AEROSPACE INFORMATION REPORT	AIR5699™	REV. A
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A Guide for the Damaging Effects of Tire and Wheel Failures

RATIONALE

This SAE Aerospace Information Report (AIR) is prepared to aid engineers and technicians in the understanding of the damaging effects caused by tire and wheel failures. Historical data is used to describe what has occurred to better understand what can happen in and around aircraft wheel wells. Document updated to include industry-accepted models for wheel and tire failures and to include the latest regulator evolution.

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1. SCOPE

Consideration for the damaging effects to aircraft from the failure of wheels and tires should be evaluated. This document discusses the types of problems in-service aircraft have experienced and methodology in place to assist the designers when evaluating threats for new aircraft design. The purpose of this document is to provide a history of in-service problems, provide a historical summary of the design improvements made to wheels and tires during the past 40 years, and to offer methodology which has been used to help designers assess the threat to ensure the functionality of systems and equipment located in and around the landing gear and in wheel wells.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

AIR5451 A Guide to Landing Gear System Integration

AIR5697 Aerospace Landing Gear - FAA Regulatory History - Airplane Wheels, Tires, and Brakes

ARP4102/3 Flight Deck Tire Pressure Monitoring System (TPMS)

ARP4752 Aerospace - Design and Installation of Commercial Transport Aircraft Hydraulic Systems

ARP4834 Aircraft Tire Retreading Practice - Bias and Radial

ARP6137 Tire Pressure Monitoring Systems (TPMS) for Aircraft

ARP6265 Tire Burst Test Methodology

AS1241 Fire Resistant Phosphate Ester Hydraulic Fluid for Aircraft

AS4833 Aircraft New Tire Standard - Bias and Radial

AS5440 Hydraulic Systems, Aircraft, Design and Installation, Requirements for

2.1.2 FAA/JAA/EASA Documents

AC documents are available from the FAA and can be found online at http://rgl.faa.gov.

AC 20-97B Aircraft Tire Maintenance and Operational Practices

AC 25-7A Flight Test Guide for Certification of Transport Category Airplanes, Change 1

AC 25-22 Certification of Transport Airplane Mechanical Systems

AC 25.491-1 Taxi, Takeoff and Landing Roll Design Loads

AC 25.735-1 Brakes and Braking Systems Certification Tests and Analysis

AC 25.1435-1 Hydraulic System Certification Tests and Analysis

AC 145-4A Inspection, Retread, Repair, and Alterations of Aircraft Tires

TGM/25/08 JAA Temporary Guidance Material TGM/25/08 Wheel and Tire Failure Model, Issue 2

TSO-C26d Aircraft Wheels and Wheel-Brake Assemblies, with Addendum

TSO-C62e Aircraft Tires

TSO-C135a Transport Airplane Wheels and Wheel and Brake Assemblies

2.2 Other References

Material related to this subject was presented during SAE A-5 panel meetings from October 2003 through October 2006. Most of the data in this report is from the presentations from the panel meetings.

[1] Schmidt, R. Kyle. The Design of Aircraft Landing Gear, SAE International, 2020.

[2] Notice of Proposed Amendment (NPA) 2013-02, Protection from Debris Impacts, European Aviation Safety Agency, 18 January 2013.

[3] Protection Against Wheel and Tyre Failures, AMC 25.734, CS 25 Book 2, Amendment 19, European Aviation Safety Agency, 12 May 2017.

[4] Notice of Proposed Amendment 2020-05, Tyre Pressure Monitoring, European Aviation Safety Agency, 5 March 2020.

2.3 Acronyms

AC Advisory Circular

AIR Aerospace Information Report

ARP Aerospace Recommended Practice

AS Aerospace Standard

BTMS Brake Temperature Monitoring System

EASA European Aviation Safety Agency

FAA Federal Aviation Administration

JAA Joint Aviation Authorities

JAR Joint Aviation Requirements

NDT Non-Destructive Test

NTSB National Transportation Safety Board

OEM Original Equipment Manufacturer

RTO Rejected Takeoff

TGM Temporary Guidance Material

TPMS Tire Pressure Monitoring System

TSO Technical Standard Order

3. INDUSTRY-ACCEPTED WHEEL AND TIRE FAILURE MODELS[1]

A variety of approaches to modeling wheel and tire failure modes have been developed—typically by aircraft manufacturers. Prior to the existence of the EASA, the Joint Airworthiness Authority of Europe published a model in their temporary guidance material (TGM). The model approach was updated [2] in 2013 following input from an industry working group to account for differences in radial ply tires and considering a variety of worldwide tire related accidents. The current models are provided in EASA guidance material AMC 25.734 [3].

The tire threat models cover ejected tire debris, flailing tire strips, and inflation medium release associated with a tire burst. The wheel threat model of reference [3] considers the partial rim release failure mode of the wheel.

3.1 EASA Tire Failure Models

There are four tire models which cover landing gear extended, retracting, and retracted threats. It is worth noting that these tire models use the rated tire speed rather than a rational speed based on aircraft takeoff or landing speeds. This is a conscious choice and is designed to ensure adequate tire debris energies are considered. For the models, the tread depth definitions shown in Figure 1 and the definitions below apply.

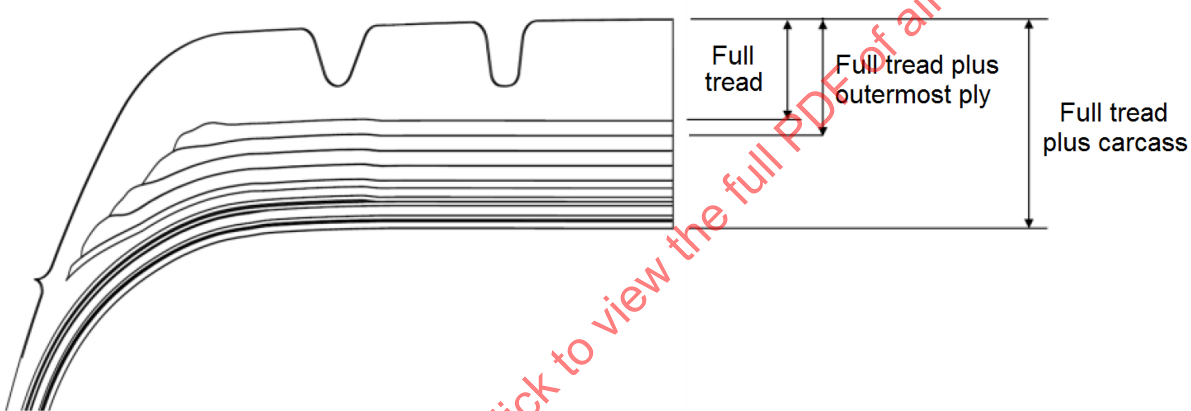

Figure 1 - Tread quantity for tire failure model

Total tread area:

$$A_{tread} = \pi \times D_g \times W_{sg} \quad \text{(Eq. 1)}$$

where:

D_g = the TRA grown tire diameter

W_{sg} = the TRA maximum grown shoulder width

Minimum tire speed rating: This is a potentially confusing term as the highest energy events occur at the highest speeds. However, recognizing that a single aircraft may have multiple tires certified for use, and that those tires may have different tire speed ratings, the “minimum tire speed rating” for use with these debris models is the rated tire speed of the tire with the lowest speed rating of the set of tires certified (or intended to be certified) for the aircraft.

Tire speed rating: The maximum ground speed at which the tire has been tested in accordance with technical standard order C62e.

