Acoustic Insulation installed in accordance with Advisory Material aimed at reducing the magnitude and number of potential fire paths. However, these materials are not required to be installed and the protection afforded is limited by gaps and discontinuities. The fire threat from Equipment Bays will still exist posing a significant threat to penetration of the cabin.

Option 2 will mitigate the threat from gaps and discontinuities to the extent feasible based on issues identified in the Fire Path Risk Assessment. It is expected that this option will not entirely eliminate all fire paths in the lower fuselage and that areas where it is not assessed to be practical to install fully compliant Thermal Acoustic Insulation will still remain - hence leaving some gaps and discontinuities. Guidance Material will provide proposed means for mitigating the effects of burnthrough protection through equipment bays, cargo bays and via discontinuities and gaps in thermal acoustic insulation materials. Consideration should be given to the use of intumescent paints in areas protected from abrasion where a significant fire path exists through to the cabin. The fire penetration resistance of such items as door seals would also be subjected to the Fire Path Risk Assessment so that material selection and installation can be optimised to provide an enhanced level of safety commensurate with what may be practically achieved. Whilst it is not possible to quantify the safety benefit provided by this option it is evident that it will address many of the safety deficiencies of Option 1 for aircraft with metallic fuselages.

Option 3 would not allow any gaps or discontinuities and the whole of the lower fuselage would need to qualified for a *Burnthrough Test Time* of 5 minutes.

4.1.4.2 Economic

Option 1: Since this is the "Do Nothing" option there are no economic impacts
.
Option 2: This option is likely to require the following enhancements to the lower fuselage:

a) Extension of the burnthrough resistant Thermal Acoustic Insulation from the aircraft centre line to the top of the cabin windows, if this is chosen as the means for providing burnthrough protection.

b) Improved burnthrough protection for any areas identified from the Fire Path Risk Assessment that are shown to be practical. Areas to be <u>considered</u> will include

- o gaps and discontinuities in the Thermal Acoustic Insulation if this is chosen as the means for providing burnthrough protection
- o enhanced protection of larger areas such as equipment bays
- o Fire paths such as those via the cargo compartment door, as illustrated in Figure 2.

Addressing each of these issues in turn:

a) Extension of the burnthrough resistant Thermal Acoustic Insulation from the aircraft centre line to the top of the cabin windows.

It was assessed in Section 4.1.3.2 that the annual cost incurred for providing burnthrough resistant Thermal Acoustic Insulation for the whole of the upper fuselage from the centre line, would be in the region of $152,000,000

It is likely that the additional area from the centre line to the top of the cabin windows represents in the order of 15% of the area of the upper fuselage measured from the aircraft centre line. It might therefore be expected that the annual cost for providing this level of protection is in the region of $23,000,000 per annum.

b) Improved burnthrough protection for any areas identified from the Fire Path Risk Assessment that are shown to be practical.

The economic impacts of improving the burnthrough protection for areas identified from the Fire Path Risk Assessment that are shown to be practical are difficult to assess. It is recognised that for many areas it will not be practical to make improvements and in other areas it will not be cost beneficial. However, the intent of this regulatory option is to identify improvements that might be made without a significant cost impact. Consideration will need to be given to various improvement strategies such as the use of intumescent paints in areas protected from abrasion where a significant fire path exists through to the cabin.

Option 3: This option is not considered to be economically feasible for the lower fuselage of metallic aircraft since gaps and discontinuities are largely unavoidable. Whilst improvements could be made as described for Option 2 it is not considered that total protection can be provided.

4.1.4.3 Environmental

It is likely that any environmental impacts associated with enhancing the burnthrough protection of the lower fuselage, afforded by this proposed regulatory action, will be minimal. However, the Fire Path Risk Assessment required by Options 2 and 3 may result in the need to introduce new materials. As part of this assessment consideration will need to be given to any environmental issues associated with the materials used, their manufacturing process, and their performance in post impact pool fires. Should there be any weight increases associated with any changes made to enhance the burnthrough protection of the lower fuselage these will result in an increased fuel burn. However any weight increases are likely to be small and the impact on the environment will be minimal.

4.1.4.4 Social

There are no social impacts associated with enhancing the *Burnthrough Protection Time* of the lower fuselage.

4.1.4.5 Other Aviation Requirements Outside EASA Scope

There are no aviation requirements outside EASA scope associated with enhancing the *Burnthrough Protection Time* of the lower fuselage.

4.1.4.6 Conclusions

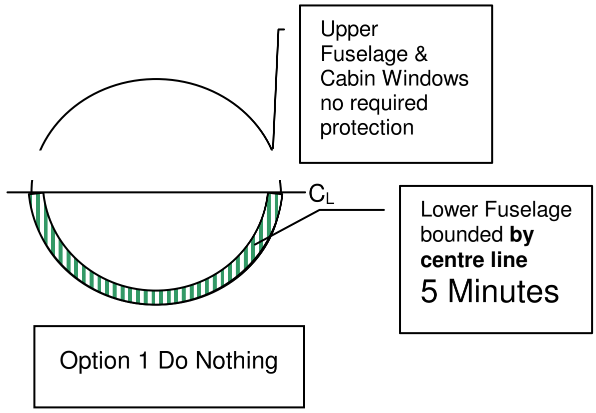
Option 1: This option has no additional safety or economic impacts.

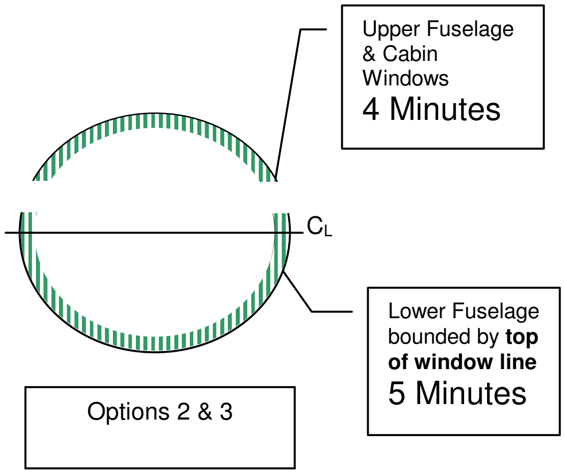
Option 2: It is considered that this option will provide positive safety benefit both by virtue of making improvements considered cost beneficial in the Fire Path Risk Assessment and by extending the upper limit of the lower fuselage to the top of the cabin window line. This option also allows the manufacturer flexibility in the means of compliance adopted. However the extended lower fuselage limit is currently considered cost prohibitive and further research is required in order to determine whether less costly means can be found of providing protection around the cabin window area. Further research is considered necessary to determining the feasibility of installing fire hardened cabin windows and this research should embrace the protection required of the areas surrounding the windows.

