Risk models and accident scenarios

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This study provides an integrated approach to risk modeling. The work comprises the following:

- Representation of safety of the current aviation system in accident scenarios;
- Representation of emerging and future risks in accident scenarios;
- Representation of safety culture and safety management in accident scenarios;
- Quantification of accident scenarios.

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Acronyms

Acronym	Definition
ASA	Aircraft Safety Assessment
AFHA	Aircraft Functional Hazard Analysis
AFM	Aircraft Flight Manual
AIS	Aeronautical Information Service
ALAR	Approach and Landing Accident Reduction
APS	APSys Company
ASD	Acceleration Stop Distance
ASM	Airspace Management
ATIS	Automatic Terminal Information Services
ATC	Air Traffic Control
ATFM	Air Traffic Flow Management
ATM	Air Traffic Management
BBN	Bayesian Belief Net
CATS	Causal Model for Air Transport Safety
CFIT	Control Flight into Terrain
COM	Communication
CRM	Crew Resources Management is the effective use of all available resources for flight crew personnel to assure a safe and efficient operation, reducing error, avoiding stress and increasing efficiency
DAL	Development Assurance Level
EASP	European Aviation Safety Plan
ESD	Event Sequence Diagram
FAST	Future Aviation Safety Team
FDM	Flight Data Monitoring
FIS	Flight Information Service
FT	Fault Tree
GC	Ground Collision
GND	GrouND
IATA	International Air Transport Association
ICAO	International Civil Aviation Organisation

Acronym	Definition
IE	Initiating Event
IRGC	International Risk Governance Council
JAA	Joint Aviation Authorities
LoCiF	Loss of Control in Flight
LOSA	Line Operation Safety Assessment
MAC	Mid-Air Collision
MET	Meteorological
NAV	Navigation
PASA	Preliminary Aircraft Safety Assessment
PIC	Pilot In Command
PRA	Particular Risk Analysis
PSSA	Preliminary System Safety Assessment
QNH	The altimeter sub-scale setting to obtain elevation when on the ground
RE-O-L	Runway Excursion/Overrun at Landing
RE-O-T/O	Runway Excursion/Overrun at Take-Off
RERAT	Runway Excursion Risk Awareness Tool
RERR	Runway Excursion Risk Reduction
RTO	Rejected Take-Off *If the Captain decides to stop a takeoff, at any time during the takeoff roll, this is referred to as a "Rejected Takeoff" (RTO).*
SFHA	System Functional Hazard Analysis
SMS	Safety Management System
SOP	Standard Operational Procedure
SSA	System Safety Assessment
SUR	Surveillance
T/O	TakeOff
TWR	ToWeR
V1	V1 is a decision / action speed
V2	V2 is a take-off safety speed. It is the minimum speed that needs to be maintained up to acceleration altitude, in the event of an engine failure after V1.
VR	VR is the rotation speed. The rotation of the aircraft begins at VR, which makes lift-off possible, at the end of the manoeuver.

Executive Summary

The objective of this work package WP 3.2 of ASCOS is to provide an integrated approach to risk modelling in which human factors and cultural aspects are considered in connection with technical and procedural aspects and with specific emphasis on the representation of emerging and future risks.

The current state of the art for the certification of aeronautical products is basically reactive in the sense that changes in certification requirements are often made as a reaction to major accidents or as a reaction to technological advances.

A key step in the proposed improved certification process (which is the main overall objective of ASCOS) is an improved hazard identification process, including a 'predictive' approach, aimed at discovering future hazards that could result as a consequence of future changes inside or outside the global aviation system and then initiating mitigating actions before the hazard is introduced.

The work comprises the following:

- Representation of safety of the current aviation system in accident scenarios.
- Representation of emerging and future risks in accident scenarios
- Representation of safety culture and safety management in accident scenarios
- Quantification of accident scenarios.

The accident scenarios are represented as event sequence diagrams and fault trees. The ASCOS model is based on the CATS model and consists of 29 accident scenarios that represent virtually all major aviation safety risks. The model is quantified in the sense that probabilities of occurrence are assigned to the various elements of the different pathways of the accident scenarios

The representation and the evaluation of the emerging/future risks using CATS ESDs can be done if each base event of the fault tree is linked to precursors and if a dedicated capture process is defined for these precursors. The application of the precursors capture process allows calculating the precursors' occurrence rates and then the emerging/future risks by using CATS ESDs.

For that it is necessary to ensure that the CATS ESDs are sufficiently complete. This means that all initiating events are envisaged, all pivotal events are recognized, no safety barrier is forgotten and no base event in fault trees is overlooked. This can be done in two steps:

- Step 1: Using safety assessments and product description and operational documentation for identification of all safety barriers implemented in the design and ensuring that all these safety barriers are considered in CATS ESDs.
- Step 2: Reviewing the CATS ESDs with experienced people having different points of view (e.g. design, maintenance operation, pilots, flight operation, ground operation, airport operation, ATM operation).

It is recommended that these steps are taken if the model is used in any of the test cases that will be conducted in ASCOS work package 4.

The ASCOS accident model supports safety management in several ways. By describing a system or service in terms of where it resides in the model and in terms of its relationship to the safety related service one is able to share a common understanding of the service or system under consideration. The accident model can be used to improve the continuous oversight function by identifying a more complete and correct set of monitoring requirements by inspection of the complete model. Inspection of a complete accident model of the aviation system also has the potential to improve the identification of the boundary of influence of a proposed change and thereby improving the management of change. Inspection of a complete model of the total system behaviour has the potential to provide a clear understanding of the safety significance of a service, supporting service or system which one is then able to use in the determination of an appropriate level of oversight.

Safety culture is essential to make a safety Management System successful and as an aggregated result the improvement of the safety performance of the entire aviation system. However, a number of reasons suggest avoiding the modelling of safety culture elements in accident scenarios to be directly attached to the Event Sequence Diagrams and fault trees of an accident model. The reasons are the following:

- The safety culture related failures are mainly negative conditions favouring long term and latent failures, while the Fault Trees are better suited for representing system failures and errors at the sharp end.
- The same safety culture failure might simultaneously contribute to several FT basic events.
- Safety Culture measurements appear more appropriate for the monitoring of trends within the same organization or for comparison between different organizations, rather than for the identification of absolute frequencies.

The ASCOS risk model is quantified by assessing the probability of occurrence of each of the different pathways in the scenarios. A quantified model gives a risk picture of the system that is described by the model, based on historic or expert opinion-derived data. It can be used to analyse the risk of individual events: for each event in the model the probability is known and the severity can be derived from the conditional probability of an accident given the said event occurring. The model can also be used to assess the impact on safety of changes to the system. Proposed changes can have an influence on the probability of occurrence of events described by the model. If this influence can be quantified, the model can be used to determine the quantitative influence of the change on accident risk. The model can also be expanded by adding new events that are specific to the particular change.

Quantifying the impact of safety management and safety culture on the level of safety of the total aviation system using an accident model is difficult. The only practical solution to this problem is to derive a modification factor that can be applied to a model element that is affected by the safety management and safety culture of a particular organization. The modification factor can be determined based on the level of maturity of a safety management system of an organization and on the level of safety culture.

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1 Introduction and background

1.1 Background and scope

The overall objective of ASCOS is to develop aviation certification process adaptations, with supporting safety tools, to ease the certification of safety enhancement systems and operations. Within ASCOS, work package 3 'Safety Risk Management' has the objective to develop a total aviation system safety assessment methodology, with supporting safety based design systems and tools, for handling current, emerging and future risks. This is to be achieved by representing current and future risks in accident and accident avoidance scenarios in such a way that it can be used in the certification process.

The current state of the art for the certification of aeronautical products is basically reactive in the sense that changes in certification requirements are often made as a reaction to major accidents or as a reaction to technological advances. For instance, following the TWA 800 accident in 1996, the FAA and EASA have developed requirements for design precautions to mitigate the risks associated to fuel tank flammability. These requirements became effective more than a decade after the occurrence of the accident. As another example, since EASA CS 25.1322 on flight crew alerting [21] was issued, there have been many advances in the design and technology of flight deck alerting devices. The new technologies associated with integrated visual, aural, and tactile flight crew alerts and alert messaging are more effective in alerting the flight crew and aiding them in decision making than the discrete coloured lights for warning, caution, and advisory alerts prescribed in 25.1322. Because 25.1322 is outdated and lacks content commensurate with state of the art flight deck display technology, applicants have to perform additional work when showing compliance to that regulation. This is being recognised by EASA, and amendments to the current regulations are proposed, but these changes are a reaction to technological developments that are already commonplace in modern aircraft. A key step in the proposed improved certification process (which is the main overall objective of ASCOS) is an improved hazard identification process, including a 'predictive' approach, aimed at discovering future hazards that could result as a consequence of future changes inside or outside the global aviation system and then initiating mitigating actions before the hazard is introduced.

This document presents the results of sub work package 3.2 'risk models and accident scenarios'.

1.2 Objectives

The objective of this task is to provide an integrated approach to risk modelling in which human factors and cultural aspects are considered in connection with technical and procedural aspects and with specific emphasis on the representation of emerging and future risks.

1.3 Approach and methodology

The approach is to base the risk model on the Causal Model for Air Transport Safety (CATS) that has been developed earlier by a consortium led by Delft University of Technology and funded by the Dutch government. The CATS model describes accident scenarios and accident avoidance scenarios as event sequence diagrams

and fault trees. . For the purpose of the ASCOS accident model some qualitative changes have been made to the CATS ESDs to incorporate the lessons-learnt of the last couple of years in which CATS has been used and studied. These changes include different naming of events, different definitions, addition or deletion of events, and combining of ESDs. This ASCOS subtask will describe if and how the original model can be improved to represent emerging and future risks, as well as elements of safety culture and safety management. An emerging risk is defined here as a familiar risk that is increasing or a new risk that becomes apparent in new or unfamiliar conditions. A future risk is defined as a risk associated with the future introduction of a novelty (e.g. new design, new procedure and new organisation).

1.4 Structure of the document

Section 2 describes the general structure of the model. Section 3 explains how future and emerging risks can be represented in the model. This is done in detail for the issue 'runway excursion at take-off' but the same procedure is considered equally applicable for all operational issues. Section 4 describes the representation of safety culture and safety management. Section 5 discusses safety management in relation to the risk model and section 6 explains the quantification process of the model. Finally, section 7 contains conclusions and recommendations.

2 Representation of the current aviation system in accident scenarios

2.1 Introduction

Every historic accident, and every accident still to come, has a different sequence of events and a unique set of circumstances. To study accidents, and their prevention, it is paramount however that accident sequences are also described at a more generic level so that generic problems can be identified and solved. Therefore unique sequences of events must be categorized into distinctive scenarios that characterize a certain type of accident. A set of such generic scenarios form a model, and are a simplified representation of a complicated and unique reality. By carefully analysing historic accidents and describing the scenarios, this representation of reality can be made sufficiently detailed to give an adequate description of the total aviation system. Such a model can be used to determine a baseline level of safety. By incorporating the influence of changes, such as operational improvements, in the model, the impact of such changes on safety can be estimated.

A model representing accident scenarios is beneficial for new certification approach that will be developed in ASCOS. The model can aid in the identification and analysis of key accident avoidance scenarios of operational changes or new systems to be certified. The safety benefits of the proposed system or operational change can also be determined using the model.

2.2 Accident scenarios

An accident scenario is a chronological description of a series of events leading up to an accident. A common way to visualize such a scenario is by the Swiss cheese model of Reason [1], see Figure 1. In the total aviation system there are, or must be, multiple safety barriers in place such that a single failure does not result in an accident. These safety barriers are not flawless, because they involve both fallible humans and systems. These flaws are represented by the holes in the cheese. As history has shown there are trajectories of accident opportunity through multiple layers, or slices of cheese, leading to accidents.

To limit the number of accident scenarios in an accident scenario model that represents the total aviation system, each scenario must represent a ‘typical’ accident. Typical accidents are for example: runway excursions, controlled flights into terrain and losses of control in flight.

An example accident scenario starts with an unstable approach, followed by a failure of the crew to initiate a missed approach, a subsequent long landing resulting in an overrun. The initiating event ‘unstable approach’ is followed by pivotal events that determine the eventual end state, in this case an overrun. The pivotal events represent choices by human actors or external circumstances that define the scenario from initiating event to end-state.

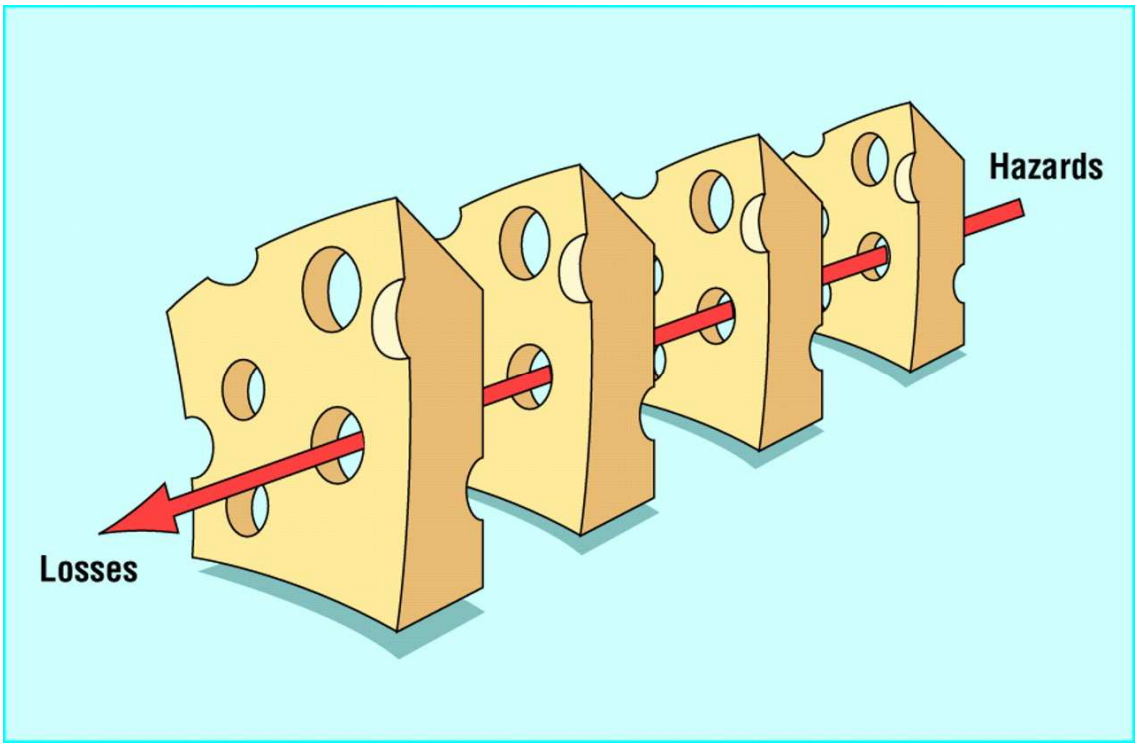

Figure 1: Reason Swiss cheese model[1]

2.3 The representation of accident scenarios

To aid in the modelling effort a systematic way of representing accident scenarios is needed. The core of a model based on accident scenarios is formed by events that may lead to accidents if safety barriers are breached. Because these events may lead to accidents they can be described as hazards. These hazards themselves occur due to sequences of events starting at a particular root cause. A particular hazard can be caused by multiple root causes, and the hazard can evolve in several types of accident. This is often represented by a bow tie, see Figure 2.

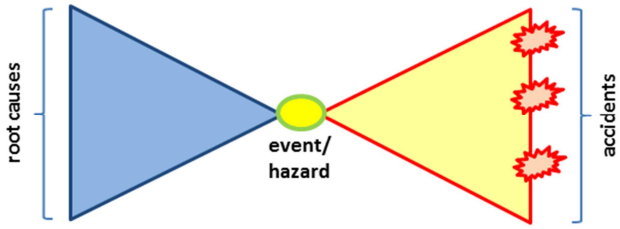

Figure 2: Bow tie

[1] Taken from internet (www.bmj.com)

To represent the total aviation system multiple bow-ties are needed to capture all hazards that can lead to accidents. The failure of safety barriers after a hazard takes place also has root causes. These root causes also need to be represented in the model. For the purpose of ASCOS the accident scenarios are represented using event sequence diagrams (ESD) and fault trees.

An ESD consists of an initiating event, pivotal events and end states. A representation of a generic ESD is given in Figure 3. ESDs provide a qualitative description of series of events leading to accidents. Because pivotal events can also cause avoidance of an accident, an ESD also models scenarios which lead to incidents and reportable occurrences. An initiating event represents the start of the main accident scenario. The initiating event of course also may have causes, and they are represented in a fault tree. Each pivotal event represents a possibility for the safety occurrence to develop into an accident, or a possibility that the accident is avoided. If all pivotal events contribute towards an unwanted outcome, than the end state is an accident or serious incident. If a pivotal event causes avoidance of an accident the end state is a safe continuation of the flight. A single ESD therefore can represent more than one accident scenario, and also represents accident avoidance scenarios. In case of the generic ESD of Figure 3 there are 2 accident scenarios and 2 accident avoidance scenarios, see the solid red (accident) and dashed yellow (accident avoidance) lines in Figure 4.

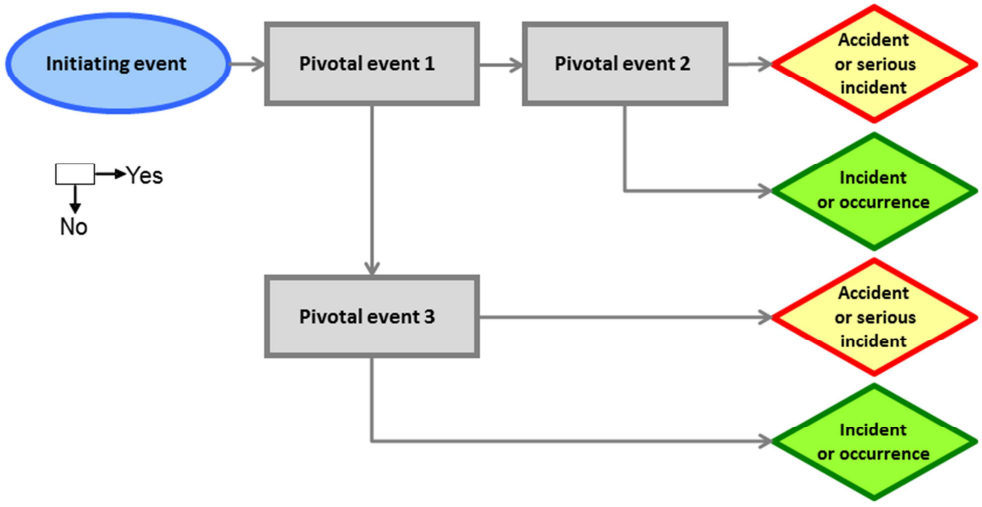

Figure 3: Generic representation of an ESD

Fault trees are used to represent the root causes of both the initiating event and the pivotal events of an ESD. A generic fault tree is given in Figure 5. Fault trees connect to the events in the ESDs: the top-event of the fault tree corresponds to the initiating or pivotal event in the ESD. The fault tree either shows failure propagation towards the top-event, or provides a specification of the top-event. A fault tree event is defined such that it is a “fault” or “failure condition”, not a “positive” event. It is unambiguously and clearly defined, generic (e.g. not based on a specific historic incident or accident), measurable and quantifiable. Each fault tree contains events that are stated as faults and are combined by logic gates.

Three types of logic gates are used:

AND-gate	a certain event occurs if the underlying events occur simultaneously
OR-gate	a certain event occurs if at least one of multiple underlying events occur
MOR-gate	a certain event occurs if one underlying event occurs, the occurrence of more than one underlying event is not possible

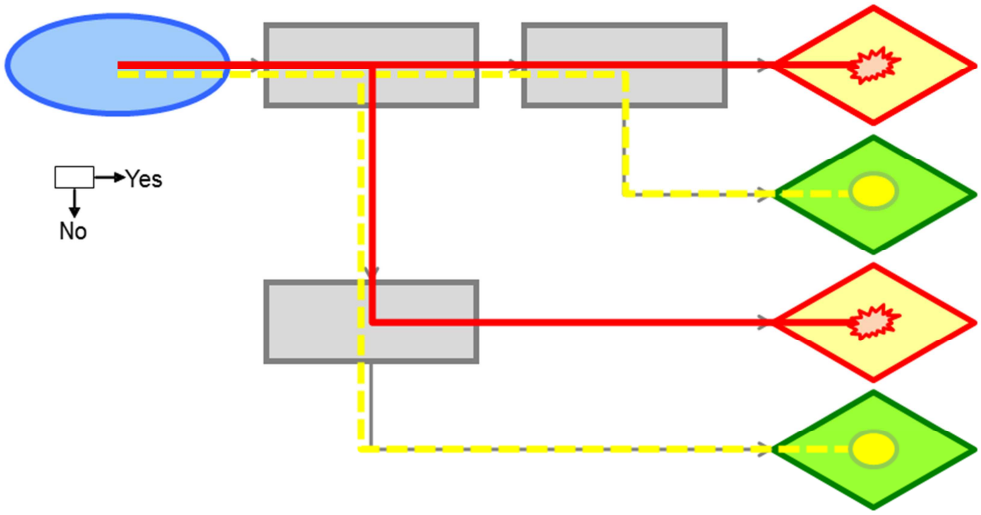

Figure 4: Representation of accident scenarios (red) and accident avoidance scenarios (yellow) in an ESD

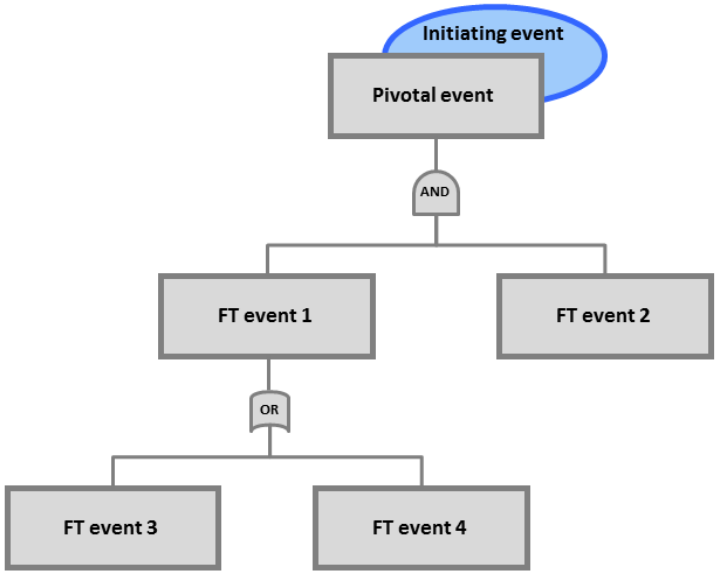

Figure 5: Generic representation of a fault tree

An ESD with its associated fault trees can be seen as a combination of bow ties. This is visualized in Figure 6. Each fault tree can be seen as the left side of a bow tie, while the combination of pivotal events can be seen as the right side of a bow tie. Multiple ESDs are needed to represent the total aviation system.

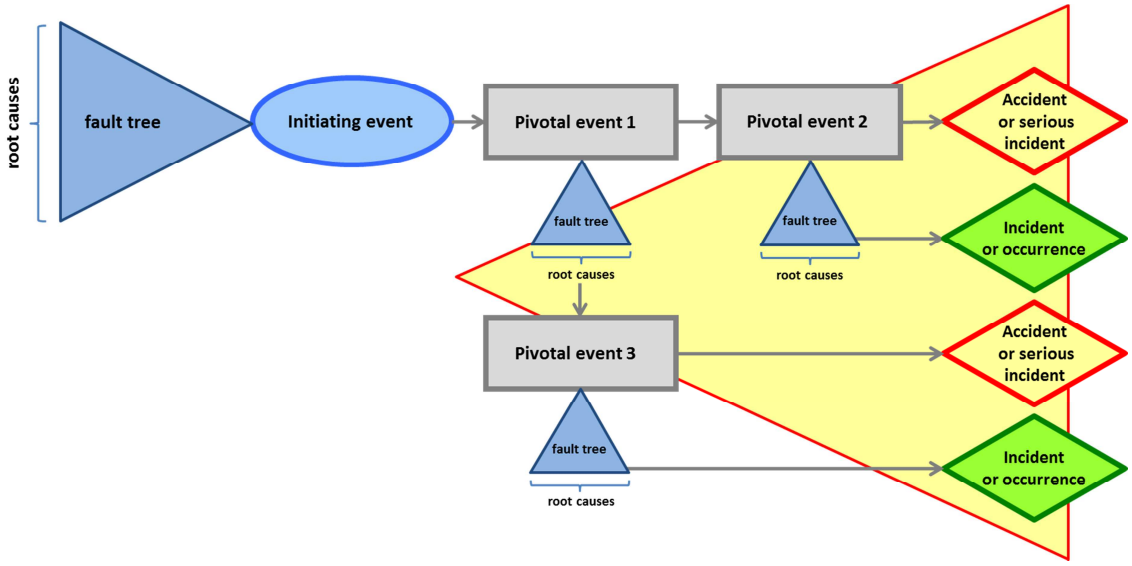

Figure 6: ESD bow tie

2.4 ASCOS accident model

The ASCOS accident model consists of ESDs and fault trees developed to represent the total aviation system. The ESDs and fault trees are given in Appendix A and B of this report. This section elaborates on how the ASCOS accident model is developed.

2.4.1 Development of the ASCOS accident model

The ASCOS accident model is based on previous accident model development work, primarily the work performed to create the Causal Model for Air Transport Safety (CATS) [2]. CATS has been developed for the Dutch Ministry of Transport and represents the total aviation system. The ESDs and fault trees of CATS are used as a starting point to create the ASCOS accident model. For the purpose of the ASCOS accident model some qualitative changes have been made to the CATS ESDs to incorporate the lessons-learnt of the last couple of years in which CATS has been used and studied. These changes include different naming of events, different definitions, addition or deletion of events, and combining of ESDs. An overview of differences between the CATS ESDs and the ASCOS ESDs is presented in Appendix C. To assure compatibility, the CATS numbering of ESDs is maintained. To avoid any confusion the prefix “ASC” is used for the ASCOS ESDs. Gaps in numbering are either because a specific ESD was dropped during the development of CATS, or because two or more CATS ESDs are combined to form a single ASCOS ESD.

In Table 1 an overview of the ASCOS ESD initiating events is given.

Table 1: Initiating events of ASCOS accident model

ESD	Initiating event
1	Aircraft system failure during take-off
2	ATC related event during take-off
3	Aircraft directional control by flight crew inappropriate during take-off
4	Aircraft directional control related system failure during take-off
5	Incorrect configuration during take-off
6	Aircraft takes off with contaminated wing
8	Aircraft encounters wind shear after rotation
9	Single engine failure during take-off
10	Pitch control problem during take-off
11	Fire, smoke, fumes onboard aircraft
12	Flight crew member spatially disorientated
13	Flight control system failure
14	Flight crew incapacitation
15	Ice accretion on aircraft in flight
16	Airspeed, altitude or attitude display failure
17	Aircraft encounters thunderstorm, turbulence, or wake vortex
18	Single engine failure in flight
19	Unstable approach
21	Aircraft weight and balance outside limits during approach
23	Aircraft encounters wind shear during approach or landing
25	Aircraft handling by flight crew inappropriate during flare
26	Aircraft handling by flight crew inappropriate during landing roll
27	Aircraft directional control related systems failure during landing roll
31	Aircraft are positioned on collision course in flight
32	Runway incursion
33	Cracks in aircraft pressure cabin
35	TAWS alert
36	Conflict on taxiway or apron
38	Loss of control due to poor airmanship

The ASCOS accident model includes a fault tree for each initiating event, and for most pivotal events. The ASCOS fault trees are based on the fault trees used in CATS. Again, lessons-learnt are applied to modify the fault trees to match the requirements of ASCOS. Furthermore, because there are differences between the ASCOS ESDs and the CATS ESDs, there are ESD elements unique to ASCOS. For these elements new fault trees have been defined. Where possible element of existing CATS fault trees are used, or multiple CATS fault trees are combined. Modifications to CATS fault trees are mainly done to come to level of detail that is appropriate for ASCOS. According to NASA's Fault Tree Handbook [4] "the development of a quantitative model is based on

the need to get the best possible estimate for the top event probability, considering the data and other information that are available. Fault trees are developed to a level of detail where the best failure probability data are available". Since detailed failure information on non-critical events is often lacking in aviation, the fault trees cannot be too detailed.

2.4.2 ASCOS accident model and the Accident-Incident Model (AIM)

The ASCOS project team is keenly aware of the development of the SESAR Accident-Incident Model (AIM) [23, 24, 25] and its predecessor the Integrated Risk Picture (IRP) [22]. Similar to the CATS model and the IRP, the SESAR AIM [26] consists of a risk model, which shows the risks of aviation accidents and provides a structured breakdown of their causes, with particular emphasis on ATM contributions (both positive and negative). Using the AIM, a risk picture for SESAR is being developed to represent the combined effects of the set ATM changes that are expected to be in place by 2013, 2017 and 2020. Each ATM change is modelled through adjustments representing its expected impacts on appropriate elements of the risk model. These effects, together with the effects of changes in traffic levels, can then be summed to estimate the total risks and contributory / causal breakdown for 2013, 2017 and 2020. This approach allows investigation of the improvements that are necessary to satisfy the ECAC wide safety targets. However, a Risk Picture for SESAR is still under development.

The ASCOS accident model and AIM are comparable; they both consist of event sequences detailed with fault trees. AIM focuses on 6 ATM-related accident scenarios. The ASCOS accident model on the other hand covers the total aviation system, and therefore also includes non-ATM-related accident scenarios. AIM does have more detailed fault trees. Because the focus of ASCOS is on the total aviation system, it cannot make use of AIM (only), and therefore needs an accident model that covers the total system. If more detailed fault trees are needed within the scope of ASCOS, suitable fault tree elements from AIM can be adopted if the latter model is fully developed. Note that ASCOS has developed a baseline risk picture for the total aviation system [26]. If the changes within the total aviation system that are expected to be in place in the future (e.g. as foreseen within the EC strategies reflected in the Vision 2020 or Flight Path 2050) are properly modelled, it is possible to estimate the risks for all the accident scenarios that are affected by the change. Subsequently, it is possible to investigate improvements needed to satisfy certain (pre-defined) safety performance targets.

2.4.3 ASCOS accident model and aviation safety in Europe

The European Aviation Safety Plan (EASP) of the European Aviation Safety Agency (EASA) [5] identified main risk areas of commercial air transport operations. These risk areas are classified according to the type of issues they highlight, amongst which are operational issues. Operational issues are brought to light by the reporting and analysis of safety occurrence data. Safety occurrences are events where the available safety margin towards accidents or serious incidents has been reduced. Accidents and serious incidents are unrecoverable and represent end states in a series of events that include safety occurrences.

The EASP lists the following operational issues as being of primary importance: runway excursions, mid-air collisions, controlled flight into terrain (CFIT), loss of control in flight (LOC-I), and ground collisions.

One of the aims of ASCOS is to progress beyond the state-of-the-art by developing and validating a continuous monitoring process in which safety occurrences will be used as safety performance indicators. These safety occurrences are a measure of safety performance because they are precursors to the five categories of end states as defined in the EASP. The ASCOS accident model can be used to translate the safety performance indictors into a measure of safety in terms of the likelihood of accidents or serious incidents taking place. Therefore, Table 2 matches the ESDs of the ASCOS accident model with the five end state categories of the EASP. A match indicates that the ESD represents scenarios involving that particular end state. Some ESD represents safety occurrences that can evolve into more than one end state depending on which safety barriers are breached.

Table 3 shows the end states as used in the ESDs and matches those with the five primary EASP operational issues. It is noted that not all end states are included in the table, as there are some end states that do not match the EASP categories. This concerns the following end states: personal injury, aircraft damage, and aircraft lands off runway.

Table 2: Matrix matching the ESDs of CATS with the EASP end state categories.

		EASP category				
ESD	**Initiating event**	**Runway excursion**	**Mid air collision**	**CFIT**	**LOC-I**	**Ground collision**
1	Aircraft system failure during take-off	√				
2	ATC related event during take-off	√				
3	Aircraft directional control by flight crew inappropriate during take-off	√				
4	Aircraft directional control related system failure during take-off	√				
5	Incorrect configuration during take-off	√			√	
6	Aircraft takes off with contaminated wing				√	
8	Aircraft encounters wind shear after rotation				√	
9	Single engine failure during take-off	√				
10	Pitch control problem during take-off	√				
11	Fire, smoke, fumes onboard aircraft				√	
12	Flight crew member spatially disorientated				√	
13	Flight control system failure				√	
14	Flight crew incapacitation				√	
15	Ice accretion on aircraft in flight				√	
16	Airspeed, altitude or attitude display failure				√	
17	Aircraft encounters thunderstorm, turbulence, or wake vortex				√	

18	Single engine failure in flight				√	
19	Unstable approach	√			√	
21	Aircraft weight and balance outside limits during approach				√	
23	Aircraft encounters wind shear during approach or landing	√				
25	Aircraft handling by flight crew inappropriate during flare	√				
26	Aircraft handling by flight crew inappropriate during landing roll	√				
27	Aircraft directional control related systems failure during landing roll	√				
31	Aircraft are positioned on collision course in flight		√			
32	Runway incursion					√
33	Cracks in aircraft pressure cabin				√	
35	TAWS alert			√		
36	Conflict on taxiway or apron					√
38	Loss of control due to poor airmanship				√	

Table 3: Table matching ESD end states with EASP categories.

ESD end state	**Used in ESD**	**EASP category**
Runway excursion	1, 2, 3, 4, 5, 9, 10, 19, 23, 25, 26, 27	Runway excursion
Collision with ground	5, 6, 8, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 21, 23, 37, 38	LOC-I
In flight break-up	17, 33	LOC-I
Collision in mid-air	31	Mid-air collision
Collision on runway	32	Ground collision
Collision with ground	35	CFIT
Collision on taxiway or apron	36	Ground collision

3 Representation of future risks in risks models

3.1 Introduction to future/emerging risks

First, let's try to define simply what we put behind the terminology of "future/emerging risks".

WHAT is a future/emerging risk?

Reminder: a risk is characterized by its likelihood and severity.

In this study:

A "**current/known risk**" is defined by its severity and the current/known likelihood of its components (failures, errors represented by fault trees) accepted in the certification process.

An "**emerging risk**" is defined as a familiar risk that is increasing or a new risk that becomes apparent in new or unfamiliar conditions (derived from IRGC, 2010).

Familiar risks here refer to the current/known risks that are identified and accepted during the certification process.

Emerging risk can be:

a) A current/known risk with the same Severity but with a different Likelihood of its components taking into account the influence of new technologies, behaviours, work organizations, regulations, operational procedures etc.,

b) A current/known risk with a new Severity and the same Likelihood of its components,

c) A current/known risk with a new Severity and a new Likelihood of its components.

d) A new risk resulting from the interactions of multiple contributors that may not have been fully anticipated, in an environment in evolution.

A "**future risk**" is defined as a risk associated with the future introduction of a novelty (e.g. new design, new procedure, and new organization)

WHY considering future/emerging risk?

Considering future/emerging risk is a good way to avoid future disasters but without forgetting that the future can never be entirely predicted.

WHERE considering future/emerging risk?

In the ASCOS project, the emerging/future risk will be linked to Events Sequence Diagrams (ESD) developed through the "Causal Model for Air Transport Safety" (CATS) tool for the five (5) risk domains identified in the EASP and reminded in section 3.1.

HOW:

Incident/accidents "precursors" associated to Future/Emerging risks will be introduced in CATS Events Sequence Diagrams (ESD). A definition of "precursor" is given in the following section.

3.2 Precursor Definition

The generic definition of precursor is given in the WP3.1 report. In this study, the following refinement of the definition is proposed:

A precursor is defined as an "**identifiable event that may be used as early warning for known or potential hazards**". Such early warnings may be:

- Events identified and currently monitored, for which the potential to become hazardous is known to be significant
- Events known yet, but for which risk to become hazardous may have been underestimated, neglected or even unidentified up till now, unless revealed by an actual occurrence of the hazard

A systematic precursors capture process is an efficient means for enhancing and maintaining risk awareness and for proactive identification of safety actions.

3.3 Causal Model for Air Transport Safety (CATS)

The following figure is extracted from the CATS final report of March 2009 [2]. It permits to remind the basic CATS constituents. The aim is to follow the events path conducting to an aircraft accident.

ESD = Event Sequence Diagram, FT = Fault Tree, BBN = Bayesian Belief Net, IE= Initiating Event

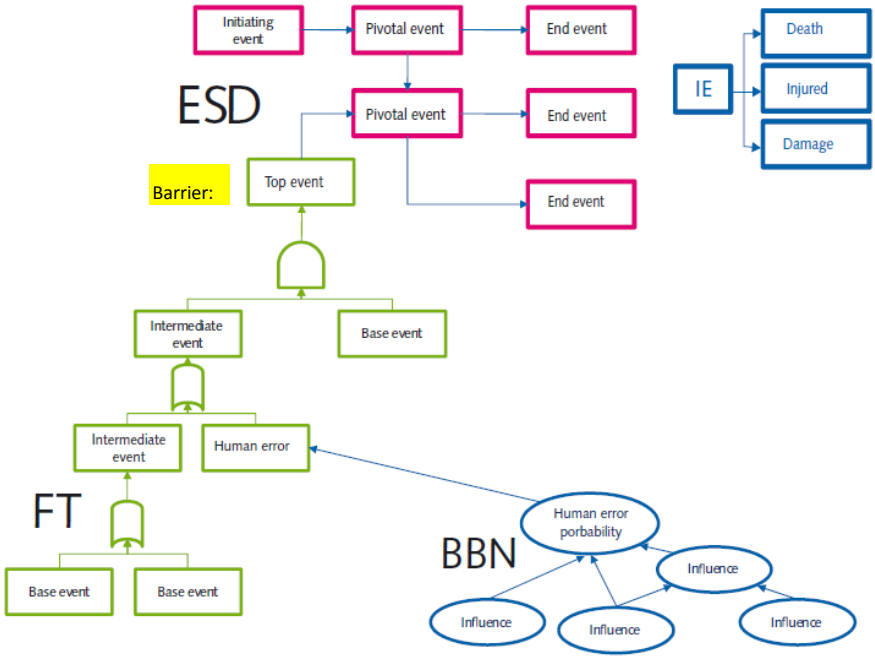

Figure 7: The basic constituents of CATS

The NLR Excel Table V0.1 for ASCOS contains 33 Events Sequence Diagrams (ESD) [6] representing the major initiating events.

The objective is now to try to find a way to enrich this causal model in order to take into account precursors to assess future and emerging risks.

3.4 Analysis of the link existing between precursor and defence/control (safety barrier)

3.4.1 Preamble

Assumption: a precursor is an event linked to a safety barrier for which it decreases its efficiency. This safety barrier is the one implemented in the design of the system (e.g. redundancies, safety studies) or in operational procedures (e.g. crew, maintenance, air traffic management, airport and training procedures).

To verify this assumption and make it generic, it is necessary to start from a set of precursors already identified in ASCOS WP 3.1 (Aviation Safety Assessment Methodology) and to make a link with the safety barriers and base events that are represented in the CATS ESDs.

This will be done in 6 steps

3.4.2 Step 1 – Association of CATS ESDs to EASA main operational issues

The first step consists in allocating each CATS ESD [6] to an EASA main operational issue:

1) Ground collision
2) Runway excursions
    a) At take-off
    b) At landing
3) Controlled Flight into Terrain (CFIT)
4) Loss of control in flight
5) Mid-air collisions

The result is presented in Table 2 (section 2.4.3.) We can see that:

- 2 Event Sequence Diagrams can be linked to Ground Collision risk domain,
- 7 to Runway Excursion at Take-Off,
- 1 to Controlled Flight into Terrain
- 19 to Loss of Control in Flight
- 1 to Mid-Air Collision
- 5 to Runway Excursion at Landing.

Runway excursion <u>at take-off</u> is selected to test the proposed methodology. The selection was made because seven ESDs are linked to it and it seems to be a representative sample to test the methodology that we are proposing in this section. Therefore the following steps deals only with the **runway excursion <u>at take-off</u>** risk domain. However, the general process is considered equally applicable for all EASA main operational issues.

In order to better understand the CATS ESDs linked to runway excursion/overrun at take-off, it is necessary to define the take-off characteristics speeds:

Speed for rejected take-off decision

Figure 8 (see reference [7]) below illustrates the relation between the speed at which a take-off is rejected and the likelihood of a runway excursion:

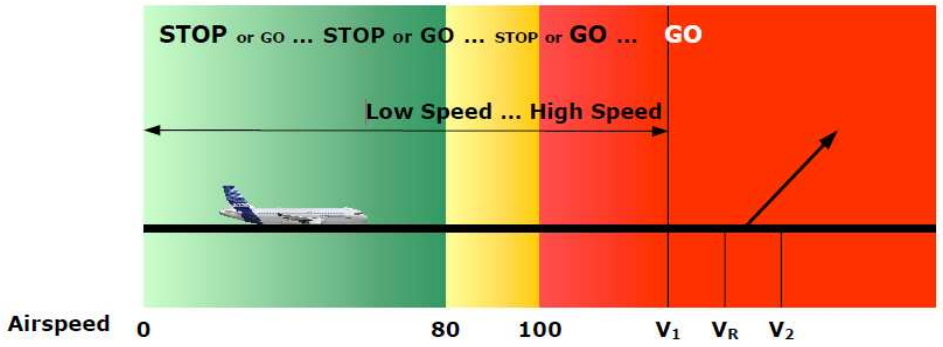

Figure 8: Schematic of the relation between take-off rejection speed and likelihood of a runway excursion

The statistics and experience have shown that, as soon as the aircraft reaches **100 knots**, the safest course of action is for the flight crew to continue the take-off, unless a major failure or a serious situation occurs. Moreover, experience has shown that if Rejected Take-Offs (**RTOs)** are performed when the take-off distance is ASD-limited (Acceleration-Stop Distance), and if the take-off is rejected at V1, the consequences could be hazardous even if the performance is correctly calculated.

