



AEROSPACE RECOMMENDED PRACTICE

ARP5644™**REV. A**Issued 2013-04
Revised 2020-07

Superseding ARP5644

(R) Landing Gear Shock Absorption Testing of Civil Aircraft

RATIONALE

The report is revised to: (1) update references for Part 23 aircraft, (2) add a section on unique Russian requirements, (3) update section on gas absorption testing, (4) add equation for drop height, (5) update all equations for latest version of Word, and (6) include other minor updates and corrections.

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1. SCOPE

The intent of this document is to provide recommended practices for conducting shock absorption testing of civil aircraft landing gear equipped with oleo-pneumatic shock absorbers. The primary focus is for Part 25 aircraft, but differences for Part 23, 27, and 29 aircraft are provided where appropriate.

1.1 Purpose

The purpose of this document is to provide landing gear shock absorber impact test requirements and recommendations for civil aircraft. Guidance on test analytical correlation is also provided. Test data acquisition is defined which allow for the evaluation of the landing gear performance in regards to energy absorption requirements and validation of the analytical model used to determine design landing loads on the aircraft. The requirements and recommendations provided herein are intended to be used in the test specification report provided to the testing facility.

2. REFERENCES

Landing gear impact testing of civil aircraft is governed by the following Parts of the Code of Federal Regulations for U.S. certification.

14 CFR Part 23: Normal, Utility, Acrobatic, and Commuter Category Airplanes

§23.723, Amendment 23-49, Feb 9, 1996

§23.725, Amendment 23-48, Feb 9, 1996

§23.726, Amendment 23-7, Aug 13, 1969

§23.727, Amendment 23-7, Aug 13, 1969

(Note: These requirements have been re-published in ASTM F3061/F3061M, Standard Specification for Systems and Equipment in Small Aircraft)

14 CFR Part 25: Transport Category Airplanes

§25.723, Amendment 25-103, May 16, 2001

AC 25.723-1, "Shock Absorption Tests," May 25, 2001

Draft revision to AC 25.723-1, ARAC LDHWG Report, March 26, 2003

14 CFR Part 27: Normal Category Rotorcraft

§27.723, original release

§27.725, original release

§27.727, Amendment 27-26, May 6, 1990

14 CFR Part 29: Transport Category Rotorcraft

§29.723, original release

§29.725, Amendment 29-3, Jan 26, 1968

§29.727, Amendment 29-30, April 5, 1990

For European certification, the regulations are provided in the following Certification Specifications (CS):

CS-23: Normal, Utility, Aerobatic, and Commuter Category Aeroplanes

§23.723, Initial Issue, November 14, 2003

§23.725, Initial Issue, November 14, 2003

§23.726, Initial Issue, November 14, 2003

§23.727, Initial Issue, November 14, 2003

CS-25: Large Aeroplanes

§25.723, Initial Issue, October 17, 2003

AMC 25.723, Initial Issue, October 17, 2003

CS-27: Small Rotorcraft

§27.723, Initial Issue, November 14, 2003

§27.725, Initial Issue, November 14, 2003

§27.727, Initial Issue, November 14, 2003

CS-29: Large Rotorcraft

§29.723, Initial Issue, November 14, 2003

§29.725, Initial Issue, November 14, 2003

§29.727, Initial Issue, November 14, 2003

For Part 25 Russian certification, the regulations are provided in the following Aviation Regulations (AP):

Aviation Regulations (AP) Part 25: Airworthiness Standards: Transport Category Airplanes

§25.723, Amendment 25-8, 2015

3. BACKGROUND

The shock absorption test requirements for civil aircraft are based on 14 CFR Parts 23, 25, 27, and 29, and on Advisory Circular (AC) 25.723-1. These requirements are essentially the same as those in European Aviation Safety Agency (EASA) Certification Specifications (CS). For Parts 23, 27, and 29 aircraft (and until 2001 for Part 25 aircraft), the primary objectives of the drop test are to validate the limit design landing load factor, and to demonstrate energy absorption capability for limit and reserve energy levels. For Part 25 aircraft, the regulations changed significantly at Amendment 25-103. For this amendment, the primary purpose of the test changed from validation of limit load factor to validation of the analytical model used to determine design landing loads. In addition, the revised requirements and accompanying Advisory Circular provide guidance on the use of analysis for certification of growth versions of the aircraft in lieu of testing.

4. DEFINITIONS

AIR CURVE (OR "GAS SPRING CURVE"): The shock strut gas pressure as a function of stroke (the gas is typically nitrogen, not air).

