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Superseding ARP1070B

# (R) Design and Testing of Antiskid Brake Control Systems for Total Aircraft Compatibility

## RATIONALE

ARP1070C has been reaffirmed to comply with the SAE five-year review policy.

## TABLE OF CONTENTS

# 1. SCOPE

This document recommends minimum requirements for antiskid brake control to provide total aircraft systems compatibility. Design and operational goals, general theory, and functions, which should be considered by the aircraft brake system engineer to attain the most effective skid control performance, are covered in detail. Methods of determining and evaluating antiskid system performance are discussed.

While this document specifically addresses antiskid systems which are a part of a hydraulically actuated brake system, the recommended practices are equally applicable to brakes actuated by other means, such as electrically actuated brakes.

## 1.1 Purpose

To recommend minimum antiskid brake control design practices, laboratory and aircraft test requirements to provide total aircraft system compatibility.

# 2. APPLICABLE DOCUMENTS

## 2.1 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.

| | |
|---|---|
| ARP490 | Pressure Modulated Valves |
| ARP598 | Determination of Particulate Contamination in Liquids by the Particle Count Method |
| AIR1739 | Information on Antiskid Systems |
| ARP1907 | Automatic Braking Systems Requirements |
| AS5440 | Aircraft Hydraulic System |
| AS8775 | Aircraft Hydraulic Components |
| AS22759 | Wire, Electrical, Fluoropolymer-Insulated, Copper or Copper Alloy |

## 2.2 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, http://assist.daps.dla.mil/quicksearch/.

| | |
|---|---|
| MIL-A-8625F | Anodic Coating for Aluminum Alloys |
| MIL-C-83723 | Electrical Connectors (Inactive) |
| MIL-E-5400 | Electronic Equipment, Airborne General Requirements for |
| MIL-H-8775D | Aircraft Hydraulic Components (Cancelled - see AS8775) |
| MIL-PRF-81322G | Lubrication |
| MIL-P-8564D | Pneumatic Components (Inactive) |
| MIL-W-5088 | Aircraft Wiring (Inactive - see AS50881) |

MIL-STD-130K Equipment Identification (Active)

MIL-STD-461 Electromagnetic Interference Characteristics, Requirements for

MIL-STD-704 Electrical Power, Aircraft Characteristics

MIL-STD-810F Environmental Test Methods (Active)

MIL-STD-882D Safety Requirements (Active)

MIL-STD-883E Test Methods Standard Microcircuits (Chg Notice 4)

NOTE: DOD cancelled or inactive documents may be applied by the contractor.

## 2.3 FAA Publications

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

AC121.195(d)-1A Operational Landing Distances for Wet Runways; Transport Category Airplanes

AC25-7A Flight Test Guide for Certification of Transport Category Airplanes

14 CFR 25.109 Accelerate - Stop Distance

14 CFR 25.735E Antiskid Systems

14 CFR 25.1301 Function and Installation

14 CFR 25.1307 Miscellaneous Equipment

14 CFR 25.1309 Equipment, Systems and Installations

14 CFR 25.1316 System Lightning Protection

14 CFR 25.1322 Warning Caution, and Advisory Lights

14 CFR 25.1435 Hydraulic Systems

## 2.4 DOD Publications

Available from http://assist.daps.dla.mil/quicksearch/.

DOD 2167A DOD System Software Development

## 2.5 ARINC Publications

Available from ARINC, 2551 Riva Road, Annapolis, MD 21401, www.arinc.com.

ARINC429 Mark 33 Digital Information Transfer System (DITS)

ARINC600 Air Transport Avionics Equipment Interface

ARINC604-1 Guidance for Design and Use of Built-in Test Equipment

ARINC629 Multi-Transmitter Data Bus

2.6 NAS Publications

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

NAS 1638 Cleanliness Requirements of Parts Used in Hydraulic Systems

2.7 RTCA Publications

Available from RTCA, 1828 L Street, NW, Suite 805, Washington, DC 20036, Tel: 202-833-9339, www.rtca.org.

DO-160 Environmental Conditions and Test Procedures of Airborne Equipment

DO-178 Software Considerations in Airborne Systems and Equipment Certification

IEEE/EIA Industry Implementation of International Standard ISO/IEC 12207: 1995 Standard for Information Technology

QQ-P-416 Plating, Cadmium (Electrodeposited)

2.8 ASME Publications

Available from American Society of Mechanical Engineers, 22 Law Drive, P.O. Box 2900, Fairfield, NJ 07007-2900, Tel: 973-882-1170, www.asme.org.

ASME-Y14.100

ASME-Y14.24

ASME-Y14.35M

ASME-Y14.34M

# 3. GENERAL REQUIREMENTS

## 3.1 System Operation

The antiskid system provides a means of detecting an incipient skid condition of the aircraft tires and functions to control the brakes so as to maximize braking efficiency, minimize tire damage, and prevent loss of aircraft control. In operation, it modulates the brake pressure at all times to generate the brake torque such that the tire runway friction force is maintained close to its peak value, and thus gives the aircraft maximum available deceleration which results in the shortest possible stop distance. The performance of the antiskid system is dependent upon the degree of compatibility achieved between the skid control equipment, the airplane's landing gear (including wheels, tires, and brakes) and airframe, and the remainder of the brake control system. For definitions of terms used herein see Section 7.

### 3.1.1 Operation

In operation, the pilot commands pressure to the brakes in proportion to the pilot's brake pedal force and/or pedal travel. If there are no incipient skids, the antiskid system does not interfere with the pilot input. If there are incipient skids, the antiskid system overrides the pilot's input and reduces the brake pressure by venting (dumping) to hydraulic return to stop the incipient skids. It does this in a manner which seeks to continuously use the available tire-runway friction braking force and minimize wheel skids.

The antiskid system controls the brake pressure through a skid control valve in response to information obtained from the wheel speed sensor (transducer). The wheel speed information is processed by an electronic controller which then sends a signal to the valve to release the brake pressure. Upon command from the controller, the skid control reduces brake pressure by releasing the fluid from the brake to the hydraulic system return. When the wheel spins up, the controller reapplies brake pressure at a controlled rate through the skid control valve until another incipient skid occurs or commanded pressure is achieved.

The antiskid system failure indication should be provided in the cockpit, preferably mounted in a prominent location within the pilot's field of vision during the landing and braking phase of flight, to indicate that there has been a system malfunction. Annunciation of system malfunction should be considered during the system design to preclude unsafe pilot reaction to minor system faults.

### 3.1.2 Performance

The antiskid system, in conjunction with the aircraft brake system, should be capable of functioning efficiently under all runway conditions from maximum rolling speed to the lowest speed compatible with ground handling of the aircraft, and should have provisions for releasing an inadvertently locked brake within the control speed range. For maximum efficiency, brake pressure should be reduced by the smallest amount necessary and for the shortest time possible. Specific areas that need to be addressed are:

a. Rapid initial adjustment to the optimum control pressure

b. Operation at partial metered pressures

c. Rapid adjustment to changing runway conditions

d. Control of high onset brake pressure (spikes)

The antiskid system should not induce nor be adversely affected by airframe dynamic instabilities such as gear walk, truck pitch, gear shimmy, brake chatter, brake oscillations, etc., throughout the full aircraft ground operation spectrum. The system should be tuned for optimum braking performance over a broad range of operational conditions, including a variety of runways such as dry, wet, icy, etc., throughout the control speed range. The impact of loss of cornering during maximum braking should be addressed. Since the total braking function involves more than the antiskid system and wheel, brake and tire assemblies, determination of the total airplane stopping performance is usually the responsibility of the airframe manufacturer. Where possible, qualified performance should be specified in terms of efficiency or stop distance.

### 3.1.3 System Features

The following features may be required for the system in addition to the basic skid control functions depending upon the aircraft configuration and landing distance requirements. The Procurement Specifications will define the type of system and the performance criteria required.

#### 3.1.3.1 Touchdown Protection

The System should provide continuous release of brake pressure where there is the possibility of applying brake pressure before wheels are on ground, rotating, and ready for braking Strut compression with wheel rotation override intelligence is normally employed to determine the aircraft is on the ground and wheels are rotating and ready for braking. In selection of touchdown protection, the probability of introducing additional failure modes and failure points should be considered.

3.1.3.2 Locked Wheel Protection

The system should incorporate means to release pressure to the brake for any wheel which is rolling at a speed some large preset amount less than the equivalent airplane speed. The system shall release brake pressure until the situation is corrected. The preset amount should preclude the release of brakes during normal turning maneuvers.

3.1.3.3 Hydroplaning Protection

Hydroplaning protection provides an extended release of pressure to a braked wheel which fails to spin up due to hydroplaning at high speed on a flooded runway. Hydroplaning protection is implemented by the use of an airplane ground speed reference which is external to the antiskid system, such as an Inertial Reference System. Brake release is based on the wheel speed being less than a set percentage of the ground speed reference. The hydroplaning protection would also provide the touchdown protection feature.

3.1.3.4 Failure Detection/Failure Mode

The failure detection circuit should be of the “passive” type; that is, it will function to provide failure indication, visual or audio, without altering remaining skid control capability. The antiskid system should fail with “brake pressure as metered by the pilot,” except for systems with four or more control valves, where the affected wheel may be isolated (made to free roll).

