



AEROSPACE INFORMATION REPORT

AIR5451™**REV. A**

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Superseding AIR5451

(R) A Guide to Landing Gear System Integration

RATIONALE

Revision A incorporates the latest information and state of the art in the landing gear industry, and conveys the information as a reference to assist in the creation of an integrated landing gear system specification for new designs. It is intended as information only, and should not be used as a mandatory requirement specification.

AIR5451A has been reaffirmed to comply with the SAE Five-Year Review policy.

TABLE OF CONTENTS

1.	SCOPE.....	4
1.1	Purpose.....	4
1.2	Field of Application.....	4
2.	REFERENCES.....	4
2.1	Applicable Documents	4
2.1.1	SAE Publications.....	5
2.1.2	FAA Publications	5
2.1.3	EASA Publications	6
2.1.4	RTCA Publications	6
2.1.5	TSO Publications	6
2.1.6	Military Specifications.....	6
2.2	List of Acronyms.....	6
3.	LANDING GEAR SYSTEM CONFIGURATION REQUIREMENTS.....	8
3.1	Aircraft Type, Purpose, and Use	8
3.2	Landing Gear System Definition	8
3.2.1	Landing Gear System Structural Configuration	8
3.2.2	Landing Gear Structural Interfaces	9
3.2.3	Landing Gear System Architecture	9
3.2.4	Landing Gear System Functional Interfaces.....	9
3.2.5	Landing Gear System Detailed Requirements	9
3.2.6	Weight	9
3.2.7	Growth Potential.....	9
4.	LANDING GEAR SYSTEM FUNCTIONAL REQUIREMENTS.....	10
4.1	Taxi/Takeoff	17
4.1.1	Functional Requirements	17
4.1.2	Verification	18
4.1.3	Other Associated Functional Requirements	18

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<https://www.sae.org/standards/content/AIR5451A/>

SAE WEB ADDRESS:

4.2	Maneuvering	18
4.2.1	Functional Requirements	18
4.2.2	Verification	19
4.2.3	Other Associated Functional Requirements	20
4.3	Landing	20
4.3.1	Functional Requirements	20
4.3.2	Verification	21
4.3.3	Other Associated Functional Requirements	21
4.4	Braking	21
4.4.1	Functional Requirements	21
4.4.2	Verification	23
4.4.3	Other Associated Functional Requirements	24
4.5	Stability	24
4.5.1	Functional Requirements	24
4.5.2	Verification	25
4.5.3	Other Associated Functional Requirements	25
4.6	Landing Gear Actuation	25
4.6.1	Functional Requirements	25
4.6.2	Verification	27
4.6.3	Other Associated Functional Requirements	27
4.7	Landing Gear Control and Indication System	27
4.7.1	Functional Requirements	27
4.7.2	Verification	29
4.7.3	Other Associated Functional Requirements	30
4.8	Special Purposes	31
4.8.1	Functional Requirements	31
4.8.2	Verification	34
4.8.3	Other Associated Functional Requirements	34
5.	LANDING GEAR SYSTEM INTEGRITY REQUIREMENTS.....	35
5.1	System Criticality.....	35
5.1.1	Functional Hazards	35
5.1.2	HIRF and Lightning	35
5.1.3	Software	35
5.2	Failure Mode and Effects Analysis.....	35
5.3	Fault Tree Analysis	36
5.4	Common Cause Analysis.....	36
5.5	System Safety Assessment	36
5.5.1	Wheel/Tire Failure.....	36
5.5.2	Brake Overheat	37
5.6	Electrical Power Interruptions	37
5.7	Flight Data Recorders	38
5.8	Highly Integrated Systems	38
6.	LANDING GEAR SYSTEM PROGRAM REQUIREMENTS	38
6.1	Life Cycle Cost	39
6.1.1	Recurring Cost	40
6.1.2	Concurrent Engineering (CE).....	40
6.1.3	Design for Manufacturing and Assembly (DFMA)	40
6.1.4	Target Cost	40
6.1.5	Cost Tracking	40
6.1.6	Cost Containment	41
6.1.7	Operating Cost	41
6.1.8	Non-Recurring Cost	41
6.2	Weight	41
6.3	Dispatch Reliability and Total Reliability	41
6.4	Maintainability	41

6.5	Certification, Crashworthiness, and Testing	41
6.6	Schedule	42
6.7	Risk	42
6.8	Roles and Responsibilities	42
6.9	Sampling Program	42
6.10	Landing Gear System Build Up, Shipping, and Receiving	42
7.	NOTES	42
7.1	Revision Indicator	42
Table 1	FAA and EASA certification requirements	11
Table 2	SAE landing gear documents	14

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1. SCOPE

The landing gear system is a major and safety critical airframe system that needs to be integrated efficiently to meet the overall aircraft program goals of minimizing the penalties of weight, cost, dispatch reliability and maintenance. As the landing gear system business develops and large-scale teaming arrangements and acquisitions become increasingly common, it may be desirable in some instances to procure an Integrated Landing Gear System. This document provides guidelines and useful references for developing an integrated landing gear system for an aircraft. The document structure is divided into four sections:

- Landing Gear System Configuration Requirements (Section 3)
- Landing Gear System Functional Requirements (Section 4)
- Landing Gear System Integrity Requirements (Section 5)
- Landing Gear System Program Requirements (Section 6)

The landing gear system encompasses all landing gear structural and subsystem elements. Structural elements include shock struts, truck beams, torsion links, braces, fittings, pins, wheels, tires, and brakes. The subsystem elements include the retraction/extension system (both normal and alternate), the steering system, the braking system (both normal and alternate, manual and automatic), the indication and monitoring systems and control systems (mechanical, hydraulic, electrical and electronic).

1.1 Purpose

The purpose of this document is to provide an airframe manufacturer or procuring agency with a framework from which a specification for an Integrated Landing Gear System may be developed and to provide guidance in the development of an integrated landing gear system. This document is not intended to be an all-inclusive detail design document or to duplicate other existing SAE landing gear documents. Rather, the intent is to provide guidance in writing and managing the top-level integration requirements, remembering that the landing gear systems must also be integrated into the airframe. This document has information applicable to both commercial and military landing gear systems.

1.2 Field of Application

In the past, it has been common for airframe manufacturers to procure the landing gear and its associated systems as separate elements, and to integrate these elements into the overall aircraft design. Using this approach, the airframe manufacturers have written separate specifications for each element and have assembled the landing gear from components delivered separately by different suppliers. In some instances, the landing gear supplier simply performs the assembly work and delivers a “dressed gear” that has been built up from components procured by the airframer. In other instances, the airframe manufacturer subcontracts the design of the landing gear, including the specification and procurement of the associated systems, to an integrator. This document includes landing gear systems for large commercial aircraft certified under 14 CFR Part 25/EASA CS 25.

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 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.

AIR1083	Airborne Hydraulic and Control System Survivability for Military Aircraft
AIR1569	Handling and Installation Practice for Aerospace Hose Assemblies
AIR1800	Aircraft Tail Bumpers
AIR4004	Guide for Installation of Electrical Wire and Cable on Aircraft Landing Gear
ARP994	Design of Tubing Installations for Aerospace Hydraulic Systems
ARP1107A	Tail Bumpers for Piloted Aircraft
ARP4404	Aircraft Electrical Installations
ARP4752	Aerospace - Design and Installation of Commercial Transport Aircraft Hydraulic Systems
ARP4754	Guidelines for Development of Civil Aircraft and Systems
ARP4761	Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems and Equipment
ARP4925	Aerospace Design and Installation of Commercial Transport Helicopter Hydraulic Systems
ARP5257	Tire Overspeed Landing Test
AS1145	Aircraft Brake Temperature Monitor Systems (BTMS)
AS5440	Hydraulic Systems, Military Aircraft, Design and Installation, Requirements For
ARP6137	Tire Pressure Monitoring Systems (TPMS) for Aircraft
ARP6152	Aircraft Tires Service Overload Capability
AS8091	Aircraft Jacking Pads Adapters and Sockets Design and Installation of
AS50881	Wire Aerospace Vehicle

2.1.2 FAA Publications

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

For a sample list of applicable landing gear FARs for large transport airplanes see Table 1. This is not meant to be a comprehensive list, and as such, each user needs to ensure that the applicable documents are used for the aircraft type intended.

2.1.3 EASA Publications

Available from European Aviation Safety Agency, Ottoplatz, 1, D-50679 Cologne, Germany, Tel: +49 221 8999 000, www.easa.europa.eu

For a sample list of applicable landing gear CSs for large transport airplanes see Table 1. This is not meant to be a comprehensive list, and as such, each user needs to ensure that the applicable documents are used for the aircraft type intended.