IATA data on runway excursions on year 2009

The following statistics illustrate the risk-factors related to runway excursions during atke-off:

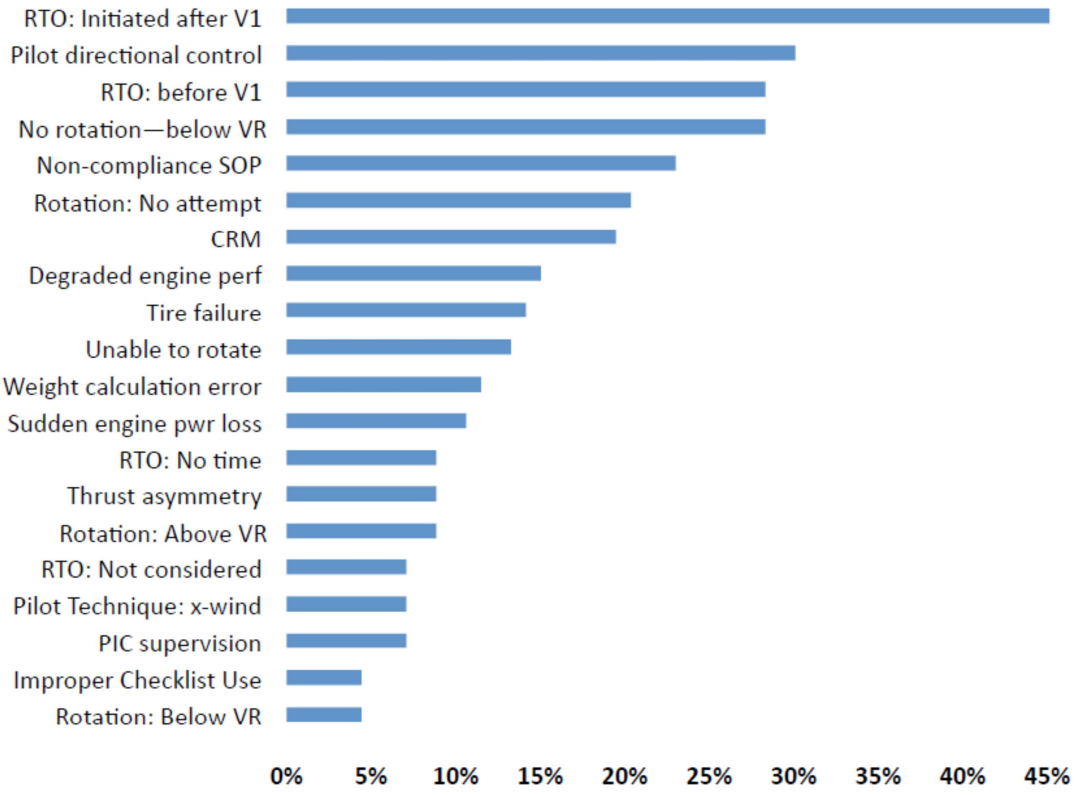

Figure 9: IATA data on runway excursions on year 2009

Runway excursions (at take-off and landing) constitute approximately 27% of all accidents. These accidents can be prevented through training, awareness of the threats, and in applying good judgment to reduce the risk (Refer to **Error! Reference source not found.** for more details).

3.4.3 Step 2 – Association of precursors (occurrences, deviations) and defences/controls when possible

The second step consists in considering a precursor list to identify the safety barriers that are impacted. In the following we consider a list of precursors identified in ASCOS WP 3.1 (Aviation Safety Assessment Methodology). This list is the results of a study performed by Michel Tremaud in the context of the Flight Safety Foundation [9].

This study provides tables of precursors (mainly considered with the point of view of a pilot) for several risk domains. It gives also a list of defences and controls (safety barriers) associated to each risk domain but without a link between precursors and defences/controls.

In the following, the table related to the runway excursion/overrun at take-off has been worked out in order to identify the links between precursors and safety barriers. Doing that, missing precursors and missing safety barriers were identified. They were introduced in the table and they are highlighted in italic font.

PRECURSORS		**DEFENCES/CONTROLS**
Occurrences (Uneventful Events)	**Deviations (Procedural/Flight Path)**	**Prevention (Detection/Recovery)**
Line-up events	Inadequate technique for line-up or 180-degree turn on runway	Line-up technique
Wild life incursion		Effective wildlife / bird control program
Bird strike		Effective wildlife / bird control program
Rejected takeoff whether initiated below or above 100 kt) ***(+) due to an aircraft system failure including engine***		Industry prevention strategies and best practices
Aircraft swerve / lateral excursion during takeoff roll		***(+) None***
Runway incursion		***(+) ATC/Airport monitoring procedure***
Takeoff from taxiway		***(+) Airport procedure + ATC clearance***
Runway confusion		***(+) Airport procedure + ATC clearance***
Inappropriate intersection takeoff or takeoff from incorrect intersection		***(+) Airport procedure + ATC clearance***
Cautions / warnings (genuine or spurious) that may lead to a low-speed or high-speed rejected takeoff		***(+) Cautions / warnings inhibition at take-off***
Other cockpit effects/malfunctions (genuine or spurious) occurring during takeoff roll		***(+) None***
Tire burst		***(+) Certification process of tire*** ***(+) Compliance of in-service tire burst with tire burst PRA model***
		(+) Effective runway maintenance program for periodic Foreign Object removal
	Late rejected takeoff decision / initiation	Readiness for possible stop or go scenarios (being go-minded whenever warranted)
	Premature rotation (i.e., below VR)	. Adherence to SOP's (task sharing, briefings, use of checklists, standard calls and excessive-deviation callouts, mutual crosscheck and backup) . Enhanced monitoring and cross-check ***(+) Premature rotation handling procedure***
	Late rotation (i.e., above VR)	***(+) Late rotation handling procedure***
	Slow rotation (i.e., low pitch rate)	***(+) Slow rotation handling procedure***
	Low pitch attitude after lift-off	***(+) Low pitch attitude handling procedure***
	Excessive taxi speed	***(+) Speed limitation procedure during taxi***
		(+) V1 Auto Callout when installed

PRECURSORS		DEFENCES/CONTROLS
Occurrences (Uneventful Events)	**Deviations (Procedural/Flight Path)**	**Prevention (Detection/Recovery)**
	Inadequate engine stand-up technique	. Cross-check of takeoff data : weight-and-balance, stab-trim setting, fuel distribution, runway conditions, wind component, outside air temperature, corrections (QNH, air conditioning, anti-ice, …) flaps setting, V1 / VR speeds, assumed temperature / reduced or full thrust setting, … . Awareness of prevailing takeoff performance-limiting factor (available acceleration-stop distance or other limitation)
	Gross error in takeoff weight entry and/or in V1 / VR speeds assessment	. Cross-check of takeoff data : weight-and-balance, stab-trim setting, fuel distribution, runway conditions, wind component, outside air temperature, corrections (QNH, air conditioning, anti-ice, …) flaps setting, V1 / VR speeds, assumed temperature / reduced or full thrust setting, … . Awareness of prevailing takeoff performance-limiting factor (available acceleration-stop distance or other limitation)
	Incorrect stab-trim setting	***(+)Take-Off Configuration Warning and associated procedure***
	Undetected incorrect takeoff configuration	***(+)Take-Off Configuration Warning and associated procedure***
	(+) Incorrect minimum turn-around time	Compliance with "minimum turn-around time", as applicable, to ensure adequate brakes energy ***(brake temperatureat line up)*** Takeoff briefing highlighting the specific / non-routine aspects of the takeoff
	(+) Airport: poor runway cleaning maintenance program	Effective runway maintenance program for periodic rubber-deposit removal

Table 3: Link between precursors (occurrences or deviations) and defences/controls when it exists

3.4.4 Step 3 – Link between updated precursors list (occurrences, deviations) and CATS ESDs initiating events

The third step consists in linking the updated precursors list with CATS ESDs initiating events.

The following initiating events associated to the seven CATS ESDs are reminded here:

CATS ESD#	Initiating event
1	Aircraft system failure
2	ATC event
3	Aircraft handling by flight crew inappropriate
4	Aircraft directional control related systems failure
5	Incorrect configuration
9	Single engine failure
10	Pitch control problem

Table 4: Reminder of CATS ESDs Initiating Events related to runway excursion/overrun at take-off

Precursors : Occurrences (Uneventful Events)	ESD#
Takeoff from taxiway	2
Runway confusion	2
Inappropriate intersection takeoff or takeoff from incorrect intersection	2
Line-up events	2-3
Rejected takeoff (whether initiated below or above 100 kt) ***(+) due to an aircraft system failure including engine***	1-2-3-4-5-9-10
Tire burst	1-4-9
Aircraft swerve / lateral excursion during takeoff roll	4
Cautions / warnings (genuine or spurious) that may lead to a low-speed or high-speed rejected takeoff	1-9
Other cockpit effects / malfunctions (genuine or spurious) occurring during takeoff roll	1-9
Runway incursion	None
Wild life incursion	2
Bird strike	9

Table 5: Link between precursors (occurrences) and CATS ESD number

Precursors : Deviations (Procedural/Flight Path)	ESD#
Excessive taxi speed	None
Inadequate technique for line-up or 180-degree turn on runway	3
Inadequate engine stand-up technique	3
Gross error in takeoff weight entry and/or in V1 / VR speeds assessment	3
Incorrect stab-trim setting	5
Undetected incorrect takeoff configuration	5
Late rejected takeoff decision / initiation	3
Premature rotation (i.e., below VR)	3-10
Late rotation (i.e., above VR)	3-10
Slow rotation (i.e., low pitch rate)	3-10
Low pitch attitude after lift-off	3-10

Table 6: Link between precursors (deviations) and CATS ESD number

3.4.5 Step 4 – Link between defences/controls updated list and CATS ESD number

The fourth step consists in linking the Defences/Controls updated list with CATS ESD#.

Defences/Controls **Prevention** **Detection / Recovery**	**ESD#**
Industry prevention strategies and best practices	1-2-3-4-5-9-10
Adherence to SOP's (task sharing, briefings, use of checklists, standard calls and excessive-deviation callouts, mutual crosscheck and backup) ***(+) Premature rotation handling procedure***	5
Cross-check of takeoff data : weight-and-balance, stab-trim setting, fuel distribution, runway conditions, wind component, outside air temperature, corrections (QNH, air conditioning, anti-ice, …) flaps setting, V1 / VR speeds, assumed temperature / reduced or full thrust setting, ...	3-5
Awareness of prevailing takeoff performance-limiting factor (available acceleration-stop distance or other limitation)	3
Compliance with "minimum turn-around time", as applicable, to ensure adequate brakes energy ***(brake temperature at line up).*** Takeoff briefing highlighting the specific / non-routine aspects of the takeoff	1-2-3-4-5-9-10/ Maximum braking
Line-up technique	3
Readiness for possible stop or go scenarios (being go-minded whenever warranted)	1-2-3-4-5-9-10
Enhanced monitoring and cross-check	1-2-3-4-5-9-10
Effective wildlife / bird control program	2-9
Effective runway maintenance program for periodic rubber-deposit removal	1-2-3-4-5-9-10/ Maximum braking
(+) Certification process of tire ***(+) Compliance of in-service tire burst with tire burst PRA model***	1-4-9
(+) Effective runway maintenance program for periodic Foreign Object removal	1-4-9-10
(+) Late rotation handling procedure	
(+) Slow rotation handling procedure	
(+) Low pitch attitude handling procedure	
(+) Speed limitation procedure during taxi	
(+) ATC/Airport monitoring procedure	
(+) Airport procedure + ATC clearance	

Table 7: Link between defences/controls and CATS ESD number

3.4.6 Step 5 – Link between defences/controls updated list and CATS ESD safety barriers

The fifth step consists in linking the Defences/Controls updated list with CATS ESD safety barriers for which the list is the following:

CATS ESD#	CATS Initiating Event	CATS Barriers
1	Aircraft system failure ***(+) excepted engine (ESD #9) and directional control (ESD #4)***	- Aircraft System Integrity - RTO **(procedure)** - Maximum Braking **(V<V1)**
2	ATC event	- Air Traffic Hazard Avoidance - RTO - Maximum Braking **(V<V1)**
3	Aircraft handling by flight crew inappropriate	- Take-off Roll Handling - RTO **(procedure)** - Maintain Control **(V<V1)** - Maximum Braking **(V<V1)** - Maintain Control
4	Aircraft directional control related systems failure	- Directional Control Systems Integrity - RTO **(procedure)** - Maintain Control **(V<V1)** - Maximum Braking **(V<V1)** - Maintain Control
5	Incorrect configuration	- Take-off configuration setting and verified - Take-Off Configuration Warning - RTO **(procedure)** - Maximum Braking **(V<V1)** - Stall avoidance **(V<V1)** - Control recovery **(V<V1)**
9	Single engine failure	- Engine integrity - RTO **(procedure)** - Maintain Control **(V<V1)** - Maximum Braking **(V<V1)** - Maintain Control
10	Pitch control problem	- Pitch control - RTO **(procedure)** - Maximum Braking **(V<V1)** - Rotation

Note: The blue text in bold is additional precision.

Table 8: List of CATS barriers associated to CATS initiating event

Defences/Controls Prevention Detection / Recovery	ESD#	ESD# Barriers
Industry prevention strategies and best practices	1-2-3-4-5-9-10	. RTO decision . Take-Off Configuration Warning
Adherence to SOP's (task sharing, briefings, use of checklists, standard calls and excessive-deviation callouts, mutual crosscheck and backup) ***(+) Premature rotation handling procedure***	5	. Take-off configuration setting and verified
Cross-check of takeoff data : weight-and-balance, stab-trim setting, fuel distribution, runway conditions, wind component, outside air temperature, corrections (QNH, air conditioning, anti-ice, …) flaps setting, V1 / VR speeds, assumed temperature / reduced or full thrust setting, ...	3-5	. Take-off roll handling . Take-off configuration setting and verified
Awareness of prevailing takeoff performance-limiting factor (available acceleration-stop distance or other limitation)	3	. Take-off configuration setting and verified
Compliance with "minimum turn-around time", as applicable, to ensure adequate brakes energy ***(Brake temperature at line up)*** Takeoff briefing highlighting the specific / non-routine aspects of the takeoff	1-2-3-4-5-9-10/Maximum braking	. Maximum braking
Line-up technique	3	. Take-off configuration setting and verified
Readiness for possible stop or go scenarios (being go-minded whenever warranted)	1-2-3-4-5-9-10	. RTO decision
Enhanced monitoring and cross-check	1-2-3-4-5-9-10	. Take-off configuration setting and verified
Effective wildlife / bird control program	2-9	. Air Traffic Hazard Avoidance . Engine integrity
Effective runway maintenance program for periodic rubber-deposit removal	1-2-3-4-5-9-10/Maximum braking	. Maximum braking
(+) Certification process of tire burst	1-4-9	. Aircraft System Integrity . Directional Control Systems Integrity . Engine Integrity
(+) Effective runway maintenance program for periodic Foreign Object removal	1-4-9-10	. Aircraft System Integrity . Directional Control Systems Integrity . Engine Integrity . Pitch Control ***because FOD can be responsible of pitch jamming, engine failure and systems failure (brakes and directional control)***
(+) Late rotation handling procedure		
(+) Slow rotation handling procedure		
(+) Low pitch attitude handling procedure		
(+) Speed limitation procedure during taxi		
(+) ATC/Airport monitoring procedure		
(+) Airport procedure + ATC clearance		

Table9: Link between defences/controls precursors and CATS ESD barriers

3.4.7 Step 6 - Link between precursors and CATS base events of safety barrier fault trees

In CATS ESD each safety barrier is associated with a fault tree showing how “base events” (failures, errors, procedure deviations) can lead to an infringement of the safety barrier. Using the identification made in step 5 between defence and control (Michel Tremaud’s safety barriers and CATS ESD safety barrier, the Michel Tremaud’s precursors can be easily put in relation with the CATS ESD base events.

If one precursor of the Michel Tremaud list has no link with a CATS ESD fault tree “base event” this means that the CATS ESD fault tree should be reconsidered for potential update.

3.5 Methodology/modifications proposal to take into account emerging risks in CATS ESDs

The results of section 3.5 have shown that precursors should be associated to base events of the CATS fault trees. In case a precursor cannot be associated to a base event, concerned CATS ESD should be reviewed to incorporate a new safety barrier or a new base event.

3.5.1 Generic CATS ESD for the risk domain “Runway excursion »

The seven (7) CATS ESD associated to the risk domain “Runway excursion at takeoff” have many pivotal events in common. Nevertheless they are not completely similar like if they have been derived from a generic ESD after customization according to the initiating event considered. From these seven (7) CATS ESDs let’s try to build a generic CATS ESD with a complete set of pivotal events and safety barriers.

The Generic ESD is illustrated in the following figure:

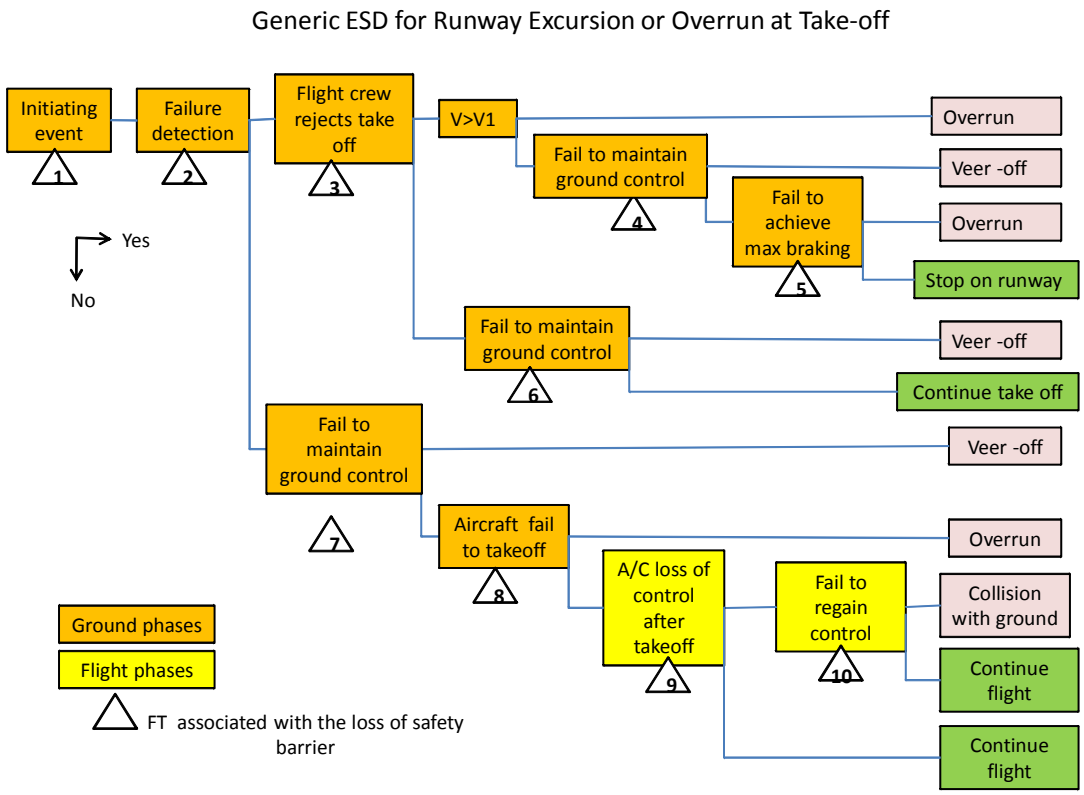

Figure 10: Generic ESD for Runway Excursion or Overrun at Take-off

3.5.2 Example of using generic ESD

Depending from the initiating event considered, the generic CATS ESDs can be customized by removing pivotal events and safety barriers that are not significant.

Example: for the initial event "Aircraft system failure" the part associated to aircraft in flight is not significant and can be deleted. The ESD is now:

Example: runway excursion/overrun at take off with Initiating event "aircraft system failure"
Boxes in italic are those that are new compared to the initial CATS ESD associated to initiating event "System failure"

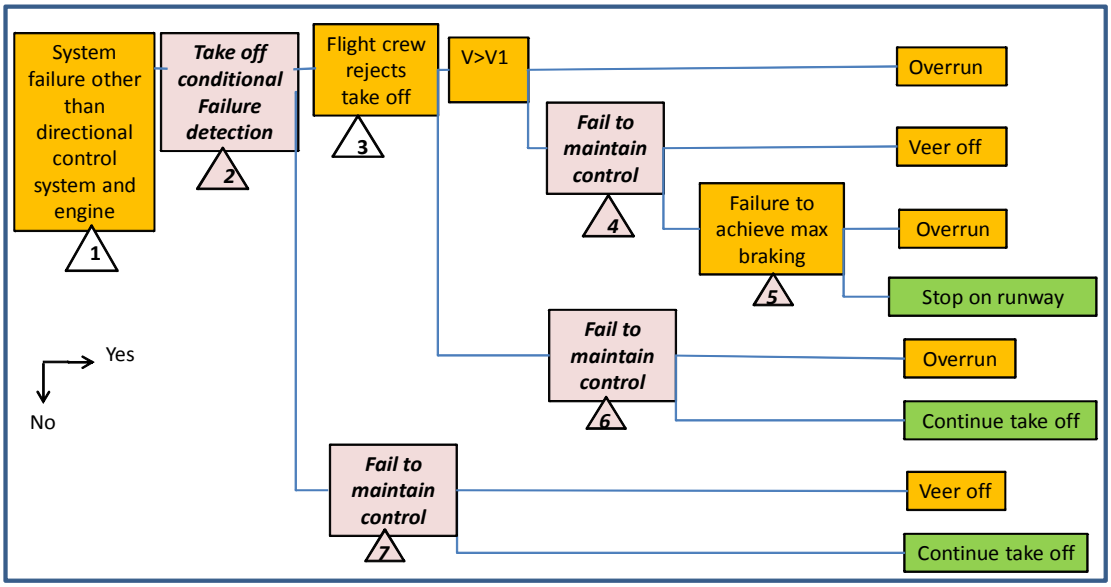

Figure 11: Runway excursion/overrun at take off with Initiating event "aircraft system failure"

If we consider that the initiating event “Aircraft system failure” has no influence on the control of aircraft on ground, it is possible to simplify the ESD by removing the “Fail to maintain control” boxes. The simplified ESD becomes:

Example: simplified runway excursion/overrun at take off with initiating event “aircraft system failure” with the assumption that system failure do not compromise aircraft control (“Fail to control boxes” can be deleted)

Boxes in italic are those that are new compared to the initial CATS ESD associated to initiating event “System failure”

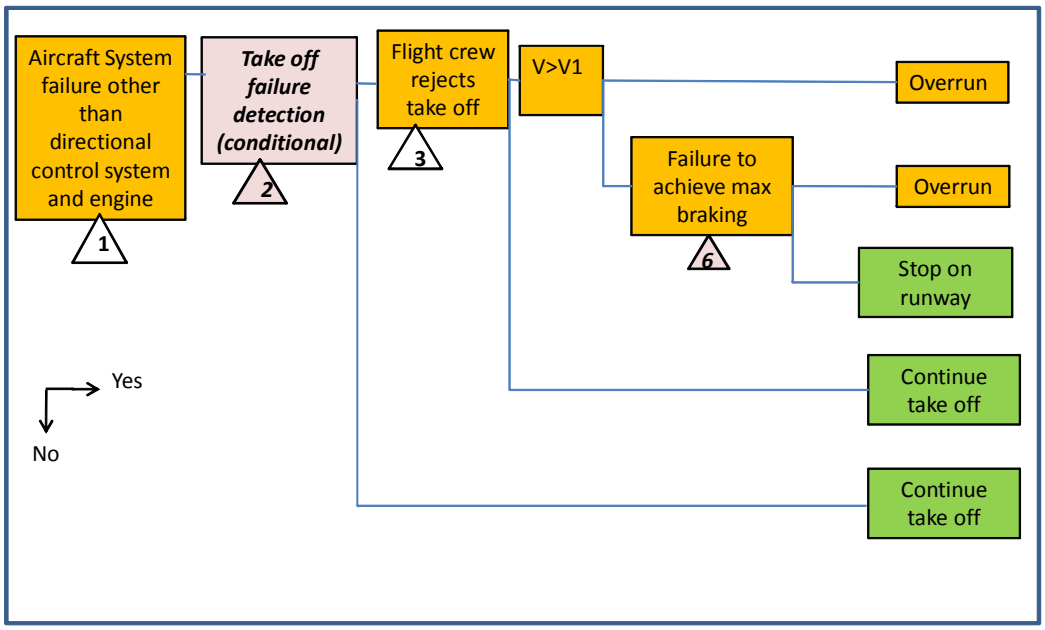

Figure 12: Simplified runway excursion/overrun at take off with initiating event “aircraft system failure”

On the above figure we can see that the original CATS ESD should be updated where there are boxes in italic:

- Introduce an additional pivotal event “take off failure detection (conditional)”: the pilot cannot decide a rejected takeoff if she/he is not aware of the system failure (warning or aircraft behavior). At take-off, above 100Kt, most system failure warnings are inhibited. This warning inhibition is a safety barrier to minimize the number of unnecessary RTO.
- Develop the fault tree associated to the above safety barrier
- Update the “failure to achieve max braking” fault tree to incorporate the following base events: “brake too hot at line up” and “runway rubber deposit removal”

The complete picture is illustrated in the following figure

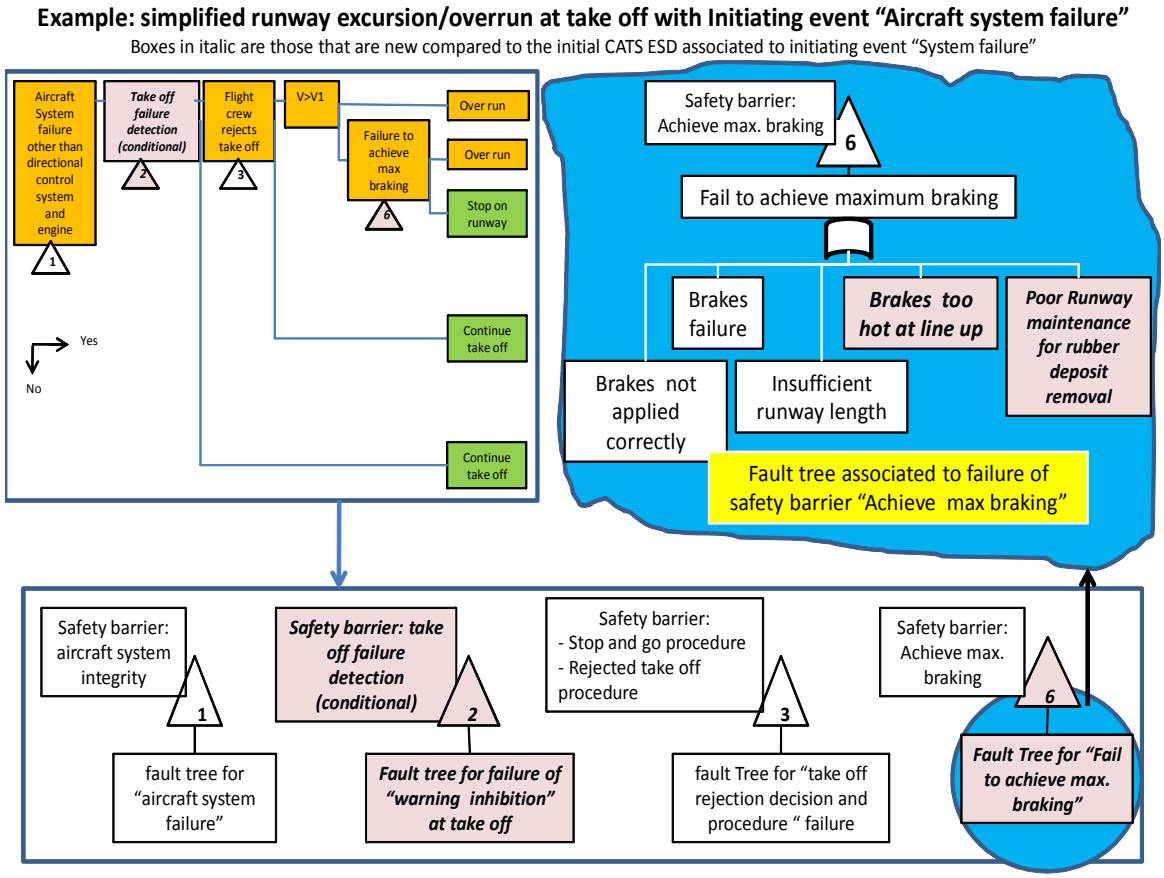

Figure 13: Simplified runway excursion/overrun at take off with initiating event "aircraft system failure" with safety barriers

An example of the Fault tree associated to the safety barrier “take off failure detection (warning inhibition at take-off)” is given here after:

Example: Fault tree associated to failure of warning inhibition system at take off

Boxes in italic are those that are new compared to the initial CATS ESD associated to initiating event “System failure”

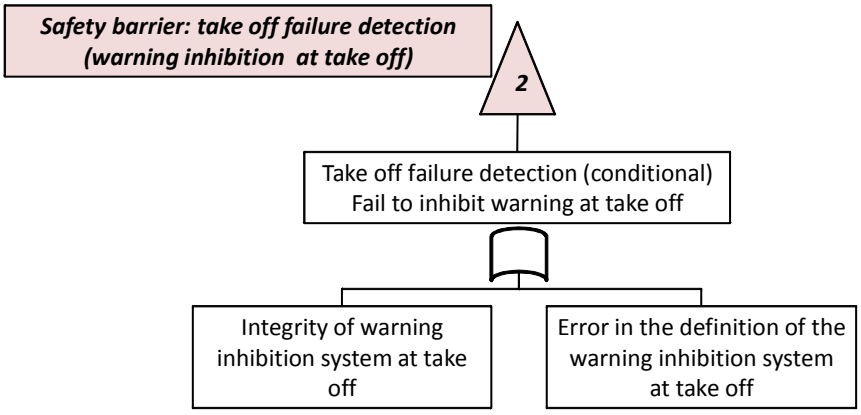

Figure 14: Fault tree associated to failure of warning inhibition system at take off

3.5.3 CATS ESD completeness

From the above described process, considering emerging risk in CATS ESD needs to work with CATS ESDs that are complete. This means that all initiating events are envisaged, all pivotal events are recognized, no safety barrier is forgotten and no base event in fault trees is overlooked. This can be done by reviewing the CATS ESDs with experienced people that have different points of view (e.g. design, maintenance operation, pilots, flight operation, ground operation, airport operation, ATM operation).

3.6 Proactive research of precursors

3.6.1 Use of updated ESD

Because precursors can be related to "base events" of the CATS ESDs, these based events after updating can be used for precursor identification and development of precursor event capture process. For example the base event "brake too hot" refers to the precursor: non application by the flight crew of the procedure "brake temperature monitoring at line up". The process for research of these precursor events should be the recording of the brake temperature at line up and analysing the deviations to the procedure. The results of these capture processes will be used to recalculate the risk level by using CATS ESDs Fault Trees. This process is illustrated in the following figure:

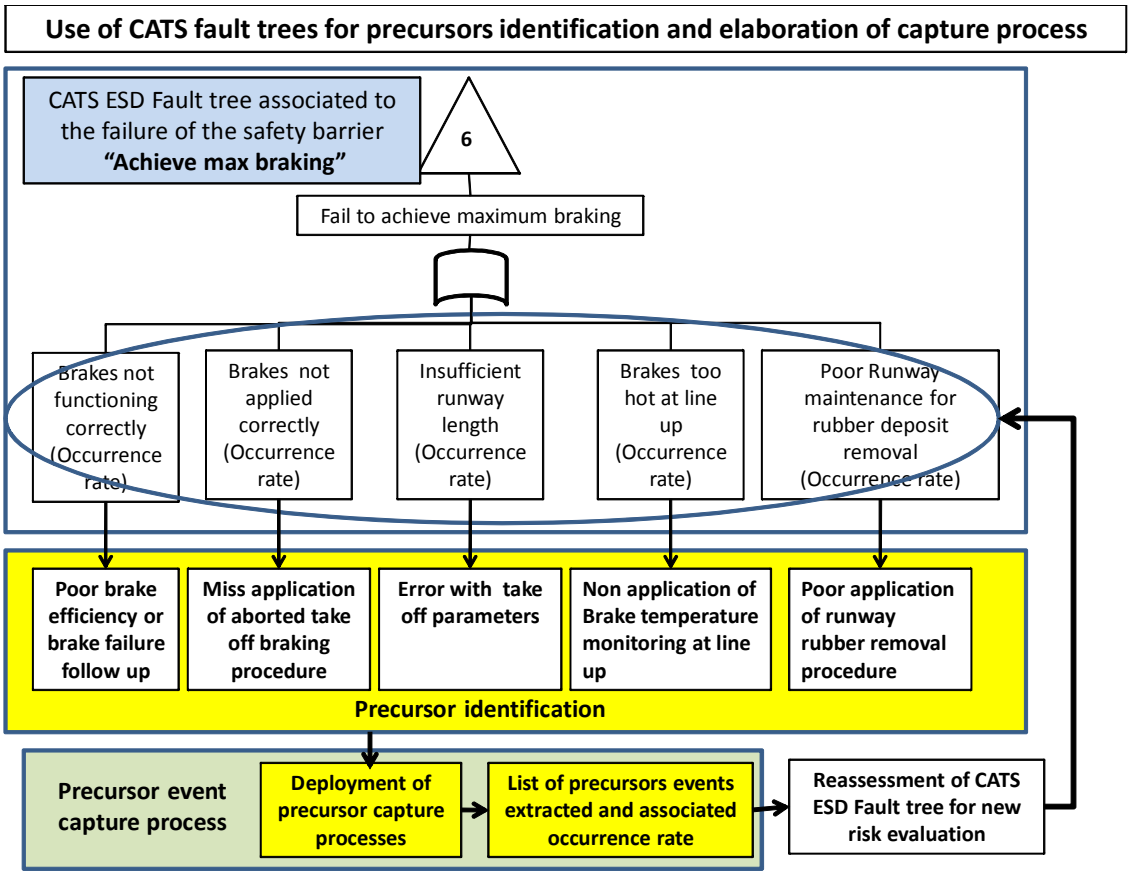

Figure 15: Use of CATS fault trees for precursors identification and elaboration of capture process

To illustrate precursor identification and related capture process, appendix A provides a more general example of identification of precursors from the base events of CATS ESDs. It starts with the analysis of the CATS base

events, considering in what respect they are an infringement of one or several safety barriers, and then how this infringement could be linked to existing or improved monitoring processes.

In this example, only ESD related to Runway excursion at Take-off are considered. They comprise ESD 1, 2, 3, 4, 5, 9 and 10. For each base event description provided in CATS ESDs, one or several precursors are attached to. Complete results of this review are presented in Appendix D.

The precursors that could have been identified in the appendix A analysis are summarized in the following table, together with a proposed method appropriate for capturing such precursors.

Precursor category	**Type of capture process**
• *Flaws in system design or manufacturing or maintenance processes.*	*Use of In-service monitoring system currently implemented for in service occurrence reporting.*
• *Inadequate maintenance of runway.*	*Use of Reporting system for events and deviations to the aerodrome manual instructions related to runway maintenance (in SMS).*
• *Poor or inefficient bird hazard reduction procedure.*	*Use of Reporting system for events and deviations to the aerodrome manual instructions related to Bird/Wildlife Control and Reduction.*
• *Lack of adherence to SOP for GND movements.* o *Inefficient / confusing TWR traffic control procedures, inefficient management of hot spots.* o *Inadequate application of call sign deconfliction rules.* o *Lack of awareness of other traffic movements through ATC communication listening.*	*Use of Reporting system for in service ground events (including Airlines, ATC, Airport).*
• *High Energy RTO rate is an indicator of improper Operator's policy for T/O operations.*	*Use of In-service monitoring system currently implemented for in service occurrence reporting.*

• *Poor application of T/O & RTO procedure:* o *Computation / check of T/O parameters.* o *Application of AFM limitations (residual brake energy,…).* o *Criteria for STOP decision.* o *Braking initiation sequence.* o *Aircraft handling (crosswind, gusts).* o *Failure recognition and preparedness (tire, engine,…).* o *Adherence to SOP* o *Use of MET/ATIS information*	*- Use of Line Operation Safety Assessment (LOSA) reports* *- Use of evaluation system for flight crew performance at the beginning and at the end of the training sessions.* *- Flight data monitoring analysis (FDM)*

Table 40: Link between precursors categories and type of capture process

3.7 Precursors list and product design process

3.7.1 Identifying Safety barriers

From the analysis made in previous chapters, precursors are linked to the base events that make fail safety barriers identified in the CATS ESDs. However safety barriers identified in CATS ESDs are those implemented in the design during the development process of a product (including operational procedures). Then the questions are:

- Can we identify early in the development process of a product the list of safety barriers the design is built upon?
- Can we find, in safety assessments used for certification, the base events that make fail the safety barriers?
- From the base events can we make early in the development process a list of precursors to look at?

The safety barriers are implemented in the design of a product by the designers (structural margins, redundancies, independences, monitoring and warnings, installation segregations, operational procedures, Development Assurance Level (DAL), compliance with a behavior model, etc.) to ensure compliance with certification objectives.

The base events that make fail the safety barriers are considered in safety assessments and used to build failure conditions fault trees showing compliance with the certification objectives (certification process). Even if the formalism used for safety assessments Fault Trees is not exactly the same as in CATS ESDs, the content of these Fault Trees can be rearranged to identify safety barriers with associated base events, and use them to populate the CATS ESDs.

As an example let's consider the aircraft braking system and its participation in the runway overrun overall risk picture. 4 types of documents can be used to identify safety barriers:

- Functional safety assessments (AFHA, SFHA, PASA, PSSA, SSA, ASA) - These safety assessments consider functional failure repercussions as well as hardware and software failure repercussions
- Structural safety analyses
- Particular Risk Analysis (PRA) (tire burst/wheel rim damage analysis)
- Flight manual (identification of all normal and abnormal operational procedures)

From these documents and for wheel/tire and braking system we can identify the following safety barriers implemented in the design and having influence on the runway overrun risk picture:

1) Inhibition of most of system failure warnings at 100 knots to minimize the rejected take-off at high speed
2) Tire pressure detection system and associated "flat tire" warning
3) Brake temperature detection system and application of "Brake temperature monitoring" procedure at line up
4) Tire robustness characteristics that allow a take-off run between 100 knots and Vloff (V Lift Off) with a flat /burst tire without the burst of the companion tire
5) Pilot instructions for aborted take-off decision (application of "Go-minded" and "aborted take-off" procedures before 100 knots, between 100 knots and V1, after V1).
6) Tire burst/thread release characteristics in accordance with the tire burst/thread release model used for particular risk analysis
7) Installation precautions to segregate the hydraulic pipes and electrical wirings of braking system to minimize destructions in case of tire burst in accordance with the certification model.
8) Braking system reliability performance

3.7.2 Establishing precursors list from safety assessments

From the above we can see that a safety barriers list and associated base events can be generated in relation with safety assessments. Nevertheless, it should be recognized that some safety barriers may remain implicit in safety assessments documents. For example, among the safety barriers listed in the previous paragraph, the three last ones (6, 7 and 8) are explicit in the systems safety assessment (SSA) and particular risk analysis (PRA). The others may be implicit assumptions in the functional hazard analysis (FHA) but described inside the product description and operational documentation. A specific task should be performed to make a complete list of safety barriers to be used in CATS ESDs.

The complete method and the way to use the safety assessments results to build risk models (e.g. CATS ESDs) will be developed in ASCOS WP3.5.

3.8 Consideration of future risks

Future risks are linked to introduction of novelties

- In product design (e.g. new technologies, new composites, new development procedure, new management organization)
- In product operating (e.g. new regulation, new operational procedure, new ground/aircraft communication protocol, new flight crew work organization)

The analysis of the impact of each novelty should be done before its implementation in order to assess the future risks and identify:

- The existing safety barriers which are affected by this novelty
- The new safety barrier to be implemented for mitigating the future risks.

This should be done by reviewing existing CATS ESDs that may be impacted and/or by developing new CATS ESDs. Then the process is similar as the one described for “emerging risk”:

- Performing safety assessments in relation with the novelty to be implemented,
- Identifying from safety assessment fault trees safety barriers and base events in relation with the novelty
- Reviewing CATS ESDs for completeness of initiating events, pivotal events, safety barriers, and base events
- Identifying events that can be considered as new precursors in case the novelty is implemented
- Defining the capture process of new precursor and applying it on existing in service events data bases to estimate precursor occurrence rate
- Assessing the future risk using CATS ESDs.

3.9 Conclusions

The representation and the evaluation of the emerging/future risks using CATS ESDs can be done if each base event of the fault tree is linked to precursors and if a dedicated capture process is defined for these precursors. The application of the precursors capture process allows calculating the precursors occurrence rates and then the emerging/future risks by using CATS ESDs.

For that it is necessary to ensure that the CATS ESDs are sufficiently complete. This means that all initiating events are envisaged, all pivotal events are recognized, no safety barrier is forgotten and no base event in fault trees is overlooked. This can be done in two steps:

- Step 1: Using safety assessments and product description and operational documentation for identification of all safety barriers implemented in the design and ensuring that all these safety barriers are considered in CATS ESDs.
- Step 2: Reviewing the CATS ESDs with experienced people having different points of view (e.g. design, maintenance operation, pilots, flight operation, ground operation, airport operation, ATM operation).

It is recommended that these steps are taken if the model is used in any of the test cases that will be conducted in ASCOS work package 4.