[1] This section is adapted from reference [1].

3.1.1 Model 1: Tire Debris Threat Model

This model is applicable for debris released from the tire when it is in contact with the ground. Two sizes of debris are considered and they are assumed to be released from the tread area of the tire and projected towards the aircraft within the zones of vulnerability as identified in Figure 2. The "large debris" is considered to have dimensions $W_{sg} \times W_{sg}$ at D_g and a thickness of the full tread plus outermost ply (i.e. the reinforcement or protector ply). The angle of vulnerability, θ, to be considered is 15 degrees. The "small debris" is considered to consist of 1% of the total tire mass, with an impact load distributed over an area equal to 1.5% of the total tread area. The angle of vulnerability, θ, to be considered is 30 degrees. The debris is considered to have a speed equivalent to the minimum tire speed rating certified for the aircraft (the additional velocity component due to the release of carcass pressure does not need to be taken into account).

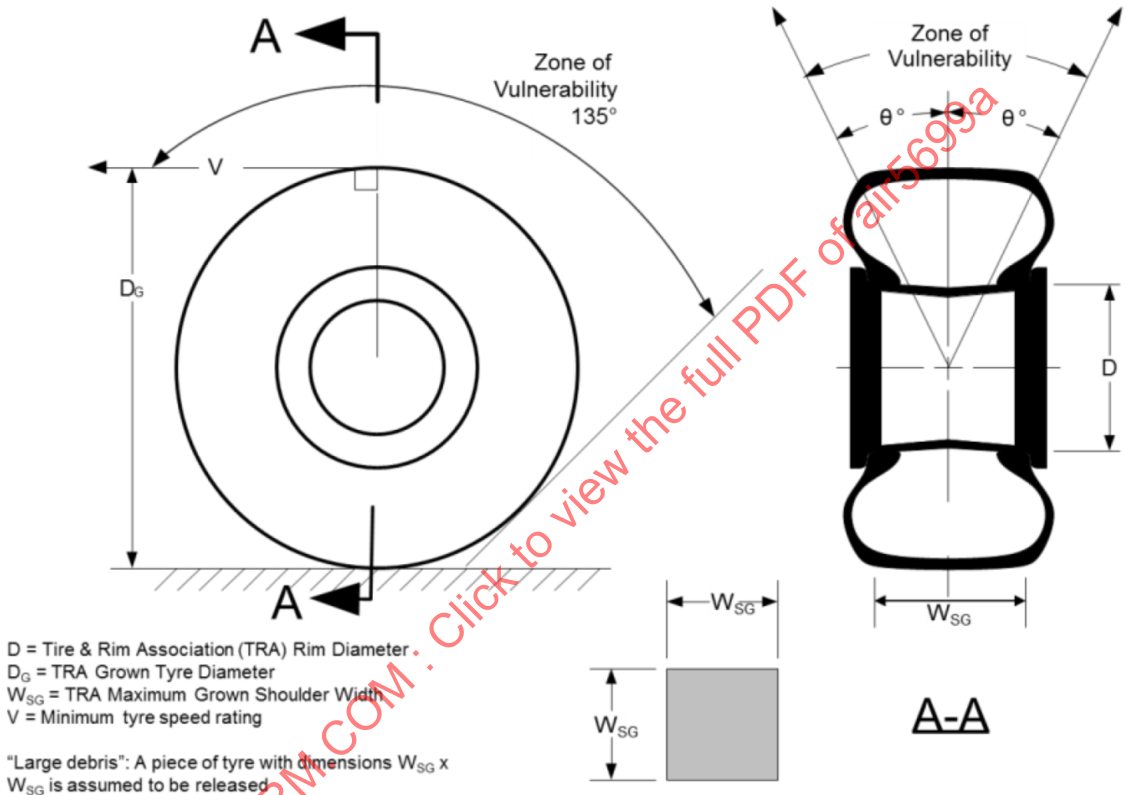

Figure 2 - Tire debris threat model

These models are relevant for any fuel tanks in the threat area and ejection of the large debris can be considered to cause a fuel leak but should not also create an ignition source (for example, by damaging electrical harnessing). Ejection of the small debris should not create a hazardous fuel leak. The large and small debris model should also be used to ensure that systems in the zone of vulnerability are appropriately segregated and, if required, armored. For the analysis of shielding or armoring, the small debris model is used. A first tire failure can also result in the failure of the companion tire (with debris being ejected from both tires). This can occur even when the tires have been designed to have double dynamic overload capability. The analysis for the segregation of systems installation and routing should take this companion tire failure into account inside the vulnerability zone defined by θ = 15 degrees (either side of the tire centerline) and considering that both tires only release large debris. Inside zones defined by 15 degrees < θ ≤ 30 degrees only small debris from a single tire needs to be considered.

3.1.2 Model 3E: Flailing Tire Strip Threat Model

A flailing tire strip typically results from the partial delamination of the tread from the carcass, although flailing strips can include large portions of the carcass. This model is relevant for the aircraft when the landing gear is extended. In the interests of conservatism, unless it can be demonstrated that the tire carcass will not fail as well as the tread, the thickness to be assumed in the model is the full tread thickness plus the carcass thickness, as shown in Figure 1. If it can be demonstrated that the carcass will remain intact then the thickness to be used is the full tread and outermost ply (the reinforcement or protector ply). The model considers that a flailing tire 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 tire at takeoff speeds. The strip is to be considered to have a speed equivalent to the minimum tire speed rating certified for the aircraft. The zone of vulnerability is considered as 30 degrees, as shown in Figure 3.

