

AEROSPACE INFORMATION REPORT

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Effects of Extremely Cold Temperature on Landing Gear Operation

RATIONALE

This SAE Aerospace Information Report (AIR) provides information for landing gear operation in cold temperature environment. This information explains the effects of extremely cold temperature on landing gear performance and actuation. Cold temperature affects hydraulic fluid and pneumatic properties, which in turn affect shock strut and tire performance during landing and ground operations, as well as gear retraction and extension. This information is intended to aid the design process as well as operation and maintenance considerations.

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1. SCOPE

This SAE Aerospace Information Report (AIR) provides information on landing gear operation in cold temperature environments. It covers all operational aspects during ground handling, takeoff, and landing. It includes effects on tires, brakes, shock struts, seals, and actuators.

2. APPLICABLE DOCUMENTS

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

2.1 SAE Publications

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

AIR1362	Aerospace Hydraulic Fluids Physical Properties
AIR4762	Compilation of Freezing Brake Experience and Potential Designs and Operating Procedures to Prevent Its Occurrence
ARP1493	Wheel and Hydraulically Actuated Brake Design and Test Requirements for Military Aircraft
ARP5146	Assessment of Aircraft Wheel Sealing Systems
ARP5265	Minimum Operational and Maintenance Responsibilities for Aircraft Tire Usage
ARP5908	Landing Gear Servicing
AS4716	Gland Design, O-Ring and Other Seals
AS4832	Gland Design: Nominal 3/8 Inch Cross Section for Compression-Type Seals
AS5857	Gland Design, O-Ring and Other Elastomeric Seals, Static Applications
AS8942	Bearings, Plain and PTFE Lined, Self-Aligning
AS81820	Bearings, Plain, Self-Aligning, Self-Lubricating, Low Speed Oscillation
AS81935	Bearings, Plain, Rod End, Self-Aligning, Self-Lubricating, General Specification for (-65 to +325 °F)

2.2 U.S. Government Publications

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

MIL-DTL-5041	Tires, Ribbed Tread, Pneumatic, Aircraft
MIL-PRF-5606	Performance Specification, Hydraulic Fluid, Petroleum Base; Aircraft, Missile, and Ordinance
MIL-PRF-87257	Performance Specification, Hydraulic Fluid, Fire Resistant, Low Temperature, Synthetic Hydrocarbon Base; Aircraft and Missile
MIL-STD-810	Department of Defense Test Method Standard: Environmental Engineering Considerations and Laboratory Tests
MIL-W-5013	Wheel and Brake Assemblies, Aircraft, General Specification for

2.3 RTCA Publications

Available from RTCA, Inc., 1150 18th Street, NW, Suite 910, Washington, DC 20036, Tel: 202-833-9339, www.rtca.org.

RTCA/DO-160 Environmental Conditions and Test Procedures for Airborne Equipment

2.4 Other Publications

Fluid Mechanics 5th edition, Frank M. White, University of Rhode Island, McGraw Hill Companies, 2003

3. REQUIREMENTS

The landing gear is required to perform its various functions at the temperature range expected in service. This depends on the type of aircraft and its intended use. Each aircraft manufacturer defines the operational environment requirements.

The environmental flight envelope of an aircraft is the space within which an aircraft can operate safely. This envelope includes the allowable range of speeds, altitudes, and temperatures that the aircraft may operate. The allowable temperature range is usually depicted as a function of altitude. The aircraft manufacturer provides two envelopes: a flight envelope, and a ground operation envelope. These envelopes may affect the requirements for landing gear materials such as hydraulic fluids, grease, seals, etc.

The flight envelope is derived from the ISO (International Standards Organization) standard as a function of altitude. For a typical commercial aircraft, the flight envelope ranges from about -54 to 55 °C (-65 to 131 °F) at sea level, and from approximately -80 to -30 °C (-112 to -22 °F) at ~40000 feet. The ground envelope is defined from sea level to about 15000 feet. The maximum temperature is typically the same as the flight envelope, but the minimum temperature usually is constant at -54 °C (-65 °F), or may increase (become warmer) as altitude increases. Also refer to MIL-STD-810 and RTCA/DO-160 for general information on environmental conditions.

Each landing gear component is typically reviewed to determine what temperature environment, static or dynamic, it will see and to which it should be designed and tested. The ground envelope is used for the dynamic functioning of the landing gear components. The static capability also considers the flight envelope, taking into account the effects of the wheel well on the static temperature at altitude.

There are no specific FAA or EASA requirements related to operation at cold temperatures, but there is a Canadian requirement related to operation after cold-soak testing. AWM 525.1301-1 states:

“Substantiation of satisfactory operation of the aeroplane as a total system, by cold weather testing or by documented evidence of satisfactory operation at low temperature, is required after the aeroplane has experienced a prolonged exposure to ground ambient temperatures equal to or less than -35 °C unless an alternative minimum ground ambient temperature has been proposed by the applicant and accepted by the Minister.”

This requirement is considered in addition to, and not instead of, the system level or component level testing to satisfy other regulatory requirements.

4. OPERATIONAL PHASES

The sections below provide a general description of the effects of extremely cold temperature on specific ground and flight segments. These effects will be described in more detail in Section [5](#).

4.1 Taxi

During taxi operation at extremely cold temperatures, there exists the potential for strut bottoming due to the softer gas spring curve. The degree of risk is related to the runway roughness and is dependent on the design of the gas spring curve. Some gas springs are designed to operate at a wide range of temperatures, and some require different servicing for operation at extremely low temperatures. In addition, there is a tendency for tire flat-spotting due to cold-set, resulting in a rougher ride after leaving the gate. (This effect is lessened as tires are heated during taxi.)