2.1.4 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-D Environmental Conditions and Test Procedures for Airborne Equipment

RTCA/DO-178B Software Considerations in Airborne Systems and Equipment Certification

RTCA/DO-254 Design Assurance Guidance for Airborne Electronic Hardware

2.1.5 TSO Publications

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

TSO-C62e Aircraft Tires

TSO-C135a Transport Airplane Wheels and Wheel and Brake Assemblies

2.1.6 Military Specifications

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

MIL-A-8860 Aircraft Strength and Rigidity, General Specification for

MIL-A-8861 Airplane Strength and Rigidity Flight Loads

MIL-HDBK-454 Military Handbook: General Guidelines for Electronic Equipment

MIL-STD-704 Department of Defense Interface Standard: Aircraft Electric power Characteristics

2.2 List of Acronyms

AC	Aircraft
AIR	Aerospace Information Report
ARP	Aerospace Recommended Practice
AS	Aerospace Standard
ASIC	Application Specific Integrated Circuit
BOM	Bill of Material
CCA	Common cause analysis
CDR	Critical design review

CE	Concurrent engineering
CG	Center of gravity
DD	Dependence diagrams
DFMA	Design for manufacturing and assembly
EASA	European Aviation Safety Agency
EICAS	Engine Indication and Crew Alerting System
F	Fahrenheit
FAA	Federal aviation administration
FAR	Federal aviation regulation
FHA	Functional hazard assessment
FMEA	Failure mode and effects analysis
FMECA	Failure mode, effects and criticality analysis
fps	Feet per second
FTA	Fault tree analysis
HIRF	High intensity radiated fields
HVOF	High Velocity Oxygen Fuel
JAA	Joint aviation administration
JAR	Joint aviation regulation
JDP	Joint Definition Phase
LRU	Line replaceable unit
MA	Markov Analysis
MEL	Minimum Equipment List
MLG	Main Landing Gear
MTOW	Maximum Take-Off Weight
NATO	North Atlantic trade organization
NLG	Nose landing gear
OEM	Original equipment manufacturer
OSP	Outside purchased
O&S	Operating and Support
PDR	Preliminary design review

PLD	Programmable Logic Device
psig	Pounds per square inch, gauge
RTCA	Radio Technical Commission for Aeronautics
RTO	Rejected take-off or Refused take-off
SSA	System safety analysis
TAS	True airspeed
TBD	To be determined
U.S.	United States of America
WOW	Weight-On-Wheels

3. LANDING GEAR SYSTEM CONFIGURATION REQUIREMENTS

The Landing Gear System Configuration Requirements section should include an overview of the aircraft type and its purpose, accompanied by a description of the landing gear system configuration.

3.1 Aircraft Type, Purpose, and Use

This section should give a brief description of the aircraft and the purpose for which it is to be used. A three-view drawing of the aircraft should be included that specifies the ground contact point of each gear (maximum taxi weight, mid CG condition), and the ground angle limit (angle between floor and line tangent to bottom of unloaded tire and tail strike point). The aircraft operational characteristics such as engine thrust, ground speed, runway flotation, altitude and temperature should also be specified, as well as the weight and cg envelopes (lateral, longitudinal, and vertical). This section should also specify the number of flights per day, the expected turnaround time, the expected life of the aircraft, and the expected life of the landing gear system and scheduled overhauls. Aircraft level configuration definitions are also needed such as hydraulic or electrical power balance, aircraft software, and avionics architecture (e.g., IMA use). An operational spectrum should be provided from which a landing gear fatigue spectrum can eventually be generated. This section should also provide the certification basis of applicable certifying authorities to which the airplane is to be certificated.

3.2 Landing Gear System Definition

This section should contain the structural configuration of the landing gear as well as the landing gear sub-system schematics. The functional interfaces (structural and systems) should also be specified. The “not-to-exceed” weight requirements and expected growth potential of the landing gear systems and sub-systems to be supplied should be specified in this section.

3.2.1 Landing Gear System Structural Configuration

A centerline diagram of the landing gear containing all structural joints and constituting the basis for the landing gear definition should be provided. The extent to which the design of the landing gear is “firm” should be specified here. It may provide the best opportunity for weight and cost avoidance if the firm gear configuration is defined as the baseline against which trade studies are performed within the context of these requirements. The airframe manufacturer must approve any changes to the baseline landing gear configuration which will certainly arise from design iterations and the successive loads loops.

The aircraft should have reached firm structural configuration by the time the associated landing gear contract is awarded to avoid the consequence of any major structural changes on the landing gear configuration (e.g., wing rear spar shifts can cause major changes in landing gear configuration). A “firm” structural configuration may be defined as a structural centerline drawing for which enough layout and sizing work has been accomplished to provide confidence that the centerlines will not change. However, this does not mean that the supplier should not have an input in establishing the firm structural configuration or the sub-system configuration prior to the contract award, and in fact early involvement with the supplier during this preliminary design phase is recommended.

3.2.2 Landing Gear Structural Interfaces

The structural joints connecting the landing gear structure to the airframe need to be specified. Also, the minimum clearance requirements with all major structures and aircraft loft lines, including minimum tire clearance using the grown tire envelope (per the Tire and Rim Association guidelines) need to be included in this section.

The landing gear structural interfaces to the aircraft must be specified, and agreed to between system and structure suppliers, in interface control drawings during the Joint Definition Phase. Specifically, the interfaces for the trunnions, brace attach points, and actuators will need to be defined and agreed to. Other structural interfaces such as those required for the mounting of the various landing gear system sub-components such as valves and actuators also need to be specified on interface definition drawings.

3.2.3 Landing Gear System Architecture

The preliminary or suggested architectures of each landing gear sub-system (steering, braking, extension system, etc.) should be included in this section and presented in the form of schematics. A detailed list of each LRU composing the sub-systems should also be proposed to complete the definition of the overall Landing Gear System. The suggested sub-system architectures and LRU breakdowns should be considered preliminary and are to be refined by the supplier during the Joint Definition Phase. Failure cases such as tire failures also need to be addressed when considering the layout of the landing gear and the associated equipment in the gear bay.

3.2.4 Landing Gear System Functional Interfaces

The landing gear system functional definition can take the form of a context diagram that shows the basic relationship of the landing gear system with other aircraft systems, such as the electrical system, the hydraulic system, the maintenance computer, the flight data recorder, etc. An overview of the landing gear system architecture following its sub-functions (e.g., extend/retract, steering, braking, etc.) is also recommended to be included in this section. General system requirements for each sub-function should be developed to encompass the overall expectation vis-à-vis the landing gear system. Similarly, as for the structural interfaces, the system functional interfaces with other aircraft systems must be specified, and agreed to between system and structure suppliers during the Joint Definition Phase.

3.2.5 Landing Gear System Detailed Requirements

Detailed requirements or specific design constraints, such as particular use of seals, grease fittings, use of HVOF, etc., pertaining to the sub-systems or the components should be indicated when applicable. Other constraints such as maximum noise levels, environmental requirements, protection against HIRF and Lightning, corrosion protection means, etc., should also be specified.

3.2.6 Weight

Weight control is of critical importance to the success of an aircraft program. Every effort should be made to minimize the landing gear system weight without compromising the program design, reliability and safety objectives.

A guaranteed not-to-exceed weight should be specified by the airframe manufacturer that will meet the overall airplane weight objectives. The not-to-exceed weight should be agreed upon by the landing gear system supplier. A detailed weight breakdown by component should be provided by the system supplier.

3.2.7 Growth Potential

The aircraft manufacturer or procuring activity shall determine if a performance growth capability is to be designed in the landing gear forging design. As a goal, this shall not impact the basic weight of the system design, but shall be achieved by space provision for modification where necessary.

4. LANDING GEAR SYSTEM FUNCTIONAL REQUIREMENTS

This section should include requirements that will allow the system to perform its intended function. For the purpose of this document, the requirements are sub-divided in terms of the Landing Gear System's top-level functions: Taxi/Takeoff, Maneuvering, Landing, Braking, Stability, Landing Gear Actuation, Landing Gear Control and Indication and Special Purposes. In certain areas, there could be a need for a refinement of the top-level function into a more detailed functional requirement, such that all functional requirements are covered in the specification document of the Landing Gear System.

Each landing gear functional requirement will contain three sections:

- Functional Requirements
- Verification
- Other Associated Functional Requirements

The Functional Requirements and Verification sections are for stating each top-level integration requirement as simply as possible along with the rationale for the requirement. The Verification Plan specifies how the functional requirement will be verified in terms of inspection, analysis, component testing, system testing, flight testing or a combination of these. A table clearly showing each of the listed requirements and the means by which it will be verified is recommended to be included in the specification document. The Other Associated Functional Requirements section is used to identify other functional requirements, which together with the functional requirement may influence the design solution.

Each landing gear functional requirement will tie to Regulatory Requirements as ruled by the FAA and EASA or other certification agencies. Table 1 includes the relationship between each Landing Gear System function and Regulatory Requirements. In principle, the basis of certification should be established and Means of Compliance (MOC) at least drafted prior to contract award.

Similarly, Table 2 includes the relationship between each Landing Gear System function and related SAE documents. The referenced SAE documents form an integral part of this AIR document and should be referred to for the specification of the Landing Gear System's requirements. SAE documents may provide guidance, recommended practices, and information related to the functional requirement.

