ICAO

Doc 10102

Guidance for Safe Operations Involving Aeroplane Cargo Compartments

First Edition, 2020

Approved by and published under the authority of the Secretary General

INTERNATIONAL CIVIL AVIATION ORGANIZATION

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AMENDMENTS

Amendments are announced in the supplements to the *Products and Services Catalogue;* the Catalogue and its supplements are available on the ICAO website at www.icao.int. The space below is provided to keep a record of such amendments.

RECORD OF AMENDMENTS AND CORRIGENDA

AMENDMENTS		
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FOREWORD

This manual, referenced in ICAO Annex 6 — *Operation of Aircraft*, Part I — *International Commercial Air Transport — Aeroplanes*, provides guidance material that addresses the safety risks associated with operations that involve the transport of items in the cargo compartments of an aeroplane. It also provides guidance material to assist States, civil aviation authorities, and the operators under their jurisdiction, in the development and/or implementation of prescriptive regulations and processes to address the provisions detailed in Chapter 15 of Annex 6, Part I.

The technological leaps in aviation made over the last century would not have been possible without parallel achievements in the control and reduction of safety risks. It is only through the disciplined application of the best safety risk management practices that the frequency and severity of aviation occurrences can continue to decline. Guidance for the hazards associated with the transport of items in aeroplane cargo compartments was previously not provided in ICAO Annex 6, Part I, and while the subject of dangerous goods was addressed in Chapter 14, other items regularly transported were not considered, and the functional capabilities of cargo compartments themselves were not directly addressed. This lack of detail in Annex 6 may have resulted in levels of risk that were higher than an operator realized, due to a lack of awareness of the limitations of the relevant aeroplane systems.

Provisions introduced through Amendment 44 to Annex 6, Part I establish the responsibility of operators to fully understand the risks associated with any items transported in the cargo compartments of their aeroplanes, while identifying the need for Type Certificate (TC) holders, Supplemental Type Certificate (STC) holders, and the original equipment manufacturers (OEM) to provide the necessary information on relevant aircraft systems and additional equipment to operators for them to adequately assess risks. Many civil aviation authorities are increasing emphasis on a risk-based approach to regulatory compliance. Many operators have the capability and resources necessary to analyse operational hazards, manage safety risks to levels as low as reasonably practicable and achieve target levels of safety performance. Together, these elements provide operational flexibility and form the framework for a proactive, self-correcting and continually improving safety system.

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EXECUTIVE SUMMARY

Various stakeholders within the global aviation community have highlighted that risks posed by the transport of cargo by air may not be sufficiently mitigated. In particular, the hazards and risks associated with items to be transported contributing to an overwhelming situation for the aircraft or aircraft systems during any potential incident are not fully considered. During discussions on risks posed by the transport of lithium batteries by air, it was identified that the safety capabilities of aircraft systems may not be fully considered in either the dangerous goods regulations or operator procedures. A need for provisions and guidance material for operators to conduct safety risk assessments on the transport of cargo was therefore determined.

Consequently, the Air Navigation Commission charged the Flight Operations Panel (FLTOPSP) with the task of introducing provisions into Annex 6 — *Operation of Aircraft* for operators to conduct safety risk assessments on the transport of cargo, including the transport of dangerous goods. The provisions developed by FLTOPSP were subsequently adopted by the ICAO Council through Amendment 44 to Annex 6, Part I — *International Commercial Air Transport — Aeroplanes.* The FLTOPSP was also tasked with the creation and ongoing revision of this manual to support these provisions. Work was conducted on behalf of the FLTOPSP by the multi-disciplinary Cargo Safety Sub-Group (CSSG).

The primary goal in formulating this manual is to maintain the safety of flight operations. First and foremost, the manual provides guidance material to support operators in the conduct of a safety risk assessment for operations that utilize the cargo compartments of their aeroplanes, from hazard identification and an assessment of the probability and severity, to the consideration of mitigation strategies. Second, the manual provides guidance for Type Certificate (TC) holders, Supplemental Type Certificate (STC) holders, or original equipment manufacturers (OEMs) regarding technical information (specifications, capabilities and certification requirements of pertinent aircraft systems) they should provide to operators in order for it to be adequately considered by an operator in a risk assessment process.

Although all hazards must be considered, special focus is given to hazards with the consequence of fire, as this can have a significant impact on the airworthiness of the aeroplane. The risk assessment is not intended to be conducted on a flight-by-flight basis, but should be revisited periodically as part of the operator’s overall safety management activities. It should consider risks associated with any item transported in the cargo compartment, irrespective of whether it is contained in cargo, baggage, or mail.

GLOSSARY

ACRONYMS AND ABBREVIATIONS

ANC	Air Navigation Commission
CAA	Civil Aviation Authority
COMAT	Operator material
CSSG	Cargo Safety Sub-Group
DG	Dangerous goods
DPO	Designated postal operator
EDTO	Extended diversion time operations
FCC	Fire containment cover
FRC	Fire-resistant container
OEM	Original equipment manufacturer
PED	Portable electronic device
SRM	Safety risk management
SMM	*Safety Management Manual* (Doc 9859)
STC	Supplemental Type Certificate
TC	Type Certificate
Technical Instructions	*Technical Instructions for the Safe Transport of Dangerous Goods by Air (*Doc 9284)
ULD	Unit load device
UPU	Universal Postal Union

DEFINITIONS

When the following terms are used in this manual, they have the following meanings:

Note.— Where an asterisk appears beside a term, the term has already been defined as such in Annexes and Procedures for Air Navigation Services (PANS).

Baggage. Personal property of passengers or crew carried on an aircraft by agreement with the operator.

Cargo. For the purposes of this manual, any property carried on an aircraft other than mail and accompanied or mishandled baggage.

Note.— This definition differs from the definition of "cargo" given in Annex 9 — Facilitation *and Annex 17 —* Security*, which does not include stores within the definition of cargo.*

COMAT. Operator material carried on an operator's aircraft for the operator's own purposes.

Hazard. A condition or an object with the potential to cause or contribute to an aircraft incident or accident.

Mail. Dispatches of correspondence and other items tendered by, and intended for delivery to, postal services in accordance with the rules of the Universal Postal Union (UPU).

Mishandled baggage. Baggage involuntarily, or inadvertently, separated from passengers or crew.

***Overpack.** An enclosure used by a single shipper to contain one or more packages and to form one handling unit for convenience of handling and stowage.

***Package.** The complete product of the packing operation, consisting of the packaging and its contents prepared for transport.

***Packaging**. Receptacles and any other components or materials necessary for the receptacle to perform its containment function.

Risk. *See Safety risk*.

Risk mitigation. The process of incorporating defences, preventive controls or recovery measures to lower the severity and/or likelihood of a hazard's projected consequence.

***Safety.** The state in which risks associated with aviation activities, related to, or in direct support of the operation of aircraft, are reduced and controlled to an acceptable level.

***Safety management system (SMS).** A systematic approach to managing safety, including the necessary organizational structures, accountability, responsibilities, policies and procedures.

***Safety performance.** A State's or service provider's safety achievement as defined by its safety performance targets and safety performance indicators.

***Safety performance indicator.** A data-based parameter used for monitoring and assessing safety performance.

***Safety risk.** The predicted probability and severity of the consequences or outcomes of a hazard.

***Stores (Supplies).** a) Stores (supplies) for consumption; and b) Stores (supplies) to be taken away.

Stores (Supplies) for consumption. Goods, whether or not sold, intended for consumption by the passengers and the crew on board aircraft, and goods necessary for the operation and maintenance of aircraft, including fuel and lubricants.

Stores (Supplies) to be taken away. Goods for sale to the passengers and the crew of aircraft with a view to being landed.

***Type certificate.** A document issued by a Contracting State to define the design of an aircraft, engine or propeller type and to certify that this design meets the appropriate airworthiness requirements of that State.

***Unaccompanied baggage.** Baggage that is transported as cargo and may or may not be carried on the same aircraft with the person to whom it belongs.

***Unit load device.** Any type of freight container, aircraft container, aircraft pallet with a net, or aircraft pallet with a net over an igloo.

Note.— An overpack is not included in this definition.

Chapter 1

INTRODUCTION AND OVERVIEW OF THE MANUAL

1.1 HISTORY

1.1.1 Various stakeholders within the global aviation community have highlighted that risks posed by the transport of cargo by air may not be sufficiently mitigated. In particular, specific hazards and risks associated with items to be transported that could contribute to an overwhelming situation for the aircraft or aircraft systems during any potential incident, are not fully considered. Research on the risks posed by the transport of lithium batteries by air led aeroplane manufacturers to expressly state that cargo compartments are not designed to contain the consequences of the unique hazards associated with the carriage of dangerous goods, including lithium batteries (see the reports of the Dangerous Goods Panel Working Group Meeting, 27 April to 1 May 2015, and the Twenty-Fifth Meeting of the Dangerous Goods Panel, 19 to 30 October 2015). With this in mind, experts in the fields of dangerous goods, operations, airworthiness, safety management and aircraft cargo fire safety research recommended that operators perform safety risk assessments in order to establish if they could manage the risks associated with the transport of lithium batteries on aircraft to an acceptable level of safety. These experts also recommended that guidance on how to conduct and evaluate a safety risk assessment be developed for operators and regulators.

1.1.2 When reviewing these recommendations, the Air Navigation Commission considered that lithium batteries might be representative of other items that may present unmitigated hazards to aircraft operations. Consequently, it charged the Flight Operations Panel (FLTOPSP) with the task of developing provisions for Annex 6 — *Operation of Aircraft* for operators to conduct safety risk assessments on the transport of cargo, including the transport of dangerous goods. This work culminated with the adoption by the ICAO Council of new provisions incorporated through Amendment 44 to Annex 6, Part I — *International Commercial Air Transport — Aeroplanes.* To support these provisions, the panel was also tasked with the creation and ongoing revision of guidance material in the form of this manual. This work was conducted on behalf of the FLTOPSP by the multi-disciplinary Cargo Safety Sub-Group (CSSG).

1.2 SCOPE AND OBJECTIVE

1.2.1 First and foremost, this manual provides guidance material to operators for the conduct of a risk assessment for operations that involve aeroplane cargo compartments. This is in accordance with the International Standards and Recommended Practices (SARPs) of Annex 6, Part I. It places the safety risk management (SRM) concepts espoused in ICAO's *Safety Management Manual* (SMM, Doc 9859) into an operationally relevant context. Second, it provides guidance on what information related to technical specifications, capabilities, and certification requirements of pertinent aircraft systems a Type Certificate (TC) holder, Supplemental Type Certificate (STC) holder, or original equipment manufacturer (OEM) should provide to the operator for it to conduct a risk assessment meeting the minimum requirements of Annex 6. The provisions and guidance are intended to be universal and flexible so that they remain applicable to goods and products that may be invented, manufactured, and presented for air transport in the future.

1.2.2 While the original mandate for the CSSG referred specifically to *cargo* operations, it became apparent as the work progressed that the provisions should seek to address *all* items that may be transported in an aeroplane cargo compartment. While the transport of lithium batteries as cargo had been identified as a major safety concern, it was important to ensure that safety risk assessments conducted by operators considered the risks associated with *any* item transported in the cargo compartment, irrespective of whether it was contained in cargo, baggage, or mail. The use of the term “items” in Annex 6 and this manual is therefore specifically intended so that operators address all the following categories in their subsequent risk assessments:

a) cargo (including COMAT/stores);

b) passenger and crew checked baggage;

c) mail; and

d) other equipment used in the transport of cargo, baggage, or mail (e.g. unit load devices).

1.2.3 The provisions developed are included in Annex 6, Part I, Chapter 15, Cargo compartment safety, which includes the following Standard:

> “The State of the operator shall ensure that the operator establishes policies and procedures for the transport of items in the cargo compartment, which include the conduct of a specific safety risk assessment. The risk assessment shall include at least the:
>
> a) hazards associated with the properties of the items to be transported;
>
> b) capabilities of the operator;
>
> c) operational considerations (e.g. area of operations, diversion time);
>
> d) capabilities of the aeroplane and its systems (e.g. cargo compartment fire suppression capabilities);
>
> e) containment characteristics of unit load devices;
>
> f) packing and packaging;
>
> g) safety of the supply chain for items to be transported; and
>
> h) quantity and distribution of dangerous goods items to be transported.”

1.2.4 This manual provides guidance on how an operator may consider each of these factors in the conduct of their specific safety risk assessment. This list is not exhaustive, and operators may need to consider other factors as part of their specific safety risk assessment.

1.2.5 It should be noted that the development of the provisions in Annex 6, Part I, Chapter 15 was driven by the need to consider the inherent hazardous properties of the items being transported. There are clearly hazards associated with the improper loading of aeroplanes when conducting operations that utilize cargo compartments, for example, the inadequate securing of loads, or loading items outside of the aeroplane centre of gravity limitations. However, these apply equally regardless of the properties of the items themselves, and hence fall outside the scope of this manual. An operator must still consider those hazards as part of their ongoing safety risk management processes, and ensure that items are loaded and properly restrained in cargo compartments in accordance with their mass and balance manuals.

