



AEROSPACE RECOMMENDED PRACTICE

ARP4955™

REV. A

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Superseding ARP4955

(R) Recommended Practice for Measurement of Static and
Dynamic Characteristic Properties of Aircraft Tires

RATIONALE

ARP4955A has been reaffirmed to comply with the SAE five-year review policy.

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FIGURE 13

SCHEMATIC OF INSTRUMENTED DYNAMOMETER USED TO MEASURE
TIRE CORNERING CHARACTERISTICS

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FIGURE 14

VARIATION OF SIDE-FORCE FRICTION COEFFICIENT OF THE SPACE
SHUTTLE ORBITER NOSE GEAR TIRE WITH VERTICAL LOAD AND YAW ANGLE

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1. SCOPE

The purpose of this SAE Aerospace Recommended Practice (ARP) is to establish guidelines for the measurement of static and dynamic characteristic properties of aircraft tires. It is intended as a general guide toward standard practice, but may be subject to frequent changes to keep pace with experience and technical advances.

This revision (Revision A) is also intended to provide suggested guidelines for synthesizing tire dynamic data necessary for landing gear shimmy analyses.

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 724-776-4970 (outside USA), www.sae.org.

- | | | |
|---------|------------------|---|
| 2.1.1.1 | SAE J670e | Vehicle Dynamics Terminology, 1976 |
| 2.1.1.2 | SAE 1999-01-5527 | An Investigation of Landing Gear Shimmy: Tire Models, Tire Test Methodologies, Analysis and Parameter Studies, John Medzorian, 1991 |
| 2.1.1.3 | SAE 961300 | Relaxation Behavior of Aircraft Tires, C. B. Alsobrook and M. G. Vogel, 1996 |
| 2.1.1.4 | SAE 2005-01-3438 | Mechanical Properties of Radial-Ply Aircraft Tires, John Tanner, Robert Daugherty, Henry Smith, 2005 |

2.1.2 NASA Publications

Available from NASA, Documentation, Marshall Space Flight Center, AL 35812, www.nas.nasa.gov.

- | | | |
|---------|---------------------|--|
| 2.1.2.1 | NASA TR R-64 | Mechanical Properties of Pneumatic Tires with Special Reference to Modern Aircraft Tires, Robert Smiley, Walter Horne, 1960 |
| 2.1.2.2 | NASA TP 1863 | Static and Yawed Rolling Mechanical Properties of Two Type VII Aircraft Tires, John Tanner, Sandy Stubbs, John McCarty, 1981 |
| 2.1.2.3 | NASA TP 1917 | Cornering of the Nose-Gear Tire of the Space Shuttle Orbiter, William Vogler, John Tanner, 1981 |
| 2.1.2.4 | NASA TM 1999-209141 | Quasi-Static Viscoelastic Finite Element Model of an Aircraft Tire, Arthur Johnson, John Tanner, Angela Mason, 1999 |
| 2.1.2.5 | NASA TM 2003-212415 | A Study of the Mechanical Properties of Modern Radial Aircraft Tires, Robert Daugherty, 2003 |

2.1.3 U.S. Government Publications

Available from the Document Automation and Production Service (DAPS), Building 4/D, 700 Robbins Avenue, Philadelphia, PA 19111-5094, Tel: 215-697-6257, <http://assist.daps.dla.mil/quicksearch/>.

2.1.3.1 MIL-PRF-5041 Military Specification for Tires, Pneumatic, Aircraft

2.1.3.2 DOT HS 905 952 Mechanics of Pneumatic Tires, Samuel Clark, 1981

2.2 Other Applicable References

2.2.1 J. of Aircraft, Vol.8, No. 9 Synthesis of Tire Equations for Use in Shimmy and Other Dynamic Studies; L. C. Rogers, H. K. Brewer, 1971

2.2.2 J. of Aircraft, Vol. 6, No. 3 Tire Parameters for Landing-Gear Shimmy, R. L. Collins, R. J. Black, 1969

2.3 Symbols

A_1 constant depending on initial tire distortion

A_2 constant depending on the initial lateral force

A_{fy} side force amplitude ratio

A_{mz} aligning moment amplitude ratio

C_ψ cornering stiffness

C_1 zero offset

C_2 initial tire lateral force

D_{fy} $-\tan(\delta_{fy}) > 0$

D_{mz} $-\tan(\delta_{mz}) > 0$

F_o steady state force

F_d drag force (parallel to the wheel plane)

