AEROSPACE RECOMMENDED PRACTICE	ARP1595™	REV. B
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(R) Design and Verification of Aircraft Nose Wheel Steering Systems

RATIONALE

This document defines the aircraft industry recommended practice for the design and verification of aircraft nose wheel steering (NWS) systems.

ARP1595B has been reaffirmed to comply with the SAE Five-Year Review policy.

1. SCOPE

This document provides recommended practices for the design, development, and verification testing of NWS systems.

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 724-776-4970 (outside USA), www.sae.org.

AS1241 Fire Resistant Phosphate Ester Hydraulic Fluid for Aircraft

ARP1383 Impulse Testing of Aerospace Hydraulic Actuators, Valves, Pressure Containers, and Similar Fluid System Components

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

ARP4852 Design Specification for Towbarless Push-Back Tow Vehicles

ARP4853 Design Specification for Towbarless Tow Vehicles

ARP5283 Nose Gear Towbarless Tow Vehicle Basic Test Requirements

ARP5284 TLTV - Aircraft NLG Steering and Tractive Force Protection Systems or Alerting Devices - Inspection, Maintenance and Calibration Requirements

ARP5285 Towbarless Towing Vehicle Operating Procedure

AS5440 Hydraulic Systems, Military Aircraft, Design and Installation, Requirements For

AS8775 Hydraulic System Components, Aircraft and Missiles, General Specification For

AS8860 Landing Gear Structural Requirements as Listed in MIL-886X Series of Specifications

AS40401 Solenoid, Electrical, General Specification For

AS50881 Wiring Aerospace Vehicle

2.1.2 EASA Publications

Available from European Aviation Safety Agency, Postfach 10 12 53, D-50452 Koeln, Germany, Tel: +49-221-8999-000, www.easa.eu.int (sections pertinent to NWS systems are identified in Table 1).

CS-23 Certification Specifications for Normal, Utility, Aerobatic, and Commuter Category Aeroplanes

CS-25 Certification Specifications and Acceptable Means of Compliance for Large Aeroplanes

CS-27 Certification Specifications for Small Rotorcraft

CS-29 Certification Specifications for Large Rotorcraft

2.1.3 FAR Publications

Available from Federal Aviation Administration, 800 Independence Avenue, SW, Washington, DC 20591, Tel: 866-835-5322, www.faa.gov (sections pertinent to NWS systems are identified in Table 1).

Part 23 Airworthiness Standards: Normal, Utility, Acrobatic, and Commuter Category Airplanes

Part 25 Airworthiness Standards: Transport Category Airplanes

Part 27 Airworthiness Standards: Normal Category Rotorcraft

Part 29 Airworthiness Standards: Transport Category Rotorcraft

2.1.4 NASA Publications

Available from NASA, Documentation, Marshall Space Flight Center, AL 35812, www.nas.nasa.gov.

NASA Technical Report R-64

TABLE 1

Part 23 CS 23	Part 25 CS 25	Part 27 CS 27	Part 29 CS 29	Regulation Title
23.305	25.305	27.305	29.305	Strength and deformation
23.405	25.405			Secondary control system
23.471	25.471	27.471	29.471	General, ground loads
23.473	25.473	29.473	29.473	Ground/landing load conditions and assumptions
	25.491			Taxi, takeoff and landing roll
	25.495			Turning
23.499	25.499			Supplementary conditions for nose wheels(23); Nose-wheel yaw and steering (25)
23.509	25.509			Towing loads
23.511	25.511		29.511	Ground load: unsymmetrical loads on multiple-wheel units
23.575				Inspections and other procedures
	25.581			Lightning protection
23.601	25.601	27.601	29.601	General, design and construction
		27.602	29.602	Critical parts
23.603	25.603	27.603	29.603	Materials and workmanship (23,25); Materials (27,29)
23.605	25.605	27.605	29.605	Fabrication methods
23.607	25.607	27.607	29.607	Fasteners
23.609	25.609	27.609	29.609	Protection of structure
		27.610	29.610	Lightning and static electricity protection
23.613	25.613	27.613	29.613	Material strength properties and design values
23.619	25.619	27.619	29.619	Special factors
23.621	25.621	27.621	29.621	Casting factors
23.623	25.623	27.623	29.623	Bearing factors
23.625	25.625	27.625	29.625	Fitting factors
23.627				Fatigue strength
23.683	25.683	27.683	29.683	Operation tests
23.685	25.685	27.685	29.685	Control system details
23.689	25.689			Cable systems
23.693	25.693			Joints
23.745	25.745*			Nose/tailwheel steering
23.771	25.771	27.771	29.771	Pilot compartment
23.777	25.777	27.777	29.777	Cockpit controls
23.779	25.779	27.779	29.779	Motion and effect of cockpit controls
23.867	25.899			Electrical bonding and protection against lightning and static electricity (23); Electrical bonding and protection against static electricity (25)
23.1301	25.1301	27.1301	29.1301	Function and installation
23.1309	25.1309	27.1309	29.1309	Equipment, systems, and installations
	25.1316			System lightning protection
23.1367		27.1367		Switches
23.1381	25.1381	27.1381	29.1381	Instrument lights
23.1419	25.1419	27.1419	29.1419	Ice protection

