



AEROSPACE INFORMATION REPORT

AIR6280™

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Overview of Aircraft Landing Gear Shimmy Analysis Methods

RATIONALE

This report provides information on the contributions of each landing gear component to shimmy stability. Landing gear shimmy design considerations, modeling assumptions, and analysis techniques are provided. The report fills a need for a document that addresses landing gear shimmy behavior and shimmy analysis broadly but concisely from the perspective of aircraft landing gear design and analysis. Other resources in the shimmy literature are more focused on specific components of shimmy modeling, such as tire modeling, or are documenting research on specific landing gears and aircraft.

AIR6280 has been reaffirmed to comply with the SAE Five-Year Review policy.

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1. SCOPE

This SAE Aerospace Information Report (AIR) provides an overview of the tire properties, strut properties, damper properties, and other landing gear mechanical properties that contribute to shimmy stability and are required for shimmy analysis. A variety of analysis techniques and assumptions are presented.

1.1 Field of Application

This AIR is applicable to large and small fixed wing and rotary wing aircraft for military or civilian use.

1.2 Purpose

The purpose of this report is to provide an airframe manufacturer, landing gear manufacturer, or component supplier with an overview of landing gear properties necessary to conduct shimmy analysis. This report provides information on how each landing gear component contributes to shimmy stability and provides an overview of shimmy analysis methods, assumptions, and techniques.

2. 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 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.

- [1] ARP1595 Design and Verification of Aircraft Nose Wheel Steering Systems
- [2] ARP4955 Recommended Practice for the Measurement of Static and Dynamic Properties of Aircraft Tires
- [3] AIR4894 Landing Gear Stability

2.2 U.S. Government Publications

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

- [4] AF-TR-6590 Landing Gear Vibration, W. J. Moreland, 1951.

2.3 NASA Publications

NASA Technical Services, NASA STI Program STI Support Services, Mail Stop 148, NASA Langley Research Center, Hampton, VA 23681-2199, 757-864-9658, Fax: 757-864-6500, <http://ntrs.nasa.gov/>.

- [5] NASA TR R-64 Mechanical Properties of Pneumatic Tires with Special Reference to Modern Aircraft Tires, Robert Smiley, Walter Horne, 1960.

2.4 NACA Publications

Available from National Technical Information Service, 5301 Shawnee Road, Alexandria, VA 22312, Tel: 1-888-584-8332 or 703-605-6050, www.ntis.gov.

- [6] NACA TM-1365 Shimmying of a Pneumatic wheel, B. Von Schlippe and R. Dietrich, 1954 pp. 125-160.

- [7] NACA TM-1299 Evaluation and Extension of Linearized Theories for Tire Motion and Wheel Shimmy, Robert Smiley, 1957.

2.5 Other Publications

- [8] SAE 1999-01-5527 An Investigation of Landing Gear Shimmy: Tire Models, Tire Test Methodologies, Analysis and Parameter Studies, John Medzorian, 1999.
- [9] SAE 961300 Relaxation Behavior of Aircraft Tires, C. B. Alsobrook and M. G. Vogel, 1996.
- [10] SAE 931402 Modeling and Analysis of a Dual-Wheel Nosegear: Shimmy instability and Impact Motions, G. X. Li, 1993.
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- [14] Technical University of Delft Shimmy of Aircraft Main Landing Gears, Ph.D Dissertation, I. Besselink, 2000.
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- [19] AGARD-R-800 Influence of Nonlinearity on the Shimmy Behavior of Landing Gear, P. Woerner, O. Noel, Proceedings of 81st Meeting of the AGAFUI Structures and Materials Panel, Banff, Canada 4-5 October 1995.
- [20] Technische Universiteit Eindhoven Tyre Models for Shimmy Analysis: from Linear to Nonlinear, Ph.D Dissertation, Shenhai Ran, 2016.
- [21] Technische Hogeschool te Delft The Wheel Shimmy Phenomenon : A Theoretical and Experimental Investigation, with Particular Reference to the Non-Linear Problem, Ph.D Dissertation, Pacejka, H. B., 1966.
- [22] Vehicle System Dynamics The Magic Formula Tyre Model, Hans B. Pacejka & Egbert Bakker, 21:S1, 1-18, 1992.
- [23] MIL-S-8812D Steering System: Aircraft, General Requirements For
- [24] UK Defence Standard 00-970 Design and Airworthiness Requirements for Service Aircraft

3. SHIMMY BACKGROUND AND DEFINITIONS

Shimmy is an oscillatory response, with lateral and yaw motion, of the landing gear and tire system. It is generally understood to be caused by an unstable resonance occurring between the tire and the landing gear structure, either self-excited or caused by some external disturbance such as a runway irregularity or asymmetric tire contact. Shimmy can occur in the nose gear or main gear [14].

The main aircraft operating conditions that are important to consider in shimmy analysis are the aircraft mass range and also the aircraft speed range. The aircraft mass affects the vertical load on the landing gear and therefore the shock absorber stroke, which affects the stiffness of the gear. The load also affects the tire properties. The aircraft speed influences the coupling between the tire response due to its elastic behavior and the gear structural response. The gyroscopic effects are also greater at higher speeds (see 5.1.4).

Typically shimmy analysis considers the full range of landing gear stroke positions, including fully extended, to account for liftoff and low sink rate conditions.