ARAC: Aviation Rulemaking Advisory Committee.

FREE DROP HEIGHT: Distance the carriage drops prior to contacting the lift cylinders; this height determines the sink rate.

LDHWG: Loads and Dynamics Harmonization Working Group (ARAC).

LIMIT DESIGN ENERGY: The maximum kinetic energy associated with the design limit descent rates and weights.

LOAD FACTOR: Equal to the peak vertical acceleration of the carriage mass (in g) resulting from the drop, plus 1 g.

LOAD PLATFORM: The surface that the tires contact during the test, which includes load measurement instrumentation.

MLW: The maximum structural design landing weight corresponding to the limit design sink rate.

MTOW: The maximum structural design takeoff weight.

MASS TRAVEL: The vertical distance travelled by the carriage after release.

METERING PIN: A shaft passing through the main orifice plate which provides a variable orifice area versus strut compression by means of a varying diameter; other examples are fluted or grooved pins. This device provides the desired strut load versus stroke as prescribed by the airplane manufacturer, or landing gear supplier.

OLEO-PNEUMATIC: Refers to hydraulic fluid damping/gas spring type of shock strut configuration.

RESERVE ENERGY: The kinetic energy associated with 1.2 times the design limit sink rate at MLW (the factor is 1.225 for Russian certification).

SINK SPEED OR SINK RATE: The vertical downward component of the landing speed at touchdown.

STROKE: The amount of shock strut compression with respect to the fully extended position.

TEST SPECIFICATION REPORT (TSR): A report issued by the airframe manufacturer or landing gear supplier providing the test requirements for the test article, test conditions, instrumentation, conformity requirements, schedule, and post-test tear down inspection instructions.

UNSPRUNG MASS: The moving portion of the gear below the gas spring (inner cylinder, truck, rolling stock, etc.).

5. TEST OBJECTIVES

For Part 25 aircraft, until the changes in 14 CFR 25.723 at Amendment 25-103 (2001), the objectives of a jig drop test were to demonstrate that the design limit load factor was not exceeded and that the gear would not fail in a reserve energy test. Due to advancements in dynamic analysis capabilities, dynamic landing analyses have progressed to the point where accurate drop test simulation is now routinely performed. In addition, 14 CFR 25.473 now requires that airframe flexibility and the dynamic characteristics of the landing gear be taken into account in the development of certification design loads, and further requires that this model be validated by drop tests. Therefore, in addition to demonstration of energy requirements, the objectives of a jig drop test with the amended Part 25 regulations include validation of the analytical model used to determine certification landing loads on the aircraft. Once validated, these models may be used to certify landing gear for derivative airplane models in lieu of drop testing. However, the drop test requirements remain in effect for new landing gear designs.

For Parts 23, 27, and 29 aircraft, the regulations were not revised in the same manner as stated above for Part 25 aircraft; thus, the objectives remain the validation of the limit landing load factor used for airframe design, and the demonstration of the limit and reserve energy requirements. It is noted that the latest version of FAA 14 CFR Part 23 and EASA CS Part 23 do not have explicit drop test requirements. The former requirements in the Reference Amendments have been re-published in ASTM F3061/F3061M as an acceptable means of compliance.

6. GENERAL REQUIREMENTS

The requirements discussed in this section are based on Title 14 of the FAA Code of Federal Regulations (CFR) and EASA Certification Specifications (CS), at the Amendment levels specified in the references above. The FAA and EASA regulations are harmonized for drop test requirements, thus references to paragraph numbers in this report may be taken as referring to both agencies. The symbol “§” refers to section number. When specifying required sink rates and drop heights in this and following sections, FAA values in English units are followed by EASA values in SI units.

6.1 Part 25 Aircraft - Transport Category Airplanes

The limit energy test requirements for Part 25 Transport Category aircraft are given in §25.723, with further guidance provided in AC 25.723-1 and AMC 25.723. During the Aviation Rulemaking Advisory Committee (ARAC) harmonization effort from 2001 to 2003, the Loads and Dynamics Harmonization Working Group (LDHWG) proposed to revise the drop test requirements and associated AC in an effort to incorporate the special conditions levied upon airplanes with more than two main landing gear units, such as the 747, DC-10, MD-11, A-340, and A-380. (All ground loads requirements with the exception of towing were revised at the same time.) The committee released a Working Group Report (WGR) along with the revised rules and ACs. At present, there are no plans by the FAA or EASA to amend the current rules with these revisions since there are currently no new development programs for airplanes with more than two main gear units. However, since the ARAC revisions have been released as part of the WGR and as special conditions for several models, they may be used as an acceptable means of compliance (subject to agreement of the certifying agencies), and are thus provided in this report.