Option 3: Whilst this option provides an improved level of safety it is considered to be cost prohibitive.

4.2 AIRCRAFT WITH NON-METALLIC FUSELAGES

4.2.1 Explanation of Options





Option 1 - Do Nothing means to make no improvements to CS-25 in relation to improved burnthrough protection. Aircraft with non-metallic fuselages are likely to be subjected to an Equivalent Level of Safety finding against CS 25.856(b) "Thermal/acoustic insulation materials", introduced by NPA 2008-13, based on protection being afforded by the fuselage skin rather than by thermal acoustic insulation. An Equivalent Level of Safety finding would result in five minutes of *Burnthrough Protection Time* being afforded to the lower fuselage only. The upper boundary of the lower fuselage would be defined as the aircraft centre line. Compliance may be established using the flame penetration test requirements prescribed in the new Part VII added to Appendix F of CS-25.

Option 2 - Partially Objective Rule This option allows the manufacturer to determine the manner in which fuselage protection is afforded to provide five minutes of *Burnthrough Protection Time* for the lower fuselage and four minutes for the windows and upper fuselage. The upper boundary of the lower fuselage is extended to the top of the cabin window line. Compliance with these times may be established using the flame penetration test requirements prescribed in the new Part VII added to Appendix F of CS-25.856. A Fire Path Risk Assessment will also be required to ensure that all practicable steps have been taken to minimise the risk. This is likely to be restricted to considerations of relatively small areas e.g. door seals. Advisory Material will provide guidance on the methodology to be adopted for carrying out the Fire Path Risk Assessment and examples of acceptable levels of risk.

Option 3 - Totally Objective Rule This option allows the manufacturer to determine the manner in which fuselage protection is afforded to provide five minutes of *Burnthrough Protection Time* for the lower fuselage and four minutes for the windows and upper fuselage. The upper boundary of the lower fuselage is extended to the top of the cabin window line. This option requires total protection of the fuselage and does not allow discontinuities in the protection to the cabin. Compliance with these times may be established using the flame penetration test requirements prescribed in the new Part VII added to Appendix F of CS-25.

4.2.2 Cabin windows

An essential element of Options 2 and 3 are the provision of four minutes of *Burnthrough Protection Time* for the cabin windows. All impacts of this particular issue are considered in this section.

4.2.2.1 Safety

The safety considerations of cabin windows in aircraft with non-metallic fuselages are similar to those for aircraft with metallic fuselages. Reference should be made to Section 4.1.2.1 of this Regulatory Impact Assessment.

4.2.2.2 Economic

The economic considerations of cabin windows in aircraft with non-metallic fuselages are similar to those for aircraft with metallic fuselages. Reference should be made to Section 4.1.2.2 of this Regulatory Impact Assessment.

4.2.2.3 Environmental

It is likely that there are no environmental impacts associated with enhancing the burnthrough protection of cabin windows afforded by this proposed regulatory action. However, consideration will need to be given to any environmental impacts associated with the use of any alternate materials. This should include issues associated with the choice of materials, the manufacturing process, and the performance of the materials in post impact pool fires. Should there be any weight increases associated with any changes made to enhance the burnthrough protection of cabin windows these will result in an increased fuel burn. However any weight increases are likely to be small and the impact on the environment will be minimal.

4.2.2.4 Social

There are no social impacts associated with enhancing the *Burnthrough Protection Time* of cabin windows.

4.2.2.5 Other Aviation Requirements Outside EASA Scope

There are no aviation requirements outside EASA scope associated with enhancing the *Burnthrough Protection Time* of cabin windows.

4.2.2.6 Conclusions

The conclusions regarding cabin windows for aircraft with non-metallic fuselages are similar to those for aircraft with metallic fuselages. Reference should be made to Section 4.1.2.6 of this Regulatory Impact Assessment. It is considered that research should be conducted in order to achieve an improved understanding of the burnthrough characteristics of cabin windows of varying designs.

4.2.3 Upper & Lower Fuselage

For aircraft with non-metallic fuselages the regulatory impacts related to the options considered in this Regulatory Impact Assessment are less complex than those for aircraft with metallic fuselages. As such the upper and lower fuselage impacts are considered together.

4.2.3.1 Safety

The pool fire threat related to aircraft with non-metallic fuselages will be similar to that for aircraft with metallic fuselages. However, the fire penetration resistance is likely to be much improved and is unlikely to be dependent on any protection from Thermal Acoustic Insulation. The EASA study (Reference 3) concludes:

> *"Non-metallic fuselages are considered likely to provide improved burnthrough characteristics to aluminium fuselages; however, test data confirming this has not been identified during the course of this study."*

Subject to confirmation of the improved burnthrough characteristics of aircraft constructed from non-metallic materials it would seem likely that many of the burnthrough issues identified as being problematic on aircraft with metallic fuselages may not be experienced on aircraft with non-metallic fuselages.

An "all composite aircraft" is likely to provide adequate levels of protection in both the upper and lower fuselage areas with any gaps and discontinuities in the level of protection achieved being restricted to small areas such as door seals.

Options 2 & 3 will provide an improved level of safety from Option 1 by virtue of the improvements that are likely to result from the Fire Path Risk Assessment. However these improvements are likely to be relatively small for aircraft with non-metallic fuselages due to the intrinsic level of protection already afforded by aircraft of this construction.

