



AEROSPACE RECOMMENDED PRACTICE

ARP4955™**REV. B**

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Superseding ARP4955A

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

RATIONALE

This document describes recommended practices to measure the various tire properties described herein. The purpose is to provide data which is comparable across test facilities and apparatus and is reliable for use in predictive models and for determination of design loads in other aircraft components.

Revision B of ARP4955 added an improved break in option for static testing, further refines definition of the loading plate, rewords "spring rate" to "stiffness," changes the method in which Fore-Aft and Torsional stiffness is determined (to improve repeatability and accuracy), and amends the load values in remaining static property tests.

TABLE OF CONTENTS

1.	SCOPE	4
2.	REFERENCES	4
2.1	Applicable Documents	4
2.1.1	SAE Publications	4
2.1.2	AIAA Publications	4
2.1.3	NASA Publications	5
2.1.4	U.S. Department of Defense Publications	5
2.1.5	U.S. Department of Transportation Publications	5
2.2	Symbols	5
3.	TIRE PREPARATION	7
3.1	Tire Conditioning	7
3.2	Tire Inflation and Ambient Temperature	7
3.3	Break-In Procedure	7
3.3.1	Break-In Procedure - Static Testing Only	7
3.3.2	Break-In Procedure - Dynamic or Alternate Static Testing	8
4.	STATIC PROPERTY TESTS	9
4.1	Loading Apparatus	9
4.1.1	Loading Plate	9
4.2	Vertical Load Deflection Curves	10
4.2.1	Vertical Load Deflection Curves	10
4.2.2	Vertical Stiffness	10
4.2.3	Bottoming Point	10

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4.3	Non-Rolling Lateral Load - Deflection Curves	12
4.3.1	Definition of Lateral Deflection	12
4.3.2	Obtaining Lateral Load Deflection Curves	12
4.3.3	Obtaining Lateral Damping	14
4.3.4	Lateral Stiffness	14
4.3.5	Vertical Sinkage	14
4.4	Measurement of Shift of the Contact Patch Centroid during Lateral Loading	14
4.5	Non-Rolling Fore and Aft Load Deflection Curves	15
4.5.1	Definition of Fore-Aft Deflection	15
4.5.2	Method for Determining Fore-Aft Load Deflection Curves	15
4.5.3	Obtaining Fore and Aft Damping	16
4.5.4	Fore-Aft Stiffness	16
4.5.5	Vertical Sinkage	17
4.6	Measurement of the Shift of the Contact Patch Centroid during Fore-Aft Loading	17
4.7	Measurement of Brake Torque Radius	18
4.8	Non-Rolling Torsional Load Deflection	18
4.8.1	Equipment Description	18
4.8.2	Applicable Range of Measured Parameters	18
4.8.3	Test Procedure	18
4.8.4	Data Reduction	20
5.	ROLLING TIRE MECHANICAL PROPERTY TESTS	21
5.1	Yawed Rolling Relaxation Length	21
5.1.1	Equipment Description	21
5.1.2	Applicable Range of Measured Parameters	21
5.1.3	Test Procedure	21
5.1.4	Data Reduction	22
5.2	Unyawed Rolling Relaxation Length	24
5.2.1	Equipment Description	25
5.2.2	Applicable Range of Measured Parameters	25
5.2.3	Test Procedure	25
5.2.4	Data Reduction	25
5.3	Rolling Cornering Properties	26
5.3.1	Equipment Description	27
5.3.2	Applicable Range of Measured Parameters	27
5.3.3	Test Procedures	28
5.3.4	Data Reduction	28
5.4	Rolling Radius	29
5.4.1	Free Rolling Radius	29
5.4.2	Yawed or Braked Rolling Radius	30
5.5	Rolling Resistance	31
5.5.1	Equipment Description	31
5.5.2	Applicable Range of Measured Parameters	31
5.5.3	Test Procedures	31
5.6	Dynamic Tire Shimmy Properties	32
5.6.1	Kinematical Parameters	32
5.6.2	Static Measurements	32
5.6.3	Tire Model Parameters	32
5.6.4	Test Procedure	33
5.6.5	Measurements	34
5.6.6	Data Reduction	34
5.6.7	Synthesis of Tire Properties	35
6.	NOTES	35
6.1	Revision Indicator	35