14 CFR 25.723(a) states: *“The analytical representation of the landing gear dynamic characteristics that is used in determining the landing loads must be validated by energy absorption tests. A range of tests must be conducted to ensure that the analytical representation is valid for the design conditions specified in Sec. 25.473.”* A similar statement is found in AC 25.723-1: *“Shock absorption tests are necessary to validate the analytical representation of the dynamic characteristics of the landing gear unit that will be used to determine the landing loads. A range of tests should be conducted to ensure that the analytical model is valid for all design conditions. In addition, consideration should be given to ensuring that the range of test configurations is sufficient for justifying the use of the analytical model for foreseeable future growth versions of the airplane.”*

Limit energy requirements are given in §25.723(a)(1): *“The configurations subjected to energy absorption tests at limit design conditions must include at least the design landing weight or the design takeoff weight, whichever produces the greater value of landing impact energy.”* This is different from past rules, which required tests at both MLW and MTOW.

14 CFR 25.723(a)(2) gives the requirements for test attitudes and drag loads: *“The test attitude of the landing gear unit and the application of appropriate drag loads during the test must simulate the airplane landing conditions in a manner consistent with the development of rational or conservative limit loads.”* Thus, the test must cover the range from level to maximum tail down attitudes. The drag load requirement drives the type of platform used in the test to ensure that a sufficiently high friction coefficient is achieved to validate the fore-aft dynamic characteristics of the gear.

The requirements for the reserve energy test are provided in §25.723(b): *“The landing gear may not fail in a test, demonstrating its reserve energy absorption capacity, simulating a descent velocity of 12 f.p.s. at design landing weight, assuming airplane lift not greater than airplane weight acting during the landing impact.”*

The requirements stated above are intended for new landing gear designs. The regulations allow the use of analysis for certification of landing gear test requirements for growth versions of the aircraft. This is stated in §25.723(c) as follows: *“In lieu of the tests prescribed in this section, changes in previously approved design weights and minor changes in design may be substantiated by analyses based on previous tests conducted on the same basic landing gear system that has similar energy absorption characteristics.”*

6.2 Part 23 Aircraft - Normal, Utility, Acrobatic, and Commuter Category Airplanes

For Part 23 aircraft, the drop test requirements are given in ASTM F3061/F3061M. Section 13.2.1 of F3061/F3061M (formerly 14 CFR 23.723(a)) states: *“...it must be shown by energy absorption tests that the limit load factors selected for design in accordance with Specification F3116/F3116M for takeoff and landing weights will not be exceeded.”* This is different than Part 25 in that the design load factor must be validated, rather than the analytical model. It does provide allowance for validation by analysis for growth airplanes (13.2.1.1 through 13.2.1.3). Detailed requirements for drop height, effective weight, and load factor for limit energy drop tests are given in 13.3.

The reserve energy requirements are given in ASTM F3061/F3061M 13.2.2 (formerly §23.723(b)): *“The landing gear may not fail, but may yield, in a test showing its reserve energy absorption capacity, simulating a descent velocity of 1.2 times the limit descent velocity, assuming wing lift equal to the weight of the airplane.”* This is similar to Part 25 except that it explicitly states that the gear *“may yield”* in the test..

ASTM F3061/F3061M 13.4.1 (formerly §23.726) provides for the allowance of the use of drop testing to satisfy the landing loads requirements. If this option is used, the drop height must be increased relative to that used for limit energy drops to either 2.25 times the height specified in in ASTM F3061/F3061M 13.3.1, or to that required to achieve 1.5 times the design load factor.

6.3 Part 27 Aircraft - Normal Category Rotorcraft

The drop test requirements for Part 27 rotorcraft are provided in §27.723, 27.725, and 27.727. These requirements are similar in nature to those for Part 23, except that there is no equivalent paragraph for §23.726. The general requirement is given in §27.723 as follows: *“The landing inertia load factor and the reserve energy absorption capacity of the landing gear must be substantiated by the tests prescribed in §27.725 and 27.727, respectively. These tests must be conducted on the complete rotorcraft or on units consisting of wheel, tire, and shock absorber in their proper relation.”* Like Part 23, the purpose of Part 27 drop tests is to validate the design landing load factor and the energy absorption capability. It also allows testing to be done either on the whole aircraft, or on the gear units if in their proper geometric relations.