1.2.6 It is important to note that the risk assessment mandated in Annex 6, Part I, Chapter 15 is not intended to be conducted by the operator on a flight-by-flight basis. Rather, it should be applied to all operations that involve the transport of items in the cargo compartment, based on the specific type of operations that the operator conducts. If an operator were to deviate from the operations that defined the initial risk assessment, then it must be revisited to ensure new hazards have not been introduced by the change in operations. Even if there are no changes to operations, the risk assessment should be revisited periodically as part of the operator’s overall safety management activities, as safety management seeks to proactively mitigate safety risks before they result in aviation accidents and incidents.

1.3 STRUCTURE OF THE MANUAL

1.3.1 This manual is structured to follow the process of conducting a risk assessment, in order to provide the most benefit to operators in terms of guidance. It is based on the principles of the SMM, but also recognizes different methods for conducting a risk assessment, providing details of the commonly used "bowtie" method. The subsequent chapters are then structured in accordance with the process, beginning with hazard identification and the associated consequences, then addressing the assessment of the actual risk involved in terms of probability of occurrence and severity of outcome, before then considering mitigating strategies that may address both.

1.3.2 Fire represents one event with significant consequences for an aeroplane during operation, with the potential of having a major impact on its airworthiness. Furthermore, there can be many possible causes of a fire, or "pathways" to the development of a fire on board. As such, the discussion of hazards that may lead to a fire comprise a major portion of this manual and the guidance contained herein.

1.4 RISK ASSESSMENT AND SAFETY RISK MANAGEMENT

Annex 6, Part I, Chapter 15 mandates the conduct of a specific safety risk assessment. In accordance with Annex 19 — *Safety Management*, this represents one part of SRM, which is itself a key component of a safety management system (SMS), representing a systematic approach to managing safety, including the necessary organizational structures, accountability, responsibilities, policies and procedures. As such, SRM includes hazard identification, safety risk assessment, safety risk mitigation and risk acceptance. SRM is a continuous activity because the aviation system is constantly changing, where new hazards can be introduced, and some hazards and associated safety risks may change over time. In addition, the effectiveness of implemented safety risk mitigation strategies needs to be monitored to determine if further action is required. The specific safety risk assessment on the transport of items in the cargo compartment is part of this SMS, and may be based on the safety risk management guidance contained in the SMM. Hazards should be identified, risks assessed, and specific mitigation measures established, according to predicted probability and the severity of the consequences based on the worst foreseeable situation.

Chapter 2

RESPONSIBILITIES

2.1 GENERAL

In order to ensure the safety of operations that involve cargo compartments, the Standards defined in Chapter 15 of Annex 6, Part I, identify certain responsibilities for each stakeholder in the process. This chapter provides guidance and additional information on those key responsibilities.

2.2 STATE OF THE OPERATOR

As part of the overall safety oversight responsibility of the State, it is the responsibility of the State of the Operator to ensure that the operator conducts a specific safety risk assessment for the transport of items in the cargo compartment.

2.3 DESIGN APPROVAL HOLDER

In accordance with Annex 6, Part I, Chapter 15, it is the responsibility of the design approval holder (e.g. Type Certificate/Supplemental Type Certificate) to ensure that the documentation supporting the operation of the aeroplane describes the elements of the design associated with cargo compartment fire protection, and a summary of the demonstrated standards that were considered in the process of certification.

2.4 MANUFACTURERS OF OTHER EQUIPMENT

The requirements referred to in 2.3 currently only apply to built-in fire protection systems in the cargo compartments of an aeroplane. It does not consider the use of other equipment that provide additional means of fire protection, such as fire-resistant containers (FRCs). However, it is expected that similar information on the capabilities and demonstrated standards of such equipment would be provided by the manufacturers or third parties responsible for the qualification of the equipment, to enable a safety risk assessment by the operator.

2.5 OPERATORS

In accordance with Annex 6, Part I, Chapter 15, an operator must conduct a specific safety risk assessment on the transport of items in the cargo compartments of their aeroplanes. This assessment is ideally conducted through the operator’s approved SMS. A list of subject areas that must be considered in this risk assessment is included in Annex 6, Part I, Chapter 15, and further guidance is provided in this manual. The risk assessment must be one element of established policies and procedures that address the items to be transported in the cargo compartment. In support of these policies and procedures, and in accordance with safety management principles, operators should implement a robust and open incident reporting culture as a way of identifying failures during the offer, acceptance, and transport of baggage, mail and cargo. Reports of incidents involving the transport of baggage, mail or cargo should be investigated to identify potential failures or weaknesses in procedures, processes, training or mitigations. Ultimately, it is the responsibility of the operator to manage the risks posed by the transport of items in aeroplane cargo compartments.

Chapter 3

HAZARDS AND THEIR CONSEQUENCES

3.1 GENERAL

3.1.1 Hazard identification is the first step in the SRM process. It precedes a safety risk assessment and requires a clear understanding of hazards and their related consequences. Hazards exist at all levels in the organization and can be identified through many sources including reporting systems, inspections, audits, brainstorming sessions and expert judgement. Hazards can also be identified in the review or study of internal and external investigation reports. Hazards generated outside of the organization and outside the direct control of the organization should also be identified, such as shipper or passenger compliance with requirements. The early identification of hazards related to emerging safety risks are an important way for organizations to prepare for situations that may eventually occur.

3.1.2 A commonly used method for aiding the conduct of a hazard analysis is the bowtie method. This method utilizes a diagram structure with the hazard defined at the centre of the diagram, a series of pathways to the left indicating the ways in which that hazard could be present, and a series of pathways to the right indicating the possible consequences of the hazard. It is the diagram structure that lends itself to the name of the “bowtie” process. This method may be used to aid the task of listing hazards that are identified in a logical manner, as each hazard will require its own unique bowtie diagram. Appendix 1 to this chapter presents further details of the bowtie method, along with an example bowtie analysis for one hazard associated with operations involving aeroplane cargo compartments.

3.2 IDENTIFICATION OF HAZARDS

3.2.1 In many cases, an item offered for transport is identified as hazardous due to the specific properties of the item itself. Many items may be inert, requiring an external influence in order to pose a hazard to the operations. However, others may pose a clear hazard due to their inherent properties, for example large quantities of liquids, or dangerous goods. It is the specific properties of the items themselves, such as flammability, toxicity, fluidity, etc., along with their combinations and overall quantities, that must be considered when evaluating the risk in transport. The hazards presented in this chapter are intended as examples only, and do not constitute the only hazards associated with transporting items in aeroplane cargo compartments. It is the responsibility of the operator to identify and consider these and any other hazards during a safety risk management process.

3.2.2 The types of goods that an operator routinely accepts for transport can directly affect the considerations for hazard identification. For example, an operator that *primarily* transports live animals and perishables such as flowers and fresh food could reasonably conclude that the risk of a fire, a possible consequence of some hazards, is lower than if their operations consisted of the transport of general cargo. Conversely, an operator that concentrates on cargo that is itself a potential ignition source would have a higher risk of fire than if the operator were carrying general cargo. Particular consideration must be given to dangerous goods. Not holding an operator approval to transport dangerous goods as cargo or holding an approval that restricts the types of dangerous goods the operator is permitted to transport can be factored into the risk assessment. All operators must consider the potential for undeclared dangerous goods to be offered for transport, regardless of the scope of their approval. Examples of hazards that may be present when transporting items in the cargo compartment of an aeroplane, including hazards associated with undeclared dangerous goods, are presented below. It is the responsibility of the operator to identify all reasonably foreseeable hazards in the safety risk management process.

Dangerous goods

3.2.3 Dangerous goods require specific consideration as, by definition, they can represent a hazard when transported in an aeroplane due to their inherent properties. Annex 18 — *The Safe Transport of Dangerous Goods by Air* provides broad principles governing the international transport of dangerous goods by air, and these are amplified by the detailed specifications in the *Technical Instructions for the Safe Transport of Dangerous Goods by Air* (Doc 9284, "Technical Instructions"). Substances and articles classified as dangerous goods in the Technical Instructions are assigned to one of nine classes according to the hazard or the most predominant of the hazards they present, as follows:

a) Class 1 — Explosives;

b) Class 2 — Gases;

c) Class 3 — Flammable liquids;

d) Class 4 — Flammable solids, substances liable to spontaneous combustion, substances which, in contact with water, emit flammable gases;

e) Class 5 — Oxidizing substances and organic peroxides;

f) Class 6 — Toxic and infectious substances;

g) Class 7 — Radioactive material;

h) Class 8 — Corrosive substances; and

i) Class 9 — Miscellaneous dangerous substances and articles, including environmentally hazardous substances.

3.2.4 It is clear that many items classified as dangerous goods represent a fire hazard as they have the potential to act as the fuel, the source of heat, or as an oxidizing element required for a fire to begin. An operator should identify the specific hazard(s) and consequence(s) associated with the specific item to be transported.

Lithium batteries

3.2.5 While lithium batteries are classified as Class 9 dangerous goods and therefore addressed in 3.2.3 and 3.2.4, they warrant further discussion in this manual due to their very specific properties. Lithium batteries are one example of an item that is capable of possessing all three elements required for the start of a fire (see 3.3, *Fire as a consequence* for details on these elements). Lithium batteries differ from other conventional batteries in that the cells are constructed with a flammable electrolyte, which can be forcibly released when a cell is in a state of thermal runaway. Thermal runaway is a chemical reaction within the cell itself that results in a dramatic and uncontrolled rise in both temperature and pressure. The temperature rise may be large enough to set adjacent cells into thermal runaway. This results in the battery expelling its contents, including the flammable electrolyte and flammable gas, which may then be ignited by the associated heat or burning surroundings of the battery. As such, lithium batteries have the capacity to act as both the ignition (heat source) and the fuel for a subsequent fire, and therefore represent a specific hazard that must be considered. Another unique and significant hazard that may result from a lithium battery thermal runaway event, is the expulsion of large quantities of flammable gas. The flammable gas has the potential to collect and ignite, resulting in a significant overpressure event.

3.2.6 Operators should consider that lithium batteries are increasingly installed in equipment that facilitates the transport of cargo, baggage and mail. They are not considered as the actual items offered for transport, however they are still present in the cargo compartment. Many shipments of time- and temperature-sensitive products including food, pharmaceuticals, medical devices, vaccines, and industrial chemicals have small battery-powered tracking devices or data loggers contained in or attached to the package. Furthermore, an increasing number of unit load devices (ULDs) are "active" and may also contain similar battery-powered devices. Most of these devices use lithium metal or lithium ion cells or batteries as a power source, which may vary in their level of power depending on the specific device.

Note.— Information related to the hazards produced by lithium cells in thermal runaway in aircraft cargo compartments has been derived from research at the United States Federal Aviation Administration (FAA) William J. Hughes Technical Center Aviation Research Division. A compilation of test data and results of this research is provided in a report available at http://www.fire.tc.faa.gov/pdf/TC-16-37.pdf.

Data loggers and transmitting and receiving devices

3.2.7 Portable electronic devices (PEDs) such as data loggers and cargo tracking devices, that are designed to remain active throughout their entire transport from shipper to consignee, including when on board an aeroplane, have the potential to interfere with aircraft navigation or communication systems. Therefore, manufacturers of PEDs, users of PEDs, and the operator itself are only permitted to use those that the operator has determined will not interfere with the safe operation of that aeroplane. Guidance material on the recommendations with respect to the use and carriage of battery-powered devices that are active during transport can be found in:

a) FAA Advisory Circular (AC) 91.21-1D, primarily the recommendations in Section 10 of the AC, which relate to active devices carried in the aircraft cargo compartment; and

b) EASA Part-CAT AMC / GM – Issue 2 – Amendment 1: Portable Electronic Devices.

Undeclared dangerous goods

3.2.8 Undeclared dangerous goods may present a significant hazard. It is essential that operators manage the risks posed by undeclared dangerous goods contained in items offered for transport.

Operator material (COMAT)

3.2.9 Operators carrying COMAT must have procedures which control the type, quantity and packaging of the material to be transported. Some COMAT requires special procedures that are similar to special cargo, and operators must have procedures to carry these items safely. Aircraft components must be installed in accordance with prescribed airworthiness specifications such that they do not present a hazard to the aircraft or its occupants. However, this safeguard may not apply to such items if they are shipped as cargo or stores without being safely classified, packed, marked, labelled and transported in accordance with Annex 18 and the Technical Instructions. This was graphically demonstrated by the ValuJet 592 accident in 1996 in which 110 passengers and crew were killed. This accident occurred following an intense in-flight cargo compartment fire caused by the improper carriage of chemical oxygen generators as company stores. These generators had previously been safely installed in aircraft passenger service units but had been removed and shipped in a manner such that they presented an extreme danger.

