



AEROSPACE INFORMATION REPORT

AIR5938™**REV. A**

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Superseding AIR5938

Information on Hard Landings and Abnormal Landing Gear Loading Events

RATIONALE

The industry requested that general reference information on hard landings be compiled including detection methods, inspection procedures, and historical incidence data which resulted in the original issue of AIR5938 in 2011. Revision A of AIR5938 provides additional information regarding abnormal high loading events in addition to hard landing events.

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1. SCOPE

The primary focus of this document is to provide information on the impacts hard landings and abnormal load conditions on landing gear and related systems. However, because hard landings potentially affect the entire aircraft, this document also includes information for non-landing gear areas. The document may be considered to be applicable to all types of aircraft. This document does NOT provide recommended practices for hard landing inspections, nor does it provide recommendations on the disposition of damaged equipment. Refer to ARP4915 and ARP5600 for information on dispositions relating to landing gear components or wheels involved in accidents/incidents.

1.1 Purpose

The purpose of this document is to provide information on the current practices used by commercial and military operators in regard to hard landings (or overload events designated as hard landings) and abnormal loading events. Since detailed information on inspections would be aircraft specific, this AIR provides only a general framework. Detailed information and procedures are available in the maintenance manuals for specific aircraft.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of the other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

AIR4566	Crashworthy Landing Gear Design
AIR4894	Landing Gear Stability
ARP4915	Disposition of Landing Gear Components Involved in Accidents/Incidents
ARP5600	Disposition of Damaged Wheels Involved in Accidents/Incidents
ARP5908	Landing Gear Servicing
AS8860	Landing Gear Structural Requirements as Listed in the MIL-886X Series of Specifications

2.1.2 AIA Publications

Available from Aerospace Industries Association, 1000 Wilson Boulevard, Suite 1700, Arlington, VA 22209-3928, Tel: 703-358-1000, www.aia-aerospace.org.

AIA Pub 05-01	Best Practices Guide, Inspection Procedures Following High Load Events
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2.1.3 ASTM Publications

Available from ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, Tel: 610-832-9585, www.astm.org.

ASTM F3061/F3061M-20	Standard Specification for Systems and Equipment in Small Aircraft
ASTM F3116/F3116M-18	Standard Specification for Design Loads and Conditions

2.1.4 FAA Publications

Available from Federal Aviation Administration, 800 Independence Avenue, SW, Washington, DC 20591, Tel: 866-835-5322, www.faa.gov.

- 14 CFR 23 Federal Aviation Regulations - Airworthiness Standards: Normal, Utility, Acrobatic, And Commuter Category Airplanes, para. 23.2220 "Ground and water load conditions"
- 14 CFR 25 Federal Aviation Regulations - Airworthiness Standards: Transport Category Airplanes, para. 25.473 "Landing load conditions and assumptions"
- 14 CFR 27 Federal Aviation Regulations - Airworthiness Standards: Normal Category Rotorcraft, para. 27.725 "Limit Drop Test"
- 14 CFR 29 Federal Aviation Regulations - Airworthiness Standards: Transport Category Rotorcraft, para. 29.725 "Limit Drop Test"

2.1.5 U.S Government Publications

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

- MIL-DTL-32648 Zinc Nickel Plating, Low Hydrogen Embrittlement, Electro-Deposition
- MIL-STD-870 Cadmium Plating, Low Embrittlement, Electrodeposition
- MIL-STD-1501 Chromium Plating, Low Embrittlement, Electrodeposition

2.1.6 Other Publications

- CS 23 Certification Specifications for Normal, Utility, Aerobatic, and Commuter Category Aeroplanes, para. 23.473 "Ground load conditions and assumptions"
- CS 25 Certification Specifications for Large Aeroplanes, para. 25.473 "Landing load conditions and assumptions"
- CS 27 Certification Specifications for Small Rotorcraft, para. 27.725 "Limit Drop Test"
- CS 29 Certification Specifications for Large Rotorcraft, para. 29.725 "Limit Drop Test"
- SAWE Recommended Practice 7 Mass Properties Management and Control for Military Aircraft
- DOT/FAA/AR-97/106 Video Landing Parameter Survey - Washington National Airport
- DOT/FAA/AR-00/72 Video Landing Parameter Survey - Honolulu International Airport
- DOT/FAA/AR-96/125 Video Landing Parameter Survey - John F. Kennedy International Airport
- DOT/FAA/AR-04/47 Commuter Aircraft Video Landing Parameter Surveys, Summary Report - London City Airport, Philadelphia International Airport, and Atlantic City International Airport
- DOT/FAA/AR-07/53 Video Landing Parameter Survey - Summary Report, LHR Heathrow International
- JSSG 2006 Department of Defense Joint Service Specification Guide: Aircraft Structures