TABLE 1 (CONTINUED)

Part 23 CS 23	Part 25 CS 25	Part 27 CS 27	Part 29 CS 29	Regulation Title
23.1435	25.1435	27.1435	29.1435	Hydraulic systems
23.1541	25.1541	27.1541	29.1541	General, Markings and Placards
23.1581	25.1581	27.1581	29.1581	General, Airplane/aeroplane flight manual and approved manual material (23,25); Rotorcraft flight manual and approved manual material (27, 29)
23.1583	25.1583	27.1583	29.1583	Operating limitations
23.1585	25.1585	27.1585	29.1585	Operating procedures

*Applicable to CS reference only.

2.1.5 RTCA

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

DO-160 Environmental Conditions and Test Procedures for Airborne Equipment

DO-178 Software Considerations in Airborne Systems and Equipment Certification

DO-254 Design Assurance Guidance for Airborne Electronic Hardware

2.1.6 U.S. Government Publications

Available from the Document Automation and Production Service (DAPS), Building 4/D, 700 Robbins Avenue, Philadelphia, PA 19111-5094, Tel: 215-697-6257, https://assist.daps.dla.mil/quicksearch/.

AFGS-87139 Air Force Guide Specification Landing Gear Systems

JSSG 2009 Joint Service Specification Guide, Appendix A, Landing Gear

MIL-DTL-31000 Technical Data Packages

MIL-DTL-38999 Connectors, Electrical, Circular, Miniature, High Density, Quick Disconnect (Bayonet, Threaded, and Breech Coupling), Environment Resistant, Removable Crimp and Hermetic Solder Contacts, General Specification for

MIL-HDBK-5400 Electronic Equipment, Airborne General Guidelines for

MIL-HDBK-516B Airworthiness Certification Criteria

MIL-PRF-5606 Hydraulic Fluid, Petroleum Base; Aircraft, missile and Ordnance

MIL-PRF-6106 Relays, Electromagnetic, General Specification for

MIL-PRF-83282 Hydraulic Fluid, Fire Resistant, Synthetic Hydrocarbon Base, Metric NATO Code Number H-537

MIL-PRF-87257 Hydraulic Fluid, Fire Resistant; Low Temperature, Synthetic Hydrocarbon Base, Aircraft and Missile

MIL-S-8812 Steering System: Aircraft, General Requirements For (Inactive for New Design)

MIL-STD-203 Aircrew Station Controls and Displays: Location, Arrangement and Actuation of, For Fixed Wing Aircraft

MIL-STD-461	Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment
MIL-STD-704	Aircraft Electric Power Characteristics
MIL-STD-810	Environmental Engineering Considerations and Laboratory Tests
MIL-STD-882	System Safety

2.2 Definitions

2.2.1 Classification of Nose Wheel Steering Systems

Nose wheel steering (NWS) systems may be classified by their importance and operational usage as follows:

Primary (or Class A) Steering System: A primary NWS system is one which is essential to safe ground operation of the aircraft. Redundancy (fail operative) is an implied requisite.

Secondary (or Class B) Steering System: A secondary NWS system is one that is normally in full time use during ground operation, but is not essential for safe ground operation of the aircraft. Fail-safety (fail passive) is an implied requisite.

Tertiary (or Class C) Steering Systems: A tertiary NWS system is one that is used primarily for taxi-parking-catapult spotting, and is not normally required or used for takeoff or landing operations. A totally passive disengaged mode is an implied requisite.

2.2.2 Type of NWS Systems

NWS systems are usually configured as one of the following types:

Mechanically Controlled, Manually Powered: Highly reliable, independent of aircraft power generation, normally employed on small general aviation aircraft.

Mechanically Controlled, Hydraulically Powered: Hydro-mechanical position servo mechanisms, commonly used on transport and business jet aircraft and some smaller military aircraft are normally very reliable, but dependent upon aircraft hydraulic system power.

Electrically Controlled, Hydraulically Powered: Inherently less reliable than mechanically controlled servos, redundancy and/or failure detection features are normally required. Such systems are now in common use on military combat aircraft and some business jet aircraft.

