



AEROSPACE RECOMMENDED PRACTICE

ARP1070™

REV. E

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Superseding ARP1070D

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

RATIONALE

One of the major prerequisites for highly efficient antiskid control is fast braking system response. Earlier versions of the document do have language recommending fast response, but it is not explicit enough or detailed enough. This has become an issue as airframe manufacturers in multiple programs have designed systems with inadequate response for good, much less excellent, antiskid control. There is a need to move consideration of braking system response into the earliest stages of airplane development programs to avoid finding out that response is slow after designs have been frozen and hardware has been produced. In general, there is a need to include desired antiskid performance in all aspects of aircraft design, but this revision will focus primarily on braking system response.

ARP1070E has been reaffirmed to comply with the SAE Five-Year Review policy.

TABLE OF CONTENTS

1.	SCOPE.....	4
1.1	Purpose.....	4
2.	APPLICABLE DOCUMENTS.....	4
2.1	SAE Publications.....	4
2.2	U.S. Government Publications.....	5
2.3	NASA Publications.....	5
2.4	FAR Publications.....	6
2.5	Other Publications.....	6
2.6	ARINC Publications.....	6
2.7	NAS Publications.....	6
2.8	RTCA Publications.....	7
2.9	IEEE Publications.....	7
3.	ANTISKID, DESCRIPTION OF OPERATION.....	7
4.	ANTISKID SYSTEM DEVELOPMENT PROCESS.....	10
4.1	Configuration Consideration.....	11
4.2	Antiskid System Operating Environment.....	11
4.3	Aircraft Braking Environment.....	11
4.4	Recommended Data Exchange.....	11
5.	AIRCRAFT SYSTEMS AND AIRCRAFT OPERATIONAL GOALS, EFFECT ON ANTISKID.....	13
5.1	Antiskid Interactions with the Aircraft, Stopping Performance.....	13
5.1.1	Braking System Response.....	14

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<https://www.sae.org/standards/content/ARP1070E/>

Documents

Standard, visit Sharing Hub

5.1.2	Aerodynamic Surfaces	14
5.1.3	Engine Thrust.....	14
5.1.4	The Touchdown Event	15
5.1.5	Vehicle Management Systems (VMS)	15
5.1.6	Aircraft Geometry	15
5.1.7	Aircraft Electrical Power System	15
5.1.8	Brakes	16
5.1.9	Aircraft Hydraulics (Hydraulically Actuated Braking System)	19
5.1.10	Tires	22
5.1.11	Landing Gear	23
5.1.12	Directional Control.....	27
5.1.13	Passenger Comfort	28
5.2	Antiskid Integration Interaction with Other Aircraft Systems.....	28
5.2.1	Integrated Modular Avionics	28
5.2.2	Communications Buses	28
5.2.3	Cockpit and Maintenance.....	29
5.2.4	Hydraulics	29
6.	ANTISKID REQUIREMENTS	29
6.1	Stopping and Cornering Performance	29
6.2	Landing Gear Stability	31
6.3	Aircraft Pitch Excitation	32
6.4	System Features	32
6.4.1	Touchdown Protection	32
6.4.2	Locked Wheel Protection	32
6.4.3	Hydroplaning Protection	32
6.4.4	Emergency Operation	32
6.4.5	Parking Brake.....	33
6.5	Wheel Speed Transducer	33
6.5.1	Inertia Type	33
6.5.2	DC Generator.....	33
6.5.3	AC Inductive Type Generator	33
6.5.4	Optic Sensor	34
6.5.5	Hall Effects Transducer.....	34
6.6	Runway Condition	35
6.7	Atmospheric Condition	35
6.8	Design and Construction Goals and Considerations	35
6.8.1	Hydraulic Equipment - General	35
6.8.2	Hydraulic Lines.....	37
6.8.3	Electrical Design	37
6.8.4	Environmental	38
6.9	Software Development.....	39
7.	COMPONENT TESTING AND EVALUATION.....	40
7.1	First Article Inspection.....	40
7.1.1	Environmental Tests	40
7.1.2	Endurance Tests	40
7.1.3	Hydraulic Tests	41
7.1.4	Performance Tests	42
8.	SYSTEM LEVEL ANTISKID PERFORMANCE AND SAFETY TESTING AND EVALUATION	42
8.1	RTHITL Brake Control Simulation.....	42
8.1.1	Aircraft Body Dynamics Simulation.....	46
8.1.2	Landing Gear Simulation.....	49
8.1.3	Wheel/Tire Simulation	51
8.1.4	Simulator Tests	53
8.1.5	Simulation Interactive with Flight Test	54
8.1.6	Antiskid Performance Methods on Simulator.....	54

8.2	Dynamometer Testing of Antiskid Systems	54
8.2.1	Test Equipment, Dynamometer	55
8.2.2	Instrumentation, Dynamometer	55
8.2.3	Procedure, Dynamometer	55
8.2.4	Antiskid Performance on Dynamometer	55
8.3	Safety of Flight	56
8.3.1	Component Testing and Evaluation, Safety of Flight	56
8.3.2	Brake Control Simulation	56
8.3.3	System Fault Analysis and Testing	56
8.3.4	Safety of Flight	57
8.3.5	Safety of Flight Certification	57
8.4	Aircraft Tests	57
8.4.1	Test Equipment	57
8.4.2	Procedure	58
8.4.3	Antiskid Performance Methods on Aircraft	60
9.	NOTES	60
9.1	Revision Indicator	60
Figure 1	Mu versus slip curve	8
Figure 2	Antiskid system schematic	9
Figure 3	Antiskid development and testing flowchart	10
Figure 4	Antiskid aircraft interactions	13
Figure 5	Brake displacement, pressure versus volume	17
Figure 6	Brake friction curve variation	18
Figure 7	Hydraulic system example	20
Figure 8	Merging supply and return lines	21
Figure 9	Brake release time	22
Figure 10	Typical types of main gear	23
Figure 11	Suspension	24
Figure 12	Shock strut step and stick	24
Figure 13	Aircraft pitch, roll, or vertical oscillation	25
Figure 14	Forward raked gear	26
Figure 15	Tire twist	27
Figure 16	Friction coefficient, tire braking and side, fixed wheel yaw angle	30
Figure 17	Wheel speed AC generator	34
Figure 18	Hardware-in-the-loop example, antiskid system	44
Figure 19	Hardware-in-the-loop example, brake by wire system	45
Figure 20	Hardware-in-the-loop example, electric brake system	45
Figure 21	Airplane free body diagram	48
Figure 22	Typical types of main gear	49
Figure 23	Gear free body diagram	50
Figure 24	Wheel free body diagram	51
Figure 25	Mu versus slip velocity	52
Table 1	Airframe manufacturer supplied data (typical, but not limited to)	12
Table 2	Antiskid manufacturer supplied data	13
Table 3	Sample aircraft antiskid test schedule - dry runway	59
Table 4	Sample aircraft antiskid test schedule - wet runway	59