3.1.3.5 Emergency Operation

The antiskid system needs to function only on the normal braking system. The backup brake system, if used, should meet the minimum requirements as stated in the procurement specification. It should be possible to stop the airplane with the antiskid system turned off.

3.2 Design Practices

3.2.1 Considerations

Advanced landing gear systems contain elastic structure and self excited systems that can cause antiskid stability and performance problems. Current design trends emphasize reduced weight and volume for wheels and brakes, increased shock strut flexibility arising from use of high strength steels, and the use of more responsive skid control braking systems.

In general, brake lining capable of withstanding high rates of energy input, high temperatures, and exhibiting low wear rates have friction variations that can excite landing gear system natural frequencies.

The performance of the antiskid system is dependent upon its mutual compatibility with the response characteristics of the aircraft brake system and associated landing gear system structures. Therefore, the designer should consider these and other variables as noted in Table 1 herein.

Poor brake control can degrade the inherent directional stability of the aircraft. Both stopping ability and directional control are dependent upon available friction ($\mu$) between the tire and runway. Current antiskid systems utilize some means to sense the skid level, such as wheel slip (difference between the actual wheel speed and free rolling wheel speed) and modulate the brake pressure to minimize this skid. A typical tire braking force (friction) wheel slip characteristic is shown in Figure 1. With increasing brake pressure, the tire is forced into an incipient skid which allows the tire to traverse onto the “back side”, or the negative sloped portion, of the $\mu$-slip curve.

TABLE 1 - FACTORS INFLUENCING STOPPING PERFORMANCE

| | | |
|---|---|---|
| Subsystem Parameters | Brake Actuation System | Pedal linkage, brake metering valve input/output characteristics, cable length and stiffness, brake pedal force vs. pressure vs. displacement characteristics |
| | Hydraulics | Hydraulic pump capacity and recovery rate; accumulator pressure/volume characteristics; fluid type; brake line length/size/stiffness; component flow restrictions; return line back pressure; hydraulic system response. |
| | Antiskid System | Wheel Speed Detector. Speed sensor drive mechanism, electric characteristics, resolution, demodulator characteristics.<br>Electronics. Skid control logic, response characteristics<br>Servovalve. Flow gain, pressure gain, second stage lap, frequency response.<br>Brake. Pressure volume characteristics, lining characteristics, heat sink load, torque onset, torque release, application time, brake-on-speed, heat transfer characteristics, mounting stiffness, vibration characteristics, torque-temp-speed-pressure characteristics, torque pressure hysterisis, internal hydraulic damping.<br>Tire footprint area, inflation pressure, radial/bias, fore and aft stiffness, lateral stiffness, mass, inertia, tread design and wear, rolling resistance, diameter, damping characteristics, friction characteristics. |
| | Landing Gear Structure | Fore and aft stiffness, strut effective mass, fore and aft damping, vertical stiffness, metering pin design, torsional stiffness, torsional damping, strut geometry, truck mass and pitch dynamics (if applicable). |
| Related Aircraft Parameter | Geometry/Configuration | Center of gravity location, landing gear arrangement, airplane weight, airplane mass moment of inertia, wing stiffness. |
| | Operational Characteristics | Pilot landing and braking technique |
| | Environmental Parameters | Runway Roughness (micro and macro texture), contamination (water, rubber deposits), slope, crown groove pattern.<br>Atmospheric ambient temperature, pressure altitude, wind velocity. |

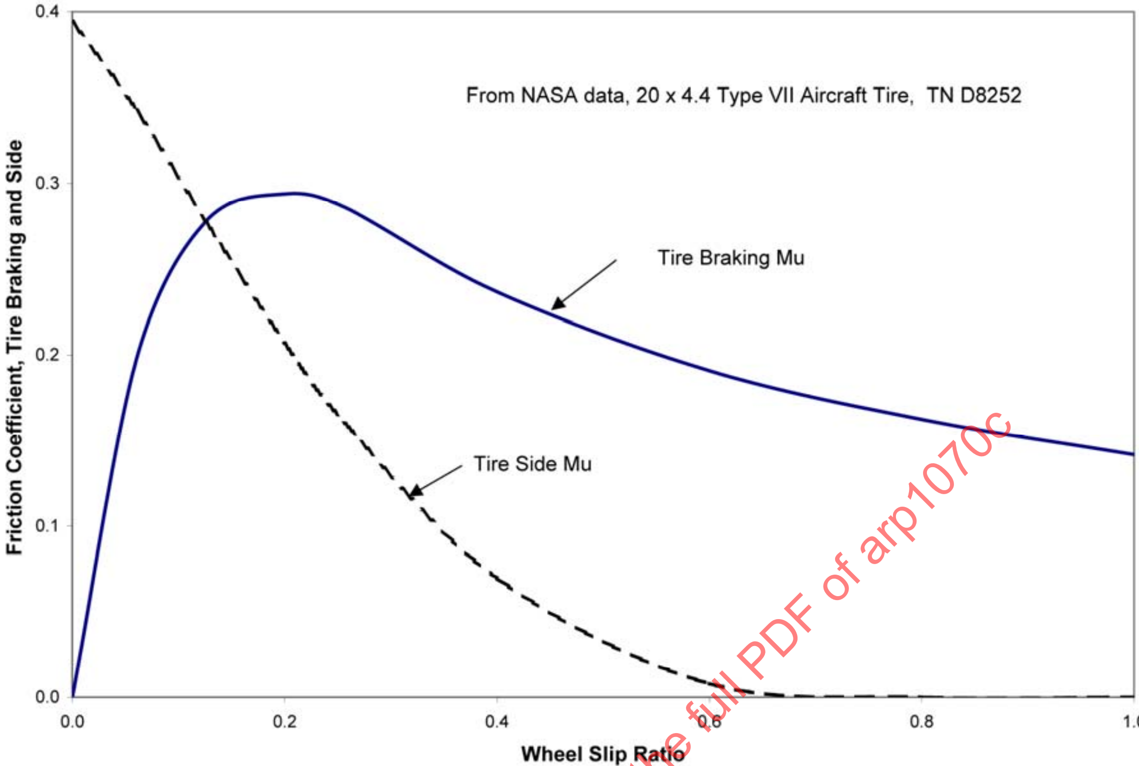


FIGURE 1 - TYPICAL RELATIONSHIP BETWEEN DRAG AND SIDE FRICTION TO WHEEL SLIP RATIO (FOR TIRE BEING ROLLED AT A FIXED YAW ANGLE)



Figure 1 shows that the side force is reduced on the "back side" of the curve. Therefore, it is most advantageous to specify brake control systems that dwell predominantly in the upper regions on the "front side", or the positive sloped portion, of the curve. Antiskid system optimization to obtain best stopping performance should also ensure high lateral force capability. This can best be accomplished by system "tuning." The least expensive method to accomplish this tuning is through the use of an analog or digital skid control simulator that enables assessment of the period of time the system dwells on the back side of the $\mu$-slip curve. The simulator can also be used to assess the effects of failure modes on system performance. Although data gained through this method are valuable in determining a measure of directional control stability for the aircraft, the total ground control problem is much more complex and consideration must be given to all aircraft related influences that combine to produce satisfactory stopping performance. Man-in-loop flight simulator tests may be conducted to assess aircraft yaw and pitch stability under various runway conditions, and to evaluate different methods of wheel control (single versus paired wheel). Final resolution should be achieved during actual aircraft evaluation.

3.2.2 Antiskid System Responses

A primary design objective is the attainment of adequate response time in each of the skid control components involved in the completion of a skid control cycle to meet performance and stability requirements. Nevertheless, this objective should be compatible with the elastic characteristics of the landing gear, airframe, tire, brake, and hydraulic system. A skid control cycle consists of the following events:

a. Measure of excessive wheel deceleration.

b. Reduction of brake pressure at antiskid system command to minimize excessive tire slip.

c. Reapplication of brake pressure to achieve the airplane deceleration commanded by the pilot or the maximum attainable, whichever is less.

In view of the fact that some skid control cycles result in oscillatory loading of the landing gear structure, it is considered good practice to perform analysis to show that the oscillatory or torsional loading resulting from skid control cycles does not cause structural damage to the landing gear or airframe. The following variables are considered pertinent to this analysis.

a. Antiskid system response characteristics

b. Brake assembly response characteristics

c. Hydraulic system response characteristics

d. Airplane gross weight and moments of inertia

e. The elastic and damping characteristics of the landing gear

f. Airplane aerodynamic characteristics

g. Tire to runway friction for various tire tread and runway conditions

h. The brake's pressure versus torque characteristics and variations in brake frictional coefficients resulting from different energy levels.

i. Brake system command pressure characteristics

j. Elastic (stiffness) and damping characteristics of the tires

k. Aircraft directional response and characteristics

l. Landing gear natural frequency (fore/aft, torsional)

m. Brake/wheel structural characteristics and natural frequencies

#### 3.2.3 Recommended Data Exchange

Technical data required for design and analysis should be defined in specification or formally agreed to in technical data exchanges to assure the least amount of system deficiencies prior to aircraft test. Data exchanges defined in Tables 2 and 3 are recommended. Table 2 identifies data and information that is usually supplied by the airframe manufacturer. Table 3 identifies data and information supplied by the skid control manufacturer.