4.2.3.2 Economic

It is likely that any economic burden incurred in the manufacture and operation of the aircraft will not be significantly different for Options 2 and 3 than for Option 1. The Fire Path Risk Assessment required in Options 2 and 3 may result in more costly or heavier materials being used however any increases are likely to be small. There will be an increase in the costs of certification both to the manufacturer and EASA due to the Fire Path Risk Assessment and its oversight as required by Options 2 and 3. However, these will be offset to a degree by the equivalent safety finding required by Option 1 not being required by these Options. The objective nature of Options 2 and 3 could result in more cost beneficial means being found by the manufacturer, in showing compliance, than that afforded by Option 1.

Overall it is concluded that any costs incurred in showing compliance with Options 2 and 3 will be minimal in comparison with Option 1.

4.2.3.3 Environmental

It is likely that there are no environmental impacts associated with enhancing the burnthrough protection of the fuselage afforded by this proposed regulatory action. However, the Fire Path Risk Assessment required in Options 2 and 3 may result in the need to introduce new materials. As part of this assessment consideration will need to be given to any environmental issues associated with the materials used, their manufacturing process, and their performance in post impact pool fires.

Certain non-metallic materials that may be used in the construction of aircraft fuselages may have environmental issues associated with them especially when consideration is given to the potential release of small particles, smoke and gases in post impact pool fires. However these considerations are not affected by the regulatory options considered in this Regulatory Impact Assessment. Should there be any weight increases associated with any changes made to enhance the burnthrough protection of the fuselage these will result in an increased fuel burn. However any weight increases are likely to be small and the impact on the environment will be minimal.

4.2.3.4 Social

There are no social impacts associated with enhancing the burnthrough protection of the fuselage of non-metallic aircraft.

4.2.3.5 Other Aviation Requirements Outside EASA Scope

There are no aviation requirements outside EASA scope associated with enhancing the burnthrough protection of the fuselage of non-metallic aircraft.

4.2.3.6 Conclusions

Both the levels of improvement in safety, and the costs incurred, for Options 2 and 3 are likely to be marginally greater than for Option 1 for aircraft with non-metallic fuselages. However, Options 2 and 3 give the manufacturer flexibility in the manner of compliance and require that a Fire Path Risk Assessment be carried out, both of which are likely to result in more cost beneficial solutions being achieved than would result from Option 1.

5 SUMMARY AND FINAL ASSESSMENT

5.1 COMPARISON OF THE POSITIVE AND NEGATIVE IMPACTS FOR EACH OPTION EVALUATED

Option 1: This is the "Do Nothing" option. It makes no changes to the safety or economic impacts resulting from the introduction of CS 25.856(b). Whilst this change to the regulations results in an improvement in safety from that afforded prior to its introduction it provides no flexibility in terms of meeting the safety objective.

Option 2: This option allows the aircraft manufacturer flexibility in meeting the safety intent of improving the burnthrough characteristics of aircraft fuselages. It does not specify that the protection required is afforded by the installation of fire resistant Thermal Acoustic Insulation that is both expensive and limited in the level of protection provided. However, compliance may be demonstrated by this means if requested by the applicant. No protection is prescribed by this option for the upper fuselages of aircraft with metallic fuselages since this cannot be shown to be cost beneficial. However, for aircraft with non-metallic structures a *Burnthrough Test Time* of 4 minutes should be demonstrated for the upper fuselage and five minutes for the lower fuselage.

Further enhancements to the level of protection afforded may be achieved if research suggests installing windows, which have been approved to a *Burnthrough Test Time* of four minutes, are economically feasible. The research recommended for this option should also encompass an investigation into the need to extend the protection afforded to the lower fuselage up to the top of the cabin window line. This intent is likely to be readily achieved for aircraft with non-metallic structures.

An essential element of Option 2 is the Fire Path Risk Assessment that is required to be carried out to ensure that risk to occupants from the effects of fire penetration into the cabin, following a post-impact ground pool fire, are minimised. This assessment is likely to result in the identification of cost beneficial improvements.

Option 3: This option and its associated impacts are the same as Option 2 for aircraft with non-metallic fuselages. For aircraft with metallic fuselages it is considered to be not cost beneficial.

5.2 A Summary Describing Who Would Be Affected By These Impacts and Analysing Issues of Equity and Fairness;

5.2.1 The Aircraft Manufacturer:

Option 1 will result in the manufacturers of aircraft with metallic fuselages being restricted in all future designs to providing burnthrough protection to the lower fuselage by the installation of Thermal Acoustic Insulation and they will continue to incur the economic penalties associated with this option. Any differences in this approach will require equivalent safety demonstrations.

Option 2 allows the manufacturer flexibility in the manner in which occupant protection in pool fires is provided. The precise nature of this option is dependent on the outcome of the proposed research into the burnthrough characteristics of cabin windows. This option will only address cabin windows and the redefinition of the lower fuselage if the research finds this to be cost beneficial. The Fire Path Risk Assessment will result in additional design and certification costs to manufacturers of aircraft with metallic structures; however this may be offset by a reduction in material costs. Manufacturers of non-metallic aircraft will incur the additional cost of demonstrating that the upper fuselage has adequate burnthrough protection and the design, certification and material costs resulting from any changes identified from the Fire Path Risk Assessment. However it is assessed that these costs will be relatively small.

This Option allows complete flexibility to the manufacturer in his approach to minimising *the risk to occupants from the effects of fire penetration into the cabin following a post-impact ground pool fire.* The manufacturer will be able to take full advantage of technological change in showing compliance with the regulation proposed by this Option. This flexibility could extend to other means for protecting occupants from the effects of fire penetration into the cabin resulting from ground pool fires. An example that could be considered is cabin water mist systems that may provide a more cost beneficial solution to the issue.

Option 3 will provide the best safety impact of all of the options considered and for non-metallic aircraft may be shown to be cost beneficial. However, it is likely that for aircraft with metallic fuselages this option is unattainable. If this is not the case the costs incurred by the manufacturer will be extremely high and are likely to be prohibitive.

5.2.2 The Operator:

Option 1 will result in the operator continuing to incur the cost penalties associated with an increased fuel burn.