1. SCOPE

This document outlines the development process and makes recommendations for total antiskid/aircraft systems compatibility. These recommendations encompass all aircraft systems that may affect antiskid brake control and performance. It focuses on recommended practices specific to antiskid and its integration with the aircraft, as opposed to more generic practices recommended for all aircraft systems and components. It defers to the documents listed in Section 2 for generic aerospace best practices and requirements. The documents listed below are the major drivers in antiskid/aircraft integration:

1. ARP4754
2. ARP4761
3. RTCA DO-178
4. RTCA DO-254
5. RTCA DO-160
6. ARP490
7. ARP1383
8. ARP1598

In addition, it covers 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, as well as methods of determining and evaluating antiskid system performance.

For definitions of terms used herein, see Section 7.

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

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

2.1 SAE Publications

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

AIR1739	Information on Antiskid Systems
ARP490	Electrohydraulic Servovalves
ARP598	Aerospace Microscopic Sizing and Counting of Particulate Contamination for Fluid Power Systems
ARP4754	Guidelines for Development of Civil Aircraft and Systems
ARP4761	Guidelines and Methods for Conducting the Safety Assessment Process on Civil Aircraft Systems and Equipment

ARP4955	Recommended Practice for Measurement of Static and Dynamic Characteristic Properties of Aircraft Tires
ARP1598	Landing Gear System Development Plan
AS8775	Hydraulic System Components, Aircraft and Missiles, General Specification for
AS22759	Wire, Electrical, Fluoropolymer-Insulated, Copper or Copper Alloy

2.2 U.S. Government Publications

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

MIL-B-8075	Brake Control Systems, Antiskid, Aircraft Wheels, General Specification For
MIL-DTL-26500	Connectors
MIL-HDBK-217	Reliability Prediction of Electronic Equipment
MIL-HDBK-454	General Guidelines for Electronic Equipment
MIL-HDBK-5400	Electronic Equipment, Airborne, General Guidelines For
MIL-P-8564	Pneumatic Components (Inactive)
MIL-PRF-81322	Lubrication
MIL-STD-130	Equipment Identification (Active)
MIL-STD-461	Electromagnetic Interference Characteristics, Requirements for (Active)
MIL-STD-704	Electrical Power, Aircraft Characteristics (Active)
MIL-STD-810	Environmental Test Methods (Active)
MIL-STD-882	Safety Requirements (Active)
MIL-STD-1568	Materials and Processes for Corrosion Prevention and Control in Aerospace Weapons Systems
MIL-W-5088	Aircraft Wiring (Inactive - refer to AS50881)

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

2.3 NASA Publications

NASA Technical Services, NASA STI Program STI Support Services, Mail Stop 148, NASA Langley Research Center, Hampton, VA 23681-2199, 757-864-9658, Fax: 757-864-6500, <http://ntrs.nasa.gov/>.

NASA TN D-1376	Influence of Tire Tread Pattern and Runway Surface Condition on Braking Friction and Rolling Resistance of a Modern Aircraft Tire
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2.4 FAR Publications

Available from Federal Aviation Regulations, <https://www.faa.gov>. Equivalent EASA CS specifications exist and are available at <http://easa.europa.eu/document-library/certification-specifications>.

AC121.195(d)-1A	Operational Landing Distances for Wet Runways; Transport Category Airplanes
AC25-7	Flight Test Guide for Certification of Transport Category Airplanes
AC23-8	Flight Test Guide for Certification of Part 23 Airplanes
AC20-152	Design Assurance Guidance for Airborne Electronic Hardware
14 CFR 25.109	Accelerate - Stop Distance
14 CFR 25.735	Brakes and Braking 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

2.5 Other Publications

NLR-TP-2001-242 Hydroplaning of Modern Aircraft Tires, National Aerospace Laboratory, NLR

2.6 ARINC Publications

Available from ARINC, 2551 Riva Road, Annapolis, MD 21401-7435, Tel: 410-266-4000, 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

2.7 NAS Publications

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

NAS1638	Cleanliness Requirements of Parts Used in Hydraulic Systems
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2.8 RTCA Publications

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

DO-160	Environmental Conditions and Test Procedures of Airborne Equipment
DO-178	Software Considerations in Airborne Systems and Equipment Certification
DO-248	Second Annual Report for Clarification of DO-178B
DO-254	Design Assurance Guidance for Airborne Electronic Hardware

2.9 IEEE Publications

Available from IEEE Operations Center, 445 and 501 Hoes Lane, Piscataway, NJ 08854-4141, Tel: 732-981-0060, www.ieee.org.

