

AEROSPACE INFORMATION REPORT

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Superseding AIR5699

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 MODELS¹

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.

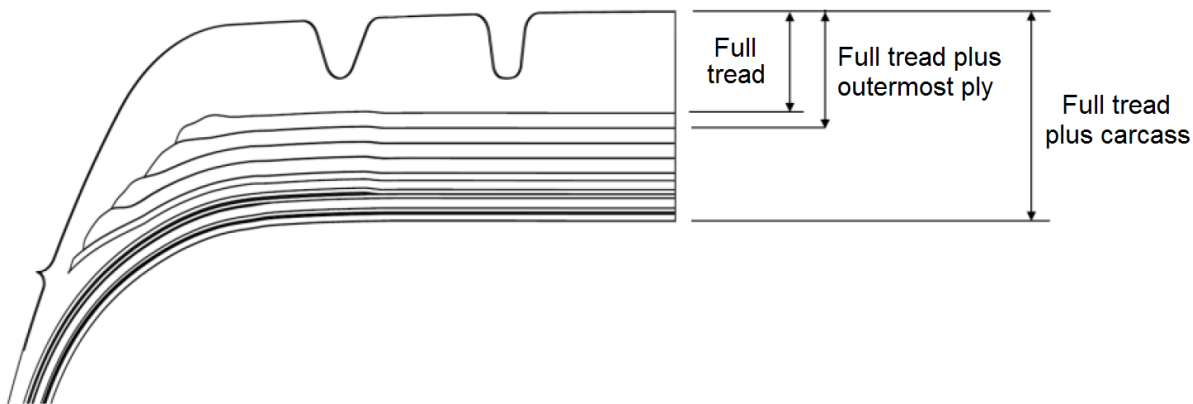


Figure 1 - Tread quantity for tire failure model

Total tread area:

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

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).

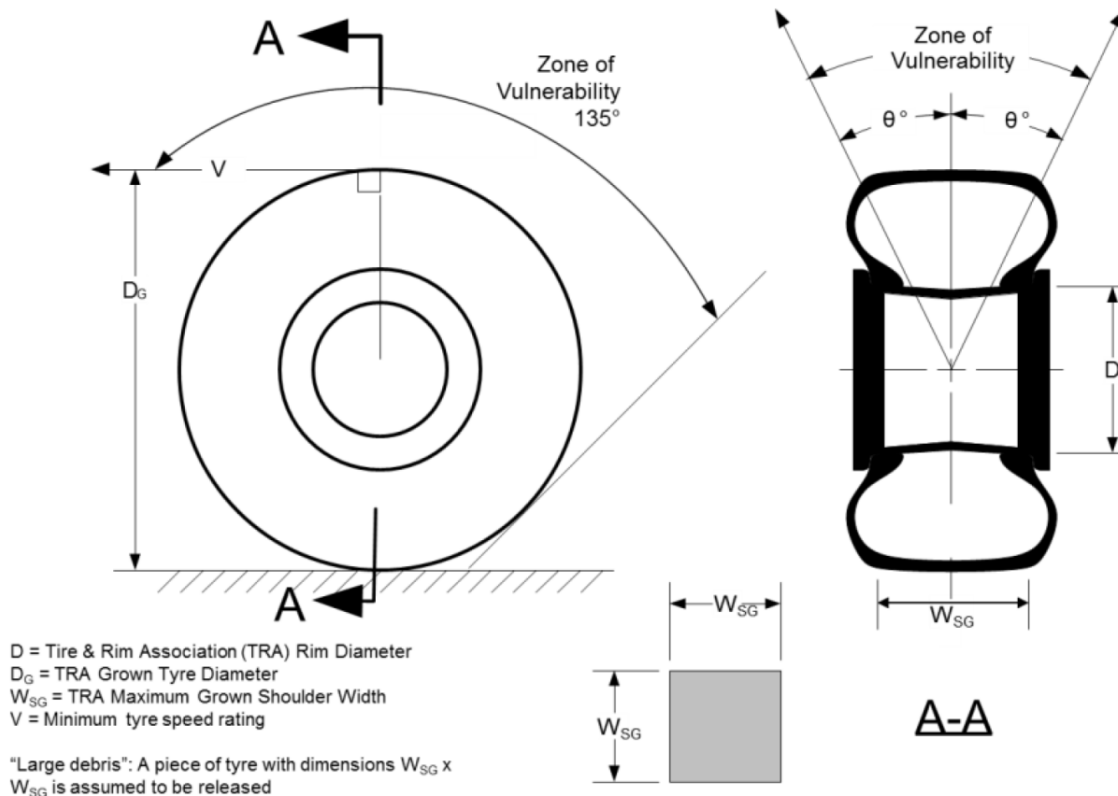


Figure 2 - Tire debris threat model

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 $\theta = 15$ degrees (either side of the tire centerline) and considering that both tires only release large debris. Inside zones defined by $15 \text{ degrees} < \theta \leq 30 \text{ degrees}$ 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](#).

