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(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.

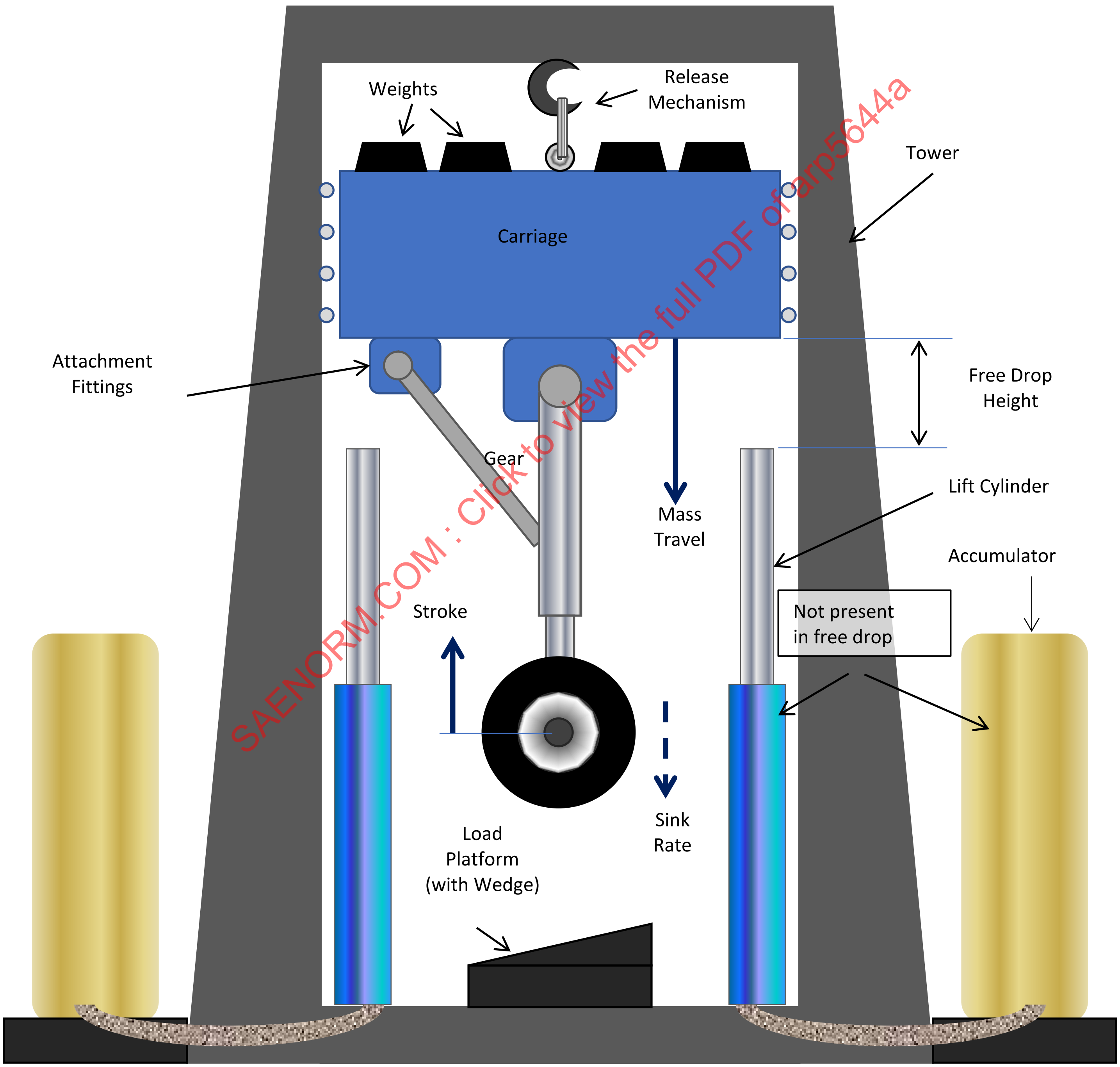

Figure 1 - Drop test equipment schematic

10.2 Carriage

The carriage supports the landing gear test article and the weights required to simulate the aircraft landing weight. The carriage accommodates the gear attaching structure in such a way as to accurately simulate the actual attachment geometry to the aircraft, and represent the structural stiffness of the actual attachments (if required). The carriage is initially held above the load platform by means of a quick release mechanism, which is controlled by the test operator. After release, the carriage comes in contact with pressurized pistons (“lift cylinders”) which simulate aircraft lift prior to contact with the load platform.

