NOTICE OF PROPOSED AMENDMENT (NPA) 2013-02

DRAFT DECISION OF THE EXECUTIVE DIRECTOR OF THE EUROPEAN AVIATION SAFETY AGENCY

amending Decision 2003/2/RM of the Executive Director of the European Aviation Safety Agency of 17 October 2003 on certification specifications for large aeroplanes ('CS-25')

'Protection from debris impacts'

EXECUTIVE SUMMARY

This NPA proposes new certification standards for protection of large aeroplanes against some categories of threats: tyre and wheel failure (debris, burst pressure effect), small engine debris and runway debris. The proposed amendment of CS-25 would rationalise the current regulatory material by developing a model for each type of threat which will be applicable to the whole aeroplane. It was prepared based on the reports made by a Working Group including representatives of the industry (Airbus, Boeing, Rolls Royce) and aviation authorities (EASA, ENAC Italy, FAA, TCCA).

The Working Group reviewed all available information from existing certification practices, studies and known in-service occurrences. Recognizing that some differences exist among manufacturers practices, the Working Group had to make compromises to reach a proposal for amending CS-25 that is acceptable by everyone and that will contribute to improve the level of safety on future designs. The proposal meets the objective of this rulemaking task without creating unacceptable costs for applicants. An economic benefit is even anticipated from the simplification of the certification process.

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A. Explanatory Note

I. General

1. The purpose of this Notice of Proposed Amendment (NPA) is to envisage amending Decision 2003/2/RM of the Executive Director of the European Aviation Safety Agency of 17 October 2003 on certification specifications for large aeroplanes ('CS-25'). The scope of this rulemaking activity is outlined in Terms of Reference (ToR) 25.028, Issue 1, dated 9 February 2009, and described in more detail below.

2. The European Aviation Safety Agency (hereinafter referred to as the 'Agency') is directly involved in the rule-shaping process. It assists the European Commission in its executive tasks by preparing draft regulations, and amendments thereof, for the implementation of the Basic Regulation[1], which are adopted as 'Opinions' (Article 19(1)). It also adopts Certification Specifications (CSs), Acceptable Means of Compliance (AMC) and Guidance Material (GM) to be used in the certification process (Article 19(2)).

3. When developing rules, the Agency is bound to follow a structured process as required by Article 52(1) of the Basic Regulation. Such process has been adopted by the Agency's Management Board and is referred to as the 'Rulemaking Procedure'[2].

4. This rulemaking activity is included in the Agency's Rulemaking Programme for 2012-2015. It implements the rulemaking task RMT.0048 (old task number 25.028).

5. The text of this NPA has been developed by the Agency. It is submitted for consultation of all interested parties in accordance with Article 52 of the Basic Regulation and Articles 5(3) and 6 of the Rulemaking Procedure.

   The proposed rule has taken into account the development of European Union and international law (ICAO), and the harmonisation with the rules of other authorities of the European Union main partners as set out in the objectives of Article 2 of the Basic Regulation. The proposed rule is more stringent than the ICAO Standards and Recommended Practices. It has been drafted by a group including representatives from FAA and TCCA. In the future, it is expected that FAA and TCCA will propose an equivalent rule that will be harmonised as much as possible.

II. Consultation

6. To achieve optimal consultation, the Agency is publishing the draft Decision of the Executive Director on its website. Comments should be provided within **3 months** in accordance with Article 6.4 of the Rulemaking Procedure.

7. Please submit your comments using the **automated Comment-Response Tool (CRT)** available at **http://hub.easa.europa.eu/crt/**.[3]

8. The deadline for the submission of comments is **22 April 2013.**

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[1] Regulation (EC) No 216/2008 of the European Parliament and of the Council of 20 February 2008 on common rules in the field of civil aviation and establishing a European Aviation Safety Agency, and repealing Council Directive 91/670/EEC, Regulation (EC) No 1592/2002 and Directive 2004/36/EC (OJ L 79, 19.03.2008, p. 1). Regulation as last amended by Regulation 1108/2009 of the European Parliament and of the Council of 21 October 2009 (OJ L 309, 24.11.2009, p. 51).

[2] EASA MB Decision No 08-2007 of 13 June 2007 concerning the procedure to be applied by the Agency for the issuing of opinions, certification specifications and guidance material ('Rulemaking Procedure'). Decision as last amended and replaced by EASA MB Decision No 01-2012, 13.3.2012.

[3] In case the use of the Comment-Response Tool is prevented by technical problems, please report them to the CRT webmaster (crt@easa.europa.eu).

III. Comment-Response Document

9. All comments received in time will be responded to and incorporated in a Comment-Response Document (CRD). The CRD will be available on the Agency's website and in the Comment-Response Tool (CRT).

IV. Content of the draft Decision

10. This NPA proposes new certification standards for protection of large aeroplanes against some categories of threats as identified in its Terms of Reference 25.028: tyre debris, wheel debris, tyre burst pressure effect, small engine debris and runway debris. The proposed amendment of CS-25 was prepared by a Working Group including representatives of industry (Airbus, Boeing, Rolls Royce) and aviation authorities (EASA, ENAC Italy, FAA, TCCA).

11. It is proposed to amend CS 25.963(e) and AMC 25.963(e) for protection of fuel tanks against the risk of hazardous fuel leakages. The applicability of the amended CS 25.963(e) is therefore not anymore limited to fuel tank access covers.

    In CS 25.963(e)(1) the threats to be considered now include wheel debris.

    AMC 25.963(e) is proposed to be amended. The consideration of wheel debris is reflected and a link is made with a new AMC 25.734 which provides a wheel and tyre failure model along with pass-fail criteria. AMC 25.963(e) also defines a small engine debris threat model (3/8 inch steel cube at 700 fps) which was already available in the current AMC for the evaluation of fuel tanks access covers. Its applicability includes the ± 15 degrees area of the engine for which a normal impact to the skin is to be considered. It further adds the need to consider expanded trajectories beyond the ± 15 degrees area, allowing credit for impact incidence angle, in response to the data review and reference recommendations.

12. A new paragraph CS 25.734 'Protection against Wheel and Tyre failures' is proposed and a corresponding AMC 25.734 introduces a tyre and wheel failure model.

    CS 25.729(f) is proposed to be deleted. The first two bullets of this subparagraph required protection of essential equipment installed on the landing gears and in the wheel wells against the effect of tyre burst and loose tyre tread. This is now encompassed in CS 25.734. The third bullet required protection against the effect of wheel brake temperature. This specification is moved into CS 25.735 'Brakes and braking systems' as a new subparagraph (l) 'Wheel brake temperature'.

    Consistently, paragraph 4.d of AMC 25.729 is deleted and its content is moved into AMC 25.735 as a new paragraph 4.l (linked to the new CS 25.735(l)).

V. Working method

13. The content of this NPA was developed based on the Working Group activity which followed several steps before being able to propose new certifications standards.

14. Step 1: Review of in-service occurrences and identification of likely threats

    During this first phase, the Working Group collected data related to all forms of threats. Letters were sent to main aeroplane, engine, tyre and wheel manufacturers asking for available information from databases and in-service events reports where description of the debris and associated damages characteristics were available. Additionally, uncontained engine failure data known as China Lake Data collected in the 1990s and an AIA 2010 report were acquired and used. The information included size, mass, trajectories, damages for each type of debris (tyre, wheel, small engine debris, runway debris).

    Note: runway debris threat is to be understood as runway foreign objects which can be thrown directly onto the aeroplane (e.g. it doesn't include the case when runway debris damages a tyre which then releases debris onto the aeroplane, which is to be covered by the tyre and wheel debris threat).

The Group also gathered and analysed existing studies reports, available data in EASA, FAA, TCCA databases, and incident/accident investigation reports.

15. Step 2: Review the existing threat models and understand their applicability

The main documents of concern are AMC 20-128A, AMC 25.963(e), JAA TGM/25/08 Issue 2, FAA AC25.963-1. Applicable EASA Certification Review Items (CRI) and other authorities issue papers were also reviewed.

16. Step 3: Develop common threat models applicable to the whole aeroplane, and to both Systems and Structure

Based on the outcome from steps 1 and 2, the objective was to establish the most appropriate models for each category of threat.

17. Step 4: To draft an amendment of CS-25 by modifying existing paragraphs and AMC, and/or introducing new paragraph(s) and AMC

This final phase led to the proposal made in this NPA after analysing the existing CS/AMC 25.729, CS/AMC 25.735, CS 25.903(d) and AMC 20-128A, CS/AMC 25.963(e).

18. The following chapters provide the outcome of this work in the form of three reports for small engine debris, tyre and wheel debris, runway debris.

VI. Small engine debris

19. References

In addition to the responses from manufacturers (turbine engines, large aeroplanes) to the request letter from this Working Group, the following studies were analysed:

1. DOT/FAA/AR-99/11 'Large Engine Uncontained Debris Analysis', Final Report 1999 (often referred to as 'China Lake' report);
2. AIA Project Report 'High Bypass Ratio Turbine Engine Uncontained Rotor Events and Small Fragment Threat Characterisation 1969-2006', Vol. 1 & 2, January 2010;
3. DOT/FAA/AR-04/16 'Uncontained Engine Debris Analysis Using the Uncontained Engine Debris Damage Assessment Model', September 2004.

20. Scope

This NPA proposes an amendment to CS 25.963(e) and AMC 25.963(e) regarding small engine debris (rotating and non-rotating), i.e. debris not considered to be 'intermediate' or 'large' as defined by AMC 20-128A, primarily in relation to fuel leaks. It does not change the current use of AMC 20-128A regarding such threats. Furthermore, it does not specifically address the related specification CS 25.903(d).

Note 1: Various terminologies exist in the regulations (systems, structures, etc.), related research publications and project Means of Compliance (MOC) addressing small engine debris. They sometimes do not provide clear and/or consistent definition of debris and/or reference clearly defined energy thresholds. Therefore, in order to provide a broad and robust definition of all data not considered to be 'intermediate' or 'large' according to AMC 20-128A, the term 'small debris' is used in this NPA.

Note 2: Before envisaging a revision of AMC 20-128A (harmonised with FAA AC 20-128A), it is recommended to complete Ref. 2 activities such that a broader and more coherent amendment can be developed in relation to systems and structures. Ref. 2 Phase 2 activities are aimed to make recommendations on the technical accuracy of rotor debris models/user guide material given in AC 20-128A.

21. **Background**

CS-25 amendment 3 (eff. 19 September 2007) introduced a new AMC 25.963(e), addressing engine and tyre debris threats, primarily in relation to fuel tank access covers.

The amendment was made, in part, in response to the B737 Manchester accident (1985)[4]. The cause of the accident was an uncontained failure of the left engine, initiated by a failure of the No 9 combustor can. A section of the can (non-rotating debris) was ejected and fractured an under-wing fuel tank access panel. This resulted in a fire which developed catastrophically.

This EASA AMC has not yet been harmonised with the FAA AC, but has been accepted in various Certification/Validation projects.

Mitigating the engine debris threat requires to show that no penetration and fuel leak will result from the impact of the fuel tank access covers located within 15 degrees forward of the front engine compressor or fan plane to 15 degrees aft of the rearmost engine turbine plane, by small engine debris. In the absence of relevant data concerning small engine debris, the currently defined threat, i.e. 3/8 inch steel cube at 700 ft/sec, perpendicular to impacted surface should be used. This threat was chosen as it matched current wing skin resistance to penetration. Based on service history, the authorities decided that wing skin penetration strength was acceptable and that the fuel tank access covers should have similar penetration resistance.

Some studies have been published (Ref. 1, 2 and 3 above) justifying the need to review the threat defined in existing regulations. Furthermore, the increasing use of composite materials in critical structure applications, including fuel tanks, has further driven the need to review, and better understand, debris impact threat data. Indeed, composite materials tend to provide different, and potentially more variable, engineering properties following debris impact, due to potentially more competing failure modes relative to metallic structure. Therefore, the existing 'acceptable' level of safety, demonstrated with metallic structures, cannot be assumed to be maintained, resulting in the need to show that the use of composites maintains an acceptable level of safety.

22. **Existing related CS-25 provisions**

'CS 25.963 Fuel tanks: general

[…]

(e) Fuel tank access covers must comply with the following criteria in order to avoid loss of hazardous quantities of fuel:

(1) All covers located in an area where experience or analysis indicates a strike is likely, must be shown by analysis or tests to minimise penetration and deformation by tyre fragments, low energy engine debris, or other likely debris.

[…]

(See AMC 25.963(e).)

[…]

AMC 25.963(e)
Fuel Tank Access Covers

[…]

[4] Accident to Boeing 737-236, G-BGJL, at Manchester International Airport on 22 August 1985. Investigation report 8/88 from the Air Accidents Investigation Branch dated 15 December 1988.

3. IMPACT RESISTANCE.

[…]

b. In the absence of a more rational method, the following may be used for evaluating access covers for impact resistance to tyre and engine debris.

[…]

(ii) Engine Debris - Covers located within 15 degrees forward of the front engine compressor or fan plane measured from the centre of rotation to 15 degrees aft of the rear most engine turbine plane measured from the centre of rotation, should be evaluated for impact from small fragments. The evaluation should be made with energies referred to in AMC 20-128A 'Design Considerations for Minimising Hazards Caused by Uncontained Turbine Engine and Auxiliary Power Unit Rotor Failure'. The covers need not be designed to withstand impact from high energy engine fragments such as engine rotor segments or propeller fragments. In the absence of relevant data, an energy level corresponding to the impact of a 9.5 mm (3/8 inch) cube steel debris at 213.4 m/s (700 fps), 90 degrees to the impacted surface or area should be used. For clarification engines, as used in this advisory material, is intended to include engines used for thrust and engines used for auxiliary power (APU's).'

23. **Difficulties faced when reviewing engine failure events**

Understandably, an engine failure event is complex and may result in the release of a large amount of debris of various dimensions, energies, and trajectories. Much of this debris may be lost during the event, and the historical recording of any recovered debris details, and impact locations, may also be incomplete and non-standardised. As a consequence, it becomes necessary to make assumptions regarding missing information in order to get the most value from the limited data available. This has been necessary to some extent within the drafting of this NPA proposal and in the frame of the studies that published the reports in Ref. 1, 2 and 3.

Furthermore, the majority of the limited available data addresses High Bypass Ratio (HBR) engines, as associated with typical larger CS-25 designs. Although this data includes some Low Bypass Ratio (LBR) data, it is not considered to be adequate to make any generic conclusions allowing any distinction to be made between HBR and LBR engines. Although AMC 20-128A does include some performance related debris criteria, it does not establish that all debris sizes and energies (rotating and non-rotating) can be directly correlated with engine performance and/or configuration. Until such data is available, it is assumed that the same debris model is considered to apply to both HBR and LBR engines.

24. **Data associated with original AMC 25.963(e) development**

Review of available records associated with the development of the original AMC 25.963(e), and discussion within the drafting Group, shows that little data was available at the time of development of the original AMC amendment and that the link between this data and the defined threat within the AMC text was not recorded formally within that process. The information reviewed suggests that the threat was defined to provide resistance to debris impact equivalent to a representative aluminium wing skin thickness. This has provided acceptable service experience for fuel tank access covers, as no new events were reported on aeroplanes equipped with covers meeting the new standard for impact resistance.

25. **Review of data and studies reports used in this rulemaking task**

Overall the information received from the various interrogated manufacturers lacked detailed data on fragments sizes, trajectories, and speed or energy. There was not enough data to make any correlation without making some hypothesis.
The Group reviewed in detail Ref. 1, 2 and 3 reports, and the following analysis and conclusions were drawn.

Ref. 1: DOT/FAA/AR-99/11 'Large Engine Uncontained Debris Analysis' Final Report 1999 (generally referred to as the 'China Lake' data)

Ref. 1 addresses 65 large engine uncontained events between 1961 and 1996 considered to have adequate information to allow development of useful data relating to predominately rotating part debris from both HBR and LBR engines.

The objectives of Ref. 1 included the development of definition of debris size, weight, exit velocity, and trajectory in order to aid amendment to AC/AMC 20-128A.

The developed data was based upon assumptions and estimations, e.g. debris velocity was estimated to be 75 % of initial part release velocity in some cases. This method was supported using reverse engineering from impact damage data. This was considered to be less accurate than calculating energy from reported damages. (See the following review and development of Ref. 2 data.) It must also be noted that most of the debris listed are identified as intermediate or large fragments and, as noted in the document, only the larger fragments have been reported.

The report provided insufficient data to make any significant conclusions regarding non-rotating debris.

The Ref. 1 report conclusions/recommendations included:

The trajectories specified in AC/AMC 20-128A (± 15 degrees) are too narrow and should be expanded significantly. (See Ref. 1, Table 5-1.) Also note that the wing mounted engine debris trajectory distribution is oriented towards the aft of the engine disk plane, partly due to drag, relative velocity with respect to the aircraft, and aircraft configuration. (See Figures 1(a) and (b) below, and Ref. 1 A-5.)

Damage events usually involve many small debris impacts (average 11.8 per event), not just a single impact (this is already identified in AMC 20-128A par. 9(d)). It was also stated that 'combined effects from small fragments pose the highest hazard potential to the aircraft', although this point is not specifically supported by any event data within the report.

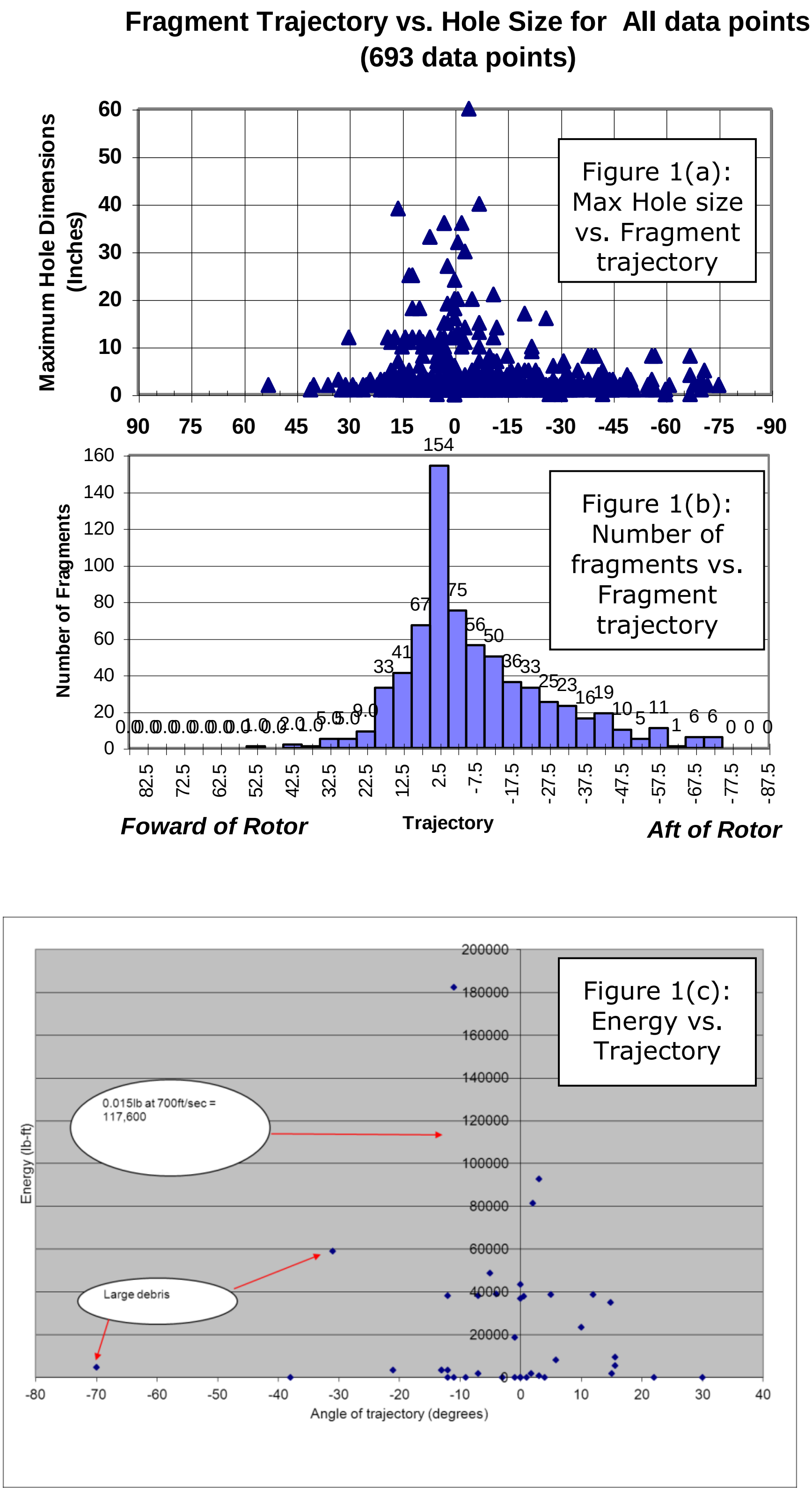

Figure 1:

a) Maximum Hole size vs Fragment trajectory

b) Number of fragments vs Fragment trajectory

c) Energy vs Trajectory for known fragment sizes (it indicates that the ± 15° trajectory window is adequate for small debris; the energy of a 3/8 inch steel cube (0.015 lb) at 700 ft/sec shown is indicated for reference)

(ref. China Lake Data)

Conclusion on Ref. 1

Ref. 1 provides data suggesting that the AMC 20-128A debris trajectories are too narrow and should be expanded beyond ± 15 degrees. Data presented in Ref. 1 does not define any distinction between small and intermediate/large fragments, and the link between fragment energy and trajectory does not appear to be clearly documented. However, Figure 1(c), developed by the Working Group using the China Lake raw data, indicates that for small debris with known energy, ± 15 degrees is adequate.

