Protecting Aircraft and Passengers from Cargo Fires

Cargo compartment linings are designed to provide an air-tight space, and are essential in protecting the aircraft and its occupants from fire and smoke.

This article looks at how these composite components have come to play such an important role in Safety, and what can be done to make sure they stay in good condition.

Aircraft certification requirements for cargo compartment fire protection have evolved in response to a number of tragic events. Today's design standard for lower deck cargo holds relies on the flame-proof and air-tight properties of the compartment liner. Inspecting the liner and making repairs when needed is important to keep it in good condition.

CARGO COMPARTMENT FIRES & THE EVOLUTION OF DESIGN STANDARDS

Origins of the fire containment principle

Regulations providing design criteria for cargo compartments in commercial aircraft were introduced in 1946, prior to the introduction of the first jet aircraft into commercial aviation. At this time, the criteria considered that cargo compartments would either be accessible to the crew and a fire would be manually extinguished, or inaccessible and equipped with fire detection and extinguishing systems.

Changes to regulations introduced in 1952 allowed for new types of inaccessible cargo holds called 'Class D' compartments. Designs were permitted to rely purely on fire containment principles, by having linings designed to be capable of restricting the supply of oxygen into the compartment, without needing any fire detection and suppression systems.

With the introduction of larger passenger jets, the size of Class D compartments grew beyond that for which the 1952 regulations had originally been intended. Larger compartments introduced new risks, including larger quantities of combustible material, and the presence of a larger volume of oxygen.

The combination of these two factors created the possibility that a fire starting in such a hold could burn for sufficient time or with sufficient strength that it would penetrate the cargo hold linings. Penetration of the linings would of course lead to availability of an increased oxygen supply, and an uncontrollable fire.

> "In 1952 fire containment designs relying on restricting oxygen supply became permitted"

In-service events

A number of uncontrolled fires have occurred in cargo compartments, which contributed to an evolution of airworthiness regulations. The FAA's 'Lessons Learnt from Civil Aviation' website identifies two tragic fatal accidents which were pivotal in driving this evolution.

In 1980 in Riyadh, shortly after take-off of a second generation wide-body aircraft, an uncontrollable fire occurred in the rear cargo hold. Tragically, all 301 passengers and crew died in the event.

The accident report of the Saudi Presidency of Civil Aviation included the conclusion that "Investigative evidence and testing indicates that the C-3, Class D compartment of the L-1011 did not meet the intent of the FAR 25.857 (d) and that the FAR is inadequate for purpose".

> "In 1980 an uncontrollable fire occurred in the rear cargo hold of a second generation widebody aircraft"

In 1996 in the Everglades near Miami, a second generation single-aisle aircraft experienced an uncontrolled fire in its forward cargo compartment shortly after takeoff, leading to the death of all 110 passengers and crew.

> "In 1996, a second generation single-aisle crashed after takeoff with the death of 110 passengers & crew"

The accident investigation report written by the US NTSB identified the following findings related to the design standard of the aircraft type:

"[…] a smoke/fire warning device would have more quickly alerted the pilots to the fire and would have allowed the more time to land the airplane"

"If the plane had been equipped with a fire suppression system, it might have suppressed the spread of the fire […] and it would have delayed the spread of the fire, and in conjunction with an early warning, it would likely have provided time to land the airplane safely."

Hence, these and similar accidents highlighted the need to update Part 25 airworthiness regulations regarding the means of fire protection in cargo holds, including through design of the compartment lining as well as by detection and suppression systems.

Changes to regulations

> "New legislation established more stringent flame resistance standards for liner materials"

Following the accident in Riyadh, amendment 25-60 to Part 25 airworthiness regulations was made effective in 1986 by the FAA. This amendment established more stringent flame resistance standards for compartment linings, to take account of the findings of a series of full-scale tests by the FAA to investigate the capability of different liner materials.

A retrofit activity was mandated to some of the existing fleets of the time in order to ensure cargo compartment panel linings were upgraded. This completion date of this retrofit was established by the legislation as March 1991.