3.2.10 It is essential that policies and procedures are established to ensure that dangerous goods can never be transported as COMAT or stores when not meeting the requirements of Annex 18 and the Technical Instructions. These policies and procedures should prevent operations and aircraft maintenance personnel from performing any functions related to the shipment or transport of dangerous goods unless they are competently trained in accordance with Annex 18 and the Technical Instructions. Responsibilities for personnel involved with the procurement, receipt, inventory, shipment and transport of dangerous goods should therefore be addressed. Procedures should explain the operator's arrangements at stores and line maintenance facilities for ensuring dangerous goods are prepared for transport by competent personnel, including an indication of whether tasks will be performed in-house or by a third party such as an appointed specialist freight forwarder. In the situation where an aeroplane is designated AOG (aircraft on ground), procedures should also address the potential for components classified as dangerous goods to be removed for shipping, including the use of a specialist freight forwarder if required. Examples of such components include passenger service units (PSUs) and fuel system components with fuel contamination.

3.2.11 Other items which may present a hazard may be carried for the purposes of sale or consumption on board, including items carried for a series of flights, e.g. perfumes and lithium batteries.

3.3 CONSEQUENCES OF THE HAZARDS

3.3.1 A consequence is an outcome that can be triggered by a hazard. An immediate outcome of the hazards described above could be the start of a fire, followed by a consequent loss of control of the aircraft. The ultimate consequence could be an accident. The damaging potential of a hazard can materialize through one or more consequences. Therefore, it is important that safety risk assessments identify all possible consequences, so that specific mitigations may be more readily identified during the safety risk management process in order to reduce the severity of the consequence.

Smoke and fumes

3.3.2 The existence of smoke may impact flight operations and cause flight diversions, delays, cancellations, declared emergencies and evacuations. In addition, the presence of smoke may physically affect passengers and crew members if it is not dealt with rapidly and efficiently. Inhalation of smoke and toxic fumes has been known to incapacitate people and limit their physical and mental abilities, to the extent that they could not react, operate the exits or evacuate. Smoke can also obscure light, making visibility difficult and further impacting general mobility or an evacuation. Not all smoke, fumes and burning odours are related to a fire, or present a significant hazard. For example, smoke may result from de-icing fluids being ingested by the engines, and burning smells may be the result of a new refrigeration compressor. Nevertheless, crew should always report such incidents and investigate to ensure no danger exists. Identifying the source of smoke and taking immediate action will significantly minimize the risk of fire on board the aircraft.

Fire as a consequence

3.3.3 A fire event presents significant consequences for the operation of an aeroplane. There can be many possible causes of a fire, or "pathways" to the development of a fire on board, and the possibility for that fire to be contained or to spread is based on a number of different factors. In accordance with the definitions in the SMM, fire is not in itself a *hazard* but rather a *consequence* of a hazard such as flammable liquids being transported. As stated earlier in this chapter, there may be many layers of different consequences that arise from the identified hazard.

3.3.4 The term "fire class" is used to identify the type of fire in relation to the materials that are involved. This has consequential impacts on the type of fire extinguishing methods and substances that can be used. Class letters are often assigned to the different types of fire, but these can differ between States. Table 3-1 provides classes of fire in three different geographical regions as an example.

Table 3-1. Examples of fire classes in different regions

Description	*Europe*	*United States*	*Australia*
Combustible materials (wood, paper, fabric, refuse)	Class A	Class A	Class A
Flammable liquids	Class B	Class B	Class B
Flammable gases	Class C	Class B	Class C
Flammable metals	Class D	Class D	Class D
Electrical fire	*not classified (formerly Class E)*	Class C	Class E
Cooking oils and fats	Class F	Class K	Class F

3.3.5 It is important to understand the possible sequence of events that may lead to a fire in order to mitigate against any single event contributing to the combined pathway to a fire. There are three elements necessary for a fire to ignite: fuel, heat and an oxidizing agent, usually oxygen. These three elements are elaborated in the following paragraphs. A fire will occur when all elements are present and in the correct proportions. The risk assessment should therefore identify the possible scenarios that could lead to a combination of these three elements being present.

Fuel

3.3.6 Many common items carried in aircraft are themselves a potential source of fuel. The larger the quantity of fuel, the more severe the consequence should a fire occur. Materials used in aircraft production require fire resistance properties, but there is no similar aviation requirement applied to items carried in cargo compartments. Some items, such as dangerous goods classified as flammable, are inherent fuel sources. Other less obvious fuel sources include cardboard packaging, material of the individual items, and baggage containing items that are combustible and may also be a potential ignition source such as lithium batteries or battery-powered devices. Baggage poses an unknown hazard due to the potential lack of awareness or carelessness on the part of passengers in what they carry. Finally, if maintenance procedures are not strictly adhered to, discarded material such as tie wraps and paper or cardboard scraps from baggage or packaging may accumulate in corners of cargo compartments, both hidden and in plain sight. This has the potential to act as fuel and should be considered in combination with scenarios where a heat source may exist.

3.3.7 The volatility of the fuel source is quantified by the tendency of the substance to vaporize, and is directly related to a substance's vapour pressure. For liquid fuels, the flash point is the lowest temperature at which the liquid gives off enough vapour to be ignited above the liquid surface in air. The flash point of a liquid is dependent on atmospheric pressure and oxygen concentration. Solid fuels have auto-ignition temperatures, which is the lowest temperature at which they will self-ignite without an ignition source. Some dangerous goods can undergo chemical reactions which can result in fire when exposed to air, water, or other chemicals. Ignition temperatures for some typical items that may be transported are as follows:

a) Paper: an auto-ignition temperature of between approximately 210°C and 250°C, depending on composition;

b) Organic solvents such as paint thinner: a flash point of approximately 40°C; and

c) Methyl ethyl ketone: a flash point of approximately -7°C.

Heat or ignition source

3.3.8 An ignition or heat source must provide sufficient heat to ignite the combustible material. In some cases, items being transported may themselves serve as the heat or ignition source. For example, if hydrogen peroxide is spilled onto an organic material, it can evaporate, increasing its concentration and creating enough oxygen and heat from the chemical reaction to start a fire. Lithium batteries are an example of an energy storage device that poses a hazard, given the potential for thermal runaway. Thermal runaway is an uncontrolled increase in the temperature of a cell or battery driven by an exothermic reaction. Once one cell goes into thermal runaway, it can propagate from cell to cell and from package to package, potentially resulting in a major fire event. Thermal runaway may result from one or more factors including external damage to the battery, manufacturing defects, or overheating. In other situations, the heat or ignition source can be generated externally to the items in the cargo compartment. For example, an energized aeroplane wire that shorts to ground may provide an ignition source that can potentially cause a fire if adjacent to combustible material.

Oxygen or oxidizing agent

3.3.9 The breathable atmosphere in an aeroplane provides a source of oxygen required for combustion. Oxygen, as a percentage of the air, remains constant at typical flight altitudes, but the oxygen density decreases with altitude. As such, higher altitudes have less oxygen to support combustion. However, the oxygen or oxidizing agent required for fire might come from a different source, such as oxygen producing articles, or chemical reactions involving items present in the cargo compartment. An example of this and the potential consequences is the ValuJet 592 accident in 1996, when improperly packed oxygen generators transported in the cargo compartment ignited and caused an uncontrollable fire, ultimately contributing to the loss of the aircraft and all people on board.

The ultimate consequences

3.3.10 As stated previously, the most extreme consequence that could arise from a hazard should be differentiated within the safety risk assessment from those that involve lesser consequences. A fire could lead to increased pilot and crew workload, and to diversion to an alternate airfield. However, fire could also result in a catastrophic loss of the aircraft, with or without associated loss of life. The immediate consequence of the hazards identified in this chapter could be fire, but the subsequent consequences of the fire must also be considered in the risk mitigation process.

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Appendix 1 to Chapter 3

EXAMPLE BOWTIE HAZARD ANALYSIS FOR LITHIUM BATTERIES

1. EXPLAINING THE BOWTIE PROCESS

The bowtie is one of many barrier risk methodologies available to assist the identification and management of risk. It is a visual tool which effectively depicts risk, providing an opportunity to identify and assess the key safety barriers either in place or lacking between a safety event and an unsafe outcome.

The bowtie model consists of different elements that build the risk picture. The risk picture revolves around the hazard (something in, around or part of an organisation or activity which has the potential to cause damage or harm) and the top event (the release or loss of control over a hazard known as the undesired system state).

Note.— The term "top event" is specific to the bowtie method.

Consideration is then turned to the threats (a possible direct cause for the top event) represented on the left, consequences (results of the top event directly ending in loss or damage) represented on the right, and the controls (any measure taken which acts against some undesirable force or intention, and otherwise referred to as mitigation strategies in this manual).

The controls can be populated on either side of the model as follows:

a) *Left-hand side of the model.* Preventative measures which eliminate the threat entirely or prevent the threat from causing the top event recovery; and

b) *Right-hand side of the model.* Measures which reduce the likelihood of the consequence owing to the top event being "live" or mitigate the severity of the consequence.

Figure A3-1 presents the basic structure of the bowtie diagram, used to capture a hazard and identify the associated threats and consequences. The following section develops this further as an example for the specific hazard of lithium batteries. The allocation of controls is addressed in Appendix 1 to Chapter 5, as Chapter 5 of this manual provides more guidance on identifying mitigation strategies.

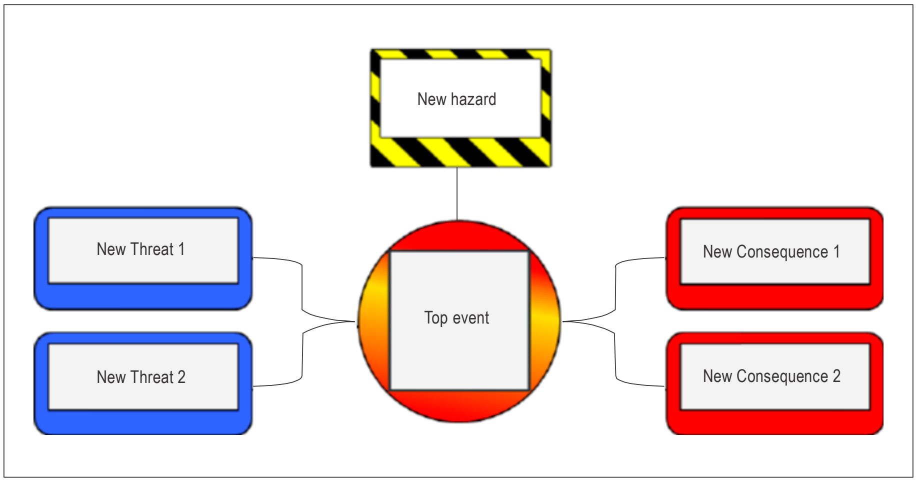

Figure A3-1. Bowtie method hazard identification template

2. EXAMPLE FOR LITHIUM BATTERIES

The transport of lithium batteries has been identified as a hazard due to their inherent properties discussed in Chapter 3. The "top event" associated with the hazard is the thermal runaway of a lithium battery cell on board an aircraft during flight. This is captured in the bowtie diagram as shown in Figure A3-2.

The next step is to identify the threats that could lead to this top event occurring. These are captured on the left-hand side of the diagram. Next, the consequences of the event should be identified, and captured on the right-hand side of the bowtie diagram. It should be noted that Figure A3-2 is for example only, and does not constitute a complete picture of all threats and consequences associated with the hazard of lithium batteries when transported in a cargo compartment.

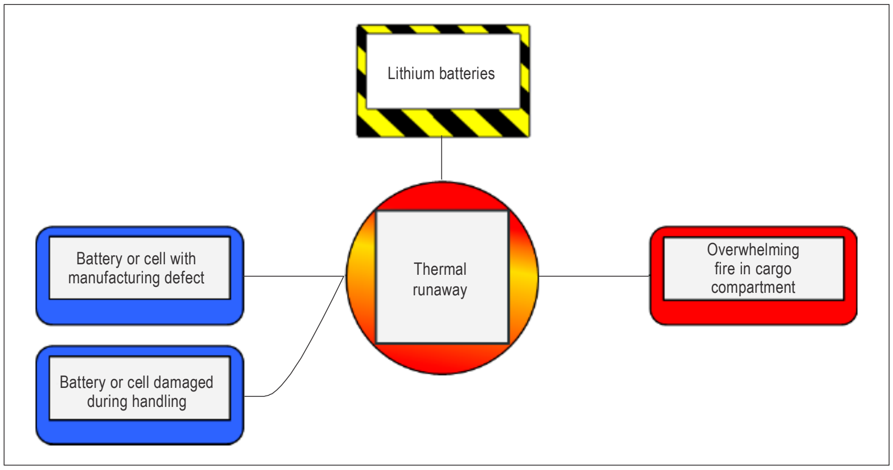

Figure A3-2. Bowtie diagram for example threats and consequences for the hazard of lithium batteries

Chapter 4

SAFETY RISK ASSESSMENT

4.1 GENERAL

Following the identification of individual hazards and their associated consequences, safety management requires an assessment of the risk associated with each hazard. This involves ascertaining the probability that a consequence of the identified hazard will occur and an assessment of the severity, taking into account all the potential consequences of the specific hazard that may occur. Guidance on these steps is provided in this chapter.