10.3 Lift Cylinders

Simulated wing lift is usually provided by means of pressurized gas cylinders. The objective is to achieve a predetermined steady aircraft lift prior to tire contact with the load platform. The cylinders must be capable to withstand the loads induced by the carriage, including any dynamic transient impact loads. There are typically load cells mounted at the top of these cylinders, which must also be capable of these transient loads. Note that for free drop tests, lift cylinders, or other means of simulating lift are not used.

10.4 Load Platform

The load platform reacts the loads imparted by the tires during the test. The platform includes load cells to measure vertical, drag, and side loads. The platform surface is designed to produce the required friction coefficient. For multi-wheel gears, as a minimum, one load platform per axle is recommended and one load platform per wheel may be requested by the airframe manufacturer or landing gear supplier

When conducting tail down drop tests it is preferable to mount the landing gear in the drop tower at the proper tail down angle. However, this approach requires additional test fixture configurations and adds time to the test program to switch the configuration for various conditions. To avoid the extra cost and time, tail down drops are often made on wedges that simulate the tail down angle. When using this approach, the drop velocity must be adjusted to provide the required velocity normal to the platform surface.

If a wedge is used in lieu of mounting the gear in the tail down attitude, it is recommended that the load cells be placed above the wedge (rather than below) so that the loads are in the ground plane system. This also avoids the added complication of inertial loads from the wedge mass adding to the platform loads if the load cells are below the wedge.

10.5 Wheel Spin Device

The spin-up drag loads are typically simulated by pre-rotation of the wheels in the reverse direction up to the required landing speed. A steel grating or other suitable surface is installed on the reaction platform in the tire contact area in order to produce the friction coefficient between the tire and the plate specified by the airframe manufacturer or landing gear supplier. For Part 25 aircraft, 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. This allows for validation of the fore-aft dynamic characteristics seen in the analytical model.

10.6 Landing Gear Test Article

The test article is a production landing gear unit meeting test conformity requirements. Some parts, such as attachment fittings, struts, etc., may be modified to support test installation and operation. For example, attachment fittings may be non-production parts provided they represent joint freedoms accurately, and they should preferably approximate structural stiffness for ease of analytical correlation. Any such modifications may not affect the dynamic characteristics of the landing gear, and must be approved by the certifying agency and documented in the conformity plan and TSR.

10.7 Data Acquisition System

The digital data acquisition system should provide sufficient sample rates to meet the requirements of the TSR. The system should be able to provide tabular time history data of all required parameters in a timely manner after each test, and should be capable to provide plots of time histories, as well as cross plots, such as load versus stroke.

10.8 Video Recording

It is common for the airframe manufacturer or landing gear supplier to require video recordings of some or all of the drop tests. Video recording requirements should be specified in the TSR. These may include both real-time and high-speed videos. High-speed videos require special lighting equipment.

11. INSTRUMENTATION

The data required to be recorded during a drop test program may vary depending upon the type of gear and/or the requirements specified by the airframe manufacturer or landing gear supplier. The list below is provided as an example of the typical data to be considered for recording.

The following data should be recorded electronically at the sample rate stipulated in the TSR with all data channels being recorded simultaneously.

- Ambient temperature
- Tore pressure (all tires)
- Carriage vertical displacement (mass travel)
- Carriage vertical descent rate
- Carriage vertical acceleration
- Vertical platform reaction (if possible, measurements of each tire are recommended)
- Horizontal (drag) platform reaction (if possible, measurements of each tire are recommended)
- Lateral platform reaction (when required)
- Summation of all axle or tire loads (net platform reactions)
- Vertical tire deflection (if possible on all tires)
- Hydraulic chamber pressure (all hydraulic chambers)
- Strut gas pressure (all gas chambers)
- Wing lift force (if mechanically simulated)
- Wheel rotational speed (all wheels)
- Shock strut stroke displacement
- Truck pitch angle (when applicable)
- Truck pitch actuator displacement (when applicable)
- Truck pitch actuator hydraulic pressures and/or axial load (when applicable)
- Unsprung mass vertical (or axial) acceleration
- Load in all calibrated members such as a drag strut or side brace and gear attachment reactions

12. DATA REDUCTION AND COMPUTATIONS

Some key parameters used for drop testing require computation either before or after each condition. These include drop height, lift, drop weight, energy absorbed, and load factor. These parameters are discussed in this section.