Option 2 & 3 may result in the operator incurring further cost penalties associated with any increased fuel burn due to the changes that are likely to result from the adoption of this Option. However, the flexibility afforded to the manufacturer in determining the means provided for occupant protection in pool fires could result in design solutions that are optimised in terms of their weight impact.

5.2.3 EASA:

Option 1 will result in no impacts on EASA.

Option 2 is likely to result in an increased burden on EASA due to their oversight of the Fire Path Risk Assessments carried out by the manufacturers. EASA may also need to fund the research into cabin windows and the proposed redefinition of the lower fuselage.

Option 3 would require a significant amount of additional guidance material. Development of this material would result in an increased burden on EASA. EASA may also need to fund the research into cabin windows and the proposed redefinition of the lower fuselage.

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5.2.4 Issues of Equity and Fairness:

There are no issues of equity and fairness associated with any of the regulatory options considered in this Regulatory Impact Assessment.

5.3 FINAL ASSESSMENT AND RECOMMENDATION OF A PREFERRED OPTION

Option 1 has no safety or economic impacts beyond those resulting from the introduction of CS 25.856(b). The manufacturers of aircraft with metallic structures will continue to bear the economic impact of installing thermal acoustic insulation materials to provide burnthrough protection to the lower fuselage. Whilst CS 25.856(b) provided a positive safety benefit its limitations regarding protection of the upper fuselage and areas of the lower fuselage do not provide the levels of safety that may be achievable. Manufacturers of non-metallic aircraft will continue to demonstrate an equivalent level of safety with CS 25.856(b). Operators will continue to incur the cost penalties associated with an increased fuel burn.

Option 2 provides a higher level of safety than Option 1 and allows the manufacturer flexibility in the approach to be adopted in providing enhanced protection for occupants in pool fire accidents. This flexible approach is in accord with that suggested by the Aerospace Industries of America (AIA)[8] :

> *"Regarding the proposal for resistance to burnthrough, the AIA believes the FAA approach of mandating a design solution for a fire barrier through regulatory action is inappropriate. A more appropriate approach would be to require that the fuselage design in the affected areas incorporate a fire barrier, and leave the actual design to industry. The FAA could address specific solutions through Advisory Circulars. The AIA recommends the FAA withdraw this part of the proposal and reissue it as a proposed fuselage design requirement."*

This preference for an objective rule is reflected by comments made by AECMA and Airbus[9]:

> *"As a general remark, we consider that an "objective orientated" requirement should be preferred to a "design orientated" requirement."*

The level of safety attained by this Option is dependent on the outcome of the proposed research into the burnthrough characteristics of cabin windows. This option will only address cabin windows and the redefinition of the lower fuselage if the research finds this to be cost beneficial.

There will be a small increase in the costs to EASA in their oversight of the Fire Path Risk Assessment carried out by the manufacturers.

This Option may result in the operator incurring further cost penalties associated with any increased fuel burn due to the changes that are likely to result from the adoption of this Option. Should any weight penalties be incurred they will have an adverse affect on the environment due to the increased fuel burn. However, the flexibility afforded to the manufacturer in determining the means provided for occupant protection in pool fires, could result in design solutions that are optimised in terms of their weight impact. Design solutions may be found that are lighter than those incurred from Option 1 with a consequential improvement in aircraft operating costs and a reduction in the impact on the environment.

[8] Reference 7
[9] Reference 19

Option 3 will provide the best safety impact of all of the options considered and for non-metallic aircraft may be shown to be cost beneficial. However, it is likely that for aircraft with metallic fuselages this option is unattainable. If this is not the case the costs incurred by the manufacturer will be extremely high and are likely to be prohibitive. Option 3 would also require a significant amount of additional guidance material. Development of this material would result in an increased burden on EASA.

Based on the assessments made in this Regulatory Impact Assessment, as summarised above, the preferred Option is Option 2 - to **amend CS-25 to provide a partially objective rule to provide protection to occupants in pool fire accidents**.

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Appendix 1 – Analysis and Interpretation of FAA Test Results

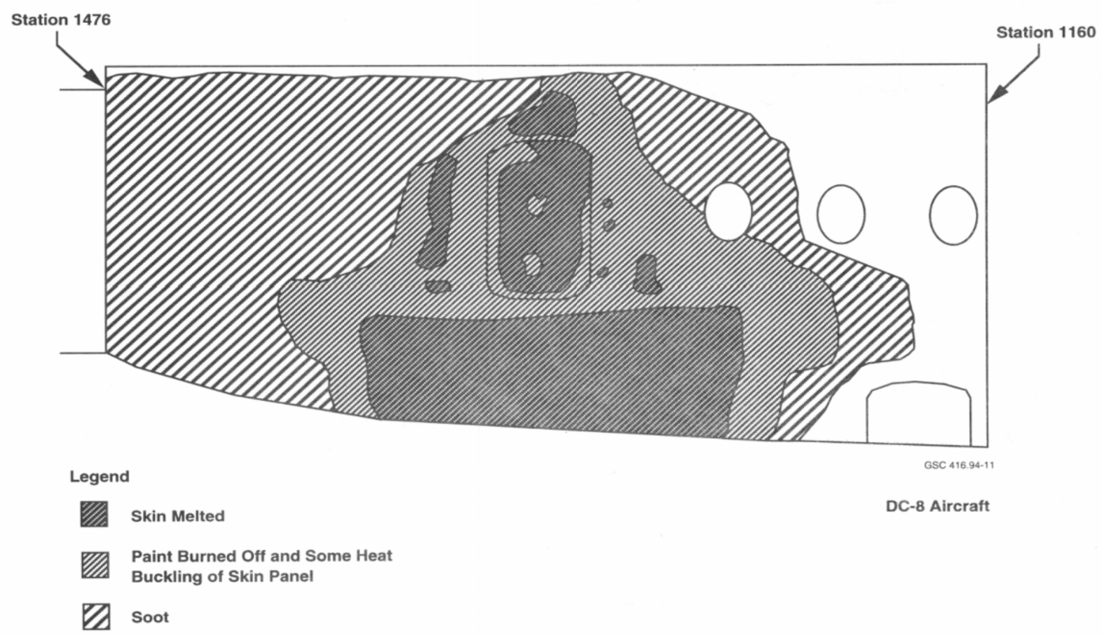
Test 1

"The fire took approximately 50 seconds to cover the entire pool. By the 68-second mark, small flames had penetrated the door seals of the aft service door and smoke and momentary flames (1/10-sec duration) emerged from the floor grills in the vicinity of the door. By the 94-second mark, smoke began pouring from the grills all along the starboard side. At 156 seconds into the test, the onboard sprinkler system was activated and the pool fire was simultaneously extinguished by the standby firemen, terminating the test."