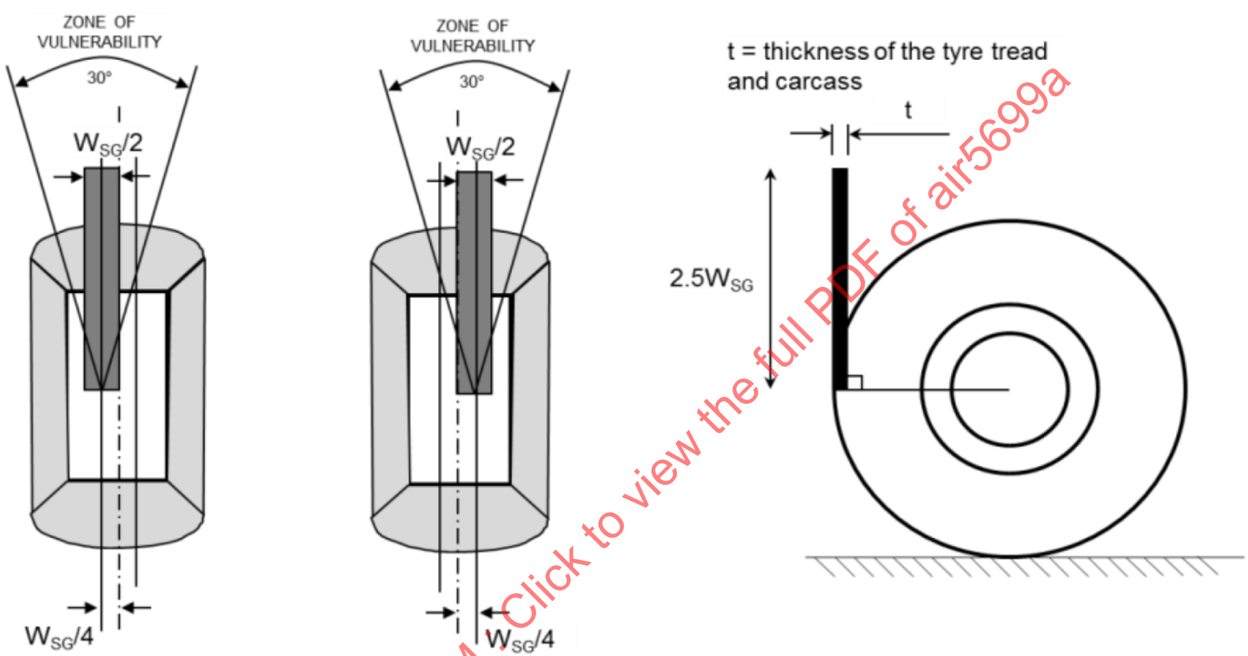

Figure 3 - Flailing tread model

3.1.3 Model 3R: Flailing Tire Strip Threat Model

This model is the same Model 3E, but for the gear while retracting and in the retracted position. The major difference is that credit can be taken for wheel spin down following takeoff and retraction brake snubbing (provided that the retraction brake system is reliable and independent from a flailing strip event). The strip is to be considered to have an initial speed equivalent to the minimum tire speed rating certified for the aircraft. Depending on the systems available, the tire can be considered to decelerate partially (wheel bearing friction and aerodynamic drag) or completely (reliable, independent retraction brake) before or during retraction. As for Model 3E, the zone of vulnerability is 30 degrees. In the case of full retraction braking, it is advisable to assess the thread of the tire strip entering the bay with no rotational speed and at all possible radial positions.

3.1.4 Model 4: Tire Burst Pressure Effect Threat Model

A bursting tire in the landing gear bay can cause disruption and displacement of components mounted in the bay due to the gas pressure jet released by the tire. In some cases permanent distortion of the bay walls has been observed. This model is applicable when the landing gear is retracting or when it is completely retracted. These cases are considered to result from previous damage to the tire, which can occur at any point on the exposed surface. A review conducted by EASA of known incidents showed that all cases of retracted tire burst occurred on main landing gear tires mounted on braked wheels. While the model is applicable to all tires, EASA only considers these effects necessary to consider on braked wheels.

The model assumes that tires do not release debris and that damage is only caused by the pressure release effects—the “blast effect.” Due to the construction differences between bias and radial tires, the blast effect has been shown to be different between the types. The model assumes a tire burst pressure of 1.3 times the maximum unloaded operational pressure. For multiple wheel gears, this is the unloaded tire rated pressure reduced by a factor of 1.07 (which is the design safety factor for transport category aircraft required by CS 25.733).

As an example: An H44.5×16.5–21, 26 ply rating tire has an unloaded tire rated pressure of 1365 kPa (198 psig), so the maximum unloaded operational pressure is 1365/1.07 = 1276 kPa (185 psig). In absolute pressure, this is 1377 kPa (199.7 psia). The tire burst pressure is then 1377×1.3 = 1790 kPa absolute pressure (259.7 psia).

For bias tires, the burst plume model shown in Figures 4 and 5 should be used, with the blast cone axis rotated over the tread surface of the tire (±100 degrees, as shown in Figure 4). The pressure distribution is a set of exponential decay functions shown in Figure 6 and following the coordinate system of Figure 5. Functions are provided in Table 1, which have been digitized from the material provided by EASA.

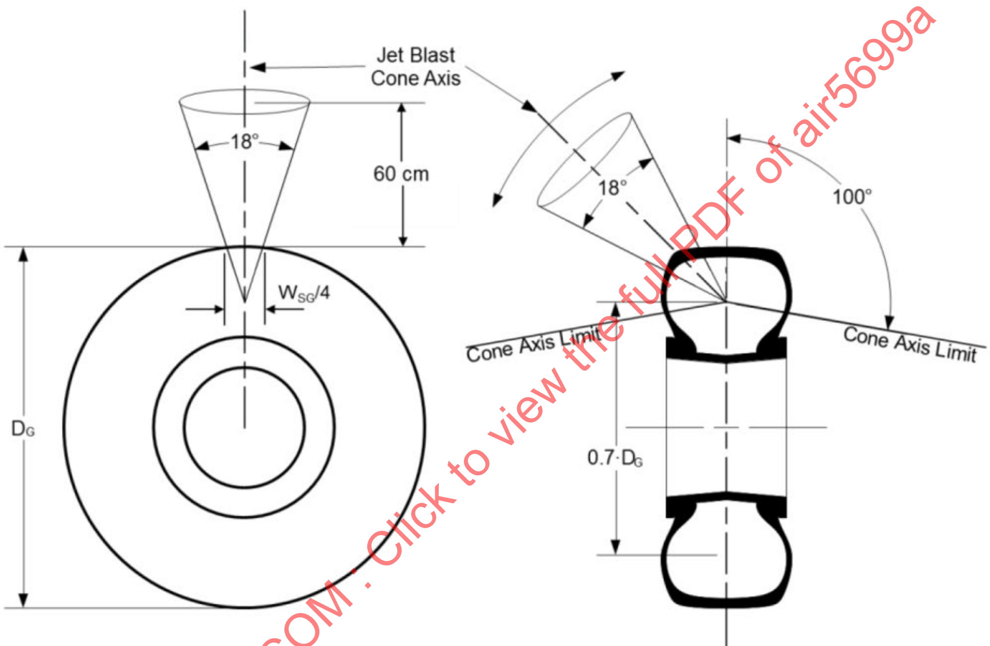

Figure 4 - Bias tire burst pressure effect - burst location

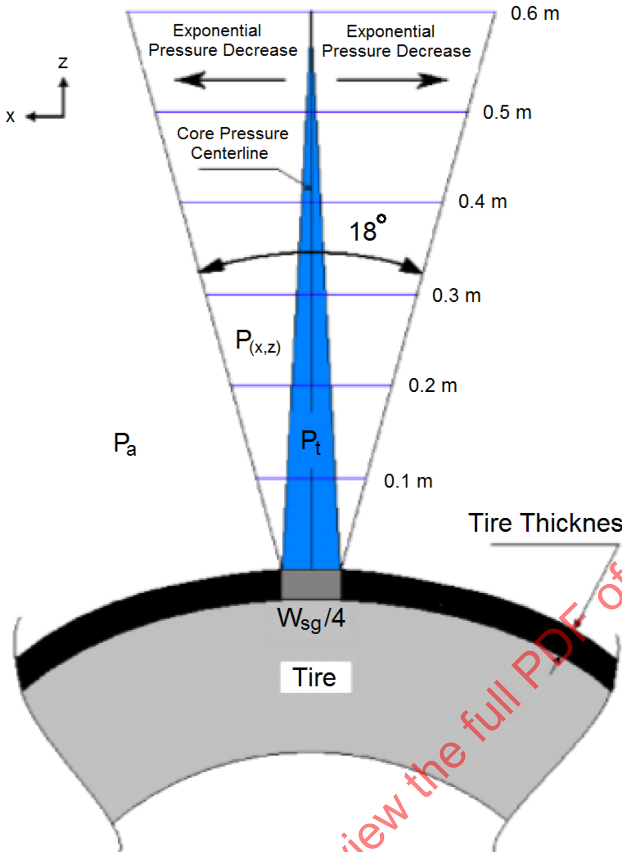

Figure 5 - Bias tire burst pressure effect - pressure cone details

In the figures and tables:

P_a = the ambient pressure

$P = P_{(x,z)}$ = the pressure inside the cone, as shown in Figure 5

P_t = the tire burst pressure

Table 1 - Bias tire burst pressure decay functions

Distance from Tire (m)	Exponential Decay Function: $(P-P_a)/(P_t-P_a)$ as a function of x (radius from centerline, m)
0.1	$(P-P_a)/(P_t-P_a) = 325.42e^{-136.4x}$
0.2	$(P-P_a)/(P_t-P_a) = 9.1038e^{-67.24x}$
0.3	$(P-P_a)/(P_t-P_a) = 3.6759e^{-50.47x}$
0.4	$(P-P_a)/(P_t-P_a) = 1.9686e^{-38.44x}$
0.5	$(P-P_a)/(P_t-P_a) = 1.3001e^{-31.34x}$
0.6	$(P-P_a)/(P_t-P_a) = 0.9621e^{-25.49x}$

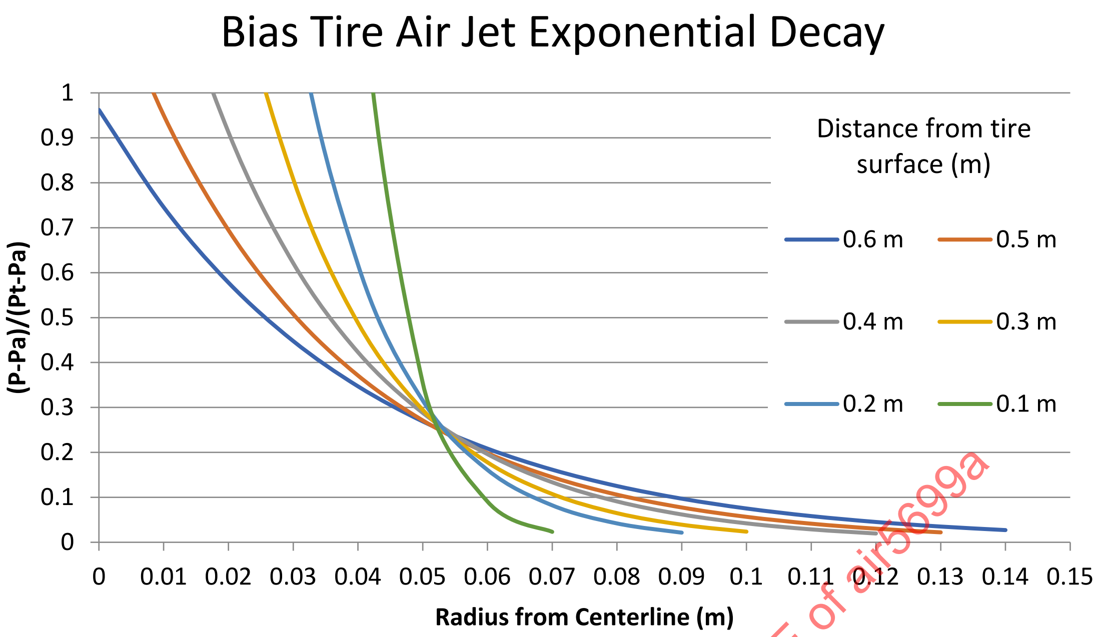

Figure 6 - Exponential decay functions for bias tire burst pressure effect

Due to the differences in carcass construction, a different model is used for radial tires. A burst plume model with a wedge shape is employed as shown in Figures 7 and 8.

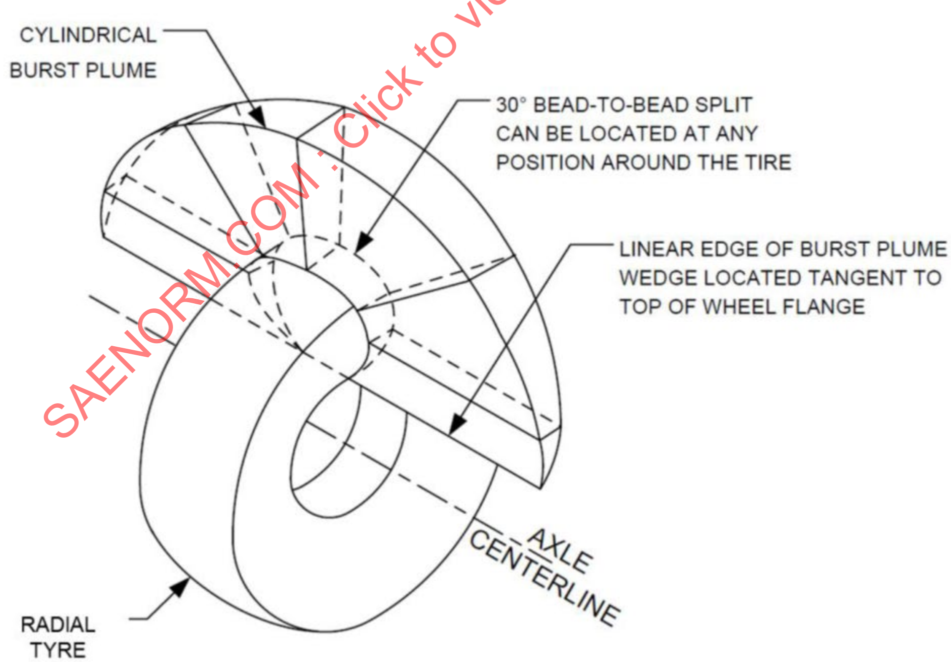

Figure 7 - Radial tire burst pressure effect

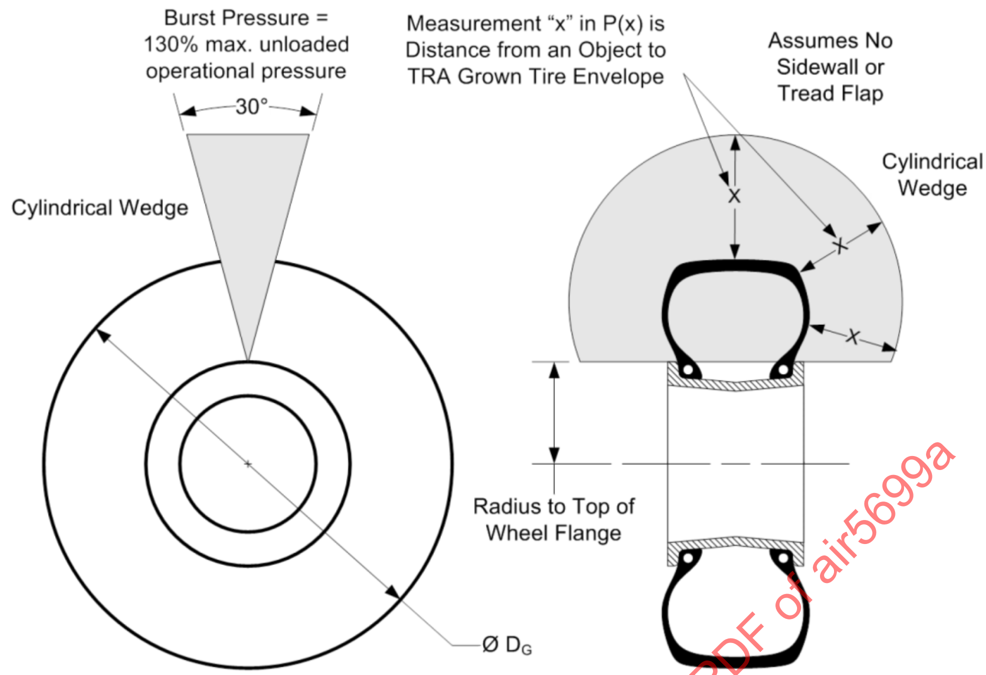

Figure 8 - Radial tire pressure burst effect - locations

The pressure at any distance, x, from the radial tire is given by the expression:

$$P(x) = 0.5283(P_t - P_a)\left[1.4e^{-\frac{\psi x}{3}} + e^{-\psi x}\right] + P_a;\ \text{if } P(x) > P_t \text{ then } P(x)=P_t \qquad \text{(Eq. 2)}$$

where:

$$\psi x = \left[\frac{C_1}{(W_g)^{C_2}} + C_3\right] x, \text{ for } W_g \text{ and x, in inches}$$

$$\psi x = \left[\frac{C_1}{\left(\frac{W_g}{25.4}\right)^{C_2}} + C_3\right] \frac{x}{25.4}, \text{ for } W_g \text{ and x, in millimeters}$$