F_s side force (perpendicular to the wheel plane)

F_x fore and aft force

F_y lateral force

F_z vertical load

H tire footprint half length

h loaded radius, axle height

K_l lateral stiffness

K_t torsional stiffness

K_x	fore and aft stiffness
L	relaxation length
L_f	unyawed rolling relaxation length
L_y	yawed-rolling relaxation length
M_{fy}	$A_{fy} > 0$
M_{mz}	$-A_{mz} > 0$
M_x	overturning moment
M_y	brake torque
r	tire undeflected radius
R_{BT}	brake torque radius
r_e	effective rolling radius
r_{eb}	effective braked rolling radius
r_{ey}	effective yawed rolling radius
t	time
V	horizontal velocity of wheel
x	distance rolled
x_c	fore-aft shift of the center of pressure
y'_c	lateral shift of the center of pressure
α	wheel slip angle = angle between SAE X axis and velocity of wheel plane on ground vector (rad)
α_a	maximum amplitude of twist during oscillation
α_m	mean tire twist
Δ	lateral displacement of footprint
δ	tire deflection
δ_{mz}	aligning moment phase angle
δ_{fy}	side force phase angle
ϕ	phase angle
η_t	torsional damping coefficient
η_x	fore and aft damping coefficient

λ	wavelength = yaw oscillation frequency / longitudinal velocity
θ_a	wheel yaw amplitude
ψ	yaw angle
ψ_t	tire twist angle
Ω	angular velocity of wheel
ω	yaw rate

3. TIRE PREPARATION

3.1 Tire Conditioning

Before break-in, the tire shall be conditioned by mounting on its design rim and inflating it to the rated inflation pressure. The tire shall be allowed to remain in this condition for 24 h at an ambient temperature ranging from 60 to 100 °F (15.6 to 37.8 °C).

3.2 Tire Inflation and Ambient Temperature

After the tire has been conditioned for 24 h on the design rim as indicated in 4.1, the tire pressure shall be readjusted to the rated inflation pressure with a gauge which has been calibrated to within 1%. All tests shall be carried out at temperatures range of 60 °F (15.6 °C) to 100 °F (37.8 °C).

3.3 Break-in Procedure

3.3.1 Break-in Procedure - Static Testing Only

This method of tire break-in prepares the test tire by inflating it to rated inflation pressure and loading the tire under direct vertical load against a hard, flat, unyielding surface to the point that the tire deflection measures 50% of the section height. The load is then removed. This load-deflection procedure is carried out five times each at two locations equally spaced around the tire, with the centerline of the contact patch being located at 180 degree intervals around the circumference of the tire. When the tire has been unloaded for 1 h or more, the break-in procedure should be repeated before resuming static loading testing. Figure 1 illustrates the effect of this break-in procedure on the hysteresis characteristics of the tire vertical load-deflection curve.

3.3.2 Break-In Procedure - Dynamic or Alternate Static Testing

This method of tire break-in prepares the test tire by inflating it to rated inflation pressure, corrected for flywheel curvature, then performing five rated load take-off cycles of a load-speed-time curve representative of the applicable aircraft.

4. STATIC PROPERTY TESTS

4.1 Loading Apparatus

The tire is to be mounted on either a suitable yoke or a mandrel and loaded vertically against a hard, flat, unyielding surface under a camber angle of $0^\circ \pm 1/4^\circ$, and under a caster angle of $0^\circ \pm 1/4^\circ$ (see Figure 2). The load measuring system shall be accurate within $\pm 1\%$ of the load applied to the tire. If a mandrel type axle is used in the testing equipment, compensation should be made for the resulting axle deflection created during the loading of the tires.