"The aluminum skin melted away in an area below the floor and centered about the aft service door. The damage extended approximately 6 feet forward and 5 feet aft of the door. The skin was buckled approximately 30 inches on all sides of the melted area."

"The skin above the door was melted in a triangular shape extending 12 inches on either side of the doorway and 30 inches above the door."

"The smoke and fire that entered the cabin came through the air conditioning return grills located on the sidewall at the floor level. These grills are open into the cheek area on each side of the cargo compartment. This area forms a duct that channels the exhaust air to the outflow valves located in the empennage crawlthrough aft of the cargo compartment. The pool fire melted the skin in the cheek area, opening a path to the grills. The fire in the overhead did not travel up through the sidewalls or through the ventilation ducts. The skin above the door was penetrated directly by the pool fire plume. Here the insulation was dislodged, allowing access to the overhead."



Observation 1.1 The elapsed time from when the pool fire had fully established to when smoke began pouring from the floor grills was 44 seconds. In this time the lower fuselage skin had melted in the cheek area. **Test 1 indicates the capability of a fuel fire to melt the lower fuselage skin in around 44 seconds.**

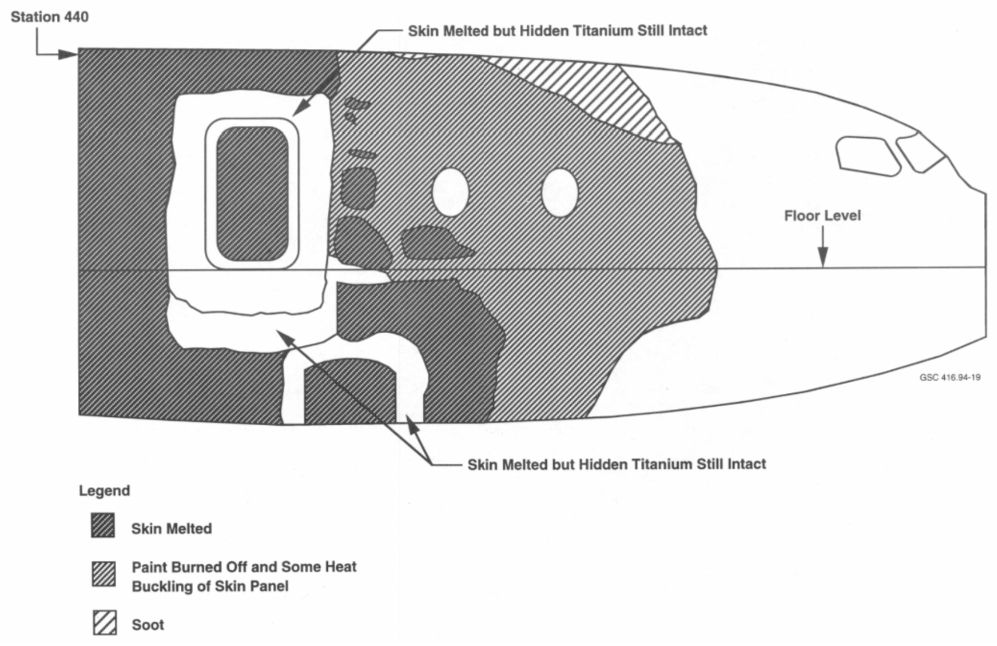
Observation 1.2 The elapsed time from when the pool fire had fully established to when extinguishing commenced was 1 minute and 46 seconds. In this time the skin above the door had melted. **Test 1 indicates the capability of a fuel fire to melt the upper fuselage skin within 1 minute and 46 seconds.**

Test 2

"The fire took approximately 30 seconds to cover the entire pool. In the next 30 seconds smoke and fire penetrated the lower door seal of the starboard service door. Smoke also penetrated the seals on the cargo compartment door. At 71 seconds into the test, smoke began to pour from the floor grills. Fire penetrated the forward service door at 80 seconds. Fire penetrated the cargo door seals at 110 seconds. By 140 seconds, the cabin and cargo compartment became totally obscured. The test was terminated at 3 minutes 45 seconds into the test by activating the sprinkler system and extinguishing the pool fire."

"The aluminum skin was extensively destroyed from the fire barrier, located at the compartment partition, to approximately 16 feet forward. The damage extended from ground level up to the center or the top of the aircraft. The skin on the service door was completely melted away. The cargo door skin was also melted away. Nearly all of the skin below the floor level was melted. The two windows on the starboard side were checkered but were still in their frames."

"The smoke initially penetrated the cabin through the floor grills. This was quickly followed by smoke and fire penetration through the starboard service door. Penetration into the cargo compartment was achieved through the cargo door."