12.1 Drop Height and Sink Rate

The theoretical free drop height (h) required to achieve a constant sink speed (V) is $V^2/(2g)$ (where g is the gravitational acceleration). For Part 25 aircraft, the typical required sink rates are 6 ft/s (1.83 m/s), 10 ft/s (3.05 m/s), and 12 ft/s (3.7 m/s), which correspond to 6.7 inches (17 cm), 18.7 inches (47.5 cm), and 27 inches (69 cm) of free drop height, respectively. For Part 23 aircraft, the drop height ranges from 9.2 to 18.7 inches (23.4 to 47.5 cm), depending upon the weight and lift assumptions used in the critical landing. For Parts 27 and 29, the height ranges from 8 to 13 inches (20 to 33 cm).

A plot of drop height versus sink rate is shown in Figure 2 in English and SI units.

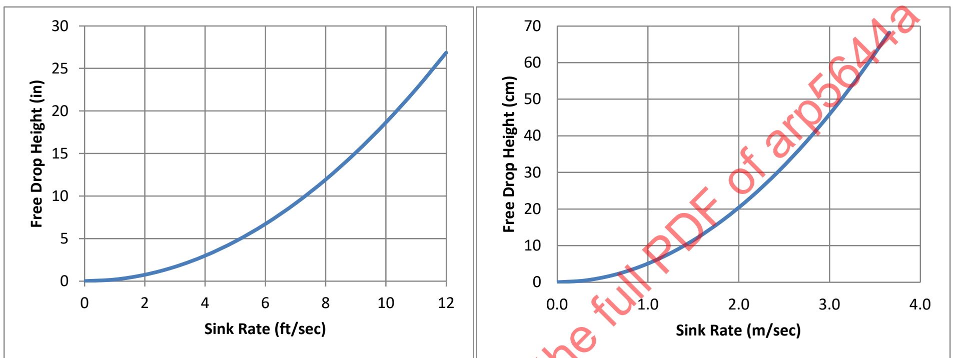

Figure 2 - Free drop height versus sink rate

However, it is expected that the drop height may be slightly different from this due to tower friction and lift force variation. Also, if lift is not equal to weight, the drop height must be adjusted to account for any acceleration or deceleration of the drop mass during the time when the carriage is in contact with the lift cylinders prior to contact with the platform. The drop height needed to obtain the required sink rate at the platform (h^*) is computed as follows:

$$h^* = h - h_L\left(1 - \frac{L_T}{W_e}\right)$$

where:

h = the theoretical free drop height corresponding to the required kinetic energy at the moment of touchdown equal to $V^2/(2g)$, where V is the sink rate and g is the gravitational acceleration

h_L = height of lift cylinder travel prior to platform contact

L_T = average drop test lift per gear during energy absorption phase of the drop test (for free drop tests, $L_T = 0$)

W_e = the effective weight to be used in the drop test (see 12.2)

If a platform wedge is used to simulate tail down attitude, the drop height is adjusted to obtain the correct sink rate normal to the platform surface. This is often an insignificant effect for small pitch attitudes (1.5% correction at 10 degrees).

12.2 Lift and Weight

For Part 25 aircraft, lift, not exceeding airplane weight, is generally simulated in the test. For Part 23, a maximum of two-thirds lift-to-weight ratio is allowed. The ratio of assumed rotor lift-to-weight for Parts 27 and 29 aircraft must be accounted for in the test. In general, the drop test uses a simulated lift force which is equal to the actual lift on the airplane (on a per gear basis). While there are provisions in the current regulations for performing a free drop test (no lift force), there is no provision for test lift to be different from the test weight.

The regulations provide the option to compute an effective drop weight to be used in a free drop test to achieve the same energy as in the actual airplane landing with lift. The effective weight (W_e) is determined using the equation found in AC 25.723-1 for Part 25 aircraft, and in ASTM F3061/F3061M 13.3.1 for Part 23 aircraft, and in §27.725 and §29.725 for helicopters:

$$W_e = W\left[\frac{h + (1 - L)d}{h + d}\right]$$

where:

d = maximum distance of carriage vertical travel after tire contact with the platform (it is assumed that d is the same for both the airplane condition and the drop test with effective weight)

L = ratio of the assumed airplane lift to the airplane weight, but not more than 1.0 for Part 25, and not more than 0.667 for Part 23 (an upper limit is not specified for Parts 27 and 29)