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Table 1 – FAA and EASA certification requirements

FAR/CS	TITLE	FUNCTION							
		TAXI/TAKEOFF	MANEUVERING	LANDING	BRAKING	STABILITY	LG ACTUATION	LG CTRL & INDICATION	SPECIAL PURPOSES
	SUBPART B - FLIGHT								
	GENERAL								
25.25	Weight Limits	X							
	PERFORMANCE								
25.101	General				X				
25.107	Take-Off Speeds	X			X				
25.109	Accelerate-Stop Distance				X				
25.125	Landing				X				
	GROUND HANDLING CHARACTERISTICS								
25.231	Longitudinal Stability and Control				X	X			
25.233	Direction Stability and Control		X						
25.235	Taxiing Condition	X							
	SUBPART C - STRUCTURE								
	GROUND LOADS								
25.301	Loads								X
25.471	General	X		X					
25.473	Ground Load Conditions and Assumptions			X					
25.477	Landing Gear Arrangement			X					
25.479	Level Landing Conditions			X					
25.481	Tail-Down Landing Condition			X					
25.483	One-Wheel Down Landing Condition			X					
25.485	Side Load Conditions			X					
25.487	Rebound Landing Conditions			X					
25.489	Ground Handling Conditions	X							
25.491	Taxi, Takeoff and Landing Roll	X		X					
25.493	Braked Roll Condition				X				
25.495	Turning	X	X						
25.497	Tail-Wheel Yawing		X						
25.499	Nose-Wheel Yaw and Steering	X	X						
25.503	Pivoting	X							
25.507	Reversed Braking								X
25.509	Towing Loads								X
25.511	Ground Load: Unsymmetrical Loads on Multiple-Wheel Units	X		X					
25.519	Jacking and Tie-Down Provisions								X
	FATIGUE EVALUATION								
25.571	Damage-Tolerance and Fatigue Evaluation of Structure	X							
	LIGHTNING PROTECTION								
25.581	Lightning Protection		X		X			X	

Table 1 – FAA and EASA certification requirements (continued)

FAR/CS	TITLE	FUNCTION							
		TAXI/TAKEOFF	MANEUVERING	LANDING	BRAKING	STABILITY	LG ACTUATION	LG CTRL & INDICATION	SPECIAL PURPOSES
	SUBPART D – DESIGN AND CONSTRUCTION								
	GENERAL								
25.601	General	X					X		
25.603	Materials	X					X		
25.605	Fabrication Methods	X					X		
25.607	Fasteners	X					X		
25.609	Protection of Structure	X					X		
25.611	Accessibility Provisions	X					X		
25.613	Material Strength Properties and Design Values	X					X		
25.621	Casting Factors	X					X		
25.625	Fitting Factors	X					X		
25.631	Bird Strike Damage	X					X		
	CONTROL SYSTEMS								
25.671	General						X		
25.683	Operation Tests						X		
25.685	Control System Details						X		
25.689	Cable Systems						X		
25.703	Take-Off Warning System				X				
	LANDING GEAR								
25.721	General			X					
25.723	Shock Absorption Tests			X					
25.729	Retracting Mechanism						X	X	
25.731	Wheels				X				
25.733	Tires				X				
25.734 CS only	Protection against Wheel and Tire Failures								X
25.735	Brakes				X				
25X745	Nose-Wheel Steering	X	X	X					X
	PERSONNEL AND CARGO ACCOMMODATIONS								
25.777	Cockpit Controls							X	
25.779	Motion and Effect of Cockpit Controls							X	
25.781	Cockpit Control Knob Shape							X	
	FIRE PROTECTION								
25.863	Flammable Fluid Fire Protection		X		X		X		
	MISCELLANEOUS								
25X899	Electrical Bonding and Protection Against Lightning		X		X				

Table 1 – FAA and EASA certification requirements (continued)

FAR/CS	TITLE	FUNCTION							
		TAXI/TAKEOFF	MANEUVERING	LANDING	BRAKING	STABILITY	LG ACTUATION	LG CTRL & INDICATION	SPECIAL PURPOSES
	SUBPART F - EQUIPMENT								
	GENERAL								
25.1301	Function and Installation	X	X	X	X	X	X	X	X
25.1302	Installed Systems and Equipment for Use by the Flight Crew (=Human Factors)								X
25.1309	Equipment, Systems and Installations	X	X	X	X	X	X	X	X
25X1315	Negative Acceleration						X		
	INSTRUMENTS: INSTALLATION								
25.1322	Warning, Caution and Advisory Lights		X		X			X	
	ELECTRICAL SYSTEMS AND EQUIPMENT								
25.1353	Electrical Equipment		X		X		X	X	
	MISCELLANEOUS EQUIPMENT								
25.1381	Instrument Lights		X		X			X	
25.1431	Electronic Equipment		X		X			X	
25.1435	Hydraulic Systems		X		X		X		
25X1436	Pneumatic Systems-High Pressure						X		
	SUBPART G – OPERATING LIMITATIONS AND INFORMATION								
	OPERATING LIMITATIONS								
25.1515	Landing Gear Speeds						X		
25.1533	Additional Operating Limitations						X		
	MARKINGS AND PLACARDS								
25.1541	General								
25.1555	Control Markings						X	X	
25.1563	Airspeed Placard						X		
	AIRPLANE FLIGHT MANUAL								
25.1583	Operating Limitations						X		
	SUPPLEMENTARY INFORMATION								
25X1591	Supplementary Performance Information	X		X					

Table 2 – SAE landing gear documents

DOCUMENT	TITLE	FUNCTION							
		TAXI/TAKEOFF	MANEUVERING	LANDING	BRAKING	STABILITY	LG ACTUATION	LG CTRL & INDICATION	SPECIAL PURPOSES
AIR1064	Braking System Dynamics			X	X	X			
AIR1243	Anti Blow-By Design Practice for Cap Seals						X		
AIR1489	Aerospace Landing Gear Systems Terminology			X					
AIR1494	Verification of Landing Gear Design Strength	X		X					
AIR1569	Handling and Installation Practice for Aerospace Hose Assemblies								X
AIR1594	Plain Bearing Selection for Landing Gear Applications	X							
AIR1739	Information on Antiskid Systems				X				
AIR1752	Aircraft Nosewheel Steering/Centering Systems		X						
AIR1780	Aircraft Flotation Analysis	X							
AIR1800	Aircraft Tail Bumpers			X					X
AIR1810	Design, Development and Test Criteria - Solid State Proximity Switches/Systems for Landing Gear Applications							X	
AIR1904	Tire Spray Suppression - Airplane Design and Consideration for	X							
AIR1934	Use of Structural Carbon Heat Sink Brakes on Aircraft				X				
AIR4004	Guide for Installation of Electrical Wire and Cable on Aircraft Landing Gear								X
AIR4012	USAF Aircraft Wheels				X				
AIR4077	Mechanical Switch Usage for Landing Gear Applications								
AIR4243	Landing Area/Landing Gear Compatibility - A Brief History of SAE/Corps. of Engineers Cooperation								
AIR4358	Steering Effect of Tilted, Free-Swiveling Nose Gears		X						
AIR4403	Selection, Testing, Lubrication, and Sealing of Single Row Tapered Roller Bearings for Aerospace Wheel Applications	X							
AIR4566	Crashworthy Landing Gear Design			X					
AIR4762	Complication of Freezing Brake Experience and Potential Designs and Operating Procedures to Prevent Its Occurrence				X				
AIR4777	Nondestructive Inspection (Ndi) Methods Used During Production and Operation of Aircraft Wheels and Brakes				X				
AIR4830	Aircraft Tire Pressure Monitoring Systems							X	
AIR4894	Landing Gear Stability			X		X		X	
AIR4912	Design Requirements for Spare Seals								
AIR5024	Landing Gear Switch Selection Criteria							X	
AIR5358	Landing Gear Shock Strut Hydraulic Fluid								
AIR5372	Information on Brake-By-Wire (BBW) Brake Control Systems				X				
AIR5388	Unique Wheel and Brake Designs				X				

Table 2 – SAE landing gear documents (continued)

	DOCUMENT	TITLE	FUNCTION							
			TAXI/TAKEOFF	MANEUVERING	LANDING	BRAKING	STABILITY	LG ACTUATION	LG CTRL & INDICATION	SPECIAL PURPOSES
AIR	AIR5479	Environmentally Compliant Processes for Landing Gear								
	AIR5487	Aircraft Tire History								
	AIR5885	Landing Gear Common Repair								
	ARP597	Wheels and Brakes, Supplementary Criteria for Design Endurance				X				
	AIR764	Skid Control System Vibration Survey				X	X			
	AIR811	Disposition of Wheels Which Have Been Overheated				X				
ARP	ARP1070	Design and Testing of Antiskid Brake Control Systems for Total Aircraft Compatibility				X				
	ARP1107	Tail Bumpers for Piloted Aircraft	X		X					X
	ARP1311	Landing Gear Structures and Mechanisms	X		X					
	ARP1322	Overpressurization Release Devices				X				
	ARP1383	Aerospace - Impulse Testing of Hydraulic Components						X		
	ARP1493	Wheel and Hydraulically Actuated Brake Design and Test Requirements for Military Aircraft				X				
	ARP1538	Arresting Hook Installation, Land-Based Aircraft								X
	ARP1595	Design and Verification of Aircraft Nose Wheel Steering Systems	X	X	X		X			
	ARP1598	Landing Gear System Development Plan			X					
	ARP1619	Replacement and Modified Brakes and Wheels				X				
	ARP1786	Wheel Roll on Rim Criteria for Aircraft Applications	X			X				
	ARP1821	Aircraft Ground Flotation Analysis Methods	X							
	ARP1907	Automatic Braking Systems				X				
	ARP1915	Aircraft Tow Bar								X
	ARP4102/3	Flight Deck Tire Pressure Monitoring System							X	
	ARP4146	Coiled Tubing, Titanium Alloy, Hydraulic Applications, Aerospace						X		
	ARP4404	Aircraft Electrical Installations								X
	ARP4752	Aerospace - Design and Installation of Commercial Transport Aircraft Hydraulic Systems								X
	ARP4754	Guidelines for Development of Civil Aircraft and Systems	X	X	X	X				X
	ARP4834	Aircraft Tire Retreading Practice - Bias and Radial	X							
	ARP4852	Design Specification for Towbarless Push-Back Tow Vehicles								X
	ARP4853	Design Specification for Towbarless Tow Vehicles								X

Table 2 – SAE landing gear documents (continued)