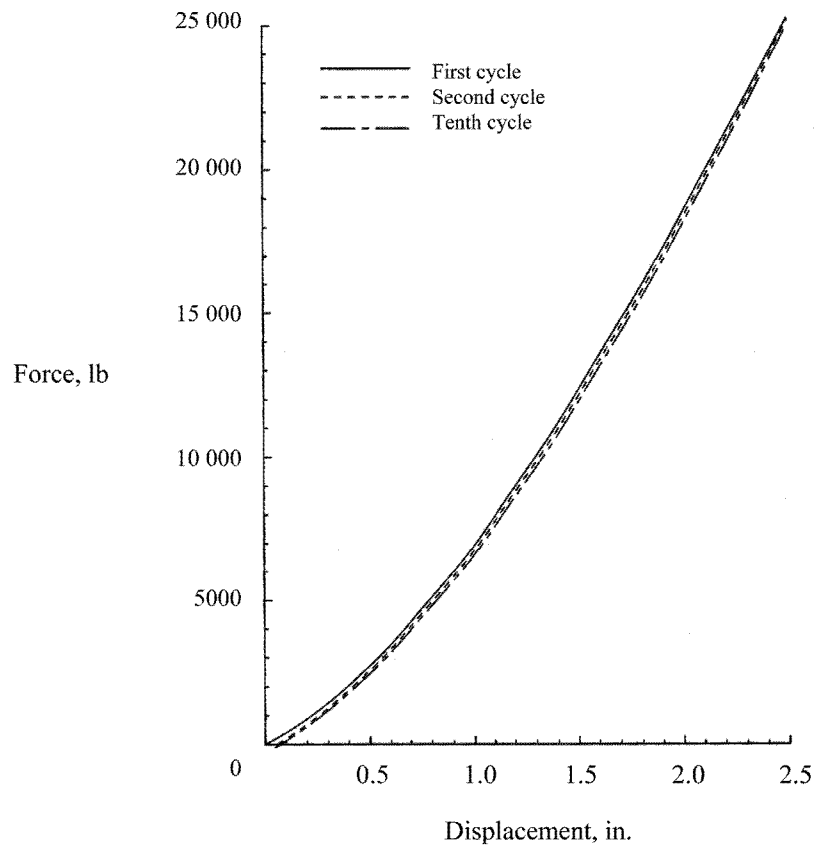


FIGURE 1 - LEAST-SQUARES APPROXIMATION OF HYSTERESIS LOOPS DURING CYCLIC LOADING

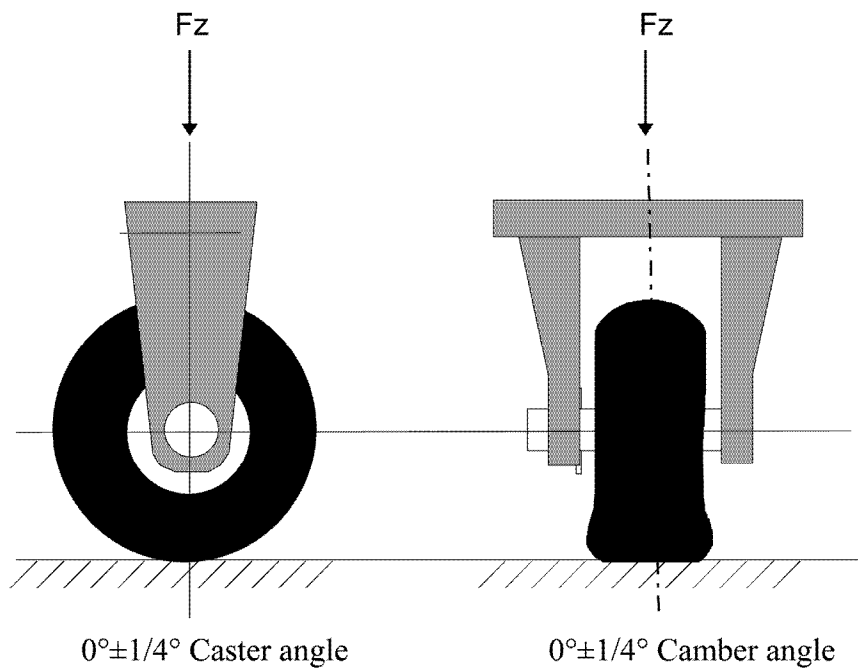


FIGURE 2 - LOAD MACHINE CONFIGURATION

4.1.1 Loading Plate

The surface of the plate in contact with the tire shall be a smooth metal plate. Other surfaces may be used in lieu of this surface but must be noted with the reporting of the data.

