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757/767 Brake and Antiskid System

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Abstract

This paper presents an overview of the 757/767 airplane brake and antiskid system design and focuses on its operation under adverse operating conditions. First, the paper presents some basic system design objectives and provides a general system design description. Then several key features that enhance its operation under adverse conditions are discussed, briefly describing their implementation and showing their significance to the pilot. Finally, the extensive antiskid/autobrake fault monitoring and BITE provisions are described. The 757/767 braking system performs at its best when conditions are at their worst.

Design Objectives

Some basic 757/767 brake system design objectives are listed below. Objectives such as simplicity, light weight, low cost, high reliability, etc., are not listed since these objectives are inherent in any aircraft system design. Rather, the objectives listed below are major objectives that are specific to the braking system.

- Maximum commonality between 757 and 767.
- Simple crew interface and procedures.
- Instinctive reaction is the correct procedure. For any normal, adverse, or failure condition the pilot only needs to apply the brake pedals.
- Tolerant of varied pilot techniques, such as less-than-full pedal application, pedal pumping, or brake application before touchdown or during hydroplaning.
- Maximum system redundancy, including two active and one passive hydraulic sources for braking, automatic hydraulic source selection, and antiskid protection in all modes.
- No antiskid ON/OFF switch required.
- Highly effective braking on all runway conditions, especially slippery runways.
- High brake energy capacity, and long-life wheels, brakes, and tires.
- Smooth automatic braking system, with five landing settings and a throttle-cut rejected takeoff (RTO) mode.
- Brake temperature monitor system and taxi speed indicator available.

Figure 1. 767 Touching Down After It's Maiden Flight

- Comprehensive fault monitor and built-in test equipment (BITE) capability, which is easily operated and isolates faults to the exact line replaceable unit (LRU).
- Maximum inoperative dispatch capability.

Since all these objectives are achieved, this list highlights many important characteristics of the 757 and 767 braking systems.

System Design Description

The 757 and 767 airplane brake and antiskid systems incorporate high commonality of design. Both the 757 and 767 are supported on the ground on two main landing gear struts and a nose gear strut (see fig. 1). The main landing gear are dual-tandem trucks, four wheels per truck. The nose gear is a single strut with dual wheels. Each of the eight main gear wheels is provided with a hydraulically actuated, multiple-disc brake. The nose gear wheels are unbraked.

Separate NORMAL and ALTERNATE brake hydraulic systems and an accumulator in the NORMAL system provide active and passive sources for brake hydraulic power (see fig. 2).

The NORMAL brake system is powered from the aircraft's RIGHT hydraulic system. The ALTERNATE system is powered from the LEFT hydraulic system on the 757 and the CENTER hydraulic system on the 767. Selection of the ALTERNATE system is automatic upon loss of RIGHT system pressure. An accumulator in the NORMAL system provides pressure for the parking brake and is automatically selected following loss of all other active sources to provide sufficient hydraulic power to complete a braking stop with antiskid protection. (A "Reserve" hydraulic power source is also available for the NORMAL brake system on the 757 and the ALTERNATE brake system on the 767. The Reserve source may be selected at the pilot's option to isolate certain hydraulic system failures remote from the brake system and repower the respective hydraulic system to the brakes.)

The NORMAL and ALTERNATE brake hydraulic systems are provided with separate brake metering valves, antiskid valves, and hydraulic fuses. The NORMAL and ALTERNATE brake lines join in the shuttle valve module, downstream of the fuses. Common brake lines (one for each wheel) continue from there to the brakes.

Manual brake application is controlled by left and right metering valves located in the main gear wheelwells (see fig. 4). The metering valves are operated, through cables and linkages, from toe pedals integral to the rudder pedal assembly. Differential control of the left and right brakes is available to both the captain and first officer. The parking brake is set by latching the brake pedals in the depressed position.

Automatic brake application on landing and RTO is available through the autobrake system (see fig. 3). The landing autobrake system controls brake pressure to maintain aircraft deceleration at one of the five selected values, provided that sufficient runway friction is available to maintain this level. The RTO autobrake system applies full braking upon cutting both throttles above 85 knots.

The antiskid and autobrake systems are controlled by microprocessor-based computer subsystems (see fig 5). Four identical subsystems each provide antiskid control for a pair of wheels. A fifth subsystem provides autobrake control, and a sixth provides monitor functions for antiskid, autobrake, and BITE for maintenance purposes. All six subsystems are separately powered.