Section 27.725 provides the regulations for limit energy drop tests. It covers requirements for drop height, sink rate, attitude, drop weight, and simulated lift. It includes equations for effective weight and load factor. The drop height is in the range of 8 to 13 inches (20 to 33 cm), equivalent to a sink rate of 6.55 to 8.35 ft/s (2 to 2.55 m/s), depending on the limit sink used for design. It also specifies that lift must be accounted for in the test either by a device simulating lift, or by use of an effective mass. The test attitude requirement is given in Paragraph (c) as follows: *“Each landing gear unit must be tested in the attitude simulating the landing condition that is most critical from the standpoint of the energy to be absorbed by it.”*

The reserve energy test requirements are provided in §27.727. The drop height is 1.5 times that used for the limit energy tests. Lift requirements are also specified. The landing gear may not collapse under this condition. *“Collapse”* is defined in Paragraph (c) as follows: *“Collapse of the landing gear occurs when a member of the nose, tail, or main gear will not support the rotorcraft in the proper attitude or allows the rotorcraft structure, other than the landing gear and external accessories, to impact the landing surface.”*

6.4 Part 29 Aircraft - Transport Category Rotorcraft

The requirements for Part 29 rotorcraft are essentially the same as Part 27, except that the limit energy drop height simply gives a minimum height of 8 inches (20 cm); a maximum value is not provided.

6.5 Russian Requirements

This report does not provide a detailed discussion of the differences in Russian regulations (AP25); however, some comments are provided for the additional requirements for Part 25 aircraft. AP 26.723(a), (b), and (c) are essentially the same as 14 CFR/CS requirements. There are two additional paragraphs in AP 25.723: (a*) and (b*).

Paragraph (a*) states: *"If tests are conducted on an isolated set, and the elasticity of the airplane assemblies to which the landing gear is attached affects significantly the values of loads then the quota of energy applied to the landing gear can be refined on the base of special calculations and in addition to that the data must be obtained from tests to confirm shock absorption characteristics taken into account for analysis."* In summary, this requirement provides that the value of strain energy absorbed by the aircraft elastic structure (based on the full aircraft dynamic landing analysis) may be taken into account when determining the effective drop weight. This will result in a lower drop weight.

Paragraph (b*) states: *"In order to evaluation effect of changes of landing gear elements subjected to wear influencing on the characteristics of amortization, to conformation of stability of these characteristics and to check certain details of the shock-absorbers on fatigue life from action of hydrodynamic loads, the landing gear must be tested for absorption of the limit energy for landing weight repeatedly."* To summarize, this paragraph requires that the limit energy test condition must be done numerous times to demonstrate that the damping elements of the shock strut are stable over time; i.e., that reoccurrence of limit energy conditions does not adversely deteriorate the shock absorption ability of the gear. (Note: this is not normal practice for FAA and EASA certification).

Other differences are the sink rate for the MTOW and reserve (maximum) energy conditions. Per AP 25.473(a)(3), the sink rate for MTOW conditions is 0.8 times the limit sink rate for MLW conditions. Per AP 25.473(a)(2)(ii), the sink rate for the maximum energy condition (reserve energy) is 1.225 times the limit sink rate for MLW conditions.

7. TEST SPECIFICATION REPORT

To ensure compliance to the drop test requirements, a test specification report (TSR) is provided by the airframe manufacturer or landing gear supplier to the testing facility. The TSR should include instructions on overall test plan, schedule, test article description, test setup, instrumentation and data reporting requirements, conformity requirements, a detailed list of test conditions, and instructions for the tear-down inspection after the testing is complete. This report is subject to approval by the certifying agency.

8. TEST WITNESSING

Certification drop testing of the conformed landing gear test article is witnessed by the certifying agency, or, if so delegated, by an authorized representative of the certifying agency, such as a Designated Engineering Representative or Engineering Unit Member of a Company having an Organization Designation Authorization (ODA) from the FAA, or Compliance Verification Engineer of a Company having an Design Organization Approval (DOA) from EASA, as appropriate.

9. TEST CONFORMITY

Conformity inspections must be performed prior to testing for the landing gear test article parts and assembly, as well as for the installation in the test rig. The test article inspections are to ensure that assembly components have been manufactured per production drawings and specifications under the approved quality systems. For the detail parts, particular attention should be placed on part numbers, specific part interface dimensions, and deviations from the drawings, such as instrumentation, pressure port installations, etc.

For conformity of the drop test rig, close attention should be placed on verification of the landing gear interface points to ensure they are in the same relative location as on the aircraft. Additionally, care should be taken to ensure that the test article is installed in accordance with the applicable installation drawings.