	DOCUMENT	TITLE	FUNCTION						
			TAXI/TAKEOFF	MANEUVERING	LANDING	BRAKING	STABILITY	LG ACTUATION	LG CTRL & INDICATION
ARP	ARP4912	Design Recommendations for Spare Seals in Landing Gear Shock Struts	X						
	ARP4915	Disposition of Landing Gear Components Involved in Accidents/Incidents							
	ARP4955	Recommended Practice for Measurement of Static and Dynamic Characteristics Properties of Aircraft Tires	X						
	ARP5146	Assessment of Aircraft Wheel Sealing Systems	X						
	ARP5257	Tire Overspeed Landing Test			X				
	ARP5265	Minimum Operational and Maintenance Responsibilities for Aircraft Tire Usage	X						
	ARP5283	Nose Gear Towbarless Tow Vehicle Basic Test Requirements							X
	ARP5284	TLTV - Aircraft NLG Steering and Tractive Force Protection Systems or Alerting Devices - Inspection, Maintenance and Calibration Requirements							X
	ARP5285	Towbarless Towing Vehicle Operating Procedure							X
	ARP5381	Minimum Performance Recommendations for Part 23, 27, and 29 Aircraft Wheels, Brakes, and Wheel and Brake Assemblies				X			
	ARP5429	Landing Gear Fatigue Tests with Equivalent Damage Spectra	X						
	ARP5481	Recommended Wheel Tie Bolt Preload Procedure	X						
	ARP5507	Aircraft Tire-to-Wheel Performance Characteristics	X						
	ARP5542	Hand Held Aircraft Tire Inflation Pressure Gauges							X
	ARP5600	Disposition of Damaged Wheels Involved in Accidents/Incidents	X						
	ARP5911	Regional Aircraft Towbarless Tow Vehicle - Test Requirements							X
	ARP5916	Design Specification for Regional Aircraft Towbarless Tow Vehicle for Pushback and/or Maintenance Towing Operations							X
	ARP5936	Landing Gear Storage							
	ARP597	Wheels and Brakes, Supplementary Criteria for Design Endurance - Civil Transport Aircraft				X			
	ARP6137	Tire Pressure Monitoring System (TPMS) for Aircraft	X						
	ARP6152	Aircraft Tires Service Overload Capability	X						
	ARP813	Maintainability Recommendations for Aircraft Wheel and Hydraulically Actuated Brake Design				X			
	ARP994	Recommended Practice for the Design of Tubing Installations for Aerospace Fluid Power Systems							X

Table 2 – SAE landing gear documents (continued)

	DOCUMENT	TITLE	FUNCTION						
			TAXI/TAKEOFF	MANEUVERING	LANDING	BRAKING	STABILITY	LG ACTUATION	LG CTRL & INDICATION
AS	AS1145	Aircraft Brake Temperature Monitor System (BTMS)				X			X
	AS1188	Aircraft Tire Inflation - Deflation Equipment							X
	AS1614	Main Line Aircraft Tow Bar Attach Fitting Interface							X
	AS4052	Gland Design: Scraper, Landing Gear, Installation	X						
	AS4088	Aerospace Rod Scraper Gland Design Standard						X	
	AS4832	Gland Design: Nominal 3/8 in Cross Section for Custom Compression Type Seals	X						
	AS4833	Aircraft New Tire Standard - Bias and Radial	X						
	AS483	Skid Control Equipment				X			
	AS50141	Tube, Pneumatic Tire, Aircraft	X						
	AS50881	Wiring Aerospace Vehicle							X
	AS5440	Hydraulic Systems, Military Aircraft, Design and Installation, Requirements for						X	X
	AS6053	Tests, Impact, Shock Absorber Landing Gear, Aircraft							
	AS665	Tapered Axle Collar Dimensions							
	AS707	Thermal Sensitive Inflation Pressure Release Devices for Tubeless Aircraft Wheels				X			
	AS85352/1	Inflator Assembly Kit							X
	AS85352/2	Inflator Assembly Remote Controller Assembly							X
	AS85352/3	Inflator Assembly Gage Elements							X
	AS85352/4	Inflator Assembly Dual Chuck Stem Gage Kit							X
	AS8584	Brake Systems, Wheel, Military Aircraft				X			

NOTE: SAE documents listed in Table 2.

4.1 Taxi/Takeoff

4.1.1 Functional Requirements

The landing gear shall support all aircraft operations at its maximum taxi weight with its associated CG range. The full weight versus CG grid should be specified, as there may be a critical loading condition at a weight less than the maximum taxi weight. The longitudinal, lateral and vertical CG envelopes should be defined. Considerations to nose landing gear cam engagement should be reviewed when defining the CG envelopes such that they do not remain engaged during taxi and towing operation.

All operational requirements must be met with the appropriate load factors for conditions specified by the regulatory agency. These factors may include, but are not limited to, such factors as a 0.5 g turn capability or 2 g taxi requirement without strut and/or tire bottoming.

Rough runway requirements should be considered in both the dynamic performance and the structural integrity. Also, if the runway type or surface condition requires some sort of protector or deflector mounted on the landing gears, appropriate provisions should be specified. Tire spray should be considered for the need for potential deflectors, including tire chine profiles.

The critical ground load cases such as those resulting from braking and max ramp weight/cg should be specified for nose and main landing gear tires. Load-Speed-Time (LST) curves should also be generated as per applicable TSO/ETSO (TSO-C62e and ETSO-C62d (or current replacement)) as well as those resulting from service overload conditions, if applicable. The combination of critical ground load cases, LST curves and runway flotation requirements should allow the selection of the appropriate tire size and service pressure setting for the application.

Tire wear should be minimized by limiting tire scrub angle. An average tire life applicable to the fleet (in number of landings) should be specified.

4.1.2 Verification

Verification of landing gear structures should be accomplished by analysis supplemented by static and fatigue tests. These analyses should address the various taxi loads in the evaluation of static strength, fatigue, damage tolerance, and dynamic performance. For derivative programs, the validation may consist in analysis correlated with previous static and fatigue tests.

Verification of wheel structure should be accomplished by analysis and qualification tests per TSO-C135a (or current replacement). Additional qualification requirements, specific to the airframe manufacturer, may also apply. For derivative programs introducing increased loads, the wheel qualification may need to be re-done either partially or entirely.

Verification of tire structure should be accomplished by analysis and qualification tests per TSO-C62e (or current replacement). Additional qualification requirements, specific to the airframe manufacturer, may also apply. For derivative programs introducing increased loads, the tire qualification may need to be re-done either partially or entirely.

Verification of water spray trajectories and clearance of critical surfaces and systems (such as the engines) from the nose and main landing gear tires should be accomplished by flight tests.

4.1.3 Other Associated Functional Requirements

Other functional requirements that are involved during Taxi/Takeoff are: Maneuvering, Braking, and Stability.

Refer to Table 1 for Regulatory Requirements and Table 2 for SAE related documents.

4.2 Maneuvering

4.2.1 Functional Requirements

The aircraft should be self-maneuverable on the ground by means of differential braking, engine differential thrust, nosewheel steering via a cockpit control, or a combination of the three.

All steering functions should be automatically disconnected prior to retracting the gear to prevent the transmission of steering commands while the gear is stowed. A means of centering the gear prior to the retraction should be specified. Whenever possible, the nose landing gear must be centered and kept in the centered position throughout the flight, even if steering power is not available and under foreseeable system failure cases. It should be noted, however, that aircraft are in use that turn the nose wheel on retraction to provide a horizontal stowage envelope in the aircraft.

Nosewheel damping should be provided to preclude shimmy, with the system "armed" and "disarmed", in free caster mode or failed, over the service life at all speeds up to the maximum tire rated speed and under cross-wind conditions.

The steering system should be tolerant to nose landing WOW oscillations that may occur during landing, taxi and take-off such that structural damage to nose landing gear centering cams is precluded. In the event cams are allowed to be overridden by the powered steering, the loading that results should be accounted for in the design of the cams.

There may need to be a switch in the cockpit to "arm" and "disarm" the steering system if full time steering is not considered to be safe (particularly at high speed). Indication in the cockpit of the systems state should be provided. If a handwheel is used to steer the gear during taxi and terminal operations, it should be designed so that full steering travel can be performed with one hand without the pilot having to change his grip.

There may need to be a cockpit switch to “disarm” the steering system for operational purposes like towing or differential braking maneuvers.

The nose wheel steering should be of a specified rate [degrees/sec] at any operational weight and center-of-gravity position. The maximum rate of steering should not lead to rates of change of direction of the aircraft that would critically load the nosewheel or the aircraft or cause controllability problems for the crew. For that reason, there may be a need to specify a variable gain of the handwheel as a function of the aircraft speed. The rate, and ultimately the feel, will be assessed during flight test and may be subject to change, so provisions should be designed into the system to facilitate rate and gain tuning.

Upon touchdown, the wheels may be in damped caster mode until powered steering becomes active. Transition from free caster mode to powered steering, and vice versa, should occur smoothly such that sudden steering inputs are avoided.

For a two-wheeled nose gear, there should be provisions for protecting the steering actuation when landing with one flat tire. If one tire were to be flat at touchdown, the other will slew around several degrees and continue to yaw, the offset couple being resisted by a twisting force at the ground from the yawed tire. In such case, the steering actuators should be protected from possible overload condition (by the use of relief valves for example). Additionally, the system should remain operational following the occurrence of transient and/or prolonged off-centered position of the nose wheels that would be expected upon touchdown with a flat tire.

Nosewheel steering should be controlled at the cockpit by a hand control or by feet using the rudder pedals, or both. The combination of hand and foot control should be specified when limited rudder pedal authority is required for maintaining correct heading during takeoff and landing, but high-authority hand control steering is required for tight turns on the taxiways and terminal aprons. Consideration may also need to be given to the sharing of command authority on the NWS between the pilot and co-pilot, if both pilots have steering handwheels.

For large multi-wheeled aircraft, steering of some of the main landing gear wheels may be necessary. The main landing gear steering system should be disabled in flight and ensure that landing gear is fully centered. The main gear steering should be activated for taxiing condition only.