Electrically Controlled, Electrically Powered: Use of all-electrical servos for NWS systems is usually limited to low speed (taxi) control, with notable exceptions on some executive type aircraft.

2.2.3 Commonly Used Terms

Definition of terms commonly used in this and other documents relating to nose wheel steering systems is as follows:

Steering Rate: Steering rate is the rate of change of nose wheel steering angle in degrees (or radians) per second.

Steering Ratio: Steering ratio describes the relationship between input control movement and output nose wheel angle change (i.e., degrees nose wheel angle per inch (mm) of rudder pedal travel).

Powered Steering Angle: The powered steering angle is the number of degrees (radians) the nose wheel is displaced from the center (straight ahead) position while powered by the NWS control system.

Cycle: A full cycle is that nose wheel motion from the center position to one extreme position, returning past the center position to the opposite extreme, and returning again to the center position.

Rated Load: The rated load is the maximum load needed to fulfill the output torque requirement specified in Section 3.

V_{Stall}: The minimum speed for level flight in the landing approach configuration with zero thrust.

3. REQUIREMENTS

3.1 Documentation

Aircraft NWS system documentation may vary widely, depending on the system application, and should include the following:

a. NWS System Specification: Prepared by the airframe manufacturer (or prime contractor), which defines overall system requirements, including performance, weight, interfaces, environment, and verification tests and analyses.

b. Component (Equipment) Specification: Normally prepared by the NWS system manufacturer (or subcontractor) to control procured components of the NWS system. Component specifications should be coordinated with and approved by the airframe manufacturer to assure compliance with the system specification requirements.

c. Drawings: The NWS system manufacturer should prepare drawings for submittal to the airframe manufacturer which define the configuration, materials, finishes, weights, envelope, and interfaces, and should include hydraulic/electrical schematics of the NWS system circuitry as seen by the respective aircraft systems.

d. Test Procedures and Reports: The NWS system manufacturer should prepare detailed test procedures based on NWS system specification requirements, to be submitted to and approved by the airframe manufacturer. Verification test results should be reported and submitted for approval as required.

e. Analyses: Appropriate analyses should be provided by the airframe manufacturer and/or NWS system manufacturer as applicable, to substantiate system stability, strength, service life, safety, and performance.

f. Certification: Commercial certification guidelines are defined in ARP4754 and ARP4761 publications. Military aircraft require similar guidelines identified in standards, performance specifications, AFGS-87139, JSSG 2009 Appendix A, and airworthiness certification criteria in accordance with MIL-HDBK-516B. There are corresponding regulations mandated by FAA and EASA that apply for certification of a steering system. A table of appropriate regulations from the FAR in 2.1.3 have been identified for Parts 23, 25, 27, and 29 aircraft. EASA 23, 25, 27, and 29 certification specifications identify NWS requirements in Sections 495, 499, and 745 similar to respective FAR part sections. The designer needs to consult the airworthiness authority for applicable certification requirements to meet either commercial or military guidelines.

g. Other technical information necessary to delineate the design and meet the program requirements.

3.2 Interface Requirements

The NWS system should be designed to meet the interface requirements of the aircraft. These interface requirements should be detailed in the NWS system specification, and should include:

a. Aircraft hydraulic and electrical supply system characteristics.

b. Aircraft envelope limits and critical clearances.

c. Mounting and structural support provisions.

d. Cockpit control input characteristics.

e. Mechanical, electrical, and hydraulic physical connections.

f. Ground handling and/or test equipment connection provisions.

g. Requirements for free-play, stiffness, and/or damping.

h. Dynamic characteristics of nose wheel(s), tire(s), shock strut and fuselage connecting points.

3.3 Design and Construction

The type of NWS system should be selected for compatibility with the aircraft configuration and expected operational usage as defined in the NWS system specification. Definitions of various classifications and types of NWS systems are provided in 2.2.1 as a guide for this purpose. External NWS components should be designed to prevent water entrapment and be sealed from dust and dirt, especially when the nose landing gear is in the extended position. Detail design and construction of the NWS system and components should conform to the need of the application.

3.3.1 Materials, Processes and Parts

To the maximum extent practicable, materials, processes and parts should be selected from applicable industry standards which are appropriate for the application and the requirements of the program. Due attention should be given to corrosion prevention, durability, and avoiding dissimilar metals in contact with one another. Protective treatment should in no way prevent compliance with performance requirements, or hinder or prevent the intended use of the items. Existing standard parts, Government, industry, and supplier should be used to the extent that they meet the requirements of the NWS system specification. Nonmetallic seals, gaskets, grommets, and similar items used in the components should be compatible with the environmental conditions specified or anticipated.