Gear retract braking (to stop the main gear wheels from spinning prior to entering the wheelwell after takeoff) is accomplished by supplying pressurized fluid to the ALTERNATE brake metering valves from the gear-up line and actuating these metering valves with small actuators also pressurized from the gear-up line.

Flight deck controls and indication include captain's and first officer's brake pedals, antiskid advisory indication, a landing/RTO autobrake selector switch and advisory indication, parking brake latch and indication, brake accumulator pressure gauge, and brake source low pressure indication. Advisory indications are repeated on the Engine Indication and Crew Alerting System (EICAS) operational display. An optional brake temperature

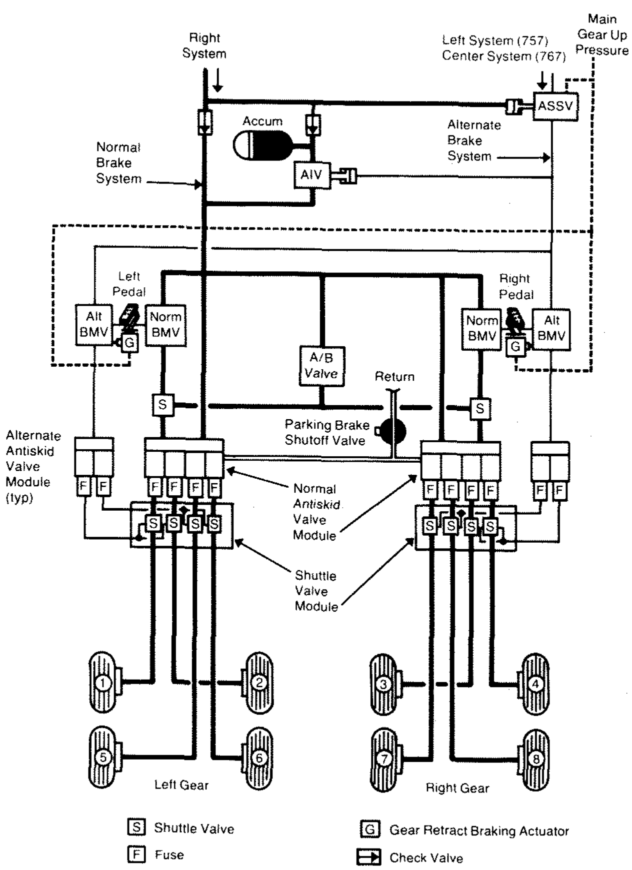

Figure 2. Brake Hydraulic System

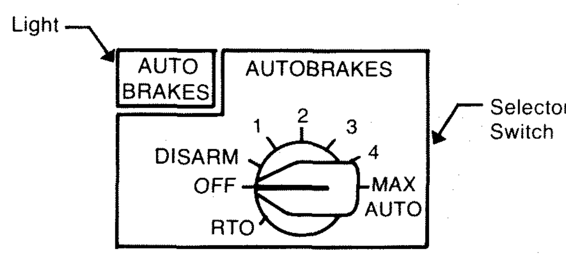

Figure 3. Autobrake Selector Switch

monitor system is available in which each of the eight brake temperatures are displayed on the EICAS status display; if any temperature is above a preset limit, a discrete brake temperature light also illuminates. Other optional controls and indications include an antiskid ON/ OFF switch and a taxi speed indicator. Brake cooling fans are installed on some 767 aircraft. The fans are controlled automatically by the brake temperature monitor system and do not require additional flight deck controls or indication.

Adverse Operating Conditions

Of primary importance in the design of the 757/767 braking system was to make it perform at its best when conditions are at their worst. For example: You are the pilot. It's been a long flight and you're tired. It's nighttime and you're preparing for landing. The winds are gusty. There's a driving rain storm – maybe even mixed with snow. The runway is relatively short and ungrooved. You just want to get this landing over with.

This is a good test of the braking system, both in terms of its performance and the ease with which the pilot may obtain that performance. The following discusses a number of key features of the 757/767 braking system that help the pilot in just these sorts of adverse operating conditions.

Autobrakes

The autobrake system can be of tremendous value to pilots under adverse landing conditions. Long before landing, the pilot can select an airplane deceleration level to be achieved by the brakes (see fig. 3). Five levels are selectable on the 757 and 767. That's all. The autobrake system does the rest. As soon as the main gears touch down, the autobrake system will automatically and smoothly apply the brakes to achieve the selected airplane deceleration level. The pilot is free to concentrate on his many other concerns such as making a smooth landing, setting down the nose, applying reverse thrust (when armed, autospeedbrakes deploy automatically on main gear touchdown), and guiding the airplane to a smooth, safe stop.