The aircraft should have the capability of performing a 180° turn at MRW over the range of longitudinal CG in a single maneuver on a specified strip width. For this turn, it is not allowed to use asymmetric engine thrust and/or differential braking. A minimum of ten feet margin should be accounted for completing this 180° turn over the specified strip width.

Failure of nose wheel steering at any speed, especially higher speed, should not result in a loss of directional control. No single failure affecting the system may result in a runaway with hazardous effects.

Multiple failures leading to a steering runaway should be shown to be commensurate with the safety objective as derived from the safety analysis.

4.2.2 Verification

A system safety assessment must be performed to determine the criticality of the nose wheel steering system. The system should then be designed to the appropriate reliability level.

Verification of the nosewheel steering system should be conducted prior to a new aircraft's first flight. This should be done on the actual aircraft by ground test

Proper functioning of the nosewheel steering system should be thoroughly checked out as part of each aircraft's normal production build sequence prior to flight. This check out should be re-accomplished whenever the system's integrity has been violated owing to component removals after the system has been tested and accepted for flight.

The nosewheel steering system should also be evaluated during the flight test, since proper operation and suitability can best be determined by normal use during the flight test program.

4.2.3 Other Associated Functional Requirements

Other functional requirements that are involved during Maneuvering are: Taxi/Takeoff, Landing, Braking, and Stability.

The size and type of hydraulic ports and connections should be defined.

Hydraulic ports with different sizes should be used, where appropriate, to avoid wrong installation.

The hydraulic pressure available in the aircraft system, specifically the limits (nominal/maximum/minimum), should be clearly defined.

Pressure spikes generated by the system operation should not exceed the defined maximum pressures that are specified for the supply and return lines.

Hydraulic flow requirements for the system operation should be specified.

Electrical connectors should be defined (sizing and key way orientation) to avoid wrong installation.

Electrical power available in the aircraft system (with tolerance limits) should be clearly defined.

Electrical wire, cable, and conduit routing should be designed and installed in accordance with AIR4004, ARP4404, and AS50881.

Hydraulic system tube and hose routing should be designed and installed in accordance with ARP4752, ARP994, AIR1569, AS5440, ARP4925 and AIR1083.

Interfaces with other aircraft systems such as the Flight Data Recorder, the Data Concentrator Unit and the Maintenance Data Computer should be defined.

Refer to Table 1 for Regulatory Requirements and Table 2 for SAE related documents.

4.3 Landing

4.3.1 Functional Requirements

The landing gear should be designed to absorb the aircraft kinetic energy during landing. Aircraft operation at its maximum landing weight with its associated CG range and specified descent rate or impact speed should be specified; including tail down attitudes. The landing gear and the airplane structure should be sized for the loads occurring during landing.

All operational requirements should be met with the appropriate load factors for conditions specified by the regulatory agency. With these factors applied, it should be shown that under no condition the strut may bottom. Temperature effects should be considered.

Nose landing gear loading under aircraft de-rotation may need to be considered if aircraft operation could result in substantial loading of the nose landing gear. For example, high nose landing gear loads may result from a combination of high pitch attitude and accelerated de-rotation rate following the use of braking and/or forward control column inputs when the nose landing gear has not yet contacted the ground.

The landing gear shock strut should not be prone to stiction that would impact WOW acquisition, result in passenger discomfort due to gear ratcheting, compromise shock strut performance, or deteriorate brake control system performance.

Stability considerations, such as shimmy or gear walk, must also be considered for landing, as well as other ground maneuvering requirements, during all foreseeable ground operations (including flat tire, imbalanced wheel, loads, speeds and runway conditions).

Tires should be qualified for overspeed requirement (per ARP5257) accounting for the most adverse speed condition on landing that may occur following a given failure condition (e.g., flapless landing).

4.3.2 Verification

Verification of landing gear structures should be accomplished by analysis supported by static and fatigue tests. These analyses should address landing loads in the evaluation of static strength, fatigue, damage tolerance, and dynamic performance. For derivative programs, the validation may consist in analysis correlated with previous static and fatigue tests.

Drop tests should be conducted on a new landing gear design to demonstrate its reserve of energy absorption capacity. The shock strut should not bottom during the drop test demonstration.

Verification of gear stability should be accomplished by analysis. In the event the analysis predicts a marginally stable gear or if the landing gear configuration is pre-disposed to instability (e.g., cantilever type), the analysis should be complemented by shimmy testing on the flight test vehicle. Shimmy tests may include various conditions such as simulated flat tire or imbalanced wheel, including landing cases.

The tire should be tested to the overspeed landing (per ARP5257) and service overload requirement (per ARP6152).

4.3.3 Other Associated Functional Requirements

Other functional requirements that are involved during Landing are: Braking and Stability.

Refer to Table 1 for Regulatory Requirements and Table 2 for SAE related documents.

4.4 Braking

4.4.1 Functional Requirements

4.4.1.1 Brake Control and Application System

The brake control and application system should be designed to provide independent control of left and right brakes. This is to enable the crew to use differential braking for directional control.

The brake control and application system should be designed for dual controls with the Captain and First Officer having independent, but linked means of applying braking force.

The brake control and application system should be designed to provide a gear retraction braking feature that automatically applies brakes when the landing gear is raised. This is to avoid possible damage to the wheel well installations as a result of a spinning wheel with a tire's flailing tread entering the wheel well. Retraction braking should be applied by a ramp function to minimize fatigue load.

If a hydraulically controlled brake system is specified, the brake control and application system should be designed to avoid the transfer of hydraulic fluid from one hydraulic system to another.

The brake control and application system should be designed so that, when the airplane is standing still, the difference in commanded braking force (i.e., metered pressure applied or electrical command (for electric brakes)) at each brake on a given side of the airplane is within acceptable limits. This is to help reduce uneven brake energy distribution.

For airplanes with four, or less than four, main landing gear braking wheels, the brake control and application system should be designed so that no single failure results in the loss of greater than 50% of braking ability. For airplanes with more than four main landing gear braking wheels, the brake control and application system should be designed so that no single failure results in the loss of greater than 25% of braking ability.

The brake control and application system should be designed so that multiple failures resulting in the loss of greater than 50% of braking ability are commensurate with the safety objective as derived from the safety analysis.

The brake control and application system should be designed so that no single failure can cause inadvertent brake application during any portion of the takeoff roll.

The brake control and application system should be designed so that multiple failures that can cause brake application during any portion of the take-off roll are commensurate with the safety objective as derived from the safety analysis.

The brake control and application system should be designed to meet the maximum brake energy, torque and deceleration requirements corresponding to the most adverse braking conditions on RTO and Landing. Failure conditions (such as those resulting in flapless landing or 50% braking) should be considered, as well as the effects of temperature and altitude. The effect of cross-winds, runway crown and tire energy absorption may have an influence on kinetic energy distribution across the braked wheels. Specified brake energies may therefore need to account for uneven brake energy distribution.

The brake control and application system should include continuous failure monitoring.

4.4.1.2 Antiskid System

The antiskid system should be designed to maximize braking efficiency by varying the clamping force of each brake commensurate with the angular velocity information of the associated wheel.

The antiskid system should be designed to incorporate individual wheel touchdown protection.

The antiskid system should be designed to incorporate individual wheel hydroplaning protection.

The antiskid system should be designed to incorporate locked wheel protection.

The antiskid system shall be designed to be compatible with the gear retract braking function.

If a hydraulically controlled brake system is specified, the antiskid system should be designed to minimize hydraulic internal leakage when the brake system is being supplied from a hydraulic brake accumulator.

The antiskid system should maintain each tire in an incipient skid condition compatible with optimum braking performance and tire wear.

The antiskid system should be tuned for maximum performance on all runway surfaces, including low and variable μ conditions.

The antiskid system should be designed to maximize braking efficiency. Among other methods, braking efficiency can be defined as the distance-weighted average of achieved μ divided by actual μ . The conditions under which the braking efficiency must be achieved should be well defined (smooth/rough runway, dry/wet runway, etc.). The trigger that signals the beginning of the efficiency calculation should also be clearly defined (brake application, first skid, all wheels have reached the skid pressure, some amount of time after brake application, etc.). The design of the landing gear can also play into the ability of brake control to achieve high efficiency stopping.

The antiskid system should be designed to be dynamically compatible with other airplane systems and structure. The landing gear leg induced frequency during braking should not interfere with the antiskid performance. Similarly, the antiskid activation frequency should be tuned to avoid resonance effects on the gear and the gear mounted equipment.

The antiskid system should be designed to provide positive damping of the landing gear strut (gear walk stability) for all positive values, including zero, of strut structural damping.

For airplanes with four, or less than four, main landing gear braking wheels, the antiskid system should be designed so that no single failure results in the loss of greater than 50% of braking ability. For airplanes with more than four main landing gear braking wheels, the antiskid system should be designed so that no single failure results in the loss of greater than 25% of braking ability.

The antiskid system should be designed so that multiple failures that can result in the loss of greater than 50% of braking ability are commensurate with the safety objective as derived from the safety analysis.

For airplanes with four, or less than four, main landing gear braking wheels, the antiskid system should be designed so that no single failure results in the loss of antiskid function to more than 50% of wheels. For airplanes with more than four main landing gear braking wheels, the antiskid system should be designed so that no single failure results in the loss of antiskid function to more than 25% of wheels.

The antiskid system should be designed so that multiple failures that can result in the loss of antiskid function to greater than 50% of wheels are commensurate with the safety objective as derived from the safety analysis.

The antiskid system should include continuous failure monitoring.