4 Representation of safety culture and safety management

The objective of this section is to represent safety culture and safety management in accident scenarios. To meet this objective the section starts with a description of safety culture in 5.1 and safety management in 5.2. This is followed in 5.3 by a description of how safety culture and safety management are linked. In 5.3 experiences and difficulties in measuring safety culture are described, while section 5.4 describes how safety culture is influenced by factors that are outside the control of the organisation. Finally, section 5.5. addresses the difficulties of representing safety culture and safety management in accident scenarios.

4.1 A framework for Safety Culture

A Safety Culture is the attitude of an organization and of its members that helps the organization to maximize its own safety regardless of the leadership's personality and of the current commercial concerns. A strong safety culture ensures that the organization defines and continues to implement adequate safety measures also in the absence of bad outcomes (e.g. accidents). In essence this means creating a safety information system that collects, analyses and disseminates information from incidents to near misses as well as from regular proactive checks on the organization's vital signs.

According to James Reason [10] a Safety Culture encompasses the following components:

1. The **Reporting Culture**, which encourages employees to divulge information about all safety hazards that they encounter.

2. The **Just Culture**, which holds employees accountable for deliberate violations of the rules but encourages and rewards them for providing essential safety-related information.

3. The **Flexible Culture**, which adapts effectively to changing demands and allows quicker, smoother reactions to off-nominal events.

4. The **Learning Culture,** which is willing to change based on safety indicators and hazards uncovered through assessments, audits, and incident analysis.

As also argued in the White Paper by EUROCONTROL and FAA [11], all these activities can be said to make up an *informed culture*, one in which those who manage and operate the system have current knowledge about the human, technical, organizational and environmental factors that determined the safety of the system as a whole (see also figure 8 below). In the following subsections the four components of a safety culture proposed framework are further illustrated.

Figure 16: Key components of Safety Culture as illustrated in the White Paper on Safety Culture by EUROCONTROL and FAA

4.1.1 A Reporting Culture

Convincing people to file critical incident and near miss reports is a difficult task, particularly when it may entail divulging their own errors. Human reactions to making mistakes take various forms, but frank confession is not usually the first choice. Even when such personal issues do not arise, potential informants cannot always see the value in making reports, especially if they are sceptical about the likelihood of management acting upon the information. Is it worth the extra work when the benefit of it is uncertain? Moreover, even when people are persuaded that writing a sufficiently detailed account is justified and that some action will be taken, there remains the overriding problem of trust. Will I get my colleagues in trouble? There are some powerful disincentives to participating in a reporting scheme: extra work, scepticism, natural desire to forget that the incident ever happened, fear of reprisal, etc.

According to Reason [10] successful reporting programs indicate that five characteristics are important to create a climate of trust and to motivate people to file reports:

- Indemnity against disciplinary proceedings, as far this is practicable.
- Confidentiality or de-identification.

- Separation of the agency collecting and analysing the reports from those bodies with the authority of deciding on disciplinary proceedings and imposing sanctions.
- Rapid, useful, accessible and intelligible feedback to the reporting community.
- Ease of making the report.

If one of these characteristics of a reporting program is not applicable in the specific context or is seriously compromised in the concrete implementation there is an opportunity for a weak Safety Culture to develop with a potential negative effect on the safety record of the organization.

4.1.2 A Just Culture

An organization with a strong Just Culture is one in which the majority of its members share the belief that justice will usually and equally be dispensed, with an appropriate balance between the capability to learn from failures and accidents and the need to make the people accountable for their potential consequences. In the words of Reason [10] it can be explained with two basic principles:

- It would be quite unacceptable to punish all errors and unsafe acts regardless of their origin and circumstances.
- It would be equally unacceptable to give immunity from sanctions to all actions that could contribute to an accident.

The real difficult lies in discriminating between the truly 'bad behaviours' (e.g. sabotage in extreme cases) and the vast majority of unsafe acts for which the attribution of blame is neither appropriate nor useful, due to their origin in organizational factors and latent conditions. Therefore a prerequisite for engineering a just culture is an agreed set of principles for *drawing the line* between acceptable and unacceptable actions. However authors like Dekker [12, 13] argue that this approach might be challenged by the fact that culpable acts do not have intrinsic properties or immutable features and that the designation of acceptability or culpability is the result of a process of social construction steeped in context, language and history. In this respect it may be difficult to establish an a priori line between the acts an organization will accept and those it will not.

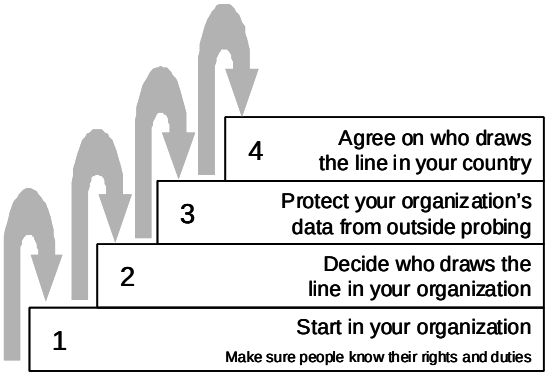

Figure 17: The staggered approach to Just Culture proposed by Sidney Dekker

Therefore the proposal of Dekker is to shift the attention from the *location of the line* to the decision about *who has the power to draw the line* in the concerned organization. Furthermore a special attention should be put on ensuring adequate protection of the organization's safety data from undue outside probing (e.g. a prosecutor). To summarize this, Dekker proposes a "staggered approach" to building a Just Culture which is described in figure 17. The approach consists of four main steps to building a just culture. Each subsequent step gets more difficult but contributes to the progress towards a just culture.

1. **Start in your organization**. This step includes the need to make sure that practitioners know their rights and duties in relation to incidents, in order to reduce the uncertainties also in a climate of potential anxiety. For example to whom they are obliged to speak (such as the investigators) and to whom not (such as the media). More in general this step is about establishing a climate of trust between the practitioners (e.g. air traffic controllers and pilots) and their managers. This may imply abolishing all financial and professional penalties in the wake of an occurrence, preventing the stigmatization of practitioners involved in an incident and building a staff safety department separate from the line organization (see previous section 4.1.1 in relation to the Reporting Culture).

2. **Decide who draws the line**. One important decision for an organization is who is going to decide whether a certain behaviour is to be considered acceptable or not acceptable. In this respect it is important to consider how to integrate the practitioner peer expertise in the decision on how to handle the aftermath of an accident, also taking into account the individual practitioner's stature. For example whether a practitioner should undergo retraining is something to be discussed not only with the practitioner in question, but also checked with a group of peers who can consider the wider implications of such a measure in the wake of an incident (for instance in the reputation of that practitioner, but also on the way incidents will be seen and treated by colleagues as a result).

3. **Protect your organization's data from outside probing**. The criteria for deciding which data can be made available to the judiciary system and which should remain protected in the event of an incident cannot be left to chance, cultural conventions or political pressure. Establishing clear criteria is essential for creating trust between stakeholders. Arguably the prosecutors will be willing to let an organization handle its own data when it has been given the assurance and confidence that the organization will come to it if a case is really like to be culpable. A more secure approach is that of clearly stating these criteria for the protection of the organization's critical data in law. However this approach should be counterbalanced with the potential consequences of this step. For example this may imply locking up the information even for those who rightfully want access to it, whose main aim is to find out something specific about what happened (consider the example of the patient, victim or family of the victim of a transportation accident).

4. **Agree on who draws the line in your country**. Having non domain experts to draw the line between acceptable and unacceptable behaviour can lead to serious risks and misjudgement of the situation occurred in the event of an accident or incident. As argued by Dekker the use of expert witnesses during a trial is likely to be inadequate or insufficient, as that role is always rather constrained and testimony limited. Therefore it would be profitable that the concerned organization starts a discussion with the prosecuting authority of the country on how to help them integrate domain expertise to support them in making better judgment about, for example, whether something is worthy of further investigation and prosecution (see also the following section 4.5.1). Different solutions have been proposed to address this goal, including the legal oversight by the judiciary of professional disciplinary rules established at local level, as well as the identification of a judge of instruction supported by a team of domain experts. However the need to overcome the potential for mistrust between the judiciary and the safety critical organization remains a very challenging goal. For example the judiciary system should be confident that all cases will be handled fairly and without prejudice in favour of colleagues who may be seen to try to protect one another. This may result even more complex in the aviation domain, being multinational and multi-cultural by definition.

Also in the case of just culture, one could argue that factors like a too vague definition of the rights and duties in case of an incident, as well as an excessive opacity of the organization in establishing who is going to discriminate between acceptable and unacceptable behaviours, or the institution of professional penalties in case of errors being reported could have negative effects on the safety culture of the organization. This, in turn, is likely to have a negative impact on the safety record of the organization itself.

4.1.3 A Flexible Culture

According to Reason[10] an organization is adequately flexible if it is able to arrange different decision making processes depending on the urgency of the decision and the expertise of the people involved. Organizations like this are able to reconfigure themselves in the face of high tempo operations or threats shifting from the conventional hierarchical mode to a flatter mode, encouraging a deference to expertise at whatever level in the organization it may be located. This may involve the creation of ad hoc decision making groups or task

forces to deal with crisis situations and an ability to switch from a bureaucratic, centralized mode to a more decentralized professional mode. To describe this idea of Flexible Culture James Reason also refers to the work of Karl Weick [14], explaining that the best way of centralizing decisions whilst maintaining flexibility is to encourage people to socialize in order to use similar decision premises and assumptions, rather than just relying on written rules and prescriptions. In this way even the decentralized operations in the single units of the organization are equivalent and coordinated and require less oversight from the higher levels of the hierarchical structure. According to Weick this is exactly the role of a flexible culture: *when centralization occurs via decision premises and assumptions, compliance occurs without surveillance. This is a sharp contrast to centralization by rules and regulations or centralization by standardization and hierarchy, both of which require high surveillance. Furthermore, neither rules nor standardization are well equipped to deal with emergencies for which there is no precedent [14].*

As for the Reporting Culture and Just Culture, an organization with a too rigid hierarchy and limited ability to adapt its own decision mechanisms to face with high tempo operations and unprecedented risks is likely to have a weak Safety Culture, with potential negative effects on the safety of its operations.

4.1.4 A Learning Culture

An organization must possess the willingness and the competence to draw the right conclusions from its safety information system and the will to implement major reforms. Reports are only effective if an organization learns from them. Two of the elements analysed before are the essential prerequisite for a learning culture. The perception of a lack of Just Culture will discourage the individual members of the organization to reveal essential information for safety, as well as a weak Reporting Culture will jeopardize the quality and quantity of safety data being collected. This in turn will make ineffective the Safety Management System of the organization due to poor reactive and proactive safety assessment activities being established (see also the following section 4.3). Nonetheless also a good provision and collection of safety data will result useless if the organization is unprepared to learn from them and to make the necessary changes in the way people, procedure and equipment are actually working. The Learning Culture is of course synergic with the Flexible Culture, since a too rigid hierarchical structure may at the same time discourage the understanding by the top management of the vital signs emerging in the organization and reduce the application in practice of what has been learnt.

4.2 A description of safety management

Civil Aviation Authorities around the world are structuring their aviation SMS requirements around the ICAO document 9859. ICAO Document 9859 has strongly influenced the FAA, EASA, Transport Canada and others to develop an SMS framework based on the following four elements or "pillars":

- Safety Policy
- Safety Risk Management

- Safety Assurance
- Safety Promotion

The premise for this section is that every organisation manages its risk (including safety risk) in some way, but not always in a way that is visible, repeatable or consistent, to support effective decision making. The task of safety management is to ensure an organisation makes cost-effective use of a safety management process that includes a series of well defined steps. The aim is to improve internal control and support better decision-making through a good understanding of individual risks and the overall risk exposure that exists at a particular time.

Accordingly, in the following text, the term 'safety management' refers to the systematic application of principles, an approach and a process to the tasks of identifying and assessing risks, and then planning and implementing risk responses.

For safety management to be effective risks need to be;

Identified – this involves considering uncertainties that would affect the achievement of objectives within the context of a particular organisational activity and then describing them to ensure there is a common understanding.

Assessed – This involves estimating the probability, impact and proximity of individual risks so they can be prioritised, and understanding the overall level of risk (risk exposure) associated with the organisational activity.

Controlled – This involves planning appropriate responses to risks, assigning owners and action takers and then implementing, monitoring and controlling these responses.

The purpose of the following text is to explore the influences of the safety risk management processes and systems (i.e the 2nd pillar of ICAO's SMS framework) on the accident scenarios through the identification of the linkage between the following;

a) The safety related risk model for a service (with particular reference to the performance of the barriers) and

b) The management of the safety related risk for that service (as expressed in the general premise above).

In this way it is envisaged that both confidence in the model can be improved and the management of safety risk will be more effective.

For the purpose of this discussion the Safety Management System is viewed as a series of functions each of which are represented by a white box in Figure 18. In the representation the functions are shown as having an

input on the left, an output on the right, guidance or instruction from the top and the assigned resource coming in from the bottom.

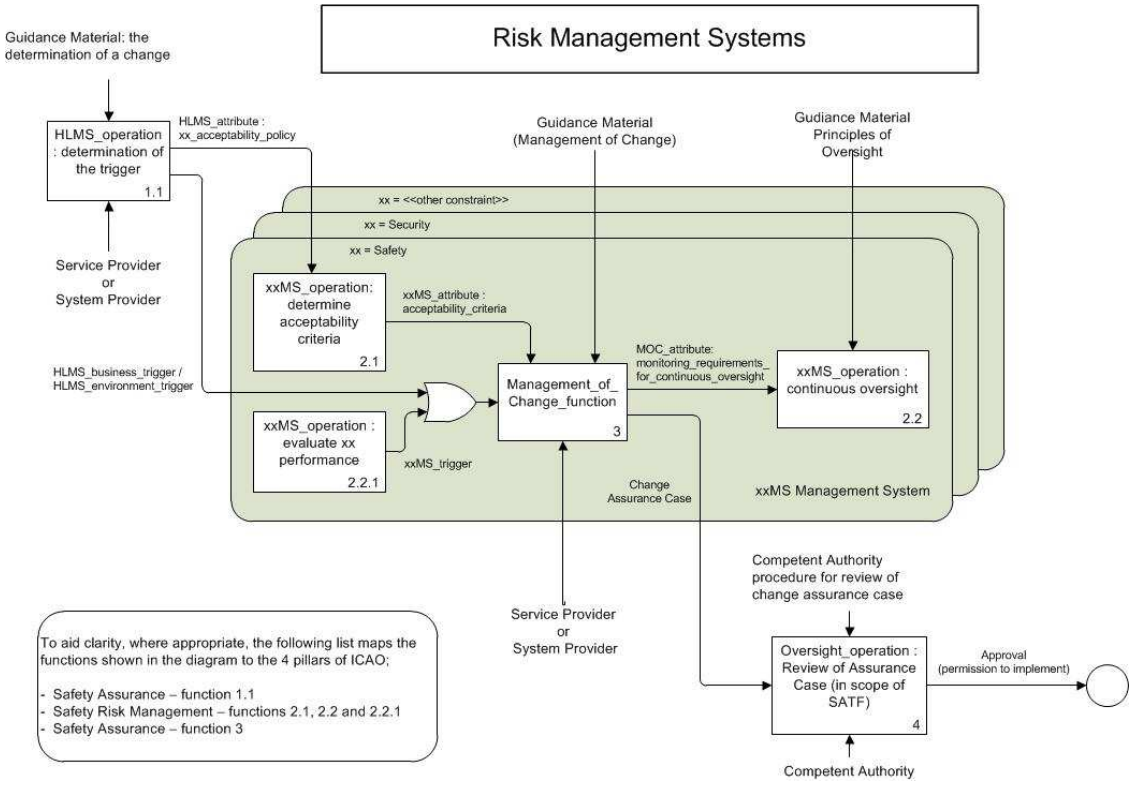

Figure 18: Model of a safety management system

4.3 The relation between the Safety Culture and a Safety Management System

Although it has been recognized that the existence of an appropriate and comprehensive Safety Management System (SMS) is necessary for maintaining and improving the safety of operations in a complex socio-technical system, it may not be sufficient to guarantee an adequate safety performance. A SMS will not assure safety if it is not used properly, and thus all the staff involved in the provision of ATM services need to be properly aware of its existence, understand its basis, and be motivated to use the SMS that is in place or being developed or implemented. A positive Safety Culture can be a strong enabler to ensure that the SMS works in practice. The reverse can also be true: implementing a good SMS can be an enabler for Safety Culture.

Organizations are managed by organizational practices, which affect both performance and reliability of safety systems. A well-developed SMS can therefore serve as an accelerator of Safety Culture. Therefore SMS and Safety Culture are interdependent: the SMS embodies the competence to achieve safety, whereas Safety Culture represents the commitment to achieving safety (see Figure 19).

Safety Culture takes time to grow and change: a SMS can be implemented, whereas a Safety Culture cannot, though it can be re-directed. Safety Management Systems can be explained explicitly as they allow a formalised safety within an organization by writing down a tangible and documented system of management policy and procedures. In contrast Safety Culture is harder to expound as it is more difficult to identify Safety Culture features and characteristics (e.g. group attitudes, perception and beliefs) that can influence the effectiveness of safety management activities. Safety Culture is inevitably more '*fuzzy*' than SMS.

SMS and Safety Culture are seen as inter-dependent, rather than SMS as part of Safety Culture or vice versa: if either one is seen as a sub-element of the other, something is lost. A negative or critical interaction between the SMS and the Safety Culture (e.g. the design of the SMS is inconsistent with agreed safety principles inside the organization or the Safety Culture is too weak to sustain the existing SMS) may certainly imply a risk for the organization to fail in maintaining an *informed culture* with regards to the most important safety threats and a potential negative record for the safety performance of the organization itself.

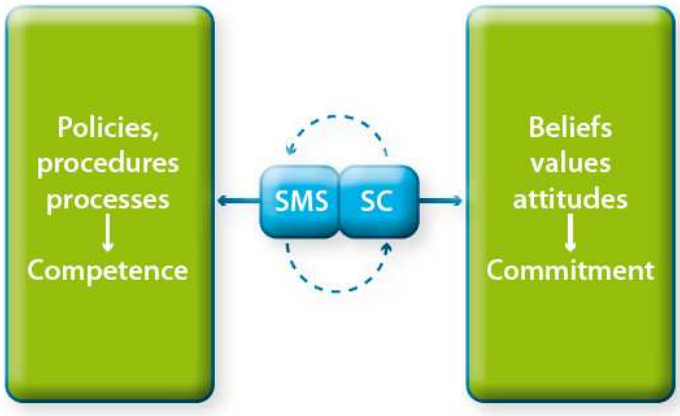

Figure 19: The interdependence between SMS and Safety Culture as illustrated in the White Paper on Safety Culture by EUROCONTROL and FAA

4.4 Experiences and difficulties in measuring Safety Culture

Different attempts have been made to measure Safety Culture within a variety of industries such as nuclear power, aviation, chemical processing, construction and manufacturing. The key in any Safety Culture improvement program is to develop effective measures to evaluate the current state of a particular safety culture, as well as to determine whether interventions have been effective in achieving the desired cultural changes. Examples of these experiences in aviation and ATM are the Aviation Safety Culture Inquiry Tool (ASC-IT) developed by NLR [15] and the Safety Culture Measurement Toolkit (SCMT) developed by EUROCONTROL for the European Air National Service Providers [16]. The first experience is essentially based on a systematic investigation through web-based questionnaires of Safety Culture indicators based on a framework derived and elaborated from the existing literature. The second relies on a triangulation of methods including

observations, questionnaires and combined interviews and workshops. There is general consensus among researchers that both quantitative and qualitative methods have unique potential for the assessment of Safety Culture [17]. The quantitative approaches and especially highly structured interviews and questionnaires are simpler to implement in different organizations and by other researchers in a common and standardized frame of reference. On the other hand the qualitative methods (e.g. ethnographic approaches such as extensive observations, employee interviews, focus group discussions, historical information reviews and case studies) are better suited to capture the nature or essence of the activity that is being studied, as opposed to the methods just based on the attempt to break down a phenomenon in order to study its individual components. However the intrinsic 'fuzziness' of the Safety Culture concept lead all the proposed measurement methods to encounter fundamental limitations (EUROCONTROL and FAA 2008), which can be summarised as follows.

- **The confusion between Safety Culture and *Safety Climate***. The Safety Culture is not just a matter of individual perception by the employees of an organization on the day of the survey. Rather it refers to people's beliefs, values and enduring attitudes reflecting the 'heart' of safety in an organization. While especially the questionnaires are often at risk of measuring the Safety Climate, which is normally conceptualized as a 'snapshot' of the perceived state of safety in a particular place and at a particular time and therefore relatively unstable and subject to change.

- **The distortions and biases in the collection of data**. People responding to a safety culture inquiry in an organization may give the picture they want to show, which does not always reflect reality. For example managers may want to give a certain impression of their organization and employees may try to hide their opinion so as not to be blamed or for reasons of social acceptability. People who are already concerned with the safety culture of the organization will be more likely to participate in a safety culture inquiry. People operating in a weak safety culture will likely reject the safety culture inquiry and consequently their perceptions remain unnoticed.

- **The long term frame of Safety Culture effects**. The question of whether improved Safety Culture leads to improved safety (e.g. according to incidents and accidents) is particularly hard to prove, firstly because it takes time and requires a proper baseline measurement followed by a Safety Culture intervention, implementation of changes, re-assessment of Safety Culture and re-evaluation of safety indicators. This is quite an undertaking for most of the organisations in the ATM and aviation domains for which is too early to have such results.

- **The difficulty in evaluating the actual role of Safety Culture in improving the safety**. In the considerably long period required to measure Safety Culture (e.g. several years between the measurements of safety culture) many other factors may have changed and probably there will have been other safety improvements. This makes it difficult to determine whether improvements in Safety Culture led to an improvement to safety, or whether such improvement was due to the other changes.

4.5 The influence on Safety Culture of factors external to the organization

4.5.1 The interfacing between the Safety Culture and the Judicial System

As pointed out in section 5.1.2, the relationship between an organization managing safety critical processes and the judicial authority is a very critical one. Even very proficient professionals like air traffic controllers and pilots might be anxious of inappropriate involvement of the judicial authorities after incidents that, according to them, have nothing to do with unlawful actions, gross negligence or violations. In the Just Culture Guidance Material by EUROCONTROL [18], the risk associated to a pathological interfacing with the judicial system are summarized as follows:

- **Judicial proceedings after an incident can have the effect that people stop reporting incidents**. Experience has shown that remarkable reduction of incident reporting rates are possible in the period following the criminal prosecution of an incident. The simple threat (real or perceived) of criminal prosecution makes people think twice before disclosing any relevant safety-related information.

- **Judicial proceedings, or their possibility, can create a climate of fear to share information even internally.** The perceived risk of prosecution can lead the operational experts to prevent the organization from using for training purposes the information about significant incidents in which they were involved. This may easily happen even if the information is de-identified, causing the organization to lose a precious resource to increase its own internal awareness and safety culture.

- **Judicial proceedings in the aftermath of an accident can impede investigatory access to information sources.** Normally a real accident does not make people less willing to report about incidents. However there might be reluctance from the operators on providing information that may be used in the accident probe. This could make more difficult for the investigators to get valuable information, particularly when judicial proceedings are launched at the same time as the safety investigation.

- **Judicial proceedings could stigmatise an incident as something shameful.** Criminalising an incident can send the message to everybody in the operational community that incidents are something shameful. For example this may occur when fines are imposed after incidents or when line managers in an organization get involved to judge the performance of pilots or controllers. Operational people may fear that an incident can reflect badly on their reputation and could make them feel like an outcast, again preventing them from providing any significant safety information.

In order to limit the negative effects described above, the States and the other regional and supranational authorities (e.g. ICAO, EUROCONTROL, EU, EASA) should make an effort to identify solutions for a positive interfacing of the aviation-related organizations (e.g. Air National Service Providers, Airlines, Airport Operators) with the Judicial System in force in each concerned situation. Based on the work of Sydney Dekker [12], EUROCONTROL has proposed a number of possible solutions turning around the following questions: (a) who should get to decide when an incident should be investigated by the judicial authority? (b) which is the role of the domain expertise in the decisions by the judicial authorities? (c) To what extent the safety data

possessed by an organization should be protected from the intervention of the judicial authorities? None of the proposed solutions is easy to implement and can be considered as a final solution for such a critical topic. Nonetheless a strong awareness by all the stakeholders of the aviation system is required to at least limit the risk of discouraging a safety culture and to prevent that the judicial authorities end up with playing a negative role in improving the safety of the aviation system.

4.5.2 The interfacing between the Safety Culture and the Media

Aviation accidents are known to have a very strong impact on the public opinion when they occur. Despite all the statistics showing that the aviation system is incomparably safer than the majority of the other transportation systems, the potential concentration of numerous and sudden deaths in only one accident is usually perceived as a socially unacceptable event, creating strong emotions in the public opinion and a spontaneous collective request to make all the efforts possible to prevent similar accidents. It is therefore inevitable that also the incidents, be them more or less severe, attract the attention of non-aviation experts seeking for information on what has happened and on which could have been the other potential adverse consequences. In this respect the media plays a critical role in how an incident is covered, and hence, in the way an organization is perceived by the public, both in time of emergency and on a day to day basis [19]. All the aviation-related organizations (e.g. Air National Service Providers, airlines, airport operators, etc.) interested in establishing a Safety Culture among their members should carefully manage their corporate communication and media relations to prevent the potential negative influence gathered by the legitimate press interest in the event of an incident or accident. A competent media relations organization may even have a beneficial impact on safety, since the organization with a good image and reputation will find it easier to attract the best staff and to improve the employee morale, which is conductive to a Just Culture and improved Safety. On the other hand organizations that ignore the need for media relations until a crisis occurs, risk suffering unnecessary damage to their credibility and their reputation for competence which could take years to repair.

As for the relationship with the judicial system, the domain expertise can play a critical role. For example most of the journalists are expected to report on a wide range of topics and cannot be expected to possess the same expert knowledge of the aviation system organizations. However this should not lead to a protective attitude by the organization leading to a climate of mistrust with the media operators and as a consequence with the general public. On the contrary, in the event of relevant incidents or accidents, the organization should be ready to provide at least essential information to the public opinion in a plain and uncomplicated language and, when possible, should try to clarify the basic elements of the Just Culture being implemented in the organization. A failure to establish an appropriate relationship with the media could transmit the message that the organization has something relevant and of public interest to hide. In turn this may end up with the judicial authorities being under pressure by the public opinion to disclose safety critical information with a potential negative effect on the efficacy or even feasibility of the safety investigation processes internal to the organization.

4.6 The difficulties of modelling Safety Culture and safety management elements in Risk Models

The previous sections have shown and described the essential elements that an organization should take into account to establish and maintain a Safety Culture. These elements provide a useful guidance to make a Safety Management System successful and effective in improving the safety record of an organization and in contributing, as an aggregated result, to the improvement of the safety performance of the entire aviation system. Plus they pave the way for the identification of Safety Culture indicators to be monitored at the level of individual organizations. However a number of reasons suggest to avoid the modelling of safety culture and safety management elements in accidents scenarios to be directly attached to the Event Sequence Diagrams and Fault Tree Analyses described in section 2. The most important reasons are shortly summarized below.

- **The safety culture related failures are mainly negative conditions favouring long term and latent failures. While the Fault Trees are better suited for representing system failures and errors at the sharp end**. A positive Safety Culture may take time to be established in a organization and does not produce its effects immediately. On the other hand a failure to establish a Safety Culture also on specific aspects of the operations can remain silent for a long period and disclose its negative effect even after a long time from the initial program for its implementation. And it is worth noting that this is not limited to the occurrence of human errors. For example a piece of equipment may have been discovered to fail in very specific circumstances which occur rarely. However this defect may have gone unnoticed for a long time due to the weak Just Culture of the organization which discouraged the controller or pilot to report the inconvenience in which they were involved, even in case of minor incidents. In this way the information about the technical inconvenience may not reach the management of the organization, thus leading to a lack of any concrete preventive measure and to a potential for a serious threat to safety once the same or very similar circumstances will be reproduced. Therefore trying to set a frequency for a condition like this, with a potential for influencing the frequency of other fault tree events, appears quite arbitrary, due to the potential combination of too many elements in ways which are difficult to predict and very peculiar to the specific context of occurrence.

- **The same safety culture failure or safety management might simultaneously contribute to several FT basic events.** Another problem in linking potential safety culture failures and safety management failures to a fault tree based accident scenario lies in the difficulty to relate them to a specific failure event. As a matter of fact if an organization has a severe limitation in its Safety Culture, this may potentially have a simultaneous impact on a large set of fault tree events, acting as a sort of common cause for several failures. For example an inadequate Reporting Culture may cause more than one safety issue to become unnoticed or misunderstood, including both technical failures and human errors. However modelling the same Safety Culture factor as a unit influencing the frequency of all the events in the fault tree does not appear appropriate, since the same factor is unlike to have the same effect on all the elements of the fault tree. The different effects upon different fault tree elements will again depend on very peculiar circumstances and combinations of events which cannot be easily captured in a fault tree.

- **Safety Culture measurements appear more appropriate for the monitoring of trends within the same organization or for comparison between different organizations, rather than for the identification of absolute frequencies.** As highlighted in section 4.4 the intrinsic fuzziness of the concept make it difficult to measure the Safety Culture in a stable, standardized and ultimately reliable way. The same can be said for safety management. Assessments and measures may certainly result precious to monitor the trend of Safety Culture factors and safety management factors over time inside the same organization, as well as it may prove useful to compare with the same method the performance of two or more organizations in a limited time frame. Nonetheless the distortion and biases that can characterize the collection of data, as well as the difficulties in evaluating the actual role of Safety Culture and safety management in improving safety, suggest to avoid using these measurements as absolute data from which it is appropriate to derive absolute frequencies of failures. Therefore the inclusion of Safety Culture elements and safety management elements into the generic accident scenarios appears of limited added value also for the difficulties that it would imply in terms of feeding the models with new data as soon as they arrive. While new data on specific incidents and safety occurrences categorized in a standard format are relatively easy to feed into the models, it would be questionable to use the result of Safety Culture and safety management investigations to update the same models.

5 Use of the risk model to support safety management

Even though it was concluded in the previous chapter that representing safety management in the risk model is not feasible, there can indeed be made a link between safety management and the risk model in the sense that the risk model can support and enhance safety management in various ways. This chapter describes how.

5.1 Use of the risk model to determine the 'visibility of safety'.

The first proposal of this section is to seek an improvement in the management of safety risk by using the risk model to provide certainty as to what is being managed i.e. is it safety of a service or is it the quality of a supporting service (e.g. contracted service) or system.

By describing a service or system in terms of where it resides in the risk model and in terms of its relationship to the safety related service one is able to share a common understanding of the safety significance of the service or system under consideration. This introduces the notion of a 'view on safety' whereby only a provider of a system or service that has direct safety significance is considered to have a view on safety. By way of illustration an example of how this might be applied to ATM/ANS is given in the following diagram. (see Figure 20). Only the providers of the services that are displayed in the top part of the figure (above the dotted line) have a view on safety.

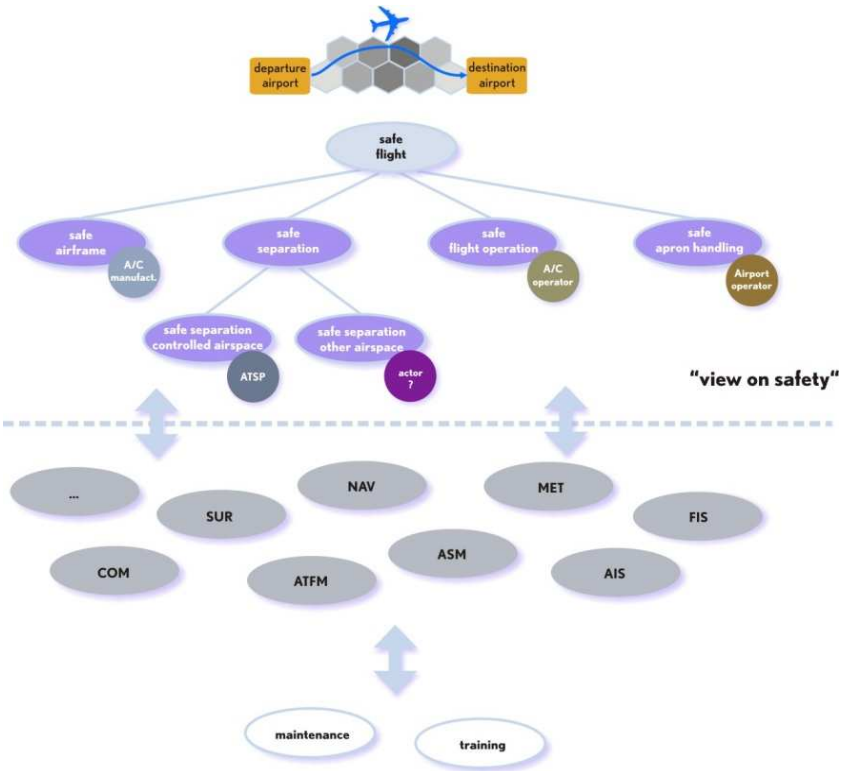

Figure 20: Visibility of safety.

It therefore follows that, for the purpose of safety assurance (i.e the 3rd pillar of SMS in ICAO's framework);

- systems or services that have visibility of safety require, prior to implementation, assurance that the systems or services are safe for a given application in a given environment whilst
- systems or services that do not have visibility of safety require, prior to implementation, assurance that the systems or services behave only as specified in a given environment .

This aligns with the definitions, currently under development within EASA Rule Making Tasks (RMT) 0469, of a 'safety assurance case' and a 'safety support assurance case' as given below;

> A safety assurance case is: "a structured argument, supported by a body of evidence that provides a compelling, comprehensible and valid case that a system is safe for a given application in a given environment".
>
> A safety support assurance case is: "a structured argument, supported by a body of evidence that provides a compelling, comprehensible and valid case that the system behaves only as specified in a given environment".

Using this approach a clear distinction can be drawn between what is required in terms of assurance from, for example, the supplier of equipment such as a radio and the user of a radio such as an ATC unit. The radio supplier would produce a safety support assurance case which the user of the radio can use as an input to their safety assurance case (e.g. as evidence that they are using a system with trustworthy components). In this scenario the minimum technical requirements for the radio would be derived by the user taking into consideration the reliance being placed on the radio (i.e. the role or significance of the radio) in terms of delivering a safe service.

This approach can be used across the whole of aviation as a way of describing the 'safety significance' of each cross domain relationship. It is envisaged that such an approach will be beneficial, for example, in the discussion of the safety significance of an SSR transponder with the aircraft manufacturer, the air traffic service provider and ultimately the airline operator.

Lack of clarity on this point can result in an equipment supplier believing they are required to produce safety cases for their products when in reality they are designing and delivering against an equipment specification without necessarily having an explicit knowledge of its intended use and / or without an explicit link to a safety target.

5.2 Use of the Safety Related Risk model to improve the Continuous Oversight function.

The second proposal of this section is to improve the Continuous Oversight function (a function of the Safety Management Systems see Figure 16). For effective Continuous Oversight the Safety Assurance case is required

to identify a complete and correct set of monitoring requirements. Inspection of a complete model of the total aviation system behaviour has the potential to identify a significantly more complete and correct set of monitoring requirements. A complete model of the total aviation system behaviour will also facilitate the better interpretation of observed events/results, incidents and accidents.

5.3 Use of the Safety Related Risk Model to improve the Management of Change.

The third proposal of this section is to improve the Management of Change (a function of the Safety Management System see Figure 16). Inspection of a complete model of the total aviation system behaviour has the potential to improve the identification of the boundary of influence a proposed change to the system will have i.e. the extent to which the proposed change will impact on other systems and services.

5.4 Use of Continuous Oversight to improve the confidence in the Safety Related Risk Model.

The fourth proposal of this section is to improve the confidence in the Risk Model by comparing the predicted performance and any assumptions expressed in the model with the actual performance of the system as determined through Continuous Oversight. It is envisaged that this will be an iterative process with corrective action as appropriate e.g. an update to the model, a reconsideration of any assumptions made or perhaps a change in the monitoring strategy.

5.5 Use of the Safety Related Risk model to determine the appropriate level of oversight.

The fifth proposal of this section is to better inform the level of oversight. Inspection of a complete model of the total system behaviour has the potential to provide a clear understanding of the safety significance of a service, supporting service or system which one is then able to use in the determination of an appropriate level of oversight. Consider, for example, the role of regulation and the regulator. For example, is it required to have regulations to reinforce contracts to assure the behaviour of those upon which you may be dependant (as determined by inspection of the model) that are beyond one's own immediate influence (e.g. a supplier of a supporting service, such as ground handling and de-icing, contracted through a third party).

6 Quantification of accident scenarios

This chapter described how accident scenarios are quantified. Actual quantification is done in work package 2.2 of ASCOS and when the risks model is being applied in the case studies.

6.1 Introduction

A quantified risk model gives a risk picture of the system that is described by the model, based on historic or expert opinion-derived data. It can be used to analyse the risk of individual events: for each event in the model the probability is known and the severity can be derived from the conditional probability of an accident given the said event occurring. The model can also be used to assess the impact on safety of changes to the system. Proposed changes can have an influence on the probability of occurrence of events described by the model. If this influence can be quantified, the model can be used to determine the quantitative influence of the change on accident risk. The model can also be expanded by adding new events that are specific to the particular change. Again the model can be used to determine the impact on safety of that new event. The changes that can be assessed are: technical or procedural changes to the system that introduce new risks, changes in the effectiveness of safety management and changes in safety culture.

The quantification of the accident model as described in Chapter 2 is part of ASCOS work package 2. This chapter includes the description of methods on how to quantify the impact of future risks (as introduced in Chapter 3), the impact of safety management (as introduced in Chapter 4), and the impact of safety culture (as introduced in Chapter 5).

6.2 Quantifying an accident risk model

6.2.1 Quantifying an ESD

The event sequence diagrams (ESDs) provide a qualitative description of the accident scenarios. They are quantified by assessing the probability of occurrence of each of the different pathways in the scenarios. An ESD is comparable to a river that starts big and then branches off into smaller arms. The total amount of water that passes through at the beginning is equal to the amount of water that flows in all the individual branches. There are three different ways of describing how big the river and its individual branches are:

1) One can describe the total amount of water in absolute terms for each part of the river. In the ESD this means that all probabilities are expressed as absolute probabilities;
2) One can normalize each branch of the river by the size of the river at the beginning. The quantities of the end-states add up to one;
3) For each individual branch point, one can describe the relative distribution of the flow among the different branches. The quantities at each individual pivotal point add up to one. In the ESD this means that all probabilities are expressed as probability of occurrence conditional to the preceding pivotal event.

From the point of view of accuracy and completeness, the three different ways are equal. There are practical reasons why it could be more appropriate to use one way instead of another, e.g. depending on communication of the ESD with experts and non-experts and on possibilities for retrieving numbers from existing datasets or by means of expert judgment. In retrieving numbers from datasets, in practice often a combination of options 1, 2 and 3 is used.

For the purpose of this model, the probabilities of the initiating events and the end states are expressed as absolute probabilities. The probabilities of the pivotal events are expressed as conditional probabilities. They are conditional to the occurrence of the (pivotal or initiating) event immediately preceding the particular pivotal event in the ESD. The probabilities refer to the 'yes' branch of the pivotal event. The use of conditional probabilities for the pivotal events facilitates calculations in the ESD. This is illustrated in Figure 21; the probability of end state E can be calculated by multiplying the probability of initiating event A with the conditional probabilities of event B (0.8) and event C (0.5): $P(E) = 2.20 \cdot 10^{-4} \times 0.8 \times 0.5 = 8.80 \cdot 10^{-5}$

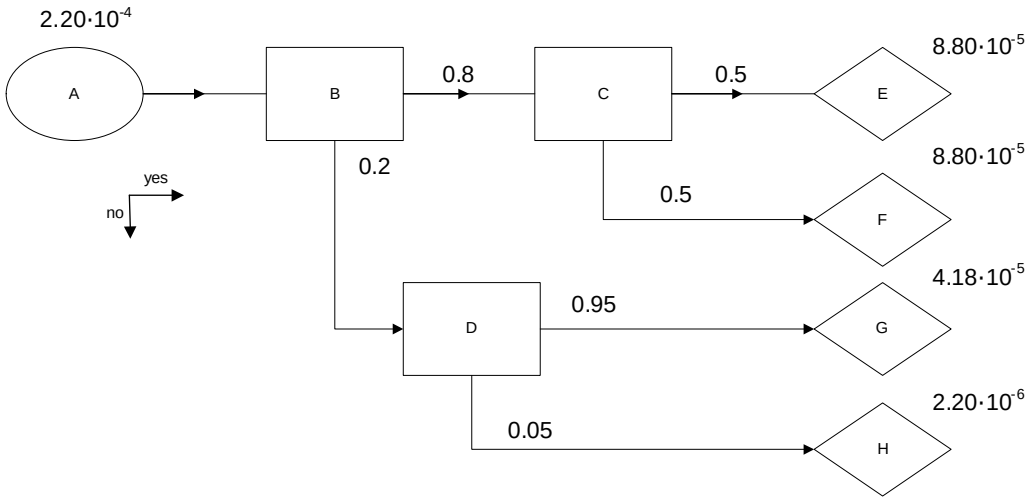

Figure 21: generic quantified ESD using conditional probabilities

6.2.2 Quantifying a fault tree

In the fault trees of the accident model three types of gates are used:

OR gate. An OR gate indicates that the top-event occurs if at least one of the input events occurs. The probability of the top event (A) with an OR gate and two base events (B) and (C) is quantified according to the formula:

$$P(A) = P(B) + P(C) - P(B \text{ and } C)$$

where P(X) is the probability of X.