4.2 SAFETY RISK PROBABILITY

4.2.1 Safety risk probability is the likelihood or probability that a safety consequence or outcome will occur. Operators should utilize a data-driven method to evaluate the probability of an occurrence, and it is important to consider different scenarios so that all potential consequences are considered. An occurrence is considered foreseeable if a reasonable person should have expected the kind of occurrence under the same circumstances. Identification of every conceivable or theoretically possible hazard is neither possible nor desirable. Judgment is therefore required to determine the appropriate level of detail in hazard identification. Operators should exercise due diligence when identifying significant and reasonably foreseeable hazards related to their operations.

Note.— Regarding product design, the term "foreseeable" is intended to be consistent with its use in airworthiness regulations, policy and guidance.

4.2.2 When assessing the probability of an incident occurring that involves items that may pose a hazard, consideration should be given to the safety of the transport supply chain. The process of moving items from origin to destination is often very complex. Cargo is handled along a supply chain of many entities with varying responsibilities including shippers, postal operators, freight forwarders, ground handlers, and operators. The cargo may transfer between other modes of transport (sea, road, rail) and several different flights before it reaches its destination. Additionally, there may be regional variances in performance that have an impact on the assessment of probability. All those involved in these often complicated movements play a role in ensuring that nothing contained in the cargo will endanger an aeroplane. The more that is understood about the supply chain, the more confidence an operator can have in an assessment of the probability of an occurrence. An operator should therefore consider any data that may help them assess the probability, which could include the following:

a) damage to items through any part of the supply chain;

b) shippers deliberately or unintentionally offering dangerous goods for transport without declaring them;

c) shippers improperly classifying, packing, marking or labelling dangerous goods;

d) freight forwarders accepting undeclared dangerous goods from shippers;

e) dangerous goods prohibited in the mail; and

f) passengers carrying prohibited dangerous goods in baggage.

4.2.3 In addition to the data collected by an operator regarding their own operations, the operator may also consider various safety data collection and analysis methods for failure rates, statistics, etc., in order to quantify the probability. Examples of relevant safety data include statistical accident data reports, reports of the discovery of undeclared dangerous goods within cargo, mail or passenger baggage, leaks/spills within the cargo compartment, and cargo fire warnings and confirmed fires involving items in the cargo compartment. Examples of publically-available data sources may include:

a) Annual Safety Reports of individual State Civil Aviation Authorities;

b) ICAO Annual Safety Report
(URL: https://www.icao.int/safety/Pages/Safety-Report.aspx);

c) ICAO's Integrated Safety Trend Analysis and Reporting System (iSTARS)
(URL: https://www.icao.int/safety/istars);

d) ICAO Dangerous Goods Electronic Bulletins
(URL: https://www.icao.int/safety/DangerousGoods/Pages/default.aspx);

e) European Co-ordination Centre for Accident and Incident Reporting Systems (ECCAIRS);

f) U.S. Department Of Transportation Pipeline and Hazardous Materials Safety Administration Form F5800.1 incident report data
(URL: https://www.phmsa.dot.gov/hazmat-program-management-data-and-statistics/data-operations/incident-statistics);

g) FAA Aviation Safety Information Analysis and Sharing system (ASIAS)
(URL: https://www.asias.faa.gov);

h) Airbus' *Statistical Analysis of Commercial Aviation Accidents 1958-2019*; and

i) Boeing's *Statistical Summary of Commercial Jet Airplane Accidents Worldwide Operations 1959-2018*.

4.2.4 Table 4-1 presents a typical safety risk probability classification table, which includes five categories to denote the probability related to an unsafe event or condition, the description of each category, and the assignment of a value to each category. This example uses qualitative terms. Quantitative terms could be defined to provide a more accurate assessment. This will depend on the availability of appropriate safety data and the sophistication of the organization and operation.

Table 4-1. Safety risk probability table

Likelihood	*Meaning*	*Value*
Frequent	Likely to occur many times (has occurred frequently)	5
Occasional	Likely to occur sometimes (has occurred infrequently)	4
Remote	Unlikely to occur, but possible (has occurred rarely)	3

Likelihood	*Meaning*	*Value*
Improbable	Very unlikely to occur (not known to have occurred)	2
Extremely improbable	Almost inconceivable that the event will occur	1

Note.— This is an example only. The level of detail and complexity of tables and matrices should be adapted to the particular needs and complexities of each organization. It should also be noted that organizations might include both qualitative and quantitative criteria.

4.3 SAFETY RISK SEVERITY

4.3.1 Once the probability assessment has been completed, the next step is to assess the severity, taking into account the potential consequences related to the hazard. Safety risk severity is defined as the extent of harm that might reasonably occur as a consequence or outcome of the identified hazard.

4.3.2 The severity assessment should consider all possible consequences related to a hazard, taking into account the worst foreseeable situation. Table 4-2 depicts a typical safety risk severity table. It includes five categories to denote the level of severity, the description of each category, and the assignment of a value to each category. As with the safety risk probability table, this table is an example only.

Table 4-2. Example of a safety risk severity table

Severity	*Meaning*	*Value*
Catastrophic	• Aircraft/equipment destroyed • Multiple deaths	A
Hazardous	• A large reduction in safety margins, physical distress or a workload such that operational personnel cannot be relied upon to perform their tasks accurately or completely • Serious injury • Major equipment damage	B
Major	• A significant reduction in safety margins, a reduction in the ability of operational personnel to cope with adverse operating conditions as a result of an increase in workload or as a result of conditions impairing their efficiency • Serious incident • Injury to persons	C
Minor	• Nuisance • Operating limitations • Use of emergency procedures • Minor incident	D
Negligible	• Few consequences	E

4.3.3 The safety risk index rating is then created by combining the results of the probability and severity scores. In the example provided, it is an alphanumeric designator. The respective severity/probability combinations are presented in the safety risk assessment matrix, shown in Table 4-3. The safety risk assessment matrix is used to determine safety risk tolerability. Consider, for example, a situation where a safety risk probability has been assessed as Occasional (4), and safety risk severity has been assessed as Hazardous (B), resulting in a safety risk index of (4B).

Table 4-3. Example of a safety risk matrix

Safety risk		**Severity**				
Probability		Catastrophic A	Hazardous B	Major C	Minor D	Negligible E
Frequent	**5**	**5A**	**5B**	**5C**	**5D**	**5E**
Occasional	**4**	**4A**	**4B**	**4C**	**4D**	**4E**
Remote	**3**	**3A**	**3B**	**3C**	**3D**	**3E**
Improbable	**2**	**2A**	**2B**	**2C**	**2D**	**2E**
Extremely improbable	**1**	**1A**	**1B**	**1C**	**1D**	**1E**

Note.— In determining the safety risk tolerability, the quality and reliability of the data used for the hazard identification and safety risk probability should be taken into consideration.

4.3.4 The index obtained from the safety risk assessment matrix should then be exported to a safety risk tolerability table that describes, *in a narrative form*, the tolerability criteria for the particular organization. Table 4-4 presents an example of a safety risk tolerability table.

Table 4-4. Example safety risk tolerability

Safety risk index range	**Safety risk description**	**Recommended action**
5A, 5B, 5C, 4A, 4B, 3A	**INTOLERABLE**	Take immediate action to mitigate the risk or stop the activity. Perform priority safety risk mitigation to ensure additional or enhanced preventative controls are in place to bring down the safety risk index to tolerable.
5D, 5E, 4C, 4D, 4E, 3B, 3C, 3D, 2A, 2B, 2C, 1A	**TOLERABLE**	Can be tolerated based on the safety risk mitigation. It may require management decision to accept the risk.
3E, 2D, 2E, 1B, 1C, 1D, 1E	**ACCEPTABLE**	Acceptable as is. No further safety risk mitigation required.

4.3.5 Safety risks are conceptually assessed as acceptable, tolerable or intolerable. Safety risks assessed as acceptable or tolerable can be managed appropriately by the operator. Safety risks assessed as initially falling in the intolerable region are unacceptable under any circumstances. The probability and/or severity of the consequences of the hazards are of such a magnitude, and the damaging potential of the hazard poses such a threat to safety, that mitigation action is required or activities are stopped.

Chapter 5

MITIGATION STRATEGIES

5.1 GENERAL

5.1.1 Safety risk mitigation is often referred to as a safety risk control. Safety risks should be managed to an acceptable level by mitigating the safety risk through the application of appropriate safety risk controls. This should be balanced against the time, cost and difficulty of taking action to reduce or eliminate the safety risk. The level of safety risk can be lowered by reducing the severity of the potential consequences, reducing the likelihood of occurrence or by reducing exposure to that safety risk. It is easier and more common to reduce the likelihood than it is to reduce the severity. Safety risk mitigations are actions that often result in changes to operating procedures, equipment or infrastructure.

5.1.2 Safety risk mitigation strategies fall into three categories: avoidance, reduction and segregation. Further information on these categories can be found in the SMM. Mitigations should be based on technical expertise (e.g. data, evidence) demonstrating the operator's knowledge and experience in the conduct of cargo compartment operations; and an assessment of relevant hazards, their probability and the severity of the consequences that may adversely impact the safety of the operation of an aeroplane when items are transported in cargo compartments.

5.2 MITIGATION STRATEGIES TO ADDRESS THE LIKELIHOOD OF OCCURRENCE

Dangerous goods

5.2.1 The Technical Instructions include some general principles which should be considered by an operator in the conduct of a safety risk assessment for the transport of dangerous goods. These principles are intended to facilitate transport while giving a level of safety such that dangerous goods can be carried without placing an aeroplane or its occupants at risk, providing all the requirements are fulfilled. However, it is important to note that the implementation of the Technical Instructions does not provide guaranteed mitigation for any scenario. They *try* to ensure that, should an incident occur, it cannot lead to an accident. The Technical Instructions identify the conditions in which the transport of dangerous goods as cargo can be permitted, for example, if they are limited to cargo aeroplanes only, or if they are also permitted as cargo on passenger aeroplanes. Prior to carrying out the risk assessment, the operator should perform an analysis of the types and quantities of the dangerous goods being transported. This should include an analysis of cargo originating from internal sources, i.e. aeroplane spare parts and other operator materials.

Fire mitigation

5.2.2 Many mitigation strategies are focused on preventing the occurrence of fire. Removing any one of the three elements required for fire will prevent it from happening, or stop it once initiated. The magnitude of the fire is dependent on the amount of available fuel, with large quantities of highly flammable fuel presenting a greater hazard than similar quantities of fuel that have low flammability. Properly maintained aeroplane systems reduce the risk of external ignition sources. Knowing which items in a cargo compartment have the potential to act as an ignition source provides the opportunity to isolate them from fuel sources. Oxygen deprivation is part of some fire suppression systems, and in some cases this is accomplished by aircraft depressurization (see 5.3.8). Some common mitigation strategies to prevent fire from starting in the first place are presented in the subsequent paragraphs.

Capabilities of the operator

5.2.3 Annex 6, Part I, Chapter 15 requires that the “capabilities of the operator” be considered during specific safety risk assessment activities required for the transport of items in a cargo compartment. Practically speaking, this means that operators must assess whether or not they possess the requisite knowledge, skills and resources to implement and oversee the systems and processes required to support its operations. The following are criteria typically met by capable operators. They should be considered in evaluating an operator’s capabilities within the context of a risk assessment by the operator and an approval process by State authorities.

Commitment and responsibility of the operator

5.2.4 An operator must be able to demonstrate that it exerts sufficient organizational control over internal systems and processes, and the use of resources. This is important, as compliance with regulation relies heavily on process management to control operational outcomes based on performance. As such, the ability of an operator to control the outcome of key organizational and operational processes becomes integral not only to the production of services, but also to the effective management of the safety risks associated with those services. To achieve these aims, management must:

a) clearly identify applicable procedures, policies and tasking;

b) establish procedures to perform activities and processes;

c) hire, train and supervise employees;

d) allocate appropriate resources; and

e) ensure staff adhere to its standard operating procedures (SOPs).

5.2.5 A focus on process management and control makes it possible for different systems to provide acceptable outcomes, as any number of potential variations in the process could provide the desired results. This attribute of performance-based systems also allows operators to consider their specific operating environment and factor in their unique requirements as long as operational and safety performance, alerts and target levels are respected. It also explains how significant differences in the process can yield a similar and acceptable result.

5.2.6 The operator should define and document the many systems, processes, policies and procedures used in support of flight operations involving the transport of items in cargo compartments. Such documentation should also clearly identify each operational activity to which an operational variation may be applied as well as address the core criteria for the production of services including related performance-based subsystems or processes. Additionally, operator documentation should address the reporting, measurement and analysis of essential data to support each system or process. Ultimately, the operator is responsible for all items that are transported on their aeroplane, and this responsibility cannot be transferred. Applicable systems or processes include but are not limited to:

a) acceptance of items for transport;

b) loading, stowage, segregation and securing of cargo;

c) in-flight emergency procedures;

d) appointment of contractors such as ground service providers; and

e) occurrence reporting and analysis.