For the aircraft speed range, the full range of landing and take-off speeds are considered, including up to tire rated speed. Often, to cover shimmy analysis uncertainty, an additional margin above the maximum operational speed is considered. There is currently no established industry standard for speed margin for analysis uncertainty. The margin is determined by the aircraft manufacturer or landing gear supplier. The margin is dependent on the confidence in the analytical model.

The objective of the shimmy analysis is to provide feedback to the design requirements based on the results of the analysis. As this report specifies, many components of the landing gear can affect the shimmy response during operation. Shimmy analysis is used to predict the conditions in which shimmy may present itself. Some aircraft have shimmy dampers to mitigate the probability of shimmy events. In this case, the analysis is used to direct mitigation strategies which may include tuning of the shimmy damper.

When the aircraft is ready for flight test, an aircraft shimmy test may be performed by producing a torsional excitation during taxi runs and observing the landing gear response. The excitation may be introduced by pilot control inputs or braking; it is important that the excitation generated is large enough for the gear torsional response to exceed the freeplay and to allow a good measurement of the damping, over several cycles, of the oscillation amplitude decay. Verifying that the lateral/torsional response induced in the test dampens out is a necessary success criterion for shimmy testing, but it is not sufficient evidence to conclude that shimmy will not occur in the fleet. The range of operating conditions and configurations present during the service life of the airplane fleet exceed the narrow range of conditions that will be tested. The test can be used to validate the damping characteristics predicted by analysis. The validated analysis is then used to examine the wider range of conditions that may exist in the fleet. Examples of variables that influence the response and are difficult to capture with testing include tire wear, joint freeplay, and friction due to wear, and runway condition. It can also be challenging to test the full range of gear loading, speeds, and steering modes. Shimmy testing occurs early in the flight test program but flight test data is monitored for shimmy throughout the flight test program.

Shimmy testing can also be done in a laboratory using a full scale landing gear assembly with a dynamometer to simulate takeoff conditions. A momentary side displacement given to the strut simulates hitting an obstacle which induces shimmy. The test is used to demonstrate evidence of sufficient shimmy damping within several cycles [22] [23]. Testing can be performed with and without the shimmy damper to show its effectiveness. Laboratory testing eliminates any risk to the aircraft and crew that may be a concern for airplane taxi testing. Additionally, laboratory testing allows for control over more variables which improves on the limited scope of conditions possible for airplane taxi testing described previously. Laboratory testing also allows the shimmy investigation to occur while the airplane is still in development. However, there are potential disadvantages to laboratory testing relative to airplane taxi tests. If a test aircraft is available, it can be cheaper and simpler to run the taxi tests than it would be to plan, setup and execute a dynamometer laboratory test. A taxi test also has the advantage of directly testing the shimmy behavior of the aircraft, rather than simulating it [16].

There are various stability requirements that have been suggested for preliminary design of landing gear. AIR4894 [3] recommends a perturbation should be reduced to 1/3 or less of the original amplitude within three cycles (this equates to 5.8% of critical damping). MIL-S-8812D [23] and ARP1595 [1] recommends the amplitude is reduced to 1/4 of the original amplitude within three cycles (7.4% of critical damping) for new equipment or reduced to 1/3 of the original amplitude within three cycles when considering adverse wear and service limits. The UK Def Stan 00-970 [24] suggests 5% of critical damping for preliminary design.

However, these preliminary requirements can be challenging to achieve and for many aircraft much lower minimum stability requirements have been used and shown to give acceptable shimmy stability in-service. In practice minimum stability requirements varying between 1% and 2% of critical damping have been used for many aircraft, and for some extreme operating conditions a minimum stability requirement of greater than 0% of critical damping has been accepted. However, it is noted that low damping levels can cause nuisance vibration and potential fatigue issues.

3.1 Nonlinear Factors Affecting Shimmy

Shimmy is a nonlinear vibration phenomenon. The primary sources of the nonlinearity are:

1. Tire Properties
2. Joint Freeplay
3. Joint and Strut Friction

4. Steering System

5. Shimmy Damper

See 5.1.2 for further comments on modeling assumptions related to nonlinear behavior.

3.2 Shimmy Analysis Challenges

Shimmy analysis provides several challenges because:

1. Shimmy onset can be sensitive to many different parameters. If these parameters are not estimated properly, then shimmy analysis results can be inconclusive or erroneous.
2. Shimmy cannot be completely studied with linear frequency domain techniques because linearization removes effects which cause shimmy.
3. Accurate shimmy analysis models require detailed design data which is not available early in the design. This means shimmy cannot be reliably analyzed until the design is settled, making changes difficult to implement.
4. When analyzing shimmy, “no degree of freedom can be neglected until numerical analysis and experiment have demonstrated the part it plays in determining the system stability” [11].
5. “No theory of shimmy can be complete. Factors such as nonlinearity of parameters backlash, fore-and-aft strut motion and extreme tire parameters play a part in the phenomenon” [11].

3.3 Contributing Factors to Shimmy

This section summarizes and describes contributing factors in the landing gear and aircraft design that are considered when designing the landing gear system, and when developing an analytical model for studying shimmy.

3.3.1 Geometry Layout Effects

This section describes effects of the landing gear layout geometry that can contribute to shimmy. Figure 1 shows a visual of the geometry. The geometric parameter definitions are consistent with reference [7].