Large trajectory angles are generally associated with damage to less critical, generally thinner, structure and debris impact energies may be reduced due to impact incidence.

The occurrence of multiple debris impact events is recognised. However, despite the conclusion that 'combined effects from small fragments pose the highest hazard potential to the aircraft', the data does not support the need for any additional actions, beyond that proposed regarding expanded trajectories for single items of debris. Protection from a single fragment in the area within spread angle also protects against multiple debris impacts in the same area.

Ref. 2: AIA Project Report 'High Bypass Ratio Turbine Engine Uncontained Rotor Events and Small Fragment Threat Characterisation 1969-2006', Vol. 1 & 2, January 2010

Ref. 2 addresses 58 large engine uncontained events (three resulting in loss of the aeroplane), between 1969 and 2006. AIA considered these events to have adequate information to develop potentially useful data relating to predominately rotating part debris from HBR engines.

The objectives of Ref. 2 included developing debris detail definition and energies. (Note: Unlike in Ref. 1 report, trajectory data was not presented.). As Ref. 1, the objectives also included the intent to support an amendment to AC/AMC 20-128A.

In order to illustrate the limited extent of directly measureable data available, Figure 2 below shows all Ref. 2 data points with mass information (only 30 of 445 data points) not identified as 'intermediate' or 'large' or 'n/a'. The Ref. 2 Event ID is identified against mass (lb). It should be noted that this figure includes debris that are beyond the definition of small debris per AMC 20-128A (9 out of 30 have mass greater than 0.5 lb). Therefore these debris were removed prior to performing the analysis.

Please note that a 3/8 inch steel cube is of mass 0.015 lb, whilst a typical 'small fragment' for a large engine disk can be represented (ref. AMC 20-128A) by a debris size up to a maximum dimension corresponding to the tip half of the blade aerofoil, which is generally well represented in the last generation HBR engine designs by a 1.1 inch steel cube of 0.37 lb. However, it is unknown how well a 1.1 inch cube corresponds to the tip half of the blade aerofoil for the engines involved in the incidents cited in the referenced reports.

Figure 2 shows that a 3/8 inch cube (0.015 lb) is of limited value when addressing the threats (rotating and non-rotating) as defined by data with direct mass information available, since only 3 of the 21 items with a recorded mass are addressed, whilst the 1.1 inch cube (0.37 lb) addresses 6 of the 21 items. Note that 9 of the 21 items are of mass greater than 0.37 lb and identified as 'static' or 'large static'.

Ref. 2, Vol. 1, page 28, indicates that even if each of the 445 debris items were considered to be of independent consequence to safety relative to the approximate total of 489 million engine cycles during 1969-2006, then the probability of a debris item affecting safety would be 445/489E+6 = 9.1E-7 per cycle. However, each event is associated with many debris items (Ref. 1 indicates that there are about 12 debris items per event), reducing this to approximately 7.6E-8 per cycle. Furthermore, if only the three catastrophic events identified are considered, this is reduced to approximately 6E-9. Of these, the smaller debris was not the cause of the critical damage.

In conclusion, the probability of occurrence of these events, although low, are not sufficiently low enough to be ignored and should be addressed.

Note (Ref. 2, Vol.1, page 28): The 530M cycle total represents the total number of cycles completed for all engine generations (first, second, third) failures. Although it is recognised that significant improvement has increased the reliability of later design engines, the recent uncontained event (A380 in 2011, currently under investigation), combined with the sparse debris data available, suggests that rule segregation (i.e. discussion that the latest generation of turbofan power plants may not need to consider UERF in cruise) based upon engine generation should not be considered at this time.

Non-rotating debris

Ref. 2 data, including mass information, also includes non-rotating debris, identified as 'static' and 'large static' (10 debris items out of 445 are identified as 'static'). None of these debris items can be identified as 'small' debris. Furthermore, all are events associated with larger rotating debris, and thus may have been projected due to impact by a larger rotating debris item.

Recognising that the original amendment to AMC 25.963(e) was made partly in response to a fatal non-rotating failure (LBR, not HBR), and resulting debris impact, the 'static' and 'large static' debris information was reviewed.

Figure 1 data above includes 'static' and 'large static' data (all items above 2 lb through 3.4 lb in Fig. 1). These items are also in the mass range of some 'intermediate' and 'large' debris masses also presented in Ref. 2 report. Although such debris may be addressed, i.e. for systems separation, structures requirements, etc., by 'intermediate' and 'large' debris, and the associated trajectories, in accordance with AMC 20-128A, the potential concern remains that such static debris impact may occur outside these defined trajectories. However, trajectory information is not presented for such events, although it is reasonable to expect that such debris trajectories will not be so well correlated with the disk planes as higher energy rotating debris. Furthermore, the velocity is unknown. Non-rotating debris may be propelled by different mechanisms for which it may be difficult to quantify velocity. For example, a combustion chamber burst may result in a direct debris impact, it may be ricocheted, and/or its velocity may be generated by impact from a failed rotating part.

Note: the details regarding the geometry of the B737 Manchester event debris were not available to the Working Group. However, from available photos/drawings, this debris could fall into the intermediate fragment size group.

Review of Ref. 2 static part HBR debris impact data suggest that static events have caused only limited damage to critical structure (other than the B737 Manchester accident). Furthermore, the limited amount of useful data available and the small proportion of data identifying static debris in detail were not adequate to identify a specific model, e.g. geometry or mass to be used to address static debris risk.

Therefore, we could not draw any conclusions regarding non-rotating debris from Ref. 2. However, considering the Ref. 1 indicated data spread beyond ± 15 degrees and the occurrence of the existing identified non-rotating events (including the B737 Manchester event — note: LBR engine), we believe that some level of structure standard should be provided for non-rotating debris for all fuel tank structure beyond the components explicitly addressed within the AMC 25.963(e), i.e. fuel tank access covers.

Rotating debris

Figure 2 includes some fan blade debris data (3 items between 0.25 and 1.25 lb). Fan blade debris is addressed separately from 'small fragment' data, in AMC 20-128A, although not defined as 'intermediate' or 'large'. However, the masses overlap with data falling under these definitions. Note that these cases did produce some potentially significant damage. However, lack of detailed information limits further conclusions of any statistical significance.

Figure 3 below shows only 'small' debris, as recorded in Ref. 2, with recorded mass plotted. Note that 'small' is not explicitly defined in the AIA report. Also, the 3/8 inch cube addresses only three of the debris items with recorded mass, whilst the 1.1 inch cube addresses all cases. Although only a small number of data points exist for data between the 3/8 inch cube threat and the typical AMC 20-128A 'small fragment' threat, i.e. 1.1 inch cube, it does suggest that the AMC 20-128A 'small fragment' threat does exist.

For engines associated with current/recent projects, approximately 15-20 % of stages provide potential 'small fragment' debris energies, as defined by AMC 20-128A, greater than the 1.1 inch cube, assuming 700 ft/sec, whilst all stages provide 'small fragment' debris above the energy associated with a 3/8 inch cube. However, Ref. 2 conclusions, par. 7.2.1, suggest that the existing AMC 20-128A small fragment model energy is too high.

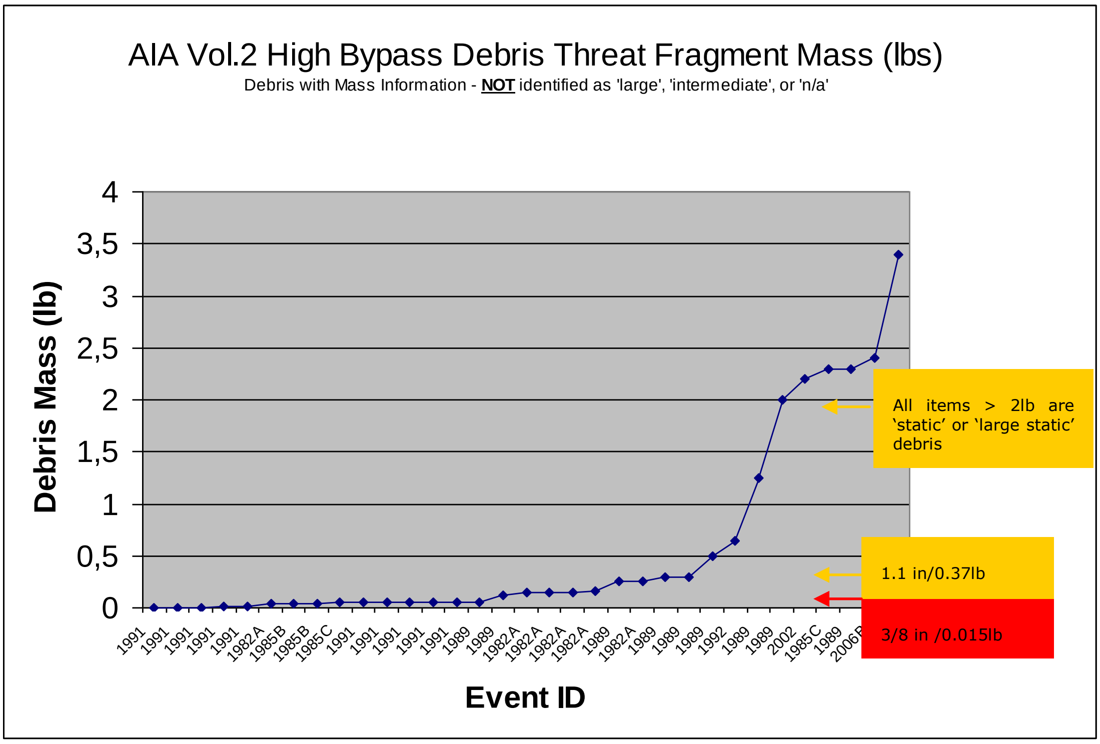

Figure 2: AIA report data with mass information, not defined as 'intermediate', 'large', or 'n/a'.

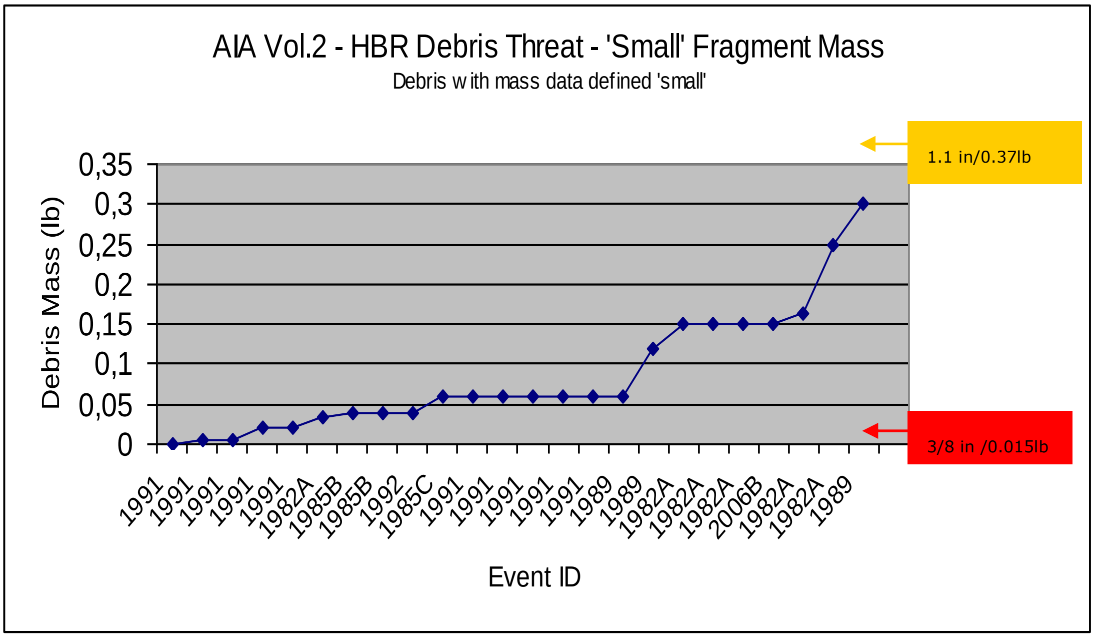

Figure 3: AIA report data with mass information, defined as 'small' (not 'intermediate', 'large', n/a, 'fan blade', 'static', or 'large static').

Further to consideration of the very limited data available, evident in Figures 2 and 3, it was considered that some value might be gained from reviewing the more recent debris data (not defined 'intermediate or 'large') with respect to the AMC defined threat, and also with respect to some manufacturer impact test damage data. By assuming that the test impact dent or penetration data could be correlated to the service data, when some information regarding service debris definition, damage, and the impacted structure configuration, was available, the number of potentially useful data points was significantly increased.

Processing of witness marks

Ref. 2, Appendix 5, detailed the witness marks left on the aeroplane by fragments, resulting from uncontained rotating part failures. This data was processed and analysed.

An assessment of the order of magnitude of energy required to create such witness marks was made.

This semi-empirical assessment was based upon the two following formulas. Those formulas have been established from available low and high speed impact tests performed in the frame of recent aircraft certification projects.

A. Dent Depth formula

From a panel thickness, this formula calculates the energy required for low speed hemispherical impactors to create a given dent depth. The formula considers various impact locations, i.e. middle bay, near frame, near stringer, etc.

For this evaluation, only middle bay has been used because fuel leak is the primary concern. The underlying structure is assumed to improve the situation with respect to such impact, these events being adequately fast to negate the need to consider structural energy absorption through bending in the middle bay locations. This formula was established for 1 to 6mm thick Aluminium (2024), impact normal to the plate.

As this formula has been established for lower speed hemispherical impactors, it is anticipated that a slightly higher energy would be required to create a similar witness mark due to high speed impact. However, sharp debris may create gouges or nicks at a significantly lower energy than the energy required to create a dent with an hemispherical impactor.

B. Penetration formula

From a panel thickness, the formula calculates energy necessary for penetration of 3/8 inch steel cube impacting at high speed. This formula integrates the worse cube face, corner, edge impact orientations for impact normal to the plate.

Note: 3/8 inch steel cube at 700 ft/sec = 153 J

All 488 entries from the AIA Ref. 2 report have been reviewed to isolate only small debris. Debris items identified as 'intermediate' or 'large' fragments were rejected as outside the scope of this rulemaking task.

Small fragments entries were classified into 3 groups:

Group A: Impact with energy below penetration energy

Entries: dents with unknown dent depth, scratches, gouges, nicks, abrasion, no penetration

Rejected: holes, dents with known dent depth, punctures (see group B) or penetrations (see group C)

The energy required to create such witness marks has been estimated from the Penetration formula, when thickness information is available.

From 20 events, 108 entries out of 123 have energies required to perforate below 153 J (3/8 inch steel cube at 700 ft/sec). This is conservative, especially for nicks/gouges on thick plates where most of the gouge/dent depths were not recorded, but penetration assumed, leading to higher energy than that required to create a gouge or dent.

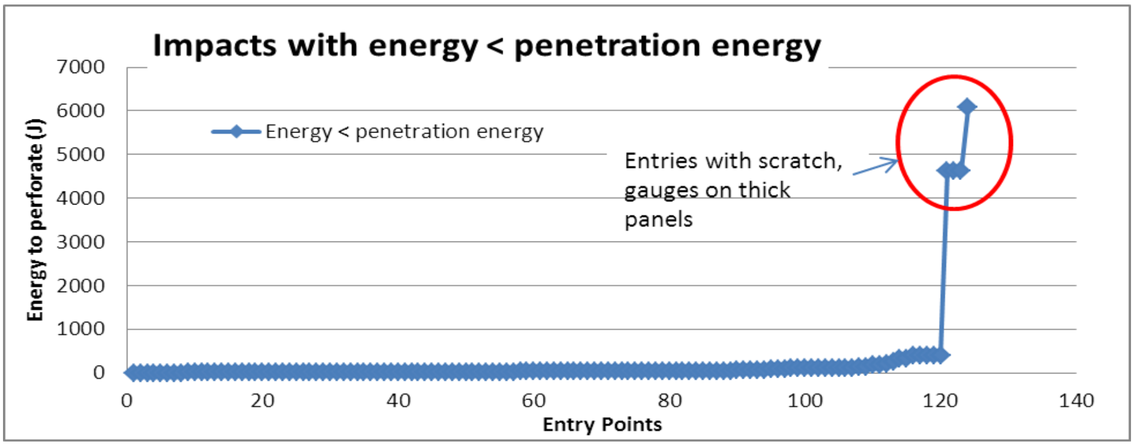

Figure 4(a): it shows that 108 out of 123 data points with adequate information regarding debris mass and material thickness information had energies less than 3/8 inch cube at 700 ft/sec (153 J).

Group B: Impact with energy assessed from dent depth by reverse engineering

Entries: dents and punctures with known dent depth

Rejected: dents with unknown dent depth, scratches, gouges, nicks, abrasion, no penetration (see group A), full penetrations (group C)

The energy required to create such witness marks has been estimated from the Dent Depth formula and from the Penetration formula for punctures, assuming a puncture is at the limit of perforation.

From 13 events, 116 entries out of 124 have evaluated energies below that of the 3/8 inch steel cube (153 J).

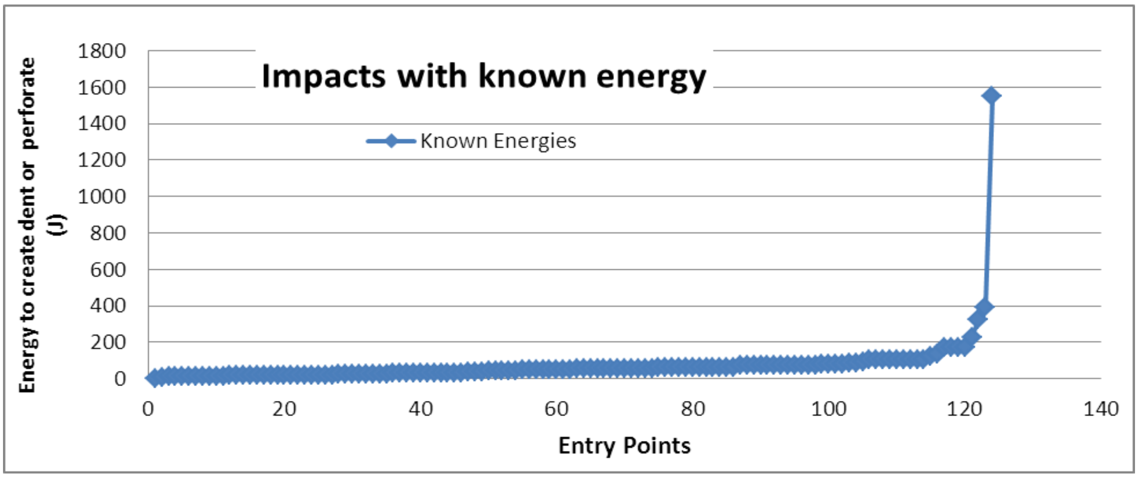

Figure 4(b): it shows that 116 out of 124 data points with evaluated energy less than 3/8 inch cube at 700 ft/sec (153 J).

Group C: Impact with energy greater than perforation energy

Entries: holes, penetration

Rejected: all dents, scratches, gouges, nicks, abrasion, puncture (see group B)

The energy has been estimated from the Penetration formula. It represents the minimum energy to make the hole, meaning that real energy could be much higher. From 19 events, 105 entries out of 110 have energies lower than 153 J, but without knowledge of the maximum.