Safety of the cargo transport supply chain

5.2.7 It may be difficult for an operator to identify all shippers and freight forwarders given the often multiple layers in the supply chain. Furthermore, such entities are typically customers of the airline rather than contracted service providers. However, an operator should still evaluate and quantify the risk associated with their cargo transport supply chain. Based on safety risks identified, the operator may consider working with one or more of the entities in the supply chain to determine and define an appropriate safety risk control strategy. The SMM refers to this process as interface management. This may involve formal agreements that establish safety standards between the operator and the specific interfacing entity. Examples may include:

a) restrictions on the nature of cargo that a shipper is permitted to offer for carriage by air;

b) obligations placed on the freight forwarder to apply safety conditions to entities earlier in the supply chain;

c) processes aimed at detecting hidden (undeclared) dangerous goods;

d) contracts obliging freight forwarders to be trained commensurate with their cargo transport responsibilities; and

e) the entity monitoring their own safety performance and the sharing of safety data between entities.

5.2.8 An operator should have procedures in place for monitoring the effectiveness of its interface management controls to ensure that nothing contained in cargo will endanger an aircraft. This would include analysis of its dangerous goods safety data collection and processing system. Controls for ensuring that undeclared dangerous goods are not offered for air transport should be present throughout the supply chain including (when involved) the shipper, freight forwarder, cargo agent and air operator. Operators should consider whether the arrangements for receiving cargo adequately address the risk of undeclared dangerous goods. Further guidance on interface management can be found in the SMM.

5.2.9 It is the responsibility of the State to investigate dangerous goods accidents and dangerous goods incidents involving undeclared dangerous goods reported by operators, ground handling agents, freight forwarders or other entities in accordance with Annex 18. States are also responsible for taking appropriate action against shippers and freight forwarders that offer dangerous goods not in compliance with the provisions of the Technical Instructions.

Acceptance of items by the operator

5.2.10 In addition to considering the transport supply chain, operators should give due consideration to the process of accepting the items offered for transport. This represents a stage where hazards may be introduced, be it from the cargo supply chain, passenger baggage, or mail. Policy and procedures should seek to mitigate the risks associated with the introduction of an identified hazard at this stage.

5.2.11 Standards for operators with and without operational approval to transport dangerous goods as cargo are presented in Annex 6, Part 1, Chapter 14, and guidance on acceptance procedures are provided in the Technical Instructions. Operators' cargo acceptance staff must be adequately trained to assist in identifying and detecting dangerous goods presented as general cargo. They should seek confirmation from shippers about the contents of any item of general cargo if there are suspicions that it may contain undeclared dangerous goods. An operator must report any occasion when undeclared or misdeclared dangerous goods are discovered in cargo. Such a report must be made to the appropriate authorities of the State of the Operator and the State in which it occurred.

5.2.12 Dangerous goods must be offered to the operator separately from other cargo, except as defined in the Technical Instructions. Dangerous goods that have been properly marked, labelled and declared to the operator are commonly processed separately from general cargo. Dangerous goods bearing UN numbers, proper shipping names or hazard labels discovered within general cargo should be queried, especially when procedures for accepting, storing and handling dangerous goods separately from other cargo are in place. It may be that the dangerous goods were not identified as such by the shipper or this was overlooked when the goods were accepted for transport.

5.2.13 With respect to the acceptance of passenger and crew baggage, normally contents will be limited to clothing and personal toiletry items that will not exhibit any hazard in transport. However, passengers and crew are permitted to carry small quantities of certain dangerous goods that are widely used in normal life. Examples of these are perfumes and colognes which are flammable liquids, portable electronic devices powered by lithium batteries, and sporting ammunition. A proactive approach should be taken with the aim of preventing undeclared dangerous goods from being loaded on an aircraft. Passengers should be well informed to ensure they are prevented from taking dangerous goods on board that are not permitted to be carried by passengers or crew. Passenger reservations, sales, and check-in staff can play a role in this by providing passengers with general descriptions of items that may contain dangerous goods and clear guidelines on what is and is not permitted in advance of their arrival to travel. Any organization or enterprise accepting baggage consigned as cargo should seek confirmation from the passenger or person acting on behalf of the passenger, that the baggage does not contain dangerous goods that are not permitted, and seek further confirmation about the contents of any item if there are suspicions that it may contain dangerous goods that are not permitted.

5.2.14 Operators should also consider the potential for an identified hazard to originate from an item contained in mail, and evaluate whether any proactive mitigating strategies are required. International air mail offered for transport by a designated postal operator (DPO) is subject to the provisions set out in the Universal Postal Union (UPU) Convention. Apart from a few very limited exceptions, the UPU prohibits dangerous goods in international mail. Those dangerous goods permitted in mail for air carriage are set out in the Technical Instructions. The Technical Instructions also specify that the procedures of each DPO for controlling the introduction of dangerous goods in mail into air transport are subject to review and approval by the Civil Aviation Authority (CAA) of the State where the mail is accepted. Additionally, the DPO must have a specific approval from their CAA to introduce the acceptance of lithium batteries contained in equipment such as phones, laptops and tablets into mail for air carriage.

5.2.15 Consideration should be given to the role that security screening may have in safety risk mitigation. The primary objective of existing security screening of cargo, baggage, and mail is the detection of any prohibited article or substance which may be used to commit an act of unlawful interference from being carried out on board an aircraft. However, the aviation security processes involved may provide benefits to aviation safety, if applied to the screening of cargo and other items to be transported in the cargo compartment. Security screening technology, procedures and policies will vary from one State to another. However, many dangerous goods are readily identifiable using existing aviation X-ray equipment. For example, X-ray images of lithium batteries will appear in a different colour/shade to batteries of other chemistries which are typically not required to be declared and labelled as dangerous goods, as can be seen in Figure 5-1. Items such as aerosols, ammunition, gas cylinders, cigarette lighters and wet acid batteries can also be readily identified from visual screening processes including X-ray. Technology exists for the automatic detection of some dangerous goods, such as lithium batteries. Such equipment is being introduced within the express courier and mail sectors, and there is the potential for the future development of automated detection systems for larger cargo items and retrofitting dangerous goods detection automation to legacy visual screening systems. Operators can take such screening equipment into account in their risk assessments if they know it is in use.

5.2.16 Operators may consider implementing additional screening for safety purposes, or coordinating closely with existing security screening processes to simultaneously evaluate for potential safety risks. Security personnel should be aware of what to do if they discover prohibited items such as dangerous goods in passenger baggage, including preventing their onward carriage and informing the air operator (or handling agent) to enable onwards reporting to aviation authorities. The Technical Instructions require personnel engaged in the security screening of passengers and crew and their baggage and/or cargo, mail or stores to undertake initial and recurrent dangerous goods training and testing.

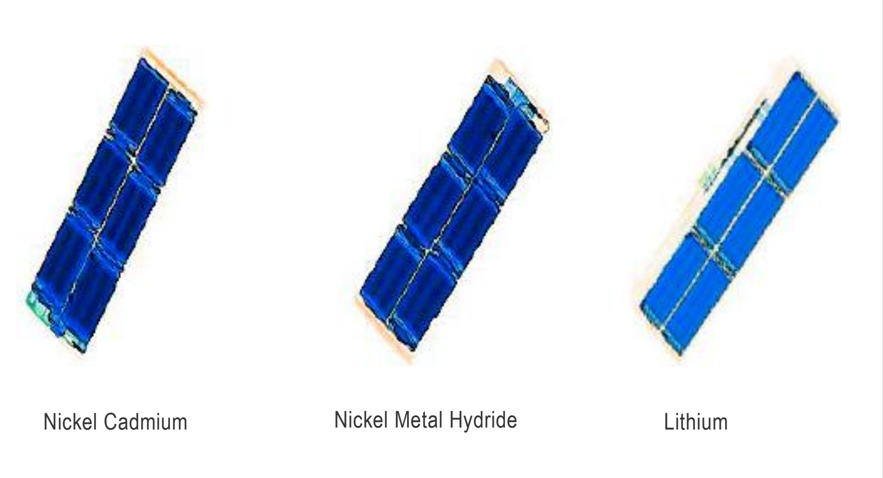

Figure 5-1. X-ray screenings of different battery types

Qualified personnel

5.2.17 The operator should ensure that key positions are staffed with a sufficient number of appropriately qualified personnel empowered with the responsibility and authority to support the operational activity and to foster continuous improvement. Operators are required to implement training programmes that ensure personnel are competent, current, and qualified to perform their functions. Such training should apply to all personnel with responsibilities in the acceptance and handling of cargo, baggage and mail, and emphasize the specific requirements associated with each operational activity. Without appropriately qualified personnel, an operator is at risk of insufficiently implementing the mitigating strategies for identified hazards, or potentially even introducing additional new hazards.

Packing and packaging

5.2.18 When determining the risk associated with transporting items in cargo compartments of an aeroplane, it is essential that an operator understands the contribution the packing and packaging of the items offered for transport makes to risk mitigation. This must of course be considered in combination with the specific properties of the items themselves. The packing, selection of packaging, and the use of overpacks are all the responsibility of the shipper. The operator must therefore be confident that shippers take the necessary steps in packaging their items so that they are safe and secure during normal conditions of transport.

5.2.19 There are no existing regulations for packing and packaging of items intended for cargo that are not classified as dangerous goods. A shipper who offers dangerous goods for transport must comply with the packing and packaging instructions of the Technical Instructions. The Technical Instructions specify the quantity limits per package and the packing instruction to be used for dangerous goods. However, as stated previously, implementation of these Technical Instructions may not provide guaranteed mitigation for every scenario.

5.2.20 It is the operator’s responsibility to ensure that a package or overpack containing dangerous goods is not loaded onto an aircraft or into a unit load device unless it has been inspected immediately prior to loading and found free from evidence of leakage or damage. Operators must also ensure that packages are not damaged during the loading process. Particular attention must be paid to the handling of packages during their preparation for transport and the method required to load the aeroplane, so that accidental damage is not caused through dragging or mishandling of the packages.

Quantity and distribution of items

5.2.21 The quantity and distribution of items transported in the cargo compartment of the aeroplane depends mainly on the aeroplane type and on the available capacity and space on board. However, an operator should give due consideration to the potential mitigations against the identified hazard that could be achieved by restricting quantity or defining the distribution of items on the aeroplane.

5.2.22 In general, the quantity of an item does not normally affect the probability of a fire involving that item from starting. In most cases, the cargo, baggage or mail that is to be transported is likely to be the "fuel" element of the fire triangle, so an ignition source is still required to initiate the fire, regardless of the amount of fuel present (the mitigation strategies to reduce the severity of the fire, should it occur, are presented in section 5.3). However, special consideration should be given to some items based on their specific properties, for example lithium batteries. As previously stated in paragraph 3.2.5, lithium batteries have the potential to self-ignite. Therefore, the quantity of these items on board an aeroplane directly affects the level of risk, as the possibility for a fire to ignite through thermal runaway of any single battery core increases as the quantity of batteries increases. Given the potential for a significant fire event that may be severe enough to overwhelm the aeroplane and its systems, an operator may therefore wish to consider the quantity of individual cells to be transported on a single aircraft when determining the acceptable level of risk.

5.3 MITIGATION STRATEGIES TO ADDRESS THE SEVERITY OF CONSEQUENCES

5.3.1 This section provides guidance to operators in identifying mitigations that reduce the severity and consequences of a fire should one occur, so that any fire can be extinguished or suppressed until a safe landing can be made. Many barriers associated with the containment of fire are inherent within the design of the aeroplane and its systems. An example would be aircraft fire suppression systems, which are designed in accordance with the provisions discussed in Chapter 6 of this manual. However, a key intent of the safety risk assessment required of operators by Annex 6, Part I, Chapter 15, is to identify fire hazards that may not be sufficiently protected against by the aeroplane certification standards. Therefore, the risk assessment should identify the mechanisms by which fires can be propagated with a special emphasis on those items and combination of items that can overwhelm the aircraft fire suppression systems. The operator must determine how long the aircraft fire suppression system is effective against possible fire loads, and ensure that this duration is greater than divert times for operator route structure. If the aircraft fire suppression systems cannot protect the aircraft for the divert times of intended flights, additional barriers to fire propagation and severity must be considered, or the probability of an incident occurring should be fully evaluated when considering the transport of the specific items. These additional mitigations may be at the package, ULD, or aircraft level, and may include augmented fire suppression systems, additional equipment, or other methods to reduce the likelihood that a fire will overwhelm the aircraft fire suppression system. The following paragraphs provide key elements that should be considered.

Fire protection elements of the aeroplane design

5.3.2 Annex 6, Part I, Chapter 15 requires that operators establish policy and procedures to ensure to a reasonable certainty that in the event of a fire, it can be detected and sufficiently suppressed or contained until the aeroplane makes a safe landing. Mitigation starts with a clear understanding of the aeroplane capability with respect to the control of a fire scenario. It is essential that the operator has a complete understanding of the capabilities and limitations of the cargo compartment systems, and of the aeroplane systems as a whole, that would be required in mitigating the severity of the consequences should a fire occur. Cargo compartments are classified in most national airworthiness requirements based on a number of factors. Therefore, an essential step in the process is to identify the classification of the cargo compartment in which the items will be transported. It is the responsibility of the TC/STC holder to provide the necessary information on the classification and capabilities of the relevant aeroplane systems to the operators, and the recommended content and format of this information is discussed in detail in Chapter 6 of this manual.