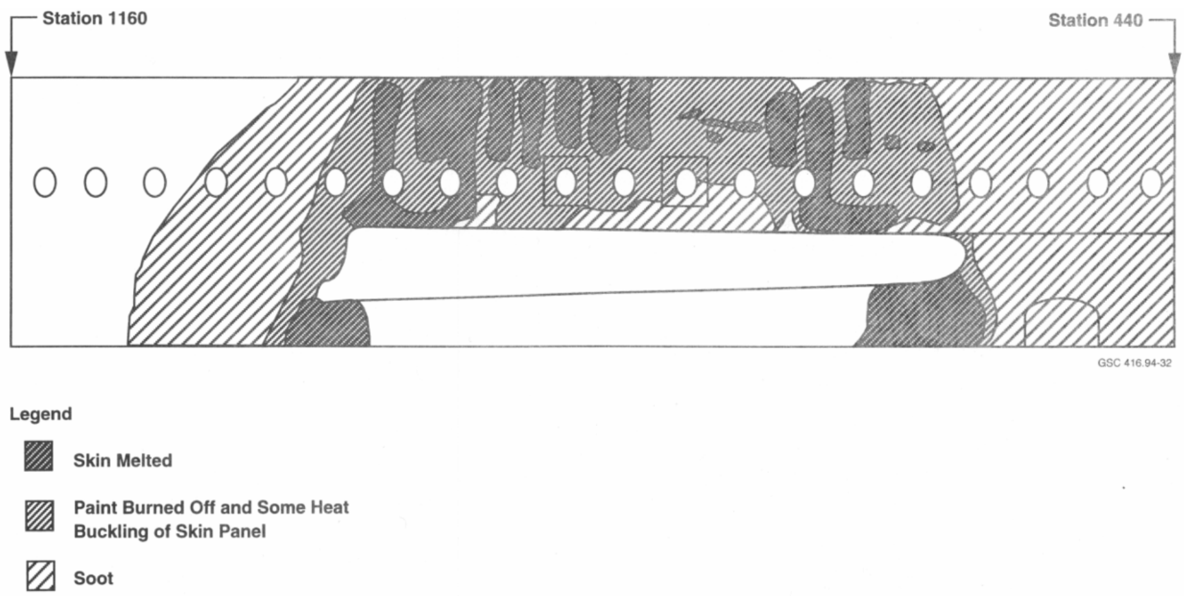
Observation 2.1 The elapsed time from when the pool fire had fully established to when smoke began pouring from the floor grills was 41 seconds. Although it is not stated explicitly within the test report, it is likely that the smoke reached the floor grills via melted skin rather than the cargo compartment door. **Test 2 indicates the capability of a fuel fire to melt the lower fuselage skin in around 41 seconds.**
Observation 2.2 The elapsed time from when the pool fire had fully established to when extinguishing commenced was 3 minutes and 15 seconds. In this time the skin damage extended from ground level up to the center or the top of the aircraft. **Test 2 indicates the capability of a fuel fire to melt the upper fuselage skin within 3 minutes and 15 seconds.**

Test 3

"The fire took approximately 35 seconds to cover the entire pool. Smoke began to pour from the floor grills at 50 seconds into the test. At 80 seconds, smoke came through the sidewall panel above the window located at station 584. Fire penetrated through the top of the window seal at station 956 at 184 seconds after ignition. Two seconds later, fire penetrated through the floor grill at station 872. At 187 seconds, fire penetrated through the sidewall panel below the window at station 866. At 5 minutes into the test the cabin was totally obscured. At 6 minutes 42 seconds the sprinkler system was activated and the pool fire was extinguished by the standby firemen, terminating the test."

"There was a 2- by 2-foot section above the trailing edge of the wing into the overhead section of the aircraft where the skin completely melted away."

"The fire penetrated the cabin in three places. The first was in the vicinity of the leading edge of the wing. Here a large section of the skin was burned away at the cheek area at the aft end of the forward cargo compartment allowing access to the floor grills. Fire penetrated through the grill and ignited the sidewall panel above the grill. The second penetration occurred through the cabin window directly above the trailing edge of the wing. The ceiling panel and the sidewall panels surrounding and above the window ignited. The third penetration occurred in the ceiling overhead. The fire was caused by a large flame penetration through the skin directly into the overhead. There was no evidence that suggested the fire travelled up through the fuselage from below the floor to the ceiling."



<u>Observation 3.1</u> The elapsed time from when the pool fire had fully established to when smoke began pouring from the floor grills was 15 seconds. **Test 2 indicates the capability of a fuel fire to melt the lower fuselage skin in around 15 seconds.**

<u>Observation 3.2</u> The elapsed time from when the pool fire had fully established to when extinguishing commenced was 6 minutes and 7 seconds. In this time the fire penetrated through the skin directly into the overhead. **Test 3 indicates the capability of a fuel fire to melt the upper fuselage skin <u>within</u> 6 minutes and 7 seconds.**

<u>Observation 3.3</u> The elapsed time from when the pool fire had fully established to when fire penetrated through the top of the window seal at station 956 was 2 minutes 29 seconds. **Test 3 indicates the capability of a fuel fire to penetrate past a window seal in 2 minutes 29 seconds.**

Test 4

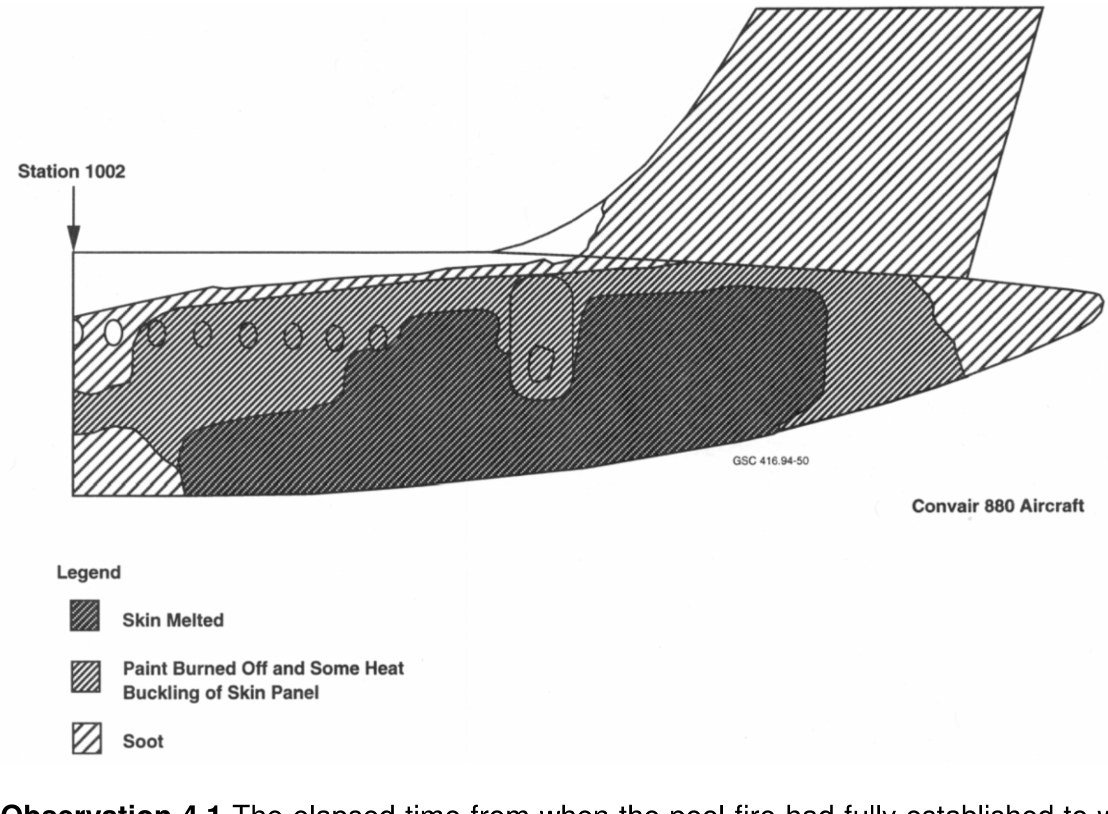
"The fire was ignited on the upwind side and took approximately 40 seconds to cover the entire pool. At 1 minute 26 seconds, smoke penetrated the cabin floor just forward of the aft port lavatory. Six minutes after ignition the sprinkler system was activated and the pool fire was extinguished by standby firemen.