Any contamination of the prepared surface of the plate should be removed prior to each load application to maintain a uniform friction coefficient.

4.2 Vertical Load Deflection Curves

This recommended practice is based on the measurement of load deflection curves at rated inflation pressure. It should be understood that any inflation pressure may be used for this test, and it is left to the specification of the user to define pressures other than rated pressures. Accordingly, such load deflection curves as are described in this section shall clearly state the inflation pressure at which they were obtained.

4.2.1 Vertical Load Deflection Curves

Vertical load deflection curves shall be obtained on the inflated tire by means of applying a vertical load designated F_z in Figure 2, and measuring the corresponding deflection between the wheel flange and the unyielding flat surface against which the tire acts. The load will be applied beginning from the point of contact of the tire with the flat surface until such time as the tire bottoms, with continuous recording of load, inflation pressure and corresponding deflection. Load will then be reduced until its value returns to zero, again continuously monitoring load, inflation pressure, and corresponding deflection. The total load deflection loop or curve shall be presented as indicative of the vertical load deflection characteristics of the tire.

This test shall be carried out at two locations around the tire 180 degrees apart. Each vertical load deflection test shall be performed at the opposite location of the last loading to minimize the effect of a flat spot.

The time rate of the tire deflection shall not be more than 2.0 in/min (50.8 mm/min).

4.2.2 Vertical Spring Rate

The vertical spring rate is defined as the spring constant associated with the average slope of a line tangent to the load deflection curve during loading at a specified deflection (preferably rated deflection). It is derived from the vertical load deflection curves created according to 4.2.1.

4.2.3 Bottoming Point

The tire bottoming point is the point at which the tire has fully deflected its sidewall and is beginning to compress the lower sidewall structure. This is recognized by a noticeable change in the slope of the load deflection curve occurring at a high load and deflection. The bottoming point is the load and deflection at that point.

4.2.3.1 Applicable Range of Measured Parameters

Bottoming point should be measured at the rated inflation pressure for the application. Additional inflation pressures may be required by the investigator for additional operating parameters.

4.2.3.2 Procedure for Approximating Bottoming Point

4.2.3.2.1 For the purpose of approximating bottoming load for a given tire and given inflation, the bottoming load shall be considered to be that load at which the rate of loading (lb/in) is 2.2 times the average rate of loading between 28% and 48% vertical deflection.

4.2.3.2.2 The bottoming load is determined as follows (see Figure 3):

- Conduct load deflection testing as described in 4.2.1, obtaining sufficient data to plot a representative curve for the inflation pressure required.
- Plot the load deflection curve.
- Calculate the inverse slope (lb/in) between 28% and 48% deflection
(Figure 3 example: $14,600 / 1.46 = 10,000$ lb/in)
- Construct a straight line (A-A) having a slope (lb/in) equal to 2.2 times that of c. (e.g., $2.2 \times 10,000 = 22,000$ lb/in).
- Draw line B-B parallel to A-A and tangent to the load deflection curve in the bottoming area.
- The bottoming load will be considered that value which occurs at the point of tangency (P).