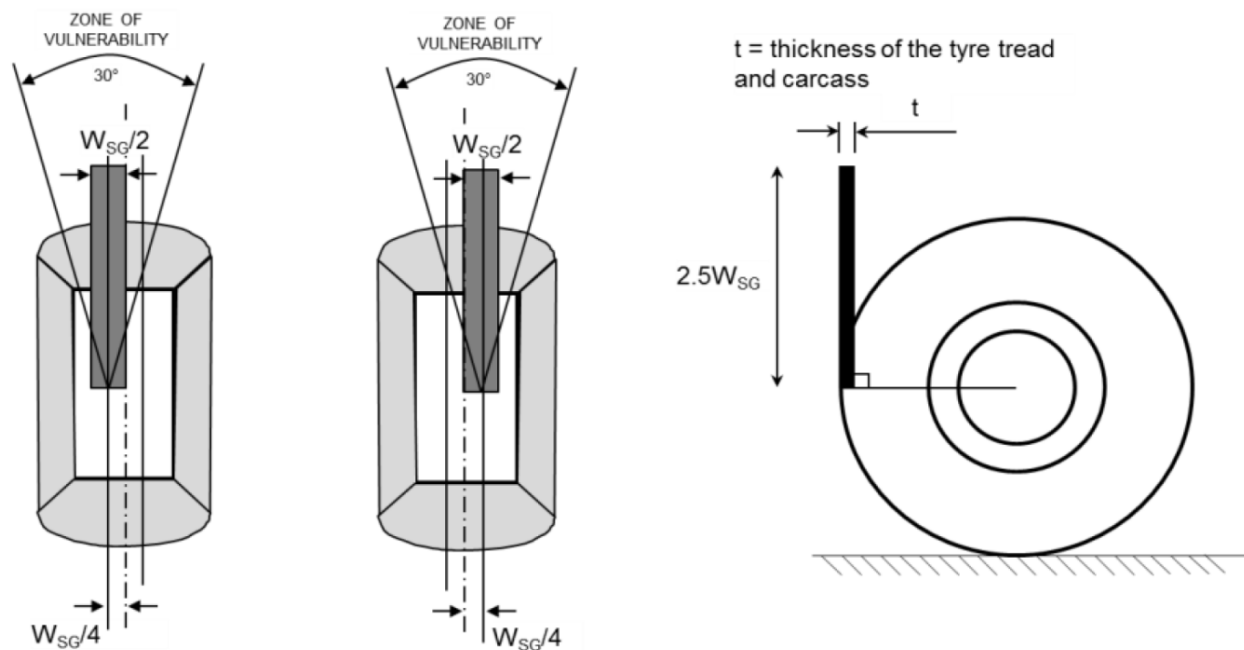


Figure 3 - Flailing tread model

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 $1377 \times 1.3 = 1790$ 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.

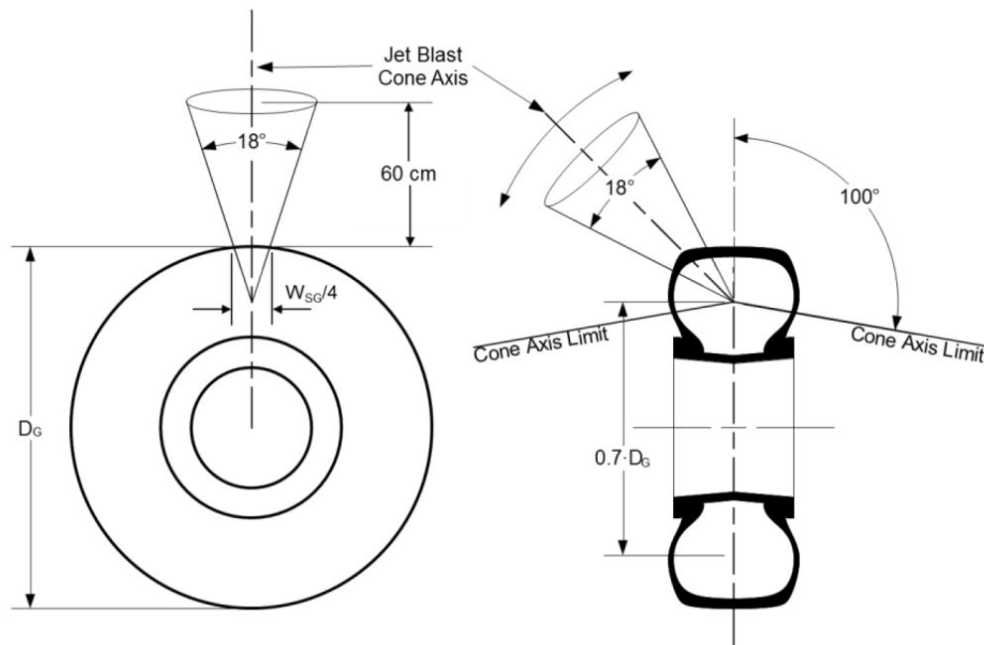


Figure 4 - Bias tire burst pressure effect - burst location