On slippery runways, where the tire-to-ground friction is not sufficient to achieve the selected deceleration level, the antiskid system takes over control of the brakes and achieves the maximum braking possible under the conditions. When a taxi speed is reached, the pilot may typically take over pedal braking by simply applying the brake pedals or by lowering the speedbrakes. (Speedbrake deployment is not required for autobrakes to apply, but later lowering the speedbrakes on the ground will release the autobrakes.)

Autobrakes are also available for RTO. The pilot may arm RTO autobrakes any time prior to takeoff. The airplane may be taxied with RTO autobrakes armed, as this will have no effect on the system. During normal takeoffs the system will remain armed until the main gears lift off, then automatically shut off. If an RTO is conducted early in the takeoff roll (below 85 knots groundspeed), the RTO autobrakes will remain armed but will not apply, allowing the pilot to smoothly bring the airplane to rest. However if, above 85 knots, the pilot brings both thrust levers to idle, the RTO autobrakes will immediately and automatically apply full braking to stop the aircraft in the shortest possible distance.

The autobrake system was pioneered on the 737 aircraft. Autobrakes represent a major advancement in landing and takeoff safety and have achieved wide and enthusiastic acceptance in the commercial airplane industry – particularly from the pilots.

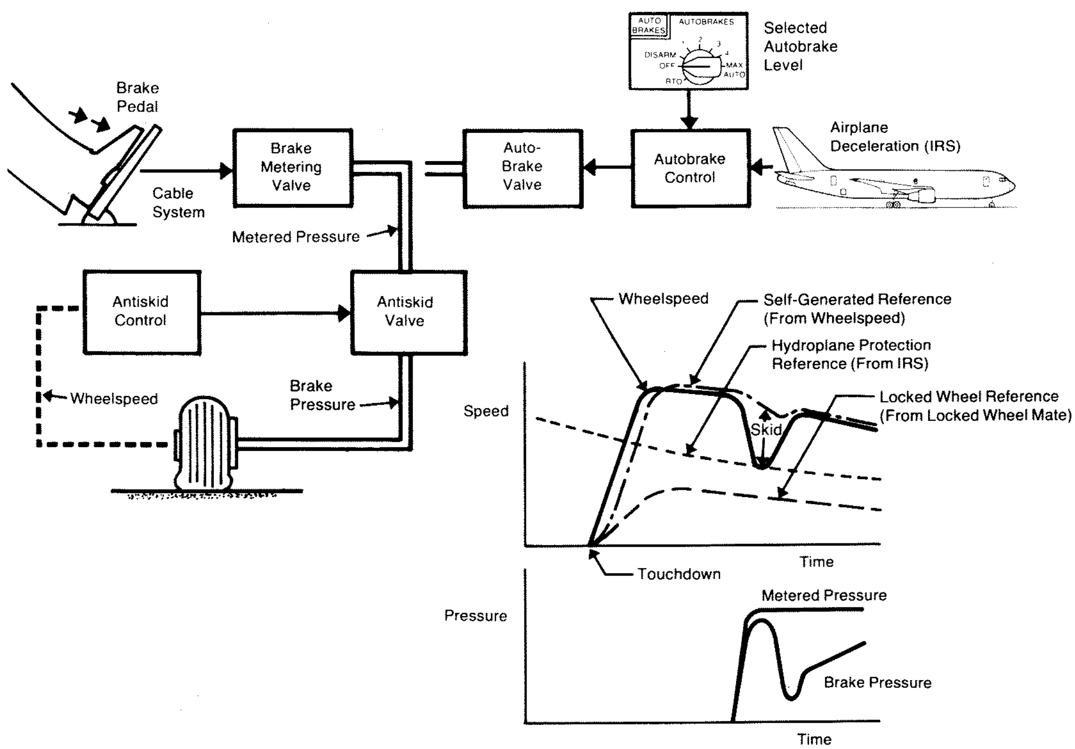

Figure 4. Antiskid Control Schematic

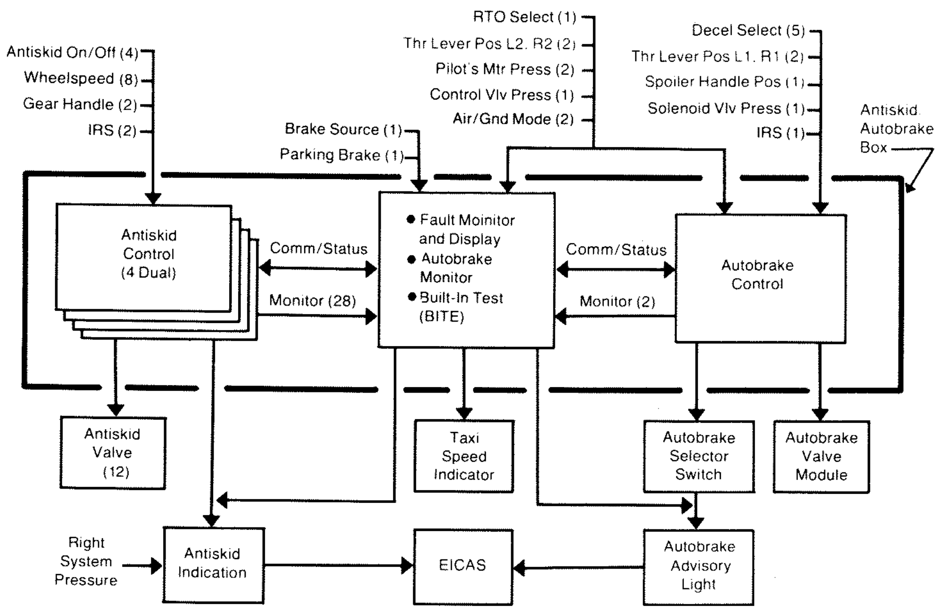

Figure 5. Antiskid/Autobrake Functional Breakdown

Digital Antiskid

About 95 percent of the time pilots do not need antiskid at all. The runway is dry and long, and he does not apply brakes anywhere near hard enough to skid the tires. However, the other 5 percent of the time when the runway is slippery and short, the ability of the antiskid to maximize braking effectiveness is suddenly very important.

Prior "analog" antiskid systems, although they have evolved to perform well under such conditions, are inherently limited relative to achieving further improvements. The 757 and 767 incorporate a new technology "digital" antiskid system (see fig. 4 and 5).