It was subsequent to the Everglades accident in 1996 that the limitations of the principle of relying purely on containment by oxygen starvation were acknowledged. In particular it was recognised that new risks needed to be considered, including potential explosions of consumer aerosol products which could damage the integrity of cargo compartment linings.

> "Fire detection and suppression systems became mandatory"

Recognising that under such circumstances, the only way to contain a fire would be through active fire detection and suppression, in 1998 the FAA introduced new legislation through Amendment 25-93 to 14 CFR 25.855, which removed the Class D cargo compartment category.

This meant that all new designs of aircraft, as well as existing aircraft in-service, were to be equipped to the standards of Class C compartments, or Class E compartments for freighter aircraft. In particular, fire detection system capable of alerting the flight crew within 1 minute of the fire starting became necessary, together with Halon gas fire suppression systems. The limit date for retrofits of existing fleets was set at March 2001.

Type	Crew Access	Fire Detection	Extinguishing or Suppression	Ventilation	Flames, Smoke & Fumes
A	Possible	By crew at workstation	By crew with extinguisher		
B	Possible	By detection system	By crew with extinguisher		Means to exclude from cabin
C	Not possible	By detection system	By dedicated system	Means to control to enable extinguishing	Means to exclude from cabin
D	Not possible	None required	None required	No ventilation into compartment	Means to exclude from cabin
E		By detection system		Means to shut off to enable extinguishing	Means to exclude from cabin

Table 1
Cargo Compartment Types

Post 25-93, types A, B, C & E remain in use in commercial aircraft

Post 25-93, type D compartments no longer exist in 25.855

CURRENT DESIGNS OF LOWER DECK CARGO COMPARTMENTS

Following the tragic events described earlier in this article, the design standard of lower deck cargo compartments was revised across the air transport industry, with Class C type compartments and cargo compartment panel fireproofing improvements being mandated.

This industry wide action significantly improved the fire protection level of commercial aircraft through the equipping of the commercial fleet with key features:

- Air-tight & fire-proof cargo holds
- Cargo fire detection systems
- Cargo fire suppression systems

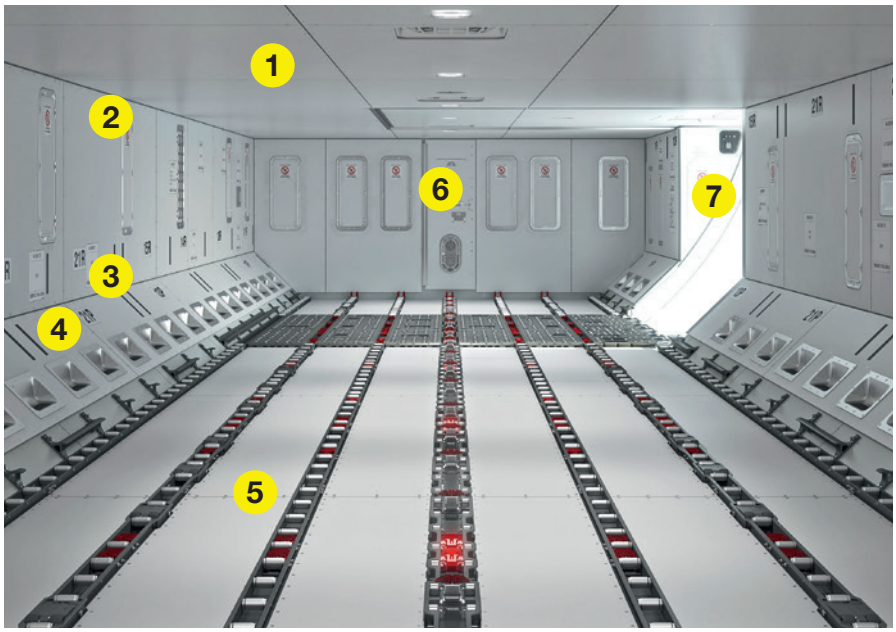
These three features are all necessary and must all work together in order to ensure that the aircraft and its occupants is protected from a cargo fire.