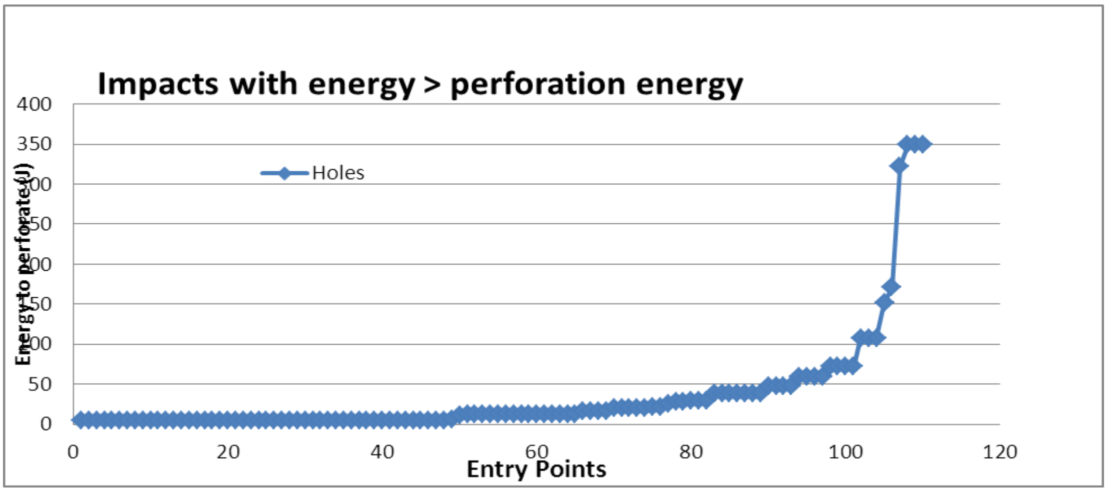

Figure 4(c): it shows that 105 out of 109 data points with impact energy lower than 3/8 inch cube at 700 ft/sec (153 J).

Interpretation of these results

Group A

Only very few debris have energy evaluated > 153 J. These 15 debris items are associated with minor damages (dent of unknown depth, gauges, nicks or abrasion) on thick panels. Therefore, it is likely that the energy required to create such damages is far below the energy required to penetrate.

In conclusion, all these debris items are assumed to have an energy below 153 J.

Group B

This is the group that gives better visibility regarding the energy from fragments, although the formula used to back calculate the energy from dent was established from low speed impacts and do not take into account possible sharp edges effects. Only 8 debris impacts have estimated energy above 153 J. It should be noted that conservative estimates were done when a range of thickness was provided.

Group C

For this group, the indication of the energy required to perforate means that debris had higher energy, but in the absence of other indications, it is difficult to conclude on the remaining energy after penetration.

From group A and B, only 8 out of 242 fragments have energies above 153 J, confirming the conclusions from the AIA report Vol. 1, i.e. most of the fragments have lower energy than the existing model assumption. It also supports the use of shielding of equivalent thickness to pressure cabin skins, as recommended in AMC 20-128A.

Available data from AIA report does not provide any information about the trajectory windows for small debris.

Conclusion on Ref. 2

The Ref. 2 report did not present trajectory information, somewhat limiting the possible conclusions.

However, the energy level comparison between the current AMC 25.963(e) defined threat (3/8 inch steel cube at 700 fps – equivalent energy = 153 J) and the service data (by further comparison with some comparative manufacturer's test data) was possible by applying several assumptions.

This indicated that the existing AMC defined threat typically addresses the vast majority of debris not defined 'intermediate' or 'large'. Of the larger debris not classified as 'intermediate' or 'large', i.e. fan blade, static, and large static items, as described in Ref. 2, inadequate data limited any conclusions. However, no critical damages have resulted from this debris (other than the original B737 Manchester accident).

Non-rotating debris trajectories are less well correlated with disk planes, thus requiring some protection outside the 'intermediate' and 'large' rotating debris trajectories. This supports the conclusions of Ref. 1. However, it also recognises, in the context of little evidence available regarding potentially critical events having occurred, that some credit could be given for debris impact incidence outside the already defined 'small', 'intermediate', and 'large' trajectories in accordance with AMC 20-128A.

Ref. 3: DOT/FAA/AR-04/16 'Uncontained Engine Debris Analysis Using the Uncontained Engine Debris Damage Assessment Model', September 2004

Ref. 3 describes an analytical tool developed by the Naval Air Warfare Center, Weapons Division (NAWC-WD) to evaluate the probability of hazard to an aircraft following uncontained engine debris events. The Uncontained Engine Debris Damage Assessment Model (UEDDAM) uses the Ref. 1 China Lake data as debris fragment model inputs and is presented in Ref. 3 with two hypothetical examples, i.e. a generic business jet and a generic twin-engine aircraft, to establish the aircraft level hazard. The tool generates a hazard probability output and provides details of critical component contributions for each Monte Carlo iteration, and/or a tabulation of risk angles for each critical component per event. Ref. 3 concludes that UEDDAM can provide early insight into the rotor burst hazard.

Conclusion on Ref. 3

The UEDDAM could provide a potentially very useful design tool, and this could contribute to the Certification process. However, the level of proposed refinement in the model requires review in the context of the very limited input data available, the necessary assumptions, and the use of probabilistic methods in general.

The current rulemaking task 25.028 Working Group did not have the resources available to investigate UEDDAM further during this review cycle, the main objective being to define the threat model, not to select a tool. However, the review of UEDDAM could form part of a future rulemaking activity, possibly including the preparation for a revision to AC/AMC 20-128A. This review process, and amendment as appropriate, should include both input from the creators of the model and recent data, e.g. AIA Ref. 2 at Phase II when completed, provided that it includes the appropriate data (e.g. trajectories).

Further to the recommendations in Ref. 3, it is suggested that, if industry sees potential in using this tool, aircraft manufacturers should exercise UEDDAM using appropriate personnel, thus gaining experience and allowing development of the proposed analysis guidelines. Such an activity may support, or otherwise, the potential acceptance of UEDDAM.

26. **Material change: composite materials**

Recent projects have significantly extended the use of composite materials into critical structure applications, including fuel tanks, which are commonly recognised to be exposed to potentially significant impact threats.

As discussed within recent Certification Review Items (CRIs) associated to composite fuel tank structure, the existing 'acceptable' level of safety relating to engine debris impact has been provided by experience with metallic structure, partly defined by design drivers other than impact, and which have not been specifically tested for engine debris impact. Therefore, considering the different engineering property values, and behaviours, which exist between metallic and composite materials, particularly those relating to impact behaviour, the material change cannot be assumed to provide the existing 'acceptable' level of safety.

In the absence of a review of impact threats and a validated threat model, recent projects have been subject to CRIs. These require 'equivalence' of penetration resistance to be shown between 'composite' and existing 'metallic' structure for several impactors, recognising composite sensitivity to impactor configuration, stiffness, etc.

These CRIs offer three basic options:

— show that all skin will not be penetrated by any defined threat;

— show 'equivalence' by reference to an agreed metallic comparative structure; and

— a combination of the above.

Further to the threat review reported above, and the experience of recent programmes, the proposed small debris threat, although defined by very limited data, is adequately defined for the purposes of the proposed AMC.

From a structures perspective, the primary concern relating to uncontained engine debris has been that of Residual Strength relating to 'intermediate' and 'large' debris. Although such debris is considered for more restricted spread angles than is considered for the existing small debris threat (ref. AMC 20-128A), it is noted that there would appear to have been no serious structural outcomes resulting specifically from small debris, or even slightly larger debris, outside the ± 15 degrees spread angle.

Furthermore, other Fatigue and Damage Tolerance (F&DT) considerations are not a primary concern because such events are annunciated and the resulting debris tends to be both sharp and hard, resulting in visible damage. Such behaviour for the current generation of materials are supported by a growing body of data. The longer term F&DT concern is further reduced by the need for such uncontained engine events to be followed by thorough internal and external inspections.

From a systems perspective, the potential for leak resulting from such damage is more broadly addressed by the proposed amendment requiring consideration of impact beyond ± 15 degrees with no resulting hazardous fuel leak.

Material change — conclusion

Considering the discussion above, the proposed amendment to the AMC 25.963(e) defined small engine debris threat is adequate from a structures and fuel systems perspective relative to the existing experience with the current generation of composite materials. However, in order to address potential material and configuration changes, a guidance material text is added to ensure that any variability in properties, or configuration, e.g. due to competing failure modes, is detected: impact tests should be completed in adequate number to show repeatable stable localised damage modes and damage extents for all impactor orientations (side-on, edge-on, and corner-on).

This is considered to be a reasonable addition, recognising that this proposal is associated with removal of the 'equivalence' based CRIs requiring testing using several impactors.

27. **Small engine debris: conclusion and proposal for CS-25 amendment**

It is proposed to amend CS 25.963(e) and AMC 25.963(e) for protection of fuel tanks against the risk of hazardous fuel leakages from small engine debris threat. Therefore, the applicability of the amended CS 25.963(e) is not anymore limited to fuel tank access covers.

The proposed AMC 25.963(e) defines the small engine debris threat as a 3/8 inch steel cube at 700 fps. This model of threat is the same as the current AMC for the evaluation of fuel tanks access covers.

The applicability of this threat includes the ± 15 degrees area of the engine for which a normal impact to the skin is to be considered. It further adds the need to consider expanded trajectories beyond the ± 15 degrees area, allowing credit for impact incidence angle.

In addition, a pass-fail criteria is provided to support the demonstration that no hazardous fuel leak will be created. This proposal is similar to the pass-fail criteria that has been used for protection against the risk of fuel leakage from small tyre debris impact on recent CRIs applied to certification projects.

The guidance material also recommends that any significant variability in structural response is detected and addressed accordingly. The proposed text is intended to help uncover other potentially significant competing damage modes (e.g. disbond, etc.).

The proposed small engine debris threat model is identical to the one provided in current AMC 25.963(e), except that it will be used to evaluate the entire fuel tanks, not only fuel tank access covers.

The advantage of this proposal is that it would set a standardised threat model protecting the fuel tank from engine non-rotating debris, small rotating debris, and ricochets. Then this threat would be usable for both metallic and composite fuel tank material. This will facilitate the assessment of aeroplanes making use of composite fuel tanks which cannot be compared in terms of impact resistance to a predecessor metallic fuel tank aeroplane for demonstrating an equivalent or superior level of safety (as was performed on some recent projects through the CRI process).

The expansion of the applicability of the threat model beyond the ± 15 degrees fuel tank access covers is not expected to create additional cost or weight impact for new CS-25 large aeroplane designs. Indeed, it is recognized that the wing skin surrounding fuel tank access covers is designed to carry main wing loads and therefore this typically drives its impact resistance capability beyond the level required to resist the 3/8 inch cube threat.

28. **Recommendation for future rulemaking**

The next review of the engine debris threat should consider the following:

— AIA Phase II activities (when complete, see Ref. 2);

— thorough review of the FAA UEDDAM tool (see Ref. 3), and consideration of its acceptability, or similar statistical approaches for inclusion/identification within AMC material; and

— review of any newly gained service experience of small engine debris impact of composite structures, particularly fuel tanks.

VII. Tyre and wheel debris

29. **References**

1. Responses from manufacturers (large aeroplane, wheel, tyre) to EASA letter requesting data on wheel and tyre failure related events.
2. Boeing presentation to the Working Group of their studies to define a radial tyre burst pressure plume.
3. JAA Administrative & Guidance Material — Section Three: Certification — Part 3: Interim Policies & Temporary Guidance Material: TGM/25/08 ‘Wheel and Tyre Failure Model’, Issue 2, dated 1.6.2002.
4. Accident to the Concorde registered F-BTSC on 25 July 2000 at La Patte d’Oie in Gonesse, France (Source report — BEA f-sc000725a).
5. Accident to Bombardier Learjet 60 registered N999LJ on 19 September 2008 at Columbia Metropolitan Airport, South Carolina, USA (Source Report — NTSB report AAR10-02).
6. Incident to Boeing 747-200 registered EC-DIA, on 1 February 1999 in Madrid Airport Barajas, Spain (Comisión de Investigación de Accidentes e Incidentes de Aviación Civil (CIAIAC), Spain, Boletin Informativo 1/99, item IN-004/99).
7. Incident to Boeing 747-200F registered N516MC on 16 July 2006 in Amsterdam, the Netherlands (Dutch Safety Board (Onderzoeksraad voor Veiligheid) — Occurrence number: 2006086).
8. Accident to Lockheed L-1011-200 registered HZ-AHJ on 23 December 1980 over international waters near the State of Qatar (flight SV162) (source: NTSB Safety Recommendations A-81-001).
9. Accident to Boeing 747-122 registration N4714U in Honolulu (USA) on 16 November 1984 (source NTSB Id: DCA85AA003).

10. Incident to Bombardier BD700 GX on 9 December 2005, Report: ASC-AOR-07-01-001 dated 25 January 2007, Aviation Safety Council Taipei, Taiwan.

11. Incident to Bombardier BD700 GX on 29 January 2008, Report: AAIB Bulletin 12/2008.

30. **Scope**

The Working Group collected and assessed available data relating to large aeroplane damage caused by debris coming from tyre and wheel failure events.

A review of existing related CS-25 provisions was also performed, as well as existing Certification Review Items (CRIs) and industry design practices.

Based on this work, this NPA proposes an amendment of CS-25 which includes the creation of a new rule dedicated to these threats and a corresponding model proposed as an AMC which provides models of the threats and the expected criteria for protection of the aircraft structure and systems. Existing related paragraphs are amended.

31. **Background**

Although the threat from wheel and tyre failure is identified by CS 25.729(f), CS 25.963(e) and CS 25.1309, it has not been quantified in the CS-25 AMC material.

Until the publication of a JAA Temporary Guidance Material (TGM) early in 2000, each project, or applicant, had proposed an individual model of the threat which inevitably lead to inconsistencies of interpretation of the threat. Over the following two years, this TGM was only slightly modified, and the final version was published as TGM/25/08, issue 2, dated 1 June 2002 (TGM — Temporary Guidance Material).

The TGM model was developed by JAA early in 2000. It was based on the A320 model from Airbus, which resulted from a BAE study of worldwide events data. Then the A320 model was updated to remove the probabilistic approach used at this time. This led to the TGM, which considers that an event will occur and that the aircraft must be protected.

Airbus also updated their model to remove the probabilistic approach and also to bring some clarifications compared to the TGM model.

The TGM model provides failure modes for the following threats:

— tyre burst: Gear extended (tyre tread debris), gear retracted (blast effects),

— flailing tread: Gear extended and gear retracting or retracted (strip of loose tread rotating with the wheel), and

— wheel rim release: Gear extended (wheel rim pieces projection) and gear retracted (complete rim release, for braked wheel).

The history of TGM/25/08 between its initiation and final publication could not be traced.

Following publication of the TGM, it has been widely applied on European projects, and on many international projects too. On projects where the JAA and later EASA were involved, it has been introduced via a Certification Review Item (CRI) as advisory or interpretative material in order to show compliance with the identified requirements (CS 25.729(f) and CS 25.1309). A few manufacturers used the model without modification. However, the majority proposed their own models either as substitutes for, or in addition to, the TGM.

A second smaller tyre debris model and an amendment to paragraph 14CFR25.963(e) were published by the FAA. The model was put in AC 25.963-1 in 1992 and was subsequently introduced by EASA in AMC 25.963(e) through CS-25 Amendment 3, as a result of NPA 21/2005 (previously, this material was prepared under JAA organisation (NPA 25E-304) after the ARAC General Structures Harmonisation Working Group (GSHWG) produced their report in June 2000). This group considered tyre impacts on fuel tank access covers and allowed either a rational model proposed by the applicant or a model comprising 1 % tyre mass impacting over an area of 1.5 % of the total tread area impacting 30 degrees inboard and outboard of the tyre plane of rotation.

The objective of the Working Group was to propose a single model that could be used to assess any structure or system on the aircraft. The TGM model was considered as a baseline model which would then be amended after consideration of in-service events and past relevant certification and design practices.

32. **Existing related CS-25 provisions**

'CS 25.729 Retracting mechanism

[…]

(f) *Protection of equipment on landing gear and in wheel wells.* Equipment that is essential to the safe operation of the aeroplane and that is located on the landing gear and in wheel wells must be protected from the damaging effects of —

(1) A bursting tyre*;*

(2) A loose tyre tread unless it is shown that a loose tyre tread cannot cause

damage; and

(3) Possible wheel brake temperatures*.*

[…]

AMC 25.729
Retracting Mechanism

[…]

4. DISCUSSION.

[…]

d. Protection of equipment on landing gear and in wheel wells. (Reference CS 25.729(f) Protection of equipment on landing gear and in wheel wells)

The use of fusible plugs in the wheels is not a complete safeguard against damage due to tyre explosion.

Where brake overheating could be damaging to the structure of, or equipment in, the wheel wells, an indication of brake temperature should be provided to warn the pilot.

[…]

CS 25.963 Fuel tanks: general

[…]

(e) Fuel tank access covers must comply with the following criteria in order to avoid loss of hazardous quantities of fuel:

(1) All covers located in an area where experience or analysis indicates a strike is likely, must be shown by analysis or tests to minimise penetration and deformation by tyre fragments, low energy engine debris, or other likely debris.

[…]

AMC 25.963(e)
Fuel Tank Access Covers

[…]

3. **IMPACT RESISTANCE**.

a. All fuel tanks access covers must be designed to minimise penetration and deformation by tyre fragments, low energy engine debris, or other likely debris, unless the covers are located in an area where service experience or analysis indicates a strike is not likely. The rule does not specify rigid standards for impact resistance because of the wide range of likely debris which could impact the covers. The applicant should, however, choose to minimise penetration and deformation by analysis or test of covers using debris of a type, size, trajectory and velocity that represents conditions anticipated in actual service for the aeroplane model involved. There should be no hazardous quantity of fuel leakage after impact. It may not be practical or even necessary to provide access covers with properties which are identical to those of the adjacent skin panels since the panels usually vary in thickness from station to station and may, at certain stations, have impact resistance in excess of that needed for any likely impact. The access covers, however, need not be more impact resistant than the average thickness of the adjacent tank structure at the same location, had it been designed without access covers. In the case of resistance to tyre debris, this comparison should be shown by tests or analysis supported by test.

b. In the absence of a more rational method, the following may be used for evaluating access covers for impact resistance to tyre and engine debris.

(i) Tyre Debris Covers located within 30 degrees inboard and outboard of the tyre plane of rotation, measured from centre of tyre rotation with the gear in the down and locked position and the oleo strut in the nominal position, should be evaluated. The evaluation should be based on the results of impact tests using tyre tread segments equal to 1 percent of the tyre mass distributed over an impact area equal to 1.5 percent of the total tread area. The velocities used in the assessment should be based on the highest speed that the aircraft is likely to use on the ground under normal operation.'

33. **JAA TGM/25/08 Issue 2**

The TGM model is provided in Appendix 1 to this NPA.

34. **Review of tyre and wheel failure events data**

General

The Working Group searched relevant data relating to tyre and wheel failures in service.

CS-25 large aeroplane accident/incident investigation reports were gathered and analysed.

In addition, request letters were sent to large aeroplane manufacturers, wheel and brake manufacturers and tyre manufacturers. The recipients were provided with a table which included various fields for assessing debris characteristics, consequences of failures on structure and systems, and also questions related to eventual use of a tyre and wheel failure model for type certification.

An example of this table for tyre debris is provided below:

TYRE DEBRIS

Aeroplane type	
Date of the event	
Dimensions of debris (number of fragments with associated length, width, thickness)	
Number of tyres affected?	
Adjacent or companion on same axle?	
Type of tyre affected (radial or new generation or bias)	
New tyre or re-tread level?	
Main gear or nose gear?	

Phase of flight	
Extended or retracted gear or during retraction phase?	
Failure type (burst, tread shed, flailing tread, etc.)	
Root cause (FOD, inflation, overheat, etc.)	
Trajectories	Mapping of debris/impact vs origin
Damages (systems, structure, location(s) and dimensions of aeroplane damage(s))	
Ingestion of debris by engine(s)?	
Effect on damaged systems?	
Do you use a wheel and tyre failure model?	
If yes, which type of model?	
If yes, are the debris characteristics in agreement with your model?	

The data received from the manufacturers varies considerably in both quality and quantity. Data was delivered in various formats, with different interpretations of the fields from table, and in several cases the table was not used.

Further data was requested and investigations were performed by Working Group members to extract as much relevant information as possible from what was supplied.

The data was compared to the TGM/25/08 model. A spreadsheet was created in which the various events from the different reporting sources were listed chronologically, along with the information provided about the type of failure (tyre burst, flailing tread or wheel rim failure), the state of the landing gear (extended or retracted), and the debris characteristics (size, angle) or gas pressure effect (‘blast effect’).

A total of 185 separate incidents or accidents were entered in the spreadsheet. Each of these were reviewed and classified according to the types of failure identified in the TGM, and also a judgement was made whether the event complied with the TGM or not. The totals in each category are shown below.