Figure 1	Least-squares approximation of hysteresis loops during cyclic loading	8
Figure 2	Load machine configuration	9
Figure 3	Approximation of bottoming point	11
Figure 4	Location of metal strips	12
Figure 5	Typical lateral hysteresis loop	13
Figure 6	Forces and moments in vertical plane perpendicular to wheel plane	15
Figure 7	Typical fore-aft rebound curve	16
Figure 8	Forces and moments in vertical plane parallel to wheel plane	17
Figure 9	Torsional stiffness characteristics	19
Figure 10	Torsional hysteresis loop	20
Figure 11	Typical test data	23
Figure 12	Unyawed rolling relaxation	24
Figure 13	Forces and moment in the tire at axle	26
Figure 14	Schematic of instrumented dynamometer used to measure tire cornering characteristics	27
Figure 15	Variation of side-force friction coefficient of the space shuttle orbiter nose gear tire	28

1. SCOPE

The purpose of this SAE Aerospace Recommended Practice (ARP) is to establish general guidelines for the measurement of static and dynamic characteristic properties of aircraft tires.

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: 1-877-606-7323 (U.S. and Canada only) or 1-724-776-4970 (outside U.S. and Canada), www.sae.org.

AIR6280 Overview of Aircraft Landing Gear Shimmy Analysis Methods

SAE J670 Vehicle Dynamics Terminology

Alsobrook, C. and Vogel, M., "Relaxation Behavior of Aircraft Tires," SAE Technical Paper 961300, 1996, <https://doi.org/10.4271/961300>.

Medzorian, J., "An Investigation of Landing Gear Shimmy: Tire Models, Tire Test Methodologies, Analysis, and Parameter Studies," SAE Technical Paper 1999-01-5527, 1999, <https://doi.org/10.4271/1999-01-5527>.

Tanner, J., Daugherty, R., and Smith, H., "Mechanical Properties of Radial-Ply Aircraft Tires," SAE Technical Paper 2005-01-3438, 2005, <https://doi.org/10.4271/2005-01-3438>.

2.1.2 AIAA Publications

Available from American Institute of Aeronautics and Astronautics, 12700 Sunrise Valley Drive, Reston, VA 20191-5807, Tel: 800-639-2422, www.aiaa.org.

Collins, R.L., and Black, R.J. (1969). Tire parameters for landing-gear shimmy. *Journal of Aircraft*, 6(3). <https://doi.org/10.2514/3.44044>.

Rogers, L.C., and Brewer, H.K. (1971). Synthesis of tire equations for use in shimmy and other dynamic studies. *Journal of Aircraft*, 8(9). <https://doi.org/10.2514/3.44295>.

2.1.3 NASA Publications

Copies of these documents are available online at <https://ntrs.nasa.gov>.

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

2.1.4 U.S. Department of Defense Publications

Copies of these documents are available online at <https://quicksearch.dla.mil>.

MIL-DTL-5041	Tires, Ribbed Tread, Pneumatic, Aircraft
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2.1.5 U.S. Department of Transportation Publications

Available from U.S. Department of Transportation, 1200 New Jersey Avenue SE, Washington, DC 20590, Tel: 855-368-4200, www.transportation.gov.

DOT HS 905 952	Mechanics of Pneumatic Tires (Samuel Clark, 1981)
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2.2 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 (previously referred to as cornering power)
C_1	zero offset
C_2	initial tire lateral force
D_{fy}	$-\tan(\delta_{fy}) > 0$
D_{mz}	$-\tan(\delta_{mz}) > 0$
F_0	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
η_y	lateral 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 should be conditioned by mounting on its design rim and inflating it to the rated inflation pressure. The tire should be allowed to remain in this condition for 24 hours 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 hours on the design rim as indicated in 3.1, the tire pressure should be readjusted to the rated inflation pressure with a gauge which has been calibrated to within 1%. All tests should be carried out at temperatures range of 60 to 100 °F (15.6 to 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 hour 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.

