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Superseding ARP1595

Aircraft Nosewheel Steering Systems

RATIONALE

ARP1595A has been reaffirmed to comply with the SAE five-year review policy.

FOREWORD

Changes in the revision are format/editorial only.

1. SCOPE:

This document provides recommended practices for the design, development, and verification testing of aircraft nosewheel steering (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 NASA Publications: Available from NASA, Documentation, Marshall Space Flight Center, AL 35812.

NASA Technical Report R-64

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3. REQUIREMENTS:

3.1 Documentation:

Nosewheel steering (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. Other technical information necessary to delineate the design and meet the program requirements.

3.2 Interface Requirements:

The NWS system should be assigned 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 controls 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.

3.3 Design and Construction:

The type of NWS steering 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 5.1.1 as a guide for this purpose. 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 System Design Requirements:

3.3.2.1 Design Arrangement: The design arrangement of the NWS system should provide for maximum compatibility with the aircraft nose gear installation, with maximum protection from damage by blown tires, missiles of thrown tire tread pieces and 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.

3.3.2.1.1 Powered Steering Angle: The powered steering angle should be defined in the applicable NWS system specification, and be based upon the aircraft configuration and ground handling requirements. Providing a slow speed, non-differential braking assisted 180° 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 nosewheel axle centerline intersects the center of the main gear tire(s) footprint. For the higher speeds to take offs and landings, it may be desirable to limit the powered steering angle to preclude loss of control authority due to excessive tire yaw angles at full input control throws.

3.3.2.1.2 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. 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° 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 take off and landing operations. For ground handling and maneuvering, a second range of control will be engaged. This provides maximum response for operational usage.

3.3.2.1.3 Free Swivel Range: Provisions should be made for unlimited free swivelling beyond the powered steering range, or alternatively a means of preventing damage if this range is exceeded. Free swivelling through 360° 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 limited free swivelling, the towing angle limits should be clearly marked on the aircraft (nosegear). Consider an easily replaceable mechanical fuse to prevent structural damage if the towing angle is exceeded. Ship based aircraft should have 360 degree free swivelling to enable effective use of 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° swivelling is provided.

3.3.2.1.4 Centering: Nosewheel centering should be provided automatically when airborne, for retraction and for proper pre-touchdown alignment. The use of centering cams built into the nosegear 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 swivelling constraint for roll back during arrestment as defined in the NWS system specification.

3.3.2.1.5 Cockpit Controls: Cockpit controls normally include provisions for commanding the steered position of the nosewheel(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. 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.

3.3.2.2 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.

3.3.2.2.1 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, but it may be considered that the wheels are 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 nosewheel(s) is not an essential feature, other considerations such as dynamic turning, asymmetrical braking, and/or minimum radius turns with co-rotating nosewheels may dictate output torque requirements.

3.3.2.2.2 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, attendant loads, and turn-on cycles should be specified in the NWS system specification. The life cycle spectrum may be determined from a rational analysis of expected operational usage, considering taxi-take off/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 - full steering angle, 25,000 cycles at 50% rated load - 50% steering angle, and 25,000 cycles at 25% rated load and ±10° steering angle) with 20,000 turn-on/turn-off cycles may be considered as a guideline.

3.3.2.2.3 Steering Rate and Ratio: The steering rate and ratio (defined in 5.1.3) 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 take-off 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 nosewheel 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 nosewheel steering torque, and a velocity rise of 100% nosewheel 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° nosewheel 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° maximum nosewheel angle.

3.3.2.2.4 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° deadband and 2° total hysteresis at 50% rated load in the center (straight-ahead) position. Larger amounts may be acceptable for low speed large turn angle applications.

3.3.2.2.5 Dynamic Stability: 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 zero to 1.3 V_{Stall} for the take-off and landing configuration(s), and in both the powered steering and free swivel modes. Maximum variations in free play due to tolerances and wear, and tire unbalance 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 tests with actual aircraft components and equipment are preferred over scale model tests.

3.3.2.2.5.1 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.

3.3.2.2.5.2 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. The type of damping, such as friction (Coulomb), viscous, or velocity-squared (fluid dynamic) 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.

3.3.2.3 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.

3.3.2.3.1 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. 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.

3.3.2.3.2 Emergency Steering Provisions: Emergency power sources for the NWS system should be provided where adequate ground directional control cannot be maintained by a pilot of average skills without nosewheel steering, considering adverse wind and runway surface conditions. The use of differential braking may be considered for emergency 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 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 emergency steering.

3.3.2.4 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. 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. Nosewheel hardover condition at high speeds during take-off and landing.

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

3.3.2.4.1 Failure Modes and Malfunction Effects: 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 nor 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 nosewheel rotation.

Design arrangements should give full consideration 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 swivelling during taxi, take off, and landing
d. Towing
e. Airborne, gear down
f. Airborne, gear retracting and/or extending
g. Gear up flight

3.3.2.4.2 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 the high speed take-off 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.

3.3.2.4.3 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 specification should specify the overall reliability level required, and 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. Electro-hydraulic (EH) servovalves 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.

3.3.2.5 Environment: The design operating environment should be specified in the NWS system specification as applicable to the aircraft. The following parameters should be addressed: Extreme temperatures, temperature change rates, moisture environment (rain, humidity, salt), humid altitude cycling, vibration, shock, dust-sand, and electromagnetic environment.

4. DESIGN VERIFICATION:

4.1 General:

Component, system, simulator, and aircraft test and analyses are needed to verify the nosewheel steering (NWS) system suitability. Appropriate aircraft mechanical/hydraulic/electrical simulation should be employed during test verification. Unless otherwise specified, the steering 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 analysis should be specified in the NWS system specification.