$W = W_M$ or W_N or W_T as appropriate (see definitions of these weights below)

For Part 25 aircraft, the ARAC draft revision to AC 25.723-1 amends this equation to include the possibility that test lift may not be equal to test weight. This may occur where the test tower is not capable of providing either sufficient lift or the desired drop weight. For this purpose, the equations for effective weight for main gear tests are:

$$W_e = W_M + (L_T - L_A)\left(\frac{d}{h + d}\right)$$

where:

L_A = assumed airplane lift per gear, however, total airplane lift may not be greater than airplane weight (L_A is typically equal to W_M)

L_T = average drop test lift per gear during energy absorption phase of the drop test (for free drop tests, $L_T = 0$)

W_M = the static weight on the main gear unit with the airplane in the level attitude (with the nose wheel clear of the ground in the case of nose wheel type airplanes), typically one half of the weight of the airplane

For example, if the test rig has a minimum drop carriage weight that is greater than the required drop weight, additional lift may be used to achieve the required energy. The equation above can be used to derive the necessary lift by setting W_e equal to the maximum rig weight, L_A equal to W_M, and solving for L_T. Conversely, if the test rig maximum carriage drop weight is less than the required drop weight, test lift may be reduced using the same equation to achieve the required test energy. Note that if the test lift or weight using this approach is significantly different from the nominal value, there may be a need to reach agreement with the certifying agency before the test plan is developed.

For airplanes with more than two main landing gear units, this equation is modified to:

$$W_e = {}^{E_A}\!/_{h} \qquad (for\ L_T = W_e)$$

$$W_e = \frac{E_A + L_T d}{h + d} \qquad (for\ L_T \neq W_e)$$

where:

E_A = maximum total energy absorbed by the landing gear unit obtained in the dynamic loads analysis in compliance with all landing loads regulations, including any special conditions

The introduction of E_A is a result of the fact that the energy absorbed by a single gear unit for airplanes with more than two main gear units is indeterminate without a dynamic analysis which includes the effects of airplane flexibility.

For nose and tail landing gear units, the drop weight is calculated as follows:

$$W_e = W_N \qquad (L_T = W_e)$$

$$W_e = W_N + (L_T - W_N)\left(\frac{d}{h+d}\right) \qquad (L_T \neq W_e)$$

where:

W_N = the vertical component of the static reaction that would exist at the nose gear, assuming that the mass of the airplane acts at the center of gravity and exerts a force of 1.0 g downward and 0.25 g forward

W_T = the static 1 g reaction of the airplane weight on the tail wheel with the airplane in the tail down attitude (this term is substituted for W_N for airplanes with tail wheels)

In some cases, at the discretion of the aircraft manufacturer, the landing gear is designed to absorb a specified amount of energy with a prescribed rate of decay of lift during the landing sequence. While this event is relatively easy to model analytically, practical limitations make it difficult to simulate in the laboratory. Verification of energy absorption with decaying lift should be done analytically using a modeling approach that has been correlated with the jig drop test with constant lift as described above.

12.3 Energy

The energy absorbed by the gear during the drop test should be calculated to verify that the required energy for each condition was obtained. This is typically done by numerical integration of the total vertical platform load over the mass travel (while in contact with the platform). It may be required to account for pitch attitude for tail down drops, depending on the orientation of the platform load cells. (If a platform wedge is used, the net vertical component of load must be used, not the normal vertical platform reaction.)

12.4 Wheel Speed

Wheel spin prior to tire contact should simulate the tire rolling speed consistent with the required forward landing speed of the aircraft. The free radius is typically used to compute wheel speed, but rolling radius is also acceptable. Care should be taken to account for deceleration of the wheel due to bearing friction in the time between disconnection of the spin-up device and tire contact with the platform. Depending on the type of wheel speed instrumentation used, the accuracy of the wheel speed during tire contact may be in question. If accurate wheel speed during this period is required, appropriate instrumentation and signal processing must be used.