$C_1 = 12.478$; $C_2 = 1.222$; $C_3 = 0.024$

P_t = the total or burst pressure, in pounds per square inch (absolute) or bar

P_a = the ambient pressure, in pounds per square inch (absolute) or bar

x = the distance from the grown tire surface, in inches or millimeters

The effect of the burst should be considered on the structure and system components located inside the defined burst plume. As a design objective, the increase in pressure inside the landing gear bay as a result of tire burst should not be detrimental to continued safe flight and landing. In some cases, it may be instructive to conduct burst tests of tires in order to substantiate the modeling approach provided here. In that case, guidance material is provided in ARP6265 as to how best to initiate the burst event and how to capture the relevant pressure profiles.

3.2 EASA Wheel Failure Model

The EASA rim release model (AMC 25.734, Model 2—Wheel Flange Debris Threat Model), shown in Figure 9, requires that a 60 degree arc of wheel flange be considered to depart the wheel at a velocity of 100 m/s (328 ft/s). For landing gears with multiple wheels on one axle, lateral release of only the outboard wheel flange needs to be considered. For single wheel gears, release of either wheel flange is to be considered. The orientation of the debris at the point of impact is to be considered as the most damaging to the item impacted. Vertical release of wheel debris is considered to be covered by the tire models.

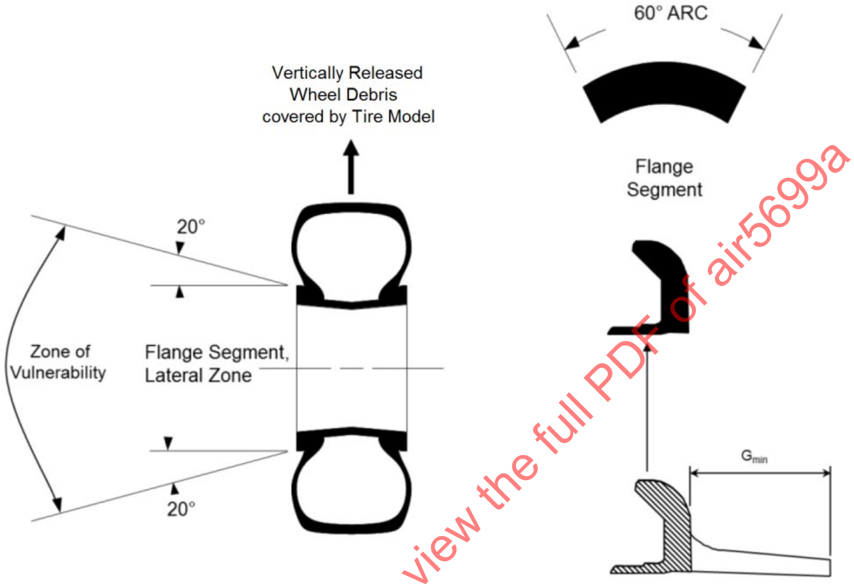

Figure 9 - Model for wheel flange release

This certification model considers effectively that the rim releases while the aircraft is rolling. Some aircraft manufacturers choose to also consider cases where the wheel is static and the complete rim detaches. This case is typically considered with the landing gear extended for all wheels and both extended and retracted for braked wheels. The logic for considering a complete rim release with the landing gear retracted is that heat from the brakes increases the tire gas pressure while simultaneously reducing the static strength properties of the wheel.

4. REGULATION HISTORY AND INDUSTRY INITIATIVES

4.1 Rulemaking and Requirements Changes Pertaining to Tire and Wheel Threats

4.1.1 Regulation Changes

Document AIR5697 provides details about all the regulation changes pertaining to aircraft landing gear systems and equipment. Below is a list of the most pertinent changes for wheels and tires:

- 1974: Order 8100.8 requires fuse plug demonstration during RTO testing. Same requirements in AC 25-7 (1986).
- 1979: TSO-C26c and TSO-C62c are updated to add tire overload testing: NTSB recommendations + FAA/Industry Taskforce. Amendment 25-49 updated regulations for tires. Addendum I corrections were added in 1984.
- 1982: AC 145-4 provides basic retreading requirements of tires, updated during 2006.
- 1987: AD 87-08-09 required inflation of braked wheels by inert gas (typically nitrogen). Amendment 25-78 in 1993 updated regulations §25.733(e) added to reflect AD.

- 1987: AC 20-97A acknowledged importance of maintenance of aircraft tires: tire maintenance and operations; Rev B was issued during 2005.

- 1990: Amendment 25-72 revised § 25.733(c)(1) to add a 1.07 factor for tire load ratings.

- 2002: Amendment 25-107; Amended § 25.731 and 25.735 for overpressure and over temperature protection of wheels; new AC 25.735-1 and TSO-C135.

- 2013: Protection from debris impacts—inclusion of upgraded TGM in advisory material to CS 25 (see 3.1 for model and 4.1.4 for details on the activity).

- 2020: Recommendation for tire pressure monitoring included in CS 25 (see 4.1.3 for details and supporting data).

4.1.2 Industry Initiatives

The manufacturers in the wheel and tire industry and aircraft manufacturers have voluntarily introduced improvements. Examples include:

- Increased applications of brake temperature monitoring systems.

- Increased wheel and tire qualification requirements.

- More installations of tire pressure monitoring systems.

- Reducing the number of times tires may be retreaded prior to being discarded.

4.1.3 EASA NPA 2020-05 Tire Pressure Monitoring

EASA undertook a study to determine whether enforcing tire pressure measurement or monitoring was warranted. Their rationale was that incorrect tire pressure, and, in particular, the under-inflation of tires, is a contributing factor to tire- and wheel-failure-related accidents or incidents of large aircraft. These kinds of occurrences have continued to arise, despite the various actions taken by industry and regulators over the last 40 years. These actions include improvements in tire maintenance practices, numerous communications on good practices for tire pressure checks, and improvements in tire and wheel robustness. Actions have also been taken to mitigate the severity of occurrences, i.e., the improvement of the protection of aircraft against the effects of tire failures. However, the review of the reported occurrences indicates that a further reduction in the risk of a tire failure is needed.

As a result of the study, EASA amended the CS 25 certification regulation for large fixed wing aircraft (in particular, CS 25.733) to require means to ensure a tire is not below its minimum serviceable inflation pressure during operation. This can be achieved either through a task in the instructions for continuing airworthiness to inspect the tire pressure at an appropriate interval, or by the inclusion of an on-board tire pressure monitoring system that will alert the crew when tire pressure is below the minimum serviceable inflation pressure.