IEEE/EIA 12207.0	Standard for Information Technology - Software Life Cycle Processes
IEEE/EIA 12207.1	Guide for Information Technology - Software Life Cycle Processes - Life Cycle Data
IEEE/EIA 12207.2	Guide for Information Technology - Software Life Cycle Processes - Implementation Considerations

3. ANTISKID, DESCRIPTION OF OPERATION

The antiskid system as used in this recommended practice is the group of interconnected components which interact to prevent inadvertent tire skidding and contribute to shorter aircraft stopping distances by controlling excessive brake pressure, including, but not limited to, wheel speed sensors, control valve(s), and control unit.

The wheel braking system refers to all elements associated with the antiskid system, which coupled together provide deceleration of the aircraft due to wheel brakes. The elements include, but are not limited to, antiskid control components and associated hydraulic installation, electrical system interfaces, wheel(s), tire(s), and brake(s).

The core function of antiskid control is stopping the aircraft as quickly as possible while maintaining directional control and staying on the runway.

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 clamping force at all times to generate 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 stopping distance.

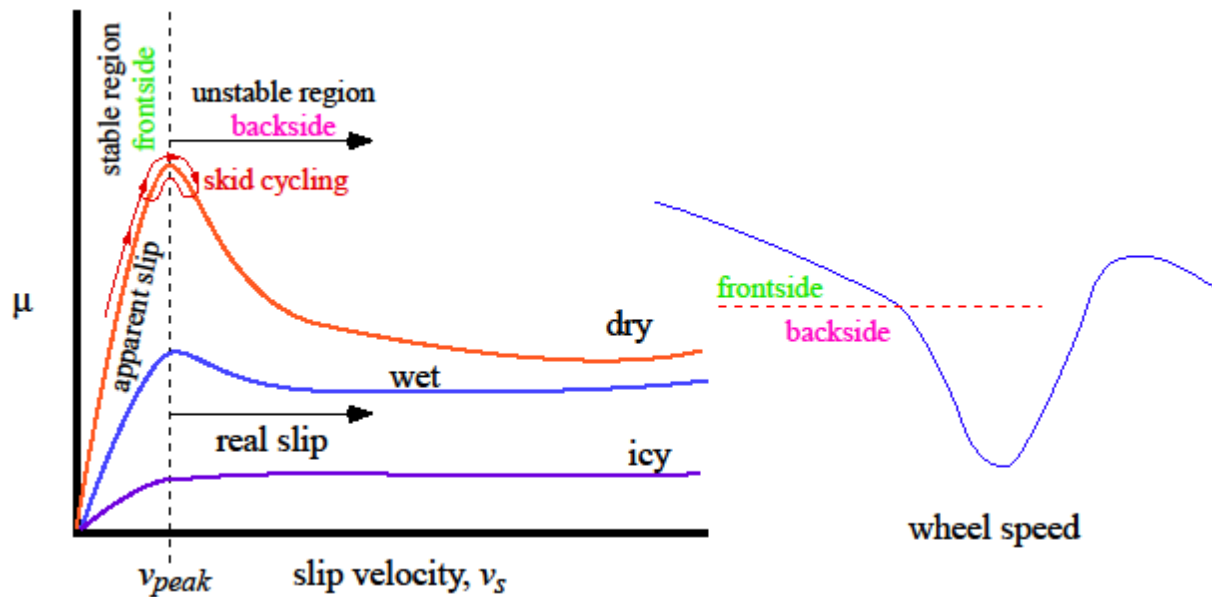


Figure 1 - Mu versus slip curve

Figure 1 shows typical mu-slip curves. The instantaneous tire-runway friction (μ or μ) is a function of wheel slip, which is the difference between the forward speed of the axle and the rotational speed of the wheel multiplied by the rolling radius of the tire. The shape of the mu-slip curve and the location of the peak changes as the aircraft slows down, as well as with runway condition, but there is always a peak. It is this peak that antiskid needs to find to maintain optimal stopping performance.

Slip on the frontside of the mu-slip curve is apparent. Tire stretching and twist about the axle cause the wheel to turn at less than synchronous speed, even though the tire is not actually slipping on the runway. For further explanation, please refer to AIR1739.

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.

In operation, the pilot commands pressure or clamping force 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 commands a reduction in the brake clamping force 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. In unmanned aircraft, or in the case of autobraking, an onboard computer commands pressure or clamping force directly.

The antiskid system controls the brake clamping force through a brake actuator (a skid control valve, an Electric Motor Actuation Controller (EMAC), or some other means) 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 brake actuator to modulate the brake clamping force. Upon command from the controller, the skid control reduces brake clamping force. When the wheel spins up, the controller reapplies brake clamping force at a controlled rate through the brake actuator until another incipient skid occurs or commanded clamping force is achieved. Several types of brake control-antiskid system types are shown in Figure 2. Note that an alternative to the "brake by cable configuration" is a "brake by master cylinder" configuration.

Note that many existing systems still use analog antiskid controllers, rather than digital computers with embedded processors.