3.3.2 Physical Characteristics

NWS system components should fit within the dimensional envelope specified in the NWS system specifications including tolerances and foreseeable failures. Critical dimensional limitations should be established to prevent aircraft structure interference. Weight limits of the NWS system may also be specified in the NWS system specifications. The structural strength of the NWS components should not permit permanent deformation or failure under maximum mechanical operating loads, accelerations, or torque requirements specified during installation. Each component's strength to weight ratio should be considered to maximize the NWS system design while adhering to material and process recommendations in 3.3.1.

3.3.3 Maintainability

Maintainability requirements should be established to allow consistency with aircraft system requirements. A maintainability program is recommended to ensure maintenance support during planned or field maintenance efforts. Maintenance factors include time, rate and costs of overall system and component maintenance. All maintenance factors should be considered during the design phase. The design should also accommodate the use of commercial standard tools and equipment during disassembly, reassembly, and service maintenance. A NWS system design requiring special maintenance support equipment should be kept to a minimum.

3.3.4 System Design Requirements

3.3.4.1 Design Arrangement

The design arrangement of the NWS system should provide for maximum compatibility with the aircraft nose gear installation, with adequate protection from potential damage caused by flat tire(s), thrown tire tread debris, fractured wheel pieces, stones, and water impingement. Susceptible components should be sealed or protected from dust, dirt, sand, and moisture to prevent corrosion, contamination, and wear to ensure satisfactory operation in the aircraft environment throughout the design service life. Design considerations should prevent misalignment of component assemblies during repair and overhaul. The failure of seals should not create a hard over condition and the design should provide a method of returning the wheels to center position.

3.3.4.1.1 Powered Steering Angle

The powered steering angle (defined in 2.2.3) should be defined in the applicable NWS system specification, and be based upon the aircraft configuration and ground handling requirements. Design limitations of steering versus aircraft speed should also be defined. Providing a slow speed, non-differential braking assisted 180 degree turn within a specific surface width has been a historical standard for land based aircraft. The turning width requirement should be derived from an operational analysis of the particular aircraft, considering nominal taxiway and runway surface widths. Ship based aircraft may require a larger powered steering angle, with a historical standard of providing sufficient angle so that continuation of the nose wheel axle centerline intersects the center of the main gear tire(s) footprint. For higher speeds or during takeoff and landing, it may be desirable to limit the powered steering angle authority to preclude loss of control due to excessive tire yaw angles at full input control throws.

3.3.4.1.2 Dual Versus Single Range Steering

A system analysis or trade study will dictate whether a single or dual range steering system is selected. The simplicity of the single range system must be weighed against the operational merits of dual range control. Dual range control allows specified steering ranges in both taxi and takeoff/landing modes. A design with dual range control takes advantage of the phenomenon of peak available cornering coefficient occurring at tire yaw angles in the 10 to 20 degree range. With normal steering control limited to this range, the pilot operates at peak control with maximum effort. Under this concept, the steering gain is limited to this range for takeoff and landing operations. For ground handling and maneuvering, a second range of control will be engaged. This provides maximum response for operational usage. Another design concept could provide an automatic transition between taxi and takeoff/landing operations at a predetermined speed. Systems that change gains through transitioning need to ensure the pilot is aware of the gain change to prevent possible loss of control. The transition speed should be such that it allows the pilot to maneuver safely at higher speeds, but establishes a design threshold speed in which the pilot can operate taxi maneuvering without additional input to maintain aircraft directional control under a certain threshold speed.

3.3.4.1.3 Free Swivel Range

Provisions should be made for unlimited free swiveling beyond the powered steering range, or alternatively a means of preventing damage if this range is exceeded. An on-ground centering device using rake, hydraulics or mechanical linkage is useful in the free swivel range or for free caster nose wheels to naturally aid in centering the nose wheel while taxiing/towing or airborne. Free swiveling through 360 degrees is desirable for ground towing, and may be provided automatically in the passive mode or with provisions to change the steering from active to passive (towing) mode by a mechanic from outside the aircraft. With unlimited free swiveling, the towing angle limits should be clearly marked on the aircraft (nose gear). Failure modes where the NWS could become reconnected and damage the gear while taxiing/towing should be considered. Consider an easily replaceable mechanical fuse to prevent structural damage if the towing angle is exceeded. If the steering motor is equipped with an automatic disengagement for towing, provisions should be made that the steering cannot be switched on when the wheel position is outside the active steering range. Ship based aircraft should have 360 degree free swiveling to enable effective use of a spotting dolly ground handling tractor. Aircraft capable of powered rearward rolling should be protected from inadvertent departure from the powered steering range, unless full 360 degree swiveling is provided.