To arrive at this change, EASA performed a review of the occurrences contained in the EASA occurrences databases (the Internal Occurrence Reporting System and the European Central Repository). The initial review encompassed the occurrences for which the main causes involved a tire or wheel failure, and which happened to aircraft with maximum takeoff weights greater than 2250 kg (4950 pounds) during commercial air transport operations (including business/corporate flights) between the years 2002 and 2016. A total of 848 occurrences were found, which are classified as follows: 57 accidents, 73 serious incidents, and 718 incidents. These are shown plotted versus year of occurrence in Figure 10.

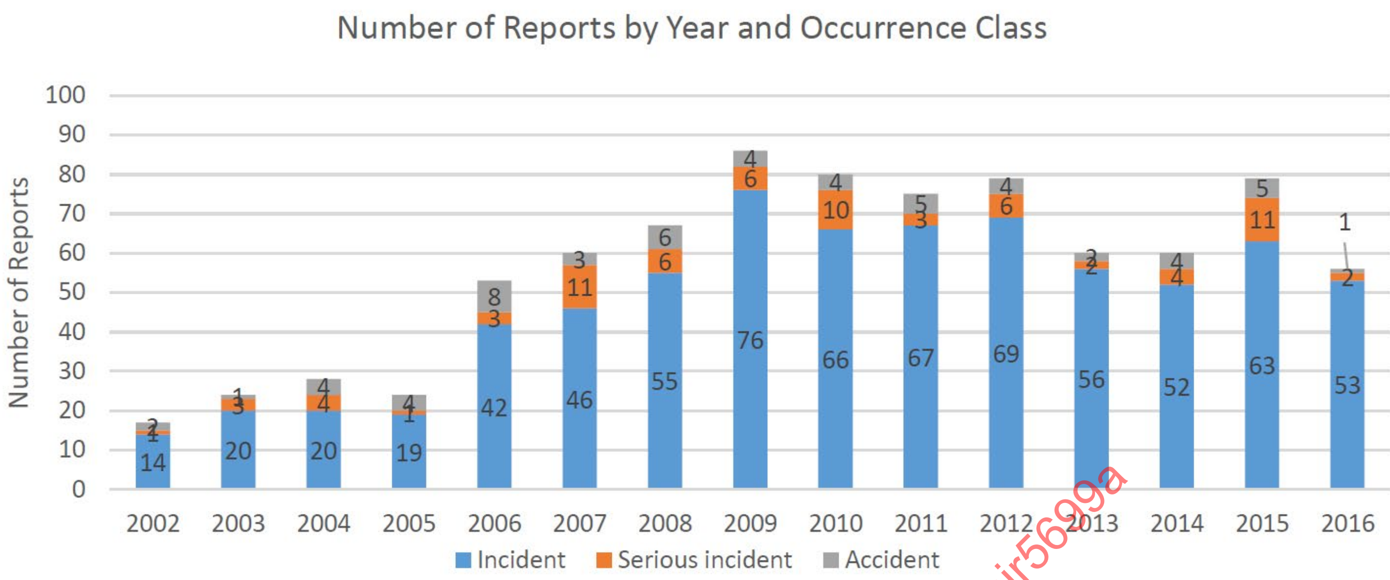

Figure 10 - Overall number of reported tire and wheel failure occurrences per year - NPA 2020-05

Figure 11 indicates the content of the database sorted by cause. It can be noted that the reports often lack sufficient information to establish the root cause of the tire or wheel failure; the main category is designated “tire burst – unknown cause” (540 occurrences or 64%).

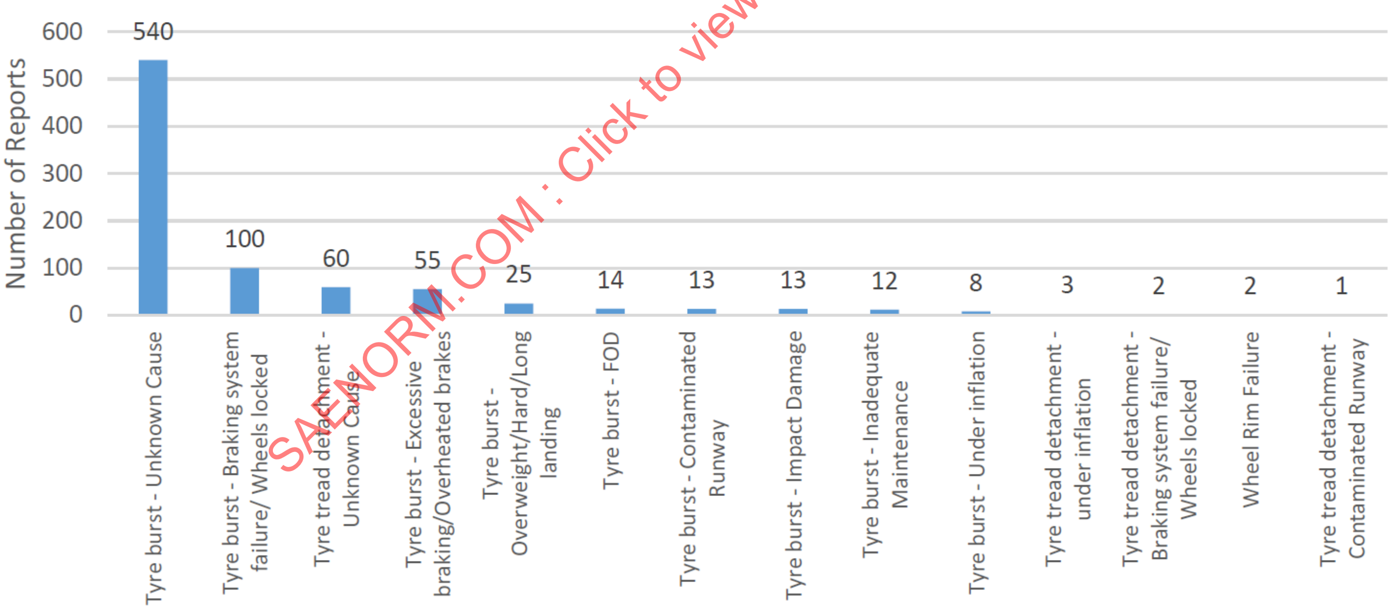

Figure 11 - Overview of tire and wheel failure reports - NPA 2020-05

Based on these findings, a further detailed review was conducted to identify the occurrences concerning large aircraft (part 25 certification) in which inadequate tire inflation was present or highly probable among the causal factors. Events in which a tire blew on the ground during inflation (i.e., maintenance actions) were excluded.

The analysis was focused on the reported serious incidents and accidents (130 occurrences). It was finally determined that there had been eight occurrences (i.e., 6% of all occurrences) between 2002 and 2016, comprising six serious incidents and two accidents. A fatal accident occurred on Learjet 60 registration N999LJ in 2008 (four fatalities and two serious injuries); the non-fatal accident with substantial aircraft damage occurred on Boeing 747 registration VT-AIM in 2005. Appendix 1 to NPA 2020-05 (reference [4]) contains more details and the full list of these occurrences. All these occurrences were related to one or more tire failures that was linked to tire under-inflation (seven tire bursts, one tire tread detachment). The causal factors included: fuse plug leaking (one), incorrect installation of the inflation valve (two), tire pressure check and inflation not adequate (under inflation) (four), and wheel bolts not adequately torqued (one). In all eight cases, the tire failures occurred during takeoff.