### 3.3 Functional Requirements and Goals

The following are recommended design goals for the antiskid system.

#### 3.3.1 System Function

The system should prevent wheel lockup under normal operating conditions including dry, wet, and icy runway.

#### 3.3.2 System Efficiency

The system should provide braking efficiencies in the order of 90% or better. Antiskid calculation methods are defined in AIR1739.

TABLE 2 - AIRFRAME MANUFACTURER SUPPLIED DATA

| | Parameter |
|---|---|
| Aircraft (General) | Aircraft Weight – maximum takeoff, design landing, minimum landing weight, weight empty.<br>Aircraft velocity at brake application - maximum takeoff gross weight rejected takeoff, overload stop, normal landing weight, minimum flying weight.<br>Geometric parameters – distance from ground to C.G. (maximum takeoff gross weight, normal landing weight, minimum flying weight), distance from nose gear to main gear, distance from nose gear to C.G. distance between main gear, distance from center of axle centerline to center of gear, distance from ground to C.G. with extended main gear.<br>Aerodynamic parameters – aerodynamic drag coefficient (takeoff and landing), aerodynamic lift coefficient (takeoff and landing), x, y, z locations for aerodynamic lift and drag, engine idle thrust, engine decay characteristics and reverse thrust.<br>Miscellaneous – mass moment of inertia about C.G. (maximum takeoff gross weight, normal landing weight, minimum flying weight). |
| Landing Gear Shock Strut | Number of wheels per nose and main gear, vertical spring rate (nose and main gear) vertical damping rate (nose and main gear), main gear lateral and longitudinal stiffness, main gear fore-aft natural frequency, main gear fore-aft damping ratio (percent of critical), main gear torsional stiffness. |
| Brake Hydraulic System | Hydraulic lines – line length size and type of supply line, brake line, and return line, location and size of restrictors, location of brake metering valve, antiskid control valve.<br>Brake Metering Valves – pressure and flow characteristics, Hydraulic Supply – maximum pressure available and flow characteristics. |
| Brake Component | Lining contact pressure (psi), pressure volume characteristics, torque –pressure characteristics including range of friction coeficients (hot brake, cold brake, worn brakes, new brakes), torque-speed characteristics, weight of brake, moment of inertia of brake rotors. |
| Wheel/tire parameters | Tire size and type, fore-aft spring rate, vertical spring rate, weight, normal tire pressure and rolling radius, wheel weight, tire peak ground coefficient versus velocity on normal dry runway (RCR=23), moment of inertia of tire and wheel. |
| Miscellaneous | Skid control components – schematic, envelope, and mounting requirements. Interface requirements for controller, control valves and wheel speed sensors. |
| | Speed Requirements – maximum and minimum operational speeds. |
| | Skid control efficiency requirements - |
| | Special Skid Control Features required – touchdown protection, locked wheel protection, paired wheel control, auto-braking, warning devices for pilot, on-off switch. |
| | Operational environment for components - |



TABLE 3 - ANTISKID MANUFACTURER SUPPLIED DATA

| Antiskid Manufacturer Supplied Data |
|---|
| • Electronic Schematics<br>• Failure modes and effects analysis<br>• Requirements verification compliance matrix – confirmation of requirements compliance, and how to be verified (inspection, demonstration, analysis test).<br>• Skid control component characteristics – as required by customer for overall brake system analysis. Includes weight, C.G, envelope, input/output characteristics, interface characteristics, control algorithms description.<br>• Maintainability – recommended system maintenance and checkout procedures, required ground support equipment.<br>• Reliability predictions<br>• Test procedures/reports – acceptance test, flight justification test, and qualification test.<br>• Complete working drawings including proprietary data appropriately marked.<br>• System safety evaluation<br>• Simulation Test Results |

### 3.3.3 Operating Range

The system should operate near the peak of the braking force-slip curve in order to maximize energy transfer to the brake and minimize energy transfer to the tire. It is necessary to minimize excursions to the backside of the μ-slip curve to prevent excessive tire wear and tire heating which limits the tire's braking capability. The development of maximum braking force requires that the "runway be tested" with slip excursions to the back side to confirm that maximum braking is being developed. The skid control should operate most of the time in as narrow a slip range as possible at the peak of the braking force curve.

### 3.3.4 Braking Versus Cornering Interaction

The system should operate in such a manner as to maintain tire cornering capability. This can be accomplished by maintaining operation of the antiskid system in a narrow range near the peak of the braking force curve.

### 3.3.5 Pilot Controllability

The antiskid system should not impair the pilot's ability to apply and release the brakes or adversely impact the controllability of the aircraft.

### 3.3.6 Landing Gear and Airframe Structural Loads

The antiskid system should not impart any adverse loads on the landing gear structure or the airframe. The system should not induce any undesirable motion or dynamic instability in the gear or airframe such as gear walk, truck pitch, or airplane pitch.

### 3.3.7 Brake Application Response

The antiskid system should not reduce the brake control system's ability to respond to the pilot's commands. However, if the addition of an antiskid system to the aircraft should cause a significant change in the brake control system's ability to respond to rapid changes in pilot command, an analysis should be performed to show that this change does not adversely affect landing gear dynamic loads or introduce any undesirable airplane pitching characteristics.

## 3.4 Design and Construction Goals and Considerations

### 3.4.1 Hydraulic-Pneumatic Components Recommended Design Goals

#### 3.4.1.1 Hydraulic Equipment-General

It is recommended that hydraulic components conform to the applicable requirements of AS8775.

##### 3.4.1.1.1 System Flow

Initial consideration should be given to provisions for decreasing brake release time. Subsequent analysis should show that components of the skid control and hydraulic brake system, when functioning together, are capable of achieving the required skid control cycle. This analysis should take into consideration possible limited hydraulic capacity which may adversely affect the braking system when combined with the flow rates that occur during skid control cycling. Extremes of operating temperatures, which will be encountered during the operation of the airplane, should also be considered in this analysis. Particular attention should be devoted to return line capacity to ensure adequate antiskid response can be achieved.

##### 3.4.1.1.2 Fluid

Hydraulic units should operate satisfactorily with the specified hydraulic fluid, filtered and controlled to a contamination level of appropriate class per NAS 1638. All testing should be accomplished with the specified operating fluid.

3.4.1.1.3 Fluid Temperature

Hydraulic units should operate with fluids in the required temperature range. Unless specified, operating temperature should range from -65 °F (-54 °C) to 225 °F (107 °C).

3.4.1.1.4 Pressure Ratings

Hydraulic units should function satisfactorily over the full range of aircraft supply pressure and return line pressure.

3.4.1.1.5 Solenoid-operated Control Valves

It is recommended that solenoid-operated control valves conform to the applicable requirements of the procurement specification.

3.4.1.1.6 Pressure - Modulating Valves

It is recommended that valves be designed in accordance with the applicable requirements of procurement specification and ARP490 and be suitable for the brake control system environment with special emphasis upon contamination tolerance, stability with life and temperature, tolerance to service handling and moisture sealing.

3.4.1.1.7 Brake Metering Valves

The valve should be designed to provide smooth metered pressure with increasing pedal load/travel. Valve ports and internal fluid passages should be sized to permit adequate flow to and from the skid control valve. Consideration should include initial brake response in addition to subsequent cyclic reapplication of pressure by the skid control valve. Additional consideration should be given to the metering valve's compatibility relative to the demands placed upon it by skid control valve in the application and release of brake pressure associated with skid control.

3.4.1.1.8 Skid Control Valve

Internal leakage of the skid control valve should be minimized (to the extent valve performance is not compromised) in installations where it is necessary to reduce the bleed-off of any accumulator pressure which is available for parking or as a stored passive emergency supply. However, consideration should be given to any reduction in valve performance that may result from reduced internal leakage.

3.4.1.2 Pneumatic Equipment

It is recommended that pneumatic components conform to the applicable requirements of procurement specification and MIL-P-8564.

3.4.1.3 Hydraulic Lines

It is recommended hydraulic lines and fittings be designed to minimize restriction of flow with the objective of optimizing skid control response time. However, one-way restrictor or flow regulators may be used to reduce initial pressure-on rate when required.

a. Size: Hydraulic lines for supply and return should be selected to provide minimum pressure drops compatible with flow requirements of the brake metering valves, skid control valves, and brake assemblies under installed environmental conditions.

b. Type: Hydraulic tubing, rather than hoses, should be installed downstream of the brake metering valves where possible to minimize the accumulator effect during pressure changes.

c. Parking Requirements: System parking requirements should recognize internal leakage of the skid control valve. Shutoff valves may be used to block quiescent flow to system return. Parking brake pressure should be maintained in a manner such that thermal expansion and contraction of the hydraulic fluid is compensated. Otherwise the brake can be seriously over pressurized or can lose parking torque due to pressure reduction.

d. System Bleeding: Provisions should be incorporated to minimize entrapped air within the system. Reverse bleeding of the system should be limited to those installations which provide adequate internal or external means to prevent entry of contaminants into hydraulic components. Some skid control valves, for example, can be rendered inoperative if contaminants reach valve spools and orifices. Self-contained inlet filters in these control valves are not effective during reverse bleeding. System designers should consider location of bleeder valves, integral bleeding devices, and number of personnel plus equipment necessary for proper system bleeding.