12.5 Load Factor

For Part 25 aircraft, validation of the limit load factor is not a requirement, but it is documented for information only. The limit load factor (n) is determined from the drop test peak vertical platform load (F_V) using the following equation:

$$n = \left(\frac{F_V + L_T}{W_e}\right)$$

The load factor is required for Parts 23, 27, and 29 aircraft. For these aircraft, the load factor (n) is determined from the carriage mass acceleration developed in the test (n_j) in accordance with the following formula:

$$n = n_j \frac{W_e}{W} + L$$

where:

W = static weight on the gear appropriate to the landing condition (refer to specific guidance in ASTM F3061/F3061M Table 8 (Part 23), §27.725, and §29.729)

12.6 Stroke Rate and Discharge Coefficient

Shock strut stroke rate is the derivative of stroke with respect to time. This is computed numerically from stroke position, but may need to be filtered to remove high frequency content. This may create a time lag that is not real, and should be accounted for during data reduction and post-test correlation. This term is used to derive the discharge coefficient of the main chamber orifice. The hydraulic pressure drop across the orifice is often modeled using incompressible flow assumptions. If incompressible flow is assumed, the discharge coefficient (C_D) is:

$$C_D = |V|\frac{A_H}{A_O}\sqrt{\frac{\rho}{2\Delta P}}$$

where:

A_H = effective hydraulic area (typically a function of stroke)

A_O = net orifice area (typically a function of stroke)

ΔP = instantaneous pressure drop across the orifice

ρ = hydraulic fluid density

V = instantaneous stroke rate

13. TEST CONDITIONS PRIOR TO DROP TESTING

Some testing is recommended prior to drop testing. These include the static isothermal “air curve” validation test, gas absorption drops, and rebound (recoil) snubbing tests to validate the recoil valve performance.

13.1 Static “Air Curve” Test

The purpose of this test is to validate the static isothermal gas pressure versus stroke used in the design. This curve is the baseline curve used for comparison with the dynamic gas pressure curves to determine the modeling terms for the dynamic gas pressure as a function of stroke.

The test may either be carried out with the shock absorber in the vertical condition, or with the shock absorber at a rake angle (as installed on aircraft if applicable).

Prior to performing this test, the shock strut must be serviced to nominal conditions and the quantity of fluid required to properly fill the strut should be measured and recorded. The precharge pressure is set at the correct value, accounting for ambient temperature (the ambient temperature should be recorded).

The test is conducted in small stroke increments at a very slow pace to ensure an isothermal process. After each increase in stroke (starting from a fully extended position) sufficient time is elapsed to stabilize the temperature before the pressure reading is taken. This process is repeated until the maximum stroke position specified in the TSR is reached. The test then continues in the reverse direction (extension) at the same stroke increments until full extension is reached.

The difference in the compression and extension curves of platform load versus stroke represents twice the friction force present in the shock strut, and is used to derive the bearing and seal friction coefficients.

13.2 Gas Absorption Test

When a shock strut (without a separator piston), is subjected to a static load for some period of time at a sufficiently high pressure, some nitrogen molecules are absorbed (entrained) into the hydraulic fluid. This affects the gas pressure during compression and extension because nitrogen molecules are removed from the gas volume, resulting in lower pressure. This phenomenon is more pronounced after landing because of the mixture of nitrogen and hydraulic fluid as the fluid ejects from the orifice and forms droplets. The effects of nitrogen absorption increase as the ratio of oil to gas volume increases. For gears with a large volume ratio, the static “air curve” during ground operation may vary significantly from the theoretical isothermal “air curve” with no absorption. This effect should be accounted for in the loads analysis, as well as in establishing proper servicing placards and procedures.

Gas absorption testing is recommended for landing gears with a relatively high oil-to-gas volume ratio (without a separator piston), and should be performed prior to drop testing. The purpose of the test is to ensure that the test unit has reached its stable gas absorption level and proper amount of gas prior to drop testing. The following procedure is recommended to perform this test:

Step 1: Perform a low sink rate drop with no tire pre-rotation and full wing lift.

Step 2: Perform another low sink rate drop with no tire pre-rotation and reduced wing lift. Wing lift value is determined by the aircraft manufacturer. (The goal is to drop the gear with minimal rebound.) Immediately following the drop, lower the carriage by reducing the wing lift until the entire weight is resting on the landing gear. Record the shock strut stroke and gas pressure during compression.

Step 3: The gear should remain in this compressed position until the gas pressure has stabilized. Record gas pressure at sufficient intervals to ensure it has stabilized.

Step 4: Raise the carriage rapidly until the shock strut is fully extended, recording pressure during extension.

Step 5: Continue recording gas pressure at regular intervals until the pressure reaches a stable value.