The advantages of the digital system are many, but one of its more significant advantages is that it works very well on slippery runways. This is because the digital system can incorporate much more sophisticated control laws, can control the brake pressure more precisely, and is inherently more reliable.

During the basic 757 and 767 flight test programs, several opportunities arose for the test pilots to evaluate the digital antiskid system on slippery runways. In one case the 767 system was even "flown" on an extremely slippery, icy runway. The system demonstrated convincingly that the digital antiskid system provides an important safety feature on slippery runways. The advantages of digital antiskid relative to airplane maintenance are also very significant and are discussed later in this paper.

Unigain Antiskid Valves

Prior antiskid systems typically achieve optimum brake control only when the pilot applies and holds full pedal braking. Applying any less braking, or allowing the pedal force to fluctuate, can seriously degrade braking even if the metered pressure is sufficient to skid the tires. The reason is that both the control and metering stage of the antiskid valves are hydraulically powered by the pilot's (or autobrake) metered pressure. Powering the metering stage with metered pressure is no problem, but powering the control stage with metered pressure creates two problems; it allows the level of metered pressure to affect the antiskid "tuning" and it allows fluctuations in metered pressure to create false inputs to the antiskid system which disturb antiskid control. The result is reduced braking effectiveness.

Past antiskid systems have dealt with this problem by optimizing the system at full metered pressure and then advising the pilots to apply and hold full pressure to achieve optimum performance. This is easier said than done. Flight simulator studies show that, even in critical situations, pilots may apply neither full nor steady brake pedal force. As a result, optimum braking performance may not be achieved and, in many cases, the loss in performance can be significant.

To solve this problem the 757 and 767 incorporate unigain antiskid valves. Unigain valves insure that, whenever the pilot is metering sufficient pressure to skid the tires, the antiskid system will achieve maximum braking effectiveness. This is true even if the pilot does not fully apply the pedals or if he does not hold the pedals steady.