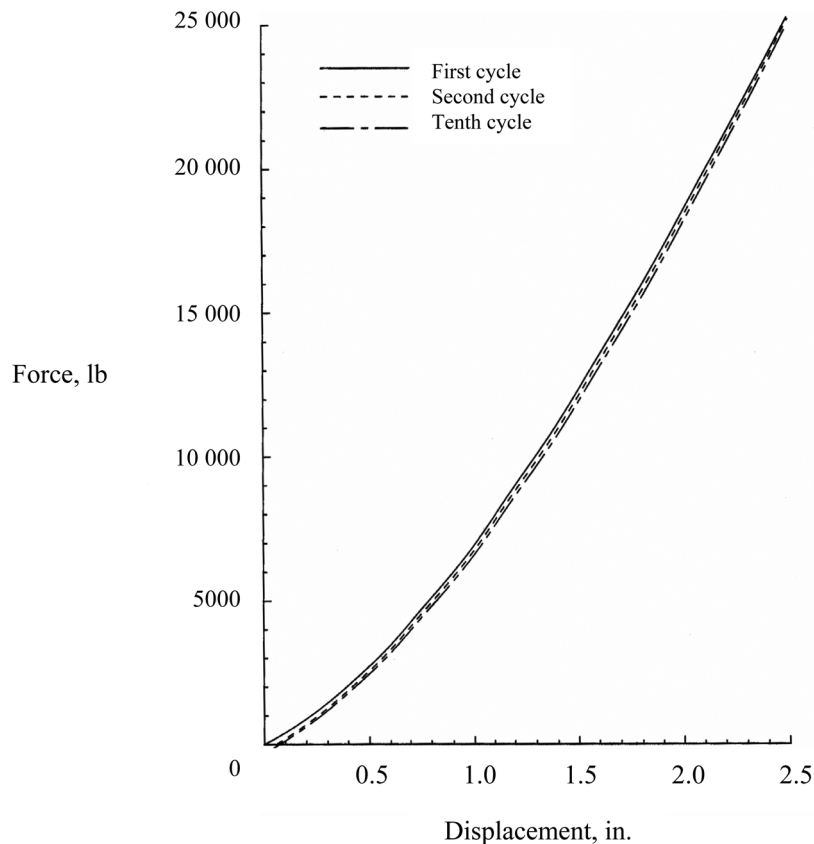


Figure 1 - Least-squares approximation of hysteresis loops during cyclic loading

When test machinery permits rolling the tire, a variation of the above method should be used: Load tire to 50% deflection as above and roll the tire back and forth in a manner that loads the tire around its entire circumference for a minimum of four revolutions.

NOTE: Repetition of five cycles is based on historical analysis showing this number provided a practical minimum cycle count to ensure tires are adequately broken in.

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 takeoff cycles of a load-speed-time curve representative of the applicable aircraft.

NOTE: Repetition of five cycles is based on historical analysis showing this number provided a practical minimum cycle count to ensure tires are adequately broken in.

4. STATIC PROPERTY TESTS

4.1 Loading Apparatus

The tire should be mounted on either a suitable yoke or a mandrel and loaded vertically against a hard, flat, unyielding surface under a camber angle of $0 \text{ degrees} \pm 0.25 \text{ degree}$, and under a caster angle of $0 \text{ degrees} \pm 0.25 \text{ degree}$ (see Figure 2). The load measuring system should 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.

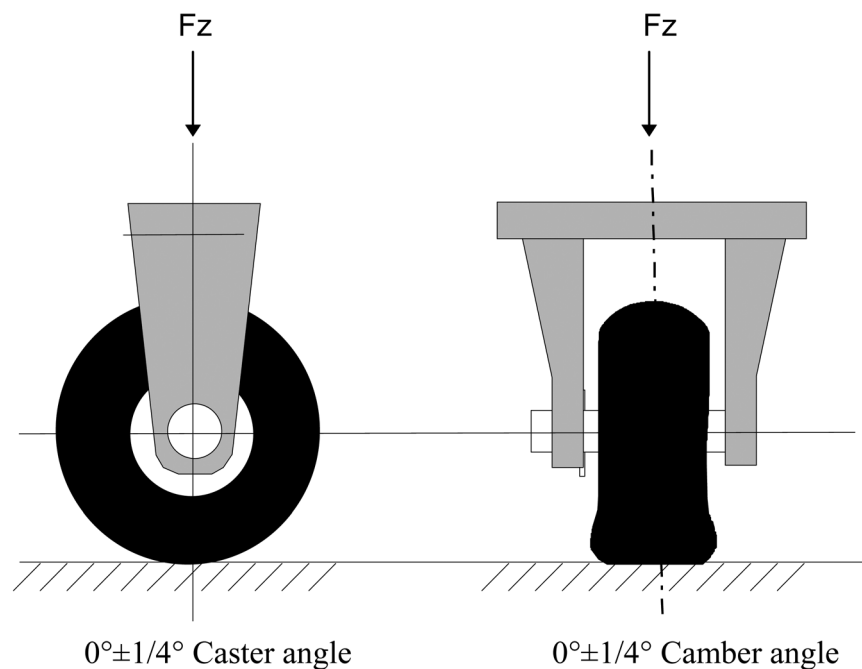


Figure 2 - Load machine configuration

4.1.1 Loading Plate

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

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

The coefficient of friction should be both high and consistent to provide meaningful results but should not be so aggressive as to restrict localized slipping within the tire footprint. This type of surface is often used when testing other components (wheels, brakes) to extreme conditions but does not allow the tire to deform locally as it would in service.