3.4.1.4 Hydraulic Units

3.4.1.4.1 Construction

The hydraulic units should comply with the design and construction requirements of AS8775 or Type II equipment and 14 CFR 25.1435.

3.4.1.4.2 Proof Pressure

The unit should be designed to withstand a proof pressure of 1.5 times maximum operating pressure.

3.4.1.4.3 Burst Pressure

The unit should be designed to withstand a burst pressure of 2.5 times operating pressure.

3.4.1.4.4 External Leakage

No external leakage should occur under any operating temperature or pressure conditions.

3.4.1.4.5 Environmental Conditions

The hydraulic units should be capable of withstanding or operating under the following environmental conditions using test methods specified in MIL-STD-810 or RTCA DO-160D as determined by the airframe manufacturer:

a. Ambient temperature

b. Humidity

c. Vibration

d. Salt fog

e. Mechanical shock

f. Altitude

g. Fungus

h. Dust

i. Explosive atmosphere

j. Electromagnetic interference

3.4.2 Brake Design

3.4.2.1 Response

Minimum brake response time is desirable. The airframe manufacturer should determine and provide brake response time data to the antiskid system manufacturer such as step response and frequency response between brake pressure and torque. This data should be a part of brake design requirement.

3.4.2.2 Pressure

Maximum aircraft hydraulic system pressure should be specified for maximum metered brake operating pressure whenever practicable.

One case that does not use maximum hydraulic system pressure is the situation where it is desired to use accumulator pressure in the hydraulic system for emergency braking. In this case, a lower brake operating pressure is required to allow a maximum number of brake applications. Another case might be the use of dual brake pressure control systems, where loss of one system is compensated by an increase in maximum output pressure from the other system.

3.4.2.3 Fluid Displacement

Hydraulic fluid volume change should be a minimum from initial brake contact pressure to maximum operating pressure for both new and fully worn brake conditions (compatibility with the antiskid system should be confirmed). A relatively high brake structural spring rate and self-adjusters should be considered to accomplish the above. A brake stiffness curve should be defined in the procurement specification.

3.4.2.4 Fluid Passages

Ports and internal fluid passages should be designed to assure minimum air entrapment and minimum flow restrictions. However, this should be balanced with the need to provide additional damping to minimize brake vibrations. For example, damping for the brake whirl modes of vibration is frequently achieved by brake passage restrictions.

3.4.2.5 Mechanisms

Brake release mechanisms, self-adjusters if employed, brake rotor wheel drive key interface, brake stator torque tube spline interface, and hydraulic seals should be designed to minimize friction and the hysteresis associated with application and release of the brakes.

3.4.2.6 Seals

The brake hydraulic seals should be adequately protected against entry of foreign material within the expected environment. The use of nonstandard seals and gland sizes should be avoided.

3.4.2.7 Port Location

The brake pressure ports should be located at the top to allow self-bleeding.

3.4.2.8 Reaction Torque

The brake's torque should be reacted in such a manner that brake applications do not result in variations of the vertical wheel loads.

3.4.2.9 Return Springs

Return springs should be strong enough to overcome brake piston seal friction and reservoir pressure plus additional force for satisfactory brake-off response. Consideration should be given to return line surge pressures.

3.4.3 Electrical Design

3.4.3.1 Electrical Components

Each item of installed electrical equipment should comply with the requirements of FAR 25.1301, 1307, 1309, 1316 and 1322 and FAA AC 25-1309-1A.

3.4.3.2 Electric Power Requirements

It is recommended the antiskid system should conform to all applicable requirements of the procurement specification, and should give specified performance from the power source configuration specified in the detail specification. During transient power interruption the system should not fail or revert to “brake pressure as metered by the pilot.” Control system performance, after sustained loss of power and/or reapplication of power, is to be defined by the procurement specification. Sufficient redundancy and isolation should be maintained to minimize total system and asymmetrical failures.

3.4.3.3 Electromagnetic Interference (EMI)

Consideration should be given to EMI design requirements sufficiently early in an antiskid system design program to preclude operational problems on the aircraft.

EMI tests should be performed on the antiskid system installed in a simulated aircraft network. EMI compatibility should be demonstrated on aircraft as well as simulated aircraft network as part of normal aircraft testing. Equipment should be protected against lightning strike on the strut.

3.4.3.4 Wiring

External wiring should be installed in accordance with MIL-W-5088 and should be of the type specified in procurement specification or AS22759. Internal wiring should be compatible with accepted industry standards and the configuration. Appropriate protection from external noise should be provided for sensitive circuits such as the wheel speed sensing circuit.

3.4.3.5 Connectors

External connectors should be environmentally sealed, high vibration resistant, screw type connectors. The large pin sizes should be used whenever possible and the maximum spacing maintained between the pins. When connectors are located in close proximity on the same unit (valve modules, control boxes, etc.), positive means to prevent misconnection such as different shell size, wire routing, or clocking connectors should be considered.

3.4.3.6 Environmental Stress Screening

Components should be capable of successfully completing environmental stress screening tests as part of the acceptance test program.

3.4.3.7 Temperature Effects

The components should be suitable for operation in the anticipated temperature environment and then reassessed after performance on the aircraft. Particular attention should be given to the cold temperature effect on servo valve response and the resultant effect on performance.

3.4.3.8 Software

If the controller incorporates digital technology, built-in-test (BIT) procedures must be incorporated in the code. The BIT system should be capable of detecting critical faults with 95% or greater confidence level and it should not compromise the operation of the antiskid or the auto brake system (if used). The detected faults should be isolated to a replaceable unit. Software management and discipline must be employed to ensure control of configuration and proper validation. Antiskid control and built-in-test software should comply with the guidance for the appropriate software levels of RTCA DO-178B.

3.4.3.9 Insulation

The resistance between mutually insulated parts should be at least 20 megohms at 500 VDC. The dielectric withstanding voltage for equipment rated over 50 V should be 1500 VRMS, 60 Hz. For equipment less than 50 V the withstanding voltage should be 500 VRMS.

3.4.3.10 Bonding

Electrical and electronic units should have a case ground pin in the connector. All conductive surfaces of the case should be bonded such that the DC resistance between the case ground pin and any point on the case does not exceed 0.011 ohms.

3.4.3.11 Programmable Logic Devices (PLD)

Programmable logic devices (PLD), such as application specific integrated circuits (ASIC), field programmable gate arrays (FPGA), etc. should comply with the following:

a. A safety assessment of each PLD within the ABS architecture should be conducted to identify the failure condition which could result from the failure or malfunction of each device.

b. PLDs associated with functions whose failure or malfunction could cause or contribute to a catastrophic failure condition for the aircraft as defined in Advisory Circular 25.1309-1A or to a hazardous/severe-major failure condition as defined in RTCA document DO-178B, should undergo testing which demonstrates correct operation under all combinations and permutations of conditions of the gates within the device, or analysis which can show analogous results.

c. PLDs associated with functions whose failure or malfunction could cause or contribute to a major or a minor failure condition for the aircraft as defined in Advisory Circular 25-1309-1A should undergo testing which demonstrates correct operation under all combinations and permutations of conditions at the pins of the device, or analysis which can show analogous results.

d. In the event that the complexity of the PLD makes the testing and analysis requirements of (b) or (c) unfeasible, the PLD should be developed using a structured development approach which provides design assurance which achieves the same result as that provided for software development by RTCA document DO-178B. The rigor of the structured approach should be commensurate with the hazard associated with failure or malfunction of the system in which the PLD is located. Guidance in this area can be found in the sections of DO-178B which describe the requirements for the software levels associated with software development and assurance.

3.4.3.12 Construction

The electronic control units should be designed in accordance with MIL-E-5400. To facilitate maintenance, the unit should employ modular plug-in circuit board construction to the maximum extent practical. Circuit boards should be keyed to prevent incorrect insertion of non-interchangeable boards. Board edge type connectors should not be used.

3.4.3.13 Mounting

When electronic equipment racks are available, mounting and hold-down should conform to ARINC 600.

3.4.3.14 Cooling

No special cooling arrangements should be required.

3.4.3.15 Environmental Conditions

The electronic control unit should be capable of withstanding or operating under the following environmental conditions using test methods specified in MIL-STD-810 or RTCA DO-160D as determined by the Airframe Manufacturer:

a. Ambient temperature salt fog

b. Explosive atmosphere

c. Mechanical shock

d. Electromagnetic interference

e. Dust

f. Altitude

g. Humidity

h. Fungus

i. Vibration voltage

j. Transients

3.4.4 Lubrication

Lubrication will be permitted on the wheel-driven unit consistent with normal maintenance practices. The contractor and customer will review the procedure and grant approval of the lubricant practice prior to final acceptance.

3.4.5 Environmental

The environment tests to which the components are subjected should be compatible with the aircraft installation environment. MIL-STD-810, Environmental Test Methods or RTCA DO-160D for Civil Airplanes, may be used as a guide for environmental test methods.



