NATIONAL TRANSPORTATION SAFETY BOARD
OFFICE OF AVIATION SAFETY
WASHINGTON, D.C. 20594

07-28-2011

SYSTEMS GROUP CHAIRMAN'S FACTUAL REPORT

NTSB ID No.: DCA11IA047

A. ACCIDENT:

Location:	Chicago, Illinois
Date:	April 26, 2011
Time:	About 1333 Central Daylight Time (CDT)
Aircraft:	Boeing 737-700
Registration Number:	N799SW

B. SYSTEMS GROUP:

Chairman:	Mike Hauf National Transportation Safety Board Washington, D.C.
Member:	Chris Dubuque Boeing Aircraft Company
Member:	A. Tom Stephens Boeing Aircraft Company
Member:	Bob Sprague Southwest Airlines
Member:	Rick Giacomello Southwest Airlines

C. SUMMARY:

On April 26, 2011 at 1:33pm central daylight time (CDT), a Boeing 737-700, U.S. registration N799SW, operated by Southwest Airlines as flight 1919, departed the left side of runway 13C after landing at Chicago Midway International Airport, Chicago, Illinois (MDW). Weather was reported as rain, with southerly winds of approximately 20 knots. There was minor damage to the airplane due to the right hand engine ingesting a taxiway light during the excursion. There were no injuries to the 2 flight crew, 3 cabin crew, and 139 passengers which included 5 lap-held children. Witness marks on the runway indicated the airplane touched down about 450 feet from the displaced arrival threshold. Runway conditions were reported as "wet and fair [braking]" by a preceding arrival.

D. DETAILS OF THE INVESTIGATION:

D.1 Air/Ground System:

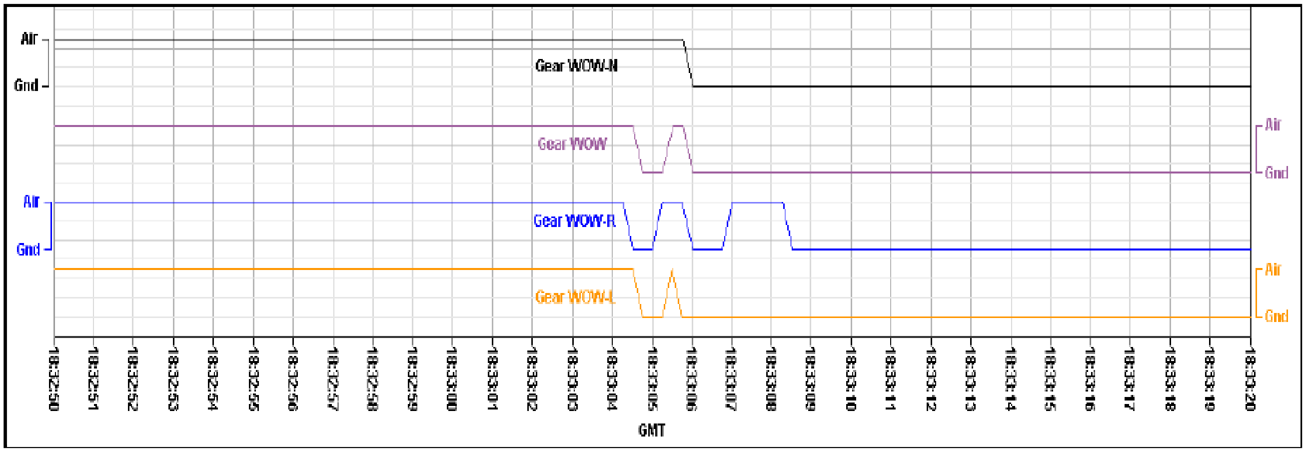
The air/ground sensing system provides two independent sources (system 1 and system 2) of air/ground information to various airplane systems including the auto speedbrake control system, thrust reversers and the autobrake control systems. The air/ground sensing system comprises multiple air/ground relays, a proximity switch electronic unit (PSEU), and proximity sensors located on each landing gear assembly. The PSEU converts signals from the proximity sensors to energize or de-energize the air/ground system relays. The PSEU also provides fault indication and maintenance built-in-test equipment (BITE).