3.3.4.1.4 Centering

Nose wheel centering should be provided automatically when airborne, for retraction and for proper pre-touchdown alignment. The use of centering cams built into the nose gear strut has proven to be a reliable and effective method of providing centering when airborne. Centering may be provided by the NWS system for gear retraction or for a swiveling constraint for roll back during arrestment as defined in the NWS system specification.

3.3.4.1.5 Cockpit Controls

Cockpit controls (defined in 2.2.1) normally include provisions for commanding the steered position of the nose wheel(s), a means for engaging and/or disengaging the powered steering mode, as applicable, and a means for selecting the desired steering range where more than one range is provided. If applicable, MIL-STD-203 should be used for cockpit controls. The recommended control input for full time and/or high speed use is the rudder pedals. For low speed, large turn angle maneuvers, a separate tiller or hand wheel is effective in larger transport type aircraft, or a shift lever or range change or selector switch may be included to change the control authority of the rudder pedal steering. For full time steering where only rudder pedals are used, a push button switch on the stick grip or control wheel is an effective means to provide greater steering angle authority when desired. On NWS systems where powered steering can be engaged or disengaged by pilot option or by automatic circuitry, an advisory light located in the pilot's normal field of view to indicate when the steering is engaged is recommended.

3.3.4.1.6 Electrical-Electronic Requirements

Where applicable, electrical operation should be designed in accordance with DO-160, DO-178, and DO-254 for commercial, and MIL-HDBK-5400 for military aircraft. Electrical components including circuit boards, relays, solenoids, wiring, and connectors should conform to general requirements. Design consideration should be given, but not limited to the following:

a. Reducing susceptibility to moisture contamination.

b. Providing tolerance compatibility throughout the aircraft temperature range and maintenance requirements.

c. Tolerance to environmental electromagnetic interference.

3.3.4.1.6.1 Electric Power Requirements

NWS system electrical power requirements should be specified in the NWS system specifications. The NWS system power will conform to MIL-STD-704.

3.3.4.1.6.2 Relays

Electrical relays when used in NWS systems should be in accordance with MIL-PRF-6106 specifications.

3.3.4.1.6.3 Solenoids

Solenoids when used in NWS systems should be in accordance with AS40401. The duty cycle of a solenoid should be capable of continuous operation through all fluid temperature ranges, maximum altitude pressure, and maximum voltage conditions. There should be sufficient force applied to the spool valve, disc, or ball to return the solenoid to the de-energized position upon removal of the electrical signal.

3.3.4.1.6.4 Wiring

Internal wiring should be compatible with accepted industry standards. External wiring should be installed in accordance with AS50881.

3.3.4.1.6.5 Connectors

External connectors for use on NWS components should conform to MIL-DTL-38999. Hermetical connections in all exposed locations will be required.

3.3.4.1.6.6 Motion Sensors

Motion sensors, such as linear and rotary variable differential transformers and proximity switches can be used as an alternative to hard stop limits. Warnings and limits can be integral to the control system on the NWS system.

3.3.4.1.7 Electromagnetic Interference (EMI) Compatibility

The generation of and susceptibility to EMI for the NWS system and its components that are susceptible to EMI should comply with requirements of RTCA DO-160 for commercial and MIL-STD-461 for military applications. The performance of the system must not be affected by EMI and will require verification testing. The environment shall be defined by the aircraft manufacturer.

3.3.4.1.8 Hydraulic Requirements

Hydraulic components for the NWS system should conform to AS8775 and AS5440 requirements. Hydraulic cylinders should conform to MIL-PRF-5503 requirements where applicable. Valves such as solenoid-operated and electro-hydraulic (EH) modulating valves should be suitable for NWS system environments. Special emphasis will be given to contamination tolerance, service handling tolerance, stability with life and temperature, and moisture sealing. Primary control NWS systems using electro-hydraulic servo valves should incorporate dual valves as a minimum.

3.3.4.1.8.1 Hydraulic Fluid

Military applications hydraulic fluid should conform to MIL-PRF-87257 or MIL-PRF-83282 for new design. MIL-PRF-5606 is used mainly for fielded applications, but is not as fire resistant as either MIL-PRF-87257 or MIL-PRF-83282. Commercial applications hydraulic fluid should conform to AS1241. Use fluids in accordance with these standards/specifications unless otherwise specified in the NWS system specifications.

3.3.4.2 Performance Characteristics

Performance characteristics requirements are determined by the airframe manufacturer, based on analysis of operational use of the aircraft and/or specific performance requirements specified by the customer. NWS system performance should provide a means of safely controlling the aircraft on all specified runway surfaces and crosswind conditions, which the aircraft is designed to operate.