JSSG 2009 (Appendix A) Department of Defense Joint Service Specification Guide: Air Vehicle Subsystems
Appendix A: Air Vehicle Landing Subsystem – Requirements and Guidance

NTSB Aviation Accident Database <https://www.nts.gov/Pages/AviationQuery.aspx>

2.2 Definitions/Abbreviations

ABNORMAL LANDING GEAR LOADING EVENT: A potential load exceedance event resulting from other than intended usage such a takeoff, landing, taxiing, and towing. Examples include departing the prepared surface (low or high speed), ground turns or ground oscillations that are out of design specification and loading events for which the landing gear was not designed, such as contact with ground obstacles (e.g., support equipment, animals, lighting poles/fixtures, etc.), or loads induced by maintenance personnel actions.

ACCIDENT: The NTSB defines accident as an occurrence associated with the operation of an aircraft which takes place between the time any person boards the aircraft with the intention of flight and all such persons have disembarked, and in which any person suffers death or serious injury, or in which the aircraft receives substantial damage.

AIA: Aerospace Industries Association

AMM: Aircraft Maintenance Manual

AUTOLAND: A system that fully automates the landing portion of an aircraft flight for low visibility and bad weather conditions.

BNI: Barkhausen Noise Inspection

CBM: Condition Based Maintenance

CLDGW (Carrier Landing Design Gross Weight): The aircraft maximum gross weight specified for landing/arrestment operations on an aircraft carrier.

CG: Center of Gravity

DLW (Design Landing Weight): The highest aircraft gross weight corresponding to the maximum required sink rate. This definition is common for both military and commercial land based fixed wing aircraft and rotorcraft.

EASA: European Aviation Safety Agency

FAA: Federal Aviation Administration

FPI: Fluorescent Penetrant Inspection

HARD LANDING: A landing event, where it is suspected that the landing gear or airframe structure, was possibly subjected to loads exceeding design limit loads. Influencing conditions such as flat tires during touchdown and rollout, a heavily rolled or yawed landing, or a shock absorber that is improperly serviced beyond the certification basis.

HVOF: High Velocity Oxygen Fuel

INCIDENT: The NTSB defines incident as an occurrence other than an accident, associated with the operation of an aircraft, which affects or could affect the safety of operations.

JSSG: Joint Service Specification Guide for Department of Defense

LHE: Low Hydrogen Embrittlement

LLDGW (Landplane Landing Design Gross Weight): This term is used in military applications and is equivalent to the DLW. Typically, the following guidelines are used to establish LLDGW. For utility, observation, and trainer aircraft, LLDGW = maximum flight weight minus the following: payload to be expended, all external fuel, and 25% internal fuel. For cargo aircraft, LLDGW = maximum flight weight minus: all external fuel and 50% internal fuel. For combat aircraft, LLDGW = maximum flight weight minus: all external fuel and 60% internal fuel.

MLG: Main Landing Gear

MLW (Maximum Landing Weight) (commercial): The term MLW, used in a commercial environment, is synonymous with the DLW and corresponds to the highest gross weight for a 10 ft/s (3.05 m/s) landing for transport airplanes. The limit sink rate for part 23 aircraft is 7 to 10 ft/s (2.13 to 3.05 m/s). It is NOT the same as the military definition of maximum landing weight.

MLW (Maximum Landing Weight) (military): The highest allowable weight for any landing. Typically, it is established by maximum flight weight minus any droppable external fuel tanks and fuel consumed or dumped during one go-around or 3 minutes, whichever provides the lightest aircraft weight. The military MLW term corresponds to the highest gross weight for a 6 ft/s (1.83 m/s) or 8.5 ft/s (2.59 m/s) landing depending on aircraft type.

MTOGW: Maximum Takeoff Gross Weight

NDI: Non-Destructive Inspection

NLG: Nose Landing Gear

NTSB: National Transportation Safety Board

OEM: Original Equipment Manufacturer

OVERLOAD: A condition or event which may have subjected the landing gear or airframe structure to damaging loads.

OVERWEIGHT LANDING: A touchdown event occurring at a landing weight above the maximum certified landing weight for that aircraft. Other landing parameters such as the sink rate, side loads, strut servicing condition, etc., are not factors in declaring an 'overweight landing'.

S: As used in the ASTM F3061/F3061M sink rate equation; S is the reference wing area in units of square feet for English units or square meters for SI units.