Step 6: If the precharge pressure does not return to the nominal value, then re-service with nitrogen and repeat steps 2 through 5 until the pressure stabilizes at the nominal precharge pressure.

13.3 Rebound (Recoil) Snubbing Test

The purpose of this test is to demonstrate the free recoil characteristics of the shock strut, and to validate that the recoil flow areas meet the design requirements and performance objectives.

The airframe manufacturer or landing gear supplier provides the success criteria for the recoil characteristics. These typically include a maximum rebound (recoil) chamber pressure, the maximum unsprung mass velocity and acceleration at contact with the outstop, and a maximum time duration of the extension. These parameters compete with each other, thus making it sometimes difficult to satisfy all criteria. The parameters that govern all of these criteria are the recoil flow area and orifice discharge coefficient. The flow area is sometimes difficult to determine accurately because of flow leakage paths. The discharge coefficient is also difficult to determine prior to testing due to the sometimes complicated flow paths. The possibility of cavitation in the main chamber also complicates the recoil analysis and flow area requirements.

The test should be performed at various initial compressed stroke positions, and using a means to suddenly release the inner cylinder, allowing free extension until the outstop is contacted. The lower stroke positions are critical for contact velocity and acceleration since there is less time for the snubber to become fully effective, while the high stroke positions are critical for rebound (recoil) chamber peak pressure. Test measurements needed for this test are all hydraulic and gas chamber pressures, stroke position, and unsprung mass axial acceleration.

For Part 25 aircraft, the minimum unsprung mass load factor for design is 20 g (limit); however, the actual value may be higher, and is determined by the airframe manufacturer or landing gear supplier. The maximum pressure is a function of the shock strut cylinder and/or seal allowable, and is also provided by the airframe manufacturer or landing gear supplier.

The initial hydraulic pressure response may be highly transient due to fluid compressibility. For this reason, the contact velocity for the low stroke positions may vary considerably for small changes in initial stroke position, thus care must be taken to determine the critical initial position. This is usually determined during the testing.

14. DROP TEST CONDITIONS

As stated in AC 25.723-1: "*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*."

All of the following tests should be conducted on the same landing gear assembly without changing components. Seals may be changed as required provided any seal failures are investigated as to the potential of chronic problems.

Perform the following checks prior to each drop to ensure test condition readiness:

a. Verify that all required measurement channels are active and reporting expected values.

b. Verify that the test article is in the proper position.

c. Verify that the ground plane test platform is clean and represents the specified friction coefficient.

d. Check that the lift cylinders represent the required lift.

e. Check (via measured data) that the precharge pressure is correct. Ensure that sufficient time has elapsed for the precharge pressure to reach its stable value accounting for absorption effects, and that the gas temperature has stabilized to ambient temperature. A correction may need to be made to the precharge pressure if the ambient temperature changes significantly during the testing.

f. Check that the tires are at the proper inflation pressure.

g. Check for any hydraulic fluid leakage and wipe sliding surfaces clean.

h. Ensure that all safety precautions are met for all personnel present.

After each test condition, the following checks should be performed:

a. Check for fluid leaks from shock strut and any other hydraulic actuators.

b. Inspect tires for any undue damage. Replace tires as required.

c. Perform general inspection of structure and joints for any visible deformations.

d. Clean the ground plane test platform.

e. Compare the test data to analytical predictions to verify that the results are within expected ranges. If not, do not proceed to the next condition until there is a satisfactory explanation and appropriate actions are taken.

The usual sequence of the drop test conditions is as follows:

1. Development drops (until metering device is verified).

2. Growth drops.

3. Certification limit energy drops.

4. Certification reserve energy drops.

5. Miscellaneous drops.

14.1 Aircraft Attitude

Main gears are generally tested at both the level and maximum tail down attitudes. The required test attitudes are supplied by the airframe manufacturer or landing gear supplier in the TSR. Nose gear drops are in the level attitude, and tail gear drops are in the tail down attitude. The attitude and applied drag loads during the test must simulate aircraft landing conditions consistent with the development of rational or conservative limit loads. Reserve energy tests are conducted in the attitude corresponding to that producing the highest energy for the limit landing conditions.