The pool fire, though centered under the fuselage, damaged the port side more than the starboard due to the crosswind. The wind blew at 3 to 7 knots across the fuselage from starboard to port. The underside of the aircraft was completely destroyed from station 1040 aft to station 1470. The skin and frame members were completely gone. The skin on the port side was melted up to the window level from station 1163 to station 1350. The remainder of the skin was buckled and perforated. The starboard side sustained minor damage with some slight sooting of the paint."

"All but two of the windows on the port side were penetrated."

"The initial penetration into the aircraft occurred in the empennage crawlthrough area behind the cargo compartment. This area is only partially insulated. The fire penetrated the skin and then the floor of the cabin.

Penetration into the cargo compartment was through the aft bulkhead separating the cargo compartment from the crawlthrough area. The cabin floor was initially penetrated by flames above the crawlthrough area in 1 minute 43 seconds and the cargo compartment in 2 minutes 14 seconds. The cargo compartment appeared to provide some protection to the cabin against a pool fire of this type".



<u>Observation 4.1</u> The elapsed time from when the pool fire had fully established to when smoke penetrated the cabin floor was 46 seconds. In this time the lower fuselage skin

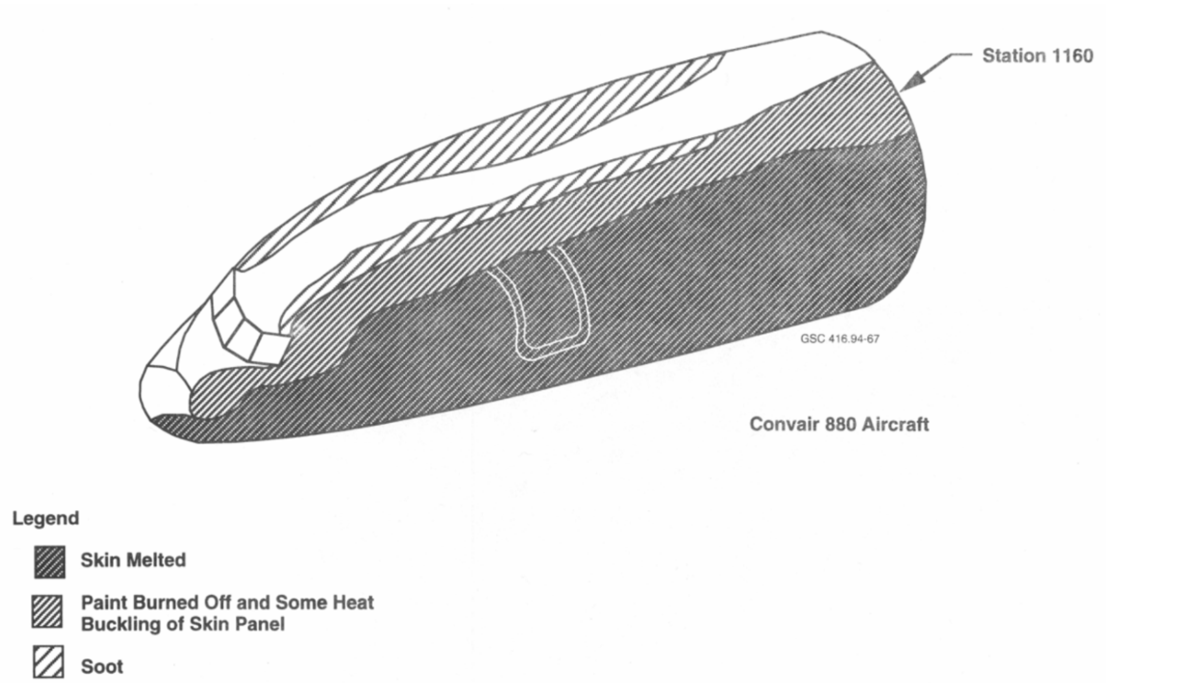
had melted. **Test 4 indicates the capability of a fuel fire to melt the lower fuselage skin in around 46 seconds.**
Observation 4.2 The elapsed time from when the pool fire had fully established to when extinguishing commenced was 5 minutes and 20 seconds. In this time the skin had melted up to the window level. **Test 4 indicates the capability of a fuel fire to melt the upper fuselage skin within 5 minutes and 20 seconds.**
Observation 4.3 The elapsed time from when the pool fire had fully established to when extinguishing commenced was 5 minutes and 20 seconds. In this all but two of the windows on the port side were penetrated. **Test 4 indicates the capability of a fuel fire to penetrate through the cabin windows within 5 minutes and 20 seconds.**

Test 5

"The fuel was ignited on the upwind side and took approximately 25 seconds to cover the entire pool. The wind was blowing across the fuselage from starboard to port at 3 to 6 knots. Thirty seconds into the test, smoke began to pour into the cabin from the cockpit. At 49 seconds after ignition, smoke penetrated the port entry door seals. At 1 minute 10 seconds into the test, the cabin became obscured, and at the same time smoke began to puff through the cargo compartment door seals. By the 2 minute mark the cargo compartment was fully obscured. At 3 minutes 49 seconds after ignition, the smoke outside of the aircraft momentarily cleared to reveal that the skin on the underside of the aircraft was mostly burned away. At 4 minutes 25 seconds, the nose began to sag. At 4 minutes 28 seconds the sprinkler system was activated and the firemen began to put the pool fire out."