An alternative way of describing this equation is:

$$P(A) = 1 - (1 - P(B)) \times (1 - P(C))$$

For *n* base events (X_1, X_2,…X_n) the formula becomes:

$$P(A) = 1 - (1 - P(X_1)) \times (1 - P(X_2)) \times \ldots \times (1 - P(X_n))$$

MOR gate. The MOR (mutually exclusive OR) gate indicates that the top-event occurs if one of the input events occurs, while both events cannot occur simultaneously. The probability of a top event (A) with a MOR gate and two base events (B) and (C) is quantified according to the formula:

$$P(A) = P(B) + P(C)$$

where P(X) is the probability of X. As the base events are mutually exclusive, P(B and C) = 0.

AND gate. An AND gate indicates that the top-event occurs if all of the input events occur. The probability of a top event (A) with an AND gate and two base events (B) and (C) is quantified according to the formula:

$$P(A) = P(B) \times P(C)$$

where P(X) is the probability of X.

6.2.3 Ways to quantify events

The probability of an event can be determined by means of several techniques. The following three are briefly discussed:

- Use of historical air safety data;
- Calculation, using other quantified events, and;
- Expert opinion.

Use of historical air safety data

The preferred way to quantify events is by using historical air safety data. Accident end states can be quantified using databases from accident investigation boards. Base and intermediate events can be quantified using databases consisting of occurrence and incident reports. These databases can be used to acquire the number of occurrences of a particular event. To calculate probabilities exposure data (flights or flight hours) is needed that matches the dataset used. In selecting databases used it should be assured that they are representative for the type of operations at which the accident model is aimed. In a properly defined accident model each historic occurrence can be uniquely and unambiguously assigned to a particular ESD. Furthermore, there should be no dependencies between the different ESDs.

Ideally, the number of relevant occurrences for a specific event in the model can be extracted from the database using a query. More often however it is necessary that analysts study the narrative of the occurrence to match it with the relevant event. The number of narratives that need to be read can be reduced by applying a broadly defined query, making sure all applicable events match the query.

There are a couple issues to be aware off when using historical air safety data:

- Databases with occurrence and incident data often display over-reporting, underreporting or any other reporting bias.
- Mistakes may be made by the analysts during analysis of a data sample. When working with multiple analysts comparable occurrence may be interpreted differently by different analysts.
- In cases where no examples of specific accident scenarios are found in the data sample, it does not mean that there is no chance of such scenario occurring.

Calculation, using other quantified events

The ESD and fault tree logic makes it possible to calculate the probability of events, given that the probabilities of other events are known. Consider Figure 22, if both the probabilities of initiating event A and end state E are known, the probability of pivotal event B can be calculated by dividing P(E) by P(A).

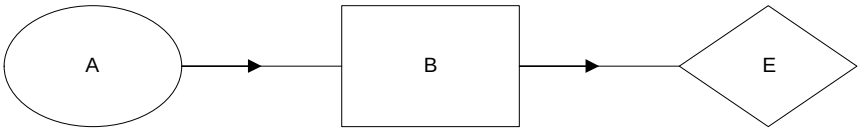

Figure 22: Simplified ESD consisting of a pivotal event, initiating event and end state, and only one scenario.

Expert opinion

In case no historical data is available to quantify events, expert opinion can be used. Experts can estimate the probability of certain events occurring. It should be realized however that it is difficult for any expert to estimate very low probabilities. Experts can also give a base event distribution of a certain event, i.e. establishing that in case of event B, FT1 has occurred in X% of the cases and FT2 in Y% (see Figure 23).

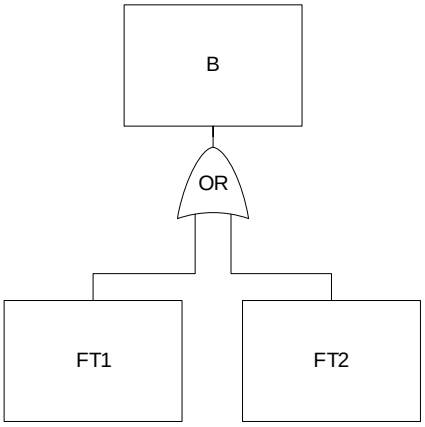

Figure 23: Generic fault tree

6.3 Quantify emerging/future risks

In Chapter 3 the following definitions of emerging and future risk are given:

An "**emerging risk**" is defined by

a) The same Severity as the current/known risk but with a different likelihood of its components taking into account the influence of new/emerging technologies, behaviours, work organizations, regulations, operational procedures etc.,

b) A new severity with the same likelihood of its components,

c) A new severity with a new likelihood of its components.

A "**future risk**" is defined as a risk associated with the future introduction of a novelty (e.g. new design, new procedure, and new organization).

Emerging risks influence the likelihood and/or severity of existing components of the total aviation system. These components are the fault tree elements that accumulate into initiating events and pivotal events. Consider the ESD with one associated fault tree, Figure 24 (this ESD does not show all possible scenarios). The (fictional) quantification represents a baseline.

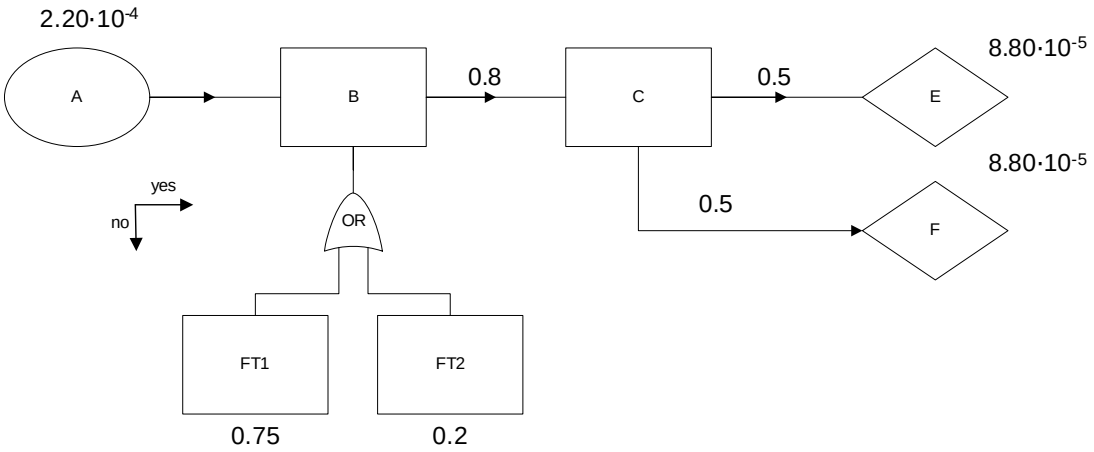

Figure 24: Quantified ESD with one associated fault tree

Now consider an emerging risk that results in an increase of likelihood of fault tree event 2 (FT2) from 0.2 to 0.3. This results in a change in probability of pivotal event B:

$$P(B) = 1-(1-P(FT1)) \times (1-P(FT2)) = 1-(0.25) \times (0.7) = 0.825$$

With all other things equal, this results in an increase in accident probability modelled by end state E:

$$P(E) = 2.20 \cdot 10^{-4} \times 0.825 \times 0.5 = 9.08 \cdot 10^{-5}$$

Using the baseline as starting point again, consider an emerging risk that causes the initiating event probability to decrease to $2.00 \cdot 10^{-4}$ and the pivotal event C probability to increase to 0.55. This implies the accident probability does not change:

$$P(E) = 2.00 \cdot 10^{-4} \times 0.8 \times 0.55 = 8.80 \cdot 10^{-5}$$

Now consider the occurrence of fault tree event 1 (FT1). In the baseline situation the probability of end state E (an accident) to occur given FT1 occurs is 0.5. In the new situation, if FT1 occurs the probability of an accident resulting from that occurrence is 0.55. This implies that although the overall accident likelihood has not changed, the severity of an occurrence of FT1 has increased.

Clearly there are combinations of influences of emerging risks imaginable, where both likelihood and severity of elements of the total aviation system change.

Future risks are associated with the future introduction of novelties. These novelties can be small and have a similar impact as the emerging risks described above. It can also be foreseen that these novelties introduce new elements to fault trees. A novelty can for example introduce an additional barrier. This is visualized in the model given in Figure 25, for pivotal event B to happen, now FT1 (old) must occur AND a failure of the newly introduced barrier (FT1b). If the probability of FT1 (old) does not change, the probability of FT1 new will reduce, assuming the probability of failure of the new barrier (FT1b) is less than 1. This implies that the probability of pivotal event B will also be reduced, assuming the probability of FT2 stays the same.

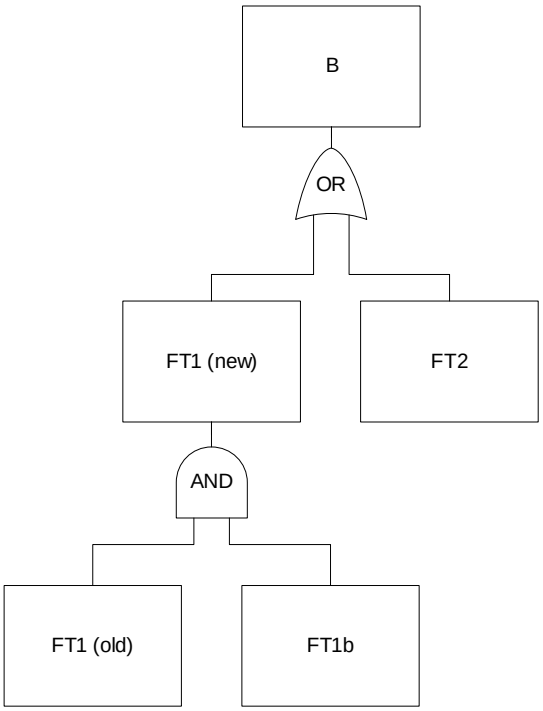

Figure 25: Generic extended fault tree, with an additional barrier.

More significant novelties can necessitate the addition of new branches to existing fault trees. These have to be quantified using traditional methods. It is likely though that these new elements will mostly be quantified using expert opinion, since historic data will be lacking for novelties. The current set of ESDs is a generic representation of accident scenarios. It is unlikely that novelties will introduce new accident scenarios, and it is therefore unlikely that novelties necessitate new ESDs, or addition of ESD events to existing ESDs.

6.4 Quantify impact of safety management and safety culture

In Chapter 5 it was concluded that representing safety management and safety culture in accident scenarios is not practically possible because:

- Measuring the level of safety management and safety culture in a particular organization is difficult. There is no agreed practise on how to do this, and;
- Measuring the effect of a certain level of safety management and safety culture on the level of safety is difficult. There is no agreed practise on how to do this.

Nevertheless, it is to some extent possible to quantify the effect of a certain level of safety management and safety culture on the existing elements of the accident model. The idea is to derive a modification factor that can be applied to a model element that is affected by the safety management and safety culture of a particular organization. The modification factor can be determined based on the level of maturity of a safety management system of an organization and on the level of safety culture. The methodology can be extended by specifically measuring the maturity level of the different pillars of safety management and the level of certain elements of safety culture. A different modification factor can then be applied to model elements that are affected by specific pillars of safety management and specific elements of safety culture. This method will rely heavily on expert opinion.

The modification factor alters the probability of occurrence of a certain element. The modification factor needs to be applied to the base elements of a fault tree; if the base events are altered, the complete model quantification will be adjusted as well. It is therefore necessary to determine per base event:

- Which type of organization (operator, MRO, ANSP etc.) affects the likelihood of this event?
- Which pillars of safety management affect the likelihood of this event?
- Which elements of safety culture affect the likelihood of this event?

It is recommended that this approach for quantification of the influence of safety management or safety culture is used, if necessary, in the case studies that are subject of WP 4 of ASCOS.

7 Conclusions and recommendations

This work package 3.2 has delivered the following progress with respect to the pre-existing state of the art:

- The CATS model has been updated in the sense that the qualitative description of the event sequence diagrams and fault trees has been updated to provide a model that is more practicable to work with. These updates are based on practical experience with applying the model, for instance experience gained in using the model in support of the evaluation of Next Gen operational improvements.
- It has been investigated if and how safety culture and safety management can be explicitly represented in the model. It is concluded that this is currently not possible due to three main reasons:
    - Safety culture and safety management are primarily linked to latent failures while the model primarily represents active system failures;
    - Safety culture and safety management are often common cause influences;
    - Safety culture and safety management cannot be precisely measured.
- However, a more general and implicit way of representing such influence by means of a modification factor to be applied to the probabilities in the model is proposed.
- The way in which these models can be used in the safety management process has been described. The model can be used to provide certainty on what is being managed i.e. is it safety or is it quality of a service provision; the model can be used to support continuous oversight, and by this type of usage the confidence in the model can gradually be improved, the model can be used to support management of change and the model can be used to determine the appropriate level of safety oversight.
- The most important novel development that has been made is the description of a process for representation and evaluation of future and emerging risks in the risk model. This process comprises the identification during system development of the safety barrier implemented in the design and operations, the consideration of the failures or inefficiency of these safety barriers as potential accident precursor, the development of precursor identification process during development phase for application during in service phase, and the linking of those elements with the base events of the model.

The current state of the art for the certification of aeronautical products is basically reactive in the sense that changes in certification requirements are often made as a reaction to major accidents or as a reaction to technological advances.

A key step in the proposed improved certification process (which is the main overall objective of ASCOS) is an improved hazard identification process, including a 'predictive' approach, aimed at discovering future hazards that could result as a consequence of future changes inside or outside the global aviation system and then initiating mitigating actions before the hazard is introduced. In this deliverable 3.2, a predictive approach is supported by describing how emerging and future risks can be represented in an accident model. This ASCOS accident model is based on previous accident model development work, primarily the work performed to create the Causal Model for Air Transport Safety (CATS) [2]. CATS has been developed for the Dutch Ministry of Transport and represents the total aviation system. The ESDs and fault trees of CATS are used as a starting point to create the ASCOS accident model. For the purpose of the ASCOS accident model some qualitative

changes have been made to the CATS ESDs to incorporate the lessons-learnt of the last couple of years in which CATS has been used and studied.

The representation and the evaluation of the emerging/future risks using CATS ESDs can be done if each base event of the fault tree is linked to precursors and if a dedicated capture process is defined for these precursors. The application of the precursors capture process allows calculating the precursors' occurrence rates and then the emerging/future risks by using CATS ESDs.

For that it is necessary to ensure that the CATS ESDs are sufficiently complete. This means that all initiating events are envisaged, all pivotal events are recognized, no safety barrier is forgotten and no base event in fault trees is overlooked. This can be done in two steps:

- Step 1: Using safety assessments and product description and operational documentation for identification of all safety barriers implemented in the design and ensuring that all these safety barriers are considered in CATS ESDs.
- Step 2: Reviewing the CATS ESDs with experienced people having different points of view (e.g. design, maintenance operation, pilots, flight operation, ground operation, airport operation, ATM operation).

It is recommended that these steps are taken if the model is used in any of the test cases that will be conducted in ASCOS work package 4.

The ASCOS accident model supports safety management in several ways. By describing a system or service in terms of where it resides in the model and in terms of its relationship to the safety related service one is able to share a common understanding of the service or system under consideration. The accident model can be used to improve the continuous oversight function by identifying a more complete and correct set of monitoring requirements by inspection of the complete model. Inspection of a complete accident model of the aviation system also has the potential to improve the identification of the boundary of influence of a proposed change and thereby improving the management of change. Inspection of a complete model of the total system behaviour has the potential to provide a clear understanding of the safety significance of a service, supporting service or system which one is then able to use in the determination of an appropriate level of oversight.

Safety culture is essential to make a safety Management System successful and as an aggregated result the improvement of the safety performance of the entire aviation system. However, a number of reasons suggest avoiding the modelling of safety culture elements in accident scenarios to be directly attached to the Event Sequence Diagrams and fault trees of an accident model.

The reasons are the following:

- The safety culture related failures are mainly negative conditions favouring long term and latent failures, while the Fault Trees are better suited for representing system failures and errors at the sharp end.

- The same safety culture failure might simultaneously contribute to several FT basic events.
- Safety Culture measurements appear more appropriate for the monitoring of trends within the same organization or for comparison between different organizations, rather than for the identification of absolute frequencies.

The ASCOS risk model is quantified by assessing the probability of occurrence of each of the different pathways in the scenarios. A quantified model gives a risk picture of the system that is described by the model, based on historic or expert opinion-derived data. It can be used to analyse the risk of individual events: for each event in the model the probability is known and the severity can be derived from the conditional probability of an accident given the said event occurring. The model can also be used to assess the impact on safety of changes to the system. Proposed changes can have an influence on the probability of occurrence of events described by the model. If this influence can be quantified, the model can be used to determine the quantitative influence of the change on accident risk. The model can also be expanded by adding new events that are specific to the particular change.

Quantifying the impact of safety management and safety culture on the level of safety of the total aviation system using an accident model is difficult. The only practical solution to this problem is to derive a modification factor that can be applied to a model element that is affected by the safety management and safety culture of a particular organization. The modification factor can be determined based on the level of maturity of a safety management system of an organization and on the level of safety culture.

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Appendix A Event Sequence Diagrams

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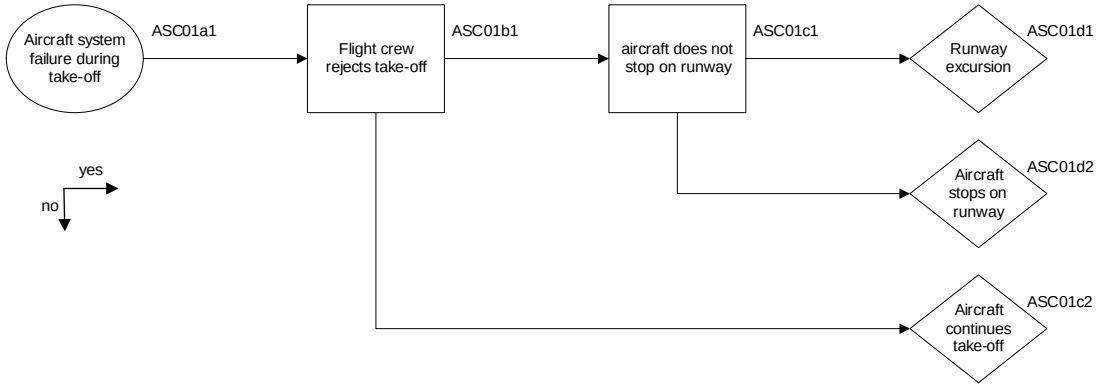

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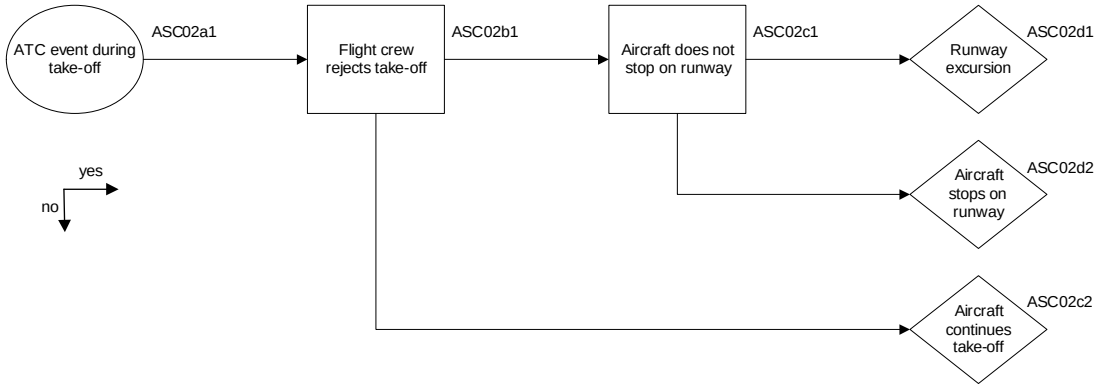

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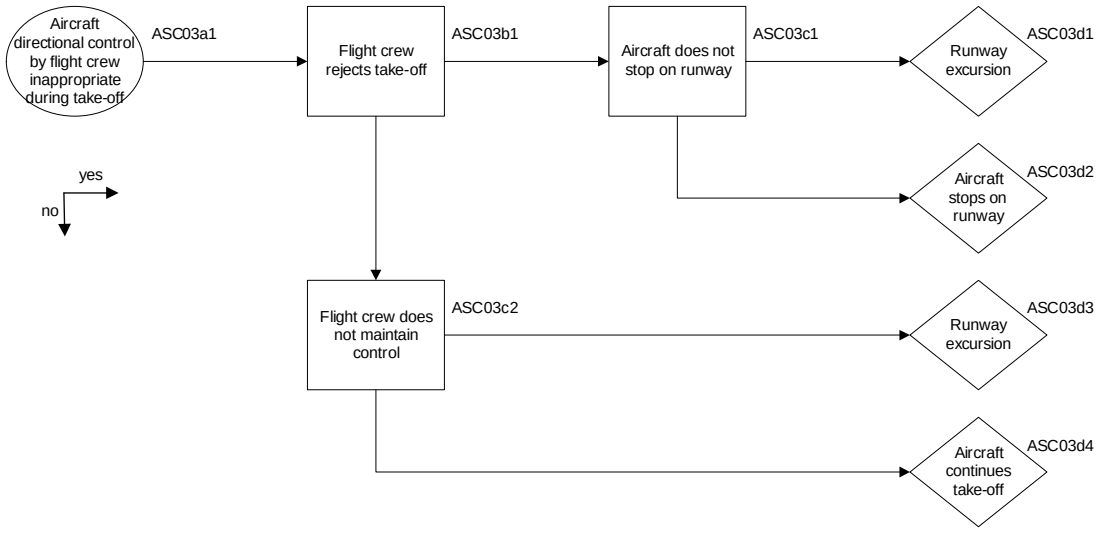

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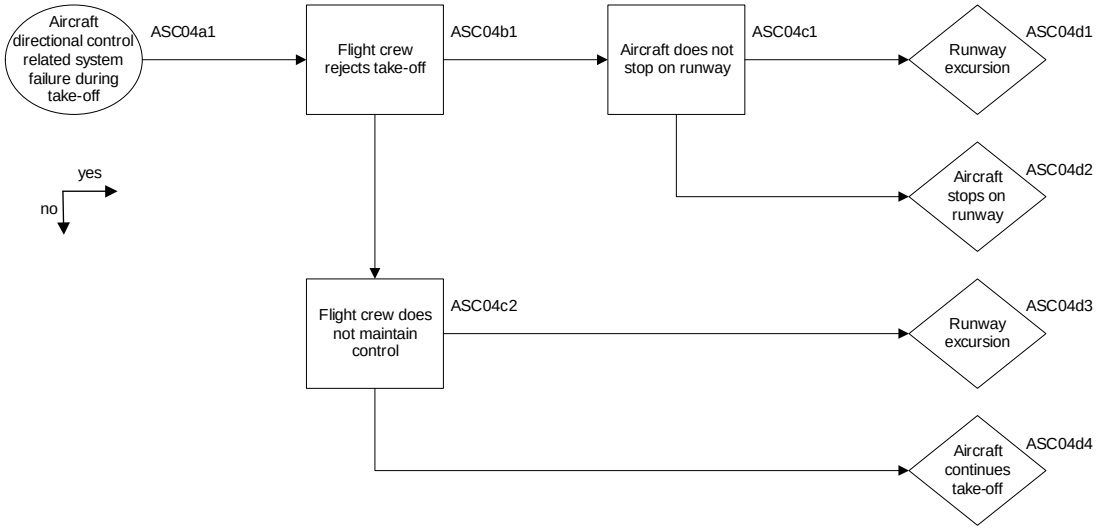

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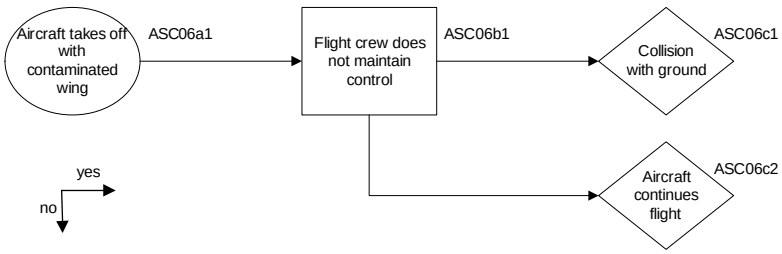

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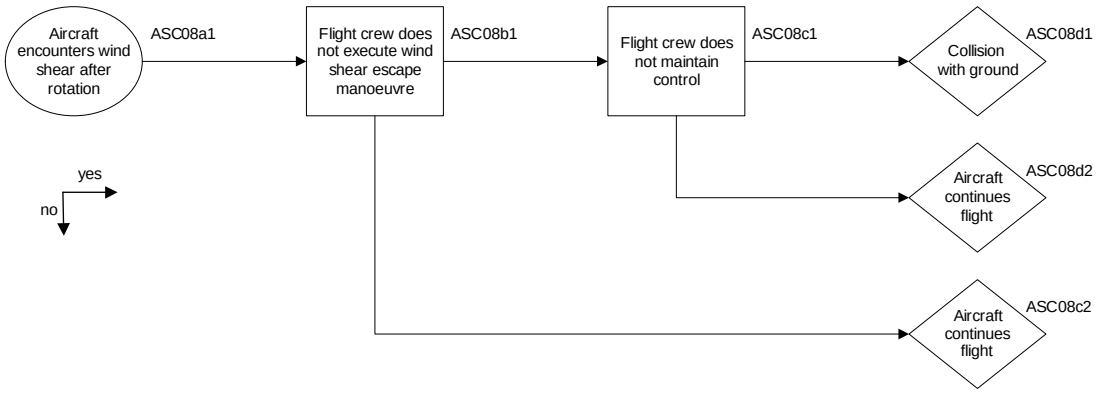

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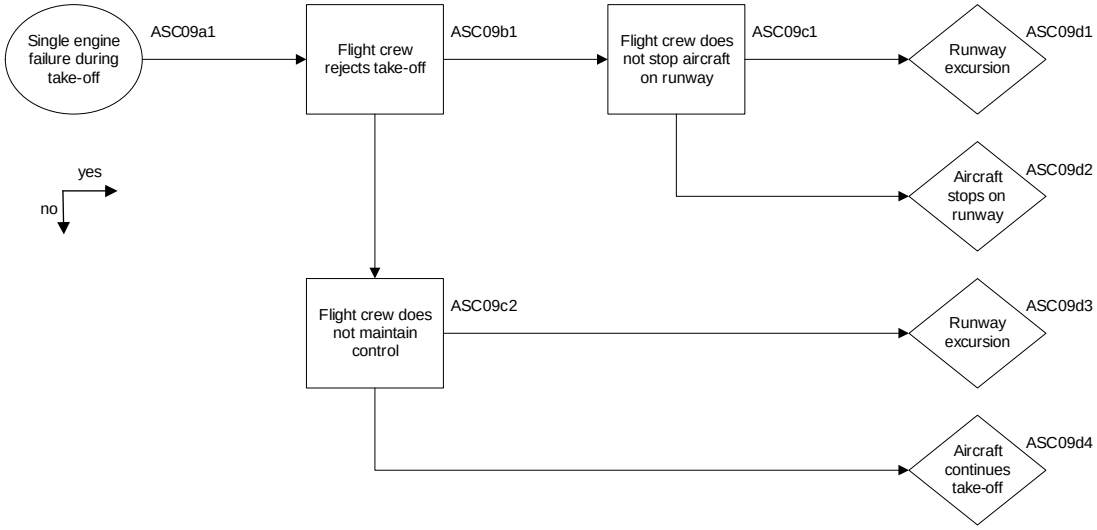

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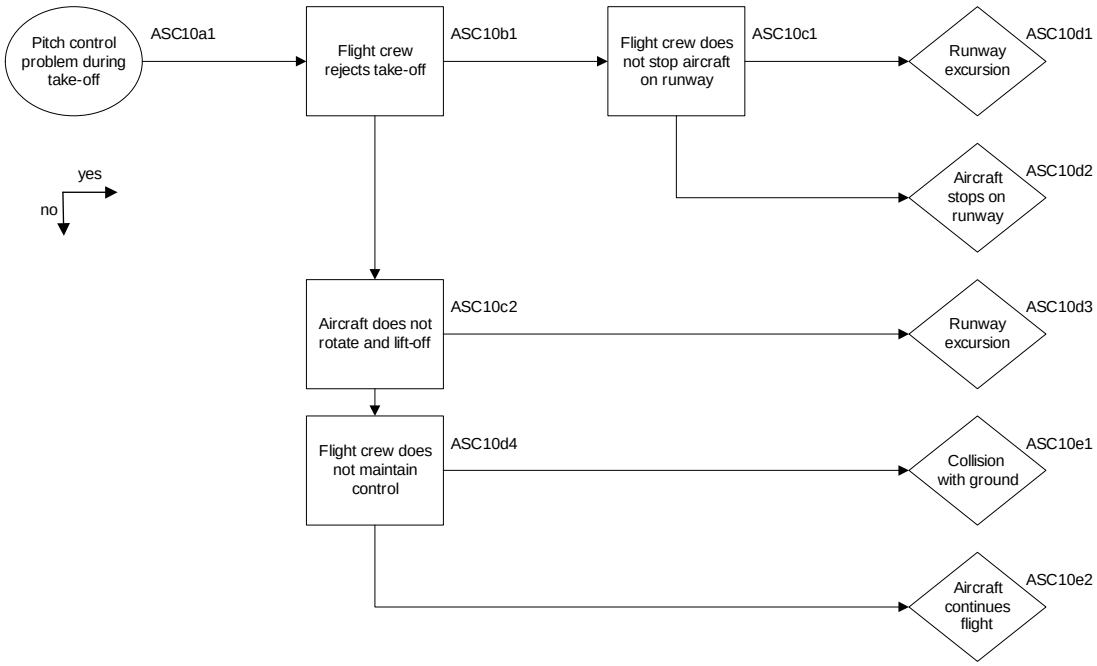

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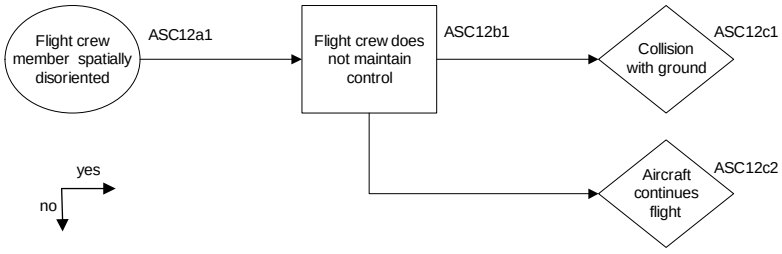

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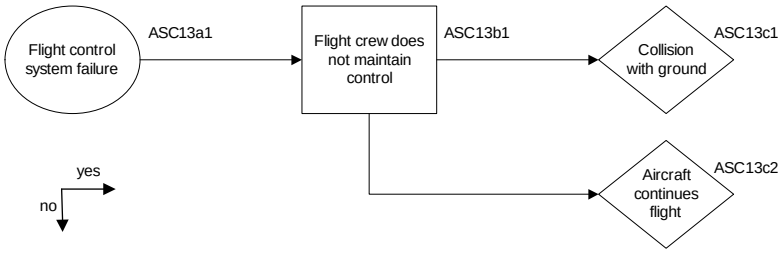

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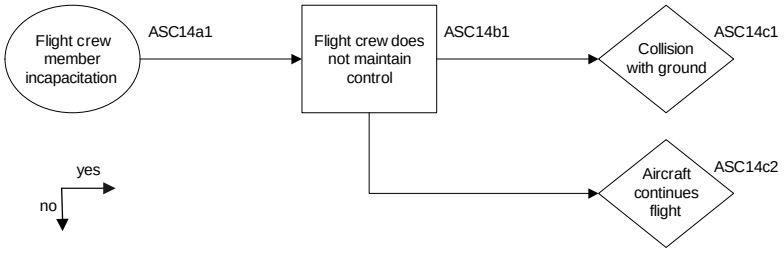

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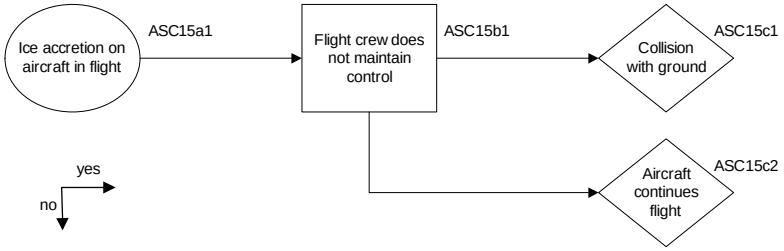

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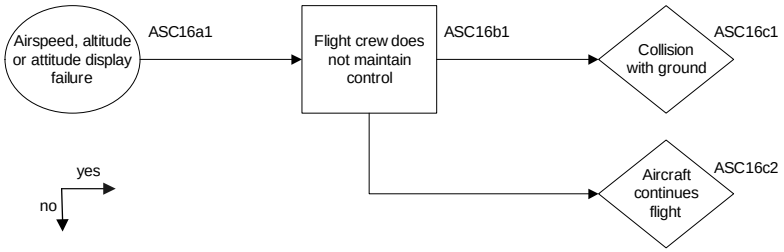

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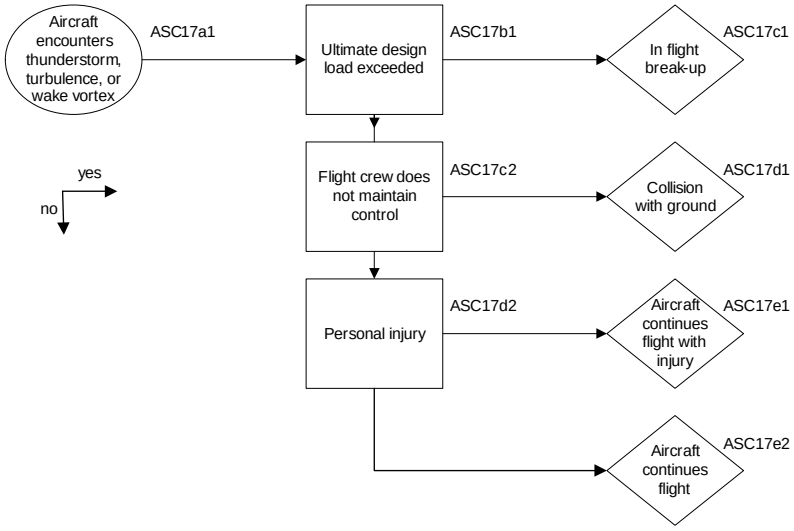

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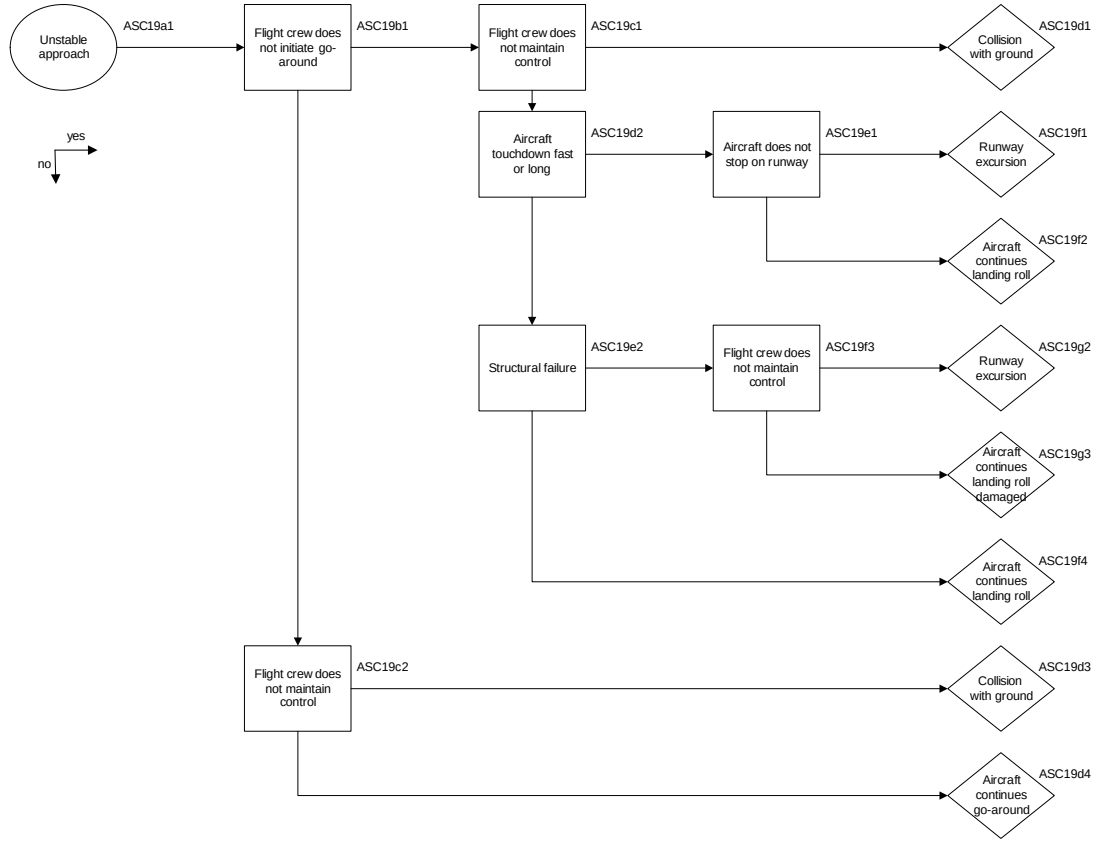

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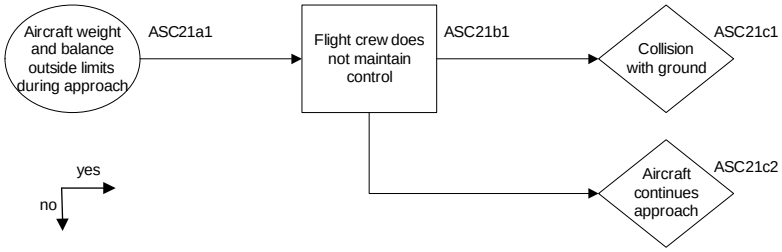

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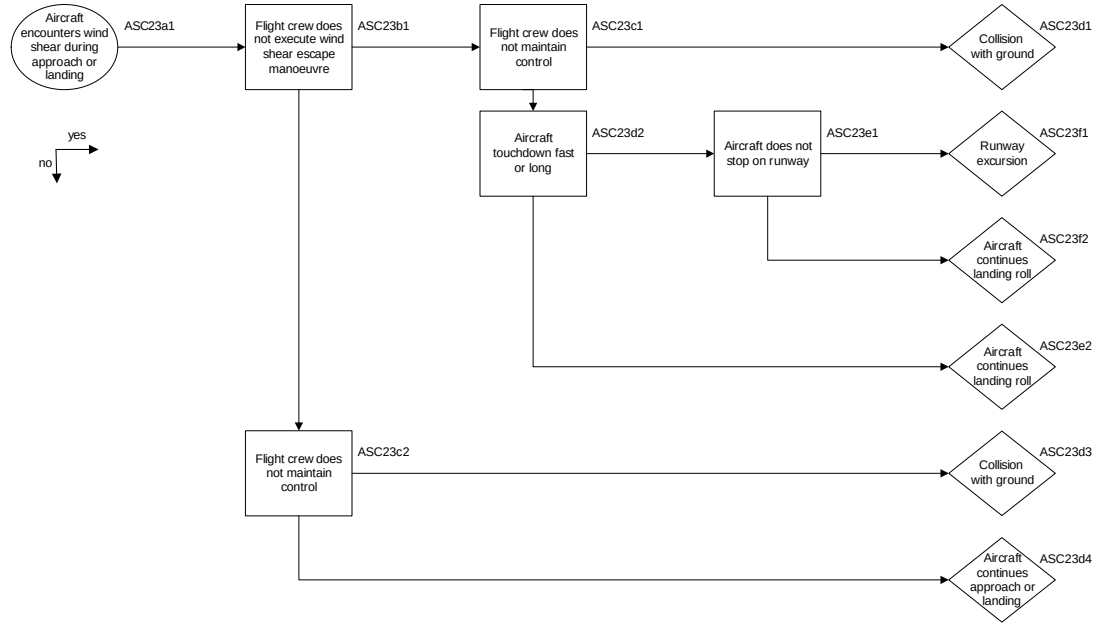

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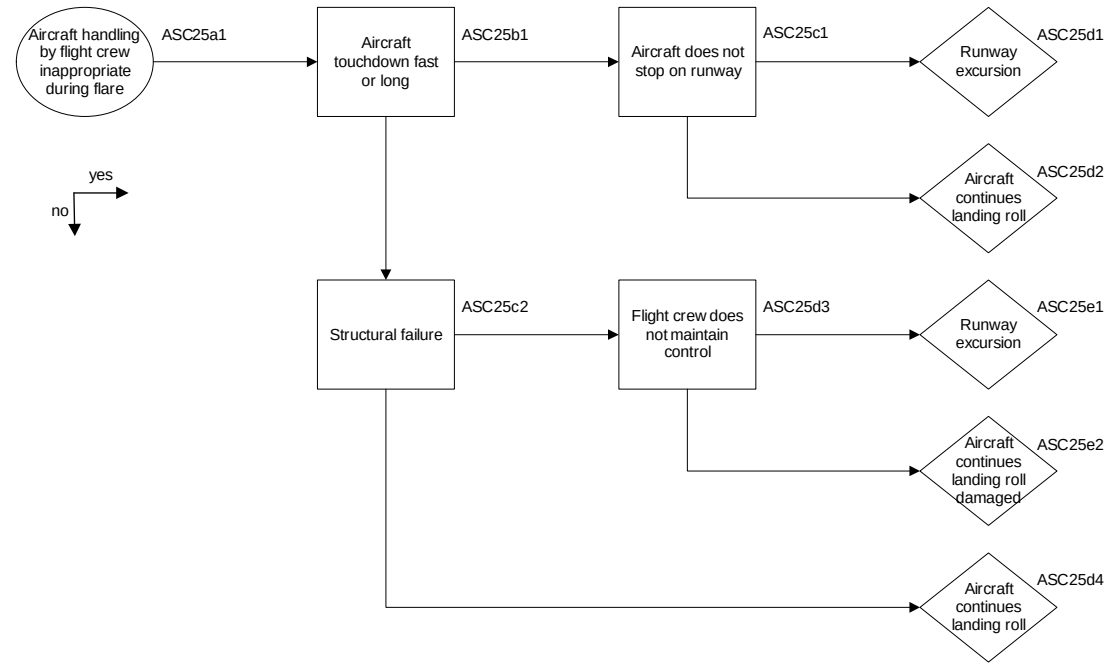