3.4.5.1 Operating Temperatures

The components should satisfactorily withstand operation at temperatures from -54 to +71 °C (-65 to +160 °F). Requirements for individual components which may be subjected to extreme temperatures should be specified in the procurement specification. Such components or systems should operate within performance limits which will provide the specific system performance.

3.4.5.2 Salt Fog

The antiskid system should operate satisfactorily when conditions are imposed which duplicate the environment of sea coast regions.

3.4.5.3 Humidity

The antiskid system should function satisfactorily in an environment of relative humidity up to 100 percent, including conditions in which condensations occurs in the form of water or frost.

3.4.5.4 Pressure

The antiskid system should operate satisfactorily when subjected to pressure variations associated with the altitude ranging from 1300 feet (396 m) below sea level to the maximum landing altitude of the aircraft. The system should operate satisfactorily following exposure to the maximum operational altitude of the aircraft.

3.4.5.5 Dust

The antiskid system should operate satisfactorily under conditions consisting of blowing sand and dust particles as encountered in desert areas.

3.4.5.6 Explosive Atmosphere

The antiskid system components, if operating in an explosive atmosphere, should not provide an ignition source.

3.4.5.7 Acceleration

The antiskid system should function properly when exposed to translational accelerations consistent with that encountered on the aircraft.

3.4.5.8 Acoustical Noise

The antiskid system should function properly when exposed to the acoustical environment encountered in the region on the aircraft where the hardware is mounted.

3.4.5.9 Vibration

The antiskid system should function properly when exposed to vibration in addition to acoustical noise which realistically will be encountered on the aircraft.

3.4.5.10 Shock

The antiskid system should withstand any shock loading expected in operation, handling, or transportation.

3.4.5.11 Fungus

The antiskid system should perform satisfactorily when exposed to fungus conditions as encountered in tropical climates.

3.4.5.12 Contaminates

Evaluation of antiskid performances where brake heat sinks (particularly carbon) are expected to be contaminated by cleaning fluids, runway de-icers, and/or other compounds should be considered.

3.4.6 Materials

Materials used in the manufacture of System components should be of high quality, suitable for the purpose intended, and should conform to applicable Government specifications as specified herein.

3.4.6.1 Aluminum Alloy

Aluminum alloy external surfaces should be anodized in accordance with MIL-A-8625.

3.4.6.2 Steel

Steel should be of stainless composition or should be plated in accordance with QQ-P-416, Type II, Class I. Alternate protective treatments may be used if approved by the procuring activity and dictated by performance requirements.

3.4.6.3 Dissimilar Metals

The use of dissimilar metals in contact should be avoided. Where complete compliance proves impractical, electrolytic action should be minimized by plating or some other suitable method of dissimilar surface isolation.

3.4.6.4 Corrosion Resistance

Corrosion prevention is of prime importance and material selection should be made accordingly.

3.4.7 Selection of Specification and Standards

Specifications and standards for all materials, parts, and customer certification and approval of processes and equipment which are not specifically designated herein and which are necessary for the execution of this specification should be selected in accordance with procedures established by the procuring activity, except as provided in procurement specification.

3.4.7.1 Standard Parts

Standard parts should be used wherever they are suitable for the purpose, and will be identified on the drawing by their part number. MS or AN utility parts such as screws, bolts, nuts, cotter pins, etc. may be used, provided they conform to all requirements of this specification.

3.4.8 Maintenance

The design should be such as to accommodate to the greatest extent, disassembly, re-assembly, and service maintenance by means of those tools and items of maintenance equipment that are normally available as commercial standard. Design requiring specially designed tools and equipment should be kept to a minimum and should be identified in the original proposal.

3.4.8.1 Special Support Equipment

Special support equipment if required should be designed to the requirements of the procurement specification and should include flight line fault isolation capability to line replaceable items without breaking aircraft wiring connections.

3.4.9 Identification of Product

Equipment, assemblies, and parts should be marked for identification per requirements of the procurement specification.

3.4.10 Workmanship

Workmanship should be of the quality necessary to produce systems free of all defects that will affect proper functioning in service. Particular attention should be given to thoroughness of assembly, alignment of parts, tightness of screws and bolts, marking of parts, protective finish and removal of burrs and sharp edges.

3.4.11 Strength

The structural strength of all the units of the brake control should be such that, when installed, operation is not impaired, and no part of the device or its mounting should give evidence of failure under the maximum imposed mechanical operating loads, accelerations, or wrench torque loads required for making connections.

3.4.12 Interchangeability

All parts having the same manufacturer's part number should be directly and completely interchangeable with each other with respect to installation and performance. Changes in the manufacturer's part numbers should be governed by the drawing number requirements of ASME-Y14.100, ASME-Y14.24, ASME-Y14.35M, and ASME-Y14.34M or as otherwise specified.

3.4.13 Physical Characteristic

3.4.13.1 Weight Limits

The production weight limits of the brake control system should be specified by component in the procurement specification.

3.4.13.2 Dimensional Limitations

Critical dimensional limitations should be specified in the procurement specification.

3.5 Safety of Flight

3.5.1 Performance and Compatibility Analysis

An analysis of brake control system performance under various antiskid, aircraft (including wing lift), runway surface conditions, and various pilot metering valve pressures should be prepared. The recommended method for analysis is described under 4.2.1. Any other method must be approved by the procuring activity. The initial analysis should be prepared prior to flight test of the first unit. A final analysis should be prepared at the conclusion of the flight test evaluation of the system and should be based on flight test information.

3.5.2 System Fault Analysis

An analysis should be conducted to determine the effects of various system part failures and submitted prior to first flight. All single level faults should be considered, and dual level faults should be considered for critical failures. Failures which cannot be adequately investigated by analysis alone should be simulated by appropriate laboratory tests to allow preparation of a complete analysis. It should be verified that operational checkout procedures can be developed to detect all failures.

3.5.3 Safety of Flight

Prior to release for first flight, a minimum amount of pre-production testing should be successfully completed on the antiskid systems and should represent the safety of flight. These requirements are identified in 4.1.4.3.1.

4. PERFORMANCE TESTING AND EVALUATION

Performance testing and evaluation of the antiskid system and associated equipment can be separated into three categories:

a. Component tests

b. System level tests

c. Aircraft tests

4.1 Component Tests

Testing of individual components of the antiskid system equipment provides valuable data for assessing the total system performance and environmental compatibility. Laboratory test data on brakes, antiskid valve, and metering valve characteristics, etc., are useful in developing an overall simulation of the brake control system. Component tests should demonstrate operational compatibility throughout environmental ranges.

4.1.1 Brake Tests

Dynamometer testing of brakes is essential to the evaluation of the skid controls system. Test data from landing energy and overload energy stops help determine the brake torque - pressure characteristics, the effect of temperature and velocity on the values of developed torque, and other nonlinear effects that need to be accounted for in the antiskid system tuning. This data should be used in simulator tuning of the antiskid system.

4.1.2 Tire Tests

Static and dynamic data from tire tests are essential for evaluation of the total system performance. Typical required data include:

a. Vertical load deflection data

b. Fore and aft stiffness

c. Cornering characteristics

d. Torsion stiffness

4.1.3 Valve Tests

Flow and pressure gain characteristics of the metering and antiskid valves are useful in assessing the impact of the valve on system performance.

4.1.4 Antiskid System Component Tests

4.1.4.1 Classification of Inspections

The inspection requirements specified herein are classified as follows:

a. First Article Inspection (see 4.1.4.3)

b. Quality Conformance Inspection (see 4.1.4.4)

4.1.4.2 Inspection Conditions

It is recommended that all inspections be performed in accordance with the test conditions specified in applicable test method document or applicable paragraph(s) in the specification.

4.1.4.3 First Article Inspections

A minimum of two test samples consisting of all the components of the antiskid system should be used for the component tests as described under 4.1.4.5.2. The samples should be subjected to the following tests:

a. Test Sample No. 1

1. Examination of product (4.1.4.5.1)

2. Immersion altitude cycling (4.1.4.5.2.1.5)

3. Dust (4.1.4.5.2.18)

4. High and low temperature (4.1.4.5.2.1.1)

5. Endurance (4.1.4.5.2.2)

| | | |
|---|---|---|
| 6. | Vibrations | (4.1.4.4.5.2.1.4) |
| 7. | Endurance (valve) | (4.1.4.5.2.4.5) |

b. Test Sample No. 2

| | | |
|---|---|---|
| 1. | Examination of product | (4.1.4.5.1) |
| 2. | Immersion altitude cycling (if required) | (4.1.4.5.2.1.5) |
| 3. | Internal leakage (valve) | (4.1.4.5.2.4.4) |
| 4. | External leakage (valve) | (4.1.4.5.2.4.3) |
| 5. | Pressure Drop (valve) | (4.1.4.5.2.4.5) |
| 6. | Proof pressure (valve) | (4.1.4.5.2.4.1) |
| 7. | Electromagnetic interference | (4.1.4.5.2.3) |
| 8. | Humidity | (4.1.4.5.2.1.6) |
| 9. | Mechanical shock | (4.1.4.5.2.1.3) |
| 10. | Temperature shock cycling | (4.1.4.5.2.1.2) |
| 11. | Explosive atmosphere | (4.1.4.5.2.1.10) |
| 12. | Fungus | (4.1.4.5.2.1.7) |
| 13. | Salt fog | (4.1.4.5.2.1.9) |
| 14. | Acceleration | (4.1.4.5.2.1.11) |
| 15. | Burst pressure | (4.1.4.5.2.4.2) |