3.3.4.2.1 Output Torque

Where specified by the aircraft prime specification, or as dictated by operational considerations, the NWS system should provide sufficient output torque to turn the wheels at all commanded positions throughout the powered steering range, under most adverse aircraft weight and C.G. conditions with no aid from forward (taxi) motion of the aircraft. The wheels may be unbraked if residual propulsion (thrust) is insufficient to cause forward motion of the aircraft. The analysis should consider the effects of aircraft strut trail/caster geometry, maximum static load and structural deflection, maximum tire-runway scrubbing friction, tire rolling/breakout friction, tire self-aligning torque, and friction in the steering mechanism and nose gear strut. A historically accepted tire-runway scrubbing friction for design has been 0.8, with a rolling/breakout friction of 0.05 for a free rolling wheel considered to be conservative. For these and other pneumatic tire characteristics which might be considered in the analysis of output torque requirements, technical publications such as NASA Technical Report R-64 (Smiley & Horne, 1960) are available. For those applications where analysis of operational requirements might prove that scrubbing the nose wheel(s) is not an essential feature, other considerations such as dynamic turning, asymmetrical braking, and/or minimum radius turns with co-rotating nose wheels may dictate output torque requirements.

3.3.4.2.2 Service Life

The NWS system should be designed to match the design life of the aircraft with no scheduled replacement of parts. The number of operating cycles (defined in 2.2.3), attendant loads, and turn-on cycles should be specified in the NWS system specification. It is suggested that the life cycle spectrum be determined from a rational analysis of expected operational usage, considering taxi-takeoff/landing-taxi cycles to be encountered during typical operations. As an alternative one of the historical approaches such as the 100 000 cycles spectrum (50 000 cycles at full rated load (defined in 2.2.3) full steering angle, 25 000 cycles at 50% rated load - 50% steering angle, and 25 000 cycles at 25% rated load and ±10 degree steering angle) with 20 000 turn-on/turn-off cycles may be considered as a guideline.

3.3.4.2.3 Steering Rate and Ratio

The steering rate and ratio (defined in 2.2.3) should be such as to result in positive aircraft directional control throughout the ground operating environment of weight, velocity, wind, and runway surface conditions. For takeoff and landing use, the steering ratio should provide for smooth transition from powered steering control to aerodynamic control, considering aircraft directional control response characteristics so that rudder aerodynamic and nose wheel steering yaw moments combine to provide positive directional control of the aircraft at all times. Steering rates should be sufficiently high to follow normally expected input control rates, with input-output differential required to obtain full rates held to a reasonable minimum to preclude inadvertent over control due to lack of responsiveness. As a guideline, a nominal steering rate of 20 degrees per second at maximum dynamic nose wheel steering torque, and a velocity rise of 100% nose wheel maximum rate per 3 to 5 degrees of input-output differential, has provided adequate steering response characteristics. Steering ratios may be either linear or non-linear, with some preference indicated for non-linear ratios where a single steering range is used for both low and high speeds. For high speed use, with rudder pedal control input, an initial ratio of 10 to 15 degree nose wheel angle for 100% pedal deflection has proven effective. Where a separate tiller or hand wheel is utilized for large steering angles, rudder pedal steering authority is generally limited to 7 to 10 degree maximum nose wheel angle.

3.3.4.2.4 Deadband and Hysteresis

NWS system specification should specify the amount of deadband and hysteresis to be allowed in the powered steering mode. Deadband and hysteresis should be kept to a minimum, consistent with control stability, friction, and dimensional tolerance considerations. Small amounts of deadband and hysteresis have not proven to be detrimental in past applications. Recommended limits are 1 degree deadband and 2 degree total hysteresis at 50% rated load in the center (straight-ahead) position up to ±5 degrees. Larger amounts may be acceptable for low speed large turn angle applications.

3.3.4.2.5 Dynamic Stability

Dynamic stability requirements should conform to AS8860. Suitable stability analysis and/or testing is necessary to provide for and assure the dynamic stability of the nose gear and the NWS system, throughout the full operational range of aircraft weight and velocity from 0 to 1.3 V_{Stall} for the most severe takeoff and landing configuration(s), and in both the powered steering and free swivel modes. Maximum variations in free play due to tolerances and wear, tire unbalance, flat spotting due to cold set, and tire failure conditions should be considered, as well as structural dynamics characteristics including shock strut, tires, and forward fuselage. Testing is recommended to validate the analysis methods and system operating characteristics parameters used in simulation. Where practicable, full scale dynamic stability tests with actual aircraft components and equipment are preferred over scale model tests.

3.3.4.2.5.1 Control Stability

The control stability of the NWS system in the powered steering mode should be analyzed using accepted principles and techniques of servo analysis. All significant system dynamic characteristics and control parameters should be considered.