Unigain antiskid valves are implemented simply by applying full system pressure, rather than metered pressure, to the control stage of the valve whenever any pilot's (or autobrake) metered pressure exists (see fig. 6). The antiskid valve itself is unchanged and the valve's metering stage is still powered by the metered pressure. A simple shutoff valve (one for each side of the aircraft) is installed in the antiskid valve module to port full system pressure to the antiskid valve control stages whenever the metered pressure is sufficient to apply the brakes.

The unigain valve feature greatly helps the pilot during slippery runway stops by making it far easier for him to maximize the braking effectiveness. No longer must the pilot apply full pedal braking to achieve optimum antiskid performance. All he has to do is push the pedals hard enough to skid the tires.

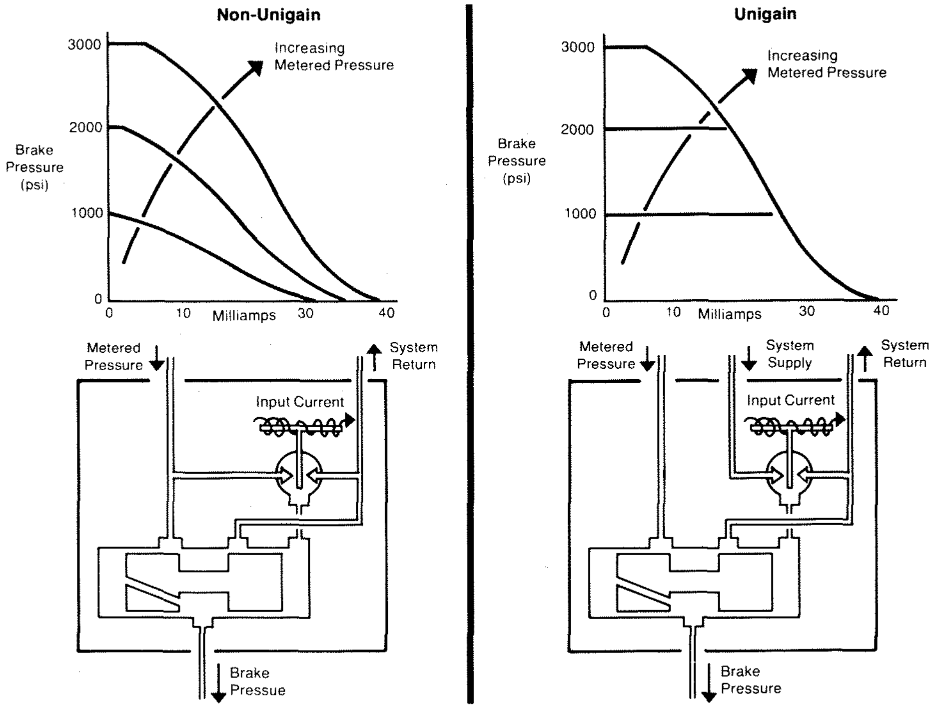

Figure 6. Non-Unigain Vs Unigain Antiskid Valves

Hydroplane Protection

During severe tire hydroplaning tire-to-ground friction can become so low that, even without the brakes applied, the wheels stop spinning. This can cause the antiskid system to get "lost" such that after the hydroplaning ceases the antiskid still keeps the wheels locked. All braking and cornering from the tires is virtually lost. The only solution is for the pilot to release the brakes to allow the wheels to spin up.

In reality, the exposure to this occurring is extremely small. But it causes the pilot a significant problem nonetheless. This is because the pilot, knowing that the potential problem exists, may be reluctant to ever apply the brakes on slippery runways or he may periodically release the brakes during the stop to allow any potentially locked wheels to spin up.

The 757 and 767 incorporate a hydroplane protection feature to solve this problem. Hydroplane protection insures that the antiskid system cannot get "lost." With hydroplane protection, the pilot need not be reluctant to apply the brakes at any time (before touchdown, during severe hydroplaning, etc.) and to keep them applied. To explain how and why hydroplane protection works, a brief explanation of how antiskid works may be helpful.

Antiskid systems sense wheelspeed and compare it to a "reference" to determine if a skid is present (see fig. 4). The "reference" represents what the wheelspeed **should be** if no skid were present. Therefore it should approximately equal the airplane's groundspeed. When the wheelspeed drops below the reference, a skid is detected and the brake is released. The reference is crucial since, without it, the antiskid has no way of knowing whether or not to release the brakes. For example, if the wheelspeed is zero when the airplane is travelling 100 knots (reference $\approx$ 100 knots), then a skid is definitely present and the antiskid should release the brake. However, if the wheelspeed is zero when the airplane is stopped (reference $\approx$ 0 knots), then there is no skid and the antiskid must not release the brake.