5.3.3 In order to account for the capability and limitations of a cargo compartment and its systems in a risk assessment, it is important for the operator to understand the testing and criteria it was subjected to for certification. Clear requirements are defined for the design of cargo compartments with provisions for smoke or fire detection systems and suppression systems. Manufacturers are required to show compliance with individual performance standards, but a full proof of performance demonstration test is not required. Current standards for the extinguishing agent and the cargo hold liners are based on fires that are "likely to occur". The term "any fire likely to occur" is, in the context of existing certification programs, a Class A fire involving combustible materials such as wood, cloth, paper, rubber and plastics. It is therefore possible that fires involving certain dangerous goods, for example lithium batteries, have not been considered in the certification and demonstration process of the cargo compartment. It is also important to note that some cargo compartments are not accessible to crew during flight, and that the design principle is to suppress and contain a fire until the aeroplane has made a safe landing; not to extinguish the fire altogether. This capability is obviously directly dependent on the magnitude and severity of the fire, which is in turn dependent on the type of combustible materials involved.

5.3.4 Annex 6, Part I provides Standards on the time capability of cargo compartment fire suppression systems. It makes the recommendation that "all flights should be planned so that the diversion time to an aerodrome where a safe landing could be made does not exceed the cargo compartment fire suppression time capability of the aeroplane." These capabilities will be identified in the relevant aeroplane documentation when they are to be considered for the operation. Annex 8 — *Airworthiness of Aircraft* provides certification Standards for aircraft, including their fire suppression systems, stating that "cargo compartment fire suppression systems, including their extinguishing agents, shall be designed so as to take into account a sudden and extensive fire such as could be caused by an explosive or incendiary device or dangerous goods." However, the extent to which that is achieved by aeroplane manufacturers is not fully understood by many operators. A driving factor in the Annex 6, Part I, Chapter 15 requirement for operators to conduct a safety risk assessment is to address the gap in safety identified, where the operator does not fully consider the capabilities of cargo compartment fire suppression systems when transporting certain items in the cargo compartments of their aeroplanes. The goal is to ensure that the severity of the consequences from fires involving items transported in the cargo compartments are mitigated, at least to the same extent as those fires considered in the airworthiness approval of the aircraft.

5.3.5 An important factor to consider is any delay in the detection of a fire. The accident investigation reports for both the UPS Flight 6 accident in 2010 and the Asiana Flight 991 accident in 2011 cited delayed detection as contributing to the un-survivability of fires in those fatal accidents. Certification standards for some fire detection systems are based on detecting fires in empty cargo compartments with no barriers to smoke detection. Packaging, pallet wrapping material, ULDs, FCCs, or other cargo can all delay fire detection. Since some fire-resistant ULDs or packaging might try to suppress a fire by oxygen starvation, they may also prevent smoke from reaching a smoke detector, delaying notification to the crew. An example of a measure to mitigate this is an STC cargo fire detection/suppression system installed by an operator in some of its Class E cargo compartments with thermal sensors to detect a fire starting inside a ULD. After detection, a nozzle would pierce the top of the ULD and inject an argon-propelled foam to completely fill the ULD in an attempt to suppress the fire. The system is effective on Class A fires and has demonstrated some success on lithium battery fires. More information on ULDs is provided in subsequent paragraphs.

5.3.6 Operators should also be aware that cargo compartments are subjected to significant wear and tear in service, and regular maintenance in accordance with approved maintenance procedures is necessary to ensure the capabilities of the compartment are maintained. For example, any damage such as holes, tears or detachment to compartment liners may reduce their effectiveness, permitting air to enter the compartment and fire suppression agent to escape, reducing the capability to handle a fire event. Examples of such damage that can occur during typical aeroplane cargo operations is shown in Figure 5-2. Repair should be performed whenever damage is discovered, and if a repair cannot be made then the operator should consider the impact on risk if intending to transport specific items with identified hazards in that cargo compartment.

Figure 5-2. Damage to cargo compartment liners that can typically occur in service

Operational considerations

5.3.7 The route structure of an operator should be considered in the risk assessment. The distance to a suitable landing aerodrome required in the case of an emergency during any particular flight will have an impact on the overall risk exposure. In fact, in the case of an emergency, the length of time that a fire may need to be suppressed until a safe landing can be performed is directly linked to the diversion time. The longer the delay in landing, the greater the potential for the fire to develop and overwhelm the cargo fire suppression system. For example, an operator that offers solely short-haul regional flights over land, where all routes have quick and easy access to alternate aerodromes, may reasonably conclude that the overall risk is lower when compared to that of a long-haul operator where the majority of flights may be over oceanic or remote areas. The mitigations considered in the risk assessment should include the implications of the procedures specific to the class or classes of cargo compartments associated with the type of operation.

5.3.8 In the event of a cargo compartment fire, the standard emergency response procedures should be followed. In the event of a fire in a Class E cargo compartment when at cruise altitude, typical procedures are to depressurize the aeroplane to reduce the oxygen concentration in the compartment. This will likely require the crew to use oxygen masks until such time as an emergency descent into a suitable airport can be initiated. It should be noted that the descent and landing phase will increase the available oxygen in the cargo compartment due to higher partial pressures at lower altitudes, making a smouldering fire capable of reigniting into flaming combustion. Consideration should therefore be given to the reduced capabilities of both the aeroplane cargo fire suppression systems and the flight crew (e.g. comfort, reduced visibility) in this depressurized scenario.

5.3.9 Finally, an operator should consider whether any operational mitigation identified to reduce the severity of a fire scenario is impacted by whether or not people other than crew will occupy a cargo compartment. The carriage of "supernumeraries" is not uncommon on cargo specific aeroplanes, although it does require special authorisation by the State of the operator. These occupants are generally addressed via formal regulatory action and not treated as regular passengers. It is possible that these individuals are not sufficiently trained for any sort of emergency, which may affect the other mitigation strategies identified. In addition, their presence on board the aeroplane increases the potential of the identified consequence of loss of life.

Containment characteristics of unit load devices (ULDs)

5.3.10 A ULD is a device used for grouping, transferring and restraining cargo, baggage or mail for transport, allowing a large quantity of items to be grouped into a single unit, resulting in fewer units to load. It may consist of a pallet and net, or it may be a container. It is important that operators understand the role ULDs can play in both mitigating risk, and in certain circumstances, potentially contributing to the risk, depending on the combination of factors applicable for the specific operations and the items to be transported. This is expanded upon in the following paragraphs.

5.3.11 ULDs may be considered as an additional risk mitigation measure in the event of a fire, as a supplement to the aeroplane fire detection and suppression systems. For example, should a fire occur outside a container, the container itself provides an extra layer of protection to the contents and limits the severity of the fire. Consideration must also be given to the scenario of fire originating from within a container, and in this respect, closed container ULDs may have the beneficial property of suppressing a fire through oxygen starvation. Some ULDs may be equipped with built-in fire detection and suppression systems, specifically designed to target a fire that may occur inside the ULD. This provides several advantages over reliance on the protection of the cargo compartment fire protection systems alone. Firstly, detection of the fire event is nearer to the source of the fire, enabling earlier detection and introducing the suppressing agent to the fire at its more incipient stage. Secondly, attacking the fire at its source and in a contained volume increases the ability to prevent the fire from spreading to other fuel sources. However, these ULDs may not be readily available to operators. If they are used, operators must ensure they understand how they interact with existing aircraft systems.

5.3.12 Standards for fire-resistant containers (FRCs) are in development by SAE International and the International Standard Organization (ISO). The intent is to define a standard for FRCs that are able to resist and contain a fire well above the capability of a typical container. Some FRCs have been developed and are available on the market now; however, there is no recognized performance standard for evaluation. The fire protection afforded by containers meeting the standards being evaluated is expected to provide an increase in safety when compared to existing container designs, and are similar to an FCC in terms of fire-resistant criteria. This proposed standard specifies the minimum design and performance criteria and testing methods of FRCs for carriage on the aeroplane main deck, to be used either (a) in those cargo compartments of aeroplanes where they constitute a means of complying with applicable airworthiness regulations, or (b) on a voluntary basis, when deemed appropriate by operators, to improve fire protection in aeroplane cargo compartments where airworthiness regulations do not currently mandate their use.

5.3.13 Operators should also consider that under certain circumstances, ULDs may have a detrimental effect. During limited laboratory testing, it has been demonstrated that a closed ULD may restrict the escape of smoke outside of the ULD, delaying detection by the compartment fire detection system and subsequent alerting of the flight crew to the presence of a fire. It may also restrict the penetration of fire suppressant agent into the ULD to fight a fire. An operator should consider whether this delayed alerting has any impact on the management of the situation. Furthermore, testing conducted at the FAA William J. Hughes Technical Center demonstrated consequences of an event involving lithium batteries in a closed ULD that should to be considered. It demonstrated that the hydrogen and hydrocarbon gases produced following a thermal runaway event can accumulate in the restricted spaces in the ULD allowing an explosive mixture to be created. A subsequent ignition of these flammable vapours can create a pressure pulse large enough to dislodge the protective compartment fire liners or decompression panels in the aeroplane. These displaced liners or panels would then allow the fire suppressing agent to escape, reducing or eliminating the fire suppression capabilities of the cargo compartment system.

5.3.14 In some cases, a fire containment cover (FCC) can be placed over the items on a pallet and a net fitted over the FCC. An FCC acts by starving the fire of oxygen and resisting the fire by the material in which it is constructed. Technical Standard Order TSO-C203 has been developed and requires that the FCC be capable of containing a fire involving shredded paper in cardboard boxes (ordinary combustible material, Class A fire) for 6 hours. The standard also requires that the FCC material pass the 5-minute oil burner flammability test required for cargo lining material. Materials that can pass these requirements offer significant improvement in the ability to contain fires.

5.3.15 Testing has also been conducted on lithium battery fire loads with ULDs that utilize FCCs and FRCs. The results have been varied and very dependent on the specific scenario or configuration tested. Batteries in equipment fire loads have been successfully contained utilizing FCCs and FRCs in the limited tests conducted. Bulk shipments of lithium batteries have been contained in some tests and not in others. Some of the variables that have affected results have been the cell or battery type, quantity, location and state of charge. The demonstration evidence may not necessarily be provided by the original manufacturer of the equipment but may be achieved by the operators themselves or a third party. Operators should review the capabilities of any equipment that they choose to use over and above the aeroplane and its systems, to consider the demonstrated risk mitigation capability of that equipment, and how it interacts with existing aeroplane systems and procedures. General factors to take into consideration are the panel construction flammability, the ability for smoke to exit, the ability for halon to penetrate inside, and the amount of free space inside the container after it is loaded with goods. As technology advances, industry may well develop and provide advanced feature ULDs for operators to consider as additional mitigation against the severity of fire and other specific hazards.

5.3.16 As a result, when evaluating risk mitigation strategies, an operator should carefully consider the specific type and properties of the ULD to be used for specific items to be transported in the cargo compartment. This also applies to the use of FRCs and FCCs where appropriate.

Quantity and distribution of items

5.3.17 Operators should consider whether the quantity of some items with specific properties, for example certain dangerous goods, may influence the severity of the identified consequence of the hazard. There is generally no restriction on the number of packages of dangerous goods which can be loaded on an aeroplane, on the basis that the Technical Instructions attempt to mitigate any hazard at the package level. However, special consideration should be given to some items based on their specific properties, for example lithium batteries. As discussed previously in paragraph 3.2.5, lithium batteries have the potential to self-ignite through thermal runaway, which may cause adjacent cells to also ignite. This potential for propagation means that the greater the number of batteries involved in the fire, the greater the severity of that fire. Should the number of batteries involved be too large, it could lead to a situation where the severity of fire is unmanageable and the cargo compartment fire suppression systems are overwhelmed, resulting in the catastrophic loss of the aeroplane and inevitable loss of life.

5.3.18 An operator may also wish to make enquiries with the aeroplane design approval holder to establish whether there were any recommendations for the placement of hazardous items (e.g. dangerous goods) within the cargo compartments equipped on that aeroplane. The operators could then consider how the distribution of certain items within the cargo compartment could affect the severity of the consequences of the hazard with respect to an impact on the continued airworthiness of the airframe or aeroplane systems. For example, were a fire to occur in close proximity to certain elements of the aircraft and aircraft systems such as flight control cables or wire paths and avionics bays, it may result in the fire having a much greater effect on the airworthiness of the aeroplane in a much shorter timescale than if the items involved had been placed away from such critical aeroplane systems.

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Appendix 1 to Chapter 5

CONTINUED EXAMPLE BOWTIE HAZARD ANALYSIS FOR LITHIUM BATTERIES

1. CONTROLS AND MITIGATIONS

This appendix builds on the foundation bowtie example developed in Appendix 1 to Chapter 3, where the threats and consequences associated with the hazard had been identified. The bowtie diagram is presented in Figure A5-1.