10. TEST EQUIPMENT

The shock absorption tests are typically performed on a stationary drop tower incorporating a drop carriage that supports the test fixture and test article. Figure 1 depicts a typical tower schematic.

10.1 Tower

The drop tower is the fixed structure which supports a vertically translating carriage, which in turn supports the landing gear test article and the test weights which simulate aircraft weight. The tower must be qualified to withstand the expected loads from the test conditions. The tower incorporates guides allowing the carriage to translate vertically with minimal friction, while reacting the resulting vertical, drag, and side loads, including all induced moments.

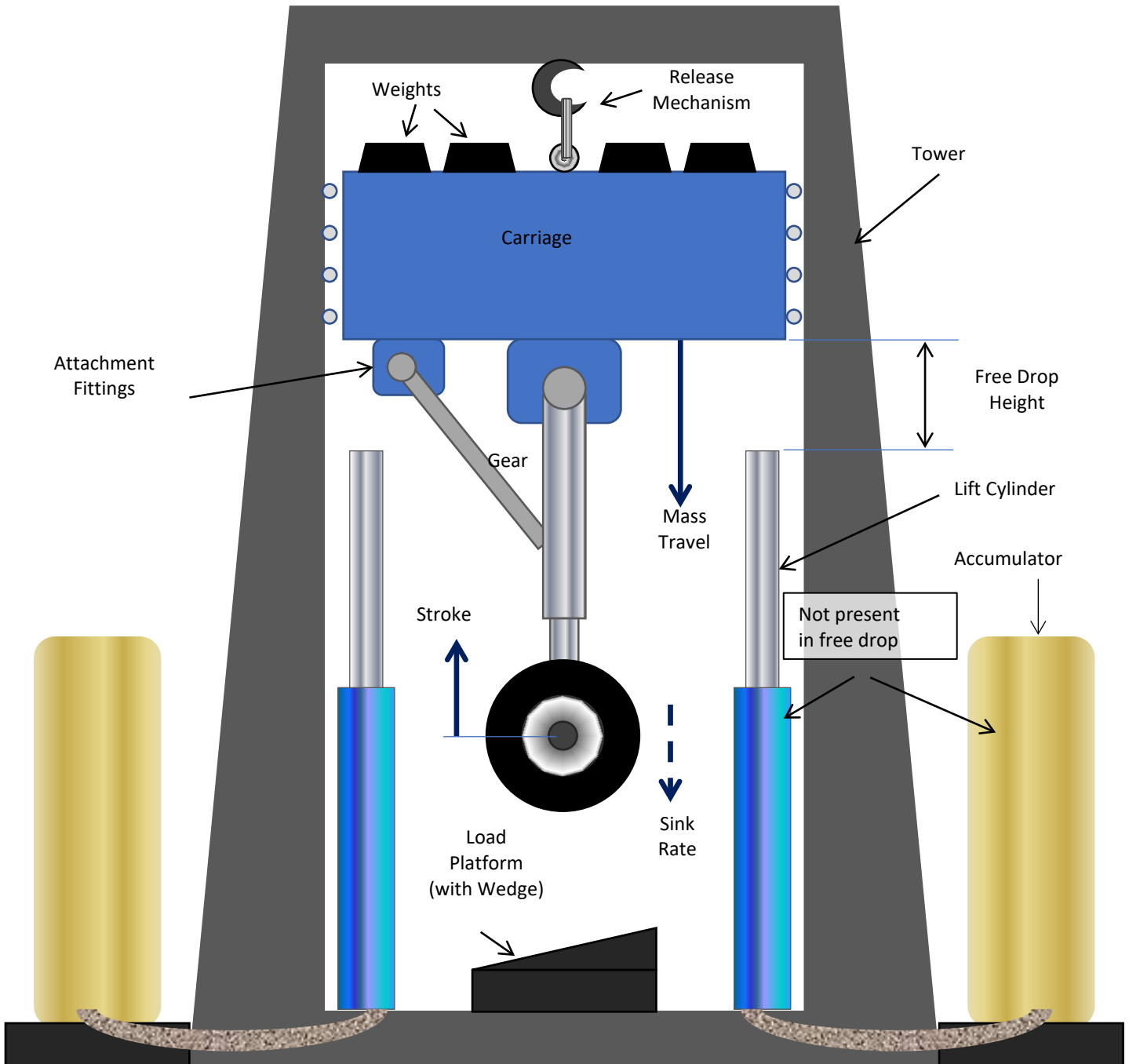


Figure 1 - Drop test equipment schematic