Most antiskid systems generate their "reference" from the actual wheelspeed itself. The reference is initially established when the wheels spin up at touchdown and is then continuously updated during the stop each time the wheels recover from a skid. Antiskid systems also use speed signals from other wheels (either braked wheels or nose wheels) for additional references, such as for "locked wheel" protection. In any event, the antiskid system cannot function without a reference.

For the most part, the wheelspeed signals themselves provide an excellent reference. However, there are two cases where they do not. One is when brakes are applied before touchdown and the other is when brakes are applied during severe tire hydroplaning. In both cases there is no reference, because none of the wheels are spun up. So the antiskid is "lost" and the wheels remain locked up until the pilot releases his pedals. The touchdown case is solved in prior antiskid systems by monitoring the squat switches for a "reference," such that air mode tells the antiskid system that the airplane speed is high. But this does not solve the hydroplaning case.

The 757 and 767 incorporate a hydroplane protection feature to solve this problem. Redundant airplane groundspeed signals from the airplane's inertial reference system (IRS) are sent to the aft main gear wheels on the airplane (see fig. 7). This provides the aft wheels with a "direct" reference so that when the hydroplaning stops, the wheels spin up and resume optimum braking control. Then, when the aft wheels spin up, their wheelspeeds provide an "indirect" reference for the forward wheels through the locked wheel protection feature. This allows the forward wheels to spin up and also resume optimum brake control. The airplane speed reference is sent to only the aft wheels to prevent the possibility of a multiple IRS failure from releasing all the brakes. The aft wheels are selected for the "direct" reference since, during

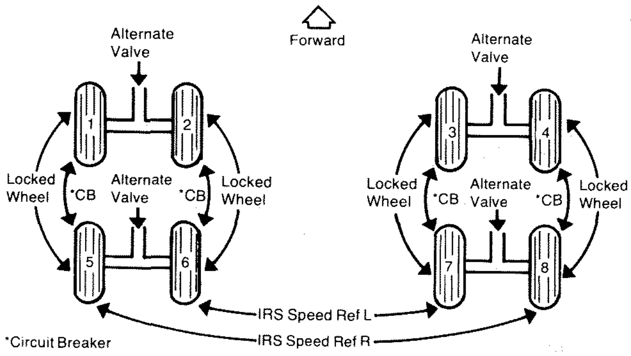

Figure 7. Locked Wheel Paring and Hydroplane Protection

hydroplaning, the forward wheels clear a path for the aft wheels causing the aft wheels to come out of hydroplaning first. Since the hydroplaning protection feature works equally well for brake applications prior to touchdown, the squat switch signals for touchdown protection are no longer used. In fact, the 757 and 767 actually refer to this feature as "touchdown/hydroplane protection." (Flight tests run with brakes applied before touchdown prove that, although the forward wheels are only "indirectly" protected, they spin up virtually as quickly as if they had received "direct" protection.)

This hydroplane protection feature, simple as it may seem, is believed to be new to aircraft antiskid systems. Hydroplane protection is considered to be a significant advancement to airplane safety not only because it will greatly improve antiskid control during severe hydroplaning situations (which are quite rare) but, more importantly, because it will relieve pilot's reluctance to apply brakes during all wet runway landings.

Automatic Hydraulic Power Source Switching

Prior brake systems have required the pilot to use special, noninstinctive procedures to retain braking capability in the event certain system failures occur. These special procedures are usually necessitated by loss of the primary brake hydraulic power source and include such actions as "manually" selecting an alternate source (i.e., throwing a special switch) or applying brakes with a special handle. These backup braking modes often do not include antiskid protection. This is highly undesirable from a pilot's standpoint, as these procedures are not instinctive and they complicate the pilot's job when coping with adverse operating conditions. The problem is not entirely solved by improving the reliability of the hydraulic power systems, because the more reliable the system, the more unprepared the pilot may be to cope with its loss.

The 757/767 brake system was designed to insure that, for any normal, adverse, or failure condition, the pilot need only apply the brake pedals. In addition, antiskid protection is provided on all brake hydraulic power sources. A key element to achieving this goal is the automatic hydraulic power source switching for the brake system.