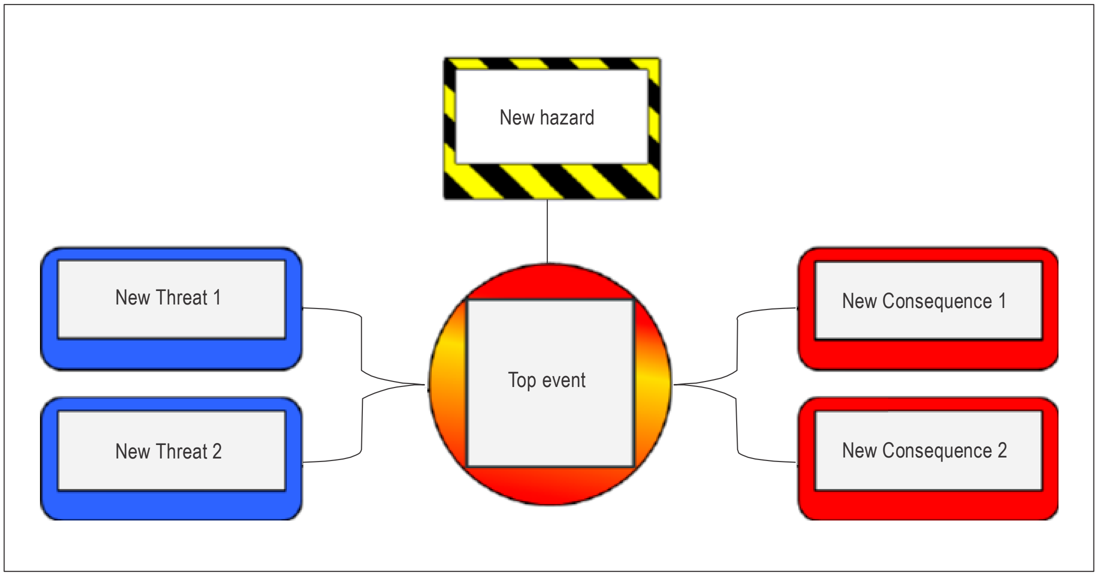

Figure A5-1. Bowtie diagram for hazard, threats and consequences

The next step is to identify the controls, or mitigations. It is possible to identify mitigations that eliminate the threats associated with the hazard entirely and prevent the "top event" from occurring or at least reduce the probability of occurrence. It is also possible to identify controls that mitigate the severity or magnitude of the consequences, should the "top event" still occur. These are presented on the left and right sides of the bowtie diagram respectively, as shown in Figure A5-2, in the path of the threat or consequence to which they relate. In each case, a reference number is provided to the relevant paragraph in Chapter 5 that presents more details on the considerations specific to that mitigation.

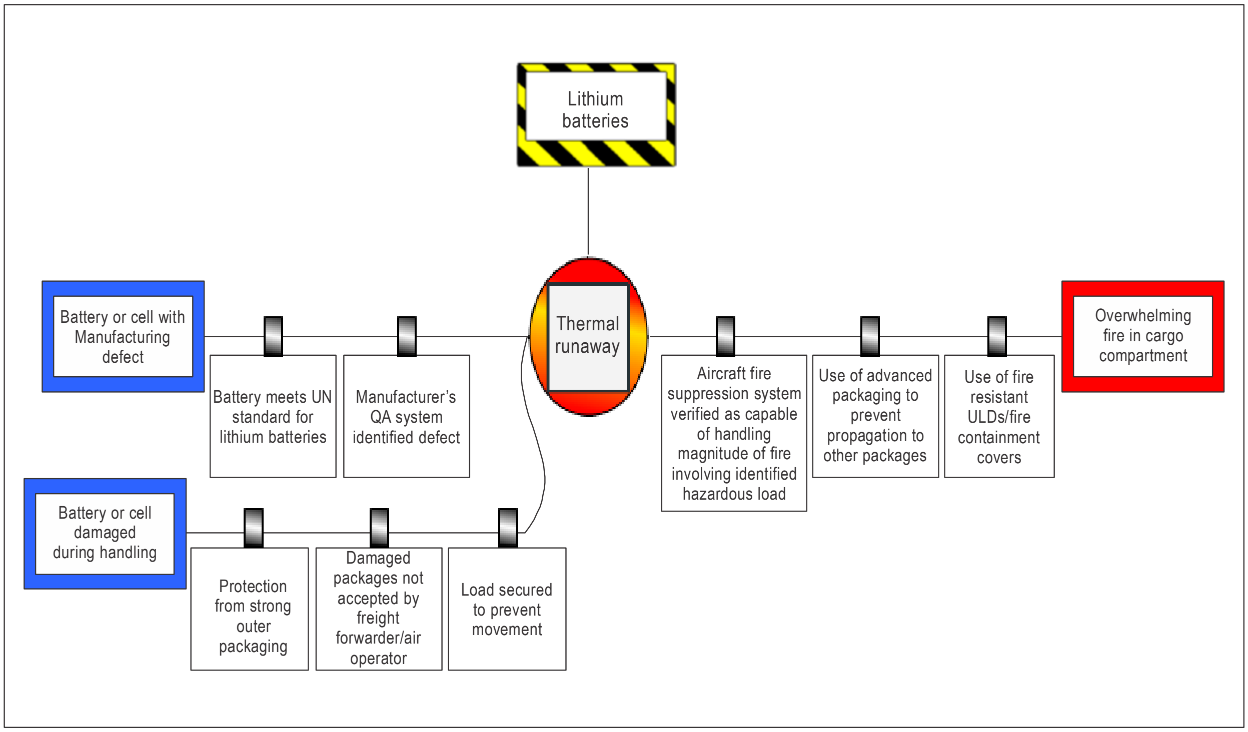

Figure A5-2. Example bowtie diagram with mitigations identified

It should be noted that Figure A5-2 is for example only, and does not constitute a complete picture of the threats, consequences and potential mitigations associated with the hazard of lithium batteries.

A more detailed example of bowtie analysis applied to the transport of lithium batteries is presented on the ICAO Safety Management Implementation website and can be viewed at the following link: https://www.unitingaviation.com/publications/safetymanagementimplementation/content/#

Chapter 6

DEFINING THE CAPABILITIES OF THE AEROPLANE AND ITS SYSTEMS

6.1 GENERAL

6.1.1 This chapter provides guidance to design approval holders for defining and operators for understanding the capabilities of the aeroplane and its systems. Operators can take these capabilities into consideration when conducting their safety risk assessments on the transport of items in the cargo compartment. As stated in Annex 6, Part I, Chapter 15, it is the responsibility of the design approval holders to provide a core set of technical information to aeroplane operators regarding the technical capabilities of the elements of the aeroplane related to fire detection, suppression, and extinguishing as required by the applicable certification requirements. An operator can only conduct a safety risk assessment on the transport of any items in a cargo compartment if they fully understand the performance capability of the cargo compartment and overall aeroplane systems to handle any identified hazard associated with the contents. As identified in Chapter 3 of this manual, fire represents the primary hazard to the safe operation of an aeroplane and is therefore the principal design element to be considered when evaluating the risk.

6.1.2 The elements of the cargo compartment fire suppression system, such as smoke detection, cargo liners, fire suppression agent and ventilation shut-off, the capabilities of which are considered during certification of the aeroplane, can be degraded once in service due to various factors. For example, the air-tightness of the cargo compartment may be degraded if some liners are dislodged or damaged, or if the cargo door seal is worn out or damaged. This could reduce the efficacy of the fire suppression agent (if installed) and reduce the time capability of the fire suppression system. In addition, the capabilities of the cargo fire suppression system may be overwhelmed in situations where the intensity of the fire exceeds that which was demonstrated during certification. For example, the capabilities of the cargo lining system to resist burn through and contain the effects of a fire, in part by reducing the rate of loss of cargo fire suppression agent for a Class C cargo compartment, can be degraded in case of increased fire intensity. It means that if the assumptions retained for the certification of the cargo compartment fire suppression system (e.g. class of fire, condition of the liners and door seals) are challenged, then there are no guarantees that the aeroplane and systems can handle the fire event. Accordingly, identifying potential causes and factors of system degradations should be part of the safety risk assessment.

6.2 CARGO COMPARTMENT CLASSIFICATION

6.2.1 Cargo compartment fire protection in Annex 8 is broadly characterized based on whether crew members have access to the compartment. Annex 8 states that fire detection, suppression or oxygen starvation must be provided as applicable. Most national airworthiness requirements are more detailed and classify cargo compartments based on a variety of factors, including whether the compartment is accessible by crew during flight (and to what degree it is), and the fire detection, suppression and ventilation features that the cargo compartment may have. Information provided by the design approval holder to support a risk assessment should therefore contain one or more of the following descriptions, depending on the class of cargo compartments installed, along with an indication of where the cargo compartments are located on the aeroplane. The following sections provide a list of typical cargo classifications that may be used for the certification of the cargo fire suppression systems, together with a summary of the demonstrated certification standards. As explained in section 6.4, a reference to this classification in the aeroplane flight manual or other documentation supporting the operation of the aeroplane may be provided to operators, supported by further explanatory information, in order to support the conduct of the safety risk assessment.

Note 1.— The class of cargo compartment is not related in any way to the class of fire, as defined in section 3.3. There is no correlation between the cargo compartment classification and the class of fire that the compartment may be capable of containing and/or suppressing.

Note 2.— Emergency Response Guidance for Aircraft Incidents Involving Dangerous Goods *(Doc 9481) contains definitions that differ slightly from the ones given in this manual. This is due to recent updates in national codes, affecting the Class B compartment and adding the Class F compartment.*

6.2.2 A Class A compartment is one in which:

a) the presence of a fire would be easily discovered by a crew member while at his station; and

b) each part of the compartment is easily accessible in flight.

Note.— Class A cargo compartments were originally intended as storage for crew baggage, rather than commercial cargo or passenger baggage. They are generally more akin to stowage compartments than other classes of cargo compartments. Therefore, it is highly unlikely that class A cargo compartments will be part of a formal risk assessment.

6.2.3 A Class B compartment is one in which:

a) there is sufficient access in flight to enable a crew member, standing at any one access point and without stepping into the compartment, to extinguish a fire occurring in any part of the compartment using a hand fire extinguisher;

b) when the access provisions are being used, no hazardous quantities of smoke, flames, or extinguishing agent, will enter any compartment occupied by the crew or passengers; and

c) there is a separate approved smoke detector or fire detector system to give warning at a flight crew member station.

An example is the ATR-72 where the forward and aft cargo compartments are classified as Class B.

6.2.4 A Class C compartment is one not meeting the requirements for either a Class A or B, but in which:

a) there is a separate approved smoke detector or fire detector system to give warning at a flight crew member station;

b) there is an approved built-in fire extinguishing or suppression system controllable from the cockpit;

c) there are means to exclude hazardous quantities of smoke, flames, or extinguishing agent, from any compartment occupied by the crew or passengers; and

d) there are means to control ventilation and drafts within the compartment so that the extinguishing agent used can control any fire that may start within the compartment.

The underfloor cargo compartments on large passenger aeroplanes currently in production, e.g. A321, A330, B737-800 and B777 are classified as Class C.

6.2.5 A Class D compartment is one in which:

a) a fire occurring in it will be completely confined without endangering the safety of the aeroplane or the occupants;

b) there are means to exclude hazardous quantities of smoke, flames, or other noxious gases, from any compartment occupied by the crew or passengers;

c) ventilation and drafts are controlled within each compartment so that any fire likely to occur in the compartment will not progress beyond safe limits; and

d) compartment volume cannot exceed 28.3 m^3 (1 000 ft^3).

The underfloor cargo compartments on older-model, narrow-body passenger aeroplanes, e.g. early-built A320, B737, Fokker F28 were classified as Class D. Many of these aircraft have now been upgraded to be Class C, although in some States there are still aeroplanes operating that only have Class D underfloor cargo compartments.

Note.— Certain Class D compartments were provided with ventilation, in which case a fire detector has also been required. In addition, Class D compartments were historically permitted to be larger, if the volume and the ventilation rate per hour sum to less than 2 000 ft^3.

6.2.6 A Class E compartment is one on aeroplanes used *only* for the carriage of cargo, and in which:

a) there is a separate approved smoke or fire detector system to give warning at the pilot or flight engineer station;

b) there are means to shut off the ventilating airflow to, or within, the compartment, and the controls for these means are accessible to the flight crew in the crew compartment;

c) there are means to exclude hazardous quantities of smoke, flames, or noxious gases, from the flight crew compartment; and

d) the required crew emergency exits are accessible under any cargo loading condition

The main deck cargo compartment on cargo aeroplanes, e.g. A330-200F and B747-400F, is classified as Class E. In addition, some cargo aeroplanes have Class E underfloor cargo compartments, e.g. B767-300F.

6.2.7 A Class F compartment must be located on the main deck and is one in which:

a) there is a separate approved smoke detector or fire detector system to give warning at the pilot or flight engineer station;

b) there are means to extinguish or control a fire without requiring a crew member to enter the compartment; and

c) there are means to exclude hazardous quantities of smoke, flames, or extinguishing agent from any compartment occupied by the crew or passengers.

The Class F cargo compartment is the main deck cargo compartment on a combi aeroplane, i.e. one where the main deck has both a passenger cabin and a cargo compartment.