TOTAL	Tyre burst		Flailing tread		Wheel rim Release	
	Extended	Retracted	Extended	Retracted	Extended	Retracted
185	155	10	28	3	23	1

TGM compliant?			
	Size	Angle	Blast effect
Yes	12	75	1
No	17	35	2
Unknown	156	73	176

Note: Where the size of debris is declared not compliant with the TGM, this indicates that the debris is larger than that described in the model.

It was apparent that the collection of data following a tyre or wheel failure was not the main focus of activity.

From the analysis of the events data, it has been concluded that:

- Each failure mode identified in the TGM/25/08 model has occurred in service at least once.
- Many more failures have occurred when the gear was extended compared to when it was retracted or in the process of retracting.

- There was insufficient data to distinguish between the failure effects of radial and bias tyres. However, based on data presented, radial tyres fail differently than bias tyres in that radial tyres tend to have a wedge shaped failure mode while bias ply tyres tend to have an X pattern failure mode. These failure patterns can affect the pattern of a tyre pressure burst on system and structure, and the shape and size of a flailing tyre strip.
- There were no noticeable differences in the failure modes recorded for re-treaded tyres.
- It was rare that damage to an aircraft could be correlated with the debris that caused the damage.
- In many cases evidence of debris impact was outside the areas defined by the TGM. However, no impact energy could be derived for these pieces because the debris could not be identified. This is why the group recommends maintaining the current region of vulnerability for the larger debris pieces, and extending the region of vulnerability for only the smaller pieces.
- Multiple tyre bursts did occur.
- There were cases of multiple fragments of tread thrown from a single tyre. In one case multiple fragments appear to have been directly linked to an accident.
- The single retracted wheel flange failure which occurred in service was not considered to be relevant.
- The cases of vertical wheel flange debris release (gear extended) were considered to be enveloped by the tyre debris threat model, and therefore it is proposed not to characterise this threat in our model. See further explanations on this point below.
- Many events reports did not permit retrieving important parameters like debris size, speed, damage. Consequently, the events where this information was available were carefully analysed and used to challenge the TGM model. Some events are commented in the following paragraph.

<u>Analysis of some events with key elements</u>

This section describes in more detail certain important events which are key when considering either change to or maintaining the model.

1) <u>Accident to the Concorde registered F-BTSC on 25 July 2000 at La Patte d'Oie in Gonesse, France (Source report — BEA f-sc000725a)</u>

   Summary:

   The aircraft ran over a piece of runway foreign object debris which initiated a tyre failure. The tyre failure 'in all probability resulted in large pieces of rubber being thrown against the underside of the left wing … a severe fire broke out under the left wing'. The tyre impact would have induced a complex failure mode ('a hydrodynamic pressure surge') in the tank which would account for the separation of a section of the tank lower surface which was found on the runway. It had 'suffered pressure directed from the inside of the tank towards the outside, causing it to rupture'.

   The tyre debris was collected and pieces were found weighing up to 4.5 kg (100*33 cm).

   In the research and tests conducted during the preparation of the accident investigation report, similarity was demonstrated to the damage, with clean cuts, when the tyre runs over a representative cutting object at various speeds. The tyres were systematically cut right through and burst, releasing pieces of significant weight and size.

Parameters Affecting Model:

The TGM model considers two sizes of debris – large (W × W) and small (W/2 × W/2) with 'W' being the width of the tyre and with the thickness defined only as 'full tread thickness'. The Concorde accident and other incidents/accidents confirmed that large pieces of debris need be considered as a debris threat.

The dimensions of the Concorde main wheel tyre was 47 × 15.75-22.1 inches.

The tyre maximum weight was 105.0 kg.

1 % of tyre mass would be 1.05 kg.

Mass of a W × W piece of tyre – full carcass thickness = 6.06 Kg

Mass of W ×W piece of tyre – tread only = 2.103 kg

Mass of W × W piece of tyre – tread + protector ply = 2.24 kg

The above calculated masses were included to demonstrate that none of the debris sizes currently modelled would have approximated to the size of debris thought to have contributed to this accident. Three would have been too small, and one too large.

Although some of the circumstances of this accident are peculiar to the design of the aircraft involved (which is specific to the Concorde and does not reflect the design of subsonic airliners), some aspects can be read across to all aircraft.

This accident confirms that tyres can be destroyed by foreign object damage (FOD) on the runway.

This accident shows that a hydrodynamic pressure failure mode exists, and the Working Group concluded that this should be specifically mentioned in the model.

2) Accident to Bombardier Learjet 60 registered N999LJ on 19 September 2008 at Columbia Metropolitan Airport, South Carolina, USA (Source Report — NTSB report AAR10-02)

Multiple tyre failures.

Summary:

In September 2008 a Learjet 60 with 8 persons on board aborted the take-off above the V_1 speed following multiple tyre failures due to severe tyres under-inflation. The tyres failures also caused failures in several aircraft systems, including some associated with aircraft retardation. These systems were not adequately protected or segregated.

Parameters Affecting Model:

This accident confirms the need to assess multiple tyre failures in the model, that a thorough review of critical system components in the tyre burst zones is necessary, and also confirms that one of the major causes of tyre failure is under-inflation.

3) Two Boeing 747 incidents

Vertical release of wheel rim debris.

(i) Boeing 747-200 registered EC-DIA on 1 February 1999 in Madrid Airport Barajas, Spain (Comisión de Investigación de Accidentes e Incidentes de Aviación Civil (CIAIAC), Spain, Boletin Informativo 1/99, item IN-004/99)

Summary:

Vertical wheel rim debris during take-off, when the aircraft reached 130 knots. It was observed that the 'landing gear not centered' light came on. After lift-off, it was detected that the landing gear did not retract, and a loss in hydraulic system No 1 was observed. It was communicated that, during take-off, something had struck the passenger cabin opening a hole near the 37th row. Next, a loss in hydraulic system No 4 was identified, which was able to be stopped. Finally, emergency procedures were executed, fuel dumped, and the aircraft landed back at Madrid.

(ii) Boeing 747-200F registered N516MC on 16 July 2006 in Amsterdam, the Netherlands (Dutch Safety Board (Onderzoeksraad voor Veiligheid) — Occurrence number: 2006086)

Summary:

Vertical wheel rim debris — On 16 July 2006, a Boeing 747-200F, N516MC, operated by Atlas Air, suffered minor damage when the left main body gear tyre burst during take-off from runway 36L at Amsterdam/Schiphol Airport. The aeroplane returned to the airport and landed on runway 06. The damaged flap system caused a flap asymmetry and roll movement. The fuselage was damaged by the wheel and tyre fragments. The three crew members were not injured.

Analysis:

— The two events above are the only cases found by the Working Group, involving vertical release of wheel debris. In both cases, the aircraft completed take-off and performed a safe landing. The length of the involved flange debris at the Madrid event are unknown, however, it is known that the debris entered the passenger cabin. The debris from the Amsterdam event included at least a flange arc around 120° which perforated the MLG bay structure (estimation from a photo).

— The level of energy of a wheel flange debris between 60 and 120° of arc is estimated to be less than or equal to the one of a small tyre debris as defined in our proposed model (Model 1). So the small tyre debris model requirement would also provide some protection against wheel flange debris.

— In term of system protection (i.e. separation), the large tyre debris W × W of our proposed model would protect against 120° flange debris, as the diagonal of the W × W debris contains the 120° flange arc for the typical wheel/tyre combinations. The Working Group particularly assessed it for the Bombardier CRJ-1000 and Boeing 747-8.

— Regarding the fuel leak risk, we consider the W × W debris hole as enveloping any threat coming from wheel flange debris.

Parameters Affecting Model:

Based on this, it is decided not to propose an explicit flange debris threat in the vertical area. Although a flange debris is not explicitly defined, it is considered that the small tyre debris calculation provided an equivalent energy level to that of the wheel flange debris.

The group also made the following comparison: a 60° flange arc is smaller than a W × W tyre debris for A320, A330, DHC-8.

4) <u>Accident to Lockheed L-1011-200 registered HZ-AHJ on 23 December 1980 over international waters near the State of Qatar (flight SV162) (source: NTSB Safety Recommendations A-81-001)</u>

Wheel flange debris release with gear retracted.

Summary:

Flight SV162 experienced an explosive decompression of the cabin while climbing through 29,000 feet over international waters near the State of Qatar. The aircraft had departed Dhahran, Saudi Arabia, and was en-route to Karachi, Pakistan. An emergency descent was initiated and a successful landing was made at Doha International Airport in Qatar. Two passengers were killed when they were ejected from the aircraft through a hole in the cabin floor which had resulted from the forces of explosive decompression. Probable cause: 'The Presidency of Civil Aviation determines that the probable cause of this accident was an in-flight, fatigue failure of a main landing gear inboard wheel flange resulting in the rupture of the aircraft's pressure hull and explosive decompression. The failure of the flange, was the result of the failure of the B.F. Goodrich Company and the Lockheed Aircraft Company to properly assess the safety hazard associated with the type of wheels installed on aircraft HZ-AHJ. Contributing to the accident was the lapse of effective quality control procedures by the B.F. Goodrich Company and the failure of the Federal Aviation Administration to provide adequate surveillance of the manufacturer.'

Analysis:

After this event, the TSO for wheel and brakes was updated by adding a new requirement to demonstrate a roll-on-rim capability. This required the flange being reinforced and therefore increased the integrity of the wheel and made it more tolerant to fatigue failure mode. Since then we found no similar event that occurred with the gear retracted.

Parameters Affecting Model:

It is concluded that current TSO/ETSO for wheel and brakes sufficiently protects against this kind of risk, and therefore it is decided to restrict this threat to the gear extended configuration.

5) <u>Accident to Boeing 747-122 registration N4714U in Honolulu (USA) on 16 November 1984 (source NTSB Id: DCA85AA003)</u>

Summary:

After accelerating to about 153 kts during the take-off roll, the No 7 tyre failed and the crew aborted the take-off. An investigation revealed the No 7 tyre had failed after the inner bearing of that wheel had failed. This caused the wheel and tyre to overheat, which allowed the fuses to melt and blow out. The reason for the bearing failure was not verified. A tyre fragment penetrated a fuel tank access panel on the right wing. Large quantities of fuel were spilled but never ignited.

Analysis:

The ability of a relatively low speed tyre failure fragment to penetrate any part of the wing should have been recognised as a potentially hazardous condition.

Parameters Affecting Model:

This incident led to the introduction of the 1 % tyre mass/1.5 % tread area model used in the revision of AC 25.963-1 and present today in AMC 25.963(e). However, this rule and advisory material were only made applicable to fuel tank access covers. The Working Group believes that there is no valid reason for not making this same impact model applicable also to the remainder of the fuel tank.

6) <u>Bombardier Global Express BD700 events</u>

(i) Event date: 09 December 2005

Report: ASC-AOR-07-01-001 dated 25 January 2007, Aviation Safety Council (ASC) Taipei, Taiwan.

Summary:

The aircraft departed Taipei and landed in Taiwan Kaohsiung airport. Upon landing failure indications for thrust reversers, hydraulic systems #2 and #3 were recorded. Also, the crew noted loss of nose wheel steering, and the aircraft drifted right and off the runway onto the adjacent grass area. The left inboard MLG tyre was damaged by a deep skid from a locked wheel during landing. Subsequently, the tyre failed and the tyre flail damaged wing substructure (broken), hydraulic systems #2 and #3 tubes (ruptured), flap torque tube (shattered), flap and spoiler harnesses in the aux spar area, and there was localised wing structural damage. The locked wheel and skid was a result of contamination of a brake control valve. Subsequently, Bombardier issued an Advisory Wire AW600-32-2265. Tyre debris dimensions included three pieces < 1.5″L × 3.0″W × 0.75″D. In addition, and of particular interest was a tyre flail dimension of 19.6″L × 17″W × 0.75″D including both tread and carcass. The aircraft MLG tyre was a bias ply 38 × 12 × 19 (Outer Diameter × Width × Rim Diameter). No injuries recorded.

Analysis:

The investigation report is included in its Appendix 4, Bombardier Engineering Document No RBS-C700-108, which analysed this event and included the following statements.

Paragraph 5.1.5:

'A review of the tire failure, and projected shedding of radial trajectories, excludes direct impact striking of components nestled in the rear spar area. It also strongly suggests that a rotation of a flailing tire is required for the level, and type of damage observed on system installations in that area.

The evidence indicating that some of the components (flap torque tube, wiring, hydraulic lines, and sheet metal shield) were "pulled down and out" by a rotating tire piece, as opposed to being "pushed in" by trajectory impact, is noted here for reference (Photo 2). Additionally, the black rubbing mark on the inboard flap, suggesting flailing tire contact must be mentioned.'

Paragraph 8.0 Conclusions, includes:

'1. The cause of the Aircraft 9009 landing incident on Dec 9th, 2005 at Taiwan Kaohsiung airport, was the failure of #2 MLG tire after touch down, causing flailing tire damage to the aircraft hydraulics and flight control systems.'

This conclusion is mirrored in the conclusion of the ASC Investigation Report.

(ii) Event date: 29 January 2008

Report: AAIB Bulletin 12/2008 plus information from Bombardier

Summary:

The aircraft departed Van Nuys, California to London Luton Airport. Upon landing the left inboard MLG tyre suffered a deep skid from a locked wheel due to frozen brakes. The locked wheel skid resulted in a skid-through tyre burst with subsequent damage to spray guard (destroyed), wing local auxiliary spar structure, flap drive torque tube (fractured), fractured hydraulic tubes (hydraulic system #2 and #3 inoperable), damage to wiring loom and localised wing structural damage, and caused metallic debris to be forced between and into contact with the two cables driving the left aileron. Tyre debris dimensions included 2 pieces <1.5″L × 3.0″W × 0.75″D and 1 piece ≥ 1.5″L × 3.0″W × 0.75″D. In addition, and of particular interest, was a tyre flail dimension of 23.62″L × 17″W × 0.75″D including both tread and carcass. The aircraft MLG tyre was a bias ply 38 × 12 × 19 (Outer Diameter × Width × Rim Diameter). No injuries recorded.

Analysis:

A number of safety recommendations were made by the AAIB including to implement shielding to protect flight critical hydraulic, electrical and mechanical systems in the vicinity of the main wheels, or develop a tyre that does not have such a flailing failure mode. These incidents support tyre debris resulting from a tyre failure, but this case resulted in multiple tyre debris from one tyre which is not currently considered in the TGM model. There is no specific evidence associating the debris with aircraft damage. However, this incident does support the proposed model for tyre flail, and there is evidence supporting the damaging effects of a tyre flail. The flail included both tread and carcass. The AAIB report brings attention to the fact the EASA certification practice (i.e. the current TGM) only considers the tread in the tyre flail model, while skid-through cases like this would result in total carcass thickness. It also concludes that this event 'demonstrates the greater vertical distance into the wing structure to which damage can be inflicted in practice, compared with the situation assumed by the certification rules'. The AAIB report also states 'Tests have shown that the radial ply type of tyre does not possess this failure mode and that detached or flailing debris is likely to be significantly smaller and lighter.' The report does not provide sufficient details as to the specific tests the AAIB are referencing, but this statement agrees with other evidence presented to the Working Group.

The analysis of the tyre flail indicated that the 2W length of the flail remaining in a tangential position like foreseen by the TGM model would not have achieved the damage incurred.

Parameters Affecting Model:

The thickness of the flailing strip of tyre should be the full tread plus the carcass. Only if the applicant is able to demonstrate that the carcass will not fail, then the thickness may be reduced to full tread plus the outermost ply.

Threat area from the flailing strip. The second event involved a flailing strip of approximately 2W (23.62 inches against a 12-inch tyre width) which is inside the TGM model considering a tangential 2W piece of tread. Therefore, there must be a mechanism explaining that this 2W flailing strip was able to create damages beyond the TGM threat defined by the 2W tangential strip of tyre. Such mechanism is not demonstrated, but it is assumed that it involves a combination of tyre strip elongation and deflection beyond the tangential position, which is not considered in the TGM model. The same physical effect is seen also on the first event, although the length of the strip is shorter.

Nevertheless, we calculated that to reach the damage area radius, this is equivalent to having a 2.5W strip tangential to the external tyre surface. We propose to update the model with this value.

Width of the flailing strip. The width of the strips involved in these two events reaches a value in excess of the width of the tread, as the tyre failed up to the sidewall. However, considering the shape of these strips (the tyres failed with an X shape) and comparing with the threat envelope defined by the TGM model (15° angle either side of the wheel flanges), it is concluded that this case is covered although the strip of the TGM has a width of W/2 (which can be positioned anywhere inside the threat envelope).

7) <u>Biman Bangladesh DC-10 departing Bombay on 29 October 1984</u>

Retracted tyre burst event — Information provide to the Working Group based on internal Douglas/Boeing reporting.

This event involved a skid damaged #6 tyre (i.e. the left side gear, aft inboard tyre). When the tyre blew, the blast was directed at the keel bulkhead separating the left wheel well from the centre wheel well. The blast effect dislodged numerous #1 hydraulic system components mounted to this bulkhead and the large reservoir in the inboard/aft corner of the wheel well. These components were knocked off their brackets but there was no leak to the hydraulic tubing. Three flap lock valves are mounted on the other side of that bulkhead (i.e. in the centre gear wheel well). The bulkhead shook so that the lock valve bracket holding the three valves pulled through the heads of the rivets and the 1/4" tubing for systems 1 and 2 failed. This led to a dual hydraulic system failure. The aeroplane turned around and headed back for a safe landing in Kabul. The keel bulkhead took a permanent 1/2" bow from that blast.

Analysis:

This event confirms that, in addition to the evaluation of structure and systems located inside the tyre burst plume, there is a need to evaluate and protect the aircraft against the effect of pressure increase in the wheel well as a result of a retracted tyre burst.

35. **Wheel and tyre failure model**

A failure model which includes criteria and guidance for protection of structures and systems is created and will be inserted as a new AMC (see next paragraph).

This model is created based on the TGM/25/08 Issue 2 model, which has been modified using the lessons learnt from incidents and accidents review as explained above, and also after review of industry models and research activities which could provide for more accurate models. The models of threats have also been complemented with pass-fail criteria whose content is reflecting recent certification projects (CRIs).

Compared to the TGM, the main changes are the following:

(i) General

— Definitions of parts and dimensions revised to be in accordance with the Tire and Rim Association (TRA) aircraft yearbook.

— Definition of the full tread thickness to be taken as the thickness of full tread rubber on a new tyre.

— Definition added for the tyre speed rating, used for tyre debris.

(ii) Tyre debris

— The region of vulnerability (lateral) for the gear extended tyre debris is increased from ± 15° to ± 30° for the small debris pieces, but remains at ± 15° for the large debris pieces. This was decided based on evidences from reported events.

— The model for the small tyre debris is changed from one based on dimension W/2 to the one currently used in AMC 25.963(e) (1 per cent of the total tyre mass, with an impact load distributed over an area equal to 1.5 per cent of the total tread area). This model was used on previous certification projects, including the recent CRI Tyre Debris vs Fuel Leakage for CFRP Fuel Tank. It has proven efficiency to protect fuel tank access covers (no penetration event on aircraft certified to this threat).

— The thickness of large tyre debris is the full tread plus the outermost ply, instead of full tread only.

— In-service events show that large pieces of tyre with a thickness of full tread plus carcass can be release (e.g. the Concorde accident in 2000). The Working Group then considered prescribing this thickness. However, this value combined with a high release speed was considered potentially over conservative. Finally, the Working Group made a decision after considering the combined effect on the energy level from both the tyre thickness and its release speed. As the debris release speed is set with some conservatism (see explanations below), the debris thickness is maintained at full tread plus the outermost ply.

— The speed of the debris is changed to the minimum tyre speed rating certified for the aircraft instead of maximum rotation speed V_R.

— The Working Group initially considered using the maximum ground speed at rotation V_R like in the TGM. It was recognised that the max V_R, although it would rarely be reached at the time of a tyre failure event, would cover all operational scenarios.

— There was also a discussion about the tyre internal pressure effect on the debris release speed, not taken into account in the TGM.

— The use of max V_R is already a conservative speed as it is rarely reached in normal operation; in addition, it was deemed improbable that debris are released exactly at the burst time (pressure release is very quick), especially when the aircraft speed is reaching V_R. So adding max V_R plus a pressure release, in addition to a thickness of the large debris of full tread plus carcass, was considered over conservative.

— Finally it was proposed to use the minimum tyre speed rating certified for the aircraft (the tyre speed rating is the maximum ground speed at which the tyre has been tested, which is always above the max V_R) but without prescribing tyre internal pressure effect and relaxing the thickness of large debris.

— In addition to being a speed value easy to determine and to use by the applicant, this adds a margin to the energy level which mitigates the case when the debris could be released with a thickness including the carcass instead of a debris with a thickness of full tread plus outermost ply only.