The design of the system consists basically of two simple shuttle valves and two check valves (see fig. 8). Upon loss of RIGHT hydraulic system pressure the alternate source selector valve shuttles to pressurize the ALTERNATE brake system. When the ALTERNATE brake system is pressurized, the accumulator isolation valve (which is physically identical to the alternate source selector valve) shuttles to preserve the brake accumulator. If the ALTERNATE brake system is also lost, then the accumulator isolation valve shuttles to power the NORMAL brake system with the accumulator. Antiskid protection is preserved in all cases, and the accumulator is

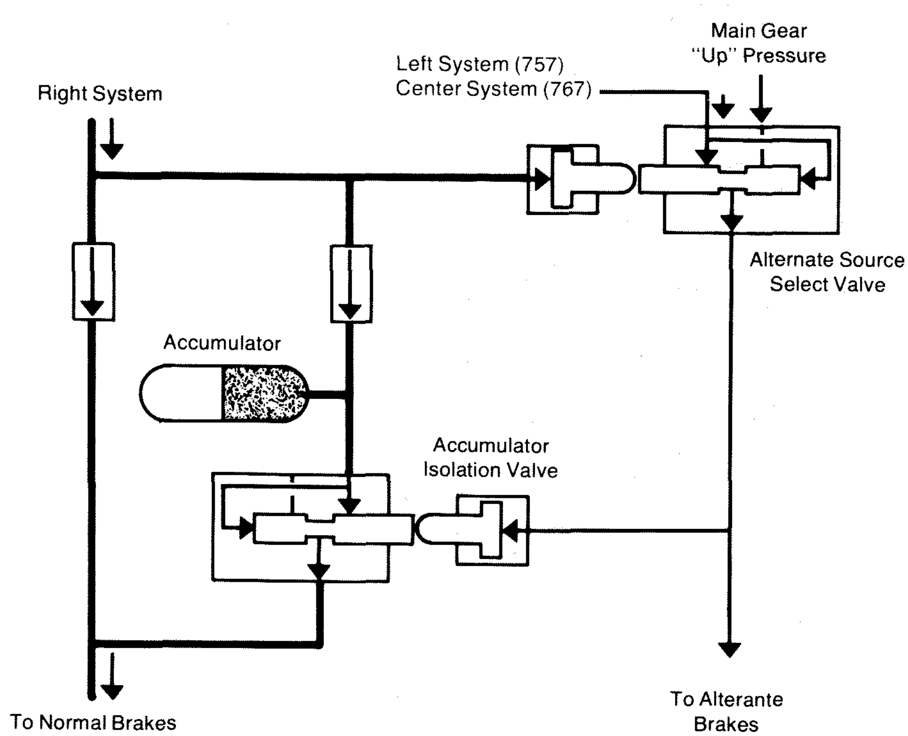

Figure 8. Automatic Hydraulic Power Source Switching

sized to complete a full braking stop with antiskid on. This design is extremely simple, reliable, and fully hydraulic – no electronics. The system always prioritizes selection of the brake hydraulic sources so that the NORMAL source is first priority, ALTERNATE is second, and the accumulator is last priority no matter in what order the systems are lost or regained.

So, when a hydraulic system failure occurs, the pilot need not use any special or unnatural procedures for the brake system. He need just step on the brake pedals as usual. Even antiskid protection is retained. The pilot may then concentrate on other consequences of losing the hydraulic system.

Fault Monitoring and Built-In Test Equipment (BITE)

Up to now, this paper has focused on 757/767 brake system features that are important to the pilot. However, the system also incorporates a new, key feature which is very important to airplane operations and maintenance people – the antiskid/autobrake box fault monitoring and built-in test equipment (BITE) capability.

Since the 757/767 antiskid and autobrake systems are microprocessor based, they lend themselves well to fault monitoring and BITE. The 757 and 767 programs, recognizing the importance of this to the airlines, devoted considerable effort to realizing this potential of the system. The result is a new, interactive, computerized troubleshooting system, operable from a single position by a single person, that continuously monitors and tests the electrical integrity of the entire antiskid and autobrake systems (see fig. 9). The system includes an 8-digit alphanumeric display with a library of 70 messages to quickly and accurately isolate problems down to the individual LRU and to actually aid the operator in running a test. No other antiskid or autobrake system has anything like it.