4.1.4.3.1 Safety of Flight

Prior to release for first flight, the following minimum amount of pre-production testing should be successfully completed on the antiskid systems and should represent the safety of flight.

a. Test Sample No. 1

| | | |
|---|---|---|
| 1. | Examination of product | (4.1.4.5.1) |
| 2. | Dust | (4.1.4.5.2.1.8) |
| 3. | High and low temperature | (4.1.4.5.2.1.1) |
| 4. | One-half (50 percent) of endurance tests | (4.1.4.5.2.2) |
| 5. | Vibration | (4.1.4.5.2.1.4) |
| 6. | Electronic component tests | (4.1.4.5.2.3) |

b. Test Sample No. 2

1. Examination of product (4.1.4.5.1)
2. Immersion altitude cycling (if required) (4.1.4.5.2.1.5)
3. Internal leakage (valve) (4.1.4.5.2.4.4)
4. External leakage (valve) (4.1.4.5.2.4.3.)
5. Pressure drop (valve) (4.1.4.5.2.4.5)
6. Proof pressure (valve) (4.1.4.5.2.4.1)
7. Humidity (4.1.4.5.2.1.6)
8. Mechanical shock (4.1.4.5.2.1.3)
9. Explosive atmosphere (4.1.4.5.2.1.10)

c. Brake control simulation as described in paragraph 4.2.1

4.1.4.3.2 Safety of Flight Certification

A letter certifying completion of the tests in 4.1.4.3.1 should be prepared and submitted to the procuring agency.

4.1.4.3.3 First Article Test Report

A test report covering the results of the tests in 4.1.4.3 should be prepared and submitted to the procuring agency.

4.1.4.4 Quality Conformance Tests

Each antiskid system should be subjected to the examination of product (4.1.4.5.1) and to component performance tests as specified in the detail specification.

4.1.4.5 Test Methods

4.1.4.5.1 Examination of Product

Each complete antiskid system should be examined to determine compliance with the requirements of this specification and the detail specification with respect to materials, workmanship, dimensions, weight, and markings.

4.1.4.5.2 Component Tests

Unless specifically noted, all component tests should be performed on an antiskid system installed in a simulated aircraft hydraulic and electrical network, including production aircraft electrical and hydraulic connections. After completing each component test, the system should operate satisfactorily.

4.1.4.5.2.1 Environmental Tests

4.1.4.5.2.1.1 High and Low Temperature

The antiskid system should be subjected to high temperature tests in accordance with MIL-STD-810 Method 502, or RTCA DO-160, Section 4, except for components that are subjected to higher temperatures as specified in 3.4.5.1 and detail specification. The system should be exercised as follows:

High Temperature. Wheel speed sensors should be accelerated from a full stop to rotational speed equivalent to one and one half the maximum operational ground speed of the aircraft, and back to full stop, at the maximum rate possible on the aircraft. This should be considered one cycle. For systems having no moving parts in the speed sensor, an appropriate signal simulation may be employed as approved by the procuring activity. The time between cycles should be such as to allow completion of the performance of all functions in the system. Two and one-half percent of the total cycles specified in 4.1.4.5.2.2.2 should be performed at high temperature.

The antiskid system should be subjected to low–temperature–tests in accordance with MIL-STD-810, Method 502, or RTCA DO-160, Section 4, except for components that are subjected to lower temperatures as specified in 3.3.22.1 and detail specification. The system should be exercised as follows:

Low Temperature. The acceleration and deceleration rates and velocities should be the same as for the high temperature test. Two and one-half percent of the total number of cycles specified in 4.1.4.5.2.2.2 should be required.

4.1.4.5.2.1.2 Temperature Shock Cycling

The antiskid system components should be subjected to 25 cycles of the temperature shock in accordance with Method 503 of MIL-STD-810 or Section 5 of RTCA D0 160 between temperature limits of -65 to +160 °F and at a rate of 100 degrees per minute ambient temperature change or to the temperature environment specified in the detail specification. After the test, the components should perform satisfactorily while warming up from -65 °F to room ambient. Wheel speed transducers should be subjected to upper temperature limits described in 3.4.5.1.

4.1.4.5.2.1.3 Mechanical Shock

The antiskid system components should be subjected to a mechanical shock test in accordance with MIL-STD-810, Method 516, Procedures I and II, or RTCA DO-160, Section 7.

4.1.4.5.2.1.4 Vibration

Unless otherwise specified in the detail specification, the antiskid system components should be subjected to a vibration test in accordance with MIL-STD-810 Method 514, or RTCA DO-160, Section 8 and as specified herein. Mounting (mechanical, electrical and hydraulic) should simulate aircraft installation. Wheel-driven units should include an axle-hubcap simulation. This test should follow the successful completion of the safety-of-flight portion of the endurance test in 4.1.4.5.2.2.

NOTE: An investigation should be made to determine the magnitude of amplitudes, frequencies, and accelerations to which these units will be subjected. In cases where these values are higher than those specified herein, the higher values should be used and specified in the detail specification.

4.1.4.5.2.1.5 Immersion Altitude Cycling

All antiskid units should be subjected to an altitude test in accordance with MIL-STD-810, Method 500.1, or RTCA DO-160, Section 4.6.

All gaskets, O-rings, or hermetically sealed components including appropriate aircraft wiring section, connectors, hydraulic fittings, and tubing sections located in unsheltered or unpressurized areas should be subjected to immersion in a 20 percent by volume salt water solution with the water evacuated to 70,000 feet pressure for 10 minutes and then reduced to ambient pressure. This procedure should be repeated ten times. The components should perform satisfactorily subsequent to the test and should be disassembled or weighed to prove no water has penetrated. There should be no evidence of moisture intrusion which would cause a reduction in the useful life of the equipment. The components should be disassembled following completion of the component test and checked for signs of moisture penetration and internal corrosion.

4.1.4.5.2.1.6 Humidity

All components, except those hermetically sealed, should be subjected to a humidity test in accordance with Method 507, Procedure 1 of MIL-STD-810, or Section 6 of RTCA DO-160.

4.1.4.5.2.1.7 Fungus

All components should be subjected to a fungus test in accordance with Method 508, Procedure I of MIL-STD-810, or Section 13 of RTCA DO-160, unless documentation is provided which proves no fungus nutrients are used in the design.

4.1.4.5.2.1.8 Dust

All components not located in sheltered compartments should be subjected to dust tests in accordance with Method 510, Procedure I of MIL-STD-810, or Section 12 of RTCA DO-160, and as specified herein. The airframe manufacturer will determine whether or not a component is in a sheltered compartment. Wheel speed transducers should be tested with the units rotating at an equivalent wheel speed of 400 rpm or as specified in the detail specification. The unit should be functionally checked after completion of the test.

4.1.4.5.2.1.9 Salt Fog

The components with aircraft connectors installed should be subjected to a salt fog test in accordance with Method 509, Procedure I of MIL-STD-810, or Section 14 of RTCA DO-160. The component performance should be checked in the salt fog environment.

4.1.4 5.2.1.10 Explosive Atmosphere

All components with unsealed contacts should be subjected to an explosive atmosphere test in accordance with Method 511, Procedure I of MIL-STD-810, or Section 9 of RTCA DO-160.

4.1.4.5.2.1.11 Acceleration

All components fastened rigidly to the landing gear structure should be subjected to translational accelerations of 50 g in all principle directions while operating.

4.1.4.5.2.1.12 Combined Environmental Tests

In the event a combined environment is more severe than individual tests, consideration should be given to including such combinations in component evaluations.

4.1.4.5.2.2 Endurance

The antiskid system, installed in simulated hydraulic and electrical network, should be subjected to the following tests.

4.1.4.5.2.2.1 Transient Cycling

The antiskid system components should be subjected to 20,000 power-on transient cycles of electrical and hydraulic pressure impulse cycles at the rates specified in the detail specification.

4.1.4.5.2.2.2 Skid Cycling

The antiskid system should be cycled to give a total equivalent to the maximum number of and character of cycles per landing experienced during testing of the system on the aircraft, multiplied by the maximum anticipated landings in the life of the gear. If the maximum number of anticipated landings is not specified, the number 8,000 should be used. In determining the number of cycles, wheel speed sensors should be subjected to an additional factor of 2.25 to reflect operation during takeoff and taxi. Five percent of the number of cycles required for this endurance test reflects the number of extreme temperature cycles which have been run previously in 4.1.4.5.2.1.1 (a) and (b). The cycles should be run at room temperature to the oil temperature specified in the detail specification. For systems with wheel-speed detectors which do not have bearings, a suitable input system signal simulation, as approved by the airframe manufacturer, may be employed. For systems having wheel-speed detectors with internal bearings, the detectors should be subjected to the tests specified in 4.1.4.5.2.2.3 and 4.1.4.5.2.2.4.