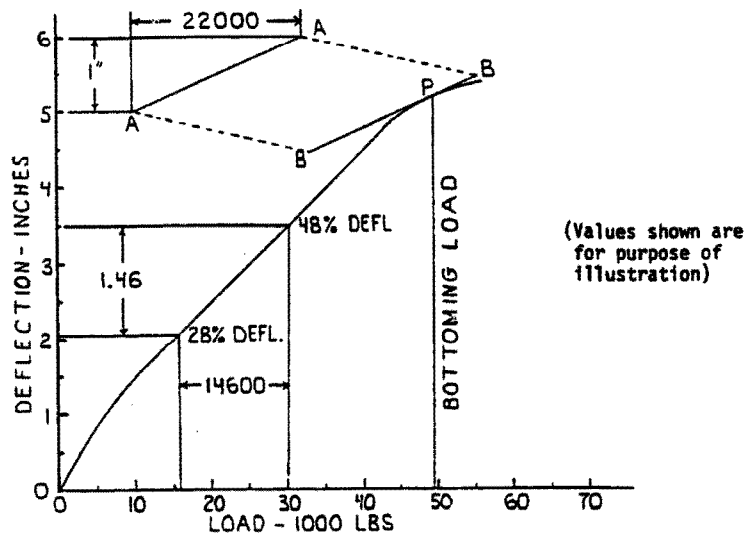


FIGURE 3 - APPROXIMATION OF BOTTOMING POINT

4.2.3.3 Alternate Procedure for Determining the Bottoming Point

- Adhere two 1.5 in (38.1 mm) wide thin metal strips with wire leaders attached, to the inside of the tire in the configuration shown in Figure 4.
- Mount the tire and inflate to the specified test pressure. Locate the strips in the center of the footprint and load the tire at a rate not exceeding 2.0 in/min (50.8 mm/min) until continuity is indicated on the ohmmeter. This indicates the metal strips are in contact with each other and the tire has reached its bottoming point. Record the load, deflection, and pressure at this point.

4.3 Non Rolling Lateral Load - Deflection Curves

4.3.1 Definition of Lateral Deflection

The lateral deflection of the tire is the relative lateral displacement between the wheel flange at a point immediately above the centerline of the tire contact patch, and the loading plate, parallel to the loading plate surface. This displacement is along the SAE Y axis from the wheel center plane on the ground and the tire footprint geometric center. The SAE vehicle axis system is defined in Reference 2.1.1.1 as a right-hand orthogonal system such that forward motion is along the SAE X axis, the SAE Y axis points to the right and the SAE Z axis points downward.

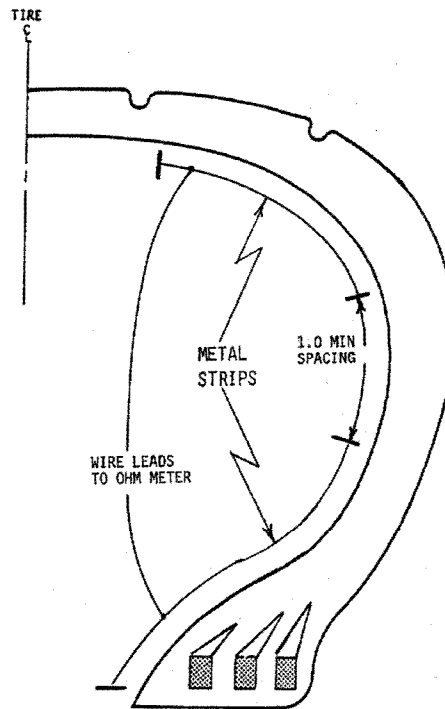


FIGURE 4 - LOCATION OF METAL STRIPS

4.3.2 Obtaining Lateral Load Deflection Curves

The surface of the plate in contact with the tire shall be covered with a material designed to prevent tire slippage, insofar as possible. Lateral load deflection curves shall be obtained by first loading the inflated tire as described in 3.1 to the rated deflection under rated load conditions, followed by lateral displacement of the tire yoke or the flat surface against which the tire rests in a direction perpendicular to the wheel plane. The lateral displacement may be obtained either by displacement of the yoke or the flat surface or both. Care must be taken to account for any structural deflections of the tire mounting fixture during these tests.

Quasi-static load deflection curves will be obtained by increasing the lateral load from zero to a value equal to 30% of the applied vertical load, then by decreasing this lateral load to zero and increasing it in the opposite direction to 30% of the applied vertical load, and finally returning to 30% of the rated vertical load, completing the loop (in Figure 5, O - A - B - A). It is suggested that this loading sequence be repeated three times to insure that the hysteresis loop is repeatable. Load, pressure, and lateral deflection will be continuously recorded. This lateral hysteresis loop, Figure 5, shall be obtained at a deflection rate of not more than 2.0 in/min (50.8 mm/min).

These lateral load deflection curves will be obtained at two points around the periphery of the tire, separated by 180 degrees, and representing the centerline of the contact patch under loaded conditions. All curves will be performed as indicative of the tire lateral load deflection characteristics.