Making the cargo hold air-tight

The volume of lower deck cargo holds on Airbus aircraft varies significantly depending upon the aircraft type and hold, but can range from as low as 7.0m³ (250ft³) on an A318 to 143m³ (5050ft³) on an A340-600. Enclosing such voluminous spaces obviously requires the use of many components.

> “Cargo compartments must be air-tight and resistant to burning”

1. Ceiling panels
2. Decompression panels
3. Vertical sidewall panels
4. Sloping sidewall panels
5. Floor panels
6. Partition
7. Door



> "The air-tight lining of the cargo compartment is created by composite panels together with their fasteners, secondary structure and the cargo door."

Lower deck cargo holds are constructed out of their doors, and many composite panels attached to the aircraft's primary and secondary structure. Various categories of panels are used, including ceiling, sidewall, sloped and floor panels, as illustrated in Figure 1. Even if we just consider the sidewalls and ceilings, a shipset of these different panels for a specific hold can include anything from 42 on an A320 up to 188 on the A380.

Together with their fasteners, secondary structure, and the cargo door, these panels create the liner of the cargo hold lining. This liner is required to provide the two fire protection functions of air-tightness and fire-proofing.

Air-tightness limits the available oxygen to any fire occurring within the cargo hold compartment. It is a key safety measure which allows to suffocate a fire, as well as to ensure that fire suppression systems have the required effect by creating an enclosed space within which the Halon gas can act.

Air-tight seals between the panels and the structure are achieved by the use of self-adhesive elastomer foam tapes applied to the rear of the panels. The seal is made when these tapes are compressed during tightening of the fasteners.

Fire-proofing the cargo hold

The second fire protection function of the liners and panels is to withstand burning. This function ensures that the passenger cabin is kept free of fire, as well as any hazardous smoke and gases. Clearly, in the case of any fire, flame resistance of the linings is essential to maintaining air-tightness.

Panels and all materials used in construction of the cargo compartment liner are required by aircraft certification regulations CS-25.855 to meet flame resistance properties are defined by airworthiness regulations.

The process to demonstrate compliance with this regulation is detailed and rigorous, involving specific test equipment and the exposure of sets of production standard panels to flames at a temperature of 927°C / 1700°F.

Detecting & suppressing a fire

Fire detection systems are designed to alert flight crew on the cockpit within 1 minute of a fire starting. Based on the information provided by the detection warnings, flight crew initiate the suppression of any fire by discharge of Halon gas into the affected cargo compartments.

Halon is a very effective suppression agent which operates by chemically reacting with the radicals generated by a fire, to inhibit the reaction.

To achieve the extinguishing effect, sufficient Halon needs to be released to achieve a volumetric concentration of 5% of the compartment air as a first shot, for a fire knock-down effect. Following this, a concentration of 3% must be continuously maintained for the rest of flight. With this approach, lower deck cargo compartment fires can be suppressed for up to 360 minutes on wide-body aircraft.

Nevertheless, maintaining the concentration of Halon is crucial to the effectiveness of the system, and therefore it is essential that the cargo compartment remains air-tight. Any damage or mis-installation of the cargo compartment lining can degrade the performance of the fire suppression system, and therefore has the potential to make a key defence against on-board fires ineffective.