14.2 Weight Requirements

Main gear drop weights are equal to half the airplane weight (for airplanes with two main gears). For airplanes with more than two main gear units, the drop weight for each main gear unit is based on the energy absorbed by each gear from a rational dynamic analysis of airplane landing impact at the prescribed sink rates and attitudes. Nose gear drop weights are determined by the airframe manufacturer or landing gear supplier and are specified in the TSR. For tail gear units the weight is equal to the static weight on the tail unit with the airplane in the tail down attitude. (See 12.2 for the specific equations used to compute drop weight as a function of the test lift requirements.)

14.3 Lift Requirements

Simulated wing lift is nominally equal to the drop weight. There may be occasions where this is not possible due to test rig limitations, or, lift may be intentionally different from weight (such as in gas absorption drops). If lift is not equal to weight, AC 25.723-1 (or the ARAC draft revision to this AC) provides equations for determining the effective drop weight (summarized in 12.2).

14.4 Wheel Speed at Tire Contact

At the point of tire contact, the wheels must be spinning in the reverse direction at a speed consistent with the specified forward velocity of the airplane. For Part 25 aircraft, for the tail down conditions, the airplane speeds are V_{L1} and V_{L2}: the 1 g stall speed, at both sea level/standard day, and high altitude/+41 °F (5 °C) hot day conditions. The tail down speed may be increased if the stall speed causes the airplane pitch attitude to exceed the maximum tail clearance angle. The level conditions are tested at speeds up to 1.25 times the 1 g stall speed (again covering both sea level/standard day and high altitude/+41 °F (5 °C) hot day conditions). For level landing conditions, the effect of increased contact speed must be investigated for downwind landings above 10 knots (if requested for certification). For reserve energy tests, wheel speed is not required for Part 25 aircraft (this is not specified in the current regulations, but is added to the ARAC draft revision to the AC).

14.5 Development Drops

The purpose of these tests is to validate the hydraulic metering characteristics of the shock strut, as well as to verify the analytical model used to determine design landing loads on the landing gear and airframe. These drops are generally conducted by incrementally increasing the sink rate until the limit design sink rate is reached. It is recommended that the first drops be at low sink rate (2 to 3 ft/s or 0.6 to 1 m/s) and without wheel spin. It is also recommended that the first drop at limit sink rate be without wheel spin. (This also provides for improved analytical correlation.)

If a metering pin change is required, these drops are repeated; though some low sink rate drops are generally eliminated. This process is repeated until a satisfactory metering pin is verified.

14.6 Limit Energy Drops

The following sink speeds and drop weights are required as certification drop test conditions.

As stated in AC 25.723-1 (for Part 25 aircraft), "*In cases where the manufacturer has supporting data from previous experience in validating the analytical model using landing gear units of similar design concept, it may be sufficient to conduct tests of the new landing gear at only the condition associated with maximum energy*." In this case, the required sink rate is either 10 ft/s (3.05 m/s) at the design maximum landing weight (MLW), or 6 ft/s (1.83 m/s) at the design maximum takeoff weight (MTOW), whichever has the higher kinetic energy. However, this was amended in the ARAC draft revision of the AC to state that both the condition with the highest energy and the condition with the highest sink rate must be tested. There may be additional test conditions for airplanes with more than two main landing gear units. These depend upon the special requirements levied upon such airplanes. Additional guidance may also be found in the ARAC draft revision to AC 25.723-1.

Four Russian certification, the limit sink rate at MLW is determined from the equation in in §25.473(a*), but may not be less than 10 ft/s (3.05 m/s). For MTOW conditions, the sink rate is 0.8 times the MLW sink rate.

For Part 23 aircraft, the sink speed is a function of landing weight per the formula in ASTM F3061/F3061M 13.3.1 (formerly 14 CFR 23.473(d)). It may not be less than 7 ft/s (2.1 m/s), and need not be more than 10 ft/s (3 m/s), at the design landing weight. The required drop height is also a function of landing weight and is computed using the formula provided in 13.3.1 (formerly 14 CFR 23.725(a)).

For rotorcraft (Parts 27 and 29), the drop height is specified in §27.725(a) and 29.725(a), and must be at least 8 inches (20 cm). For Part 27, the maximum drop height requirement is 14 inches (33 cm). The drop weights are specified in §27.725(d) and 29.725(d).

14.7 Reserve Energy Drops

The purpose of the reserve energy certification test is to demonstrate “ultimate” energy absorption capability without failure (or collapse) of the gear. Non-detrimental yielding is permissible.