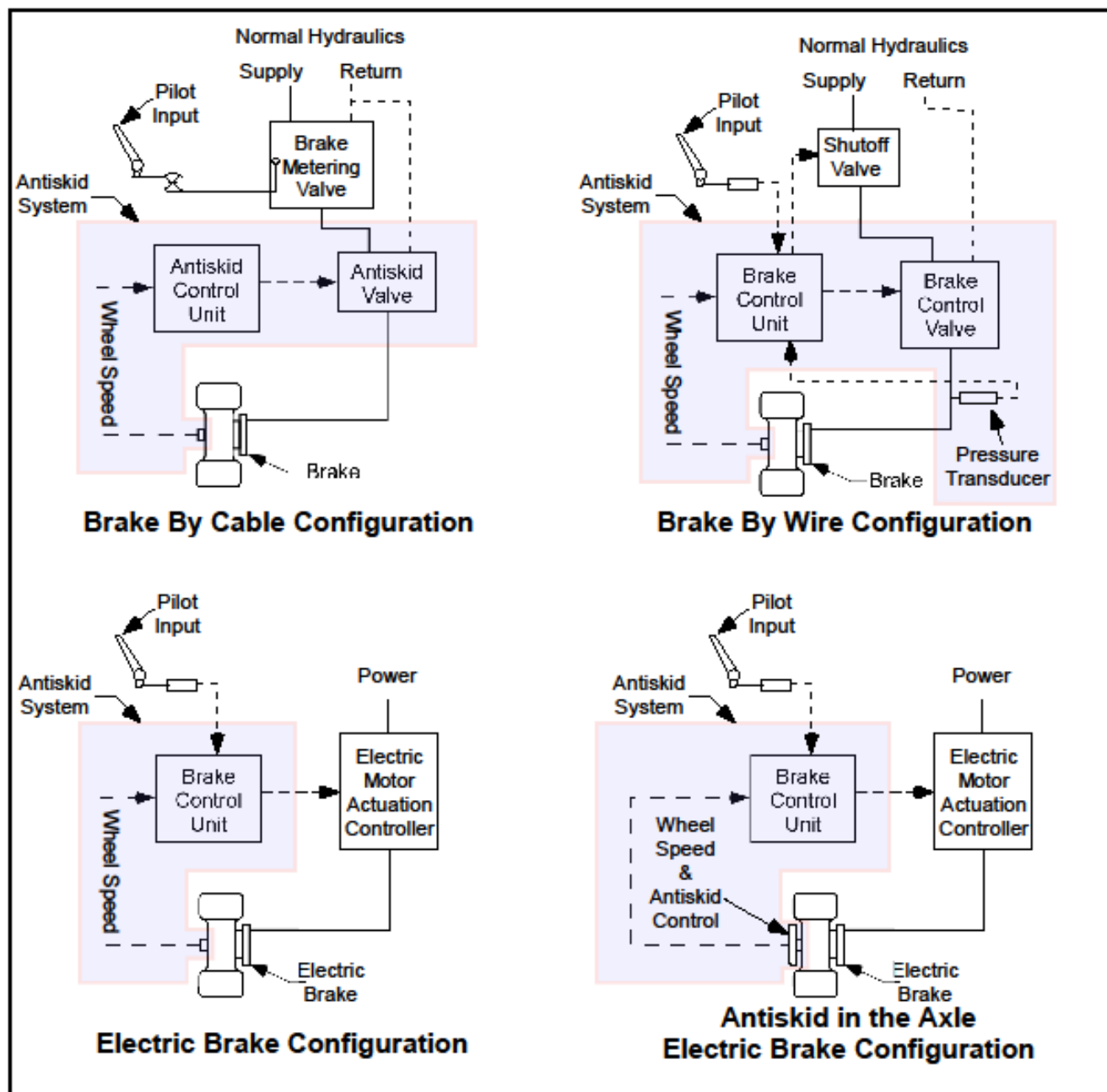
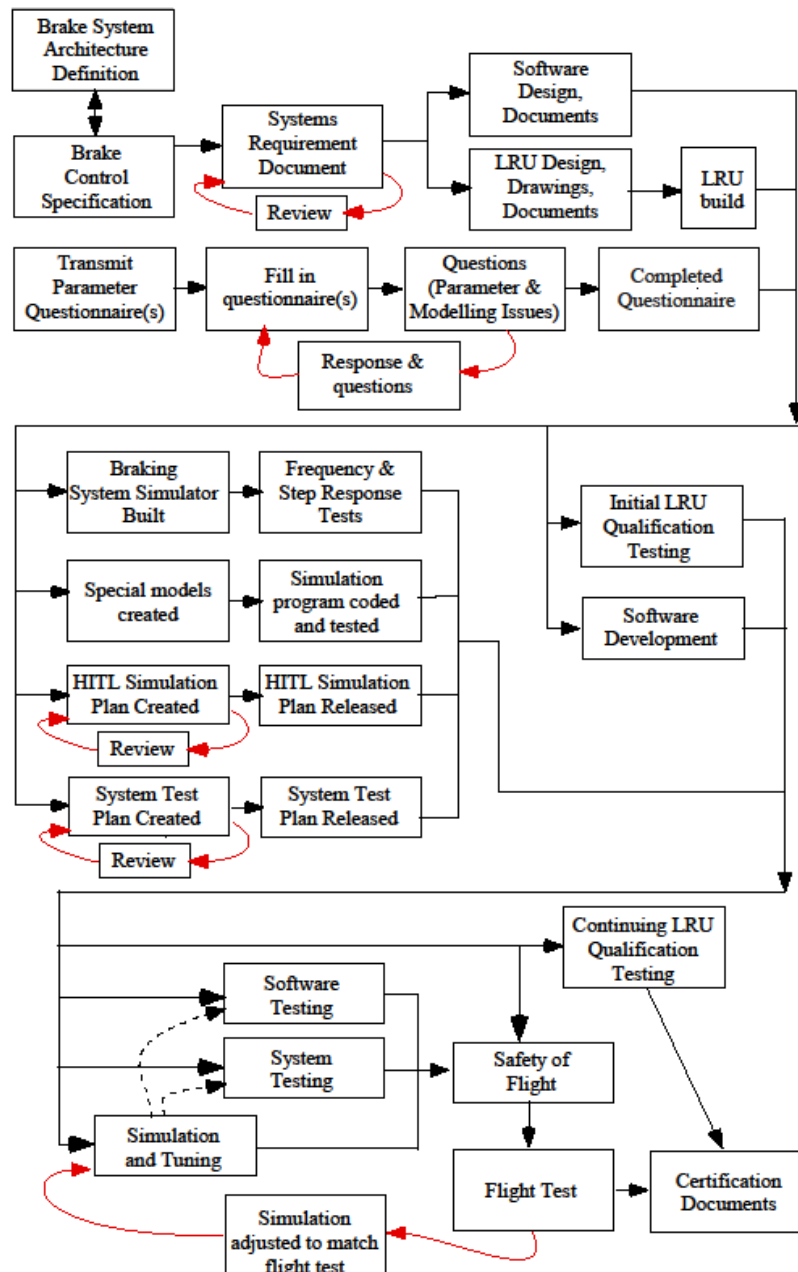


Figure 2 - Antiskid system schematic

Test equipment and fixtures should be developed to perform the validation and verification activities required by ARP4754.