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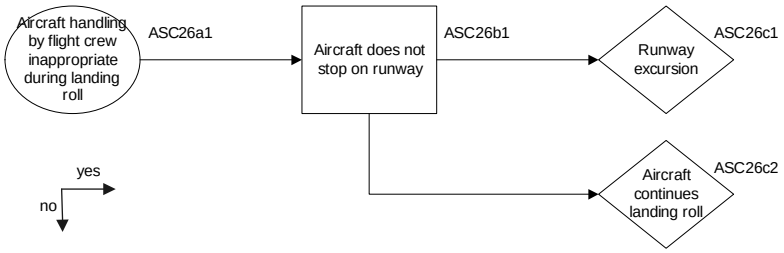

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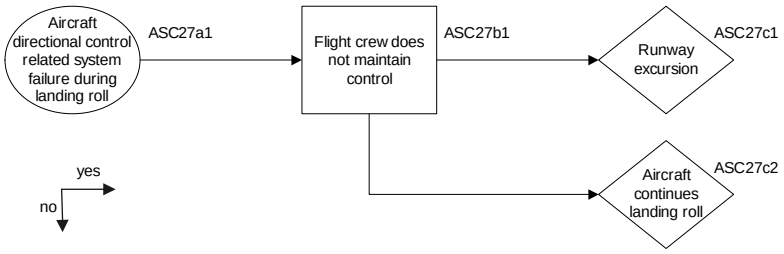

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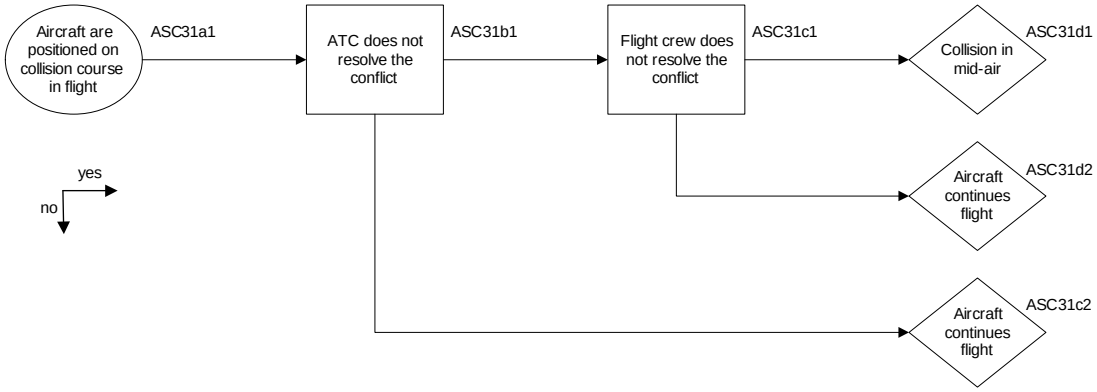

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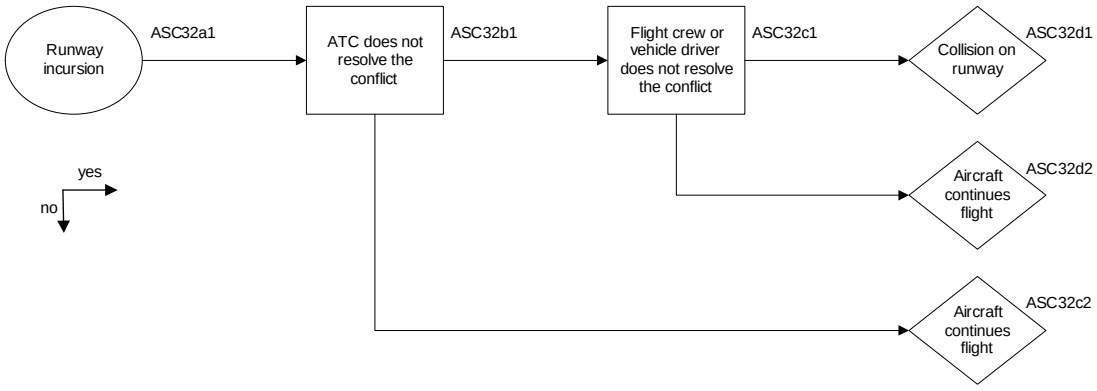

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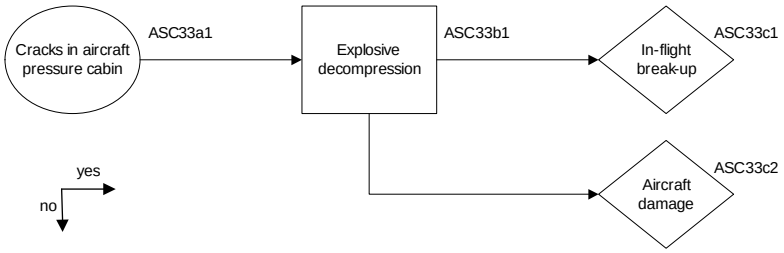

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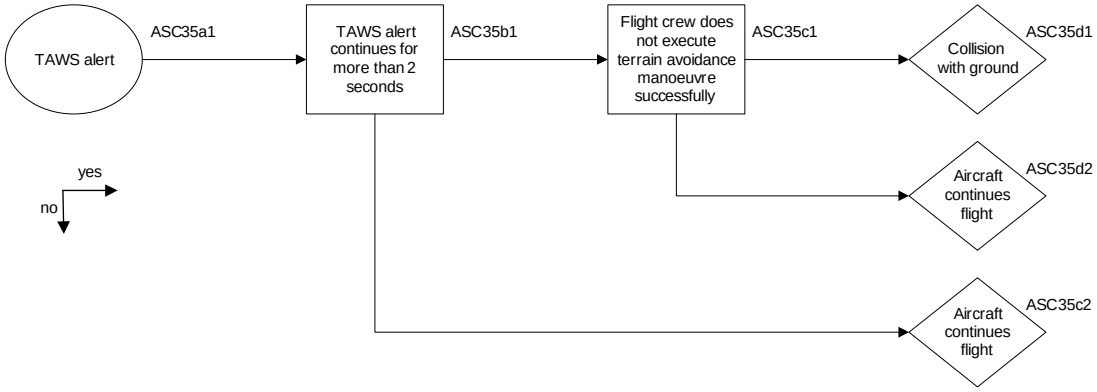

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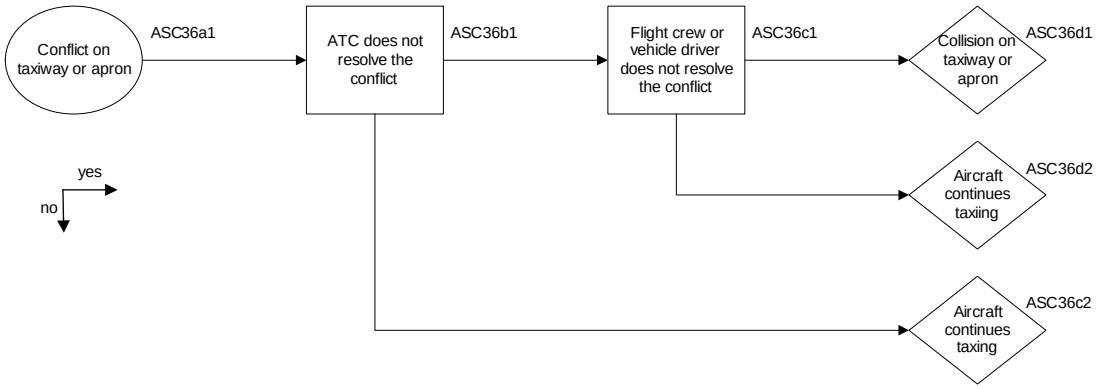

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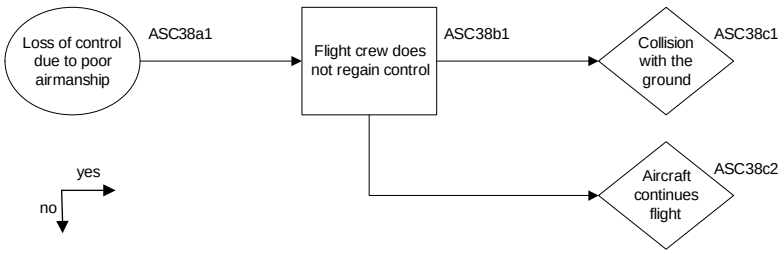

Appendix B Fault trees

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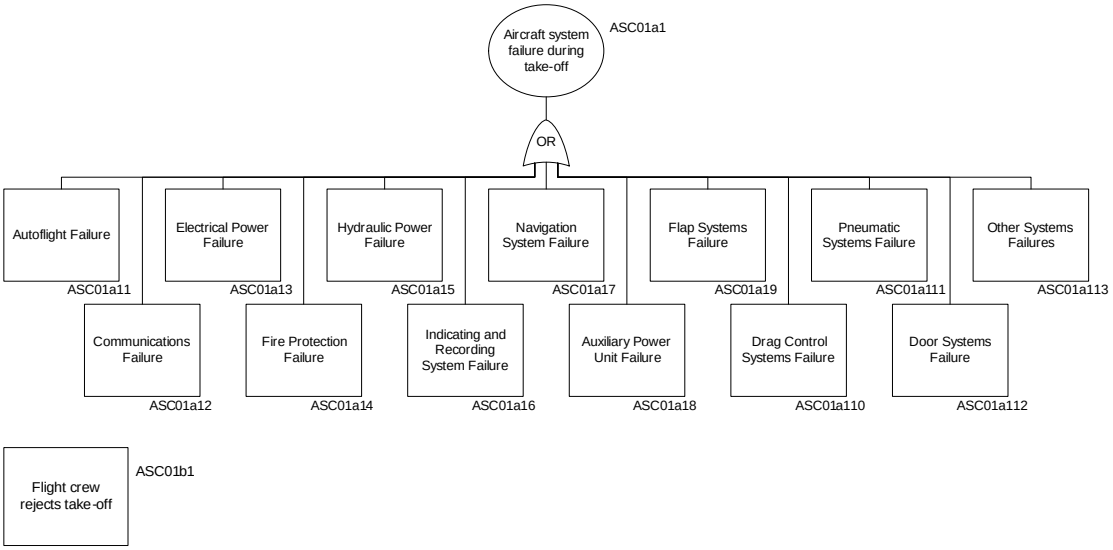

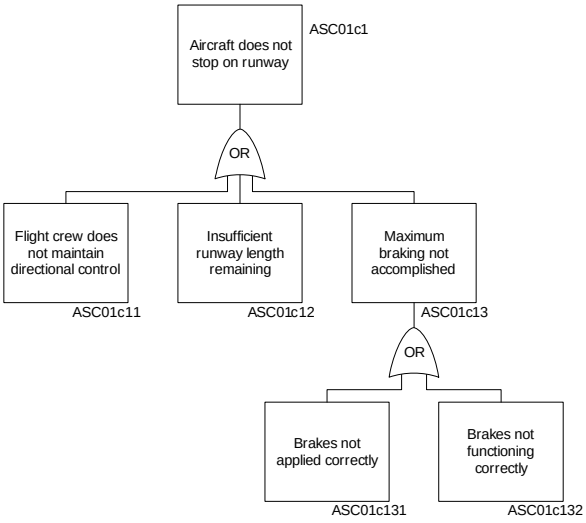

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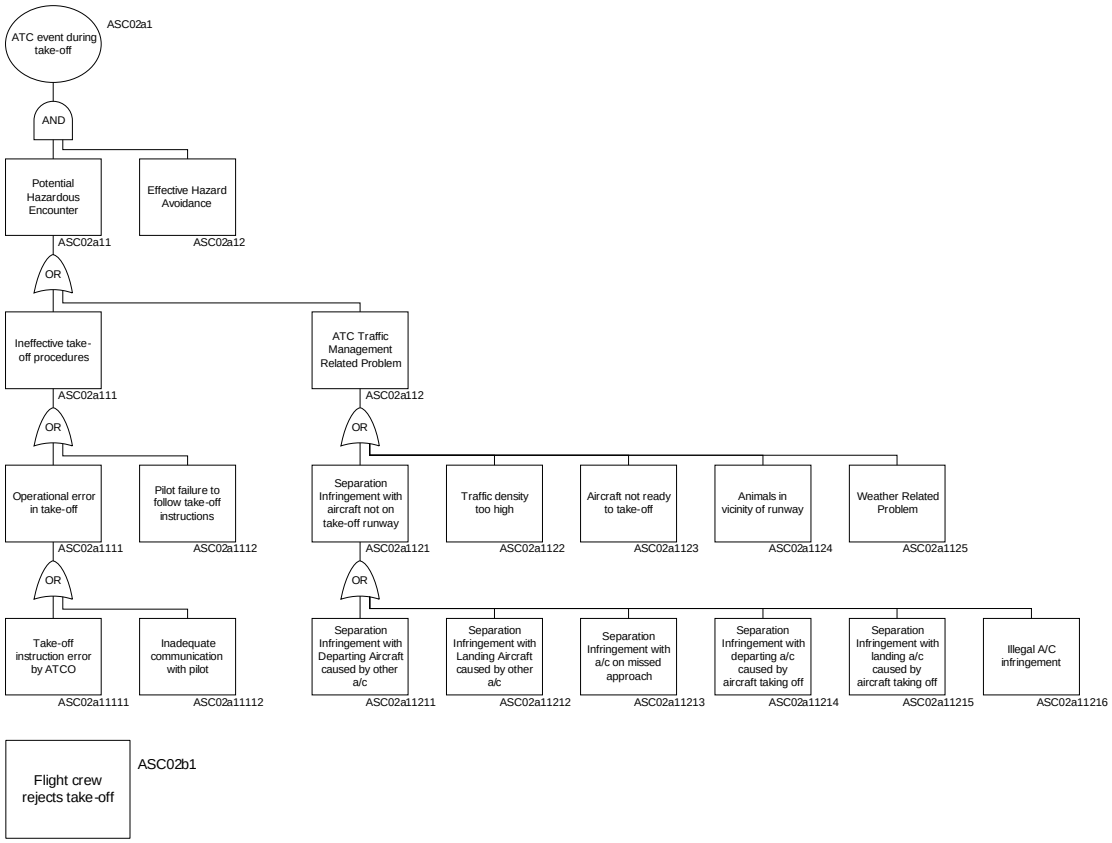

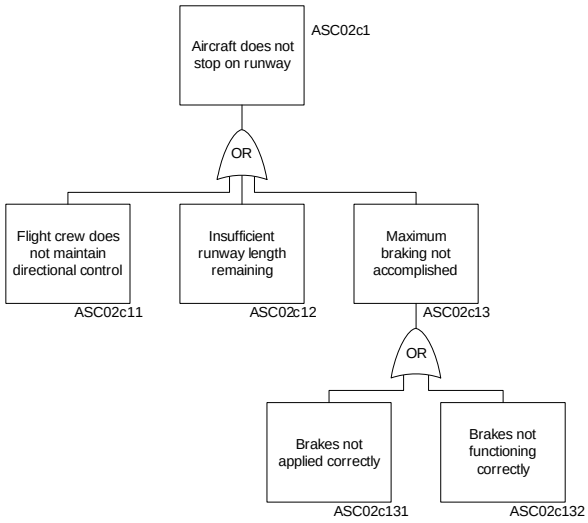

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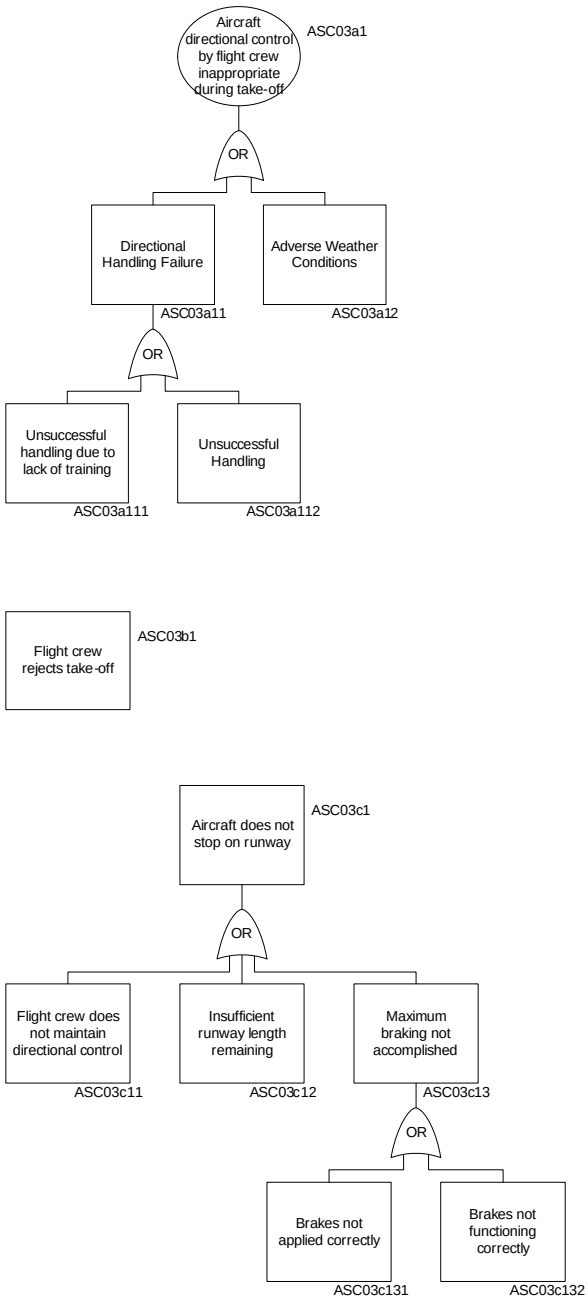

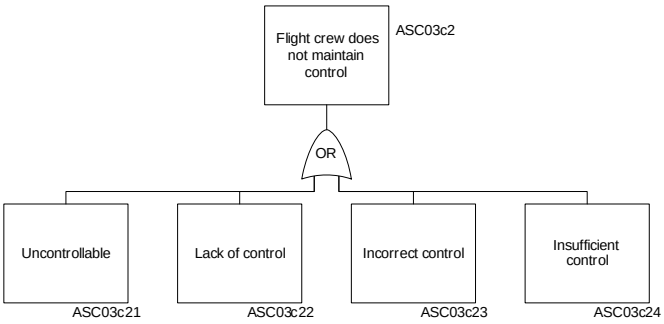

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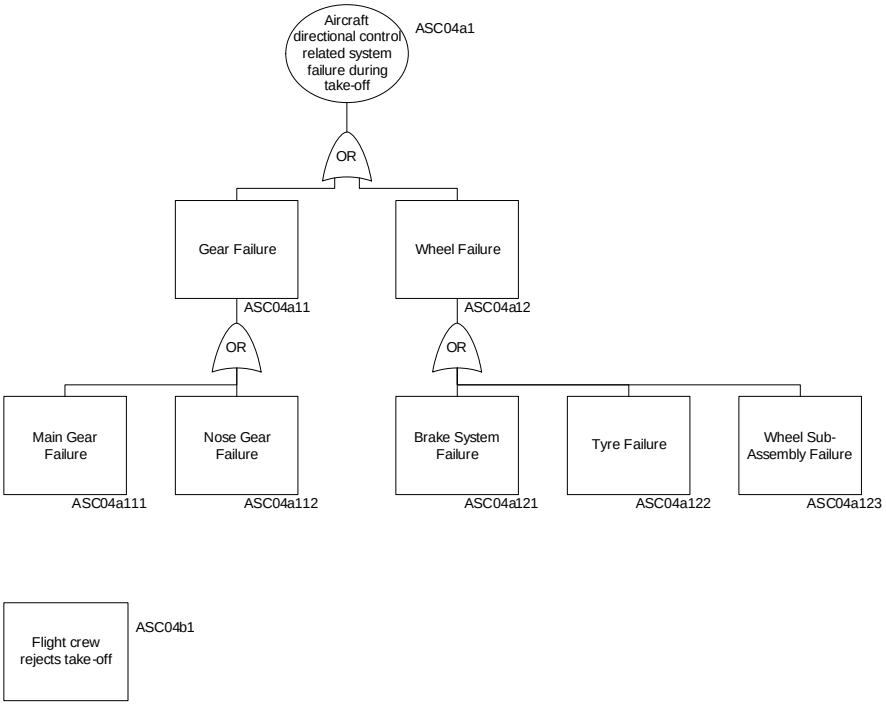

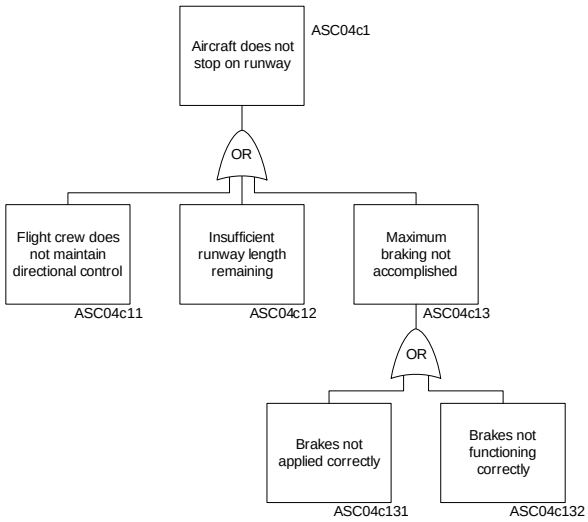

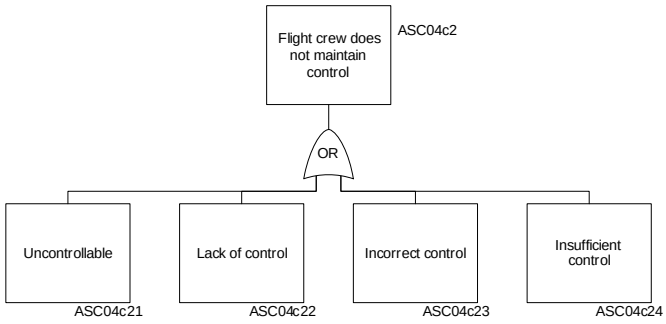

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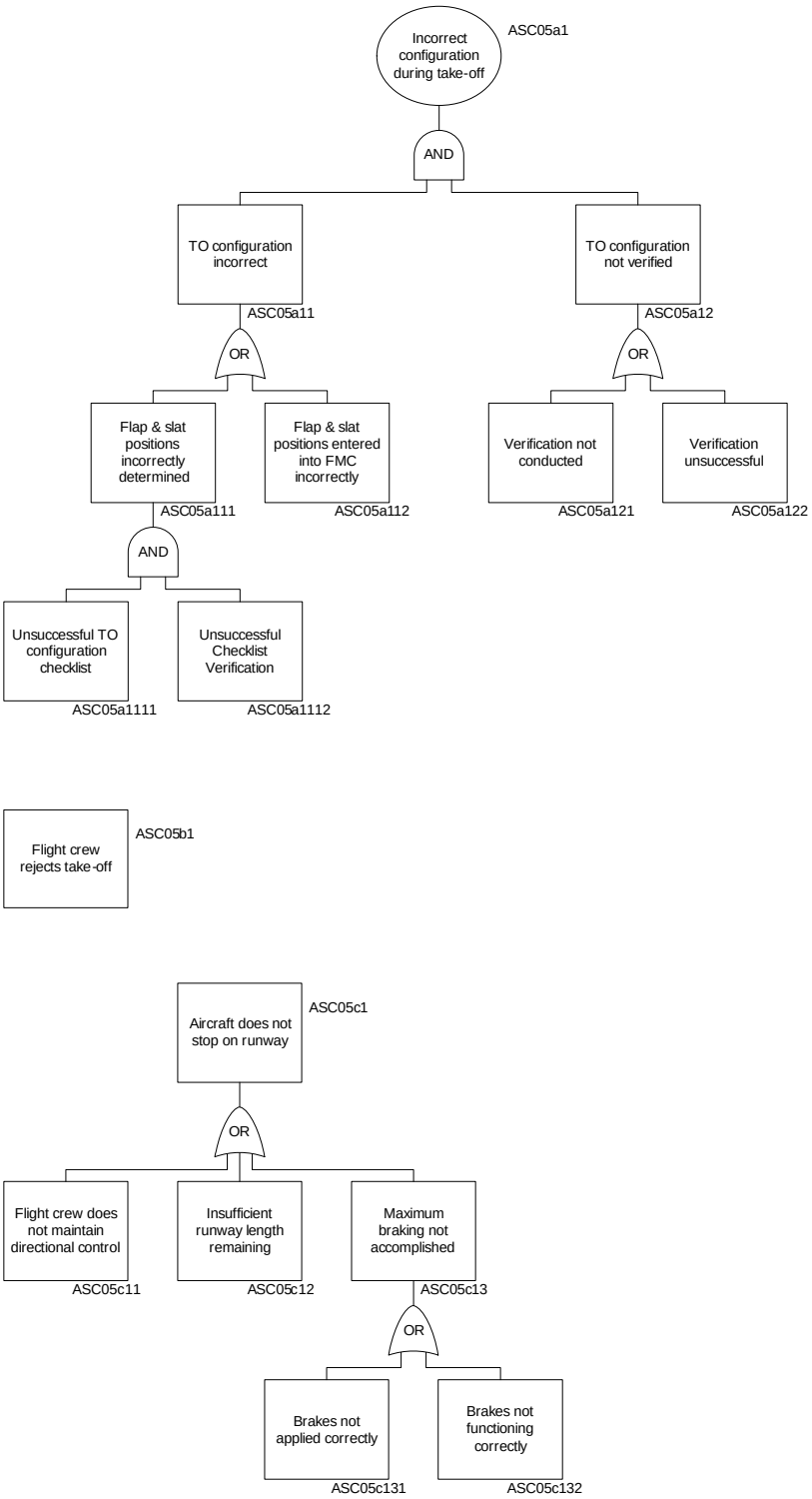

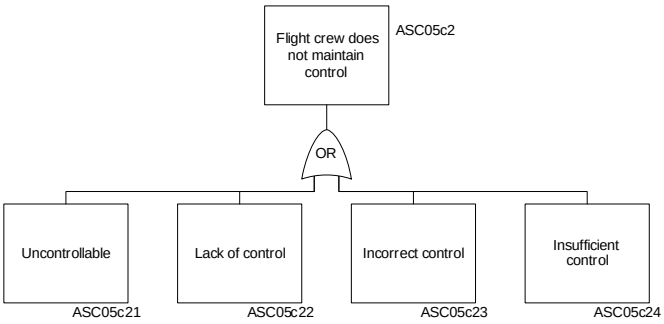

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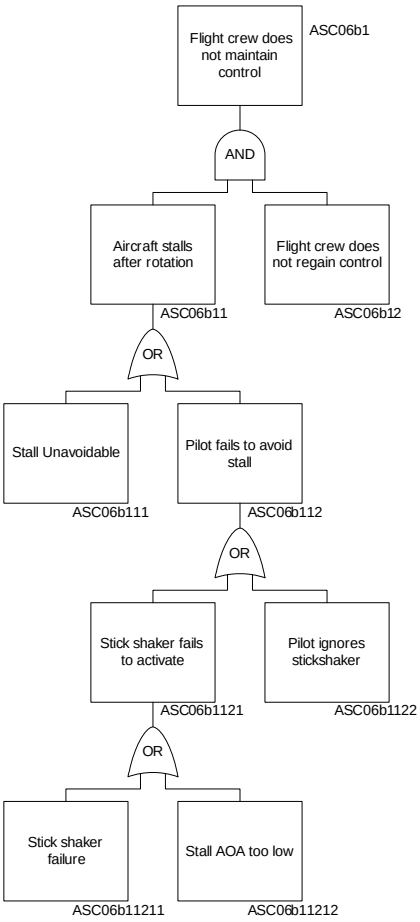

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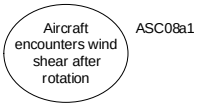

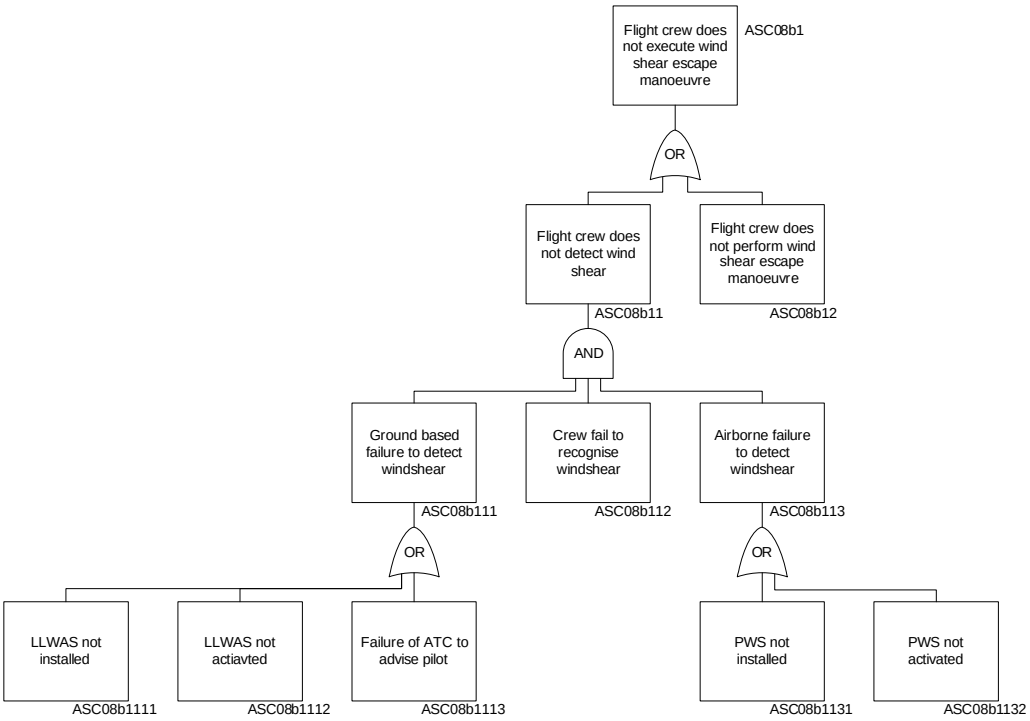

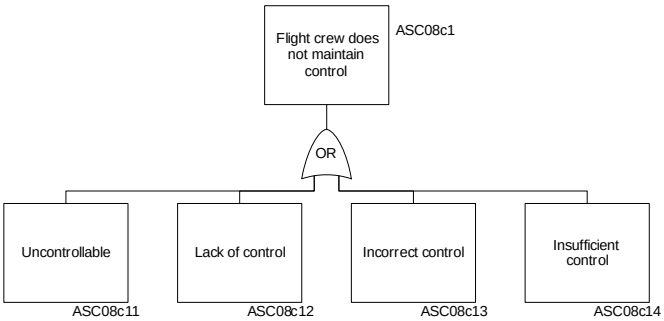

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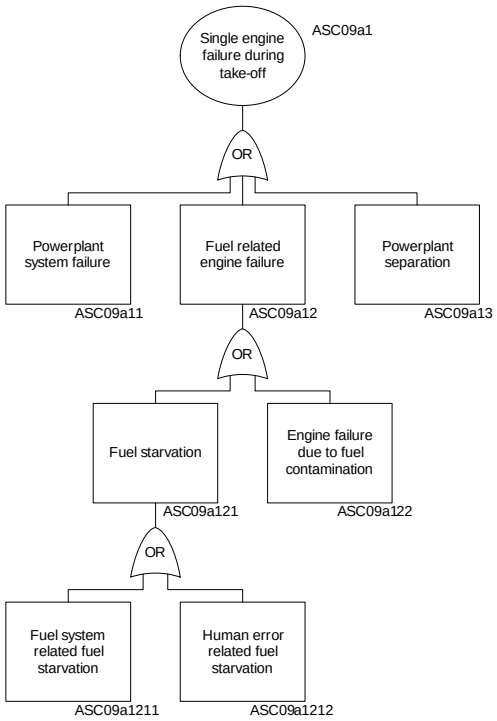

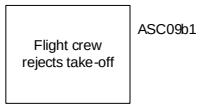

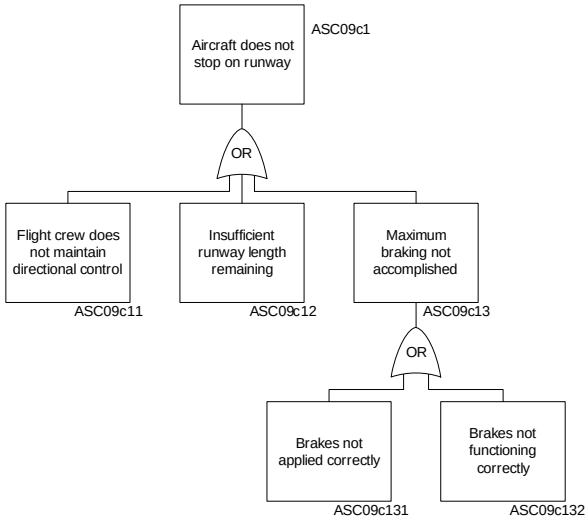

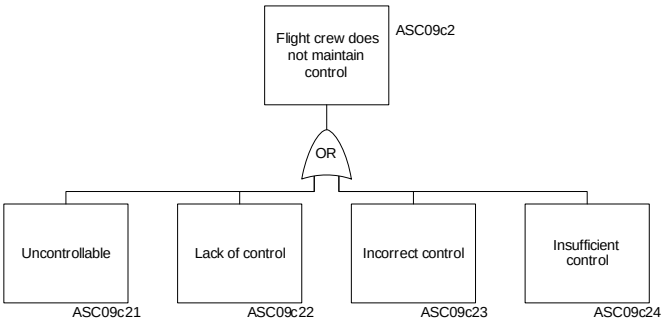

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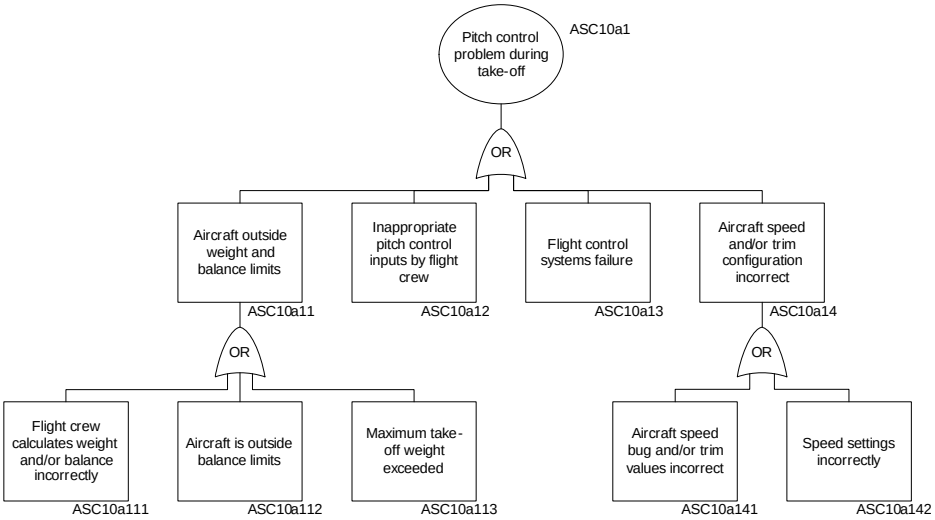

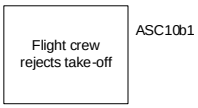

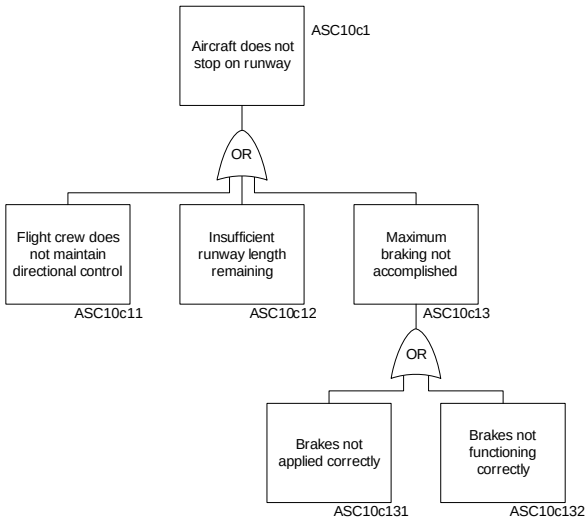

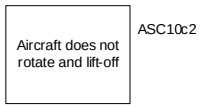

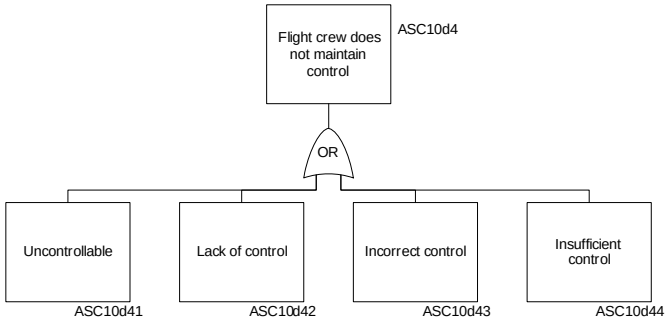

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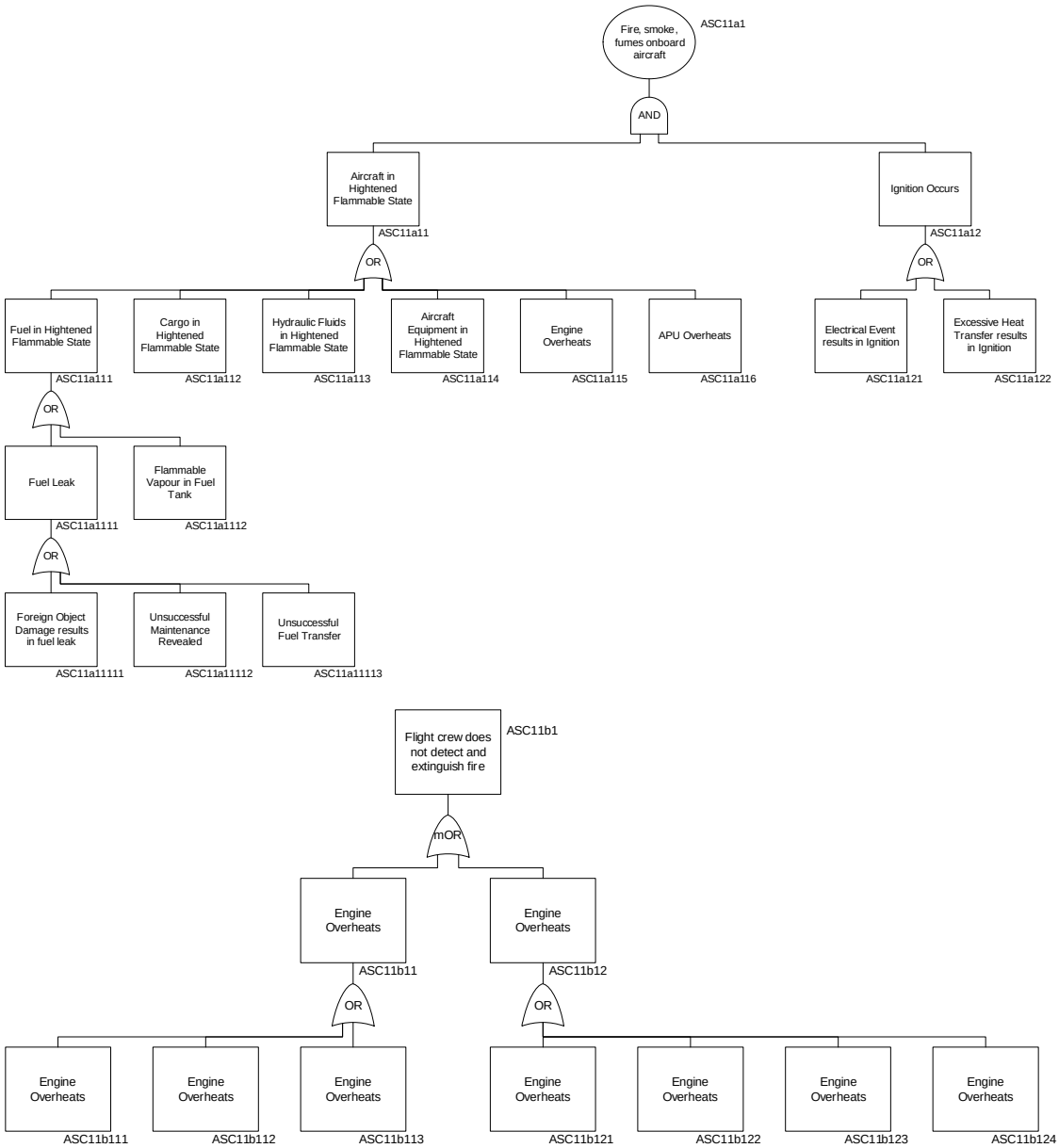