4.2 Takeoff

In addition to the higher risk of strut bottoming, there is a higher potential for tail contact at rotation due to increased strut compression caused by the reduced gas volume. This risk may require strut servicing placards that take operational temperature into account. In addition to a rougher ride during the takeoff roll, tire flat-spotting due to cold-set can also result in higher vibration in the cabin and cockpit after liftoff due to the rotational forces caused by tire imbalance.

4.3 Retraction

The retraction system is typically designed and tested to perform at extreme temperatures. Cold temperature testing is usually performed at the component level due to the impracticality of testing the full scale assembly. Cold temperature can affect the retraction time, depending on the actuator design.

4.4 Flight

With the gear stowed in the wheel-well, there is a risk of cold-soaking prior to landing. The effect of this is highly dependent on the aircraft and wheel well design, landing gear door seal performance, the flight altitude, and the flight duration.

4.5 Extension

During flight the strut may become slightly inverted, causing hydraulic fluid to move into the gas chamber above the orifice plate. It is important that the full amount of fluid be returned to the hydraulic chamber after extension prior to landing to ensure proper shock absorption performance during landing impact. At very cold temperatures, the fluid viscosity increases dramatically. This can significantly reduce the flow rate of the fluid as it returns to the hydraulic chamber after extension, depending on the design of the flow paths. The orifice design with the strut at full extension directly affects the flow rate at cold temperatures. It has been observed that the use of multiple holes can greatly increase the flow rate by creating separate paths for the fluid and the escaping gas.

4.6 Landing

At extremely cold temperatures, the strut gas curve becomes “softer,” making it more possible to bottom the strut during hard landings. This is somewhat offset by the higher damping force. If a gas spring curve depends on very low reserve gas volume to prevent bottoming during normal temperatures, it will be more affected by low temperature conditions than struts with a large reserve gas volume. (See [5.2](#) for a detailed description of this phenomenon.)

4.7 Pre-/Post-Flight

Landing gear maintenance activity is performed before and/or after the flight. The types of maintenance that may be affected by extremely cold temperatures are shock strut servicing, joint lubrication, tire pressure servicing, etc. Aircraft manufacturers typically provide special instructions for maintenance in cold temperatures. Refer to ARP5908 for detailed information on shock strut servicing. If tires are serviced at normal temperatures and then operated at a cold location, there is a risk of under-inflation below recommended levels. Manufacturers typically recommend that tire pressure be checked at the cold location—it is generally better for tires to be slightly over-inflated in a warmer climate than under-inflated in a cooler climate, since operating with under-inflated tires can cause damage to the tires. For general information on tire operation and maintenance, refer to ARP5265.

Lubrication of joints may be very challenging if performed at temperatures below freezing, with greater risk of not completely filling grease grooves due to increased viscosity of the grease and/or blockage due to frozen moisture. For this reason, lubrication is normally performed at temperatures above freezing. In addition to the hardship on the maintenance crew due to protective clothing, servicing equipment performance is also degraded, making maintenance at cold temperature very difficult or impractical. Specialized equipment is often needed to perform these tasks.

5. EFFECTS OF OPERATING LANDING GEAR AT EXTREMELY COLD TEMPERATURES

The following sections discuss the various effects of extremely cold temperature on landing gear operation, covering shock strut performance, tires, brakes, and systems.

5.1 Structural

The landing gear structure is designed with temperature variation taken into account. Some areas of particular importance when operating at extremely cold temperatures include thermal contraction (and expansion) of joints and mating or sliding parts, and ice formation in trapped voids or pockets. Lubrication of joints can be an issue in cold temperature operation due to increased grease viscosity and potentially blocked grease ports. A lack of grease in the joints can cause wear, corrosion, heat damage, etc. Lubrication is most effective when performed at temperatures above freezing. Aircraft manufacturers provide maintenance procedures for cold weather operation. In general, cold temperatures have little detrimental effect on structural components when properly serviced. The influence of cold temperature on the shock absorber gas spring and hydraulic damping is addressed in [5.2](#).

5.2 Shock Strut

The effect of cold temperature on the shock strut is discussed below for the gas spring, hydraulic damping, bearings, and seals. The resulting effects on landing and takeoff performance can be very significant.

5.2.1 Gas Spring

The gas spring of an oleo-pneumatic shock strut is directly affected by temperature changes. In general, the nominal gas spring curve is designed assuming a standard day temperature of 15 °C (59 °F). This nominal curve is used in developing servicing placards as well as in developing design loads. In addition, this curve is validated during load-stroke tests and drop testing at ambient lab temperature.

The gas spring curve in conventional oleo-pneumatic shock struts approximately follows the gas law: $PV/TZ = \text{Constant}$. (It is noted that gas absorption may affect this relationship, as well as other effects, such as real gas behavior and compression of the oil at high pressures; empirical corrections are often included, as needed.) For a fixed gas volume, as temperature decreases, the gas pressure decreases. In addition to the gas temperature effect, a significant pressure drop also occurs due to the contraction of the oil volume, which correspondingly increases the gas volume and thus decreases pressure. The change in gas pressure at a given stroke is determined by the equations below.

$$\frac{P_1 V_1}{Z_1 T_1} = \frac{P_2 V_2}{Z_2 T_2} \quad (\text{Eq. 1})$$

where:

T_1 = temperature at state 1 (e.g., at standard day servicing temperature)

T_2 = temperature at state 2 (e.g., at cold day operating temperature)

P_1 = gas pressure at state 1

P_2 = gas pressure at state 2

V_1 = gas volume at state 1 (at a given stroke)

V_2 = gas volume at state 2 (at a given stroke)

Z_1 = nitrogen compressibility at state 1 (function of temperature and pressure)

Z_2 = nitrogen compressibility at state 2 (function of temperature and pressure)