6.2.8 Table 6-1 provides a summary of different commonly-classified cargo compartment characteristics.

Table 6-1. Summary of different commonly-classified cargo compartments characteristics

	Class A	Class B	Class C	Class D	Class E	Class F
Fire detection	Detection via crew/passenger	Automatic fire (smoke) detection	Automatic fire (smoke) detection	No (automatic) detection except if compartment is ventilated	Automatic fire (smoke) detection	Automatic fire (smoke) detection
Principal crew action	Hand-held fire extinguishing	Hand-held fire extinguishing	Activate fire suppression system	No action unless indication of fire is present	Depressurize and set to a prescribed flight level	Depends on design
Aeroplane fire fighting means	Active fire-fighting via hand-held extinguisher	Active fire-fighting via hand-held extinguisher	Built-in fire suppression system	Isolation	Flight level procedure, reducing oxygen partial pressure	Depends on design
Fire fighting principle	Extinguishing	Extinguishing	Fire suppression via extinguishing agent	Fire containment and oxygen consumption	Oxygen starvation	Depends on design
Post-fire suppression conditions or actions	Monitoring	Monitoring	Suppressed environment until end of flight (see paragraph 6.2.9)	(Small) increase of oxygen partial pressure during descent phase	(Large) increase of oxygen partial pressure during descent phase	Depends on design
Design steady-state conditions	Extinguished	Extinguished	Suppressed fire with cargo compartment temperature potentially above 200°C	Smoldering fire depending on oxygen concentration left	Similar condition as Class C cargo	Depends on design

6.2.9 As per Annex 6, Part I, 4.3.10, it is recommended that all flights are planned so that the diversion time to an aerodrome where a safe landing could be made does not exceed the cargo compartment fire suppression time capability of the aeroplane, reduced by an operational safety margin (e.g. 15 min) specified by the State of the Operator. Additionally, in accordance with Annex 6, Part I, 4.7.2.3, the maximum diversion time for aeroplanes engaged in extended diversion time operations (EDTO) shall not exceed the cargo compartment fire suppression time capability of the aeroplane, reduced by an operational safety margin (e.g. 15 min) specified by the State of the Operator, should this capability be identified as the most limiting EDTO significant system time limitation. The *Extended Diversion Time Operations (EDTO) Manual* (Doc 10085) provides additional guidance on EDTO, and in particular for the consideration of relevant time limitation of the cargo fire suppression system.

6.2.10 Ceiling and sidewall liner panels of Class C and D cargo compartments, as well as shrouds in Class E compartments used to protect critical/essential systems, must meet more severe requirements than other cargo compartment liners or features. Therefore, these liners/protective features will have a higher degree of fire resistance than liners in other compartments. This also applies to certain liner panels in Class F compartments, although as the Class F cargo compartment permits different methods of compliance, not all liner materials must satisfy this same standard.

6.3 CARGO COMPARTMENT CERTIFICATION STANDARDS

6.3.1 Approved fire detection systems are required for Class B, C, E and F cargo compartments, and for Class D when ventilation is present. The systems must be capable of detecting a fire at a temperature significantly below that at which the structural integrity of the aeroplane would be substantially decreased. The detection system must provide a visual indication to the flight crew within a specified time (one minute is typical) after the start of a fire. This is usually demonstrated through flight testing with the use of a simulated smoke source representing the early stage of a fire when it is smouldering or before it is hazardous to the aircraft. There must be a means to allow the crew to check the correct functioning of each fire detector circuit during flight. Additionally, the effectiveness of the detection system must be demonstrated for all approved operating configurations and conditions.

6.3.2 A Class C cargo compartment is required to have a built-in fire suppression system. This is the classification of underfloor compartments found on most commercial passenger aeroplanes. These compartments currently use Halon 1301 as the fire suppression agent. Testing has shown that Halon 1301 at concentrations greater than 5 per cent will extinguish open flames from Class A (combustibles) and Class B (liquid fuel) fires. Whether there is complete extinguishment of the fire is dependent on the class of material, rate of burning, stacking of material and Halon 1301 concentration. Testing has also demonstrated that Halon 1301 in concentrations greater than 3 per cent prevents the ignition of flammable vapours resulting from suppressed fires of typical combustible materials and limited concentrations of typical flammable goods. The typical combustible materials for which aircraft cargo fire suppression systems have been designed include Class A materials like paper, cardboard, and plastics. Class C cargo compartment fire suppression systems are typically shown to meet the classification requirement by demonstrating an initial Halon 1301 concentration of at least 5 per cent, followed by a continuing concentration of at least 3 per cent for some period of time. The demonstrated time capability of the fire suppression system is the time duration the concentration will remain above 3 per cent. Further information on the minimum performance standard for cargo compartment fire suppression agents is contained in the U.S. Department of Transportation document *Minimum Performance Standard for Aircraft Cargo Compartment Halon Replacement Fire Suppression Systems (2012 Update)* (DOT/FAA/AR-TN12/11).

6.3.3 If a built-in fire extinguisher is provided, the extinguishing agent that is likely to enter personnel compartments must not be hazardous to the occupants, and the discharge of the extinguisher must not cause structural damage. The capacity of each required built-in fire extinguishing system must be adequate for any fire likely to occur in the compartment, with consideration to the volume and the ventilation rate of the compartment. The capacity of each system must be adequate to extinguish the fire or suppress the fire anywhere within the cargo compartment for a duration corresponding to the suppression time capability of the system (see 6.2.9).

6.3.4 Manufacturers are required to show compliance with design standards at an overall aeroplane level, and as such, flight tests are conducted to demonstrate:

a) cargo compartment accessibility;

b) the prevention of entry of hazardous quantities of smoke or extinguishing agent into compartments occupied by the crew or passengers; and

c) the dissipation of the extinguishing agent in all Class C compartments and, if applicable, in any Class F compartments.

During these tests, it is demonstrated that no inadvertent operation of smoke or fire detectors in any compartment would occur as a result of fire contained in any other compartment, either during or after extinguishment, unless the extinguishing system floods each of those compartments simultaneously. That is, detection in one compartment should not be the result of a fire in any other compartment, unless the suppression system is designed to protect all compartments so affected.

6.4 INFORMATION PROVIDED IN AEROPLANE DOCUMENTATION

6.4.1 As required by Annex 6, Part I, Chapter 15, 15.2.1, the elements of the cargo compartment(s) fire protection system, and a summary of the demonstrated cargo compartment fire protection certification standards, shall be provided in the aeroplane flight manual or other documentation supporting the operation of the aeroplane. The design approval holder is the best source for this information.

6.4.2 The details discussed in section 6.3 of this manual may be used as the starting point for a design approval holder to compile the information to be provided, depending of course on the class of cargo compartments installed on the specific aeroplane of the operator. An indication of where the cargo compartments are located on the aeroplane should also be provided. Further information should then be provided regarding the demonstrated cargo compartment fire protection certification standards that apply to each cargo compartment. This will enable the operator to fully assess the risk in accepting items for transport, as the cargo compartment capability for containing possible consequences will be fully understood. Any other information the design approval holder identifies as valuable to the operator in conducting a risk assessment may also be provided. If an operator identifies additional information regarding the aeroplane and its associated systems and capabilities that would support the conduct of a risk assessment, then the operator should request that information to be provided by the design approval holder.

6.4.3 The specific document in which information is provided is not prescribed to the design approval holder, but it should be located in a manual easily identified by the operator’s personnel responsible for developing the safety risk assessment. The design approval holder should identify the most appropriate location for this information, for example, the aircraft maintenance manual and/or the flight crew operations manual. Appendix 1 to this chapter provides an example of the information that may be provided by the design approval holder.

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Appendix 1 to Chapter 6

EXAMPLE STRUCTURE AND CONTENT TO BE PROVIDED BY THE DESIGN APPROVAL HOLDER

This appendix presents an example of the possible structure and primary elements of information that should be provided by the design approval holder to an operator to support the conduct of a risk assessment. The information may apply to a specific aeroplane or series of aeroplanes as identified by the design approval holder. The expectation is that in each section proposed below, the design approval holder would provide more detailed information regarding the elements of the cargo compartment(s) fire protection system, and where relevant, a summary of the standards used for the certification of the cargo compartment fire protection.

ELEMENTS OF INFORMATION ON THE AEROPLANE'S CARGO COMPARTMENT FIRE SUPPRESSION SYSTEM

1. Characteristics of the cargo compartments

This section should detail the following physical characteristics of the cargo compartments of the aeroplane:

a) the location of each cargo compartment (e.g. aft or forward, main deck or underfloor, etc.); and

b) the available volume of each cargo compartment (in ft^3 or m^3).

This section should also clarify if the cargo compartment is fitted with a cargo-loading system, and the types of unit load devices (ULDs) (pallets and/or containers) that may be utilized.

2. Characteristics of the cargo compartment fire suppression system

Information provided in this section should specify the classification of the cargo compartment, e.g. "the aft cargo compartment is a Class C cargo compartment.''

Additionally, information provided in this section should summarize the standards considered in the process of certification of the cargo compartment fire suppression system and on its characteristics. It should in particular:

a) specify the time capability of the cargo compartment fire suppression system, if applicable. It should be noted that for Class E cargo compartment, this time capability is limited by the available oxygen supply to the flight crew and other aircraft occupants, as this oxygen is required to be able to safely maintain the required pressure altitude in the cabin during the diversion;

b) confirm whether the ability of the system to detect smoke from a fire before the structural integrity of the aeroplane would be substantially decreased has been assessed. In particular, the class of fire that was considered in this assessment should be specified;

c) specify (if applicable) that the different configurations of the fire suppression system that support EDTO are identified in the applicable configuration, maintenance and procedures (CMP) document for EDTO; and

Note.— Refer to Doc 10085 for further guidance on EDTO, and in particular for the consideration of the relevant time limitation of the cargo fire suppression system.

d) confirm whether the ability to prevent cargo fire smoke and fire suppression agent vapours from entering occupied compartments has been demonstrated.

More detailed information of the various features of the cargo compartment fire suppression system should be provided as applicable in sections A to E below.

A. Sidewall/ceiling liners

This section should specify the features and capability of the cargo compartment sidewalls and liners. The sidewall and ceiling liners provide containment of a cargo fire. Liners are a passive fire protection feature. The primary purpose of a cargo liner is to prevent a fire originating in a cargo compartment from spreading to other parts of an aeroplane. Other features of the cargo compartment also provide containment and serve the same purpose as a traditional liner. These are light assemblies, panels, smoke detector housings, and air ducts. Additional information on the fire resistance characteristics of the liners that were considered in the process of certification of the cargo compartment fire suppression system should also be listed in this section.

B. Ventilation shut-off

This section should specify whether the heat and/or air conditioning systems (as applicable) can be shut off during a fire event in the cargo compartment.

C. Air conditioning flow

This section should specify whether the air flow provided from the air conditioning system keeps smoke out of the occupied areas such as the flight deck and passenger cabin (as applicable).

D. Smoke detection system

This section should specify whether the concerned cargo compartment has a smoke detection system. These systems are designed to provide an aural and visual indication to the flight crew in the early, smouldering phase of a fire prior to it breaking out into a large fire. It should also specify if there are provisions to minimize blockage of smoke to the detectors, and where such provisions, if any, are described in detail as this may be located in separate design approval holder documentation.

E. Fire suppression system

This section should specify whether the concerned cargo compartment has a built-in fire suppression system, and whether this system is shared with other cargo compartment(s) on the aeroplane. The intent is to identify whether the system provides fire suppression capability for one or more cargo compartment(s) on the aeroplane when activated during a cargo fire event. Accordingly, it should be specified whether the cargo fire suppression system, if activated for one compartment, has sufficient suppression capability remaining for the other compartment, should a fire occur in that second compartment. If a fire suppression agent is utilized, additional information on the type of agent (e.g. Halon 1301) should be provided.

Attachment A

REFERENCES

ANNEXES

Annex 6 — *Operation of Aircraft*

Annex 8 — *Airworthiness of Aircraft*

Annex 18 — *The Safe Transport of Dangerous Goods by Air*

Annex 19 — *Safety Management*

MANUALS

Safety Management Manual (SMM) (Doc 9859)

Technical Instructions for the Safe Transport of Dangerous Goods by Air (Technical Instructions) (Doc 9284)

Emergency Response Guidance for Aircraft Incidents Involving Dangerous Goods (Doc 9481)

Extended Diversion Time Operations (EDTO) Manual (Doc 10085)

REPORTS

Dangerous Goods Panel Working Group Meeting Report (DGP-WG/15-WP/38), 27 April to 1 May 2015
(URL: https://www.icao.int/safety/DangerousGoods/DGPWG15/DGPWG.15.WP.038.en.pdf)

Report of the Twenty-Fifth Meeting of the Dangerous Goods Panel (DGP/25), 19 to 30 October 2015

EXTERNAL REFERENCES

Minimum Performance Standard for Aircraft Cargo Compartment Halon Replacement Fire Suppression Systems (2012 Update) (DOT/FAA/AR- TN12/11)

Summary of FAA Studies Related to the Hazards Produced by Lithium Cells in Thermal Runaway in Aircraft Cargo Compartments (DOT/FAA/TC-16/37), June 2016

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