In addition, at least three other accidents are known to have occurred before 2002 that were also caused by inadequate tire pressures, including one fatal accident:

- DC-8, registration C-GMXQ, on 11 July 1991, crashed after takeoff from Jeddah, Saudi Arabia, resulting in 261 fatalities. Cause: Under-inflated tires, two tires bursts during takeoff roll.

- BAC 1-11, registration G-AWYR, on 21 November 1997, tire burst during rotation for takeoff at Birmingham airport, UK. Cause: Tire under-inflation.

- B757-300, registration 4X-BAU, on 3 October 2000, two tire bursts during landing at London Gatwick airport (UK). Cause: Tire under-inflation.

EASA compiled data from one aircraft manufacturer (having one of the largest fleets worldwide):

The manufacturer reviewed tire failure reports on all of its aircraft types between May 2004 and December 2013.

Out of 595 occurrences, there were 141 occurrences (23.7%) related to tire under-inflation, 43 occurrences (7.2%) were caused by foreign object damage (FOD), 64 occurrences (10.8%) were caused by tire manufacturing or re-treading defects. There were also 286 occurrences (48.1%) with unknown causes.

Looking at the reasons for the 141 tire under-inflation cases, it appears that:

- Seventy-three cases (51.8%) were caused by unknown reasons.

- Twenty-six cases (18.5%) were caused by a tire defect which was not detected and not rectified during the retread process.

- Eighteen cases (12.8%) were caused by leakage of the wheel (crack, O-ring, tie bolt fracture).

- Eleven cases (7.8%) were caused by a leaking or melted fuse plug.

- Nine cases (6.4%) were caused by tire leakage (inner liner or internal separation).

- Four cases (2.8%) were caused by (suspected) incorrect (low) inflation pressures.

Additionally, EASA collected data from a tire manufacturer comprising commercial, regional, and general aviation operations. The period reported was 30 years of data for injuries and fatalities, and January 2010 to October 2017 for aircraft damage. These cases excluded tire tread separation as the manufacturer did not consider that those events were related to under-inflation. The data indicated that:

Three occurrences on the ground have been reported where injuries or fatalities occurred during inflation tasks. There were 69 tire bursts that caused aircraft damage. The tires that were involved in these occurrences were 43% bias ply tires and 57% radial tires (the base rate regarding the number of each type of tire in service was not reported). The statistics gathered confirm that under-inflation was identified in 10% of the occurrences. In 51% of the occurrences, the inflation was correct, and in 39% of the occurrences, the condition of the tire in terms of its pressure was unknown. In terms of root causes, in 52% of the cases, it is unknown; in 36% of the cases, FOD is identified as a cause or is probable. Other root causes include operational factors and other issues at the tire or wheel level.

4.1.4 EASA NPA 2013-02 Protection from Debris Impacts

As part of an activity to investigate aircraft protection from debris impacts of all types, EASA convened a working group that searched relevant data relating to tire and wheel failures in service. Part 25 large aircraft accident/incident investigation reports were gathered and analysed. Additionally, request letters were sent to large aircraft manufacturers, wheel and brake manufacturers and tire 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 tire and wheel failure model for type certification. The data received from the manufacturers varied considerably in both quality and quantity and follow-up was performed by the working group to extract as much relevant information as possible from what was supplied.

The resulting 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 (tire 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 categorized. 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 in Table 2 (some events met multiple criteria; individual events do not sum to the total).

Table 2 - EASA NPA 2013-02 study data

Total	Tire Burst		Flailing Tread		Wheel Rim Release	
	Extended	Retracted	Extended	Retracted	Extended	Retracted
185	155	10	28	3	23	1

TGM Complaint?			
	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.

From the analysis of the events data, it was concluded that:

- Each failure mode identified in the TGM/25/08 model had occurred in service at least once.
- Many more failures had 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 tires. However, based on data presented, radial tires fail differently than bias tyres in that radial tires tend to have a wedge shaped failure mode while bias ply tires tend to have an X pattern failure mode. These failure patterns can affect the pattern of a tire pressure burst on system and structure, and the shape and size of a flailing tire strip.
- There were no noticeable differences in the failure modes recorded for retreaded tires.
- 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 tire bursts did occur.

- There were cases of multiple fragments of tread thrown from a single tire. 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 tire debris threat model, and therefore it is proposed not to characterise this threat in our model.
- 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.

The NPA (reference [2]), from which the foregoing is adapted, includes review of specific cases and has additional commentary on the specific choices. The results of this NPA are the adapted EASA tire and wheel threat models provided in Section 3.

4.1.5 JAA TGM/25/08

Prior to the introduction of EASA, the JAA issued temporary guidance material (TGM) to be used by aircraft manufacturers to assist in showing compliance to JAR 25.729(f) and JAR 25.1309. This TGM provided threat geometry for bursting tires, flailing tires and wheel rim release. It offered no relief for equipment meeting the latest requirements or for differences in tire construction techniques (bias versus radial). SAE Panel A5-03-01 was formed to address the subject on tire and wheel threat and to validate and/or update the TGM. Although there were presentations provided at panel meetings suggesting that tire retreads may increase the frequency of flailing tread, and that radial tires produced smaller tire projectiles when burst than bias tires, insufficient data was provided to update the TGM. The TGM offers no relief for wheels incorporating over pressure release devices as required in TSO-C135 issued after the TGM was written. The SAE panel was concluded with the initial publication of this AIR.

Furthermore, the TGM is intended to address the protection of systems and equipment from the damaging effects of wheel and tire failures. It provides geometric zones around wheels and tires that should be kept free of critical systems and equipment. While these zones provide reasonable stay out areas for systems and equipment, they do not address the aircraft structure. If the fuselage is damaged, decompression could occur as shown in the NTSB data discussed below. During the panel meetings there was concern raised pertaining to the fact that JAA/EASA and FAA have not harmonized on the guidance provided in the TGM. The harmonization of the certification requirements for protecting the aircraft from the damaging effects of wheel and tire failures would streamline the certification process. The TGM could be used as a beginning point with additional consideration for recent regulation changes and industry damage reports.

5. IN-SERVICE OPERATIONAL DATA

5.1 NTSB Data

A representative from the FAA office in Seattle, Washington, retrieved public records of wheel and tire failure events and provided details of the data to the panel for analysis. This data was from events recorded with some level of aircraft damage. It is understood that events considered proprietary and events with no damage are not included in this database. Table 3 provides the NTSB data sorted by the type of damage. Approximately 40 years of data are included from 1966 through 2005.

Table 3 - NTSB event damage data

Type of Damage	Quantity of Events
Fatal accidents	11
Hull loss with no fatalities	8
Debris entered fuel tank or engine	11
Airframe damage	36
Decompression	7

Analyzing the NTSB data provides an opportunity to understand how events have evolved during the time period when regulations and industry initiatives to enhance aircraft safety have been introduced. Figure 12 provides the events grouped by decade along with the fleet growth. The more important regulations introduced are also shown. The data for the 1960s and 2000s represent partial decades.