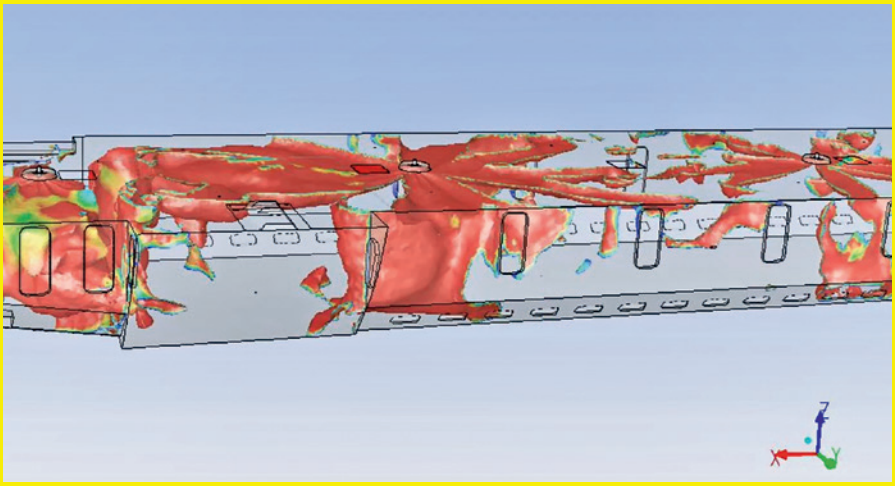
> “Any damage or mis-installation of the cargo compartment lining can degrade the performance of the fire suppression system”

Certification of the A350-1000 fire suppression system

To comply with the airworthiness authorities’ certification requirements, aircraft manufacturers must prove that a new aircraft type’s fire suppression system can maintain the required amount of Halon present in a cargo compartment over time. Traditionally, this activity has only been possible by flight test, usually requiring five individual flights.

For the certification of the A350-1000, Airbus has taken advantage of the successful flight test campaign performed for the A350-900 and developed a Computational Fluid Dynamic (CFD) model of the cargo hold together with its Halon release system. Both EASA and the FAA have accepted this model as an acceptable means of compliance. This significant advancement will enable Airbus to perform more complex analyses in the support of Safety objectives.

CFD simulation of halon discharge into the aft cargo hold of the A350-1000



MAKING SURE THE CARGO COMPARTMENT IS IN GOOD CONDITION

Cargo unloading and loading operations are a crucial part of the often time constrained ground handling operations, so it hardly needs to be mentioned that the cargo compartment can experience rough treatment. Whilst cargo compartment liners are designed to be tolerant of such an environment, damages do occur.

To make sure that the crucial fire protection function of the cargo compartment lining is assured, regular maintenance inspections are required by the Maintenance Planning Document. Additionally, the IATA Ground Operations Manual specifies that a cargo hold inspection should be completed after each unloading operation.

Scheduled inspections

The Maintenance Planning Document (MPD) of all Airbus aircraft specifies a regular visual inspection of each cargo hold. The maintenance procedures associated with the MPD tasks specify a general visual inspection of the entire compartment, including all types of panels identified in figure 1, to identify any damage or deformation, or any panels which are in the wrong position.

Other elements which must be inspected include panel seals, fastener assemblies, and the position of decompression panels.

Program	MPD Revision	MPD Task Number	Interval
A350	Rev.03 Issue Jul 2015/16	501300-00001-01M 01300-00004-01M	8 days 200 FH
A380	Rev. 13 Issue Feb 01/17	501000-00101-01 501300-00001-01 501400-00001-01 501500-00001-01	16 days 750 FH 750 FH 750 FH
A330/A340	Rev.22 Issue 14 Sep 2017	255200-00001-01 255300-00001-01 255400-00001-01	8 days 8 days 8 days
A320 Family	Rev.44 Issue Sep.2017	2550000-01-1	8 days
A300/A310	Rev.31 Jul 01/17	255100-01-1 255610-02-1	8 days 8 days

Inspections during cargo loading operations

On a daily basis, it is clear that the people who will have the most opportunity to identify any damages or other issues with the cargo hold linings are ground operatives.

There are no mandatory inspection requirements for ground operatives to complete during cargo loading. However, ground operations procedures such as those defined by IATA in the Ground Operations Manual (IGOM) provide a reference for recommended safe practices during cargo loading operations, and in practice also inform the expectations of local authorities.