Each landing gear contains two proximity sensors, installed on the shock strut, that detect when the landing gear is compressed: one sensor sends inputs to air/ground system 1 and the other sensor sends inputs to air/ground system 2. Each sensor has a metal target and a sensor. The targets move near the sensors when the main and nose landing gear shock strut compresses when the airplane is on the ground. When the target is outside of the sensing range, the status of the sensor is set to target “far”.

A review of the flight data recorder (FDR) data revealed that there were four air/ground weight-on-wheel (WOW) parameters recorded for the incident landing:
1) “Gear WOW L”: Left main landing gear (MLG),
2) “Gear WOW R”: Right MLG,
3) “Gear WOW N”: Nose landing gear (NLG),
4) “Gear WOW”: Air/ground signal that is provided to the airplane systems.

Upon touchdown (about 18:33:05 GMT), the air/ground system indicated that both MLG transitioned from “air” to “ground” for approximately one second, then transitioned briefly back to “air” and then back to “ground” a second time. Refer to figure 1. The nose gear then transitioned from “air” to “on ground” where it remained for the landing rollout. At about 18:33:07 GMT, the right MLG transitioned to “air” and then back to “ground” one additional time.

Figure 1 Air/Ground position data from the incident landing



A review of the Southwest Airline's maintenance records revealed that between February 2, 2011 and April 26, 2011, the airplane had no non-routine write-ups for the air/ground control system.

D.2 Auto Speedbrake Control System:

The auto-speedbrake control system is designed to automatically drive the speedbrake lever to its full "up" position (48 degrees) to deploy all of the spoilers (there are four flight spoilers and two ground spoilers on each wing) upon landing.

There are two methods in which the system can automatically drive the speedbrake lever to its full up position. The first method requires the pilot to raise the speedbrake lever out of its down and locked detent (0 degrees) and move it aft to its "armed" detent (4 degrees) before landing. Upon touchdown[1], the auto-speedbrake system will automatically drive the speedbrake lever from its "armed" detent to its full "up" position to deploy all of the spoilers. The second method was designed to deploy the auto speedbrake system from the speedbrake lever in the DOWN detent when either of the reverse thrust levers is moved to or past the "idle reverse" position. Movement of either reverse thrust lever results in the following two actions: 1) the speedbrake lever is automatically lifted up out of its down detent and, 2) the "refused takeoff" switch (S650) is closed (activated to "reverse"). When closed, the switch bypasses the auto-speedbrake arming switch (S276) to complete the circuit to enable the auto-speedbrake actuator to extend

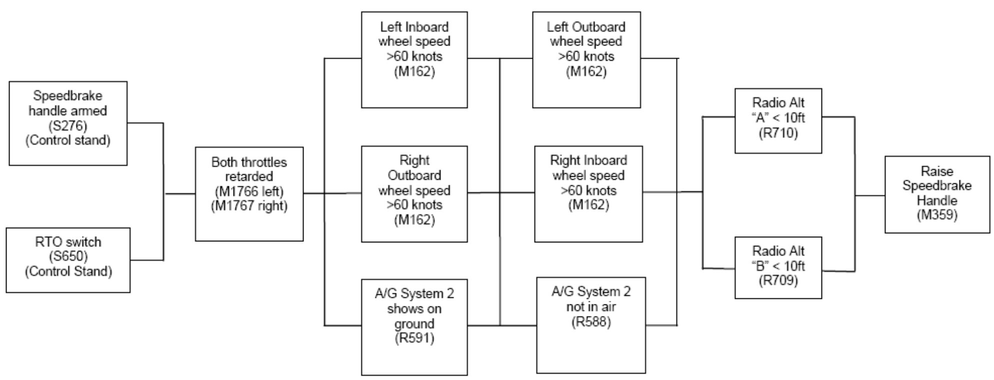
When the speedbrake lever is in its "armed" detent or beyond, the speedbrake "armed" light will illuminate if all of the arming requirements are met. This light provides the crew with a visual indication that the automatic operation of the speedbrake system has armed correctly. This will occur when the speedbrake lever is in the "armed" detent or <u>either</u> thrust lever is in reverse, and all of the following conditions are satisfied: 1) One or more