3.3.4.2.5.2 Shimmy Damping Provisions

Based on the results of the nose gear dynamic stability analysis, requirements for shimmy damping provisions should be developed and specified in the NWS system specification, as applicable. Shimmy stability requirements should be determined by non-linear dynamic analysis which accounts for free play, friction (Coulomb), viscous flow (laminar or turbulent), wheel unbalance, realistic damping characteristics, or combinations thereof should be specified, as well as the required damping levels, for both the powered steering and free swivel modes as applicable. If possible, shimmy damping response characteristics or effectiveness should be specified in terms of frequency and amplitude through the expected range of potential shimmy or limit cycle conditions. Excitation of the shimmy condition will include impulse, cyclic and initial displacements of the nose gear. The NWS system should provide sufficient damping to reduce the shimmy oscillation amplitude after three cycles to 0.25 or less of the original perturbation magnitude. Testing can also be completed on nose landing gear systems (shock strut assembly and tire) at maximum tolerance values specified in aircraft technical publications. For the maximum test condition, the shimmy event should dampen after three cycles to 0.33 or less of the original perturbation magnitude.

3.3.4.3 Operating Characteristics

The operating characteristics of the NWS system are mainly determined from past experience and practices, operational use requirements, and compatibility with other cockpit controls.

3.3.4.3.1 Input Forces

The steering input control forces should be defined in the NWS system specification. Where steering input controls are connected to the flight controls, such as rudder pedals, the input force requirements for the steering should be kept to a minimum, and should be fully considered in determination of total force-feel characteristics of the flight control. Pilot control force limits are identified in Section 405 in FAR and EASA regulations. For mechanically controlled steering, rudder system operation should not be adversely affected or impaired if the steering system input mechanism is jammed while the aircraft is in flight. For this type system, consider the use of override bungees and/or disconnect mechanisms for in flight protection. Steering input control forces should be equal for turns in either direction, and the control should automatically return to center position when input forces are removed.

3.3.4.3.2 Alternate Steering Provisions

Alternate power sources for the NWS system should be provided where adequate ground directional control cannot be maintained by a pilot of average skills without nose wheel steering, considering adverse wind and runway surface conditions. The use of differential braking may be considered for alternate steering, augmented by aerodynamic (rudder) control at the higher speeds such that the capability to brake the aircraft to a safe stop is not adversely affected. Aircraft braking systems equipped with antiskid provide improved differential braking capability by greatly reducing the probability of tire skidding and skid-through blowouts, provided that the same conditions which rendered the NWS system inoperative do not also degrade the differential braking capabilities. For propeller driven aircraft, propeller wash in conjunction with rudder displacement may also be an effective means for alternate steering.

3.3.4.4 Safety and Reliability

The NWS system safety and reliability requirements, appropriate to the dependence of aircraft safety on its correct and sustained functioning, should be identified at the initial design stage and included in the NWS system specification. ARP4754 and ARP4761 for commercial and MIL-STD-882 for military documents can be used to establish safety requirements. A hazard analysis should identify failure modes and attendant hazard levels, and basic redundancy and fail-safe criteria be established. Among the more serious failure modes to be considered are:

a. Nose wheel hard over condition that may cause a jam or runaway at high speeds during takeoff or landing.

b. Sudden loss of steering while maneuvering in tight quarters or making sharp turns on narrow taxiways.

3.3.4.4.1 Failure Modes and Malfunction Effects

A failure modes and effect criticality analysis should be provided to determine NWS system design failures. The system design failure mode should satisfy basic fail-safe criteria, and should be compatible with the aircraft pilot operational context. No single electrical or hydraulic failure should result in undesirable steering effects that cannot be overcome or offset by normal and natural application of available cockpit controls. If the steering cannot be turned off, or if the aircraft cannot be controlled by differential braking the steering control system should have the reliability of a flight control system. No system failure should need pilot interpretation or action to disengage the system to retain control of the aircraft. Malfunction of the NWS system should not interfere with motion of the rudder pedals or flight controls, nor adversely affect stability of the system. No single NWS component failure or malfunction should result in turning the wheels when airborne. The powered steering should be made positively inoperative when the nose gear is retracted to prevent inadvertent steering motion.