— In order to assess the proposed combination large debris thickness = full tread plus outermost ply and release speed = tyre speed rating, the Working Group considered the case of the Concorde accident.

— In this event, the burst occurred at 87m/s, V_R was 102m/s and the tyre speed rating was 123 m/s. The ratio between the energy level reached during the accident and the one which would have been reached using the speed rating is 2.

— It was also calculated that typically, the mass ratio between a large debris with full tread plus carcass and one with full tread plus outermost ply is in the range of 2 to 3. Therefore the margin added by selecting the tyre speed rating will cover (most of) the potential energy increase due to a full tyre thickness case. Overall the proposed combination is deemed to provide a balance between margin and operational scenarios.

— Multiple tyre fragments due to companion tyre failures is limited to large debris. Reported events confirmed this threat exists and essentially concerns protection of systems. Therefore, it is proposed to limit the assessment to large debris. For structure protection, events data do not support the simultaneous (same location) double debris case with high energy as proposed (tyre speed rating). It is considered very improbable and too conservative. Therefore, for structure protection a single debris analysis should be considered.

— Introduction of a requirement to consider fuel leakage as a result of tyre debris impacts. This requirement is part of the structure pass fail criteria. This is formalising previous CRIs and also takes into consideration accident history.

— Introduction of requirement to consider structural effects of debris impacts in accordance with CS 25.571 and AMC 20-29. This is formalising previous CRIs.

— Remark on the arc of vulnerability: the value of the arc is unchanged at 135°. The Working Group had envisaged proposing extension to 180° based on the numerous events of small debris ingested by engines. There was nevertheless very limited events where marks were found on zones like Horizontal Tail Planes (HTP), and in these cases no damage was created. Between 135° and 180°, the speed and energy of fragments appears very low and do not represent a hazard. Also, no large debris events were found in this range. So protection against high energy debris for angles up to 135° is considered sufficient.

(iii) Tyre burst pressure effect

— Introduction of two tyre burst pressure effect models to distinguish the tyre technologies radial and bias.

— Although the TGM cone model was not put into question by in-service events, it was also recognised that the number of such occurrences is very limited (10 found by this Working Group) and do not necessarily inform if the model is realistic or not.

— Furthermore, evidences were presented that radial tyres have a failure mode which is significantly different compared to bias tyres. Radial tyres tend to have a wedge shaped failure mode while bias ply tyres tend to have an X pattern failure mode. These failure patterns can affect the pattern of a tyre pressure burst on system and structure.

— Such evidence was confirmed by theoretical and empirical studies made by Boeing.

— A radial tyre failure model ('wedge' plume) is thus proposed reflecting the Boeing model. This model and its pressure decay formula were determined empirically and correlated with cannon tests and CFD analysis. Although a full tyre burst test with full instrumentation has not been performed, this model is considered the best available. The shape of the plume correlate well with videos of real radial tyre burst tests. Note that Boeing used to add a 22° cone plume model on radial tyre sidewall based on the assumption of a theoretical failure case of a damaged sidewall. However this case never happened, and the wedge plume already extends to the sidewall area, so the Working Group decided not to add this plume model. Airbus expressed its disagreement with the proposed wedge plume model and filed a minority position provided farther below.

— For bias tyres, it is proposed to maintain the TGM cone model. This type of model was developed by Airbus based on bias tyre tests at the time of the A300 in 1976. In the absence of adverse service evidence with bias tyre and on the absence of a study that would provide a better model, it is maintained.

— The angle of the TGM cone model, now proposed for bias tyres only, has been corrected from 36° to 18°. The 36° value was present in error in the TGM model but was corrected to 18° by Airbus. JAA and the Agency also accepted the 18°.

— The diameter of the opening hole ($W_{SG}/4$) and the height of the cone (60 cm) for the bias tyre plume model are added. These values are derived from the Airbus experience which was gathered by test on A300 tyres. In fact the value for the opening hole was determined as 10 cm; the Working Group determined that, assuming a fulcrum of the cone set at 0.7D, $W_{SG}/4$ is a good approximation of the size of the hole.

— Pressure distribution curves are provided for the bias tyre cone plume model. These curves were developed by Airbus at the time of the A300 investigations mentioned above.

— A tyre burst pressure value is added (the same for all types of tyre), as the TGM did not provide any guidance.

— Due to the number of parameters that influence the pressure, it is proposed to specify an increase of pressure (ratio vs max tyre pressure), instead of providing a relationship between pressure and temperature plus method for temperature determination. This would simplify the assessment and ensure that all applicants use similar assumptions. The proposal is 125% of the maximum unloaded tyre pressure. This is considered as an average value reflecting industry practice, determined after considering the contribution of various parameters influencing the tyre temperature and pressure like the aircraft loading, outside temperature, taxi profile (brake thermal analysis), type of tyre.

(iv) Flailing tyre strip

— The term 'flailing tread' is replaced by 'flailing strip' as the model considers a strip of tyre with a thickness of full tread plus carcass. Some events confirmed that tyres can fail and produce flailing strips with full tyre thickness.

— The speed of the strip is changed to the minimum tyre speed rating certified for the aircraft instead of maximum rotation speed V_R, for consistency with the tyre debris model.

— For gear retracting or retracted cases, the applicant may take credit from a retraction brake under some conditions. The applicant has to evaluate potential damages created by the protruding strip at zero speed when entering the wheel bay.

— Length of the tangential tyre strip. The length is increased from 2W to 2.5W. This is intended to take into account the effect of acceleration loads on the strip which result in its elongation and deflection. Two events (described above) demonstrated this effect and the resulting damages outside of the TGM model.

(v) Wheel flange debris

— Deletion of the gear retracted wheel rim release threat.

There was only one reported event. After this event, the TSO for Wheel and brakes was updated by adding a new requirement to demonstrate a roll-on-rim capability. This required the flange being reinforced and therefore increased the integrity of the wheel and made it more tolerant to fatigue failure mode. Since then we found no similar event that occurred with the gear retracted.

— Gear extended case

Precision added to distinguish landing gears with multiple wheels (lateral release of wheel flanges on the outer wheel halves only)

An explanation is added about the coverage of wheel flange vertical release which is a recognised threat, but which is deemed to be covered by the tyre debris model.

36. **Tyre and wheel debris — conclusion and proposal for CS-25 amendment**

The overall objective of the proposal is to introduce a complete tyre and wheel failure model in CS-25, which can be used for assessment and protection of the entire aircraft structures and systems.

A new paragraph CS 25.734 'Protection against Wheel and Tyre failures' is proposed, and a corresponding AMC 25.734 introduces the tyre and wheel failure model.

CS 25.729(f) is proposed to be deleted. The first two bullets of this subparagraph required protection of essential equipment installed on the landing gears and in the wheel wells against the effect of tyre burst and loose tyre tread. This is now encompassed in CS 25.734. The third bullet required protection against the effect of wheel brake temperature. This specification is moved into CS 25.735 'Brakes and braking systems' as a new subparagraph (l) 'Wheel brake temperature', as this location is deemed more appropriate than in paragraph 'Retracting mechanism'.

Consistently, paragraph 4.d of AMC 25.729 is deleted and its content is moved into AMC 25.735 as a new paragraph 4.l (linked to the new CS 25.735(l)).

Concerning CS 25.963(e)(1), which was devoted to protection of fuel tank access covers against debris threats that includes tyre debris, its applicability is extended to fuel tanks, and the threats to be considered now include wheel debris. However, CS 25.963(e)(2), dealing with fuel tank access covers fire withstanding capability, remains unchanged.

Similarly, AMC 25.963(e) is proposed to be amended. The applicability is for fuel tanks, and not only tyre debris should be considered but also wheel debris, and a link is made with AMC 25.734 which provides a wheel and tyre failure model along with pass-fail criteria.

37. **Airbus minority position**

Airbus did not agree with the proposal to adopt the Boeing 'wedge' plume model for radial tyre burst pressure effect, their position is as follows:

- The model applied by Airbus for both Bias and Radial tyres since A300 has proven to give an acceptable level of safety.

  This model was initially based on tests performed for the A300 in 1976, in which a 100 mm hole was created in a bias tyre.

  The TGM model issued in 2000 was based on the above Airbus model, with the main difference of a cone angle of 36° rather than the 18° used by Airbus. This was introduced by error in the TGM and never corrected since then, despite the fact that 18° cone is accepted until now by Aviation Authorities as a valid model.

- Although there is some evidence that bias tyre burst could create larger diamond holes, and Radial tyre tend to burst creating a wedge ('Pacman' effect), it should be highlighted that the model was not intended to accurately represent any possible mode of failure for all tyre type/models. Rather, it was intended to provide a minimum level of robustness for the systems located in the wheel well. This level of robustness was mainly achieved by segregation means.

- Although only very few events (two events in Airbus history) can support this statement, the TGM model, and specially the way it is applied within Airbus, has proven to give an acceptable level of safety.

- Although Boeing has made a huge theoretical work, including CFD analysis to characterise pressure effects when radial tyre burst, there is no available test evidence performed with radial tyre to validate the proposed model.

  Videos taken from radial tyre tests performed by tyre manufacturers seems to support Boeing assumptions concerning the wedge opening. However, without any pressure measurement within the plume, the pressure distribution remains a pure theoretical approach.

Other tests have been performed with a cannon, to validate theoretical analysis, but in this case opening was not representative of the radial tyre opening.

All possible modes of failure for radial tyres have not been tested (FOD on the sidewall, etc.). Overpressure tests performed in the frame of Single Aisle (SA) tyre qualification confirms a large variability in radial tyres different failure modes, under overpressure condition. Therefore, a potential risk exists to have other failure modes not covered by the wedge model.

- Pressure considered today by the Airbus model (core pressure considered in the cone up to 600 mm) is significantly higher than in the proposed wedge model. Therefore, this could be un-conservative.

In conclusion, it is Airbus position that the current TGM Model as applied within Airbus provides an acceptable level of safety. Airbus is reluctant to adopt a different model for the radial tyre without any supporting test evidence, including pressure measurements, demonstrating that the proposed model is more adequate than the TGM.

Airbus proposal is to continue to use the TGM (corrected and including definition of pressure decay as used by Airbus) for both bias and radial tyres, and allow as an alternative the wedge model for radial tyres only.

Commentary from the Agency on the Airbus minority position

Since the tyres tested in 1976 were bias tyres, there is certainly an argument for continuing to use the model developed at that time for this tyre technology. No remaining experimental data from these tests was provided to the group. However, in the 35 years since those tests, further testing has been performed and new tyre technology has been introduced. Both test and in-service evidence exists to show that the two technologies fail in different ways: the radial tyre fails from bead to bead with a radial split vertically across the sidewall, and the bias tyre fails diagonally along the line of the crossed plies of the carcass. Evidence is not available to the group regarding the pressure distributions of the two failures, so the only way to model this is theoretically. Boeing provided such a theoretical model.

Boeing also provided high speed photography of the different modes of tyre burst, which shows that the cone is not the correct representation of a radial tyre failure mode, which in fact covers a wider region of vulnerability. The evidence related to bias tyre failure was more limited.

The database of incidents available to the Working Group records only one instance of an Airbus (A320) retracted tyre failure, in 1997, so it could be argued that the Airbus model has not been tested at all.

38. **Recommendation for future rulemaking activity**

A) Installation of a TPMS

The main contributor of tyre failure events is the low pressure condition. The excessive pressure condition is also a contributor though it happens less frequently. Requiring the installation of a tyre pressure monitoring system (TPMS) has the potential to provide a significant safety improvement and should therefore be considered in the next rulemaking actions. This would further protect the aeroplane by decreasing its exposition to the tyre burst threat caused by out-of-range tyre pressure.

The same conclusion was reached in the frame of an SAE review of events in 2007. An SAE group (SAE committee A-5, Aerospace Landing Gear Systems) conducted a review of damaging effects of tyre and wheel failures, and they issued the information report AIR5699[5] (issued 2007-11). The report provides an in-service operational data analysis based on databases from the NTSB and from major aircraft manufacturers, over approximately 40 years (up to 2005). It is confirmed that tyre pressure related events are preponderant, representing about 65 % of all data events. This group assessed how regulation changes or industry practices would mitigate any of the events. The outcome is that the most promising future action would be the implementation of a TPMS.

Finally, several safety recommendations have been issued by accident investigation bodies (NTSB, AAIB UK) in this domain, inviting aviation authorities to consider rulemaking actions for mandating the installation of TPMS on transport aeroplanes.

B) Aircraft tyre TSO/ETSO improvement

The Working Group also discussed about other ways of improving safety at the level of tyre design. It was recognised that various aeroplane manufacturers have already implemented tyre technical specifications in excess of the standards required by the ETSO/TSO C-62e specifications. These measures, taking into account service experience of tyre failures, contribute to the existing level of safety on in-service aeroplanes. Therefore, it would be reasonable to incorporate them in the ETSO/TSO specifications, and the following improvements are recommended:

— Events showed that failure of one tyre on a landing gear sometime propagates to companion tyre on the same gear due to overload. It is therefore recommended to revise the ETSO/TSO to require analysis and/or test of a such overload cases to increase robustness of the tyre in such situation (this analysis is also being developed through industry standard, for instance see SAE ARP6152).

— Many events have been created by FOD of the tyre; such events include the fatal Concorde accident in 2000). Therefore, a FOD test should be added to the ETSO/TSO to demonstrate tyre non-failure during take-off after rolling on a foreign object (for instance metallic blade, other puncture mechanisms).

— A skid through test. A SAE group has started investigations into a possible test. This would provide requirements to improve tyre robustness against brake/wheel blockage at landing.

Finally, it was reminded that the specifications of ETSO/TSO C-62e applies only to brand new tyres and there is no demonstration made today that re-tread tyres would perform like brand new tyres. Therefore it is recommended to consider rulemaking action with the aim to ensure that re-tread tyres are qualified so that they provide the same safety level compared to a brand new tyre.

VIII. Runway debris

39. References

The main useful information gathered and reviewed by the Working Group were found through the feedback received from large aeroplane manufacturers, and from other available reports that are referred below.

1. 'Improved Aircraft Tire and Stone Models for Runway Debris Lofting Simulations', Sang N. Nguyen, Emile S. Greenhalgh, Robin Olsson and Lorenzo Iannucci, Department of Aeronautics, Imperial College, London, and Paul T. Curtis, Physical Sciences Department, Dstl Porton Down, Salisbury, Wiltshire (UK) — paper presented in 2009 (AIAA conference).

[5] SAE AIR5699 document ('A Guide for the Damaging Effects of Tire and Wheel Failures') available on the SAE website at: http://standards.sae.org/air5699/.

2. EASA internal report 'Foreign object damage/excluding tyre failures, Fixed wing aircraft over 5700 kg MTOM', dated 24 September 2008. Extract from the ICAO ADREP data base, for all occurrences in which there was an event related to foreign object damage but no tire failure.

3. In-service events data from Large Aeroplane manufacturer B.

4. In-service events data from Large Aeroplane manufacturer C.

5. In-service events data from Large Aeroplane manufacturer D.

6. In-service events data from Large Aeroplane manufacturer F.

7. Presentation 'SRG FOD Collection Project' from CAA UK (S. James, JAA D&F Study Group), October 2003 .

8. Presentation from Boeing to the Working Group dated 8 June 2010, B767 FOD study (2000-2002) (283 aeroplanes surveyed from 5 airlines — 46 FOD events).

9. ATR72-212A FOD Damage during Power Assurance check (Airworthiness Review Sheet TI: 113/2010 — event dated 30 June 2010).

10. 'Characterisation of the realistic impact threat from runway debris', QinetiQ/University College London. Published in The Aeronautical Journal, October 2001.

40. **Research on debris lofting**

The study made within Ref. 1 has been reviewed. The aim of this study was to develop accurate models to understand and predict the stone lofting processes.

The main conclusion from this report is that:

— The simulations predicted vertical speeds no greater than 5 m/s for all types of stones. The implication was that only leading edge strikes were considered as viable causes of damage, and horizontally-oriented structures could only receive highly oblique impacts during the rotation phase of take-off and at touchdown.

— Lofting to high vertical speeds is a rare event.

41. **Analysis of in-service events**

In-service events have been analysed from available data within Ref. 2 to 6, 8 and 9.

A total of 150 events related with FOD events have been screened, and a summary table has been produced in order to identify relevant events.

Each event was then categorised into several categories (engine ingested, engine plume projected, tyre projected and other FOD)

<u>Assumptions</u>

As the definition and scope of runway debris or objects is subjective, the Working Group had to consider some assumptions when reviewing the in-service events in order to only retain the cases related to runway debris impacting the airframe or the aircraft systems.

<u>Events that have NOT been retained</u>

— Events leading to tyre bursts, as they are analysed under the Tyre and Wheel debris activity,

— Events originated from engine UERF, as they are analysed under the small engine debris activity,

— All impacts with wildlife (birds and other animals). An occurrence of impact with a deer has been noticed. However, it is not judged reasonable, nor practical to design aircraft structure against this threat,

- Impact/collision with ground vehicles or ground equipment (de-icing tools, trucks, etc.),
- Damages during maintenance (tools drops, etc.),
- Impact/collision with other aircraft,
- Impact/collisions outside the runway (such as end of runway lights), except if originally caused by runway debris impact,
- Hailstones damages in flight or on ground,
- Other 'Natural' threats encountered in flight (e.g. volcanic ashes),
- Damages due to foreign objects left on the aeroplane during maintenance,
- Parts lost from the same aeroplane, then impacting other structures/systems (not part of this group anyway), and
- Operation on unpaved runways (outside ICAO airports).

Events that have been retained

- Debris projected by the tyres,
- FOD projected by other aircraft in front,
- Debris projected by engine plume,
- Debris projected by propeller blades, and
- Other FOD from unknown origin that impacted the Airframe of Aircraft systems.

42. **Runway FOD characterization**

The review of the retained events revealed the following characteristics:

- Most FOD events impacted and potentially created damages to tyres or engines. The threat coming from subsequent tyre and engine debris are covered in dedicated activities and models. Therefore, they are not retained here (not part of Table 2 below). In the end, 40 events out of 150 have been retained as relevant for Runway Debris analysis. See table 1 below.
  - FOD did not cause any injuries.
  - Most of the events lead to minor aircraft damages.
  - FOD caused neither fuel leaks nor fires.
  - There is very limited data showing ejected foreign objects from tyre pinch (only two events have been identified as potentially created by such effect: a first event created small damages to lower wing trailing edge secondary structure panels, a second event created a 0.145 inch dent depth in fuselage lower skin in line with Nose Landing Gear).
  - There were significant damages from engine plume ejected debris (17 events out of 40).
  - Few occurrences of windshield cracking were caused by FOD. These may have been caused by plume projected debris from another aeroplane (three events).
  - In one event, fuselage damage was caused by stones projected by propeller blade.
  - The other occurrences covered: foreign objects damaging a Pitot probe, telephone wire, tow strap stuck in NLG, damage to lamps and covers.