[1] For auto speedbrake deployment, touchdown is defined as the point in time in which the air/ground system indicates an "on-ground" signal or if wheel speed is greater than 60 knots. This occurs when any two of the four MLG proximity sensors indicate ground.

antiskid channel is functional, 2) the auto speedbrake actuator is in the fully retracted position, and 3) there is not a disagreement with the wheel speeds and the air/ground signals. Upon touchdown, the auto-speedbrake system will automatically drive the speedbrake lever from its "armed" position to its full "up" position to deploy all of the spoilers (two ground spoilers and four flight spoilers on each wing) when all of the following conditions occur. Refer to Figure 2.

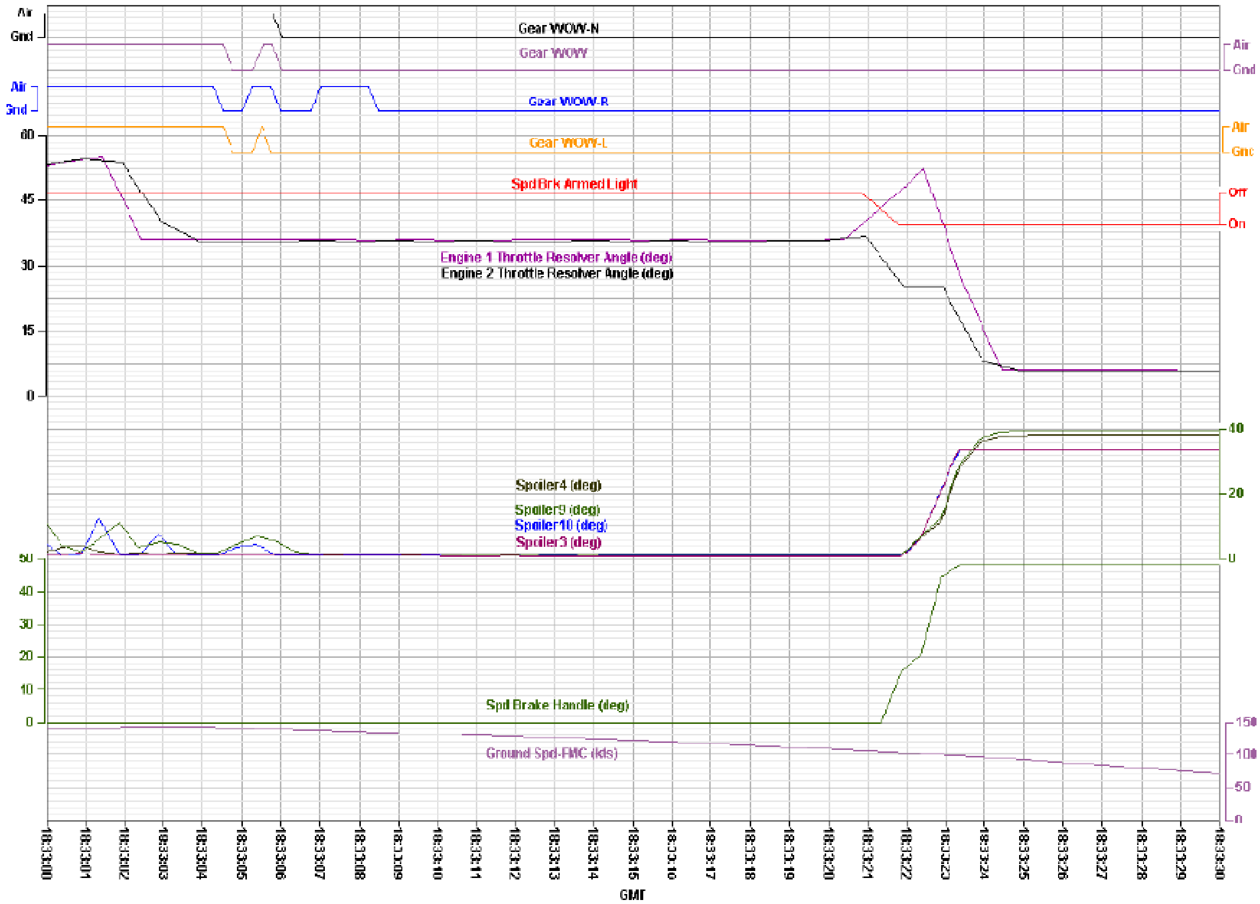
1. The speedbrake lever is in the armed position **<u>or</u>** speedbrake RTO switch is closed.
   <u>AND</u>
2. Both throttles are retarded (less than 44 degrees of throttle resolver angle TRA).
   <u>AND</u>
3. Right outboard wheel speed is >60 knots **<u>or</u>** left inboard wheel speed is >60 knots **<u>or</u>** air/ground system 2 provides an "on-ground signal".
   <u>AND</u>
4. Right inboard wheel is >60 knots **<u>or</u>** left outboard wheel is >60 knots **<u>or</u>** air/ground system 2 provides a "not in air" signal.
   <u>AND</u>
5. Either Radio altitude system "A" **<u>or</u>** system "B" indicates less than 10 feet.