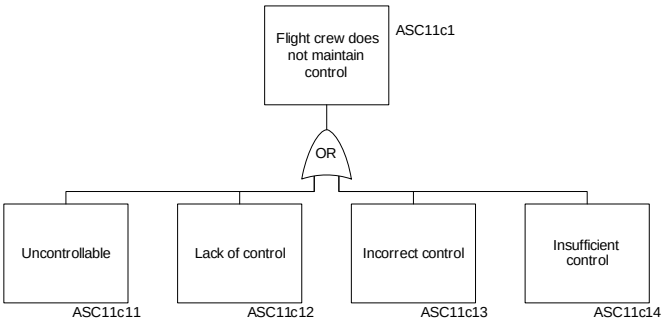

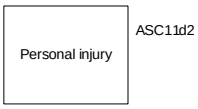

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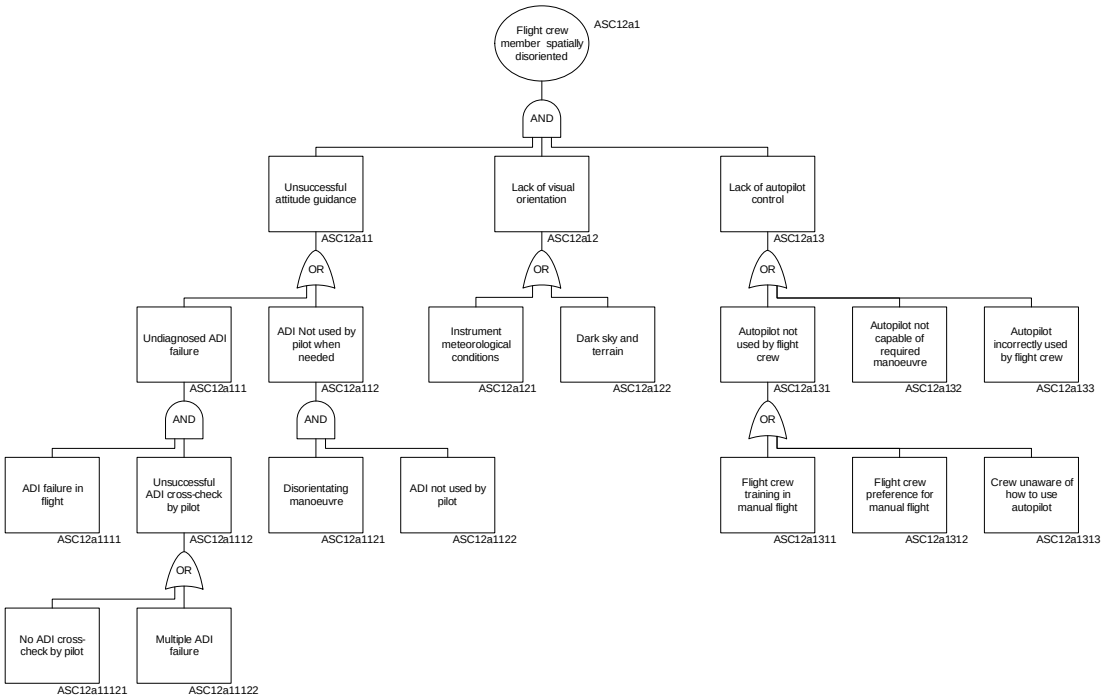

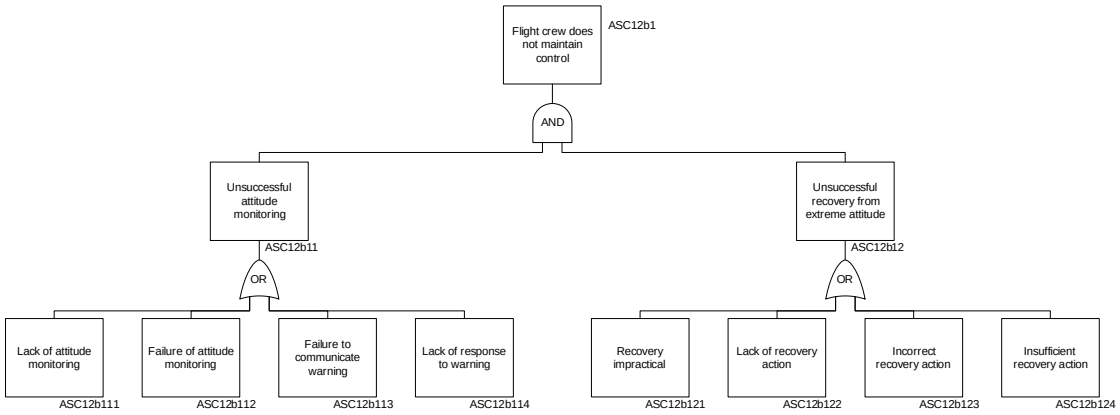

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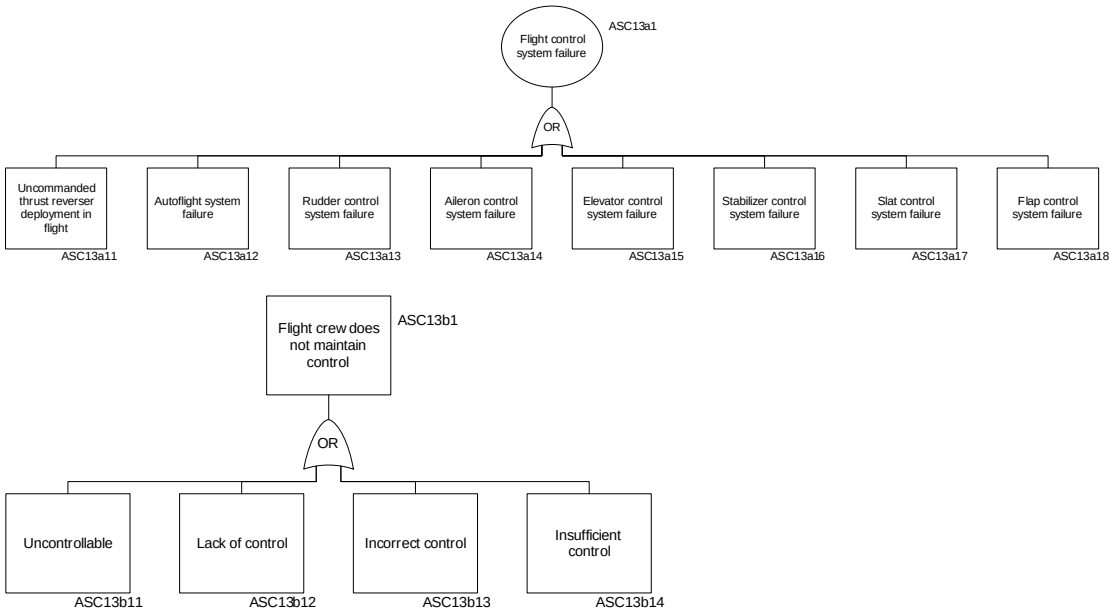

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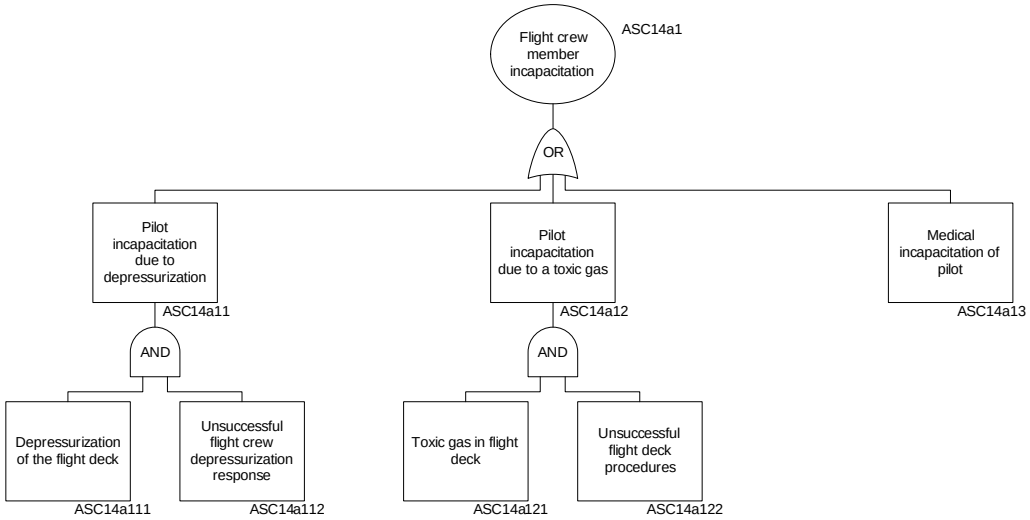

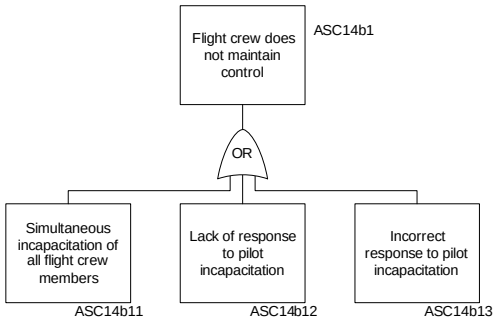

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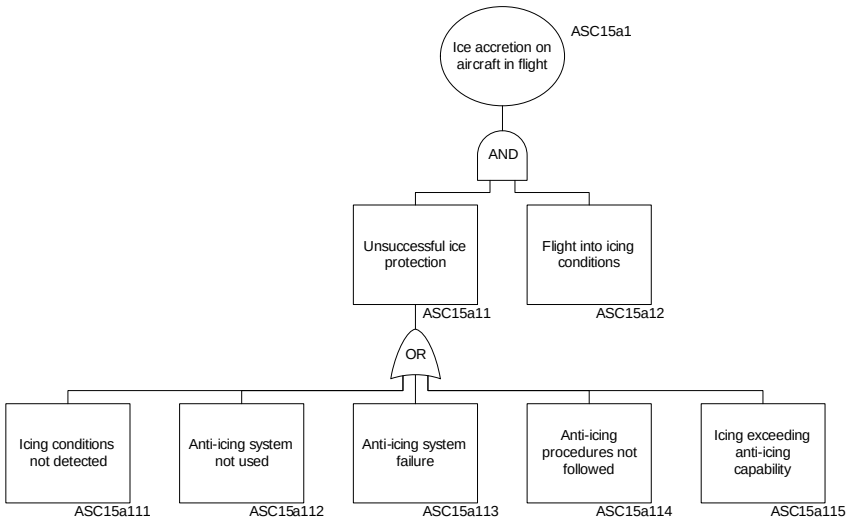

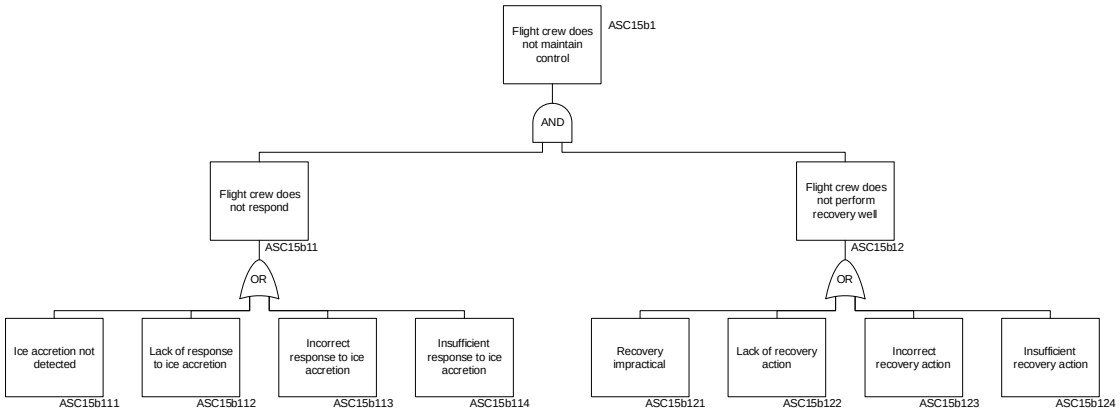

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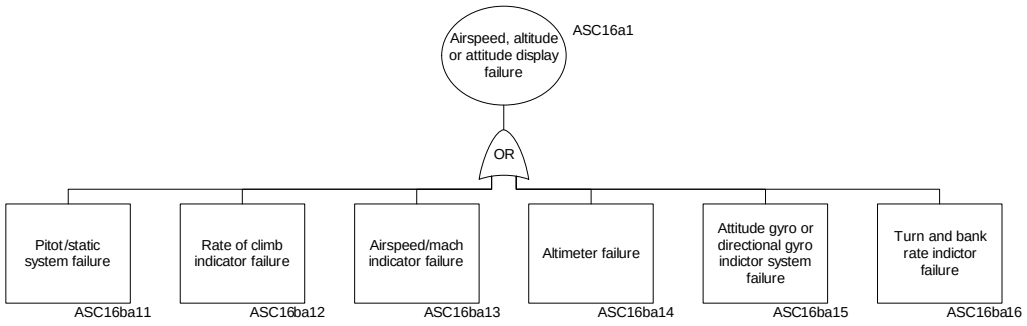

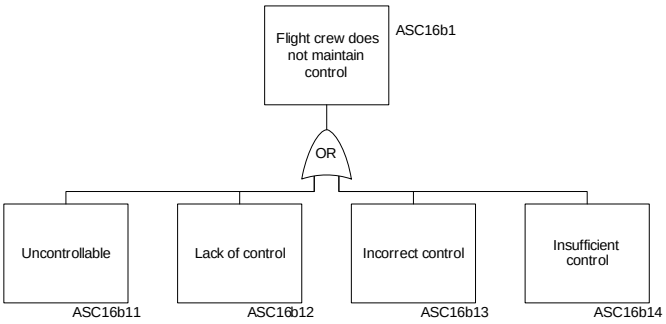

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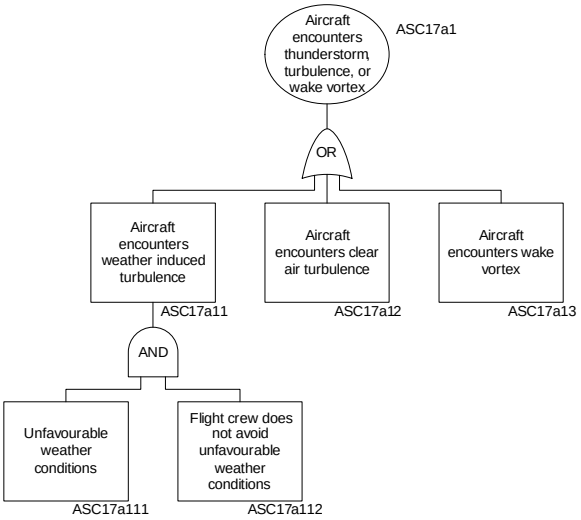

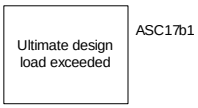

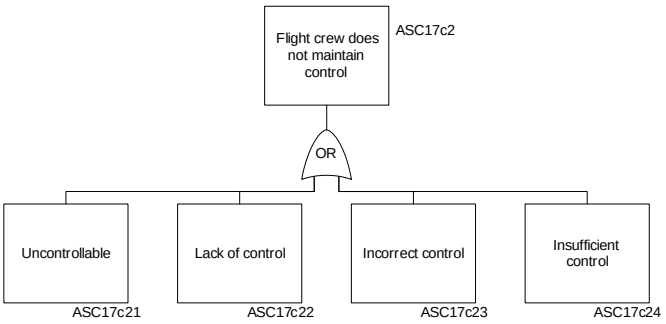

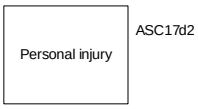

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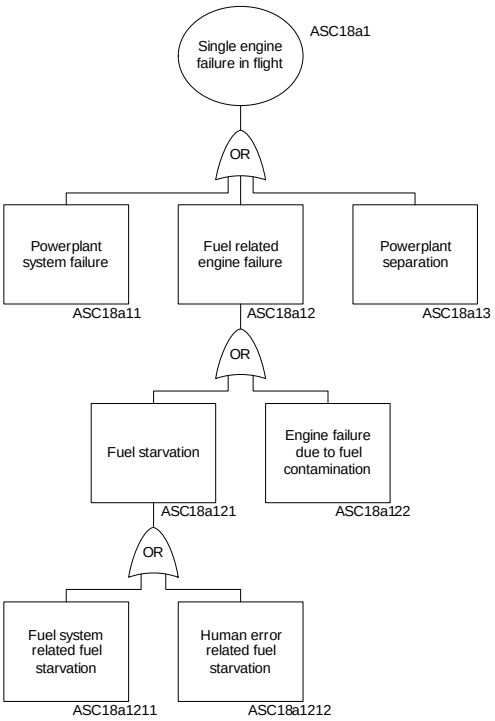

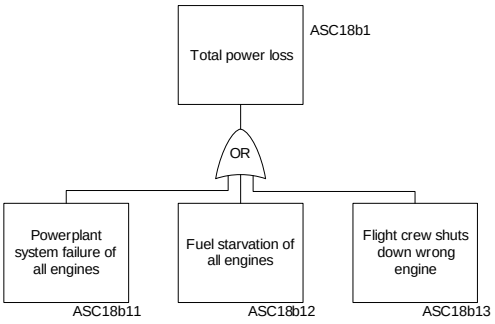

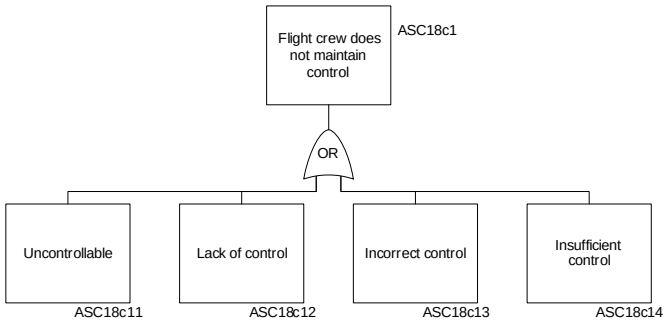

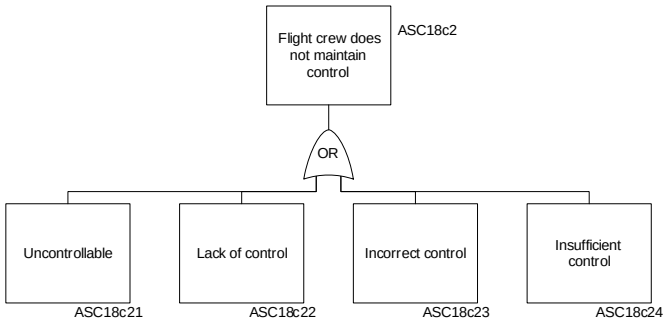

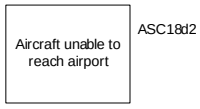

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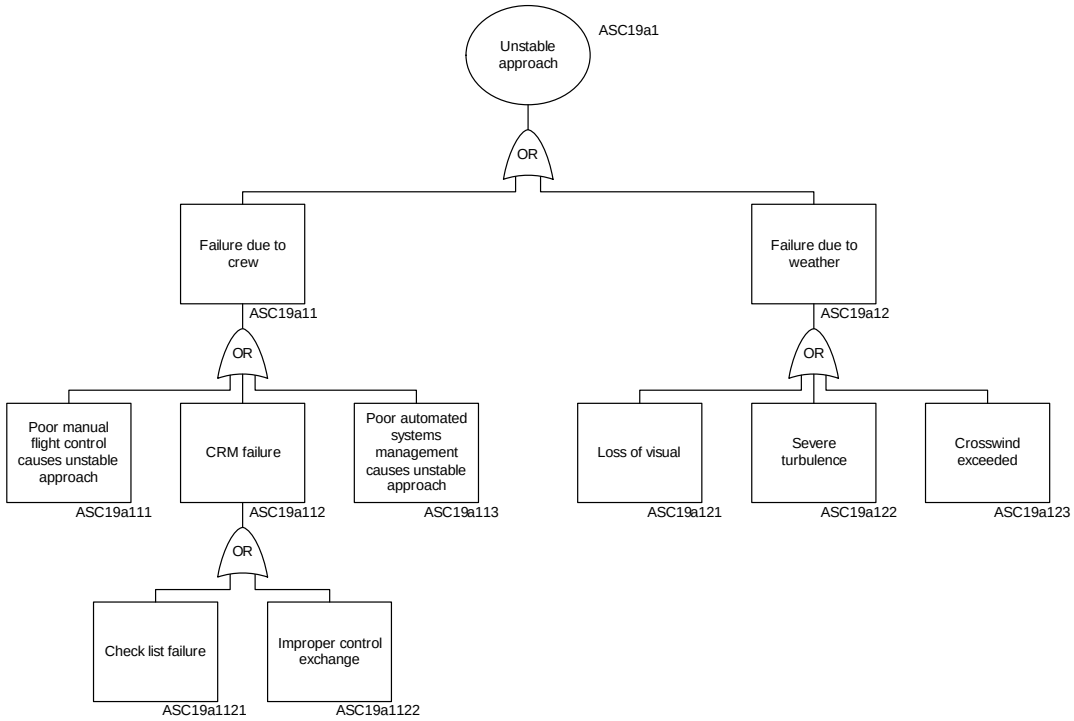

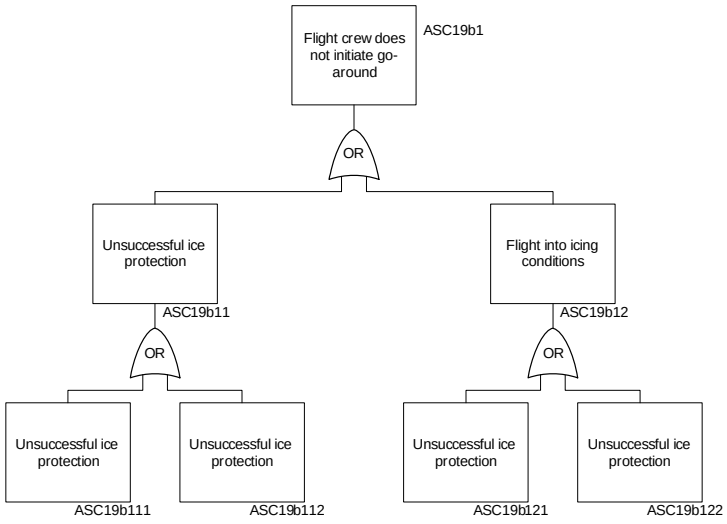

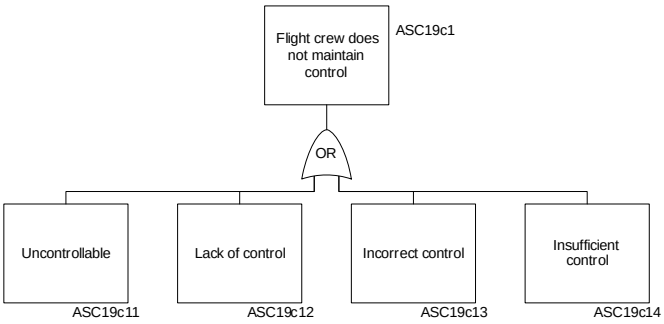

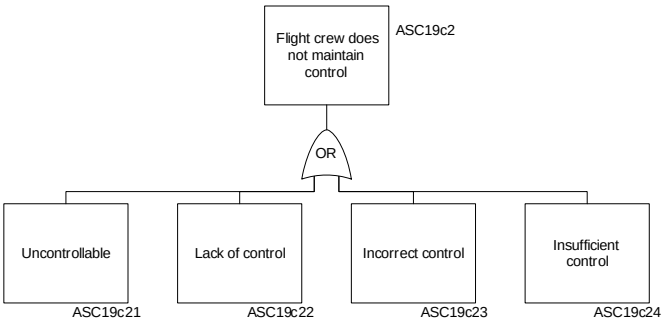

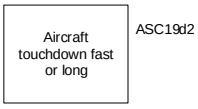

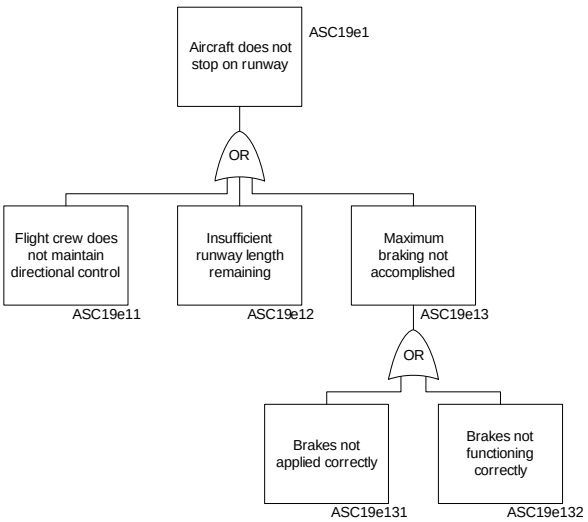

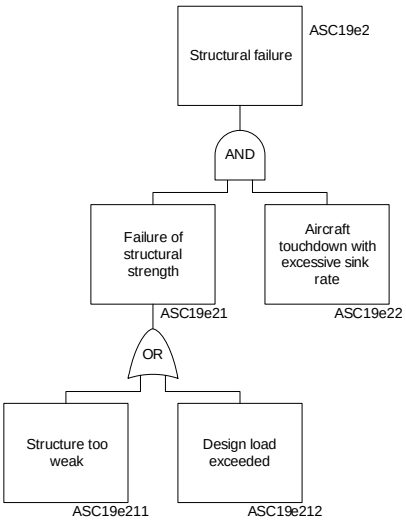

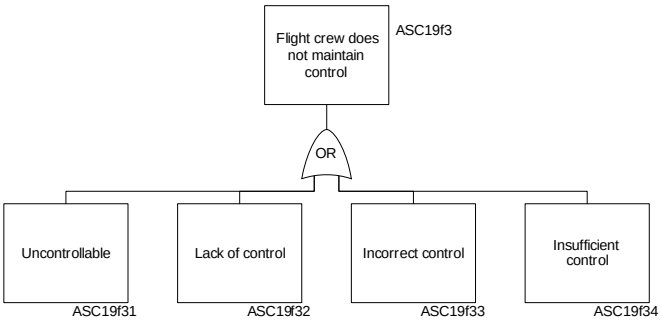

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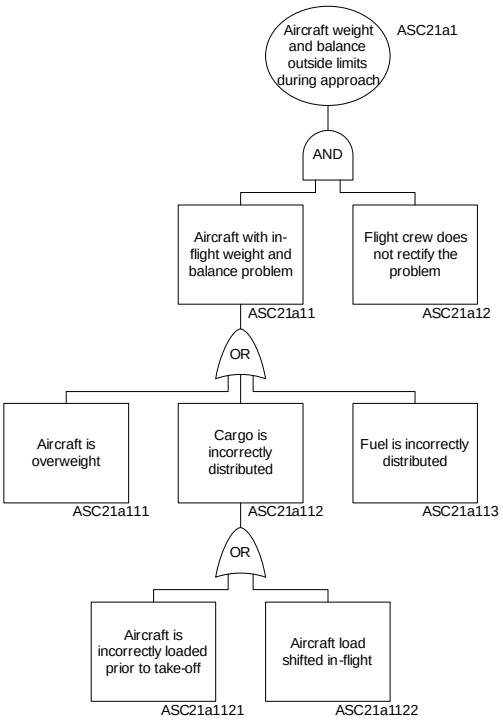

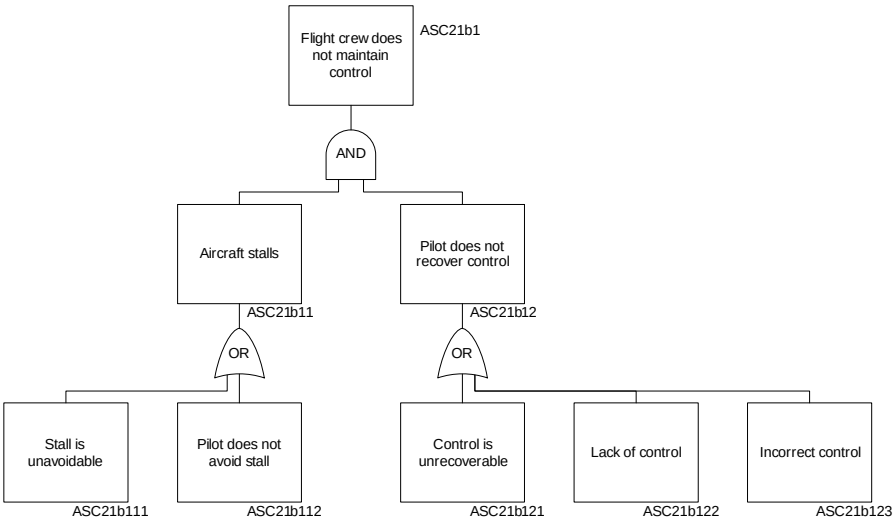

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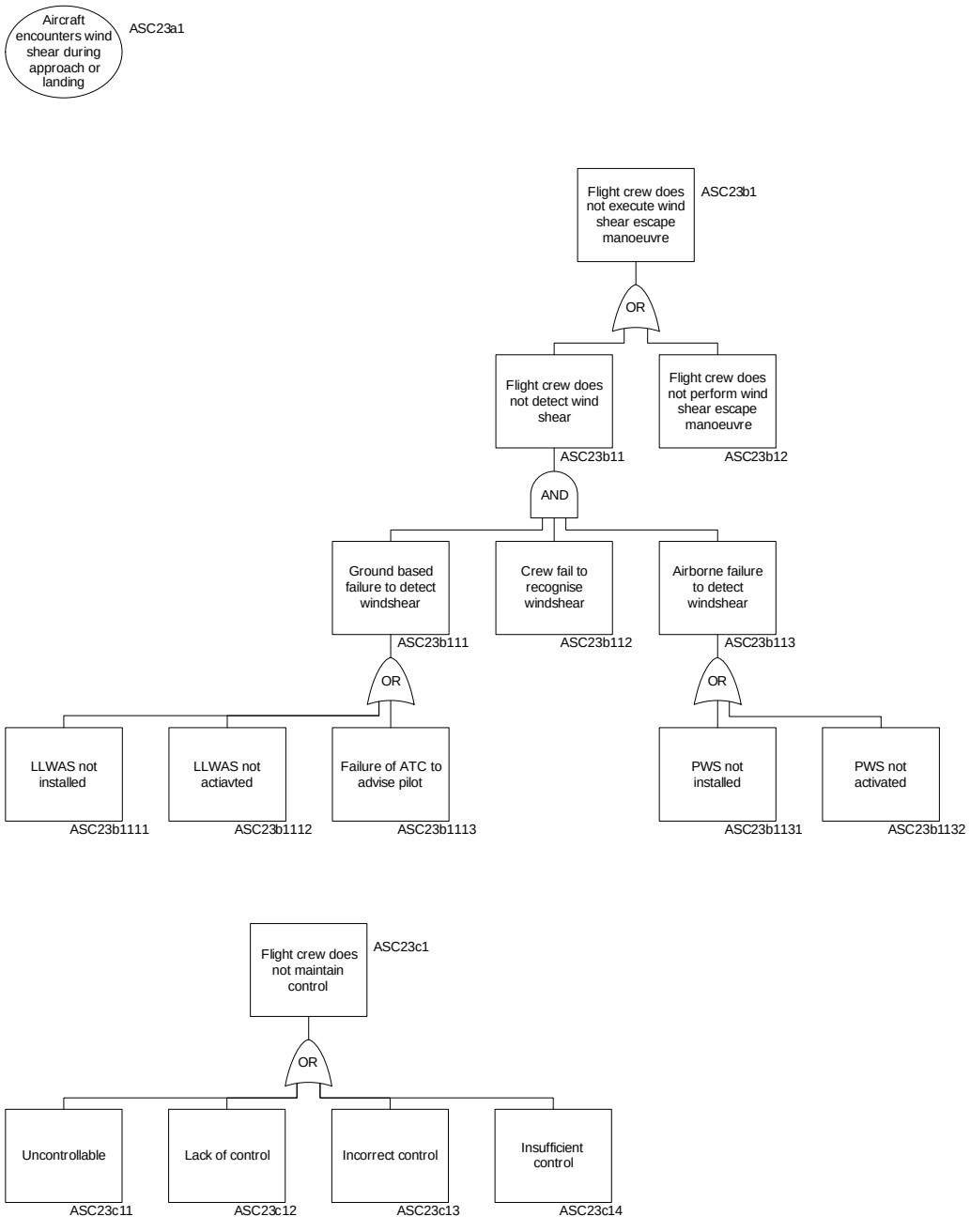

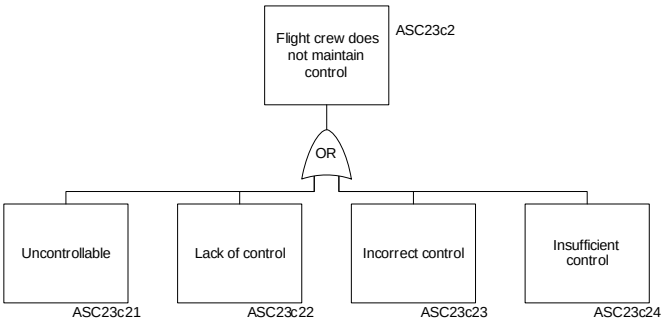

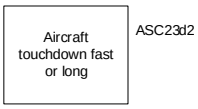

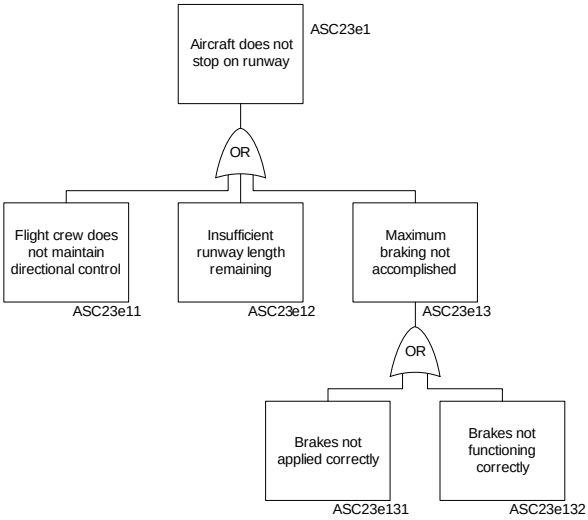

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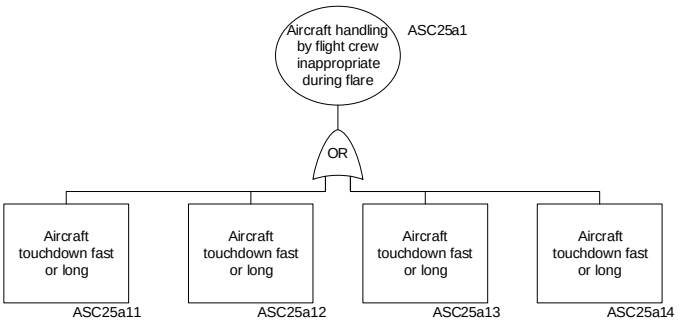

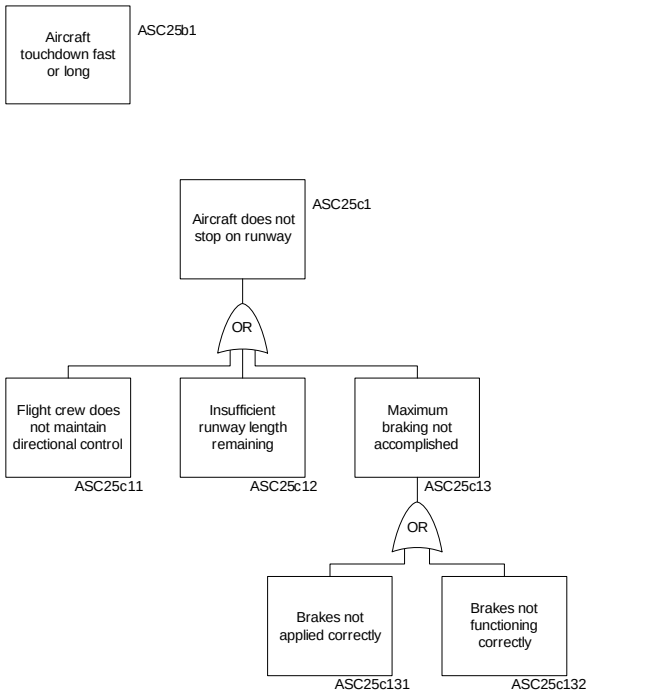

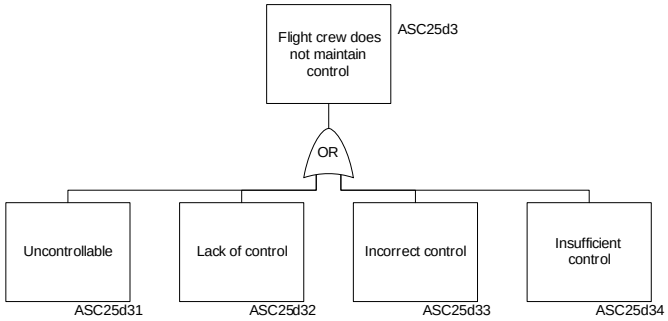

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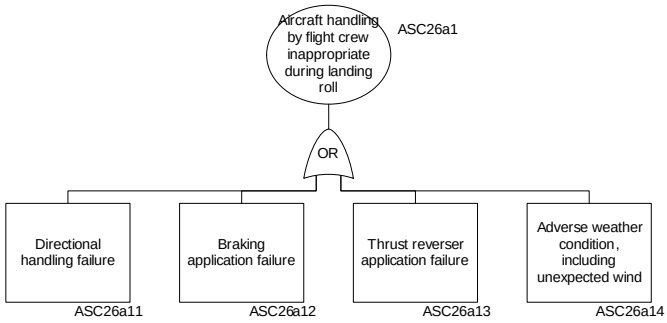

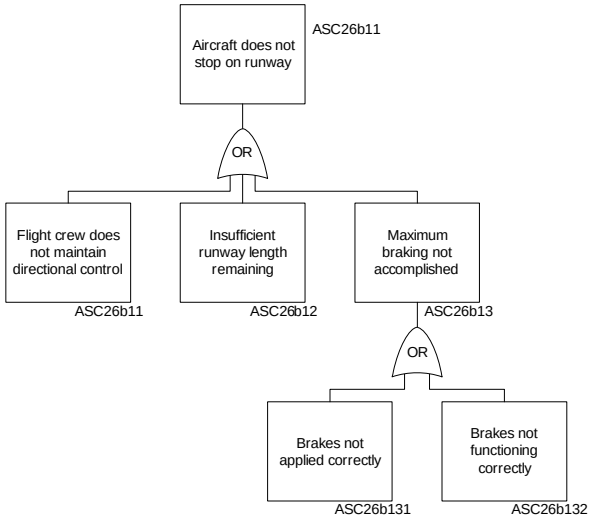

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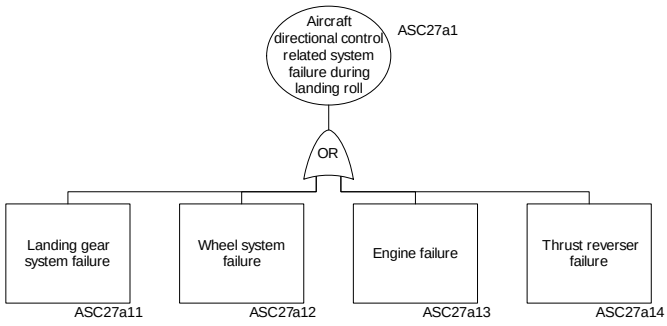

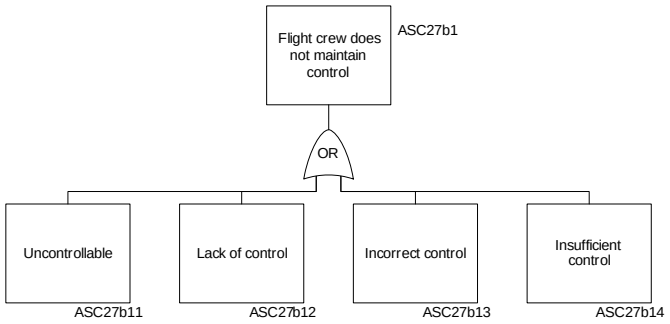

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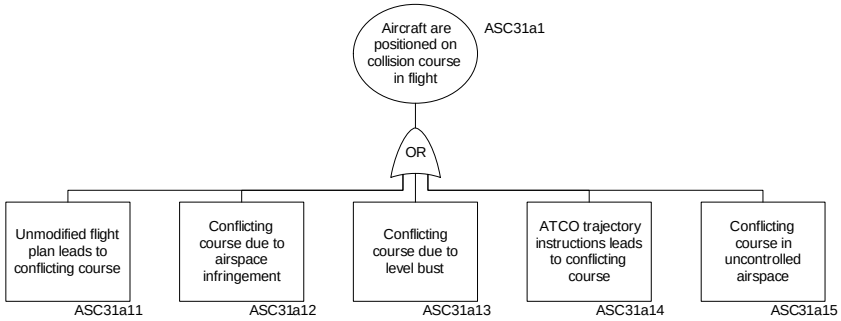