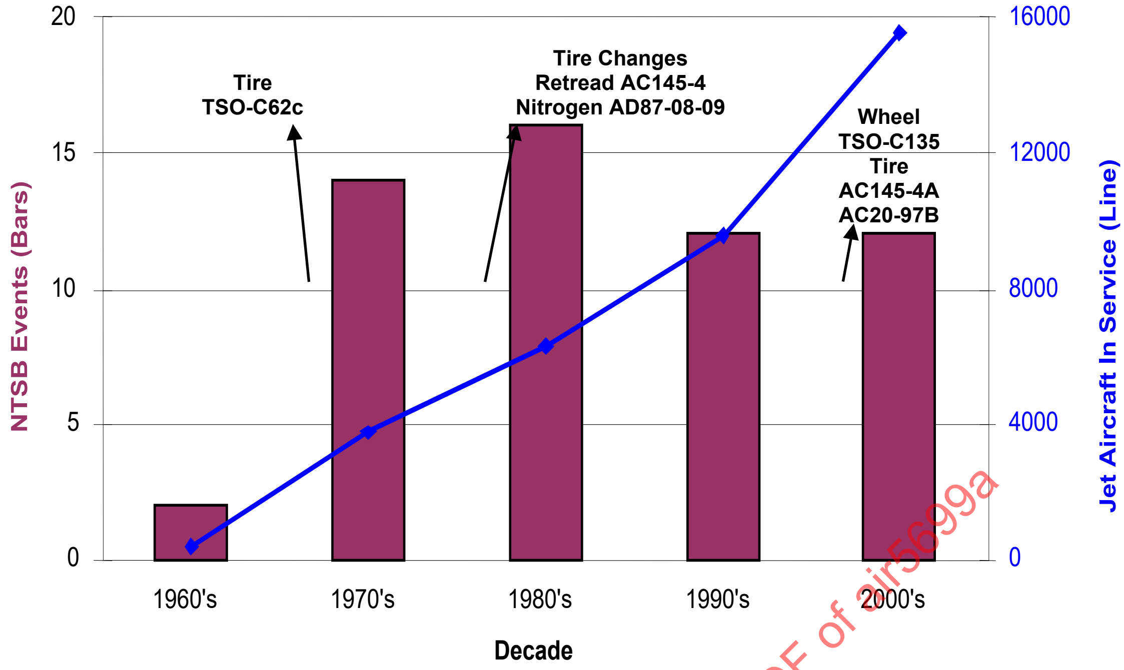

Figure 12 - NTSB wheel/tire events versus quantity of aircraft by decade

Figure 12 can be interpreted that events have not grown proportional to fleet size, perhaps due to enhanced safety regulations. Excluding the 1960s and the 2000s, as they encompass NTSB data for only a portion of the decade, leaves three decades to compare. The ratio of NTSB events to total aircraft flying is shown in Table 4. This indicates that the number of events per aircraft in service has reduced during the 1980s and 1990s.

Table 4 - Events per aircraft in service

Decade	1970s	1980s	1990s
NTSB event per quantity of A/C in service	0.0037	0.0025	0.0013

Figure 13 provides the distribution of main and nose tire events. It is interesting to note that none of the events are considered to be caused by a wheel problem. Figure 14 provides a distribution of the events using a damage assessment consistent to the one provided in the OEM data shown later in this report. Notice that there are no events in the “none” category for the NTSB data. With no aircraft damage, apparently no report to the NTSB is filed. Figure 15 provides the distribution of the flight phase when the event occurred.

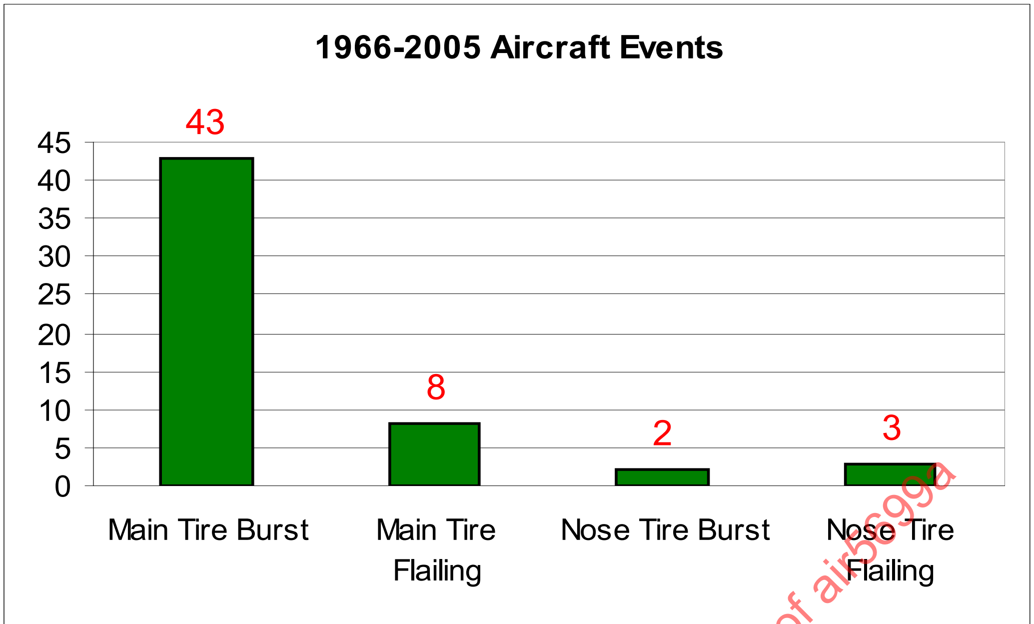

Figure 13 - Distribution of NTSB events by cause

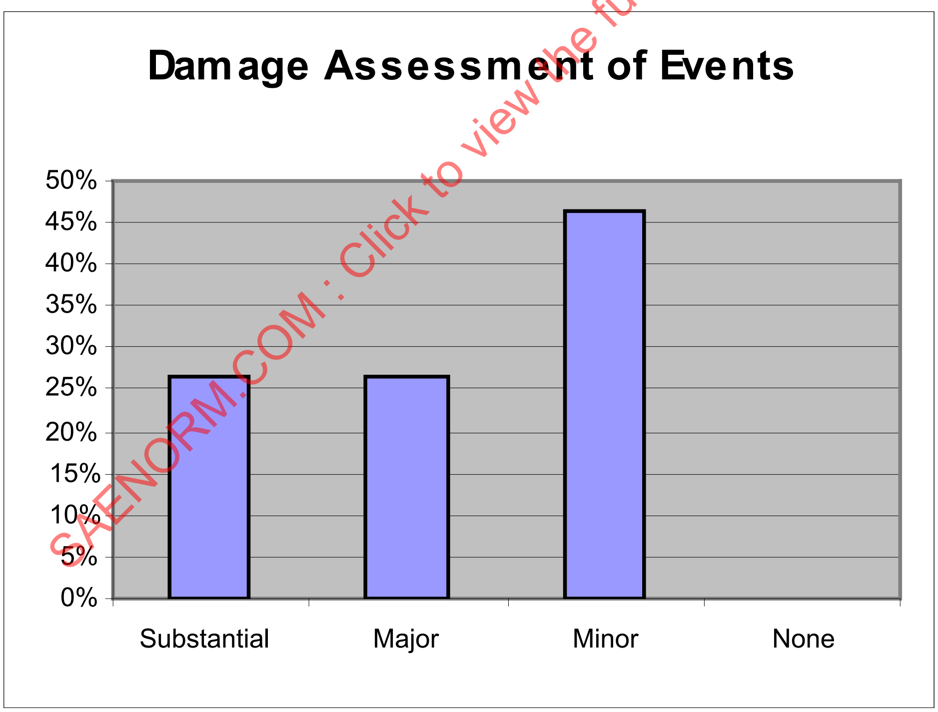

Figure 14 - Criticality distribution of NTSB events