LRU: Line-Replaceable Unit.
HITL: Hardware-in-the-Loop Simulation. Real-time.

4.1 Configuration Consideration

The selection of an antiskid system configuration (architecture) is conditioned by considerations usually including the following:

- a. Number and arrangement of braked wheels.
- b. Degree of emphasis on stopping/cornering performance.
 1. Individual wheel control refers to the feature where each braked wheel is controlled individually, as a function of its wheel speed. For this function each braked wheel requires its own wheel speed transducer, servo valve, and control circuit.
 2. The antiskid system may be configured to control brake pressure to two or more braked wheels requiring skid control. Pairing or grouping of wheels is a function of landing gear arrangement, performance required, and aircraft directional stability required and should be defined in the procurement specification.
 3. The ability to achieve high antiskid stopping efficiency is dependent on braking system hydraulic response (or electro-mechanical response for electric brake systems). Fast response is necessary for highly efficient antiskid control.
- c. Available space.
- d. Airplane electrical wiring configuration.
- e. Wheel brake friction variation.
- f. System cost.
- g. Reliability and maintainability.
- h. Weight.
- i. Failure modes/redundancy.

4.2 Antiskid System Operating Environment

The antiskid system operating environment is the environment in which the antiskid performs its intended function. The environment contains numerous factors with influence antiskid performance, including the wheel braking system, the airframe elastic structure (including struts), the wheel dynamic loading, tire elastic properties, runway friction levels available, runway roughness, ambient and hydraulic fluid temperature, and external influences including EMI, fluid susceptibility, etc.

4.3 Aircraft Braking Environment

The aircraft braking environment is that environment the aircraft experiences during the landing and braking phase of operations, including runway length/width/surface texture/slope/crown/contamination level, wind conditions, temperature/pressure/altitude, touchdown velocity and alignment, and touchdown point proficiency.

4.4 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. Example data exchanges are shown in Tables 2 and 3. Table 2 is an example of data supplied by the airframe manufacturer, airframe user, or the brake control supplier/integrator. The higher the fidelity of the antiskid simulation models used in the development process, the more data will be required. Table 3 identifies data and information supplied by the skid control manufacturer.

Table 1 - Airframe manufacturer supplied data (typical, but not limited to)

	Parameter
Aircraft (General)	<u>Aircraft weight</u> - Maximum takeoff, design landing, minimum landing weight, weight empty. <u>Aircraft velocity at brake application</u> - Maximum takeoff gross weight rejected takeoff, overload stop, normal landing weight, minimum flying weight. <u>Geometric parameters</u> - 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. <u>Aerodynamic parameters</u> - 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. <u>Miscellaneous</u> - 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	<u>Hydraulic lines</u> - 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. <u>Brake metering valves</u> - Pressure and flow characteristics, <u>Hydraulic supply</u> - Maximum pressure available and flow characteristics. Hydraulic supply and return pressure. Predicted frequency and step response of the brake hydraulic system as a whole (which may involve iterative interaction, analysis, and simulation with the participation of the antiskid, brake, and other LRU suppliers).
Electric Power System	<u>If brakes are electrically actuated, electric wire location and size, means of selecting normal or reserve power to the brake system, and voltage(s) and power available.</u> Predicted frequency and step response of the brake system.
Brake Component	Lining contact pressure (psi), pressure volume characteristics, torque-pressure characteristics including range of friction coefficients (hot brake, cold brake, worn brakes, new brakes), torque-speed characteristics, weight of brake, moment of inertia of brake rotors. Number of stators and rotors. Number of pistons and piston area.
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, moment of inertia of tire and wheel.
Miscellaneous	<u>Skid control components</u> - Schematic, envelope, and mounting requirements. Interface requirements for controller, control valves and wheel speed sensors. System fault isolation and indication requirements.
	<u>Speed requirements</u> - Maximum and minimum operational speeds.
	<u>Skid control efficiency requirements</u> -
	<u>Special skid control features required</u> - Touchdown protection, locked wheel protection, paired wheel control, auto-braking, warning devices for pilot, on-off switch, parking brake, etc.
	<u>Operational environment for components</u> -

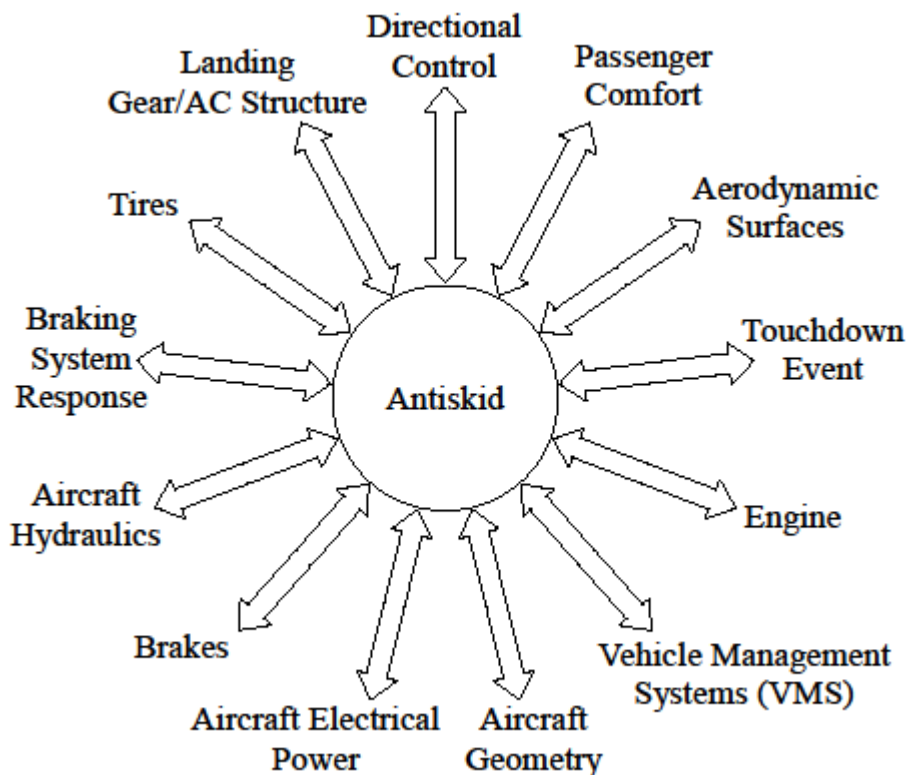
Table 2 - Antiskid manufacturer supplied data