KEYPOINT

The IATA Ground Operations Manual (GOM) states that ground crew must complete a final check of all holds to inspect for damage

IATA IGOM section 4.11 'Aircraft Loading' contains a dedicated section 4.11.5 'Cargo Hold Inspections', with the following key recommendations in relation to damage to the cargo holds:

- When an offload is completed, a final check of ALL cargo holds must be conducted to inspect each cargo hold for damage to the compartment […]
- If any damage is found to the compartment […] it must be immediately reported to a supervisor, the flight crew, and/or a company representative as required by the operating airline
- Any damage to the structure or linings of containerised or bulk holds may lead to specific loading limitations. Therefore, any damage must be reported. The load controller shall be informed accordingly.

In addition to section 4.11.5, cargo hold inspections are also specified in section 6 'Airside Safety Operational Oversight'. This section of the GOM deals with the activities which are expected to be performed by trained and qualified supervision personnel of airlines and their subcontractors.

Turnaround Coordination/Supervision Requirements are defined in section 6.3 by the use of a checklist table, the primary purpose of which is to prevent unsafe acts. Checklist item 11 states 'Ensure all cargo holds offloaded according to LIR (Load Inspection Report) and inspected for damage'.

KEYPOINT

The IGOM includes a checklist item for turnaround supervision staff, to 'Ensure all cargo holds offloaded according to LIR (Load Instruction report) and inspected for damage'.

TYPICAL REPORTS OF CARGO COMPARTMENT DAMAGE AND THEIR CAUSES

Typical abnormalities found during cargo compartment inspections are identifiable from reports sent to Airbus by operator airlines. A study of reports over the period 2015-2017 reveals that types of abnormalities are generally quite consistent according to their source.

Damage to sidewall panels, ceiling panels or cargo doors from cargo operations

The majority of damage to cargo compartments are caused during cargo loading or unloading operations. Reports of such damage total around 65% of reports to Airbus, and include cases of damage to vertical or sloping sidewall panels, ceiling panels or doors.

> "About 65% of damages identified on widebody aircraft are related to the use of out of contour cargo containers."

Typical damage identified on widebody aircraft types are related to out of contour cargo containers or pallets impacting and/or scratching the sidewalls, with ceilings being damaged less frequently. Damage to the cargo door linings are also typically caused by impact with out-of-contour containers, and often result in cracking of the panel around fixation holes upon door closure.

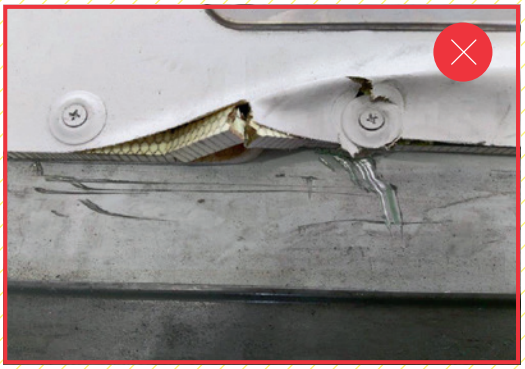
Additionally, poor maintenance of containers can make them more susceptible to warping of the contour when under flight loads, leading to damage of sidewalls and doors.

On A320 Family aircraft, both ceilings and sidewalls can be damaged during bulk loading operations. This damage is usually due to abnormal impacts from bags and suitcases under manual handling, and typically results in delamination or puncturing of the top layer of the panels, or crushing of the honeycomb core.

CARGO LININGS PROTECT AGAINST FIRE

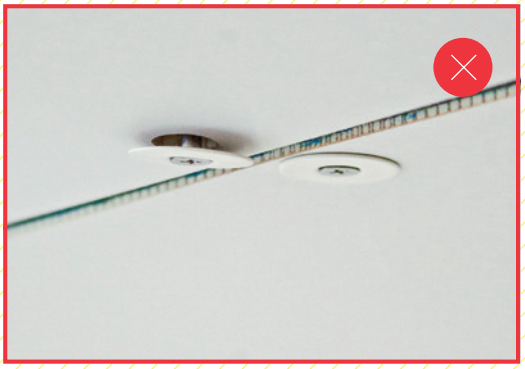
Keeping aircraft cargo linings in good condition is key to ensuring aircraft are protected from cargo hold fires