Fault Monitoring. Whenever powered, the antiskid and autobrake systems are continuously and completely monitored by a separate computer in the antiskid/autobrake box. Problems are detected and isolated down to the LRU level. These self-tests completely check the electrical integrity of the system, including power checks, transducer and valve impedance checks, and a multitude of box self-tests, as well as whatever additional checks are possible on other hydraulic and mechanical elements of the system. All faults that are detected are stored in the nonvolatile memory. (Certain faults, of course, will also illuminate the pilot's antiskid or autobrake annunciators.) The system will also detect and store intermittent faults down to the LRU level; this feature alone is of great value in quickly and easily solving problems that might otherwise be extremely difficult and time consuming to solve. Whenever a fault is stored in memory, a message appears on the "maintenance page" of EICAS, telling the maintenance crew to check the box. By pressing a single toggle switch on the box the display will then tell him the exact LRU(s) that malfunctioned. After fixing the fault he can press a guarded reset button on the box to clear the nonvolatile memory for continued fault storage. It's that quick and easy!

BITE. A complete electrical integrity test of the antiskid/autobrake system down to the LRU level can be performed by a single operator at the box using just two buttons. A rotary selector switch can be used to conduct additional hydraulic and mechanical checks on the autobrake system and on each individual antiskid control

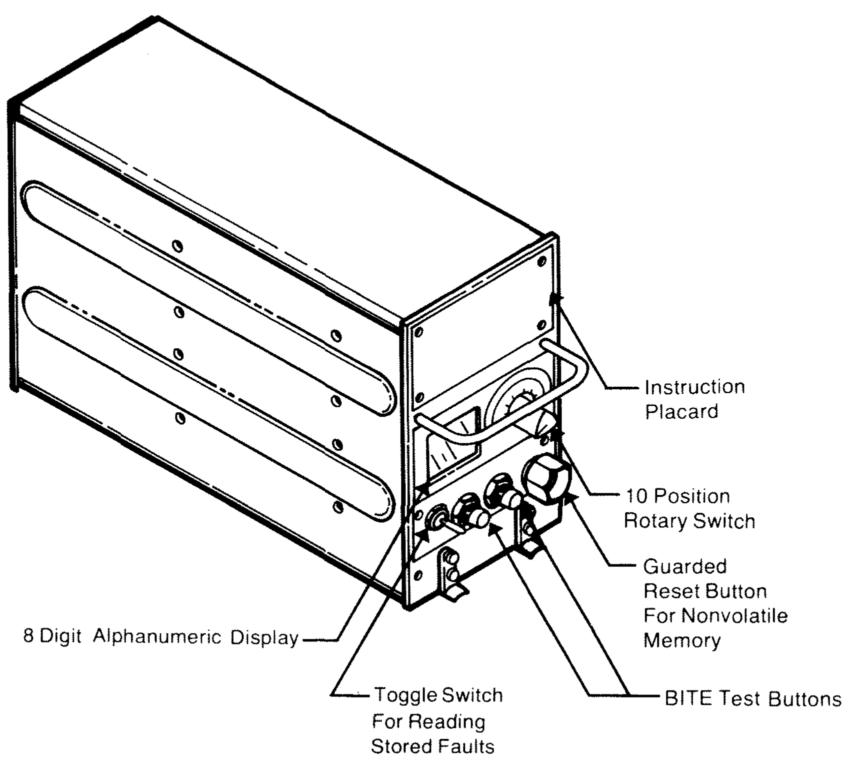

Figure 9. Antiskid/Autobrake Box Front Panel

channel. The box even tells the operator the airplane configuration for the test, such as each thrust lever position, each metered brake pressure high/low status, inertial reference system status, etc. This immediately tells the operator if the airplane is not correctly configured for the subsequent tests, and, if so, exactly why.

So, the fault monitor and BITE feature allows a single operator from a single position, to simply, comprehensively, and quickly test the electrical integrity of the entire system, isolate faults to the exact LRU level, and confirm the system integrity after repairs. This feature is particularly important since antiskid/autobrake systems are inherently (and historically) very difficult to troubleshoot and test. The 757/767 antiskid/autobrake fault monitoring and BITE feature sets a major new standard for rapid, accurate antiskid/autobrake system maintenance.

Conclusions

The 757/767 brake system incorporates many features, such as autobrakes, digital antiskid, unigain antiskid valves, hydroplane protection, and automatic hydraulic power source switching to maximize braking effectiveness and simplify the pilot's procedures under adverse operating conditions. The system also incorporates a fault monitoring and BITE feature that sets a major new standard for rapid, accurate antiskid/autobrake system maintenance. The 757/767 braking system performs at its best when conditions are at their worst.