Antiskid Manufacturer Supplied Data
• Electronic schematics. • Interface control documents (ICDs). • Operational considerations. • Failure modes and effects analysis. • Requirements verification compliance matrix - Confirmation of requirements compliance, and how to be verified (inspection, demonstration, analysis test). • 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. • Maintainability - Recommended system maintenance and checkout procedures, required ground support equipment. • Reliability predictions. • Test procedures/reports - Acceptance test, flight justification test, and qualification test. • Complete working drawings including proprietary data appropriately marked. • System safety evaluation in accordance with ARP4761. • Simulation test results. • Data demonstrating compliance with DO-178 (clarification in DO-248). • Data demonstrating compliance with DO-254. • Data demonstrating compliance with ARP4754.

5. AIRCRAFT SYSTEMS AND AIRCRAFT OPERATIONAL GOALS, EFFECT ON ANTISKID

5.1 Antiskid Interactions with the Aircraft, Stopping Performance

Figure 4 shows some of the important interactions between antiskid core function, aircraft systems, and aircraft operational goals.

**Figure 4 - Antiskid aircraft interactions**

5.1.1 Braking System Response

Fast brake response is a prerequisite for highly efficient antiskid control. Fast response also improves the robustness of the control and its ability to adapt to future changes to the aircraft. Both large and small signal response should be considered. (Note that other aircraft systems may also affect the maximum achievable antiskid efficiency.)

Note that, when necessary, it is always possible for brake control to slow down response in consideration of other aircraft requirements, such as pressure ramp-up (and its associated loads), as well as aquaplane logic.

The airframe manufacturer is responsible for bringing all of the relevant parties together to ensure that all analysis and testing is performed to achieve the response necessary for the required level of antiskid performance. For system upgrades not involving the airframe manufacturer, a systems integrator may take on that role.

As a starting point, the following level of response should be targeted. In-depth analysis of the system may modify these numbers.

Step response (large signal):

- Brake release from maximum command to zero torque:
 - Should be 40 ms or less for maximum antiskid efficiency (typically 90% or higher).
 - Should be 80 ms or less for reasonable antiskid efficiency (typically 85% or higher).
 - See the definition of brake release time in Figure 9.
 - Note that the “maximum command” is generally system pressure for hydraulic brakes or the maximum force that can be applied to the brake pistons for an electric brake. If the brake torque gain is high enough so that the skid level is always significantly lower than the maximum command, maximum skid level (generally seen during maximum rejected take off or overload landings) may be substituted for maximum command.

Frequency response (small signal):

- 90 degree crossing point of the phase shift in a frequency sweep:
 - Should be 12 Hz or higher for maximum antiskid efficiency.
 - Should be 8 Hz or higher for reasonable antiskid efficiency.

5.1.2 Aerodynamic Surfaces

For optimal stopping capability, it is recommended that the aerodynamic surfaces generate as much drag as possible while directing the greatest possible load onto the main wheels while maintaining enough load on the nose wheels for effective steering.

At high speeds, rudder control may reduce or eliminate the need for differential braking to maintain directional control.

5.1.3 Engine Thrust

The effect of engine thrust on stopping performance should be considered.

The effect of reverse thrust should be considered.

The effects of feathering propeller driven airplanes should be considered. The effect of propellers on aerodynamic surfaces should also be considered.

5.1.4 The Touchdown Event

The touchdown event affects stopping distance, as well as the time it takes for antiskid to reach the peak of the mu-slip curve.

After a hard landing, if the aircraft bounces and significantly lowers the weight on the wheels, the task of antiskid initializing itself to find the skid level may be much more difficult.

Note that a touchdown protection feature should be included to prevent brake application before touchdown and wheel spin up.

5.1.5 Vehicle Management Systems (VMS)

Vehicle Management Systems (VMS) may perform functions that might traditionally be performed in the antiskid controller, as well as additional functions that may affect antiskid performance and control. These functions might include (but not be limited to):

- Touchdown protection.
- Delay of brake application until such application will not cause adverse aircraft structural issues. (Example: Delay until all landing gears are on the ground.)
- Limitation of brake torque magnitude or rate of application to prevent aircraft structural damage.
- Directional control.

Specification of antiskid performance requirements should take VMS limitations of brake application into account.

Conversely, the design of VMS software related to braking should take antiskid into account.

Interfaces between the VMS and the antiskid controller should be designed to have enough bandwidth and speed (including margin for potential expansion) to meet all of the control interaction requirements.

5.1.6 Aircraft Geometry

It is recommended that stopping capability and steering capability be considered when laying out the geometry of the main landing gears, nose landing gear, and range of center of gravity location.

A center of gravity too far forward of the main gears, in relationship to the wheelbase (distance between the nose and main gears) will increase the weight on the nose as compared to the main gears. As the aftward directed braking force is the product of the weight on the main wheels and the tire runway coefficient of friction, the lower the proportion of weight on the main wheels, the longer the stopping distance.