Don't load out of contour ULDs (containers or pallets)



Report any damage to the lining

Check decompression panels and catches are in the correct position



Ensure fasteners are present, tightened, and flat on the panel

Damage to decompression panels when incorrectly used as access panels

Damage to decompression panels comprise about 25% of reports to Airbus about damage to the cargo compartment. Whilst some of these reports are attributed to damage caused during cargo loading operations, the majority are attributed to the use of decompression panels as access panels during aircraft maintenance.

Typical damage is found around at the edge of the cut-out for the decompression panel (e.g. on the upper assembly, where the decompression panels attaches to the vertical sidewall).These reports are often due to a removal and installation of the decompression panel by pushing on it, without properly unlocking the catch. Other findings include missing or dislodged panels, or incorrectly latched panels.

> “About 25% of reports to Airbus of lining damage are due to incorrect use of decompression panels as access panels”

Correct
Access by removal of sidewall panel assembly to perform maintenance

Incorrect
Access by removal decompression panel to perform maintenance

Decompression panels are clearly identified with placards mentioning ‘DO NOT PUSH’ and ‘DO NOT REMOVE’. In case any panel is found partially or totally dislodged, it must be reinstalled as per AMM procedures in order to avoid additional damage. These require removal of the sidewall panel upper assembly for proper completion.

Loose or missing panel fasteners

All lower deck cargo compartment lining panels are attached to the structure and/or systems by a quick release fastening system (fasteners). About 10% of reports of damages to the cargo hold are related to either missing, or incorrectly installed fasteners. The reports principally impact the ceiling panels.

Investigations into these reports allowed Airbus to identify clear recommendations for fastener tightening and cargo lining installation. The appropriate torque value to be applied when tightening a fastener is between 0.055 and 0.060 m.daN (4.87 and 5.31 lbf.in).

> “About 10% of reports of damage to the cargo hold are about missing or incorrectly installed fasteners”

KEYPOINT

The correct torque to be applied when tightening a fastener is between 0.055 and 0.060 m.daN (4.87 and 5.31 lbf.in)

Cargo Hold Visual Inspection tasks

The number and location of missing fasteners which are permitted is contained within the relevant Cargo Hold Visual Inspection tasks of the maintenance documentation.

A300/A310:
AMM 25-50-00 PB 601
A320 Family:
AMM 25-50-00-200-002-A
A330/A340 (fwd):
AMM 25-52-00-210-801-A
A330/A340 (aft):
AMM 25-53-00-210-801-A
A330/A340 (bulk):
AMM 25-54-00-210-801-A
A350 XWB:
MP 50-13-XX-00001-310A-A
A380 (fwd):
AMM 50-13-00-210-801-A
A380 (aft):
AMM 50-14-00-210-801-A
A380 (bulk):
AMM 50-15-00-210-801-A

ACTIONS TO TAKE WHEN ANY LINING DAMAGE IS FOUND

Regulations for flight with damaged cargo hold linings are stringent, since any failure of the air-tight and/or flame-proof features of the cargo lining can lead to an uncontrolled fire on board.

For this reason, operational constraints can be triggered when any damages are found to the cargo lining, particularly flying with the cargo hold empty under MMEL.

Once any damage has been identified and alerted to the operator, it is the responsibility of maintenance staff to classify the damage and initiate the appropriate corrective actions. The maintenance manuals contain the appropriate procedures for visual inspection, damage classification, and general repair of panels.

Abnormalities which are not considered as damage

Small dents to the skin of the lining panels are not considered as damage as long as the upper skin is not damaged, and there is no visual debonding of the upper skin from the panel core.

Additionally, a small number of missing fasteners for ceiling, sidewall and partition linings (but not decompression panels) are often considered temporarily acceptable, as per limits defined in the Cargo Hold Visual Inspection tasks. Pending replacement of the fastener within the specified time period, the holes left by the missing fasteners must be sealed in line with the maintenance procedures.