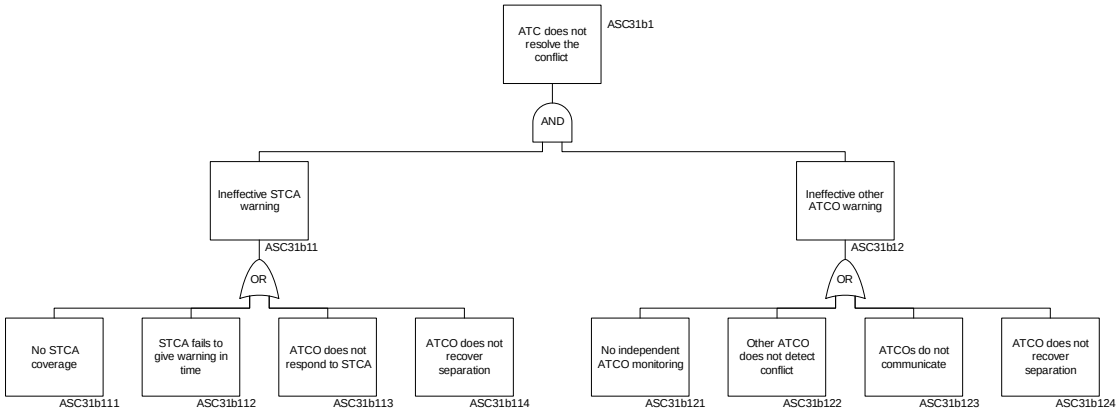

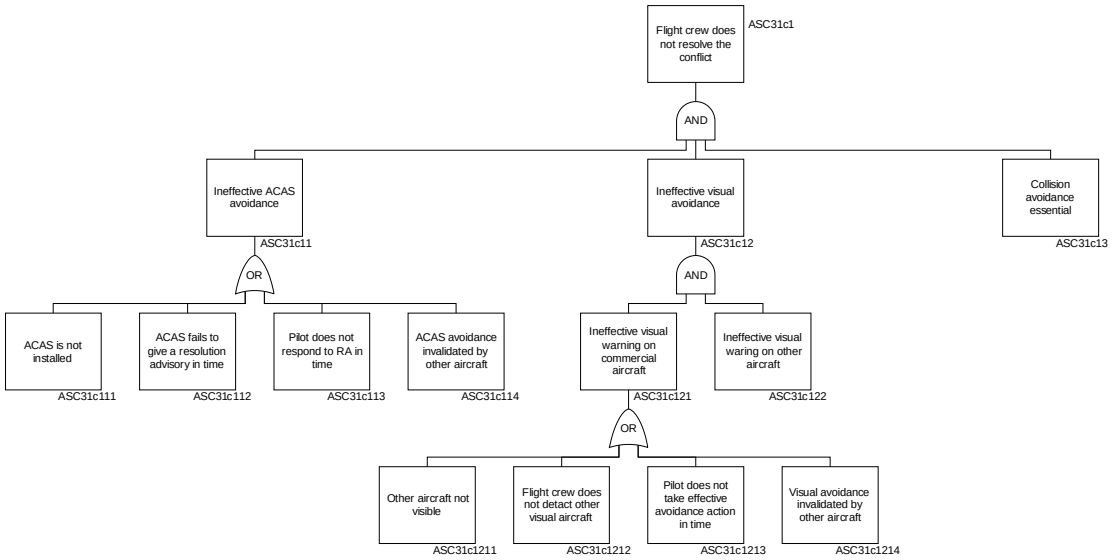

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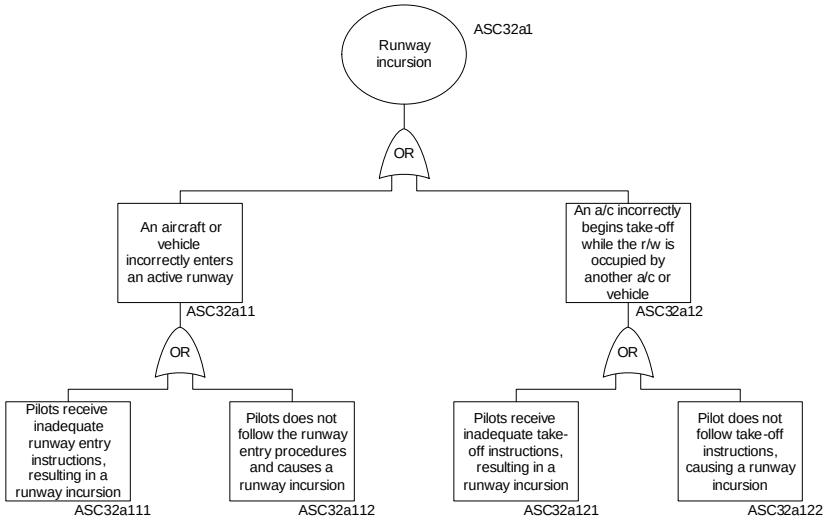

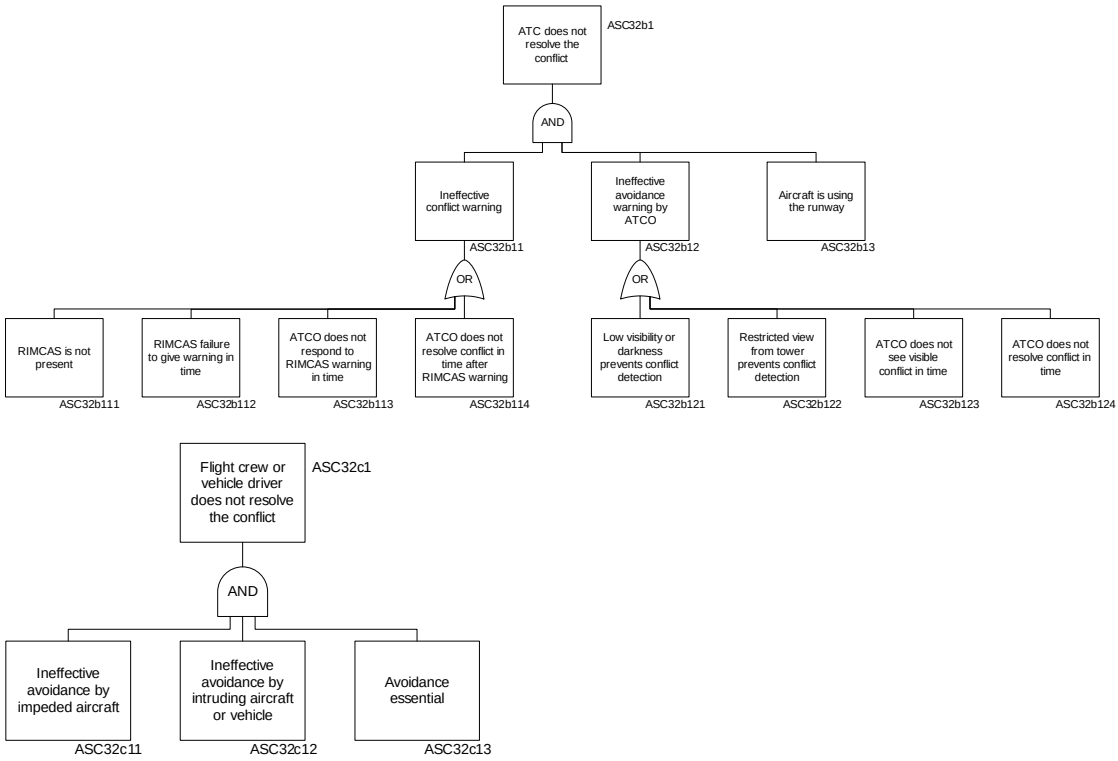

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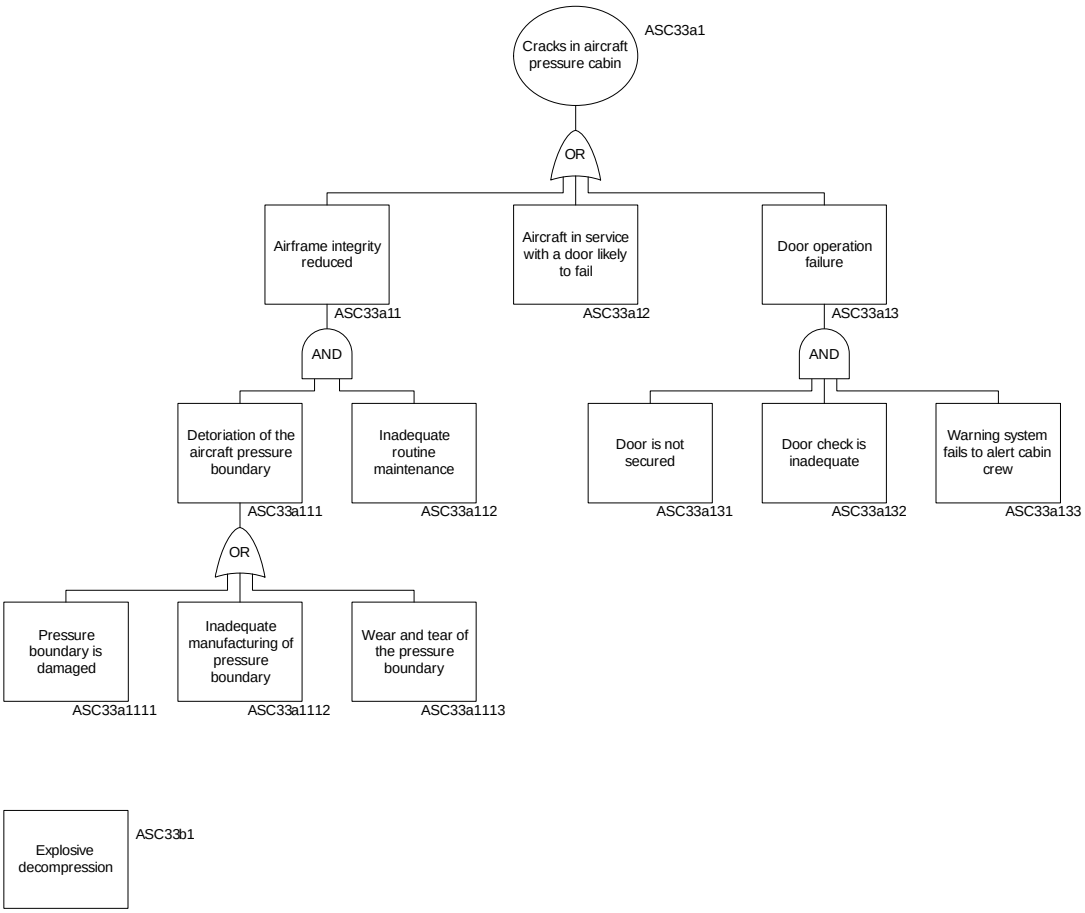

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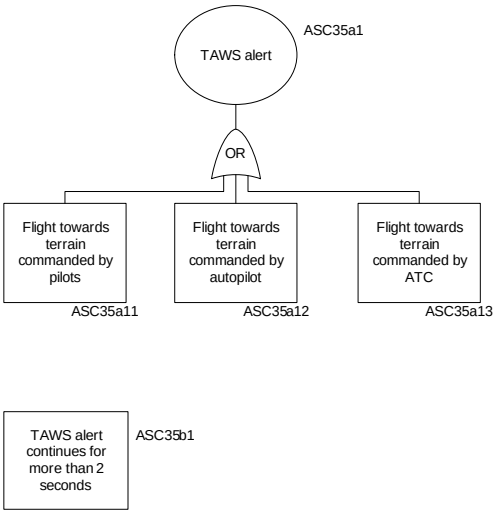

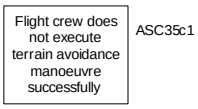

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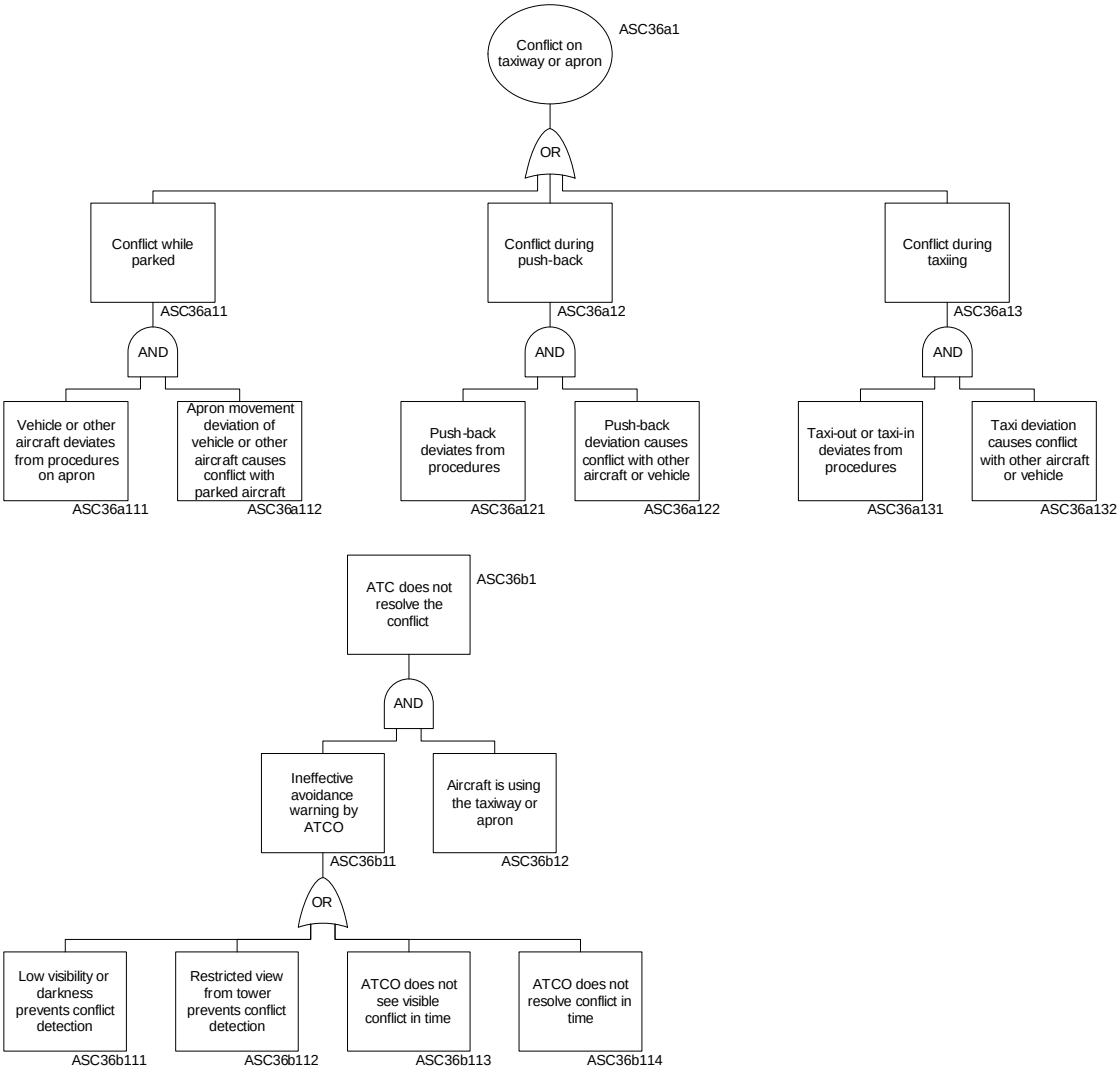

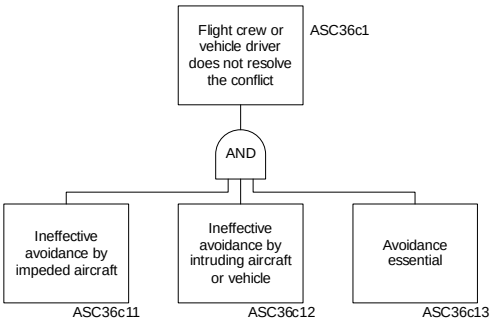

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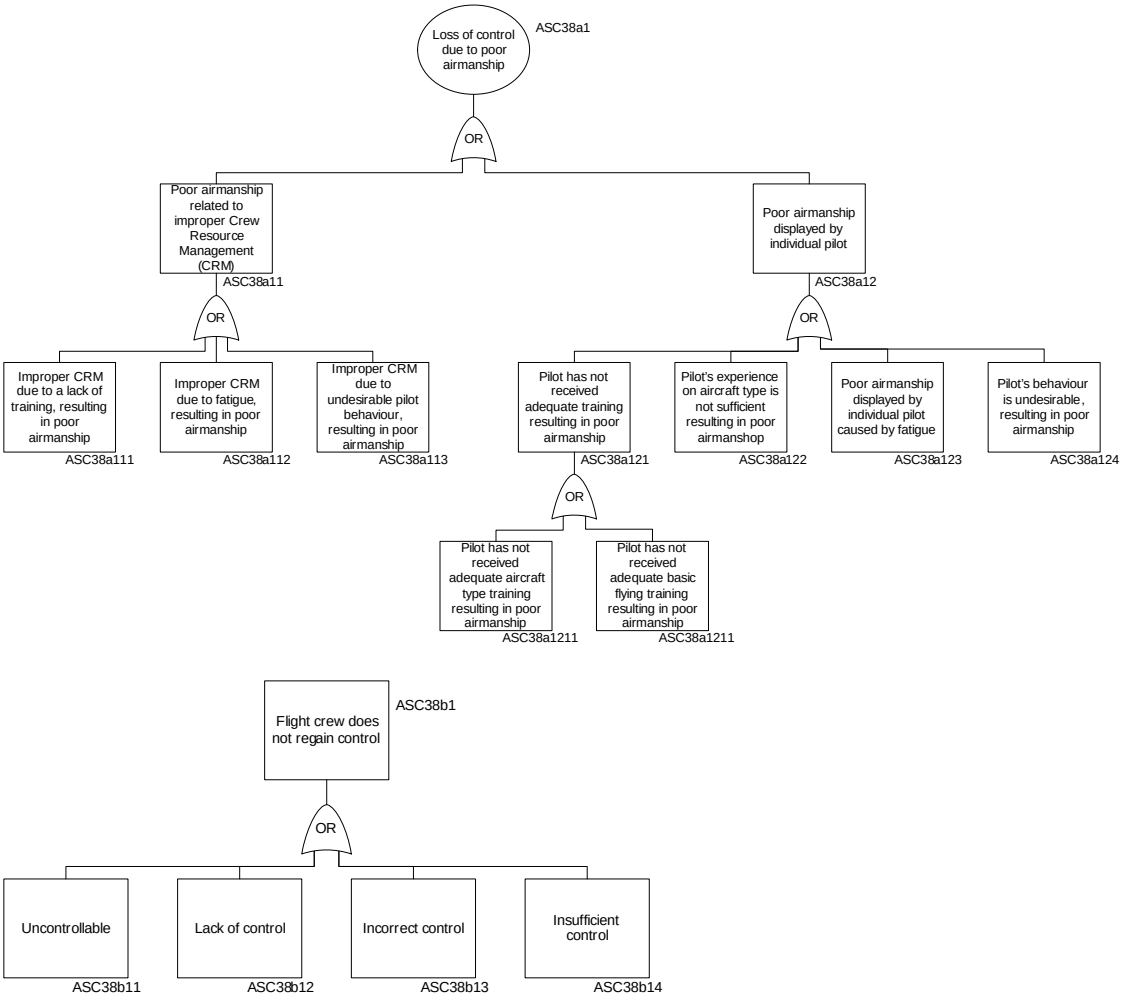

Appendix C Overview of differences between CATS and ASCOS ESDs

The basis for the development of the ASCOS ESDs is the set of ESDs from CATS. In the last couple of years lessons have been learned with application of the CATS ESDs and these lessons have been incorporated as much as possible. In comparison with the set of CATS ESDs described in [18] some changes have been made. These changes are briefly described in the table below. Slight changes to the naming of initiating events and pivotal events are not included in the table.

Table 5: Changes made to CATS ESDs to acquire ASCOS ESDs.

ESDs		Changes to CATS ESDs
CATS	**ASCOS**	
1	ASC-1	The two end states “runway overrun” are combined into one end state “runway excursion”. This necessitated a new pivotal event: “aircraft does not stop on runway”.
2	ASC-2	The two end states “runway overrun” are combined into one end state “runway excursion”. This necessitated a new pivotal event: “aircraft does not stop on runway”.
3	ASC-3	The end states “runway overrun” and “runway veer-off” after a rejected take-off are combined into one end state “runway excursion”. This necessitated a new pivotal event: “aircraft does not stop on runway”. The end state “runway veer-off” after a loss of control is changed to “runway excursion”.
4	ASC-4	The end states “runway overrun” and “runway veer-off” after a rejected take-off are combined into one end state “runway excursion”. This necessitated a new pivotal event: “aircraft does not stop on runway”. The end state “runway veer-off” after a loss of control is changed to “runway excursion”.
5	ASC-5	The pivotal event “Take-off configuration warning” is removed. The pivotal events “Aircraft stalls after rotation” and “Flight crew fails to regain control” are combined into “Flight crew does not maintain control”. The end states “runway overrun” and “runway veer-off” after a rejected take-off are combined into one end state “runway excursion”. This necessitated a new pivotal event: “aircraft does not stop on runway”.
6	ASC-6	The pivotal event “Aircraft stalls after rotation” and “Flight crew fails to regain control” are combined into “Flight crew does not maintain control”.
7	---	ESD removed. Content is incorporated in ESD ASC-10.
8	ASC-8	The pivotal event “Flight crew fails to detect windshear” is removed.
9	ASC-9	The end states “runway overrun” and “runway veer-off” after a rejected take-off are combined into one end state “runway excursion”. This necessitated a new pivotal event: “aircraft does not stop on runway”. The end state “runway veer-off” after a loss of control is changed to “runway excursion”.
10	ASC-10	ESD ASC-10 includes weight and balance problems during take-off, originally included in ESD 7. Therefore the pivotal event “Flight crew fails to maintain control” is added after the aircraft has rotated and lifted off, the accident end state added is “Collision with the ground. The two end states “runway overrun” are combined into one end state “runway excursion”. This necessitated a new pivotal event: “aircraft does not stop on runway”. The end state “runway veer-off” after a failure to rotate and lift-off is changed to “runway excursion”.
11	ASC-11	Detecting and extinguishing the fire are combined into one pivotal event. The pivotal event “fire propagates” is removed. The pivotal event “personal injury” is added to account for injuries due to the fire or due to the emergency evacuation.
12	ASC-12	No changes
13	ASC-13	No changes

ESDs		Changes to CATS ESDs
CATS	ASCOS	
14	ASC-14	No changes
15	ASC-15	The pivotal event “Flight crew fails to respond” is removed.
16	ASC-16	No changes
17	ASC-17	ESD ASC-17 includes wake vortex encounters, originally included in ESD 37. The pivotal event “Personal injury” is added to account for injuries due to aircraft upset.
18	ASC-18	The pivotal events “Flight crew fail to restart engine” and “Flight crew shut down wrong engine” are removed.
19	ASC-19	The pivotal event “insufficient fuel available for next approach” is removed. The pivotal event “aircraft touchdown with excessive sink rate” is combined with “structural failure” to include tail strikes. The end states “runway overrun” and “runway veer-off” are changed into the end state “runway excursion”. This necessitated a new pivotal event: “aircraft does not stop on runway”.
21	ASC-21	No changes
23	ASC-23	The detection and execution of a wind shear escape manoeuvre are combined. The pivotal event “Flight crew does not maintain control” is added to account for unsuccessful wind shear escape manoeuvres. The events “Aircraft touchdown with excessive sink rate” and “Structural failure” are removed, and are now seen as collisions with the ground. The end states “runway overrun” and “runway veer-off” are combined into one end state “runway excursion”. This necessitated a new pivotal event: “aircraft does not stop on runway”.
25	ASC-25	Pivotal events “aircraft touchdown with excessive sink rate” combined with “structural failure” to include tail strikes. “Runway overrun” after long or fast landing is replaced by end state “runway excursion”. “Runway veer-off” after loss of control is replaced by end state “runway excursion”.
26	ASC-26	ESD ASC-26 Includes unexpected wind during landing roll, originally in ESD 30. The end states “runway overrun” and “runway veer-off” are combined into one end state “runway excursion”. This necessitated a new pivotal event: “aircraft does not stop on runway”.
27	ASC-27	The new ESD ASC-27 combines three system failures related to aircraft directional control problems during landing roll, which were originally included in CATS ESD 27, 28 and 29 separately.
28	---	ESD removed. Single engine failure during landing roll included in ESD ASC-27.
29	---	ESD removed. Thrust reverser failure during landing roll included in ESD ASC-27.
30	---	ESD removed. Unexpected wind during landing roll included in ESD US-26.
31	ASC-31	No changes
32	ASC-32	No changes
33	ASC-33	No changes
35	ASC-35	New initiating event “TAWS alert”. New first pivotal event “flight towards terrain”. The pivotal event “GPWS failure” is combined with “flight crew fails to execute GPWS manoeuvre” into the new pivotal event “flight crew does not execute terrain avoidance manoeuvre successfully”.
36	ASC-36	The pivotal events “flight crew fails to resolve the conflict” and “ground crew fails to resolve the conflict” combined into the new pivotal event “flight crew or vehicle driver does not resolve the conflict”.
37	---	ESD removed. Wake vortex encounter included in ESD ASC-17.
---	ASC-38	New ESD to incorporate those accidents scenarios where flight crew loses control without apparent reason.

Appendix D Tables of CATS base events and identifiable precursors

The following tables give a more general illustration of a method for precursor identification and the related capture process. It starts with the analysis of the CATS base events identified in the model, assessing in what respect they are an infringement of one or several safety barriers, and then how this infringement could be tracked down to an existing or improved monitoring process.

In the example below, **application is limited to the ESDs related to runway excursion/overrun at take-off**. They comprise CATS ESD #1, 2, 3, 4, 5, 9 and 10. For each base event identified and description provided for the failure in the ESD CATS model, one or several precursors have been assessed, that may indicate an infringement to the related safety barrier. Precursors resulting from this review are shown in the column "Identifiable precursor".

When no precursor is identified for a given base event and failure description, it does not mean that it would be strictly impossible to find any precursor that could be tracked through a monitoring process. It is more probable that a better refined and detailed breakdown of the failure mode description may give way to identification of a precursor identifiable through monitoring.

Table 1 : ESD 1 Aircraft system failure base events

Base Events	Code	Definition	Identifiable Precursor
Aircraft System Failure			
Autoflight Failure	TO01B11	Failure of any of the systems associated with the autopilot and auto throttle	Flaws in system design or manufacturing or maintenance processes
Communications Failure	TO01B12	Failure of any communications equipment such that the crew are unable to communicate with ATC	None identified for the moment (*)
Electrical Power Failure	TO01B13	Failure of any of the power supplies such that any critical system fails	Flaws in system design or manufacturing or maintenance processes
Fire Protection Failure	TO01B14	Failure of the system designed to warn of and extinguish any fire within the aircraft.	None identified for the moment
Hydraulic Power Failure	TO01B15	Failure of any of the hydraulic systems	Flaws in system design or manufacturing or maintenance processes
Indicating and Recording System Failure	TO01B16	Failure of any of the flight instruments critical for safe flight	None identified for the moment
Navigation System Failure	TO01B17	Failure of any of the navigation systems	None identified for the moment
Auxiliary Power Unit Failure	TO01B18	Failure of a critical part of the APU leading to failure of the APU itself	None identified for the moment
Flap Systems Failure	TO01B19	Failure of flap systems	Flaws in system design or manufacturing or maintenance processes
Drag Control Systems Failure	TO01B110	Failure of drag control systems	Flaws in system design or manufacturing or maintenance processes
Landing Gear Systems Failure	TO01B111	Failure of landing gear systems	Flaws in system design or manufacturing or maintenance processes
Pneumatic Systems Failure	TO01B112	Failure of pneumatic systems	None identified for the moment
Door Systems Failure	TO01B113	Failure of door systems	None identified for the moment
Other Systems Failures	TO01B114	Failure of other systems that may cause take-off rejection	None identified for the moment
Take-off Rejection by Flight Crew			
Pilot Misdiagnosis	TO01B211	The pilot either fails to realize the failure or diagnoses the failure as something else, perhaps more serious and as a result aborts the take-off	Poor application of T/O & RTO procedure, failure recognition and preparedness
Pilot Misjudgement	TO01B212	The pilot diagnoses the aircraft system failure but misjudges the situation and incorrectly aborts the take-off	Poor application of T/O & RTO procedure, criteria for STOP decision
Take-off rejected correctly when below V1	TO01B22	If the take-off is rejected when the aircraft is below V1 then this is a success, but it must be included to obtain the pivotal event probability	High energy RTO rate is an indicator of improper Operator's policy for T/O operations.
Failure to Achieve Maximum Braking			
Insufficient Runway Length	TO01B31	The runway can be too short under wet or icy runway conditions for the plane to come to a halt even if the take-off is aborted before V1 is reached	Poor application of T/O & RTO procedure, computation of unreliable T/O parameters.
Brakes not functioning correctly	TO01B32	The braking systems are improperly maintained or damaged during the take-off roll	Flaws in system design or manufacturing or maintenance processes.
Brakes not applied correctly	TO01B33	Failure of the flight crew to apply all the braking systems immediately after take-off rejection	Poor application of T/O & RTO procedure, braking initiation sequence

(*) Identification of precursors may require in-depth analysis

Table 2 : ESD 2 ATC event base events

Base Events	Code	Definition	Identifiable Precursor
Air Traffic related event			
Take-off instruction error by ATCO	TO02B11111	Inadequate take-off instruction is given by the Air Traffic Control Officer (ATCO) which causes a potential hazardous encounter	inefficient / confusing TWR traffic control procedures, inefficient management of hot spots
Inadequate communication with pilot	TO02B11112	Ineffective communication between ATCO and flight crew that leads to misunderstanding, and which causes a potential hazardous encounter	Lack of adherence to SOP for GND movements. Inadequate application of call sign de-confliction rules
Pilot failure to follow take-off instructions	TO02B1112	Flight crew fails to carry out the instruction given by ATCO and which causes a potential hazardous encounter	None identified for the moment
Separation Infringement with Departing Aircraft caused by other a/c	TO02B11211	Aircraft loses separation with an aircraft departing which is caused by the other aircraft	Lack of adherence to SOP for GND movements. Lack of awareness of other traffic movements through listening of ATC communications
Separation Infringement with Landing Aircraft caused by other a/c	TO02B11212	Aircraft loses separation with an aircraft landing which is caused by the other aircraft	Lack of adherence to SOP for GND movements. Lack of awareness of other traffic movements through listening of ATC communications
Separation Infringement with a/c on missed approach	TO02B11213	Aircraft loses separation with an aircraft performing a missed approach	Lack of adherence to SOP for GND movements. Lack of awareness of other traffic movements through listening of ATC communications
Separation Infringement with departing a/c caused by aircraft taking off	TO02B11214	Aircraft loses separation with an aircraft departing which is caused by the aircraft preparing to take-off	Lack of adherence to SOP for GND movements. Lack of awareness of other traffic movements through listening of ATC communications
Separation Infringement with landing a/c caused by aircraft taking off	TO02B11215	Aircraft loses separation with an aircraft landing which is caused by the aircraft preparing to take-off	lack of adherence to SOP for GND movements. Lack of awareness of other traffic movements through listening of ATC communications
Illegal A/C infringement	TO02B11216	Aircraft deliberately infringes separation disregarding the instruction from ATC	None identified for the moment
Traffic density too high	TO02B1122	Traffic density above the airport is too high to allow the departing aircraft to take-off	None identified for the moment
Aircraft not ready to take-off	TO02B1123	Flight crew are still preparing the aircraft for take-off when clearance is given resulting in the aircraft missing the allotted clearance slot	Lack of adherence to SOP for GND movements.
Animals in vicinity of runway	TO02B1124	The presence of animal in the runway area and which may cause a collision hazard	Poor or inefficient bird hazard reduction procedure
Weather Related Problem	TO02B1125	ATC advise the flight crew that the weather is unsuitable for take-off	None identified for the moment
Effective Hazard Avoidance	TO02B12	ATC instructs aircraft to stop during take-off roll	None identified for the moment
Flight Crew rejects take-off			
Pilot Misdiagnosis	TO02B211	The pilot fails to understand the air traffic situation and as a result aborts the take-off above V1	Poor application of T/O & RTO procedure, adherence to SOP and AFM limitations
Pilot Misjudgment	TO02B212	The pilot diagnoses the air traffic situation but misjudges the response and incorrectly aborts the take-off above V1	Poor application of T/O & RTO procedure, adherence to SOP, criteria for STOP decision
Take-off rejected correctly when below V1	TO02B22	If the take-off is rejected when the aircraft is below V1 then this is a success, but it must be included to obtain the pivotal event probability.	High energy RTO rate is an indicator of improper Operator's policy for T/O operations.
Failure to achieve maximum braking			
Insufficient Runway Length	TO02B31	The runway is too short under wet or icy runway conditions for the plane to come to a halt even if the take-off is aborted before V1 is reached.	Poor application of T/O & RTO procedure, computation of T/O parameters.

Brakes not functioning correctly	TO02B32	Brakes are not giving maximum braking, i.e. because of improper maintenance and damages	Flaws in system design or manufacturing or maintenance processes
Brakes not applied correctly	TO02B33	Failure of the flight crew to apply all the braking systems immediately after take-off rejection.	Poor application of T/O & RTO procedure, braking initiation sequence

Table 3 : ESD 3 Aircraft handling by flight crew base events

Base Events	Code	Definition	Identifiable Precursor
Inappropriate handling by flight crew			
Unsuccessful handling due to lack of training	TO03B111	Untrained pilot flying (PF) handling take-offs with one engine inoperative on four engine aircraft.	Poor application of T/O & RTO procedure, adherence to SOP and AFM limitations
Unsuccessful Handling	TO03B112	The pilot flying (PF) applies inappropriate handling that affects the directional stability of the aircraft during the take-off roll.	Poor application of T/O & RTO procedure, adherence to SOP and AFM limitations
Adverse Weather Conditions	TO03B12	The prevailing weather conditions affect the directional stability of the aircraft during the take-off roll. The weather conditions that can cause this failure including strong winds and slippery runway conditions.	Poor application of T/O & RTO procedure, use of MET / ATIS information, aircraft handling.
Take-off Rejection			
Pilot Misdiagnosis	TO03B211	The pilot either fails to realize the problem or diagnoses the problem as something else, perhaps more serious and as a result aborts the take-off.	Poor application of T/O & RTO procedure, failure recognition and preparedness
Pilot Misjudgment	TO03B212	The pilot diagnoses the correct aircraft system failure but misjudges the situation and incorrectly aborts the take-off.	Poor application of T/O & RTO procedure, adherence to SOP, criteria for STOP decision
Take-off rejected correctly when below V1	TO03B22	If the take-off is rejected when the aircraft is below V1 then this is a success, but it must be included to obtain the pivotal event probability.	High energy RTO rate is an indicator of improper Operator's policy for T/O operations.
Failure to maintain control (V <= V1)			
Uncontrollable	TO03B31	No input to controls will allow the pilot to maintain control of the aircraft with speed less than V1	None identified for the moment
Lack of control	TO03B32	The pilot makes no attempt to control the aircraft with speed less than V1	Poor application of T/O & RTO procedure, aircraft handling
Incorrect Control	TO03B33	The pilot applies incorrect control to the aircraft, which has speed less than V1. This can be due to improper training, stress and fatigue	Poor application of T/O & RTO procedure, aircraft handling
Insufficient control	TO03B34	The pilot applies correct measures but are not enough to prevent aircraft leaving off the side of the runway	Lack of adherence to AFM limitations for Take-off.
Failure to Achieve Maximum Braking			
Insufficient Runway Length	TO03B41	The runway is too short under wet or icy runway conditions for the plane to come to a halt even if the take-off is aborted before V1 is reached.	Poor application of T/O & RTO procedure, computation of T/O parameters.
Brakes not functioning correctly	TO03B42	Brakes are not giving maximum braking, i.e. because of improper maintenance and damages	Flaws in system design or manufacturing or maintenance processes
Brakes not applied correctly	TO03B43	Failure of the flight crew to apply all the braking systems immediately after take-off rejection.	Poor application of T/O & RTO procedure, braking initiation sequence
Failure to maintain control			
Uncontrollable	TO03B51	No input to controls will allow the pilot to maintain control of the aircraft when take-off continued	None identified for the moment
Lack of control	TO03B52	The pilot makes no attempt to control the aircraft when take-off continued	Poor application of T/O & RTO procedure, aircraft handling
Incorrect Control	TO03B53	The pilot applies incorrect control to the aircraft when take-off continued. This can be due to improper training, stress and fatigue	Poor application of T/O & RTO procedure, aircraft handling
Insufficient control	TO03B54	The pilot applies correct measures but are not enough to prevent aircraft leaving off the side of the runway	Lack of adherence to AFM limitations for Take-off.

Table 4 : ESD 4 Aircraft directional control related systems failure base events

Base Events	Code	Definition	Identifiable Precursor
Directional control systems failure			
Main Gear Failure	TO04B111	Failure of any part of the main gear	Flaws in system design or manufacturing or maintenance processes
Nose Gear Failure	TO04B112	Failure of any part of the nose gear including the steering system	Flaws in system design or manufacturing or maintenance processes
Brake System Failure	TO04B121	Failure in any part of the brake system that results in asymmetric braking force being applied to the wheels and hence causes directional instability	Flaws in system design or manufacturing or maintenance processes
Tyre Failure	TO04B122	Failure of a tire, i.e. bursting or delamination	Flaws in system design or manufacturing or maintenance processes
Wheel Sub-Assembly Failure	TO04B123	Failure of any part of the wheel excluding tire or braking system, i.e. an axle failure or wheel rim failure	Flaws in system design or manufacturing or maintenance processes
Take-off rejection			
Pilot Misdiagnosis	TO04B211	The pilot either fails to realize the directional control system failure is the cause of the handling problems or diagnoses the failure as something else, perhaps more serious and as a result aborts the take-off.	Poor application of T/O & RTO procedure, failure recognition and preparedness
Pilot Misjudgment	TO04B212	The pilot diagnoses the situation, realizing that a directional control related system failure has resulted in handling problems but misjudges the situation and incorrectly aborts the take-off.	Poor application of T/O & RTO procedure, adherence to SOP, criteria for STOP decision
Take-off rejected correctly when below V1	TO04B22	If the take-off is rejected when the aircraft is below V1 then this is a success, but it must be included to obtain the pivotal event probability.	High energy RTO rate is an indicator of improper Operator's policy for T/O operations.
Failure to maintain control (take-off rejected)			
Uncontrollable	TO04B31	No input to controls will allow the pilot to maintain control of the aircraft with speed less than V1	None identified for the moment
Lack of control	TO04B32	The pilot makes no attempt to control the aircraft with speed less than V1	Poor application of T/O & RTO procedure, aircraft handling
Incorrect Control	TO04B33	The pilot applies incorrect control to the aircraft, which has speed less than V1. This can be due to improper training, stress and fatigue	Poor application of T/O & RTO procedure, aircraft handling
Insufficient control	TO04B34	The pilot applies correct measures but are not enough to prevent aircraft leaving off the side of the runway	Lack of adherence to AFM limitations for Take-off.
Failure to Achieve Maximum Braking (V<V1)			
Insufficient Runway Length	TO04B41	The runway is too short under wet or icy runway conditions for the plane to come to a halt even if the take-off is aborted before V1 is reached.	Poor application of T/O & RTO procedure, computation of T/O parameters.
Brakes not functioning correctly	TO04B42	Brakes are not giving maximum braking, e.g. because of improper maintenance and damages	Flaws in system design or manufacturing or maintenance processes
Brakes not applied correctly	TO04B43	Failure of the flight crew to apply all the braking systems immediately after take-off rejection.	Poor application of T/O & RTO procedure, braking initiation sequence
Failure to Maintain control (take-off continued)			
Uncontrollable	TO04B51	No input to controls will allow the pilot to maintain control of the aircraft.	None identified for the moment
Lack of Control	TO04B52	The pilot makes no attempt to control the aircraft.	Poor application of T/O & RTO procedure, aircraft handling
Incorrect Control	TO04B53	The pilot applies incorrect control to the aircraft. This can be due to improper training, stress and fatigue	Poor application of T/O & RTO procedure, aircraft handling
Insufficient Control	TO04B54	The pilot applies correct measures but are not enough to prevent aircraft leaving off the side of the runway	Lack of adherence to AFM limitations for Take-off.

Table 5 : ESD 5 Incorrect configuration base events

Base Events	Code	Definition	Identifiable Precursor
Incorrect configuration			
Unsuccessful TO configuration checklist	TO05B111	Co-pilot fails to determine the position of the flap and slats required for a successful take-off	None identified for the moment
Unsuccessful Checklist Verification	TO05B112	Captain fails to identify the incorrect position of the flap and slats determined by co-pilot	None identified for the moment
Flap & slat positions entered into FMC incorrectly	TO05B12	Co-pilot fails to enter the correct flap and slat settings into the FMC that the aircraft is incorrectly configured prior to push-back from the stand	Poor application of T/O & RTO procedure, computation of T/O parameters.
Verification not conducted	TO05B21	Captain fails to perform the take-off configuration check prior to the application of take-off power	None identified for the moment
Verification unsuccessful	TO05B22	Captain performs the take-off configuration check but fails to notice that the aircraft is configured incorrectly.	None identified for the moment
Take-off configuration warning			
Unsuccessful Manufacture	TO05B311	TOCW system fails due to unsuccessful manufacture and hence the take-off is not rejected	Flaws in system design or manufacturing or maintenance processes
Unsuccessful Maintenance	TO05B312	TOCW system fails due to unsuccessful maintenance and hence the take-off is not rejected	Flaws in system design or manufacturing or maintenance processes
Unsuccessful Operation	TO05B313	TOCW system fails because the flight crew operate it incorrectly. This includes the failure of the flight crew to check that the TOCW is working prior to taxi or the failure of the crew to reset the TOCW circuit breaker following testing	Flaws in system design or manufacturing or maintenance processes
Unsuccessful Manufacture	TO05B321	TOCW power supply fails due to unsuccessful manufacture and hence the take-off is not rejected	Flaws in system design or manufacturing or maintenance processes
Unsuccessful Maintenance	TO05B322	TOCW power supply fails due to unsuccessful maintenance and hence the take-off is not rejected	Flaws in system design or manufacturing or maintenance processes
Aircraft takes-off with incorrect configuration	TO05B33	Aircraft is still able to take-off even with the incorrect configuration	Poor application of T/O & RTO procedure, computation of T/O parameters.
Flight crew rejects take-off			
Pilot Misdiagnosis	TO05B411	The pilot misdiagnoses the situation and misunderstands the warning and allows the aircraft to reach V1 before incorrectly aborting the take-off	Poor application of T/O & RTO procedure, adherence to SOP, criteria for STOP decision
Pilot Misjudgment	TO05B412	The pilot diagnoses the TOCW but misjudges the situation and allows the aircraft to reach V1 before incorrectly aborting the take-off	Poor application of T/O & RTO procedure, adherence to SOP, criteria for STOP decision
Take-off rejected correctly when below V1	TO05B42	If the take-off is rejected when the aircraft is below V1 then this is a success, but it must be included to obtain the pivotal event probability.	High energy RTO rate is an indicator of improper Operator's policy for T/O operations.
Failure to achieve maximum braking			
Insufficient Runway Length	TO05B51	The runway is too short under wet or icy runway conditions for the plane to come to a halt even if the take-off is aborted before V1 is reached.	Poor application of T/O & RTO procedure, computation of T/O parameters.
Brakes not functioning correctly	TO05B52	Brakes are not giving maximum braking, e.g. because of improper maintenance and damages	Flaws in system design or manufacturing or maintenance processes
Brakes not applied correctly	TO05B53	Failure of the flight crew to apply all the braking systems immediately after take-off rejection.	Poor application of T/O & RTO procedure, braking initiation sequence
Aircraft stalls after rotation			

Stall Unavoidable	TO05B61	No input to controls will allow the flight crew to avoid the stall	None identified for the moment
Pilot ignores stick shaker	TO05B622	Flight crew take no action to the activated stick-shaker	Poor application of T/O & RTO procedure, aircraft handling
Stick shaker failure	TO05B6211	Stick-shaker fails due to improper manufacture or maintenance	Flaws in system design or manufacturing or maintenance processes
Stall AOA too low	TO05B6212	Stall occurs at an AOA that is less than the AOA required to activate the stick-shaker	None identified for the moment
Flight crew fails to regain control			
Uncontrollable	TO05B71	No input to controls will allow the flight crew to maintain control of the aircraft.	None identified for the moment
Lack of control	TO05B72	The pilot makes no attempt to control the aircraft.	Poor application of T/O & RTO procedure, aircraft handling
Incorrect Control	TO05B73	The pilot applies incorrect control to the aircraft. This can be due to improper training, stress and fatigue	Poor application of T/O & RTO procedure, aircraft handling
Insufficient control	TO05B74	The pilot applies correct measures but are not enough to prevent aircraft leaving off the side of the runway	Lack of adherence to AFM limitations for Take-off.