Figure 2 737-800 speedbrake logic



A review of the FDR data revealed that just prior to touchdown, about 18:33:04 GMT, the speedbrake lever remained at zero degrees (not armed) and the speedbrake "armed" light was not illuminated. The speedbrake lever remained in its down position upon touchdown, about 18:33:05 GMT, and for the first sixteen seconds of the landing rollout. The data also indicates that the ground spoilers did not deploy until approximately seventeen seconds after touchdown. During this time, the thrust levers were at their forward idle position of 36 deg TRA.

Figure 3 FDR data for the event landing



The data indicates that between fifteen and twenty seconds after touchdown, the thrust levers and the reverse thrust levers were positioned in a way that satisfied the logic to command the speedbrakes to be automatically deployed.

1. Time = 15 – 16 seconds after touchdown:
   a. The value for the left TRA increased from its flight idle position up to a value slightly less than 44 degrees TRA indicating that this thrust lever had moved forward of its forward idle position.
   b. The value for the right TRA began decreasing from 36 degrees to 24 degree TRA indicating that this thrust lever remained in forward idle and its reverse lever had been moved towards idle reverse.
   c. The speedbrake lever began to deploy, the speedbrake "armed" light illuminated, and the ground spoilers began to deploy.

2. Time = 16 – 18 seconds after touchdown:
   a. The value for the left TRA increased from a value of about 44 degrees TRA up to a value slightly greater than 50 degrees TRA.
   b. The value for the right TRA decreased to and remained at 24 degree TRA indicating that this thrust lever remained in forward idle and its reverse lever was in its idle reverse position.

c. The data indicates that during the speedbrake lever extension, the rate of the lever movement decreased, at a lever position of about 20 degrees. According to the speedbrake system logic, if the value for any TRA exceeds 44 degrees, the auto speedbrake system will command the auto speedbrake actuator to retract (providing it was not fully retracted).

3. Time = 18 – 20 seconds after touchdown:
   a. The value for the left TRA decreased from about 50 degrees TRA to a value slightly less than 24 degree TRA.
   b. The value for the right TRA began decreasing from 24 degrees to 6 degree TRA indicating that this thrust lever remained in forward idle and its reverse lever had been activated towards max reverse.
   c. Approximately nineteen seconds after touchdown, the data indicates that the speedbrake lever was fully extended, the speedbrake "armed" light remained illuminated, and the ground spoilers were fully deployed.