"The nose section was severely damaged by the fire. The port side was completely destroyed up to the centerline of the top of the fuselage. The cockpit windows were still intact; all other windows on the port side were gone. The starboard side fared a little better."

"Initial smoke penetration came from the cockpit area. The cockpit, however, did not receive the most extensive damage. The fire may have come into the cabin through the electronics bay and up through the crew access tunnel. The electronics bay was not insulated."



<u>Observation 5.1</u> Although the lower fuselage skin was extensively burned through, the burnthrough time cannot be clearly established from the test records. Smoke may have entered via electronics bay then crew access tunnel.

<u>Observation 5.2</u> The elapsed time from when the pool fire had fully established to when extinguishing commenced was 4 minutes and 3 seconds. In this time the port side was completely destroyed up to the top of the fuselage. **Test 5 indicates the capability of a fuel fire to melt the upper fuselage skin <u>within</u> 4 minutes and 3 seconds.**

<u>Observation 5.3</u> The elapsed time from when the pool fire had fully established to when extinguishing commenced was 4 minutes and 3 seconds. In this time all windows on the port side were ‘gone’. **Test 5 indicates the capability of a fuel fire to penetrate through the cabin windows <u>within</u> 4 minutes and 3 seconds.**

Test 6

"The fire took approximately 25 seconds to reach a fully developed state. At 40 seconds there was a small explosion under the fuselage. At 1 minute 5 seconds, smoke began to rise from the floor of the cabin at station 980. At the 4-minute mark the landing gear collapsed and the fuselage fell to the ground. The pool fire was extinguished at this time by the standby firemen."

"The port side skin that was forward of the leading edge of the wing was completely burned away up to the top of the fuselage."

"The only penetration into the cabin occurred on the aft starboard side where the windows were burned away. Here the sidewall panels were damaged. There was no ceiling overhead fire in this test. The acoustical insulation remained in place and supplied the inner sidewall panels with substantial protection from the fire."

Observation 6.1 The elapsed time from when the pool fire had fully established to when smoke began to rise from the cabin floor was 40 seconds. In this time the lower fuselage skin had melted. **Test 6 indicates the capability of a fuel fire to melt the lower fuselage skin in around 40 seconds.**
Observation 6.2 The elapsed time from when the pool fire had fully established to when extinguishing commenced was 3 minutes and 35 seconds. In this time the skin had melted up to the window level. **Test 6 indicates the capability of a fuel fire to melt the upper fuselage skin within 3 minutes and 35 seconds.**
Observation 6.3 The elapsed time from when the pool fire had fully established to when extinguishing commenced was 3 minutes and 35 seconds. In this time the windows on the starboard side had burned away allowing fire penetration. **Test 6 indicates the capability of a fuel fire to penetrate through the cabin windows within 3 minutes and 35 seconds.**

Appendix 2 – Cost Assessment related to Enhanced Burnthrough Resistant Thermal Acoustic Insulation

Estimates relating to the cost of installing burnthrough resistant Thermal Acoustic Insulation are based on the assessments made by the FAA, as part of their regulatory process leading to the amendment to FAR 25.856, and the industry comments on the associated NPRM (Reference 8).

The FAA assessed (Reference 18) that the cost of compliance with the amended FAR 25.856 could be achieved *"…by laminating a layer of ceramic paper to the inside of the outboard side (the aluminium skin side) of the film encasing material"*. Their cost assessment based on this approach amounted to $18 per square yard – which equates to approximately $21.5 per square metre.

Estimates made by AIM Aviation on the FAA NPRM (Reference 14) include the following statements:

> *"We estimate that at present the lowest weight construction without performance degradation would add in excess of $25,000 in material costs alone to a typical single deck, twin aisle aircraft.*
>
> *This construction would add in excess of 205 pounds to a typical single deck, twin aisle aircraft. Other likely successful approaches would add up to 600 pounds to the same aircraft."*

It is estimated that a typical single deck twin aisle aircraft would require approximately 433 square metres of burnthrough resistant Thermal Acoustic Insulation. Based on the AIM estimate of $25,000 this would amount to a cost of approximately:

$58 per square metre

Similar estimates made by Airbus, on the FAA NPRM (Reference 19), suggest material costs of $64,000 for a single deck twin aisle aircraft and $18,500 for a single deck single aisle aircraft.

Assuming again that the area to be covered is 433 square metres for a single deck twin aisle aircraft this would amount to a cost of approximately:

$148 per square metre

It is estimated that a typical single deck single aisle aircraft would require approximately 193 square metres of burnthrough resistant Thermal Acoustic Insulation. Therefore for a total cost of $18,500 per aircraft this amounts to a cost of approximately:

$96 per square metre

These costs are summarised in RIA Table 7.

RIA Table 7 Assessment of Cost for Thermal/Acoustic Liners

A/C Type	Company	Cost/m^2
Twin Aisle	AIM	$58
Twin Aisle	Airbus	$148
Single Aisle	Airbus	$96
AVERAGE	-	$101

It may be seen that the average of the AIM and Airbus costs approximates to $100 per square metre.

If it is assumed that the fuselage area above the centre line is approximately the same as the lower fuselage then the material cost associated with providing burnthrough compliant Thermal Acoustic Insulation might be expected to be:

$100 x 193 = $19,300 for a single deck single aisle aircraft and

$100 x 433 = $43,300 for a single deck twin aisle aircraft