Design arrangements should give full consideration to fail-safety in all modes of operation of the aircraft, including the following:

a. Powered steering, low speed

b. Powered steering, high speed

c. Free-castor or swiveling during taxi, takeoff, and landing

d. Towing (towbar or towbarless)

e. Airborne, gear down

f. Airborne, gear retracting and/or extending

g. Gear up flight

3.3.4.4.2 Redundancy and Fail Safety Features

Where the NWS is essential to ground directional control of the aircraft; no single hydraulic or electrical failure should result in loss of the steering function. Electrical control systems should have redundant circuits with failure detection capabilities. Where the design fail-safe mode is to revert to the free swivel (passive) mode, failure detection circuits should cause automatic disengagement and turn on a cockpit caution/warning light. Where feasible, electrical control systems should warn the pilot of system failure before landing. Where engagement or disengagement of the steering is a pilot option, provide the capability for the pilot to quickly override the automatic disengagement feature. If automatic fail-safe disengagement features are not provided, or are provided only for high speed takeoff and landing mode, the pilot should be able to manually disengage the system quickly and positively in the event of system malfunction. Where automatic cross-over to a redundant or secondary circuit and/or power source is featured, provide the flight crew with an advisory light to indicate failure of the primary system. Where the steering unit is essential to nose gear stability, a compensator/reservoir should be considered to provide an adequate supply of fluid for a minimum landing time and to prevent cavitation if hydraulic lines are lost or severed.

3.3.4.4.3 Component Reliability

Selection of components and types of equipment should consider achievement of maximum reliability for the operating environment of the NWS system. The NWS system should be assigned a Design Assurance Level (DAL) and categorized in one of the following categories: catastrophic, hazardous, major, minor, or no effect when completing a component level Failure Modes and Effects Analysis (FMEA). The NWS system specification should specify the overall reliability level required. Individual component specifications should reflect allocated reliability requirements necessary to achieve the overall requirement. Use of components of known low reliability in the landing gear environment should be avoided, such as variable resistance transducers (potentiometer), electro-mechanical relays and switches, and circuit boards with unsupported electronic elements. Linear variable differential transformer (LVDT) type transducers, solid state relays, proximity type switches, and encapsulated or hybrid type electronic circuitry exhibit very high reliability characteristics. EH servo valves should be provided with inlet filters of the non-bypassing type, fully accessible for periodic replacement, with a filtration size requirement larger (never smaller) than the aircraft hydraulic system filters.

3.3.4.5 Environment

The design operating environment should be specified in the NWS system specification as applicable to the aircraft. The following parameters should be addressed and are defined in 4.2:

Extreme temperatures, moisture environment (rain, humidity, salt), humid altitude cycling, vibration, shock, acceleration, acoustic noise, icing, dust and sand particles, fungus, deicing chemicals, and electromagnetic environment.

4. DESIGN VERIFICATION

4.1 General

Component, system, simulator, and aircraft test and analyses are needed to verify the NWS system suitability. Appropriate aircraft mechanical/hydraulic/electrical simulation should be employed during test verification. Unless otherwise specified, the NWS system manufacturer is responsible for all testing germane to his equipment, and the airframe manufacturer is responsible for definition of test and analysis requirements as well as total system verification. All required verification testing and analyses should be specified in the NWS system specification.

4.2 Environmental Tests

Where the NWS system is electrical, the complete system, including electrical connectors and harness should be utilized for environmental testing without disturbing the connections. Also a typical maintenance series of disconnecting and re-connecting should be performed between test segments to determine their effect on the system. The following environmental tests should be conducted with the general requirements described in RTCA DO-160 for commercial applications or MIL-STD-810 for military applications. Applicable tests/sections should be identified in the airframer specifications.

4.2.1 High and Low Temperature

NWS system components should be subjected to high and low temperature tests in accordance with RTCA DO-160, Section 4 or MIL-STD-810, Methods 501.5 and 502.5, Procedure I. High and low temperatures will differ between aircraft platforms for both commercial and military applications. However, components should withstand operation at temperatures identified in applicable standards such as AS5440. Individual components requiring higher temperatures will be specified in the NWS system specifications.

4.2.2 Temperature Variation/Shock

NWS system components should be subjected to temperature shock testing in accordance with RTCA DO-160, Section 5 or MIL-STD-810, Method 503.5, Procedure I. Components experiencing sudden changes of air temperature should be evaluated to determine the effects of sudden temperature changes without experiencing physical damage or deterioration in performance.

4.2.3 Waterproofness/Rain

NWS system components should be subjected to rain, water spray, or dripping water testing in accordance with RTCA DO-160, Section 10 or MIL-STD-810, Method 506.5, Procedure I. The effectiveness of seals, protective covers, and the method of water removal to prevent water penetration into the NWS system should be determined.

4.2.4 Humidity

NWS system components should be subjected to humidity testing in accordance with RTCA DO-160, Section 6 or MIL-STD-810, Method 507.5, Procedure I. All NWS components except those that are hermetically sealed will be required to resist the effects of a warm, humid environment.

4.2.5 Fungus

NWS system components should be subjected to fungus growth testing in accordance with RTCA DO-160, Section 13 or MIL-STD-810, Method 508.6, Procedure I. The requirement for this test will not apply where it can be shown by analysis or exhibit that fungus nutrient materials have not been used in the design.