Braking itself produces a nose down pitching moment on the aircraft. The higher the center of gravity, the more weight will be transferred to the nose during braking.

A short wheelbase and wide track (lateral distance between the main gears) will increase the yaw moment produced on the aircraft when antiskid releases pressure on one side of the airplane but not the other, thus causing the aircraft to veer to the left or right. Methods insuring that antiskid releases pressure on both sides simultaneously can alleviate this problem but they may increase the stopping distance.

5.1.7 Aircraft Electrical Power System

The antiskid/brake control equipment should be compatible with the aircraft power quality environment.

For electric brake systems, the electrical power system should have sufficient voltage and current capability to meet the needs of the brake system. Reserve electrical power should also be available if the primary electrical power system fails.

5.1.8 Brakes

5.1.8.1 Brake Response

Brake system response is a shared responsibility between the airframe manufacturer (or system integrator for certain aircraft upgrade programs), the antiskid manufacturer, and the brake manufacturer. The airframe manufacturer should manage the roles and responsibilities of these three players to ensure that the system as a whole is responsive enough for highly efficient antiskid control.

Fast brake response, as measured by both step and frequency response, is a prerequisite for highly efficient antiskid control. Note that the response of the entire braking system must be considered; thus, the brake itself must be fast enough for that response to be achievable. See 5.1.1.

Airframe manufacturer requirements for brake response should be included in the brake procurement specification.

Brake fill time, or the time from the initial command to the brake and piston contact, should be minimized.

Brake release time should be as fast as possible. If a wheel locks up or goes into a very deep skid, antiskid must be able to reduce torque quickly to allow it to spin up again. When antiskid commands zero brake torque, the response of the brake system must be as fast as possible.

At a system and brake level, response speed at low command levels for hydraulic brakes may be increased by the concept of zero torque pressure (ZTP), whereby the brake is released enough for the wheel to be unbraked, but the pressure does not drop to zero. As brake torque is not usually measured, care must be taken to ensure that the ZTP command is set low enough to reliably result in zero torque and not a small amount of torque which would lead to a dragging brake.

Note that the response of the system will be tested as a whole, using a rig that duplicates the aircraft braking hydraulic system or the electric brake system (see 8.1).

5.1.8.1.1 Fluid Displacement, Hydraulic Brake

Hydraulic fluid volume change from return pressure to initial brake contact pressure should be minimized to reduce the amount of flow required to quickly fill the brake. In combination with long brake lines, high flow rates can result in water hammer when the pistons contact the brake stack.

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. This part of the displacement curve is particularly important for determining the flow that must be driven through the system during antiskid modulation, including brake releases. The higher the slope of pressure versus volume, the better.

Figure 5 shows how brake fluid displacement can be better or worse for antiskid hydraulic system response, depending upon the brake design and brake wear level.

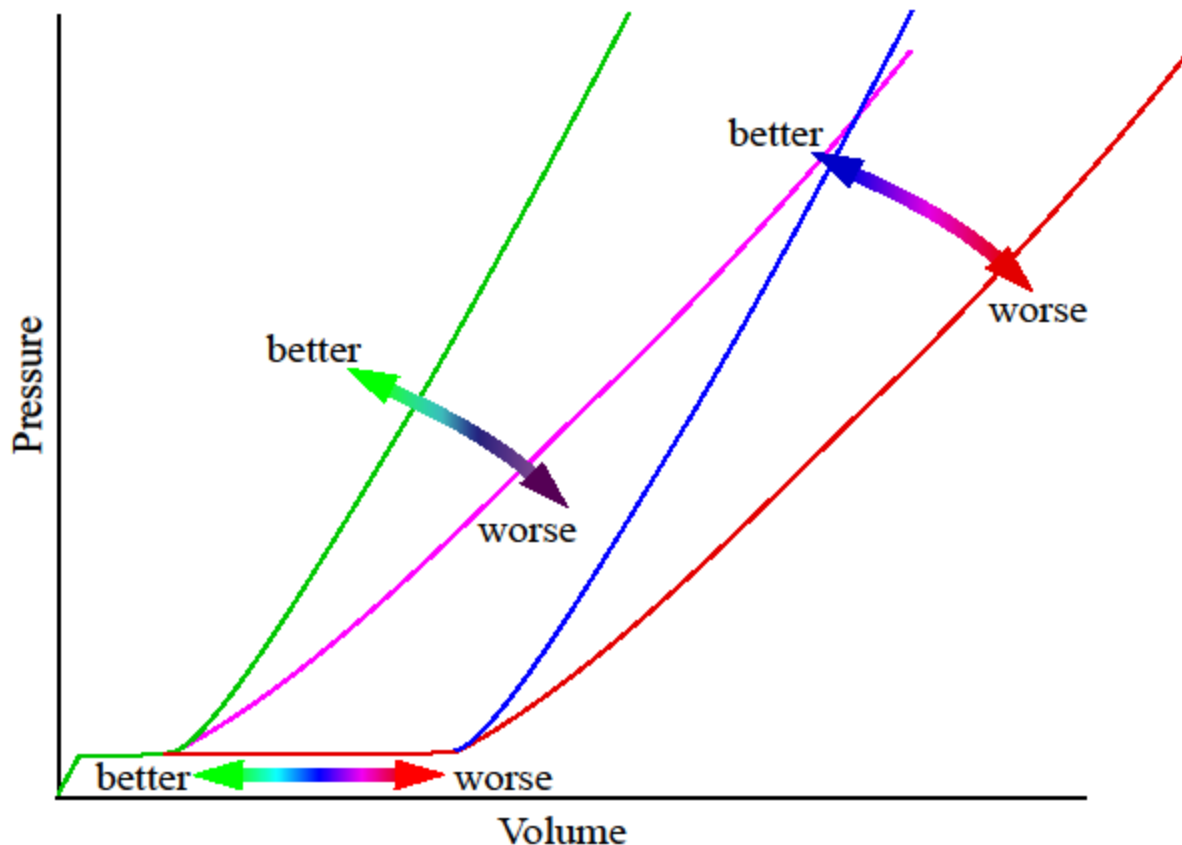


Figure 5 - Brake displacement, pressure versus volume

5.1.8.1.2 Fluid Passages, Hydraulic Brake

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 include brake passage restrictions 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. Flow restrictions should not be so severe that, during a brake fill, an upstream piston contacts the brake stack noticeably before pistons further downstream. Small diameter restrictions can significantly affect brake hydraulic response.