Occurrence Number	Rationale	Date of event	Categorisation: Engine ingestion	Plume ejected debris	Tire projected	Other FOD
1	Windshield cracked due to FOD	28/04/1996	N	N	N	Y
2	Alphalt impacting the HTP	08/08/2001	N	Y	N	N
3	Alphalt impacting the HTP	24/08/2001	N	Y	N	N
4	FOD projected by propeller	31/08/2001	N	N	N	Y
5	Parts of runway (concrete) projected on rear fuselage	24/09/2001	N	Y	N	N
6	Alphalt impacting the HTP	08/06/2002	N	Y	N	N
7	Parts of runway projected on tail	09/10/2002	N	Y	N	N
8	Parts of runway projected on tail	18/05/2003	N	Y	N	N
9	Brake unit damage due to FOD	08/01/2003	N	N	N	Y
10	Parts of runway projected on Aircraft	27/09/2004	N	Y	N	N
11	HTP hit by debris of "ascon"	24/03/2005	N	Y	N	N
12	Parts of runway projected on tail	05/04/2005	N	Y	N	N
13	Damage to fuselage due to FOD	23/06/2005	N	N	N	Y
14	Part of runway impacted the tailplane	07/08/2005	N	Y	N	N
15	Plate 25 x 60 inches impacted the HTP	06/08/2006	N	Y	N	N
16	Landing on gravel-surfaced runway	06/08/2008	N	N	N	Y
17	part of runway projected on tailplane	07/02/1991	N	Y	N	N
18	part of runway projected on tailplane	25/07/1995	N	Y	N	N
19	part of runway projected on tailplane	20/05/1998	N	Y	N	N
20	FOD (telephone impacted the fuselage)	17/12/2002	N	N	N	Y
21	part of runway projected on tailplane	14/06/2005	N	Y	N	N
22	FOD from another A/C impacting Tailplane	22/11/2006	N	Y	N	N
23	FOD damaging windshield (14 planes)	16/02/2007	N	N	N	Y
24	part of runway projected on tailplane	17/05/2009	N	Y	N	N
25	Taxi/Takeoff light lamp cracking (FOD suspected)	06/05/2005	N	N	N	Y
26	Taxi&Takeoff Light Lamp	16/03/2008	N	N	N	Y
27	anti-collision light lens damaged	10/07/2009	N	N	N	Y
28	FOD that damaged a door seal	03/01/1995	N	N	N	Y
29	FOD damaged hydraulic brakes	26/02/1998	N	N	N	Y
30	Windshield cracked due to FOD	07/10/2007	N	N	N	Y
31	Wing TE panel damaged by FOD	approx dec-2007	N	N	Y	N
32	Fod into the pitot tube	07/03/2001	N	N	N	Y
33	Tow strap stuck in NLG	24/01/2008	N	N	N	Y
34	Tow strap stuck in NLG	26/01/2008	N	N	N	Y
35	Flap track fairing damage	29/07/2004	N	N	N	Y
36	Damage to T/R cascade	16/03/2009	Y	N	N	Y
37	FoD impact on Radome	08/04/2000	N	N	N	Y
38	dent on S41 bottom skin in line with LH nose LG door	19/08/2002	N	N	Y	N
39	Sheet metal torn in S46 RH	15/07/2000	N	N	N	Y
40	Fuselage perforated by stone protected by propeller blade	30/06/2010	N	N	N	Y

Table 1 : Retained events

43. **Discussion**

Foreign objects ejected by the tyres: It appears that runway foreign objects ejected from tyres are very rare events. The review of in-service experience indeed confirms the conclusion from Ref. 1 research study. Only two potential occurrences have been identified and the corresponding reports provide very little details. The consequence on the airframe or aircraft systems is judged to be minor. Based on this, it is proposed not to characterise this threat.

Foreign objects impacting Pitot probes: These events are considered minor as only one probe was lost.

Foreign objects impacting the aircraft (excluding plume projected debris): Only minor damage to the airframe or aircraft systems has been identified.

The design of the aeroplane based on existing rules (e.g. CS/FAR 25.571 Damage-tolerance and fatigue evaluation of structure, 25.631 Bird strike damage, 25.1309 Equipment, systems and installations) appears to provide an adequate level of protection against impact from this type of runway debris.

Additionally separation of aircraft during taxi, take-off and landing phases also helps preventing foreign object projections from other aircraft in front.

Engine plume projected debris, or propeller blade projected debris:

Several events have created significant damage to the aeroplane aft fuselage or horizontal tail plane, although no damage to essential systems has been reported.

Most of these events have not a clear reporting of the debris size.

The most severe damage found is the event faced by Airbus A320 F-GFKI on 7 February 1997 when taking off from Nîmes-Garons airport, France (see BEA report f-ki910207). During this event very large asphalt parts of the runway were detached and projected by the engine plume effect and impacted the horizontal tail plane (see Table 2 below).

Type	Weight (kg)	Shape/Size	Speed at impact Vx (m/s)	Speed at impact Vz (m/s)	Projection distance	Speed of debris impacting the HTP
A	50	Flat 80 cm × 70 cm Thickness 7 cm	14.6 12.5 11.2 10.2	8.3 11.1 13.5 15.6	25 m	17 m/s
B	10	Flat 33 cm × 33 cm Thickness 7 cm	14.6 12.5 11.2 10.2	8.3 11.1 13.5 15.6	50 m	27 m/s
C	1	Flat 10 cm × 11 cm Thickness 7 cm	14.8 12.6 11.2 10.3	8.5 11.2 13.6 15.7	100 m	43 m/s
D	0.10	Spherical Diameter 5 cm	15.0 12.7 11.3 10.4 9.4	8.7 11.8 14.0 16.2 17.4	200 m	65 m/s

Table 2: Debris ballistic analysis from BEA report f-ki910207

It is not considered reasonable, nor practical, to design an aeroplane capable to sustain impacts from debris such as above Type A (50 kg) or type B (10 kg) projected by the engine plume. This type of debris should be more appropriately addressed by airport design and maintenance standards.

Moreover, according to a CAA UK runway debris collection study (Ref. 7), the maximum size of debris found on runway was a 734 grams lamp.

Other events have shown that smaller parts could also be projected to the aeroplane tail or aft fuselage (typically less than 1 lb), but these events typically created minor damage.

An assessment of the level of protection provided when designing a tail plane to the 8 lb bird strike FAR 25.631 specification has been conducted (note: the equivalent CS 25.631 specification uses a 4 lbs bird).

Two areas have been assessed:

- <u>Leading edges</u>

  The level of leading edge resistance to runway debris impact cannot only be based on the comparison of impact energies relative to bird strike.

  During the impact, a bird has a behaviour that is close to a viscous fluid; on the contrary, runway debris have a higher density and strength leading to a larger penetration capability for the same impact energy.

  The horizontal tail plane (HTP) leading edge is designed to sustain an 8 lb bird impact at Vc speed (impact energy is about 55500 J assuming Vc = 340 knots). To sustain such impact, an Aluminium leading edge would require a typical thickness that range from 3.0 mm to 4.2 mm depending of the curvature (about 5.7 mm for CFRP).

  In addition, to prevent damages from bird strike, essential systems are usually segregated or located in bird strike protected areas thus providing inherent tolerance against FOD.

  Some tests have been performed for the purpose of hard debris resistance characterization within the frame of aircraft program currently in development: 1.1 inch steel cubes have been used. Flat, edge or corner impacts have been tested. The typical density of runway debris from Ref. 1 report being 2.7, these impact tests can be considered as a conservative representation of a runway debris impact.

  From the tests above, a 4.0 mm aluminium flat plate (representative of a typical HTP leading edge) can sustain the impact from a 1.1 inch steel cube impacting at 90° (normal impact) up to a speed of 123 m/s, leading to an energy of 1322 J. A similar resistance has been found with CFRP material (6 mm CFRP plate can sustain a 1.1 inch steel cube impacting at 90° up to a speed of 109 m/s, leading to an energy of 1038 J).

  By comparison, the impact energy from similar debris in size and mass from Table 2 (type D debris) is 211 Joules.

  Based on this comparison, it can be concluded that when designed to sustain an 8 lb bird impact at Vc speed, a leading edge has an inherent capability to sustain reasonable runway debris size impacts without significant damage.

- <u>Horizontal Tail Plane lower panels</u>

  Runway debris impact on HTP lower panels could lead to oblique impact at angle that could be larger than oblique bird strikes (which are closer to glancing impacts).

  From BEA report f-ki910207, the impact angle on lower panel can be estimated at about 37 degrees (debris lifted from 8 m ahead of HTP up to 4.8 m high).

  A concern raised with the HTP lower skin is the possibility to create fuel leakages.

Current practice is to design composite fuel tanks covers with a minimum thickness, this minimum thickness (typically 3 mm) being required to meet other requirements such as lightning strike or damage tolerance.

Several sets of tests have been performed for characterization of CFRP impact resistance:

Hard debris resistance characterization: 1.1 inch steel cubes have been used. Flat, edge or corner impacts have been tested on flat CFRP panels with various impact angles. From these tests results, it can be shown that a CFRP panel of 4.6 mm thick can resist to 1.1" steel cubes at 182 m/s impact for 11 degrees angle (2895 J)

When extrapolating these results to the estimated obliquity angle from report f-ki910207 (37 degrees), an energy of about 600 J would be required to reach perforation of a typical HTP lower panel (CFRP 3 mm thick).

Based on this comparison, it can be shown that typical HTP lower panels should be capable to sustain reasonable runway debris sizes without perforation, when taking into account a typical impact obliquity angle.

44. **Damage tolerance considerations**

Although most of the impacts from runway debris create visible damage indications such as dents, scratches, holes or marks, the theoretical possibility of small/soft debris that could create undetected damage has been discussed by the Working Group.

For metallic structures, hidden damage resulting from a runway debris impact may lead to crack initiation and possibly propagation. Thanks to design compliant with CS/FAR 25.571, these cracks will be detected within the normal maintenance activity before they could become critical.

For composite structures, general damage tolerance approach includes the assessment of the effects of impact damage. Guidance material is available on these matters.

According to EASA AMC 20-29, harmonised with FAA AC20-107B (Composite Aircraft Structure), paragraph 7.f: 'It should be shown that impact damage that can be likely expected from manufacturing and service, but not more than the established threshold of detectability for the selected inspection procedure, will not reduce the structural strength below ultimate load capability.'

The CMH-17 (Composite Material Handbook[6]) proposes to represent runway debris by Visible Impact Damages (VIDs). These VIDs could be created using a 1.0 inch hemispherical impactor and energies up to 136 J or up to energy required to create a visible dent (2.5 mm deep).

Therefore, it was concluded that actual available Damage Tolerance rules or guidance material, applicable to either metallic or composite structures, are adequately addressing potential impacts from runway debris.

45. **Runway debris — conclusion and recommendation**

Based on the discussions above, summarised below, it is not recommended to characterise the runway debris threat.

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[6] The Composite Materials Handbook (CMH) provides information and guidance necessary to design and fabricate end items from composite materials. Its primary purpose is the standardization of engineering data development methodologies related to testing, data reduction, and data reporting of property data for current and emerging composite materials. In support of this objective, the handbook includes composite materials properties that meet specific data requirements. The CMH is a volunteer organization consisting of participants from industry, government, and academia. More information available at: http://www.cmh17.org.

Indeed, tyre projected FOD are very rare events and their impact on the airframe or aircraft systems have been minor. The aeroplane is protected against tyre, wheel and engine debris which indirectly provides robustness and protection against runway debris impacts.

Propulsion engine plume projected debris are mainly impacting the horizontal tail plane leading edge. The level of protection provided by typical tail plane leading edge sizing, in particular thanks to the 8 lb bird strike requirement from FAR 25.631 is found to be adequate to cover most of events involving reasonable runway debris sizes (typically up to 1 lb).

Propulsion engine plume projected debris could also impact the tail plane lower skin. It has been shown that taking into account the oblique impact angle, a typical lower skin thickness would be capable to sustain reasonable runway debris sizes without perforation.

Other FOD impacts have minor effects on the structure and/or systems.

Damage Tolerance rules and guidance material applicable to either metallic or composite structures are adequately covering potential impacts from runway debris. This coverage is provided by CS 25.571 and its AMC and for composite structures there is the additional guidance of AMC 20-29/AC 20-107B explicitly identifying runway debris threat which is addressed into more details in CMH-17.

It is recommended to improve airports FOD prevention to complement the current dispositions of ICAO Annex 14, so as to ensure that large debris on the runway will be detected before they create severe damage to the aircraft.

IX. Regulatory Impact Assessment

1. Process and consultation

This RIA was developed by the Agency and is a 'light RIA' as no significant economic impact has been envisaged by the Working Group. The Working Group included experts representing large aeroplane manufacturers (Airbus, Boeing), engine manufacturers (Rolls-Royce), and aviation authorities (EASA, ENAC-Italy, FAA, TCCA).

2. Issue analysis and risk assessment

2.1. Issue which the NPA is intended to address and sectors concerned.

Aeroplanes are subject to damage by various objects or debris impacts while in service.

Among this variety of debris and objects encountered, debris originating from tyre/wheel failure, engine failure (small fragments) and runway debris (including foreign objects) are of particular concern, and form the focus of this rulemaking task.

These kinds of threats are already addressed in CS-25 (mainly through CS 25.729(f); CS 25.903(d); CS 25.963(e); and CS 25.1309). However, service experience has shown that these provisions need to be improved and a standardised certification approach developed to ensure that the relevant CS-25 paragraphs are addressed consistently. Some threat models have been developed over the years by manufacturers and aviation authorities but are not fully reflected in CS-25 (i.e. tyre and wheel failure).

2.2. What are the risks (probability and severity)?

In the absence of available standardised threat model and guidance material, the certification projects may use different models to show compliance with the rules.

This leads to variable levels of protection from one project to another as the identification of the involved threats and the way to manage them will differ.

Furthermore, the introduction of new composite materials or technologies should be performed ensuring at least the same level of safety as the one present on equivalent previous designs (metallic aeroplane).

3. Objectives

Upgrading CS-25 by modifying existing paragraphs and AMCs, and/or introducing new paragraph(s) and AMC(s), in order to cover the protection of the whole aeroplane against tyre/wheel failure debris, engine debris (small fragments), other likely debris (runway debris including foreign objects) and subsequent threats.

As today various models are used for different paragraphs, the goal of this NPA is to rationalise the current regulatory material by developing a model for each type of threat which will be applicable to the whole aeroplane. Experience from previous certification projects and in-service events should also be reflected.

Finally, another objective is to harmonise the EASA regulatory material with other foreign aviation authorities such as FAA and TCCA.

4. Options identified

Option 1: Do nothing.

CS-25 would not be amended and aviation authorities would continue investigating each project (CRI process by EASA) on a case by case basis.

Option 2: Amend CS-25

Review existing threat models, outcome of studies, in-service occurrences and use this information to amend CS-25. Amend the rules and the acceptable means of compliance to provide applicants with a standardised means to assess the threats coming from tyre and wheel failure debris, small engine fragments and other foreign objects/debris projected on the runway.

5. Analysis of the impacts

5.1. Safety impacts

Option 1 would be theoretically neutral. An eventual safety improvement would depend on applicants taking the initiative to improve their design and certification practices based on available knowledge or experiences. The Agency would support the applicant and raise special conditions when unsafe conditions were identified on existing designs or if a new design presents more vulnerabilities. But there is no guarantee that this would happen.

Option 2 would provide a safety benefit. The best available knowledge on the involved threats and experience from in-service occurrences would be reflected in CS-25. Some incidents or accidents may be prevented in the future. The upgraded threat models and guidance material would be available to all applicants and it is expected that this would become a standard. Consequently, a harmonised higher level of safety is expected on new projects.

5.2. Social impacts

No impacts for both options.

5.3. Economic impacts

Option 1 is neutral.

Option 2 would save certification costs for both large aeroplane manufacturers and the Agency. By providing standardised means of compliance in CS-25, the Agency would give the applicants a better certainty of what is an acceptable way to comply with the rules. This would decrease the discussions and exchanges between the Agency and the applicants (e.g. CRI items). The proposed new rule would not introduce requirements that would increase the cost of design or production of new aeroplanes. Finally, the prevented incidents or accidents mentioned in 5.1 would also save the costs induced by serious incidents or accidents investigations, fatalities and injuries.

5.4. Environmental impacts

No impacts for both options.

5.5. Proportionality issues

No impacts for both options.

5.6. Impact on regulatory coordination and harmonisation

The Working Group included representatives from FAA and TCCA. No dissenting opinion has been recorded from both authorities during the NPA drafting process. Therefore it is expected that FAA and TCCA would harmonise their regulatory materials with EASA in the future.

6. Conclusion and preferred option

The Working Group reviewed all available information from existing certification practices, studies and known in-service occurrences. Recognizing that some differences exist among manufacturers practices, the Working Group had to make compromises to reach a proposal for amending CS-25 that is acceptable by everyone and that will contribute to improve the level of safety on future designs.

The proposal is considered balanced by the Agency and would meet the objective described above without creating unacceptable costs for applicants. An economic benefit is even anticipated from the simplification of the certification process.

Therefore Option 2 is the preferred option.

B. Draft Decision CS-25

The text of the amendment is arranged to show deleted text, new text or new paragraph as shown below:

1. deleted text is shown with a strike through: ~~deleted~~
2. new text is highlighted with grey shading: new
3. […] indicates that remaining text is unchanged in front of or following the reflected amendment.

BOOK 1

Delete CS 25.729(f) as follows:

CS 25.729 Retracting mechanism

[…]

~~(f) Protection of equipment on landing gear and in wheel wells. Equipment that is essential to the safe operation of the aeroplane and that is located on the landing gear and in wheel wells must be protected from the damaging effects of –~~

~~(1) A bursting tyre;~~

~~(2) A loose tyre tread unless it is shown that a loose tyre tread cannot cause damage; and~~

~~(3) Possible wheel brake temperatures.~~

Create a new CS 25.734 as follows:

CS 25.734 Protection against wheel and tyre failures

(see AMC 25.734)

The aeroplane must be protected from the damaging effects of:

- tyre debris;
- tyre burst pressure effect;
- flailing tyre strip;
- wheel flange debris.

Create a new CS 25.735(l) as follows:

CS 25.735 Brakes and braking systems

(See AMC 25.735)

[…]

(l) *Wheel brake temperature*. Equipment and structure that are essential to the safe operation of the aeroplane and that are located on the landing gear and in wheel wells must be protected from the damaging effects of possible wheel brake temperatures.

Amend CS 25.963(e) as follows:

CS 25.963 Fuel tanks: general

(e) Fuel tanks ~~access covers~~ must comply with the following criteria in order to avoid ~~loss of~~ hazardous ~~quantities of~~ fuel leak:

(1) ~~All covers~~ Fuel tanks located in an area where experience or analysis indicates a strike is likely, must be shown by analysis supported by test or test~~s~~ to minimise penetration and deformation by tyre and wheel fragments, ~~low energy~~ small engine and APU debris, or other likely debris (such as runway debris).

(2) All fuel tank access covers must have the capacity to withstand the heat associated with fire at least as well as an access cover made from aluminium alloy in dimensions appropriate for the purpose for which they are to be used, except that the access covers need not be more resistant to fire than an access cover made from the base fuel tank structural material.

(See AMC 25.963(e).)

BOOK 2

Delete paragraph 4.d of AMC 25.729 as follows:

AMC 25.729

Retracting Mechanism

[…]

4. DISCUSSION.

[…]

~~d. *Protection of equipment on landing gear and in wheel wells.* (Reference CS 25.729(f) Protection of equipment on landing gear and in wheel wells)~~

~~The use of fusible plugs in the wheels is not a complete safeguard against damage due to tyre explosion.~~

~~Where brake overheating could be damaging to the structure of, or equipment in, the wheel wells, an indication of brake temperature should be provided to warn the pilot.~~

de. *Definitions*. For definitions of V_{SR} and V_C, see CS-Definitions 2, titled Abbreviations and symbols.

Create a new AMC 25.734 as follows:

AMC 25.734

Protection against wheel and tyre failures

1. Purpose

This AMC provides a set of models defining the threats originating from failures of tyres and wheels. Furthermore, protecting the aircraft against the threats defined in this model would also protect against threats originating from foreign objects projected from the runway.

2. Related Certification Specifications

CS 25.571 Damage tolerance and fatigue evaluation of structure

CS 25.734 Protection against wheel and tyre failures

CS 25.963(e) Fuel tanks: general

CS 25.1309 Equipment, systems and installations

AMC 20-29 Composite Aircraft Structure

3. General

The models provided below encompass the threats applicable to landing gear in the extended, retracting and retracted positions. The corresponding threats are tyre debris, flailing tyre strips, tyre burst pressure effect and wheel flange debris.

With the landing gear in the extended position, the following models are applicable:

Model 1 — Tyre Debris Threat Model

Model 3a — Flailing Tyre Strip Threat Model

Model 4 — Wheel Flange Debris Threat Model

With the landing gear retracting or in the retracted position, the following models are applicable:

Model 2 — Tyre Burst Pressure Effect Threat Model

Model 3b — Flailing Tyre Strip Threat Model

Note: In addition to the pass-fail criteria identified in the following sections, these threat models need to be addressed in accordance with CS 25.571 and AMC 20-29.

Definitions

Carcass of a tyre: this comprises the entire main body of a tyre (also named the casing) including the materials under the tread, the sidewall, and steel belts if any.

Full tread: the thickness of the complete tread of rubber on a new tyre.

Terms used in accordance with the Tire and Rim Association (TRA) aircraft yearbook[7]:

- D = Tire and Rim Association (TRA) Rim Diameter
- D_G = TRA Grown Tyre Diameter
- W_{SG} = TRA Maximum Grown Shoulder Width

Tyre speed rating: the maximum ground speed at which the tyre has been tested in accordance with (E)TSO C62e.

4. Threat models

Model 1 — Tyre Debris Threat Model

Threats occurring when the tyre is in contact with the ground release tyre debris.

Two tyre debris sizes are considered.