The friction limits of the tire/surface should be measured as part of the test by braking until slip occurs, and this will provide adequate information to compare data from different test setups, across time and facilities.

A smooth aluminum surface is easily cleaned and provides a friction coefficient which will exceed that of most runways. These data can then be truncated to simulate tire behavior on runways of any condition for which the effective μ is known.

4.2 Vertical Load Deflection Curves

This recommended practice is based on the measurement of load deflection curves at rated inflation pressure. 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 should clearly state the inflation pressure at which they were obtained.

Inflation pressure increases as the tire is deflected, increasing by approximately 4% at rated load and to approximately 20% at bottoming load. The reported pressure for Load Deflection Curves, as for all other mechanical properties tests, is the unloaded pressure.

4.2.1 Vertical Load Deflection Curves

Vertical load deflection curves should 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 should be presented as indicative of the vertical load deflection characteristics of the tire.

This test should be carried out at two locations around the tire 180 degrees apart. Each vertical load deflection test should 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 should not be more than 2.0 in/min (50.8 mm/min).

4.2.2 Vertical Stiffness

The vertical stiffness is defined as the 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

To approximate bottoming load for a given tire and given inflation, the bottoming load should be considered to be that load at which the stiffness (lb/in) is 2.2 times the average rate of loading between 28 and 48% vertical deflection.

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: $14600 / 1.46 = 10000$ lb/in).
- Construct a straight line (A-A) having a slope (lb/in) equal to 2.2 times that of c. (e.g., $2.2 \times 10000 = 22000$ 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 tangent intersection (P).

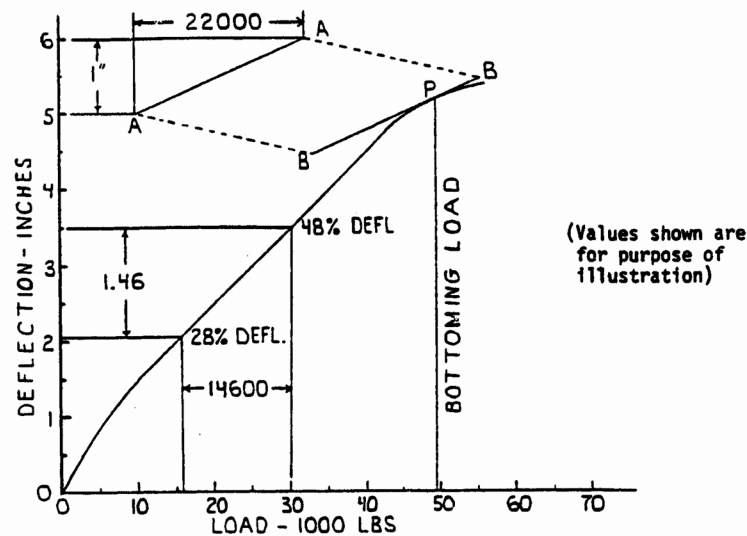


Figure 3 - Approximation of bottoming point

- Note, any mathematical procedure which accurately determines the vertical stiffness at rated load and the load at which the vertical stiffness reaches 220% of this value is acceptable.

For example, finding an equation which fully characterizes the curve, then differentiating it gives an equation describing the stiffness at any point. This can be evaluated at the rated load to determine the base stiffness (or its inverse, depending on whether the function describes load/deflection, or deflection/load as shown in Figure 3).

NOTE: Beyond bottoming, tire deflection will transition into a linear deflection referred to as “crush loading.” This loading is likely to result in permanent damage to the structure of the tire and will ultimately result in tire failure. Determination of bottoming should only deflect the tire sufficient to determine the bottoming point has been met, as detailed above. Any deflection beyond bottoming and into crush loading should only be conducted with the direct input of the relevant tire manufacturer.