5.1.8.1.3 Communication and Computational Delays, Electric Brake

Communication delays between the antiskid system and the electric brake motor actuator (EMAC) and between the EMAC and the brake actuators should be minimized. This lag is the equivalent of transport delay down a long hydraulic line in a hydraulic brake.

The computation time of the EMAC should be fast enough to maximize the response of the electric brake actuator.

5.1.8.1.4 Electric Brake Actuator

The response of the actuators should be sufficient to allow for highly efficient antiskid control. See 5.1.1.

5.1.8.1.5 Mechanisms, Hydraulic and Electric

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. Excessive hysteresis can interfere with antiskid control and its ability to reduce brake torque as required.

5.1.8.2 Brake Vibration

Interactions between antiskid and brake dynamics should be considered. It is also sometimes possible to relieve adverse effects of brake dynamics by changing the antiskid system characteristics.

Brake vibrations that can interfere with the antiskid control should be avoided. These include:

- Vibrations that cause cycling in piston pressure sufficient to interfere with antiskid's modulation of brake pressure.
- Vibrations that occur at some multiple of wheel speed. Steel brakes with the same number of brake pistons as expansion slots in the rotors and the stators are an example of a design that can produce this sort of vibration.
- Vibrations that cause the wheel speed transducer to measure incorrect wheel speed.
- Vibrations that excite landing gear natural frequencies.

5.1.8.3 Brake Friction Properties

A goal of brake design for antiskid systems should be consistent friction characteristics. Antiskid can adapt more easily when the shape of the friction curve and its rough level is similar from stop to stop throughout the life of the brake.

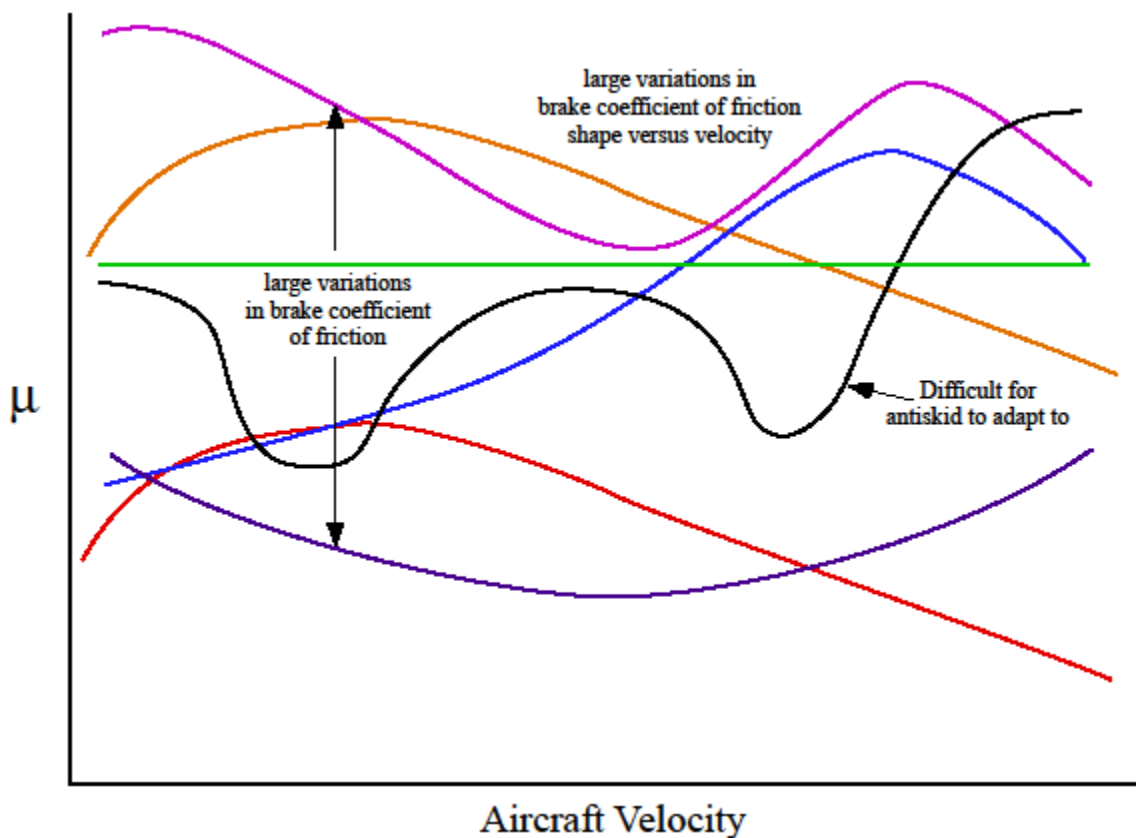


Figure 6 - Brake friction curve variation

Figure 6 shows a variety of brake μ curve shapes. Each of these curves requires antiskid to adapt in quite different ways as the airplane slows down. The flat, green curve is the "ideal." Variations in μ such as those shown in the black line are very difficult for antiskid to adapt to and should be avoided.

If under some conditions brake friction increases throughout a given speed range and, in other conditions, brake friction decreases throughout that same speed range, antiskid has to be tuned for both possibilities. The compromise may result in a reduction in overall stopping performance.