These debris are assumed to be released from the tread area of the tyre and projected towards the aircraft within the zones of vulnerability identified in figure 1:

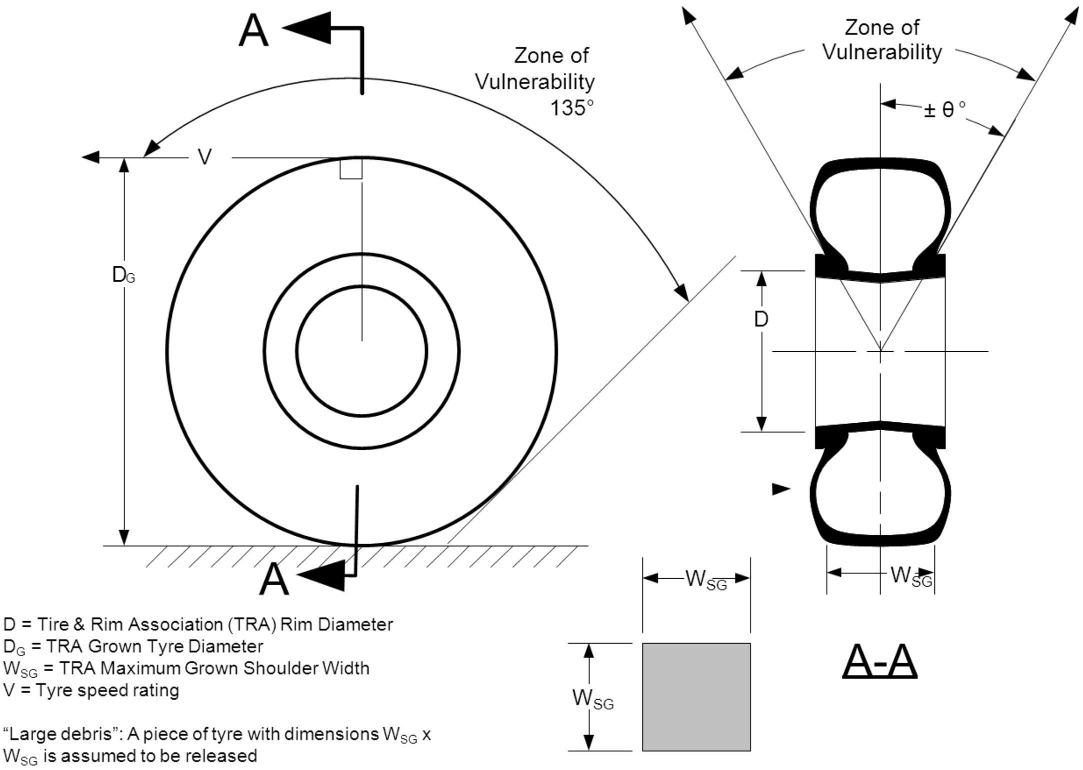
(i) a 'large debris' with dimensions $W_{SG} \times W_{SG}$ and a thickness of the full tread plus outermost ply (i.e. the re-enforcement or protector ply). The angle of vulnerability θ is 15°.

(ii) a 'small debris' consisting of 1 per cent of the total tyre mass, with an impact load distributed over an area equal to 1.5 per cent of the total tread area. The angle of vulnerability θ is 30°.

The debris have a speed equivalent to the minimum tyre speed rating certified for the aircraft (the additional velocity component due to the release of carcass pressure need not be taken into account).

[7] The Tire and Rim Association, Inc. (TRA) is the standardizing body for the tire, rim, valve and allied parts industry for the United States. TRA was founded in 1903 and its primary purpose is to establish and promulgate interchangeability standards for tires, rims, valves and allied parts. TRA standards are published in the Tire and Rim Year Book, Aircraft Year Book and supplemental publications. More information available at: http://www.us-tra.org/index.html.

Figure 1 – Tyre Debris Threats



Protection of the structure and pass-fail criteria on effects of penetration

1) The large tyre debris size as defined in (i) above is assumed to penetrate and open the fuel tank or fuel system structure located in the zone of vulnerability defined in (i). It is used to define the opening size of the structural damage. A fuel leakage is assumed to occur whenever either the fuel tank structure or any structural element of fuel system components is struck by this large debris or when fuel tank deformation or rupture has been induced (for example, through propagation of pressure waves or cracking sufficient to allow a hazardous fuel leak). It need not be used as a sizing case for structural design.

The fuel leakage should not result in:

a) hazardous quantities of fuel entering the following areas of the aeroplane:

1. an engine air intake,
2. an APU air intake, or
3. a cabin air intake;

b) fuel coming into contact with an ignition source.

This should be shown by test or analysis, or a combination of both, for each engine forward thrust condition and each approved reverse thrust condition.

Alternatively, it is acceptable to demonstrate that the large tyre debris as defined in (i) above will not cause damage sufficient to allow a hazardous fuel leak.

2) The small tyre debris as defined in (ii) should not create damage sufficient to allow a hazardous fuel leak in the zone of vulnerability defined in (ii).

A hazardous fuel leak results if debris impact to a fuel tank surface (or resulting pressure wave) causes:

a) a running leak,

b) a dripping leak, or

c) a leak that, 15 minutes after wiping dry, results in a wetted aeroplane surface exceeding 6 inches in length or diameter.

The leak should be evaluated under maximum fuel pressure (1 g on ground with full fuel volume, and also considering any applicable fuel tank pressurisation).

Protection of systems and pass-fail criteria

The two tyre debris sizes (defined in (i) and (ii) above) are considered. The sizes of debris are to be considered for the separation of systems.

When shielding is required (to protect a component or system), or when an energy analysis is required (for instance, for the validation of the structural parts of systems), the small debris defined in (ii) should be used.

An initial tyre failure can also result in failure of, and debris from, the companion tyre. This can occur even when the tyres have been designed to have double dynamic overload capability.

The analysis for the segregation of systems installation and routing should take this companion tyre failure into account inside the vulnerability zone defined by $\theta = 15°$ (either side of the tyre centreline) and only considering both tyres releasing large debris. Inside zones defined by $15° \leq \theta \leq 30°$, where only the small debris size is applicable, only debris (defined in (ii)) from a single tyre needs to be considered.

A 'companion' tyre is a tyre on the same axle.

To demonstrate compliance with applicable certification specifications, the following approach should be used:

1) Identify all hazards associated with the possible impact areas defined by the figure 1-tyre failures, including the simultaneous/cascade failure of companion tyres.

2) All practicable design precautions should be taken to eliminate all Catastrophic failure situations by means of system separation and/or impact resistant shielding and/or re-design. Impact resistance should be assessed for small debris (type (ii)) impacts only. Consideration should also be given to Hazardous failure situations when showing compliance in accordance with CS 25.1309.

3) Any Catastrophic failure situation that remains after accomplishment of step 2 above will be submitted to the Agency for consideration in accordance with step 4.

4) If the Agency concludes that the applicant has taken all practicable precautions to prevent a Catastrophic failure situation and the probability of the occurrence is consistent with the hazard classification (assuming a probability of companion tyre failure, if applicable, equal to 10 per cent), the design would be considered as compliant with the intent of CS 25.734.

Model 2 — Tyre Burst Pressure Effect Threat Model

In-flight tyre bursts with the landing gear retracted are considered to result from previous damage to the tyre, which could occur at any point on the exposed surface. A review of the known incidents shows that all cases of retracted tyre burst have occurred to main gear with braked wheels. This hazard is therefore considered to be applicable only to tyres mounted on braked wheels.

It is assumed that tyres do not release debris and consequential damage is considered to be caused only from the pressure effects of resulting gas jet ('Blast Effect'). The blast effect has been shown to differ between radial and bias tyres.

The tyre burst pressure is assumed to be 125 % of the maximum unloaded rated tyre pressure.

For bias tyres, the burst plume model shown in figures 2a and 2b should be used, with the blast cone axis rotated over the tread surface of the tyre (± 100° as shown on Figure 2a). The pressure distribution is provided in Figure 2b and 2c.

For radial tyres, the burst plume model ('wedge' shape) is shown in figures 2d and 2e. The pressure decay formula provided in Figure 2e below should be used. It provides the level of pressure as a function of the distance from the tyre burst surface.

The effect of the burst should be evaluated on structure and system items located inside the defined burst plume. In addition, there should be no effect detrimental to continued safe flight and landing due to the increase in pressure of the wheel well as a result of a retracted tyre burst.

Figure 2a – Tyre Burst Pressure Effect – Bias Tyre

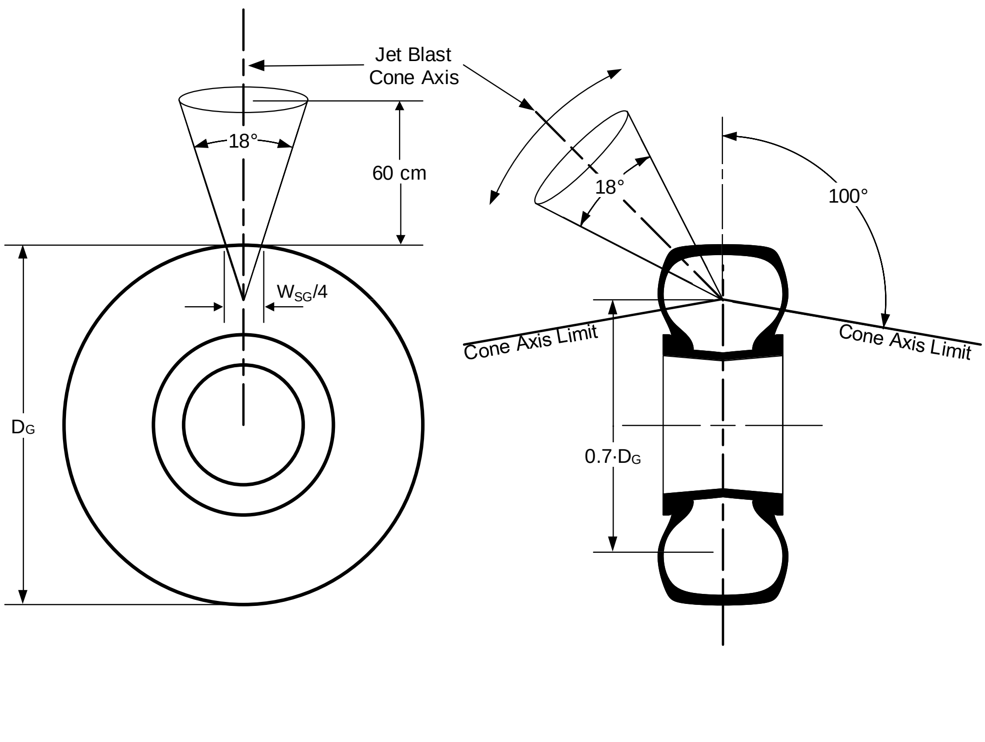


Figure 2b – Tyre Burst Pressure Effect – Bias Tyre

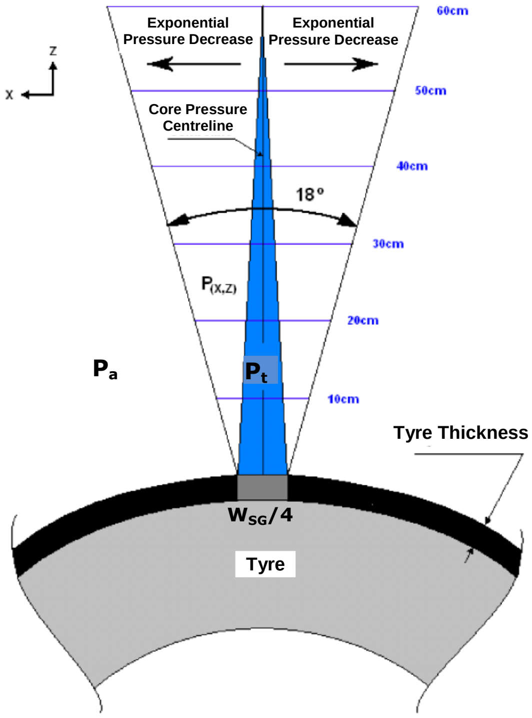
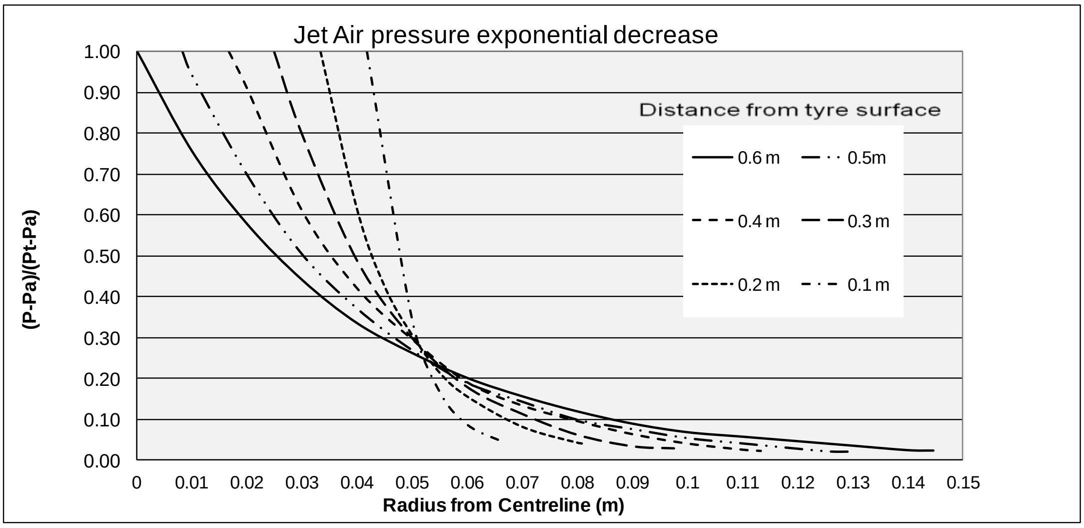


Figure 2c – Tyre Burst Pressure Effect – Bias Tyre
Air jet pressure distribution



Pa= Ambient pressure
P= P(x,z)= Pressure inside the cone as shown on Figure 2b
Pt= Tyre Burst pressure

Figure 2d – Tyre Burst Pressure Effect – Radial Tyre

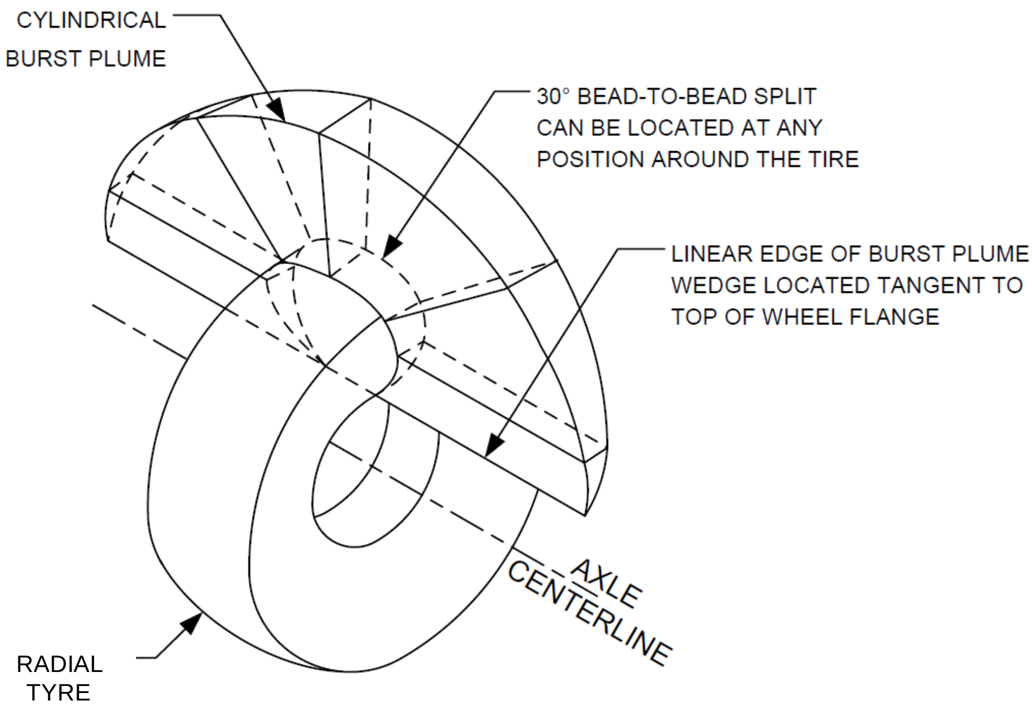
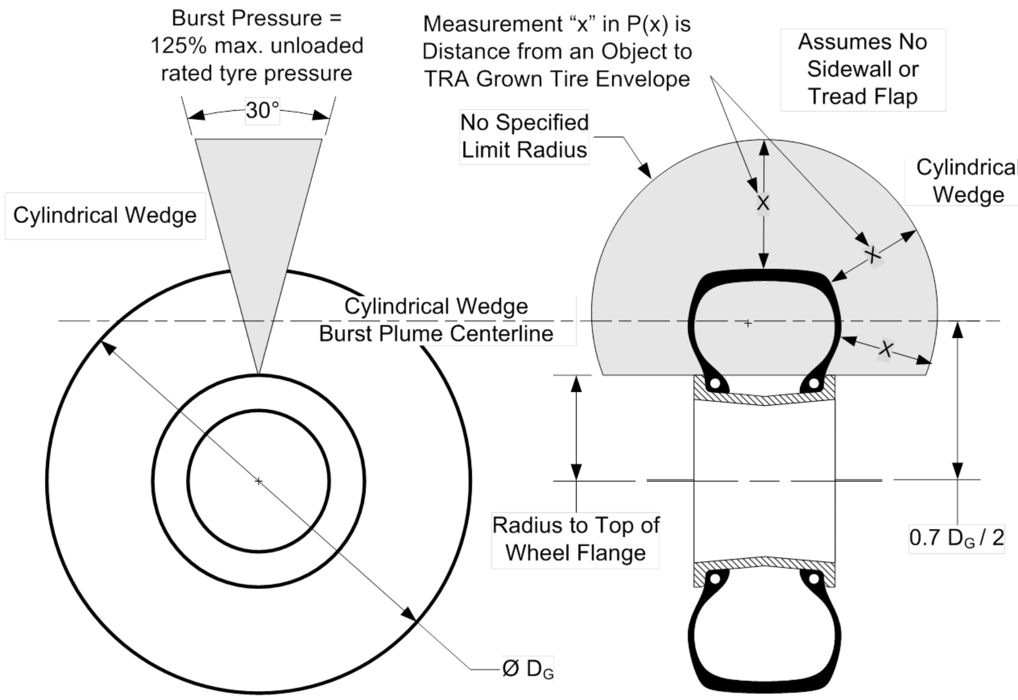


Figure 2e – Tyre Burst Pressure Effect – Radial Tyre



Radial Tyre Burst Pressure Decay Formula

$$P(x) = 0.5283 \cdot (P_t - P_0)\left[1.4 \cdot e^{-\left(\frac{\psi}{3}\right)\cdot x} + e^{-\psi \cdot x}\right] + P_0$$

Where:

$$\psi.x = \left(\frac{C_1}{\left(\frac{W_G}{in.}\right)^{C_2}} + C_3\right).\frac{x}{in.}$$

Or:

$$\psi.x = \left(\frac{C_1}{\left(\frac{W_G}{25.4mm}\right)^{C_2}} + C_3\right).\frac{x}{25.4mm}$$

and:

C_1 = 12.478,

C_2 = 1.222,

C_3 = 0.024

W_G = the Maximum Grown Section Width of the tyre[in or mm] as specified in the Tyre& Rim Association (TRA) designation for the tyre

P_t = Total or burst pressure[psia or bar]

P_0 = Ambient pressure[psia or bar]

x = Distance from object to grown tyresurface [in or mm]

Model 3 — Flailing Tyre Strip Threat Model

a) Landing Gear Extended

A flailing tyre strip with a length of 2.5 W_{SG} and a width of $W_{SG}/2$ will remain attached to the outside diameter of the rotating tyre at take-off speeds.

The thickness (t) of the loose strip of tyre is the full tread plus the carcass of the tyre. If the applicant demonstrates that the carcass will not fail, then the thickness may be reduced to full tread plus outermost ply (i.e. the re-enforcement or protector ply).