SI: International System of Units

SAWE: International Society of Allied Weight Engineers

UAV: Unmanned Aerial Vehicle

US: United States

USAF: United States Air Force

USN: United States Navy

W: As used in the ASTM F3061/F3061M sink rate equation; W is the aircraft gross weight in units of pounds for English units or kg for SI units

Zn-Ni: LHE Zinc-Nickel

3. BACKGROUND OF LANDING DESIGN REQUIREMENTS

Table 1 describes the limit sink rates and aircraft gross weights used for various types of aircraft. For the land based fixed wing aircraft, these limit sink rates are for zero roll angle, zero roll rate, and 100% lift conditions.

Table 1 - Landing design requirements (reference only)

Aircraft Type	Gross Weight	Limit Sink Rate, ft/s	Limit Sink Rate, m/s
Part 23	Design/Maximum Landing Weight	4.4 (W/S) ^{0.25} Must be ≥7 Need not exceed 10	0.902 (W/S) ^{0.25} * Must be ≥2.133 Need not exceed 3.05 m/s
Part 25	Design/Maximum Landing Weight	10	3.05
	Maximum Takeoff Gross Weight	6	1.83
US Land Based Fighter/Bomber	DLW (Landplane Landing Design Gross Weight)	10	3.05
	Maximum Landing Weight	6	1.83
US Land Based Trainer	DLW (Landplane Landing Design Gross Weight)	13	3.96
	Maximum Landing Weight	8.5	2.59
US Ship Based Fixed Wing	Carrier Landing Design Gross Weight	See note**	N/A
Part 27	Maximum Takeoff Gross Weight	8	2.44
Part 29	Maximum Takeoff Gross Weight	6.55	2.00
US Military Rotorcraft	Various (refer to applicable requirements)	US Army/USAF (per subsystem specification) USN 12 (basic design gross weight)	US Army/USAF (per subsystem specification) USN 3.66 (basic design gross weight)
UAV	Various	Per subsystem specification***	Per subsystem specification***

* Note: Gross weight (W) must be in kg and reference wing area (S) must be in m² for this equation.

** Note: Landing sink rates are design values, unique to the aircraft, based on multivariate analysis accounting for approach speed, roll rate, ship motion, etc. Typical values for design sink rate are 25 to 28 ft/s (7.62 to 8.53 m/s) but can be lower based on subsystem specification requirements.

*** Note: For reference, one US military UAV is limited to 6 ft/s (1.83 m/s).

For commercial transport applications, landing gear design landing loads are governed by the following regulations. The first part of 14 CFR 25.473 states "the airplane is assumed to contact the ground 1) in the attitudes defined in par. 25.479 and 25.481; 2) with a limit descent velocity of 10 ft/s (3.05 m/s) at the design landing weight; and 3) with a limit descent velocity of 6 ft/s (1.83 m/s) at the design take-off weight. This requirement and those defined for side and drag loads in para. 25.479, 481, and 485 establish the threshold above which hard landing events occur."

For commercial small airplane applications, landing gear design landing loads and the threshold above which hard landings occur, are governed by the following regulations: formerly 14 CFR 23.471, 23.473, 23.479, 23.481, and 23.485, now documented in ASTM F3116/F3116M-18. Additional reference for the design and construction of landing gear systems can be found in ASTM F3061/F3061M-20.

On land-based US military applications, the design loads are given in AS8860 (formerly the MIL-L-886X series). Background information is also available in JSSG 2006 and JSSG 2009 Appendix A. For trainers, the limit sink rates are 13 ft/s (3.96 m/s) and 8.5 ft/s (2.59 m/s) at LLDGW and MLW respectively. All other classes of aircraft have limit sink rates of 10 ft/s (3.05 m/s) and 6 ft/s (1.83 m/s) for those same weights. Also, the landing gear design limits shall not be exceeded by landing at 15% higher sink rates as long as the weights are 15% lower. The conventional military aircraft criteria differ slightly from the commercial requirement in that the 6 ft/s (1.83 m/s) sink rate applies at a maximum landing weight and not necessarily at the takeoff weight.

USN design requirements for landing loads also come from AS8860, 3.1.4.8. For carrier-based aircraft, the analysis involves a complex multivariate check of probabilities of various factors to establish a design sink rate. The typical design limit sink rate is between 25 and 28 ft/s (7.62 and 8.53 m/s). For static strength ultimate loads are 1.5 times design limit load.

Historically, it is worth noting that some initial hard landing levels were based on reserve energy drop levels and modified based on initial flight testing and model validation efforts.