Table 6 : ESD 9 Single engine failure base events

Base Event	Code	Definition	Identifiable Precursor
Single Engine Failure			
Unsuccessful Manufacturing	TO09B11	Manufacture failure of a part of the engine which creates an undetectable defect or a defect that is detectable by the manufacturers testing but not by maintenance testing	Flaws in system design or manufacturing or maintenance processes
Unsuccessful Maintenance	TO09B12	Maintenance on the engine is not conducted or conducted incorrectly, an incorrect modification is made or the manufacturer's guidelines are inadequate such that the maintenance performed is incorrect	Flaws in system design or manufacturing or maintenance processes
Unsuccessful Manufacture and Maintenance	TO09B13	Engine is both unsuccessfully manufactured and where maintenance fails to detect the defect that arise from manufacturing	Flaws in system design or manufacturing or maintenance processes
Foreign Object Damage	TO09B14	Engine ingests objects such as debris left on the runway by other aircraft or it suffers a bird strike	Inadequate maintenance of RWY. Poor or inefficient bird hazard reduction procedure
Flight crew rejects take-off			
Pilot Misdiagnosis	TO09B211	The pilot either misdiagnoses the situation or misunderstands the effects caused by a single engine failure, and hence incorrectly aborts the take-off.	Poor application of T/O & RTO procedure, failure recognition and preparedness
Pilot Misjudgement	TO09B212	The flight crew diagnoses the engine failure but misjudges the situation and incorrectly aborts the take-off	Poor application of T/O & RTO procedure, failure recognition and preparedness
Take-off rejected correctly when below V1	TO09B22	If the take-off is rejected when the aircraft is below V1 then this is a success, but it must be included to obtain the pivotal event probability.	High energy RTO rate is an indicator of improper Operator's policy for T/O operations.
Flight crew fails to maintain control (Take-off rejected)			
Uncontrollable	TO09B31	No input to controls will allow the pilot to maintain control of the aircraft after take-off rejection	None identified for the moment
Lack of control	TO09B32	The pilot makes no attempt to control the aircraft after take-off rejection	Poor application of T/O & RTO procedure, aircraft handling
Incorrect Control	TO09B33	The pilot applies incorrect control to the aircraft after take-off rejection. This can be due to improper training, stress and fatigue	Poor application of T/O & RTO procedure, aircraft handling
Insufficient control	TO09B34	The pilot applies correct measures after take-off rejection but are not enough to prevent aircraft leaving off the side of the runway	Lack of adherence to AFM limitations for Take-off.
Failure to achieve maximum braking			
Insufficient Runway Length	TO09B41	The runway is too short under wet or icy runway conditions for the plane to come to a halt even if the take-off is aborted before V1 is reached.	Poor application of T/O & RTO procedure, computation of T/O parameters.
Brakes not functioning correctly	TO09B42	Brakes are not giving maximum braking, i.e. because of improper maintenance and damages	Flaws in system design or manufacturing or maintenance processes
Brakes not applied correctly	TO09B43	Failure of the flight crew to apply all the braking systems immediately after take-off rejection.	Poor application of T/O & RTO procedure, braking initiation sequence
Flgiht crew fails to maintain control (Take-off continued)			
Uncontrollable	TO09B51	No input to controls will allow the pilot to maintain control of the aircraft after take-off continuation	None identified for the moment
Lack of control	TO09B52	The pilot makes no attempt to control the aircraft after take-off continuation	Poor application of T/O & RTO procedure, aircraft handling
Incorrect Control	TO09B53	The pilot applies incorrect control to the aircraft after take-off continuation. This can be due to improper training, stress and fatigue	Poor application of T/O & RTO procedure, aircraft handling
Insufficient control	TO09B54	The pilot applies correct measures after take-off continuation but are not enough to prevent aircraft leaving off the side of the runway	Lack of adherence to AFM limitations for Take-off.

Table 7 : ESD 10 Pitch control problem base events

Base Event	Code	Definition	Identifiable Precursor
Pitch Control Problem			
Trim settings incorrectly determined	TO10B1111	Flight crew fail to complete the trim configuration checklist and fail to verify the checklist	Poor application of T/O & RTO procedure, use of T/O parameters.
Speed settings incorrectly determined	TO10B1112	Flight crew fail to complete the speed bug checklist and fail to verify the checklist	Poor application of T/O & RTO procedure, use of T/O parameters.
Trim settings incorrectly entered into FMC	TO10B112	Given that the trim settings have been correctly determined, the co-pilot enter the settings incorrectly and these are verified by the captain during the taxi checklist	Poor application of T/O & RTO procedure, use of T/O parameters.
Speed settings incorrectly entered into FMC	TO10B113	Given that the speed bugs have been correctly determined, flight crew enter the settings incorrectly and these are verified by the captain during the taxi checklist	Poor application of T/O & RTO procedure, use of T/O parameters.
Unsuccessful Pitch Control Inputs	TO10B12	Flight crew applies inappropriate inputs to the flight controls causing pitch control problems and resulting in difficulty taking off.	Poor application of T/O & RTO procedure, use of T/O parameters.
Unsuccessful Design	TO10B1311	Unsuccessful design of one of the integral components causes the failure of a flight control system	Flaws in system design or manufacturing or maintenance processes
Unsuccessful Manufacture	TO10B1312	Unsuccessful manufacture of one of the integral components causes the failure of a flight control system	Flaws in system design or manufacturing or maintenance processes
Unsuccessful Maintenance	TO10B1313	Maintenance of the flight control system is not conducted or not successfully completed such that one of the flight control system fails	Flaws in system design or manufacturing or maintenance processes
Foreign Object Damage	TO10B1314	A foreign object strikes one of the control surfaces rendering it ineffective. Such objects include birds and runway debris	Inadequate maintenance of RWY. Poor or inefficient bird hazard reduction procedure
Severe Flight Control System Failure	TO10B132	Given the occurrence of a flight control system failure, the failure is severe enough to cause a pitch control problem	Flaws in system design or manufacturing or maintenance processes
Flight crew rejects to take-off			
Crew Misdiagnose Situation	TO10B211	The pilot misdiagnoses the situation and either fails to realise what is causing the pitch control problems or wrongly attributes them to something else.	Poor application of T/O & RTO procedure, aircraft handling
Crew Misjudge Situation	TO10B212	The flight crew diagnoses the situation, realising what is causing the pitch control problems but misjudges the situation and incorrectly aborts the take-off when the aircraft is above V1	Poor application of T/O & RTO procedure, aircraft handling
Take-off rejected correctly when below V1	TO10B22	If the take-off is rejected when the aircraft is below V1 then this is a success, but it must be included to obtain the pivotal event probability.	High energy RTO rate is an indicator of improper Operator's policy for T/O operations.
Failure to achieve maximum braking			
Insufficient Runway Length	TO10B31	The runway is too short under wet or icy runway conditions for the plane to come to a halt even if the take-off is aborted before V1 is reached.	Poor application of T/O & RTO procedure, computation of T/O parameters.
Brakes not functioning correctly	TO10B32	Brakes are not giving maximum braking, i.e. because of improper maintenance and damages	Flaws in system design or manufacturing or maintenance processes
Brakes not applied correctly	TO10B33	Failure of the flight crew to apply all the braking systems immediately after take-off rejection.	Poor application of T/O & RTO procedure, braking initiation sequence
Aircraft fails to rotate and lift off			
Pitch Control Misdiagnosed	TO10B41	Flight crew fail to diagnose the cause of the pitch control problems and hence fails to rectify the problem.	Poor application of T/O & RTO procedure, aircraft handling

Unsuccessful Pitch Control Rectification	TO10B42	Flight crew diagnoses the causes of the pitch control problem but fails to rectify it	None identified for the moment

Appendix E Definitions of ESD events

ESD ASC-1

Code	ESD event name	Definition
ASC01a1	Aircraft system failure during take-off	All system failures that could lead to an aborted take-off, with the exception of engine failures and system failures that can result in directional control problems.
ASC01b1	Flight crew rejects take-off	Flight crew does not complete the take-off manoeuvre after take-off power has been applied.
ASC01c1	Aircraft does not stop on runway	An aircraft system failure occurs and the flight crew rejects the take-off and the aircraft overruns.
ASC01d1	Runway excursion	An aircraft system failure occurs and the flight crew rejects the take-off and the aircraft overruns.
ASC01c2	Aircraft continues take-off	An aircraft system failure occurs and the flight crew does not reject the take-off. The aircraft continues the take-off.
ASC01d2	Aircraft stops on runway	An aircraft system failure occurs and the flight crew rejects the take-off. The aircraft comes to a stop on the runway.

ESD ASC-2

Code	ESD event name	Definition
ASC02a1	ATC event during take-off	Any ATC event which could result in a decision to reject a take-off, with the exception of runway incursions.
ASC02b1	Flight crew rejects take-off	Flight crew does not complete the take-off manoeuvre after take-off power has been applied.
ASC02c1	Aircraft does not stop on runway	An ATC event occurs and the flight crew rejects the take-off and the aircraft overruns.
ASC02d1	Runway excursion	An ATC event occurs and the flight crew rejects the take-off and the aircraft overruns.
ASC02c2	Aircraft continues take-off	An ATC event occurs and the flight crew does not reject the take-off. The aircraft continues the take-off.
ASC02d2	Aircraft stops on runway	An ATC event occurs and the flight crew rejects the take-off. The aircraft comes to a stop on the runway.

ESD ASC-3

Code	ESD event name	Definition
ASC03a1	Aircraft directional control by flight crew inappropriate during take-off	Aircraft handling error that result in loss of directional control, e.g. improper use of the steering tiller, improper directional braking, improper rudder input and asymmetric engine thrust settings.
ASC03b1	Flight crew rejects take-off	Flight crew does not complete the take-off manoeuvre after take-off power has been applied.
ASC03c1	Aircraft does not stop on runway	Aircraft directional control by flight crew inappropriate and the flight crew rejects the take-off and the aircraft overruns.
ASC03d1	Runway excursion	Aircraft directional control by flight crew inappropriate and

Code	ESD event name	Definition
		the flight crew rejects the take-off and the aircraft overruns.
ASC03c2	Flight crew does not maintain control	An incident where the flight crew loses control of the aircraft, i.e. the aircraft's lateral movements are not in accordance with the flight crew's intentions.
ASC03d2	Aircraft stops on runway	Aircraft directional control by flight crew inappropriate and the flight crew rejects the take-off. The aircraft comes to a stop on the runway.
ASC03d3	Runway excursion	The flight crew loses control of the aircraft and veers off the runway.
ASC03d4	Aircraft continues take-off	Aircraft directional control by flight crew inappropriate and the flight crew does not reject the take-off. The aircraft continues the take-off.

ESD ASC-4

Code	ESD event name	Definition
ASC04a1	Aircraft directional control related system failure during take-off	Failure in any of the aircraft system that severely affects the directional controllability of the aircraft during the take-off roll, i.e. failure of the aileron controls, rudder and rudder controls, tyres and nose wheel steering.
ASC04b1	Flight crew rejects take-off	Flight crew does not complete the take-off manoeuvre after take-off power has been applied.
ASC04c1	Aircraft does not stop on runway	Aircraft directional control related system failure and the flight crew rejects the take-off and the aircraft overruns.
ASC04d1	Runway excursion	Aircraft directional control related system failure and the flight crew rejects the take-off and the aircraft overruns.
ASC04c2	Flight crew does not maintain control	An incident where the flight crew loses control of the aircraft, i.e. the aircraft's lateral movements are not in accordance with the flight crew's intentions.
ASC04d2	Aircraft stops on runway	Aircraft directional control related system failure and the flight crew rejects the take-off. The aircraft comes to a stop on the runway.
ASC04d3	Runway excursion	The flight crew loses control of the aircraft and veers off the runway.
ASC04d4	Aircraft continues take-off	Aircraft directional control related system failure and the flight crew does not reject the take-off. The aircraft continues the take-off.

ESD ASC-5

Code	ESD event name	Definition
ASC05a1	Incorrect configuration during take-off	An incident where the flight crew commences the take-off while the aircraft is not properly configured for take-off, i.e. a system failure or configuration not correctly set by crew.
ASC05b1	Flight crew rejects take-off	Flight crew does not complete the take-off manoeuvre after take-off power has been applied.
ASC05c1	Aircraft does not stop on runway	Incorrect configuration during take-off and the flight crew

Code	ESD event name	Definition
		rejects the take-off and the aircraft overruns.
ASC05d1	Runway excursion	Incorrect configuration during take-off and the flight crew rejects the take-off and the aircraft overruns.
ASC05c2	Flight crew does not maintain control	An incident where the flight crew loses control of the aircraft, i.e. the aircraft's lateral movements are not in accordance with the flight crew's intentions.
ASC05d2	Aircraft stops on runway	Incorrect configuration during take-off and the flight crew rejects the take-off. The aircraft comes to a stop on the runway.
ASC05d3	Runway excursion	The flight crew loses control of the aircraft and veers off the runway.
ASC05d4	Aircraft continues flight	Incorrect configuration during take-off and the flight crew does not reject the take-off. The aircraft continues the flight.

ESD ASC-6

Code	ESD event name	Definition
ASC06a1	Aircraft takes off with contaminated wing	Aircraft wings, horizontal stabiliser, tail and/ or flight control surfaces (i.e. ailerons, elevator, trim, rudder) are contaminated with frost, ice, slush or snow, as the aircraft commences take-off.
ASC06b1	Flight crew does not maintain control	An incident where the flight crew loses control of the aircraft after lift-off, i.e. the aircraft's lateral movements are not in accordance with the flight crew's intentions.
ASC06c1	Collision with ground	Aircraft impacts terrain (ground, water) or obstacles, which results in injuries, fatalities or damage to the aircraft.
ASC06c2	Aircraft continues flight	The flight crew maintains control and continues the flight to destination airport, returns to the airport of departure or diverts the aircraft to another airport.

ESD ASC-8

Code	ESD event name	Definition
ASC08a1	Aircraft encounters wind shear after rotation	An abrupt change in wind direction and velocity. Some is dangerous to air transport such as a downburst or microburst.
ASC08b1	Flight crew does not execute wind shear escape manoeuvre	Flight crew does not perform the prescribed escape manoeuvre, either by mistake or on purpose when the crew decides that it is not necessary because control can be maintained without following the procedure.
ASC08c1	Flight crew does not maintain control	An incident where the flight crew loses control of the aircraft after lift-off, i.e. the aircraft's lateral movements are not in accordance with the flight crew's intentions.
ASC08d1	Collision with ground	Aircraft impacts terrain (ground, water) or obstacles, which results in injuries, fatalities or damage to the aircraft.
ASC08c2	Aircraft continues flight	The flight crew executes a wind shear escape and continues the flight.

Code	ESD event name	Definition
ASC08d2	Aircraft continues flight	The flight crew does not execute a wind shear escape manoeuvre but maintains control and continues the flight.

ESD ASC-9

Code	ESD event name	Definition
ASC09a1	Single engine failure during take-off	Any failure during take-off of one of the systems that correspond with the ATA codes between 6100 and 6197 or between 7100 and 8097.
ASC09b1	Flight crew rejects take-off	Flight crew does not complete the take-off manoeuvre after take-off power has been applied.
ASC09c1	Flight crew does not stop aircraft on runway	Single engine failure during take-off and the flight crew rejects the take-off and the aircraft overruns.
ASC09d1	Runway excursion	Single engine failure during take-off and the flight crew rejects the take-off and the aircraft overruns.
ASC09c2	Flight crew does not maintain control	An incident where the flight crew loses control of the aircraft, i.e. the aircraft's lateral movements are not in accordance with the flight crew's intentions.
ASC09d2	Aircraft stops on runway	Single engine failure during take-off and the flight crew rejects the take-off. The aircraft comes to a stop on the runway.
ASC09d3	Runway excursion	The flight crew loses control of the aircraft and veers off the runway.
ASC09d4	Aircraft continues take-off	Single engine failure during take-off and the flight crew does not reject the take-off. The aircraft continues the take-off.

ESD ASC-10

Code	ESD event name	Definition
ASC10a1	Pitch control problem during take-off	A pitch control system malfunction or the aircraft's centre of gravity or the aircraft's weight differs from the flight crew's expectation, leading to a failure to rotate the aircraft.
ASC10b1	Flight crew rejects take-off	Flight crew does not complete the take-off manoeuvre after take-off power has been applied.
ASC10c1	Flight crew does not stop aircraft on runway	Pitch control problem during take-off and the flight crew rejects the take-off and the aircraft overruns.
ASC10d1	Runway excursion	Pitch control problem during take-off and the flight crew rejects the take-off and the aircraft overruns.
ASC10e1	Collision with ground	Aircraft impacts terrain (ground, water) or obstacles, which results in injuries, fatalities or damage to the aircraft.
ASC10c2	Aircraft does not rotate and lift-off	When flight crew continues the take-off attempt, the aircraft reaches rotation speed VR, aircraft cannot be rotated and fails to lift off
ASC10d2	Aircraft stops on runway	Pitch control problem during take-off and the flight crew rejects the take-off. The aircraft comes to a stop on the runway.

Code	ESD event name	Definition
ASC10e2	Aircraft continues flight	Pitch control problem during take-off and the flight crew does not reject the take-off. The aircraft continues the take-off.
ASC10d3	Runway excursion	When flight crew continues the take-off attempt, the aircraft reaches rotation speed VR, aircraft cannot be rotated and fails to lift off, overrunning the runway.
ASC10d4	Flight crew does not maintain control	An incident where the flight crew loses control of the aircraft, i.e. the aircraft's lateral movements are not in accordance with the flight crew's intentions.

ESD ASC-11

Code	ESD event name	Definition
ASC11a1	Fire, smoke, fumes onboard aircraft	A situation where a combustible substance on-board the aircraft is burning, e.g. aircraft's payload, systems, or interior. Indicators of a fire are visible flames, visible smoke, burning smell or fumes.
ASC11b1	Flight crew does not detect and extinguish fire	Flight crew are not aware of fire developing on-board, due to failure of Fire Detection/ Warning system, no installation of the system, or detection is impractical or flight crew is not able to extinguish the fire, due to no available or insufficient Fire Extinction System on board, or delay and incorrect operation by crew
ASC11c1	Flight crew does not maintain control	An incident where the flight crew loses control of the aircraft, i.e. the aircraft's lateral movements are not in accordance with the flight crew's intentions.
ASC11d1	Collision with ground	Aircraft impacts terrain (ground, water) or obstacles, which results in injuries, fatalities or damage to the aircraft.
ASC11e1	Personal injury	Flight crew does maintain control but the fire sustains injury to a person on board the aircraft.
ASC11c2	Aircraft continues flight damaged	Flight crew does maintain control but the fire sustains damage to the aircraft.
ASC11d2	Personal injury	Flight crew does maintain control but the fire sustains injury to a person on board the aircraft.
ASC11e2	Aircraft damaged	Fire is extinguished and the aircraft continues with damage caused by the extinguished fire.

ESD ASC-12

Code	ESD event name	Definition
ASC12a1	Flight crew member spatially disoriented	Flight crew suffers spatial disorientation, i.e. has inadequate visual information or fails to attend to or properly interpret available information regarding the airplane's pitch, roll or yaw angle or rate of rotation.
ASC12b1	Flight crew does not maintain control	An incident where the flight crew loses control of the aircraft, i.e. the aircraft's lateral movements are not in accordance with the flight crew's intentions.
ASC12c1	Collision with ground	Aircraft impacts terrain (ground, water) or obstacles, which

Code	ESD event name	Definition
		results in injuries, fatalities or damage to the aircraft.
ASC12c2	Aircraft continues flight	After a spatial disorientation, the flight crew maintains control and the aircraft continues the flight.

ESD ASC-13

Code	ESD event name	Definition
ASC13a1	Flight control system failure	A failure of any part of the control system, i.e. control surface, autopilot, autothrottle, thrust Reverser.
ASC13b1	Flight crew does not maintain control	An incident where the flight crew loses control of the aircraft, i.e. the aircraft's lateral movements are not in accordance with the flight crew's intentions.
ASC13c1	Collision with ground	Aircraft impacts terrain (ground, water) or obstacles, which results in injuries, fatalities or damage to the aircraft.
ASC13c2	Aircraft continues flight	After a flight control system failure, the flight crew is able to maintain control and the aircraft continues the flight

ESD ASC-14

Code	ESD event name	Definition
ASC14a1	Flight crew member incapacitation	An occurrence where one or more flight crew are unable to perform an in-flight duty as result of reduced medical fitness, e.g. illness, depressurisation of flight deck or presence of toxic gas from fire in flight deck.
ASC14b1	Flight crew does not maintain control	An incident where the flight crew loses control of the aircraft, i.e. the aircraft's lateral movements are not in accordance with the flight crew's intentions.
ASC14c1	Collision with ground	Aircraft impacts terrain (ground, water) or obstacles, which results in injuries, fatalities or damage to the aircraft.
ASC14c2	Aircraft continues flight	After an incapacitation, the flight crew maintains control and the aircraft continues the flight.

ESD ASC-15

Code	ESD event name	Definition
ASC15a1	Ice accretion on aircraft in flight	Ice accretion on the aircraft's outside structure, i.e. fuselage, wings, tail, and flight control surface.
ASC15b1	Flight crew does not maintain control	An incident where the flight crew loses control of the aircraft, i.e. the aircraft's lateral movements are not in accordance with the flight crew's intentions.
ASC15c1	Collision with ground	Aircraft impacts terrain (ground, water) or obstacles, which results in injuries, fatalities or damage to the aircraft.
ASC15c2	Aircraft continues flight	After ice accretion on the aircraft, the flight crew maintains control and the aircraft continues the flight.

ESD ASC-16

Code	ESD event name	Definition
ASC16a1	Airspeed, altitude or attitude display failure	Failure of flight instrument to correctly display airspeed, attitude or altitude of the aircraft. In the case of dual instruments and/or if a standby instrument is available, even a failure of only one of the instrument to correctly display is considered to be an airspeed, altitude or attitude display failure.
ASC16b1	Flight crew does not maintain control	An incident where the flight crew loses control of the aircraft, i.e. the aircraft's lateral movements are not in accordance with the flight crew's intentions.
ASC16c1	Collision with ground	Aircraft impacts terrain (ground, water) or obstacles, which results in injuries, fatalities or damage to the aircraft.
ASC16c2	Aircraft continues flight	After an airspeed, altitude or attitude display failure, the flight crew maintains control and the aircraft continues the flight.

ESD ASC-17

Code	ESD event name	Definition
ASC17a1	Aircraft encounters thunderstorm, turbulence, or wake vortex	An encounter with severe thunderstorm, turbulence or wake vortex that results in occupant injuries, an aircraft upset or structural damage to the aircraft as a result of overstress of the aircraft structure.
ASC17b1	Ultimate design load exceeded	The ultimate design load of the aircraft is exceeded as a direct result of the aircraft's encounter with adverse conditions.
ASC17c1	In flight break-up	After encounter with adverse conditions, where the ultimate design load of the aircraft is exceeded, the aircraft breaks up.
ASC17d1	Collision with ground	Aircraft impacts terrain (ground, water) or obstacles, which results in injuries, fatalities or damage to the aircraft.
ASC17e1	Aircraft continues flight with injury	After encounter with adverse conditions, the flight crew maintains control of the aircraft and continues the flight, but one or more persons aboard receives injuries.
ASC17c2	Flight crew does not maintain control	An incident where the flight crew loses control of the aircraft, i.e. the aircraft's lateral movements are not in accordance with the flight crew's intentions.
ASC17d2	Personal injury	After encounter with adverse conditions, the flight crew maintains control of the aircraft, but one or more persons aboard receives injuries.
ASC17e2	Aircraft continues flight	After encounter with adverse conditions, the flight crew maintains control of the aircraft and continues the flight.

ESD ASC-18

Code	ESD event name	Definition
ASC18a1	Single engine failure in flight	A significant loss of thrust from one of the aircraft's

Code	ESD event name	Definition
		engines, including cases where the engine detaches from the aircraft.
ASC18b1	Total power loss	A significant loss of thrust from all the aircraft's engines. Includes cases where the wrong engine is shut off.
ASC18c1	Flight crew does not maintain control	An incident where the flight crew loses control of the aircraft, i.e. the aircraft's lateral movements are not in accordance with the flight crew's intentions.
ASC18d1	Collision with ground	Aircraft impacts terrain (ground, water) or obstacles, which results in injuries, fatalities or damage to the aircraft.
ASC18e1	Aircraft lands off runway	All power is lost. Flight crew maintains control but does not reach a suitable airport. Aircraft lands off the runway.
ASC18c2	Flight crew does not maintain control	An incident where the flight crew loses control of the aircraft, i.e. the aircraft's lateral movements are not in accordance with the flight crew's intentions.
ASC18d2	Aircraft unable to reach airport	All power is lost. Flight crew maintains control but does not reach a suitable airport.
ASC18e2	Aircraft continues landing	All power is lost. Flight crew maintains control and does reach a suitable airport for landing,
ASC18d3	Collision with ground	Aircraft impacts terrain (ground, water) or obstacles, which results in injuries, fatalities or damage to the aircraft.
ASC18d4	Aircraft continues flight	There is a single engine failure. The flight crew does maintain control and continues the flight.

ESD ASC-19

Code	ESD event name	Definition
ASC19a1	Unstable approach	Unstable approach is when one or more of the parameters set out by the operator of the aircraft are incorrect. These parameters include, correct glide path; small changes in heading/ pitch; speed between Vref and Vref+20knots; correct landing configuration; sink rate is no greater than 1000ft/ mins; power setting appropriate for the aircraft configuration; all briefings and checklists have been conducted; approach type specific (ILS approaches, Cat. II or III ILS approach, circling approach).
ASC19b1	Flight crew does not initiate go-around	Flight crew does not reject approach under unsafe circumstances and/or does not carry out a new approach and land under a safer conditions.
ASC19c1	Flight crew does not maintain control	An incident where the flight crew loses control of the aircraft, i.e. the aircraft's lateral movements are not in accordance with the flight crew's intentions.
ASC19d1	Collision with ground	Aircraft impacts terrain (ground, water) or obstacles, which results in injuries, fatalities or damage to the aircraft.
ASC19e1	Aircraft does not stop on runway	Flight crew maintains control after an unstable approach, but lands long or fast resulting in insufficient runway length remaining to stop the aircraft on the runway.
ASC19f1	Runway excursion	Flight crew maintains control after an unstable approach, but lands long or fast resulting in insufficient runway length remaining to stop the aircraft on the runway. The aircraft

Code	ESD event name	Definition
		overruns the runway.
ASC19c2	Flight crew does not maintain control	An incident where the flight crew loses control of the aircraft, i.e. the aircraft's lateral movements are not in accordance with the flight crew's intentions.
ASC19d2	Aircraft touchdown fast or long	Flight crew maintains control after an unstable approach, but lands long or fast.
ASC19e2	Structural failure	Flight crew maintains control after an unstable approach, but lands hard resulting in structural failure.
ASC19f2	Aircraft continues landing roll	Flight crew maintains control after an unstable approach, lands long or fast, but is able to stop the aircraft on the runway.
ASC19g2	Runway excursion	Flight crew maintains control after an unstable approach, but lands hard resulting in structural failure and a subsequent runway veer-off due to a loss of directional control.
ASC19d3	Collision with ground	Aircraft impacts terrain (ground, water) or obstacles, which results in injuries, fatalities or damage to the aircraft.
ASC19f3	Flight crew does not maintain control	An incident where the flight crew loses control of the aircraft, i.e. the aircraft's lateral movements are not in accordance with the flight crew's intentions.
ASC19g3	Aircraft continues landing roll damaged	Flight crew maintains control after an unstable approach, but lands hard resulting in structural failure. The aircraft is stopped on the runway.
ASC19d4	Aircraft continues go-around	A successful go-around is initiated after the unstable approach.
ASC19f4	Aircraft continues landing roll	The unstable approach is continued and the aircraft lands without further incident.

ESD ASC-21

Code	ESD event name	Definition
ASC21a1	Aircraft weight and balance outside limits during approach	Aircraft's centre of gravity or the aircraft's weight differs from the flight crew's expectation such that flight crew has to take additional action to maintain control during approach.
ASC21b1	Flight crew does not maintain control	An incident where the flight crew loses control of the aircraft, i.e. the aircraft's lateral movements are not in accordance with the flight crew's intentions.
ASC21c1	Collision with ground	Aircraft impacts terrain (ground, water) or obstacles, which results in injuries, fatalities or damage to the aircraft.
ASC21c2	Aircraft continues approach	Aircraft weight and balance outside limits during approach, nut the flight crew maintains control and can continue the approach.

ESD ASC-23

Code	ESD event name	Definition
ASC23a1	Aircraft encounters wind shear	An abrupt change in wind direction and velocity is

Code	ESD event name	Definition
	during approach or landing	encountered. A particularly hazardous type is a downburst or microburst.
ASC23b1	Flight crew does not execute wind shear escape manoeuvre	Flight crew does not perform the prescribed wind-shear escape manoeuvre, either because they are not aware of the wind shear, or by mistake or on purpose when the crew decides that it is not necessary because control can be maintained without following the procedure
ASC23c1	Flight crew does not maintain control	An incident where the flight crew loses control of the aircraft, i.e. the aircraft's lateral movements are not in accordance with the flight crew's intentions.
ASC23d1	Collision with ground	Aircraft impacts terrain (ground, water) or obstacles, which results in injuries, fatalities or damage to the aircraft.
ASC23e1	Aircraft does not stop on runway	Flight crew maintains control after a wind shear encounter, but lands long or fast resulting in insufficient runway length remaining to stop the aircraft on the runway.
ASC23f1	Runway excursion	Flight crew maintains control after a wind shear encounter, but lands long or fast resulting in insufficient runway length remaining to stop the aircraft on the runway. The aircraft overruns the runway.
ASC23c2	Flight crew does not maintain control	An incident where the flight crew loses control of the aircraft, i.e. the aircraft's lateral movements are not in accordance with the flight crew's intentions.
ASC23d2	Aircraft touchdown fast or long	Flight crew maintains control after a wind shear, but lands long or fast.
ASC23e2	Aircraft continues landing roll	Flight crew maintains control after a wind shear encounter and is able to stop the aircraft on the runway.
ASC23f2	Aircraft continues landing roll	Flight crew maintains control after a wind shear encounter, lands long or fast, but is able to stop the aircraft on the runway.
ASC23d3	Collision with ground	Aircraft impacts terrain (ground, water) or obstacles, which results in injuries, fatalities or damage to the aircraft.
ASC23d4	Aircraft continues approach or landing	A successful wind shear escape manoeuvre is executed after the wind shear encounter and the aircraft continues the approach or landing.

ESD ASC-25

Code	ESD event name	Definition
ASC25a1	Aircraft handling by flight crew inappropriate during flare	A landing flare is a sub phase of landing and starts when the transition from nose-low to nose-up attitude occurs up until the point of touchdown. If pilot does not arrest the rate of descent significantly during the landing flare, the aircraft will touch down hard. A flare that starts from a stabilised condition at the runway threshold but the manoeuvre itself is conducted inappropriately. A stabilised condition at the runway threshold is defined as where the aircraft is not more than 10 ft above or below the prescribed height and not more than 10kts faster or slower than the target (or bug) speed.

Code	ESD event name	Definition
ASC25b1	Aircraft touchdown fast or long	Aircraft lands long or fast after inappropriate handling during flare.
ASC25c1	Aircraft does not stop on runway	Aircraft lands long or fast after inappropriate handling during flare resulting in insufficient runway length remaining to stop the aircraft on the runway.
ASC25d1	Runway excursion	Aircraft lands long or fast after inappropriate handling during flare resulting in insufficient runway length remaining to stop the aircraft on the runway. The aircraft overruns the runway.
ASC25e1	Runway excursion	Aircraft lands hard after inappropriate handling during flare resulting in structural failure and a subsequent runway veer-off due to a loss of directional control.
ASC25c2	Structural failure	Aircraft lands hard after inappropriate handling during flare resulting in structural failure
ASC25d2	Aircraft continues landing roll	Aircraft lands long or fast after inappropriate handling during flare but the flight crew is able to stop the aircraft on the runway.
ASC25e2	Aircraft continues landing roll damaged	Aircraft lands hard after inappropriate handling during flare resulting in structural failure. Flight crew maintains control and stops the aircraft on the runway.
ASC25d3	Flight crew does not maintain control	An incident where the flight crew loses control of the aircraft, i.e. the aircraft's lateral movements are not in accordance with the flight crew's intentions.
ASC25d4	Aircraft continues landing roll	The inappropriate handling during flare does not cause any further incident during landing roll.

ESD ASC-26

Code	ESD event name	Definition
ASC26a1	Aircraft handling by flight crew inappropriate during landing roll	A touchdown is made with a correct speed and sink rate, but due to an action by the crew during landing roll, control of the aircraft is lost or maximum braking is not achieved. Inappropriate aircraft handling includes inappropriate use of rudder and aileron, inappropriate use of the steering tiller, delayed operation of deceleration devices such as life dumper, thrust reverser and wheel brakes and inappropriate differential braking. This initiating event includes cases where unexpected wind was encountered during landing roll.
ASC26b1	Aircraft does not stop on runway	Due to the inappropriate handling during landing roll the flight crew is unable to stop the aircraft on the runway.
ASC26c1	Runway excursion	Due to the inappropriate handling during landing roll the flight crew is unable to stop the aircraft on the runway. The aircraft veers off or overruns the runway.
ASC26c2	Aircraft continues landing roll	The inappropriate handling during landing roll does not cause any further incident during landing.

ESD ASC-27

Code	ESD event name	Definition
ASC27a1	Aircraft directional control related system failure during landing roll	Failure of any part of the aircraft's systems that affects the directional controllability of the aircraft during the landing roll. Included are failures of the aileron and aileron controls, rudder and rudder controls, tyres and landing gear, and engines including thrust reversers.
ASC27b1	Flight crew does not maintain control	An incident where the flight crew loses control of the aircraft, i.e. the aircraft's lateral movements are not in accordance with the flight crew's intentions.
ASC27c1	Runway excursion	Due to the directional control related system failure during landing roll the flight crew is unable to maintain control and the aircraft veers off the runway.
ASC27c2	Aircraft continues landing roll	The directional control related system failure during landing roll does not cause any further incident during landing.

ESD ASC-31

Code	ESD event name	Definition
ASC31a1	Aircraft are positioned on collision course in flight	Two airborne aircrafts are positioned such that their trajectories, if unaltered, will bring the aircraft closely together leading to a risk of collision.
ASC31b1	ATC does not resolve the conflict	The air traffic controller does not resolve the collision risk that has been arisen due to the aircraft trajectories.
ASC31c1	Flight crew does not resolve the conflict	The flight crew does not resolve the collision risk that has been arisen due to the aircraft trajectories.
ASC31d1	Collision in mid-air	ATC and flight crew both do not resolve the conflict and aircraft collide in mid-air.
ASC31c2	Aircraft continues flight	ATC is able to avoid collision. Aircraft continues flight.
ASC31d2	Aircraft continues flight	Flight crew is able to avoid collision. Aircraft continues flight.

ESD ASC-32

Code	ESD event name	Definition
ASC32a1	Runway incursion	Any occurrence involving the incorrect presence of an aircraft or vehicle on the protected area of a surface designed for the landing and take-off of aircraft
ASC32b1	ATC does not resolve the conflict	The air traffic controller does not resolve the collision risk that has been arisen due to the runway incursion.
ASC32c1	Flight crew or vehicle driver does not resolve the conflict	The flight crew or vehicle driver does not resolve the collision risk that has been arisen due to the runway incursion.
ASC32d1	Collision on runway	ATC, flight crew or vehicle driver do not resolve the conflict and aircraft collide on the runway.
ASC32c2	Aircraft continues flight	ATC is able to avoid collision. Aircraft continues flight.
ASC32d2	Aircraft continues flight	Flight crew or vehicle driver is able to avoid collision. Aircraft continues flight.

ESD ASC-33

Code	ESD event name	Definition
ASC33a1	Cracks in aircraft pressure cabin	Presence of crack in an aircraft pressure boundary, which are, or should have been, detected during maintenance or line checks.
ASC33b1	Explosive decompression	The aircraft cabin quickly decompresses, resulting in major structural failure to the aircraft fuselage.
ASC33c1	In-flight break-up	Aircraft undergoes an explosive decompression due to cracks in pressure boundary. Aircraft breaks up in flight.
ASC33c2	Aircraft damage	Presence of crack in an aircraft pressure boundary does not lead to an explosive decompression. Aircraft continues flight damaged.

ESD ASC-35

Code	ESD event name	Definition
ASC35a1	TAWS alert	Occurrences of GPWS Mode 1 (Sink Rate), GPWS Mode 2 (Terrain), and EGPWS alerts.
ASC35b1	TAWS alert continues for more than 2 seconds	Occurrences of GPWS Mode 1 (Sink Rate), GPWS Mode 2 (Terrain), and EGPWS alerts that continue for more than 2 seconds.
ASC35c1	Flight crew does not execute terrain avoidance manoeuvre successfully.	If the crew detects the flight towards terrain, e.g. because of a TAWS warning, it can execute a terrain avoidance manoeuvre. If a TAWS “terrain, terrain” or “pull up, pull up” warning occurs the flight crew should immediately and simultaneously advance the power levers to the maximum available while disengaging the auto throttle and rotate smoothly to a target pitch attitude of 15 degrees while disconnecting the autopilot. A wing-level pull-up should be made unless terrain being avoided can be seen.
ASC35d1	Collision with ground	Aircraft impacts terrain (ground, water) or obstacles, which results in injuries, fatalities or damage to the aircraft.
ASC35c2	Aircraft continues flight	The flight is continued after the TAWS alert without further incident.
ASC35d2	Aircraft continues flight	The flight is continued after the TAWS alert without further incident.

ESD ASC-36

Code	ESD event name	Definition
ASC36a1	Conflict on taxiway or apron	A taxiing aircraft moves towards an object (other aircraft, vehicle, either stationary or moving, or a stationary object like a blast fence, lamp post, etc) or a vehicle moves towards a taxiing aircraft (either moving or temporarily stationary) such that a collision will result unless avoidance acting is taken by flight crew or ground crew. only refers to situations in which the subject aircraft is in the process of taxiing from the gate to the runway of departure (including

Code	ESD event name	Definition
		the pushback process) or taxiing from the arrival runway to the gate, including the process of docking at the gate. This event includes also aircraft landing on taxiways and causing conflict situations with taxiing traffic.
ASC36b1	ATC does not resolve the conflict	The air traffic controller does not resolve the collision risk that has been arisen due to conflict on the taxiway or apron.
ASC36c1	Flight crew or vehicle driver does not resolve the conflict	The flight crew or vehicle driver does not resolve the collision risk that has been arisen due to conflict on the taxiway or apron.
ASC36d1	Collision on taxiway or apron	ATC, flight crew or vehicle driver do not resolve the conflict and aircraft collide on the taxiway or apron.
ASC36c2	Aircraft continues flight	ATC is able to avoid collision. Aircraft continues flight.
ASC36d2	Aircraft continues flight	Flight crew or vehicle driver is able to avoid collision. Aircraft continues flight.

ESD ASC-38

Code	ESD event name	Definition
ASC38a1	Loss of control due to poor airmanship	A situation where the flight crew (temporarily) loses the control of the aircraft because of poor airmanship. This means that all systems are working properly but the flight crew makes a mistake, does not follow procedures or applies a wrong technique.
ASC38b1	Flight crew does not regain control	The flight crew does not succeed in regaining control after the loss of control.
ASC38c1	Collision with the ground	Aircraft impacts terrain (ground, water) or obstacles, which results in injuries, fatalities or damage to the aircraft.
ASC38c2	Aircraft continues flight	The flight crew continues the flight after the control is regained.