The strip has a speed equivalent to the minimum tyre speed rating certified for the aircraft. For this threat the zone of vulnerability shall be 30°, as shown in figure 3.

b) Landing Gear Retracting or Retracted

The loose tyre strip and the conditions remain unchanged from that considered for the Gear Extended case. However, due to the wheel spin down after take-off, the rotational speed of the wheel may be lower or even zero as it enters the wheel bay. If the aeroplane is equipped with a system braking the wheel during landing gear retraction ('retraction brake') then:

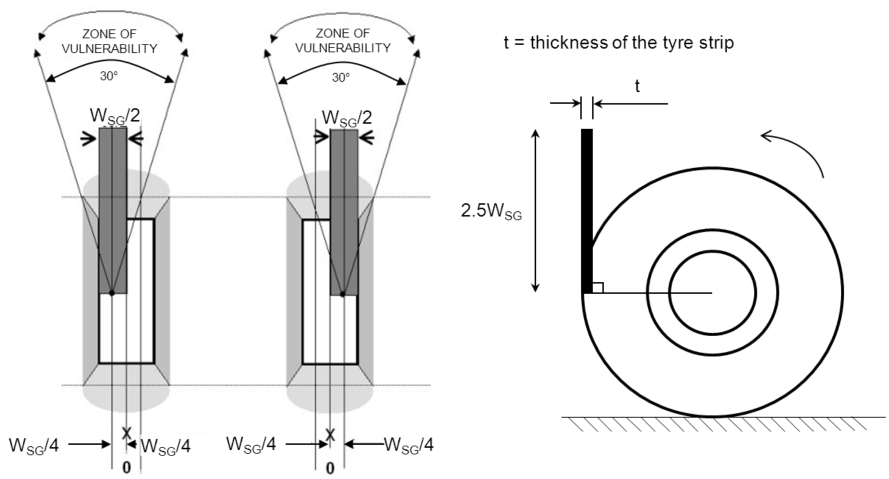
(i) the applicant may take credit from a retraction brake provided that the failure of the retraction brake is independent from a flailing tread event, and

(ii) the combination of flailing strip and loss of the retraction braking function shall be consistent with the hazard classification, and

(iii) the effect of a zero velocity retraction with the loose strip of tread is assessed.

The strip has an initial speed equivalent to the minimum tyre speed rating certified for the aircraft. Allowance for rotation speed reduction during retraction may be substantiated by the applicant. For this threat the zone of vulnerability shall be 30°, as shown in figure 3.

Figure 3 – Flailing Tyre Strip Threat



Model 4 — Wheel Flange Debris Threat model

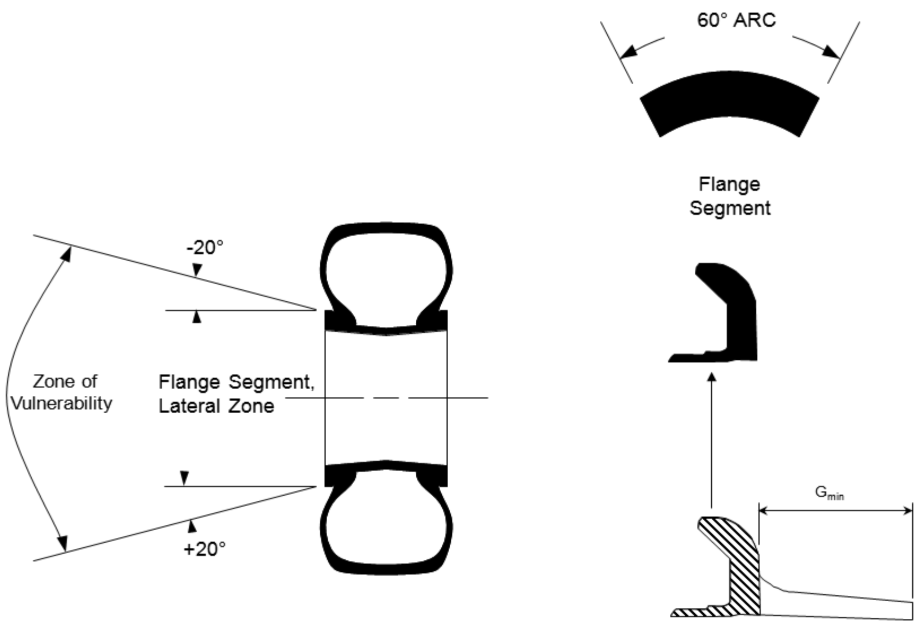
This failure case should only be considered when the landing gear is extended.

It is considered that a 60° arc segment of the wheel flange can be released laterally, in the zones identified in figure 4. The speed of release is 100 m/s.

Where multiple wheels are installed on a landing gear leg, the lateral release of only the flange on the outer wheel halves need be considered.

If only a single wheel is installed on a landing gear leg, then the lateral release of either flange shall be considered.

Figure 4 Wheel Flange Release Threat



Create a new paragraph 4.l. in AMC 25.735 as follows:

AMC 25.735

Brakes and Braking Systems Certification Tests and Analysis

[…]

4. DISCUSSION

[…]

l. Ref. CS 25.735(l) Wheel brake temperature.

The use of fusible plugs in the wheels is not a complete safeguard against damage due to tyre burst. Where brake overheating could be damaging to the structure of, or equipment in, the wheel wells, an indication of brake temperature should be provided to warn the pilot.

Amend AMC 25.963(e) as follows:

AMC 25.963(e)

Fuel Tank Protection ~~Access Covers~~

1. PURPOSE.

This AMC sets forth a means of compliance with the provisions of CS-25 dealing with the certification requirements for fuel tanks (including skin and fuel tank access covers) ~~access covers~~ on large aeroplanes. Guidance information is provided for showing compliance with the impact and fire resistance requirements of CS 25.963(e).

2. BACKGROUND.

Fuel tanks ~~access covers~~ have failed in service due to impact with high speed objects such as failed tyre tread material and engine debris following engine failures. Failure of ~~an access cover on~~ a fuel tank may result in ~~loss of~~ hazardous ~~quantities of~~ fuel ~~which could subsequently ignite~~ leak.

3. IMPACT RESISTANCE.

a. All fuel tanks ~~access covers~~ must be designed to minimise penetration and deformation by tyre fragments, wheel fragments, ~~low energy~~ small engine and APU debris, or other likely debris (such as runway debris), unless the ~~covers~~ fuel tanks are located in an area where service experience or analysis indicates a strike is not likely. The rule does not specify rigid standards for impact resistance because of the wide range of likely debris which could impact the ~~covers~~ fuel tanks. The applicant should, however, choose to minimise penetration and deformation by analysis supported by test or test of ~~covers~~ fuel tanks using debris of a type, size, trajectory and velocity that represents conditions anticipated in actual service for the aeroplane model involved. There should be no hazardous ~~quantity of~~ fuel leak~~age~~ after impact. ~~It may not be practical or even necessary to provide access covers with properties which are identical to those of the adjacent skin panels since the panels usually vary in thickness from station to station and may, at certain stations, have impact resistance in excess of that needed for any likely impact. The access covers, however, need not be more impact resistant than the average thickness of the adjacent tank structure at the same location, had it been designed without access covers. In the case of resistance to tyre debris, this comparison should be shown by tests or analysis supported by test.~~

b. ~~In the absence of a more rational method, t~~The following may be used for evaluating ~~access covers~~ fuel tanks for impact resistance to tyre, wheel, ~~and~~ engine and APU debris.

(i) Wheel and Tyre Debris ~~– Covers located within 30 degrees inboard and outboard of the tyre plane of rotation, measured from centre of tyre rotation with the gear in the down and locked position and the oleo strut in the nominal position, should be evaluated. The evaluation should be based on the results of impact tests using tyre tread segments equal to 1 percent of the tyre mass distributed over an impact area equal to 1.5 percent of the total tread area. The velocities used in the assessment should be based on the highest speed that the aircraft is likely to use on the ground under normal operation.~~

Fuel tanks must be protected against threats from wheel and tyre failures. Refer to AMC 25.734, which provides wheel and tyre failure threat models.

(ii) Engine Debris ~~– Covers located within 15 degrees forward of the front engine compressor or fan plane measured from the centre of rotation to 15 degrees aft of the rearmost engine turbine plane measured from the centre of rotation, should be evaluated for impact from small fragments. The evaluation should be made with energies referred to in AMC 20128A “Design Considerations for Minimising Hazards Caused by Uncontained Turbine Engine and Auxiliary Power Unit Rotor Failure”. The covers need not be designed to withstand impact from high energy engine fragments such as engine rotor segments or propeller fragments. In the absence of relevant data, an energy level corresponding to the impact of a 9·5 mm (3/8 inch) cube steel debris at 213·4 m/s (700 fps), 90 degrees to the impacted surface or area should be used. For clarification, engines as used in this~~

~~advisory material is intended to include engines used for thrust and engines used for auxiliary power (APU's).~~

The following provides the definition of a debris model to be used for protection of the fuel tanks against the threat of small engine debris (propulsion engines). It also describes how the debris model impacts a surface and a pass-fail criteria is provided.

This debris model is considered to be representative of the threat created by engine small non-rotating and rotating parts debris, including ricochets, occurring after an uncontained engine failure event. It is considered to address High Bypass Ratio and Low Bypass Ratio turbine engines.

Note 1: AMC 20-128A remains applicable for engine debris, other than small engine fragments, threatening fuel tanks as described here, and also remains applicable for all engine debris to other areas of the aircraft structures and systems.

Note 2: This threat needs to be addressed in accordance with CS 25.571 and AMC 20-29.

A. Definition of the debris

A solid steel cube with a 3/8 inch (9.5 mm) edge length.

B. Velocity of the debris

The velocity of the cube at the impact is 700 ft/sec (213.4 m/s).

C. Impact areas and pass-fail criteria

Two areas are to be considered. See also figure 1 below.

(1) ± 15 degrees area

Within 15 degrees forward of the front engine compressor or fan plane measured from the centre of rotation to 15 degrees aft of the rearmost engine turbine plane measured from the centre of rotation, a normal impact is used (i.e. the angle between the trajectory of the debris and the surface is 90 degrees).

The impact should not create a hazardous fuel leak.

A hazardous fuel leak results if the debris impact to a fuel tank surface causes:

— a running leak,

— a dripping leak, or

— a leak that, 15 minutes after wiping dry, results in a wetted aeroplane surface exceeding 6 inches in length or diameter.

The leak should be evaluated under maximum fuel pressure (1 g on ground with full fuel volume, and also considering any applicable fuel tank pressurisation).

(2) Area beyond the ± 15 degrees area

Beyond the ± 15 degrees area defined above, the angle of impact is defined by the trajectory of the debris originating from the centre of rotation of the front engine compressor or fan plane, and debris originating from the centre of rotation of the rearmost engine turbine plane.

Similarly, as within the ± 15 degrees area, the impact should not create a hazardous fuel leak.

D. Guidance material

— When showing compliance with oblique impacts (which is possible beyond the ± 15 degrees area), it is acceptable to consider a normal impact using a debris velocity at impact equal to the normal component of the oblique velocity vector.

— Orientation of the cube at the impact: testing and analysis should ensure that all orientations (side-on, edge-on, and corner-on) are represented.

— Impact tests should be completed in adequate number to show repeatable stable localised damage modes and damage extents for all impactor orientations (side-on, edge-on, and corner-on).

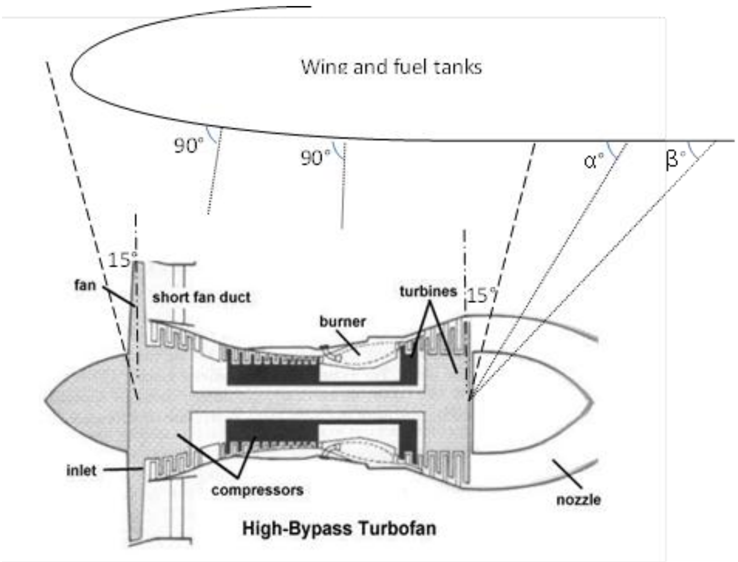


Figure 1 — Cube impact angles

(iii) APU Debris — For small APU debris, the small fragment model as defined in AMC 20-128A applies. The impact should not create a hazardous fuel leak (as defined in paragraph 3.b (ii)(C)(1) above).

Note 1: AMC 20-128A remains applicable for APU debris, other than small APU fragments, threatening fuel tanks as described here, and also remains applicable for all APU debris to other areas of the aircraft structures and systems.

Note 2: This threat needs to be addressed in accordance with CS 25.571 and AMC 20-29.

[…]

Appendix 1: TGM/25/08 issue 2

JAA Administrative & Guidance Material
Section Three: Certification Part 3: Interim Policies & Temporary Guidance Material

Guidance Number	: TGM/25/08	Issue 2 Date: 01-06-2002
Subject	: Wheel and Tyre Failure Model	
Regulation affected	: JAR 25.729(f), JAR 25.1309	

Problem :

In order to have a standardised set of conditions for the evaluation of the consequences of wheel and tyre failures, a failure model has been derived from a study of occurrence reports. The analysis uses a theoretical wheel and tyre failure model in order to show that compliance with the appropriate airworthiness requirements is achieved and that the design and construction of the aeroplane is adequate to provide the necessary protection from the effects of such failures.
Addressing the failure modes so defined, would be an acceptable means to demonstrate compliance with applicable airworthiness requirements.

Guidance :

To demonstrate compliance with applicable airworthiness requirements, the failure modes to be covered are :

1. **Tyre Burst**
[JAR 25.729(f)]

1.1. Gear extended (tyre debris) (see figure 1)

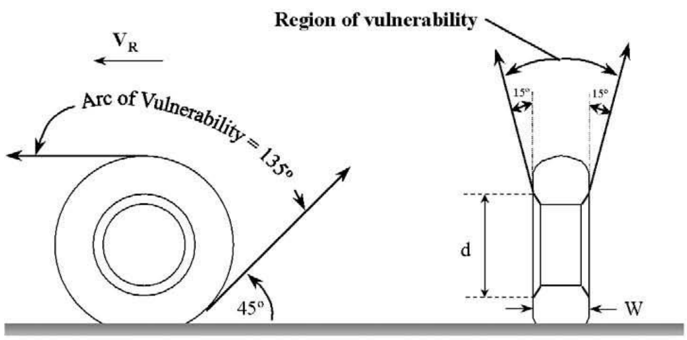


FIGURE 1
TYRE BURST - GEAR EXTENDED

Tyre burst occurring when the wheel is in contact with the ground produces tyre tread debris. This may be projected in the wheel plane between 45° measured from the ground horizontal plane in a rearward direction and parallel to the ground horizontal plane in a forward direction. There is assumed to be a uniform risk of debris projection over this 135° arc.

In addition tyre pieces may be projected at up to 15° either side of the wheel plane (within an boundary originating at the wheel rim diameter 'd'). Thus the possibility of an item being struck and damaged by debris is dependent on its location, the area of the item presented to the debris, and its position relative to the tyre. A chart or "window diagram" can be constructed from drawings for each wheel defining the area over which strikes can occur.

Two sizes of tread debris are considered, each with a full tread thickness:

(i) A large piece with dimensions W x W and ;

(ii) A small piece 0.5W x 0.5W ;

where W is the width of the tyre.

The speed will be the maximum rotation speed (V_R) which can be derived from the Aeroplane Flight Manual.

An initial tyre failure can also result in failure of, and debris from, the companion tyre. This can occur even when the tyres have been designed to have double dynamic overload capability. Therefore the analysis and the required protection should take this into account.
A "companion" tyre is a tyre on the same axle.

<u>1.2. Gear retracted (blast effects) (see figure 2)</u>

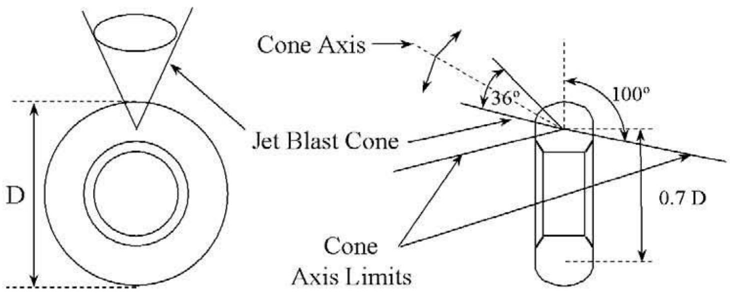


FIGURE 2
GEAR RETRACTED (BLAST EFFECTS)

In-flight tyre bursts are considered to result from previous damage to the tyre, which could occur at any point on the exposed surface. Consequential damage is considered to be caused by contact with locally displaced sections of the tyre (no debris separation) and from the pressure effects of resulting air jet. For the model, this air jet is taken as a cone with an included angle of 36° with its axis normal to the tyre surface at the point of origin of the damage. The point of origin, and hence the axis of the cone, is assumed to have a maximum angular range of +/-100° from the wheel plane at the tyre centre section (the cone centre point should be taken from a point on the tyre surface from the 0.7D line) unless the design of the wheel and tyre assembly result in a lower maximum angular range.

Debris separation from a stationary tyre is almost unknown and therefore damage is assumed to result from pressure effects of which there are two types :

(i) Localised blast effects due to the nitrogen jet emanating from the tyre failure.
(ii) Overpressure of the wheel bay causing possible deflection of panels and doors.

2) **Flailing Tread**
[JAR 25.729(f)]

2.1. Gear extended (see figure 3)

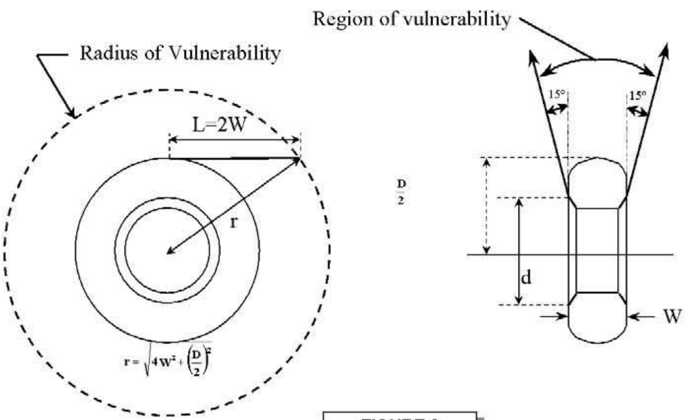


FIGURE 3
FLAILING TREAD - GEAR EXTENDED
- GEAR RETRACTING OR RETRACTED

A strip of loose tread, attached at one end only, is considered to rotate with the wheel. It follows this point of attachment in a straight line tangential to the tread diameter. The tread strip has dimensions 2W x 0.5W (where W is the tyre tread width and a strip thickness of the full tread), and has a spread 15° either side of the wheel plane (within a boundary originating at the wheel rim diameter 'd').
The strip has a speed equivalent to the tyre at the aeroplane's speed at rotation, V_R.

2.2. Gear retracting or retracted (see figure 3)

The strip of loose tread and the conditions remain unchanged from that considered for the Gear Extended case, however due to wheel spin down after take-off and retraction braking, if provided and if it is considered to remain operational, the rotational speed of the wheel may be lower or zero as it enters the wheel bay.

3) **Wheel Rim Release**
[JAR 25.1309]

In a similar manner to that used for tyre debris, the possibility of an item being damaged can be determined as follows:

3.1. Gear extended (see figure 4)

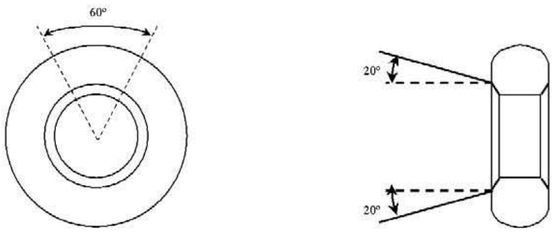


FIGURE 4

WHEEL RIM RELEASE - GEAR EXTENDED

Wheel rim pieces may be projected uniformly over a range 0° to 20° from the axial direction and uniformly over the 360° circumferential range. A 60° sector of rim with a velocity of 100 m/second should be considered.

3.2. Gear retracted (see figure 5)

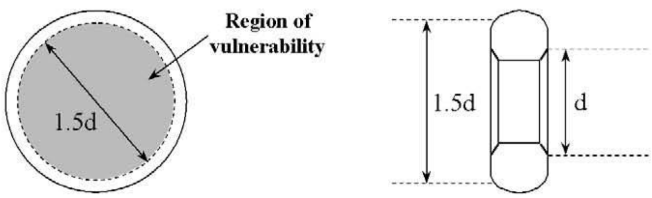


FIGURE 5

WHEEL RIM RELEASE - GEAR RETRACTED

The model considers that the complete rim is released and projected at a speed of 100 m/second in a direction approximately parallel to the wheel axis. To account for break-up and spread of debris a area affected equivalent to 1,5 x the nominal rim diameter centred on the wheel axis is used.
Service history indicates that failures of this nature need only be considered for braked-wheels.