4.4.1.3 Autobrake System

Autobrake systems, when utilized, should provide a means of selecting a desired level of automatic landing braking for use during the landing rollout or desired level of automatic rejected take-off braking for use during take-off.

The autobrake system should be designed to automatically apply and maintain airplane deceleration upon landing recognition or upon rejected takeoff recognition during take-off at the level selected by the flight crew.

The autobrake system should be designed to control airplane deceleration within the accuracy of $\pm 0.2 \text{ ft/s}^2$ specified by the aircraft manufacturer exclusive of airplane data errors.

The autobrake system should be designed to operate smoothly in response to spoiler or thrust reverser operation without significant overshoot (e.g., $< 2 \text{ ft/s}^2$).

The autobrake system should be designed so the selected deceleration level can be changed during braking.

The autobrake system should be designed to transition smoothly from one level to the next when the setting is changed.

The autobrake system should be designed to transition smoothly from automatic braking to pedal braking when the pilot depresses the brake pedals.

The autobrake system should incorporate a latching selector switch that is enabled only when arming conditions are met.

The autobrake system should incorporate a hardware means of positively preventing the application of braking force with any thrust lever advanced.

The autobrake system should include continuous failure monitoring.

4.4.2 Verification

A system safety assessment must be performed to determine the criticality of the brake system and its sub-systems. They should then be designed to the appropriate reliability level.

Verification of the wheel and brake assemblies should be accomplished by analysis and qualification tests per TSO-C135a (or current replacement). Additional qualification requirements, specific to the airframe manufacturer, may also apply. For derivative programs introducing increased energies and/or increased torque requirements, the wheel and brake qualification may need to be re-done either partially or entirely.

Verification of the brake system should be conducted prior to a new aircraft first flight. This can be done either on the actual aircraft or on a simulator.

Proper functioning of the brake system should be thoroughly checked out as part of each aircraft's normal production build sequence prior to flight. This check out should be re-accomplished whenever the system's integrity has been violated owing to component removals after the system has been tested and accepted for flight.

The brake system should also be evaluated during the flight test, since proper operation and suitability can best be determined by normal use during the flight test program.

4.4.3 Other Associated Functional Requirements

Other functional requirements that are involved during Braking are: Taxi/Takeoff, Maneuvering, Landing, and Stability.

The size and type of hydraulic ports and connections should be defined.

Hydraulic ports with different sizes should be used, where appropriate, to avoid wrong installation.

The hydraulic pressure available in the aircraft system, specifically the limits (nominal/maximum/minimum), should be clearly defined.

Pressure spikes generated by the system operation should not exceed the defined maximum pressures that are specified for the supply and return lines.

Hydraulic flow requirements for the system operation should be specified.

Electrical connectors should be defined (sizing and key way orientation) to avoid wrong installation.

Electrical power available in the aircraft system (with tolerance limits) should be clearly defined.

Electrical wire, cable, and conduit routing should be designed and installed in accordance with AIR4004, ARP4404, and AS50881.

Hydraulic system tube and hose routing should be designed and installed in accordance with ARP4752, ARP994, AIR1569, AS5440, ARP4925, and AIR1083.

Interfaces with other aircraft systems such as the Flight Data Recorder, the Data Concentrator Unit, and the Maintenance Data Computer should be defined.

Refer to Table 1 for Regulatory Requirements and Table 2 for SAE related documents.

4.5 Stability

4.5.1 Functional Requirements

The dynamic response of the airplane and its landing gear resulting from ground operations and transient or sudden application of loads should be included in the determination of design loads. In addition, the airplane and its landing gear should be free from any static or dynamic instabilities over the range of weights and cg positions.

Vibration limits should be established that reflect the allowable vibration from three viewpoints. One is passenger discomfort. Another is levels which jeopardize other functions of the aircraft and landing gear, such as steering and control. A third is levels which jeopardize the structural integrity of the aircraft and landing gear components. Care must be taken in establishing such limits to avoid over-design, and to relate the tolerance levels to experience with revenue service operation of similar aircraft gears.

During all ground operations (taxi, takeoff, and landing, including cross-wind conditions) all landing gears as installed on the airplane should be free from shimmy, divergence, and other related gear instabilities for all attainable combinations of configurations, ground handling phases, ground operation speeds, loadings, and tire pressures. Conditions of overnight cold flatspotting, flat tire and maximum wheel/tire unbalance up to FAA allowances, per TSO-C62e (or later replacement), should be considered. This requirement should apply for both normal and failure operations including hydraulic system failures. For the nose gear, the steering system should be considered "armed" or "disarmed and also failed". In some cases, the nosewheel steering system may require means (such as a hydraulic compensator) to ensure that proper hydraulic damping will affect an induced yawing moment at the nose wheels under conditions of steering "disarmed" or failed. Vibration of landing gear components can also be induced by the frictional characteristics of the brakes and active clamping force modulation by the anti-skid system, and can be aggravated by passive structural feedback in the design of the brake structure and the hardware associated with the brake-gear interface. The stability of different modes of vibration tends to be different on different landing gear designs and needs to be evaluated carefully for the landing gear application.

4.5.2 Verification

Laboratory tests are often used to verify the landing gear braking system is stable. In such tests, usually performed on a roadwheel dynamometer, the brake is often subjected to a variety of conditions representative of typical aircraft operating conditions. During these tests, the brake is screened for objectionable brake vibration which may cause instability to the landing gear system.

Further brake testing and analytical models should be used to identify and solve objectionable vibration. When necessary, brake testing may include experimental modal analysis or roadwheel dynamometer test with the actual aircraft landing gear or equivalent fixturing that simulates the landing gear. Analytical models are useful in defining simulated gear interface structures and simulated gear fixturing.

Verification of gear stability should ultimately be confirmed on aircraft. In the event the analysis predicts a marginally stable gear or if the landing gear configuration is pre-disposed to instability (e.g., cantilever type), the analysis and laboratory testing should be complemented by dedicated shimmy testing on the flight test vehicle.

4.5.3 Other Associated Functional Requirements

Other functional requirements that are involved with Stability are: Taxi/Takeoff, Maneuvering, Landing, and Braking.

Refer to Table 1 for Regulatory Requirements and Table 2 for SAE related documents.

4.6 Landing Gear Actuation

4.6.1 Functional Requirements

4.6.1.1 Normal Extension and Retraction

Normal extension and retraction of the landing gear should be controlled by a single lever mounted on the main instrument panel that is easily accessed by either pilot. The lever design should be of a two-detent type to prevent inadvertent command of the landing gear, such as pull and move up to command gear up, and pull and move down to command gear down.

The internal shock strut pressure should allow the landing gear strut to extend fully prior to landing gear retraction. Use of weight-off-wheel sensors may be used to confirm the proper state of the landing gear prior to retraction in the wheel wells. Mechanically shortening the main and nose landing gear oleo strokes prior to their retraction into the wheel well is a non-preferred design and should be avoided if possible.

Upon landing gear down command, the landing gear should be powered down to the down and locked position. The landing gear should not free fall under gravity when the normal system is used.

The downlock mechanism should be capable of maintaining the gear extended without hydraulic pressure during landing, taxiing, and ground handling.

The downlock mechanisms should be designed to minimize the possibility of the entry of foreign material, including build-up of ice that could prevent the gear from locking in the down position.

An attempt to retract the gear with the shock struts or the nose wheels or main gear truck beam not in the normal positions, including mis-serviced gear or strut not fully extended, should not result in major damage to the gear or to structure and should not result in jamming that would prevent subsequent extension of the gear by either the normal or alternate means.

A means to prevent inadvertent gear retraction while on the ground should be provided. This may be done with the inclusion of a mechanical safety stop to the landing gear lever design that would remain latched as long as the airplane is on the ground.

Means should be provided to manually override any safety stop on the landing gear lever. Manual override should be located on the instrument panel or adjacent to the landing gear lever.

Inadvertent landing gear lever motion, as well as any single failure affecting the system, should not result in uncommanded retraction of the landing gear. Combination of multiple failures leading to uncommanded retraction should be commensurate with the safety objective as derived from the safety analysis.

The uplock mechanism should be capable of holding the gear in the retracted position during all flight conditions, including negative g conditions, without hydraulic pressure.

The uplock should be designed to minimize the probability of loss of both the normal and alternate extension systems from a single or common mode failure affecting the uplock.

The uplock should be designed such that foreign material normally encountered during operation of the aircraft, including ice, cannot jam the mechanism or disturb its normal operation.

For ground maintenance purposes, an interlock should be installed in the ground door release mechanism that will prevent the door from being returned to the door closed position unless hydraulic power is available to close the doors.

The operating means for ground door release should be positioned to enable the operator to have a clear view of all landing gears.

The door mechanism should be designed such that foreign material normally encountered during operation of the aircraft, including ice, cannot jam the mechanism or disturb its normal operation.

Provisions should be made for ground locking the landing gear in the extended position with locking pins (or sleeves) that are capable of resisting the maximum retraction force without any detrimental effect on the retraction/locking mechanism.

It should not be necessary to install the ground locking pins except during maintenance or during repairs to the landing gear system.

It should be possible to install the ground locking pins only if the landing gear is properly locked.

Provisions should be made for ground locking hydraulically operated landing gear doors in the open position with equipment capable of resisting the maximum door closure forces.

Full system reversibility must be possible at any time, with or without the use of the alternate release system and also following a power interruption.

The gear actuation system should operate at the airspeed and sideslip conditions as specified by the aircraft manufacturer.

Landing gear extension and retraction times should be minimized as much as possible to limit the effect of drag on aircraft performance. In the case of aircraft with multiple landing gears and doors moving in close proximity to each other, it may be necessary to introduce a sequencing logic during retraction/extension to minimize the possibility of clashes.