For Part 25 aircraft the required sink rate is generally 12 ft/s (3.7 m/s) at the design maximum landing weight (MLW) per §25.723(b). However, if the limit 6 ft/s (1.83 m/s) MTOW condition has higher energy than the 10 ft/s (3.05 m/s) MLW condition, then the reserve energy condition is 1.2 times 6, or 7.2 ft/s (2.2 m/s) at MTOW, per the ARAC draft revision to AC 25.723-1. (The factor is 1.225 for Russian certification per AP 25.473(a)(2)(ii)). (For Russian certification, the same approach is used, but the limit sink rates may be different is defined above, and the factor used for reserve energy condition is 1.225 instead of 1.2.) There may be alternate sink rate requirements for airplanes with more than two main landing gear units. These depend upon the special requirements levied on such airplanes. The test is typically performed in the level attitude with lift equal to weight; however, the attitude should be the same as the limit landing condition which produced the highest energy. The wheel speed may be zero based on past accepted practice and per the ARAC draft revision to AC 25.723-1 (this test is not intended to represent a rational condition). The main reason for this is that zero wheel speed generally produces the highest vertical reaction due to lower strut friction. Note that for levered gears wheel spin may be necessary to maximize strut compression.

While it is permissible for the shock strut and/or tires to bottom in this test, it should be noted that if this occurs, an analytical certification approach may not be used for future growth versions, and a reserve energy test will be required, even if the limit energy test conditions are not required.

For Part 23 aircraft, the drop height is 1.44 times that used for limit energy drops. The drop weight is typically the same as that used for the limit energy drops. Wheel speed and attitude are not specified in the regulations; these values are provided by the airframe manufacturer or landing gear supplier in the TSR.

For rotorcraft (Parts 27 and 29), the drop height is 1.5 times that used for the limit energy drops. The drop weight and lift are based on the limit energy drops. Wheel speed and attitude are not specified in the regulations; these values are provided by the airframe manufacturer or landing gear supplier in the TSR. Paragraphs §27.727(c) and §29.727(c) provide details on the definition of what constitutes collapse of the gear.

14.8 System Failure Drops

For Part 25 aircraft, there may be drop tests required which represent system failure conditions. These failure conditions are considered as design conditions per FAA and EASA regulations regarding the interaction of systems and structures.

FAA requirements are levied on each airplane as special conditions or as Issue Papers. EASA requirements are covered in CS 25.302. These conditions are typically at a reduced safety factor. If such failures affect the landing gear configuration, sink rate, lift, etc. at landing, and if they are critical for landing gear or airframe design, then they should be drop tested and may be considered as certification conditions.

Examples of failures that fall into this category are: failures of the truck pitch actuator which may affect the truck angle at landing; failures affecting the damping orifice area for active controlled gears; control system failures which may affect the sink rate or lift at landing; and failures of a system which may alter the wheel spin at landing (for airplane equipped with a tire pre-rotation device).

14.9 Growth Drops

AC 25.723-1 states that "*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*." This generally results in drop test conditions at higher than the design landing weights tested in the certification limit drop tests. The increased landing weights are determined by the airframe manufacturer or landing gear supplier. These tests may be performed after the certification tests, and are included in the final drop test report so that they may be referenced for future growth certification programs. However, the use of these test conditions for future certification is dependent on the scope of changes made to the landing gear, and must be approved by the certifying agency.

14.10 Miscellaneous Drops

Additional miscellaneous test conditions may be performed at the discretion of the airframe manufacturer or landing gear supplier. These may include conditions representing various mis-serviced conditions, cold temperature conditions, fatigue conditions, alternate tire configurations, etc. These are not typically certification tests, and may be performed after the certification tests.

14.11 Summary of Drop Test Conditions

Table 1 summarizes the main gear drop test conditions typically performed in a Part 25 drop test program.

15. GEAR TEAR DOWN INSPECTION

Following completion of all tests specified in the TSR, the test article is removed from the test rig and disassembled for inspection. Prior to disassembly, it is recommended that the shock strut fluid be drained and the total volume of fluid measured. The measured volume of fluid can then be compared against the estimated volume.

All of the test article components should be visually inspected for evidence of wear, scoring, permanent set, or other obvious damage. Dimensional inspection is performed as specified by the aircraft manufacturer. All inspection results must be documented, which should include photographing each component and any areas with inspection findings.

Manufacturer instructions for the tear down inspection should be included in the TSR. Disposition of the test article shall be determined by the aircraft manufacturer.