Damages for which repairs can be scheduled

On A320, A330/A340, and A380 Families, when damage to ceiling, sidewall or partition linings are within the damage limits defined in the AMM Repair/Protection tasks, a limited number of small damage affecting the upper skin only, can be scheduled to be completed rather than be completed immediately. The dimensional and time limits of these small 'not-through' damages are also listed in the AMM Repair/Protection tasks.

Similar repair scheduling allowances exist for door linings, as long as the damage is to edge of the lining only, and within dimensional and time limits specified in the Cargo Door Lining General Repair tasks.

Damages requiring immediate repairs

Protection of the aircraft and its passengers from fire means maintaining in good condition, the components which assure the air-tight and fire-proof properties required by aircraft certification. When these components are damaged, immediate repairs are therefore often required.

Damages to ceiling, sidewall or partition linings in the following categories must be rectified before flight, either with a panel repair or with a replacement panel:

- Damage to the edge of panel
- Damage which goes through both faces of a panel
- Not-through damage, larger than the limited allowances defined in AMM Repair/Protection tasks for repairs which can be scheduled (see previous section)

Since door linings are not made of honeycomb composite materials, the conditions for immediate repair or replacement are different than those above. The relevant assessment conditions can be found in the Cargo Door Lining General Repair tasks.

If repairs cannot be made immediately

If panel repair or replacement cannot be completed immediately, the aircraft can be dispatched under MMEL with the relevant cargo hold empty, or not containing flammable or combustible materials. If a fly-away kit box is present, the operator must ensure that it doesn't contain flammable or combustible materials.

Repair/ Protection tasks
Ceiling, sidewall linings

The dimensional limits which apply for assessment of repairs to damage of ceiling and sidewall linings can be found in the procedures listed below

A300/A310:
AMM 25-00-00 PB 801
A320 Family:
AMM 25-50-00 PB 801
A330/A340:
AMM 25-50-00 PB 801
A350:
MP 50-13-XX-0M001-685A-A
A380:
AMM 50-10-00 PB 801

Repair/ Protection tasks
Cargo door linings

The dimensional limits which apply for assessment of repairs to damage of cargo door linings can be found in the procedures listed below

A300/A310:
AMM 52-30-13 PB 801
A320 Family:
AMM 52-31-13 PB 801
A330/A340 (fwd):
AMM 52-31-15-300 PB 801
A330/A340 (aft):
AMM 52-32-15-300 PB 801
A330/A340 (bulk):
AMM 52-33-15-300 PB 801
A350:
MP 50-13-XX-0M001-685A-A
A380 (fwd):
AMM 52-31-15 PB 801
A380 (aft):
AMM 52-32-15 PB 801
A380 (bulk):
AMM 52-33-15 PB 801

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Today's design standard for cargo compartment fire protection is encoded in airworthiness regulations, having evolved to take into account Safety lessons learnt following a number of tragic events.

The key features of cargo hold design that today protect passengers and aircraft from a cargo hold fire are fire detection and suppression systems, combined with an air-tight and fire-proof cargo compartment lining. A cargo compartment lining comprises not only the various composite panels of the ceiling, sidewall, floor, and partition, but the panel fasteners, and the cargo door lining.

Keeping the cargo compartment lining in good condition is an important activity for safety. In addition to regular scheduled checks of the lining, checks should also be made at each aircraft turnaround by ground operatives.

The largest cause of damage to the lining is the use of out-of-contour or poorly maintained cargo containers. Damage on decompression panels is also reported from the incorrect use of these panels as access panels during aircraft maintenance activities.

Any failure of the air-tight and fire-proof features of the cargo lining can lead to an uncontrolled fire on-board. For this reason, operational restrictions can be triggered when any damages to the cargo lining are identified, including flying with the cargo hold empty, or not containing flammable or combustible materials, under MMEL.

Safety first

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