4.6.1.2 Alternate Extension

Alternate control for extension of the gear should be accomplished by gravity, aerodynamic and/or spring forces or other stored energy source without the aid of the primary power source. Temperature effects should be considered.

Direct means, separate from the normal gear control, should be provided to release the landing gear and door uplocks.

If down lock springs are required to achieve down and lock position, dual down lock springs should be provided. However, a single downlock spring alone should provide positive means of ensuring that the gear will lock in the down position when using the alternate control.

If down lock springs are required to achieve down and lock position, downlock springs should preferably be externally mounted and of unenclosed type. If enclosed springs are used, internal corrosion protection and adequate venting should be employed to prevent any kind of seizure. Spring material should not be sensitive to notches and corrosion.

Operation of the alternate control system during flight should not preclude subsequent normal operations after the alternate system has been returned to normal.

Unrestrained gear free fall should not cause any failure of the primary structure or distortion in downlock mechanism components and attachments.

Operational test of alternate mechanical controls (such as uplocks, extend/retract actuators) should be possible without jacking the aircraft.

Use of the gear alternate extension should not result in serious damage to the landing gear or its doors/fairings during subsequent landing/taxi.

The alternate extension system should operate at the airspeed and sideslip conditions as specified by the aircraft manufacturer.

4.6.2 Verification

Verification of the normal and alternate extension systems should be conducted by analysis and system rig testing validating the performance of the systems over the flight envelope. Temperature effects on joint friction and hydraulic fluid viscosity as well as conditions of ice buildup should be evaluated.

Proper functioning of the normal and alternate extension systems should be thoroughly checked out as part of each aircraft's normal production build sequence prior to flight. This check out should be re-accomplished whenever the system's integrity has been violated owing to component removals after the system has been tested and accepted for flight.

The normal and alternate extension systems should also be evaluated at all expected operating flight conditions during the flight test, since proper operation and suitability can best be determined by normal use during the flight test program. Extension and retraction at maximum airspeed and yaw conditions should be demonstrated.

4.6.3 Other Associated Functional Requirements

Another functional requirement that is involved with Landing Gear Actuation is: Landing Gear Control and Indication.

If required, actuator snubbing and or damping characteristics should be clearly defined. It may be used to slow down the actuator at end of stroke during extension and retraction, but care should be taken for its sizing not to impair the capability of the landing gear to lock down under gravity in alternate mode of extension.

Depending on the system type, actuator with internal locks may be used, and in this case, should be defined clearly.

The size and type of hydraulic ports and connections should be defined.

Hydraulic ports with different sizes should be used, where appropriate, to avoid wrong installation.

The hydraulic pressure available in the aircraft system, specifically the limits (nominal/maximum/minimum), should be clearly defined.

Pressure spikes generated by the system operation should not exceed the defined maximum pressures that are specified for the supply and return lines.

Hydraulic flow requirements for the system operation should be specified.

Refer to Table 1 for Regulatory Requirements and Table 2 for SAE related documents.

4.7 Landing Gear Control and Indication System

4.7.1 Functional Requirements

4.7.1.1 Landing Gear Control and Indication

The landing gear control and indication system should determine aircraft ground and air states for its own landing gear control logic, but may also be required to support other aircraft systems state logics (e.g., spoilers, fuselage doors, etc.). The system may rely on a set of proximity sensors and switches in order to accomplish this task. Other aircraft systems need to determine their reliability requirements for the air/ground indication, and if the criticality is high enough, redundant means of determining the air ground condition should be considered (e.g., wheel speed sensors, RADALAT, thrust lever settings, etc.).

The landing gear control and indication system may also be required to perform output load monitoring and indication for other aircraft systems.

Indication of landing gear and WOW status should be determined by fault tolerant logic.

The landing gear control and indication system should have appropriate safeguards to preclude inadvertent or unsafe output data related to normal functions.

Retraction of the landing gear while the aircraft is on ground should be inhibited regardless of the landing gear lever position.

The landing gear control and indication system should permit reversal of the landing gear lever position and command at any time during the gear extension or retraction cycle without going out of sequence or causing damage.

The landing gear control and indication system should provide extension and retraction capability without generating warnings when the aircraft is on jacks.

The landing gear control and indication system should maintain cockpit indication of landing gear position during and after use of the Alternate Extension System.

A landing gear position indicator (as well as devices necessary for activating the indicator) that informs the pilots that the gear and its associated doors are either secured in the extended position, in an intermediate position, or in the retracted position should be provided for each separate landing gear assembly.

The indicators should be located on the instrument panel or adjacent to the landing gear control lever, and be easily visible to the pilots when they are seated in their normal positions.

A clear indication or warning should be provided whenever the landing gear position is not consistent with the landing gear control lever position.

If switches are used to activate the indicators, they should be located and coupled to the landing gear mechanical systems in a manner that prevents an erroneous indication of "down and locked" if the landing gear is not in a fully extended position, or of "up and locked" if the landing gear is not in the fully retracted position. Switches may be located where they are operated by the actual landing gear locking latch or device.

The flight crew should be given an aural warning that will alert them if a landing is attempted when the landing gear is not locked down (i.e., one or more throttles retarded, aircraft below a preset altitude/airspeed, wing flaps extended to approach position and gear not extended and locked). The warning should be continuous or periodically repeated, and should be given in sufficient time to allow the landing gear to be locked down or a go-around to be made.

Any shut-off means provided to the flight crew for turning off the aural warning should not be one that could be operated instinctively, inadvertently, or by habitual reflexive action. If there is a manual shut-off for the warning device, it should be designed in such a manner that advancing the throttles will reset the warning device.

The system used to generate the aural warning should be designed to reduce the probability of false or inappropriate alerts. Any failures of the systems used to inhibit the landing gear aural warning that would prevent the warning system from operating should be extremely remote.

The landing gear control and application system should include continuous failure monitoring.

4.7.1.2 Brake Temperature Indication

Brake temperature indication system, when utilized, should provide temperature indication of individual brake assemblies for display in the flight deck. Brake temperature indication is also important to prevent retraction of hot brake into LG bay.

Information provided by the brake temperature indication system should be used to allow dispatch for takeoff. The maximum brake temperature at which takeoff would be allowed should be such that residual energy in the brake will not compromise braking performance and safety in the event of an RTO. The maximum temperature for takeoff dispatch should be determined from appropriate brake dynamometer testing.

Information provided by the brake temperature indication system should be indicative of imminent wheel fuse plugs release. Under this condition, the brake should be allowed to cool down to a safe temperature prior to aircraft dispatch.

Information provided by the brake temperature indication system should be indicative of the occurrence of a brake overheat. In that event, it should trigger appropriate maintenance for the replacement and inspection of the wheel, tire and brake.

The brake temperature monitoring system should be designed so that no single failure can cause false low brake temperature readings.

The brake temperature monitoring system should be designed so that the probability of failures that can result from false low brake temperature readings is commensurate with the safety objective as derived from the safety analysis.

The brake temperature indication system should include continuous failure monitoring.

4.7.1.3 Tire Pressure Indication

The tire pressure indication system, when utilized, should measure individual tire pressures and provide indication to the flight deck of any abnormal high or low tire pressure conditions.

The tire pressure indication system should function both while the aircraft is on the ground and in flight. Any required parameter corrections for temperature should be automatic.

The tire pressure indication system should not interfere with the regular maintenance of the tire, including nitrogen servicing.

The tire pressure indication system should not reduce the overall reliability of the wheel and tire assembly. The pressure retention of the wheel and tire assembly should not be affected.

The tire pressure indication system should be designed so that no single failure can cause false low tire pressure readings.

The tire pressure indication system should be designed so that the probability of failures that result in the system displaying false readings is commensurate with the safety objective as derived from the safety analysis.

As a design goal, failure of the system should not cause tire deflation. No single failure should ever cause more than one tire to deflate.

The tire pressure indication system should include continuous failure monitoring.

A tire pressure indication system is considered to be the best protection against operating an aircraft with under-inflated tires which in turn is the primary cause of tire failures in service.

4.7.2 Verification

Components used in the landing gear control, brake temperature and tire pressure indication/warning systems should be qualified for their intended purpose.

Verification of the landing gear control and indication/warning system under normal operation and operation when specific malfunctions are simulated should be conducted prior to a new or derivative aircraft first flight. This can be done either on the actual aircraft while it is up on fuselage jacks or on a landing gear extension/retraction simulator.

Proper functioning of the landing gear control, brake temperature and tire pressure indication/warning (per ARP6137) systems should be thoroughly checked out as part of each aircraft's normal production build sequence prior to flight. This check out should be re-accomplished whenever the system's integrity has been violated due to component removals after the system has been tested and accepted for flight.

Temperature settings of the brake temperature indication system should be correlated by proper thermal analysis of the brake assembly and brake dynamometer testing.

The landing gear control, brake temperature and tire pressure indication/warning systems should be evaluated during the flight test, since proper operation and suitability can best be determined by normal use during the flight test program.

4.7.3 Other Associated Functional Requirements

Other functional requirements that are involved with Landing Gear Control and Indication are: Landing Gear Actuation, Taxi/Takeoff, Maneuvering, Landing, and Braking.

Indicator systems that use lights should include two bulbs in each indicator with a light test function either as an integral part of the indicator or as part of the airplane lighting system. It should be possible to detect that one bulb is burned out, and bulbs should be easily replaceable without major instrument or control panel disassembly. Duplicate bulbs are not required when LEDs are used.

Indicators should function from a positive signal rather than lack of a signal. Negative logic can result in a broken wire giving a false down and locked indication.