4.1.4.5.2.2.3 Maximum Velocity (V) Test

Ten percent of the cycles defined in 4.1.4.5.2.2.2 should be performed in the following manner. The wheel-speed detectors should be accelerated from zero rpm to the rpm equivalent to maximum gross weight takeoff (standard hot day 8,000 feet altitude) in minimum expected time, and then decelerated equivalent to the maximum deceleration rate experienced on the aircraft, as specified in the detail specification. This operation should be considered to be one cycle. The time interval between accelerating and decelerating should be sufficient to allow all internal parts of the wheel driven components to perform their prescribed function, if applicable. A more rational duplication of takeoff and landing function may be considered, if applicable.

4.1.4.5.2.2.4 Medium Velocity Test

Eighty-five percent of the cycles specified in 4.1.4.5.2.2.2 should be made in the following manner. The wheel-speed detector should be accelerated from the equivalent wheel rpm for 0.25V or less to the equivalent wheel rpm for 0.5V and then decelerated to the equivalent wheel RPM for 0.25V or less. The acceleration and deceleration should be specified in the detail specification, consistent with aircraft usage. This operation should be considered to be one cycle. The time interval between acceleration and deceleration, and vice versa, should be sufficient to allow all internal parts of the wheel-speed detectors to perform their prescribed function, if applicable. A more rational duplication of takeoff and landing function may be considered if applicable.

4.1.4.5.2.3 Electronic Component Tests

4.1.4.5.2.3.1 EMI tests in accordance with MIL-STD-461, or the equivalent RTCA DO 160 sections, as applicable, should be performed on the antiskid system installed in a simulated aircraft network. For the purpose of EMI testing, the entire antiskid system will be considered to be external to the aircraft, unless otherwise defined in the detail specification.

4.1.4.5.2.3.2 Power Input Tests:

The electronic control units should be subjected to the applicable power input and voltage spike tests in accordance with RTCA DO-160 Section16 and/or MIL-STD-704.

4.1.4.5.2.3.3 Dielectric Withstanding Tests

All Control Units should be subjected to a dielectric test. The test voltage should be 1500 VRMS, 60 Hz for a 1 minute period for equipment rated over 50 V, and 500 VRMS for equipment rated under 50 V. Leakage current should not exceed 1 milliampere during these tests.

4.1.4.5.2.3.4 Insulation Resistance Test

The resistance of the insulation between all mutually insulated parts of the control unit should be measured, after the dielectric test, to make certain that no unobserved insulation damage or insulation breakdown occurred. The resistance should not be less than 20 megohms with an applied voltage of 500 VDC.

4.1.4.5.2.4 Hydraulic Tests

The test fluids and level of filtration specified in AS8775 should apply for the following tests.

4.1.4.5.2.4.1 Proof Pressure

The hydraulic components should be subjected to proof pressure tests in accordance with AS8775 or FAR 25.1435.

4.1.4.5.2.4.2 Burst Pressure

The hydraulic components should be subjected to burst pressure tests in accordance with AS8775 or FAR 25.1435.

4.1.4.5.2.4.3 External Leakage

The hydraulic components should be subjected to external leakage tests in accordance with AS8775.

4.1.4.5.2.4.4 Internal Leakage

The hydraulic components should be subjected to internal leakage tests in accordance with the paragraph entitled, "Qualification or Pre-production Tests" of AS8775.

4.1.4.5.2.4.5 Endurance

In addition to the testing in 4.1.4.5.2.2, the hydraulic components should be subjected to additional endurance cycles in accordance with AS8775. The number of additional cycles should be determined by adding the maximum number of anticipated landings in the life of the gear (used in 4.1.4.5.2.2.2) and the maximum number of anticipated parking brake applications (when parking brake pressure is applied through the skid control valve) and multiplying the total by a safety factor of two. The hydraulic set-up should match the aircraft as closely as possible (hydraulic line sizes, lengths, components, etc.) when performing endurance testing.

4.1.4.5.2.5 Extreme Tolerance Analysis

The units used for pre-production component tests should be physically measured and the electrical output determined. These measurements should be compared with the proposed production tolerances. Based on performance of hydraulic leakage and electrical output exhibited during the component tests, the performance at the extremes should be analytically determined. Performance at the extremes should be within the limits identified in the detail specification.

4.1.4.5.2.6 Pressure Drop Test

The hydraulic units should be subjected to a pressure drop test in accordance with AS8775.

4.1.4.5.2.7 Fluid Contamination Tests

The hydraulic units should be capable of operating at least 10 hours when supplied with the specified hydraulic fluid contaminated to an appropriate class level of NAS 1638. Contamination count should be made in accordance with ARP598.

4.1.4.5.2.8 Impulse Test

The hydraulic control units should be subjected to an impulse test at system operating pressure in accordance with ARP1383. Details of the test should be defined in the procurement specification.

4.2 System Level Laboratory Tests

Total performance laboratory testing and evaluation of a brake control system can be conducted on:

a. Brake control simulators

b. Dynamometer

Brake control simulation testing should be conducted prior to aircraft testing to minimize risk and to tune the antiskid components for the particular aircraft application. Dynamometer tests should not be considered a substitute of aircraft or computer simulation tests in determining and optimizing overall braking efficiency and effectiveness. Dynamometer testing, while not mandatory during the development cycle of an antiskid system, can offer information on potential problem areas.

4.2.1 Brake Control Simulator

Computer simulation testing should be conducted to ascertain the degree of flexibility that exists within the control loop of the antiskid system. The minimum variations that should be explored are:

a. Gear damping

b. Reduced pressure input

c. Truck pitch

d. Variations in runway μ including step inputs

e. Brake torque gain

Other variations to be considered include:

a. Step changes in ground coefficient

b. Step changes in applied brake pressure

c. Significant differences in rolling radius (flat tire) on multi wheel gear which have wheel pairing (paired wheel control or locked wheel protection.)

Performance testing and evaluation of antiskid systems should be conducted on a real time, hardware in loop, brake control simulator. These hybrid simulators are a combination of components, brake hydraulic hardware, antiskid controllers, and associated interface equipment. The characteristics of the aircraft must be simulated accurately to test the controller in a repetitive fashion under a variety of operational conditions.

4.2.1.1 Description

The following is a brief description of the simulators and their operation. Figure 2 illustrates an overall schematic.

a. Computers: The computers are used to simulate the aircraft dynamic characteristics. These include mathematical models for the airplane, landing gear, wheel, tire, brake dynamics, and tire to ground interface. Until recently, these simulations have been done using all analog or hybrid (analog/digital) computers. However, the state-of-the-art parallel processing digital computers can now perform all calculations in real time that previously necessitated the use of analog computers. Figure 3 shows a typical schematic of 3 degrees of freedom (longitudinal) aircraft simulation model. The laboratory data from the brake dynamometer tests are used to model the dynamic characteristics of the brake to include torque fade, peaking, and other nonlinear effects. The expense and the inability to make frequent repetitive runs precludes the use of the dynamometer as an antiskid system tuning/evaluation tool

b. Computer Simulation Model (Parameters in Figure 3)

1. D - Drag due to brake torque
2. $D_A$ - Aerodynamic drag
3. $F_G$ - Braking drag acting on aircraft mass
4. $F_M$ - Vertical load on main gears
5. $F_N$ - Vertical load on nose gear
6. L - Aerodynamic lift
7. $P_B$ - Brake pressure
8. $T_B$ - Brake torque
9. $\dot{X}$ - Aircraft velocity
10. $\dot{X}_G$ - Gear fore - aft velocity
11. $\dot{X}_S$ - Tire-runway slip velocity
12. $\dot{\theta}_W$ - Wheel angular velocity
13. $\dot{Z}$ - Aircraft vertical velocity at CG
14. Z - Aircraft vertical displacement at CG
15. $\dot{\theta}$ - Pitch rotation velocity
16. $\theta$ - Pitch rotation
17. $T_J$ - Idle thrust

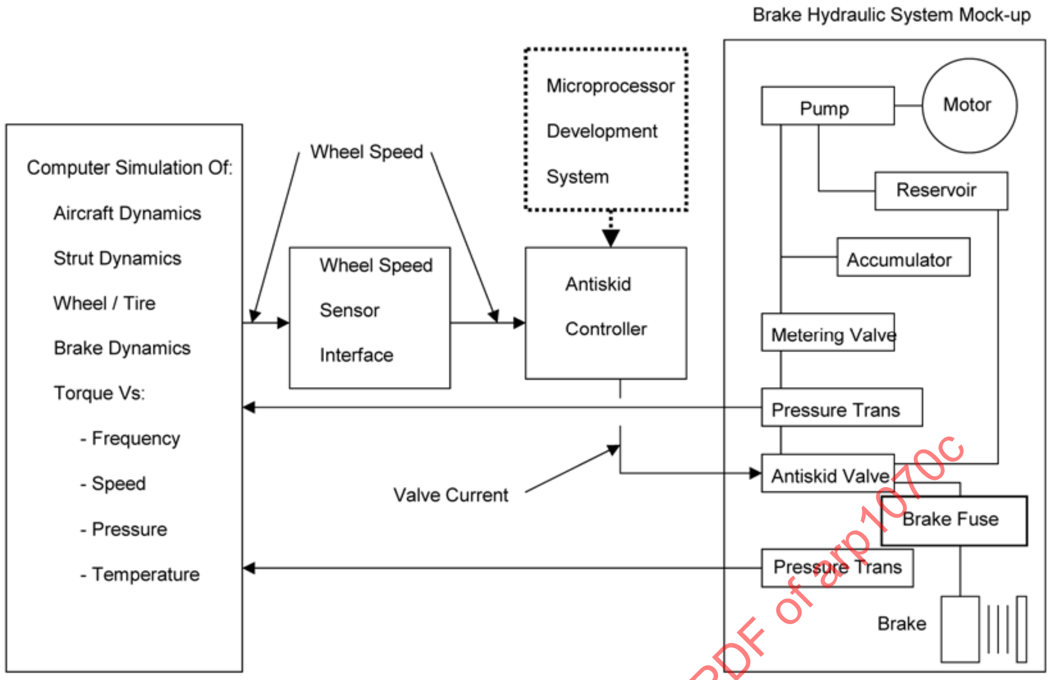


FIGURE 2 - BRAKE CONTROL SIMULATIR (TYPICAL)



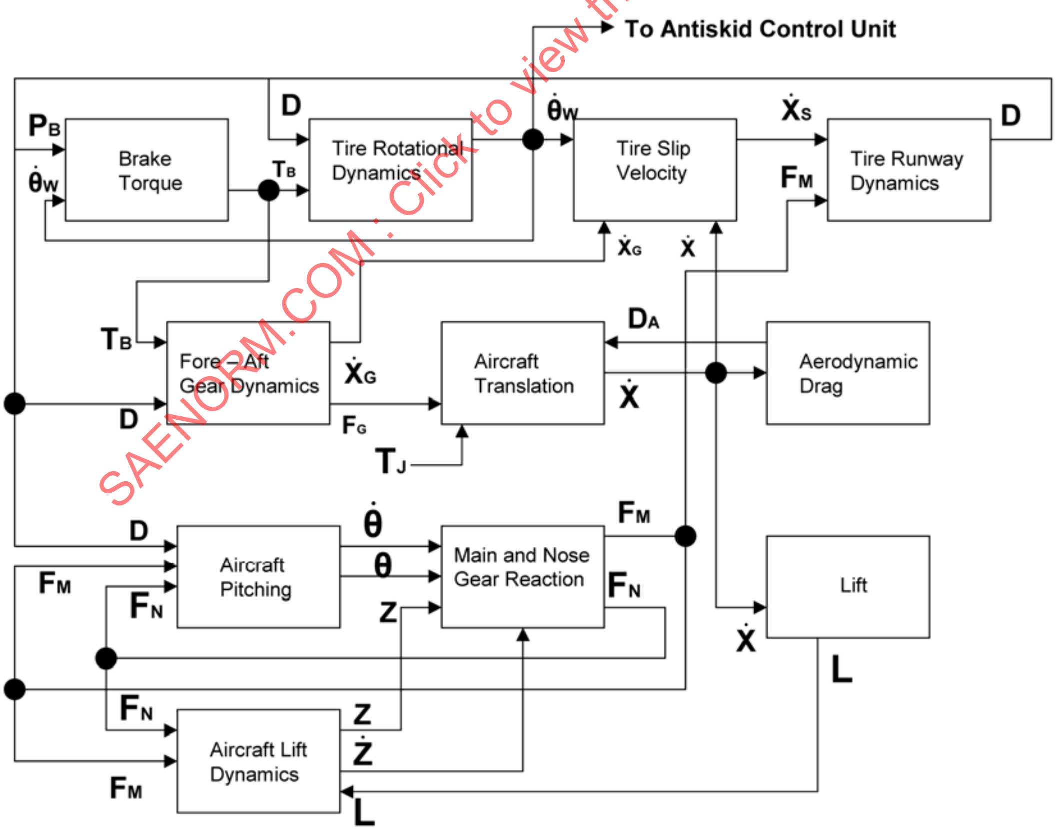


FIGURE 3 - COMPUTER SIMULATION MODEL

c. Brake Hydraulics: A mockup of the actual hydraulic system is built and used as an integral part of the simulator. This is done to simulate the hydraulic dynamic response of the air vehicle. Typically, this includes all the hydraulic components associated with a brake control system and is unique for each airplane. Use of the following hardware should be considered.

1. Brake metering valve(s) for one side of the airplane

2. Non-rotating brake stacks and pistons connected to skid control valves for the brakes on one side of the airplane

3. Pump, accumulator, reservoir, and other components

4. Representative lines and hoses between brakes, valves, and components

5. Skid control valves

The brakes should preferably be actual aircraft brakes, or a hardware simulation having the same pressure-volume characteristics. An objective of the hardware system is to achieve representative brake fill, dump, and transient response characteristics of brake pressure. Brake pressure is measured and interfaced with the computer simulation of brake pressure-torque and wheel-runway interaction. The use of the mockup ensures accurate hydraulic system response and allows detailed antiskid evaluation.

d. Controller: During real time testing, a prototype breadboard or an actual controller is in the simulation loop as shown in Figure 2. Wheel speed information from the computer is sent to the controller using a wheel speed sensor interface. In some instances, this can be replaced by an actual wheel speed transducer with a motor drive that is controlled by the computer to introduce the nonlinear effects of the wheel speed drive mechanism. In addition, prior to the availability of the controller card, a simulated model of the controller can be used to test and validate the computer simulation.

4.2.1.2 Simulator Tests

Simulator testing of brake control system hardware permits evaluation in a controlled environment. The computer simulation is tuned to match brake characteristics from dynamometer testing and airplane test data time histories by varying computer parameters. The simulation can then be used for optimizing stopping performance by changing control parameters in the skid control box. Efficiencies and performance parameters can be calculated by comparing computer predictions of drag force, stopping distance, etc., with “perfect stop” reference data. “Perfect stop” reference data is obtained by calculating performance when the maximum available drag force occurs continuously during a stop. Literally thousands of simulated landing rollouts can be made covering a wide variety of operational conditions. These tests are used to optimize the performance of the control systems and ensure good control under both normal and adverse runway/weather conditions. In addition, simulators permit evaluation of the controller under failed/or hazardous conditions that could not be conducted on the airplane because of safety and control limitations.

Typically, testing and tuning of the brake control system should include the following tests:

4.2.1.2.1 System Performance Tests

Stopping distance evaluation for a variety of constant friction conditions $\mu$ = 0.05 to maximum level expected on the runway.

a. Adaptability: Control system performance to sudden changes in runway friction conditions (wet puddles, icy patches, etc.) and runway roughness (steps, bumps, discontinuity, etc.)

b. Effect of Varying Metered Pressure: Control system performance at various constant metered pressure levels and varying cyclic metered pressures.

c. Family Variations: Stopping distance and system performance for variations in tire sizes, brakes, initial velocity, and landing weights.

d. Dynamic Stability: Determination of the effect of system performance by varying gear fore and aft stiffness and system damping. Investigation of the effect of dynamic variations in wheel speed.

e. Touchdown Protection/Locked Wheel Protection: Demonstrate acceptable touchdown protection/locked wheel protection feature.

The antiskid should be tuned to provide optimum control and performance under all operational conditions.

Once the airplane is available, flight test and laboratory tests should be done interactively. Problems and inefficiencies observed during flight test should be analyzed and duplicated on the simulator. System tuning parameter changes and control algorithm modifications need to be defined and incorporated in the flight test control unit, and then flight tested again. The cycle is repeated until satisfactory performance is achieved. Besides reducing flight test time, this approach produces state-of-the-art brake control systems, which operate over the entire friction coefficient range with braking efficiencies above 90 percent.

4.2.1.3 Software Development

If the brake controller incorporated digital microprocessor technology, software documentation and testing should be done. This includes all the following phases:

a. Documentation of requirements, design, and coding

b. Code execution

c. Performance, timing, and data handling

d. Built-in test equipment (BITE) tests

e. Failure response tests

Code analysis and documentation versus part checks ensure that software is properly coded and implemented. Code execution, performance, timing and data handling tests are done on the simulator. These tests ensure that the controller performs as intended. BIT check and failure response checks ensure that BIT monitors the operation status and detects the faults.

Software development should be done in accordance with the design specification. IEEE/EIA 12207 (Standard for Information Technology) or RTCA DO-178 (Software Considerations in Airborne System and Equipment Certification) are examples of industry software development standards.

4.2.1.4 Antiskid Performance Methods on Simulator

Methods of determining and evaluating antiskid system performance on the simulator are discussed in AIR1739. These methods include:

a. Stopping distance efficiency which is the ratio of minimum distance required to stop for a given condition and the actual distance required to stop.

b. Developed ground coefficient efficiency which is the ratio of the distance-weighted average actual friction coefficient and the distance-weighted average available friction coefficient.

c. Drag Force/torque/pressure efficiency. For this method the drag force, brake torque, or brake pressure versus time curves are integrated from brake application to brake release to get the actual area under the curve. The peaks (not transients) of the curves may be connected and integrated to get the optimum area under the curve. The efficiency of braking is defined as the ratio of the actual area divided by the optimum area. A better approximation can be made by using a velocity-weighted summation. This summation is done by multiplying both measured and peak values of drag force, brake torque, or brake pressure by velocity before the integration is performed. This method also lends itself to on aircraft performance evaluation of the measured parameter of drag force, torque, or brake pressure are available.