Position indicator circuits and landing gear control circuits should be separate insofar as possible. This minimizes the possibility that a single switch failure will not only prevent landing gear operation, but also falsely indicate the malfunction.

All switches and wiring should be sealed from moisture, and the wiring should be routed in conduit with drain provisions at low points. Consideration should be given to the possible effects of dirt or ice accumulation on the operation of switches. Operating links and switch brackets should be rigid to prevent deflection when load is applied, since excessive deflections can cause a faulty indication. Conduit should be routed and secured in a manner that prevents it from getting caught in the landing gear mechanism while the gear is articulating during extension and retraction.

A backup system of gear position indication should also be provided. This may be accomplished by the use of dual redundant channel controllers.

The brake temperature monitor system should be designed in accordance with AS1145.

Electrical connectors should be defined (sizing and key way orientation) to avoid wrong installation.

Electrical power available in the aircraft system (with tolerance limits) should be clearly defined.

Electrical wire, cable, and conduit routing should be designed and installed in accordance with AIR4004, ARP4404, and AS50881. Hydraulic system tube and hose routing should be designed and installed in accordance with ARP4752, ARP994, AIR1569, AS5440, ARP4925, and AIR1083.

Interfaces with other aircraft systems such as the Flight Data Recorder, the Data Concentrator Unit, and the Maintenance Data Computer should be defined.

Refer to Table 1 for Regulatory Requirements and Table 2 for SAE related documents.

4.8 Special Purposes

4.8.1 Functional Requirements

4.8.1.1 Towing and Push Back

4.8.1.1.1 General

The Nose Landing Gear should be designed for quick and easy connection with the tow vehicle using a conventional aircraft towbar and/or a towbarless towing vehicle.

If it is intended that the aircraft should have the push back capability incorporated into either the main or nose gears, specific and appropriate consideration should be given to the particular loading resulting from this configuration.

The design should ensure that the unit will safely secure the aircraft Nose Gear to the towing device without damage to the interface during normal use.

A load and torque limiting device should be incorporated in the towing bar and/or towbarless vehicle. The limiting device settings should be a function of the aircraft to be towed. The limit loads must not be exceeded during normal towing (acceleration/deceleration/braking/steering).

If damage to the steering cannot be precluded at all times during towing operation, a device that will alert the pilot before he starts his taxi roll should be specified in the event the Nose Landing Gear has endured towing loads beyond its maximum design loads and/or oversteer has occurred. The device warning should be visible from the flight deck. A warning device could also be part of the towing vehicle.

Maneuvering aircraft on inclined surfaces of grade, hanger thresholds, and rough ground should be specified as required.

If the torque links must be disconnected for towing, it should be specified.

4.8.1.1.2 Conventional Towing Requirements

The Tow Bar operating procedures should be detailed and reviewed by the Nose Landing Gear designer to ensure all applied loads are understood and accounted for.

Specific features such as torque link disconnects, steering bypass valves, limit switches, pilot warning indication, etc., should be addressed in the design requirements. The Nose Landing Gear to Tow Bar interface should be specified. Various interfaces are available such as axle bushings, horizontal pin and clevis, rings, and lugs. Towing loads applied at the axle will generate higher moments than applied at the steering collar or higher up the Nose Landing Gear.

The Nose Landing Gear should be designed to withstand the pull/push and turning forces when connected to the Tow Bar. The Tow Bar may incorporate a fuse(s) to protect the Nose Landing Gear. If towing is done via the axle, the torque links can be disconnected during towing to allow for 360° rotation. This protects the Nose Landing Gear and aircraft from any induced towing torque. The torque links must be positioned so that, with the shock strut fully compressed, the Nose Landing Gear tire maximum radius freely rotates under the upper torque link. The disconnected torque links should be secured (i.e., with a spring, detent, etc.) to prevent a jamming condition with the shock strut and tire during towing operations.

The maximum steering angle of the Nose Landing Gear and Tow Bar should be specified. Clearance with doors, antennas, probes, etc. should be detailed under all aircraft weight conditions.

Safety devices such as shear pins (on the Nose Landing Gear or Tow Bar) or quick-disconnect torque links, etc., should be specified. The Tow Bar design should be reviewed by the Nose Landing Gear designer. The Tow Bar can incorporate the following:

1. A shear pin that will relieve fore, aft, and torsional towing forces applied to the aircraft Nose Landing Gear through the Tow Bar in order to preclude damage to the Nose Landing Gear. Shear pin sizing should account for the most critical fore/aft towing angle condition relative to the aircraft longitudinal axis.
2. A means of simultaneously alerting the tow vehicle operator audibly, visually, or both that the safety device(s) has functioned.
3. A means of transferring overload to a retaining feature preventing separation and subsequent loss of control of the aircraft from the towing vehicle.

Tire envelope and rolling radius versus load should be detailed to provide working clearances with the Nose Landing Gear and Tow Bar.

Some commercial aircraft require a steering powered range (e.g., $\pm 65^\circ$) and a towing range (e.g., $\pm 120^\circ$). An automatic disconnect is permitted when the nosewheels are turned by a tow bar beyond the powered steering range. However, automatic re-engagement of the powered steering system is required when the nosewheels re-enter the powered steering range.

4.8.1.1.3 Towbarless Towing Requirements

Towbarless Towing Vehicle operating procedures should be detailed and reviewed by the Nose Landing Gear designer to ensure all applied loads are understood and accounted for.

Specific features such as torque link disconnects, steering bypass valves, limit switches, pilot warning indication, etc., should be addressed in the design requirements.

The Nose Landing Gear to Towbarless Towing Vehicle coupling system (Interface between Towbarless Vehicle and Nose Landing Gear) should be specified. The interfaces should include:

1. The tire envelope and rolling radius versus load.
2. The shock strut envelope and load versus stroke characteristics.
3. Surrounding aircraft envelope (i.e., belly, doors, antennas, etc.)
4. The Towbarless Vehicle envelope and mating interfaces.

If the Nose Landing Gear is "canted", a turning maneuver will cause uneven loading on the Nose Landing Gear. The retention feature provided should allow for uneven tire displacement without imposing additional loads on the Nose Landing Gear or should be accounted for in the Nose Landing Gear and aircraft design.

While in the fully engaged position, the nose wheel must remain stabilized in the locking mechanism under all dynamic conditions. The nosewheel tires must be retained above the axle to prevent escape in the upward direction. The wheel retaining feature should be detailed. Wheel holding loads should be detailed.

When the positioning pick-up/release sequence involves a relative motion between the vehicle and the aircraft, only the Towbarless Towing Vehicle should be allowed to move. The aircraft parking brake should be applied or main wheels properly chocked during this phase. However, for certain types of Towbarless Towing Vehicles (such as those using a soft strap cable affixed around the landing gear strut), this requirement may not apply since they may require the Nose Landing Gear to be pulled in the cradle by the Towbarless Towing Vehicle.

The tractive/brake/turning force setting must be defined for the Nose Landing Gear design. Abrupt or oscillating loads during the pick-up/release sequence should be defined. The Towbarless Towing Vehicle should incorporate safety devices to limit towing braking forces and oversteer torques applied to the gear and aircraft.

Some Towbarless Towing Vehicles feature the ability to tow various categories of aircraft weights, with different settings of overload safety feature applicable to each category of aircraft weight. It should be confirmed that a suitable aircraft weight category can be selected for towing that will not exceed the maximum towing loads as specified by the aircraft manufacturer. The Towbarless Towing Vehicle should be tolerant to failure conditions that could cause the pre-selected aircraft weight category to revert to a heavier category of aircraft, which could potentially put at risk the structural integrity of the Nose Landing Gear.

4.8.1.2 Jacking

Jacking is the operation of lifting the aircraft using mechanical supports under the aircraft to provide a minimal ground clearance for various maintenance activities. Jacking differs from hoisting in that hoisting supports the aircraft from above and is intended to move the aircraft from place to place.

Provisions for jacking of the aircraft should be provided on the landing gear, and/or the fuselage.

Jacking point requirements are listed in AS8091.

Jacking of individual landing gears should be accommodated.

Axle jacking should allow for the removal/replacement of the wheel and tire, or brake. When the axle is jacked, removal of the wheel and tire should be possible without removal of any other part of the landing gear or aircraft.

Fuselage jacking should allow for removal of the entire landing gear strut assembly.

Jacking should also permit the checking of landing gear retraction, the checking of gear steering, weighing the aircraft, positioning the aircraft for fuel gauge calibration or bore sighting, and securing the aircraft for engine replacement or other major maintenance.

The jacking point should be located to prevent interference between the jacks and the operation of the landing gear system.

The use of cradle jacks is recommended because of their greater stability and versatility compared with bottle jacks.

Coverage or removal of the jack pads to provide a smooth aerodynamic surface is recommended. Removable jack pads should meet the requirements of AS8091.

All jacking points and jack pad installations should meet the various load requirements including asymmetrical jacking, crosswind conditions, c.g. positions, and range of vehicle gross weights as specified in AS8091, MIL-A-8860, and MIL-A-8861.

If appropriate, consideration should be given to the requirements of international ground support equipment (i.e., NATO, EASA). Axle jacks should be able to fit under the axle of a multi-wheeled gear with all tires flat.

The Nose Landing Gear should have a means that avoids inadvertent powered or non-powered rotation of the NLG while jacked at the axle.

4.8.1.3 Mooring

Provision should be made for mooring the aircraft from mooring points located on each landing gear unit or specify where tie down straps can be attached to the gear in the case of exceptionally high winds.

The design loads for the landing gear mooring points should be specified.

The aircraft should be safe in expected wind speeds as determined by the design authority for the respected aircraft, but to a minimum of up to 65 kts from any direction when mooring in accordance with FAR/CS25.519.