Between twenty-six and twenty-eight seconds after touchdown, with the speedbrake lever fully extended, FDR data indicate that the speedbrake "do not arm" light briefly illuminated and then remained illuminated for about nine seconds, at which time the speedbrake lever moved to its down position. When the light began to illuminate, the data indicates that the airplanes computed airspeed was decreasing from about 50 knots to 45 knots and the ground speed was decreasing from about 65 knots to 50 knots. The speedbrake "do not arm" light illuminates during landing if the wheel speed is <60kts and the speedbrake lever is in the "UP" position. The light will remain on until the speedbrake lever is stowed. This is the normal operation of the speedbrake "do not arm" light and does not indicate a system fault.

Approximately thirty-eight seconds after touchdown, the speedbrake lever moved from its "full-up" position to its down detent and all spoilers transitioned to "full-down". There are two methods in which a speedbrake lever can be moved from its "full-up" position to its down detent after landing. The first way is automatically when either thrust lever is moved to a position greater than 44 degrees TRA and the second way is manually by the flight crew. FDR data indicates that when the speedbrake lever moved to its down detent, the airplanes computed airspeed remained at about 45 knots and the ground speed was decreasing through 5 knots. Additionally, the recorded TRA for both thrust levers indicates that, just prior to the speedbrake lever moving, both thrust levers moved from a position of about 6 degrees TRA (max reverse) to a position of about 36 degrees TRA (forward idle). Both thrust levers remained at this position for the remainder of the flight.

A review of the Southwest Airline's maintenance records revealed that between February 2, 2011 and April 26, 2011, the airplane had no non-routine write-ups for the auto speedbrake control system.

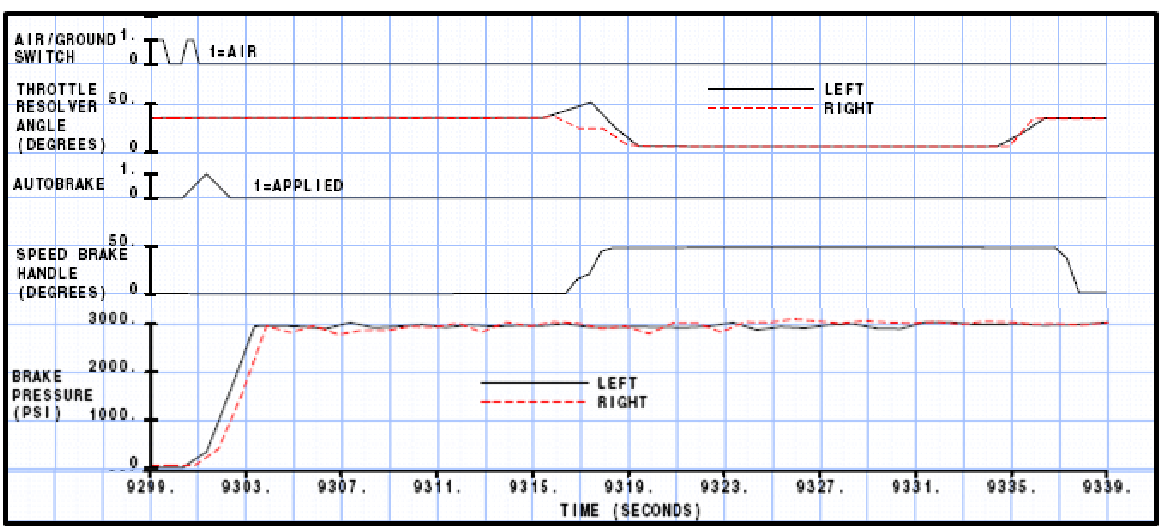
On April 30, 2011, a Southwest Airlines maintenance technician performed the following system tests contained within the Boeing AMM 27-62-00/501, titled "Speed Brake Control System - Adjustment/Test" dated 06 May 2011: "Spoiler Operational Time Test' (task 27-62-00-820-805), “Speed Brake Squat Switch Test” (task 27-62-00-820-808), and the “Speed Brake Control System Operational test’ (task 27-62-00-710-801). Each test was completed with no discrepancies; all systems functioned per the AMM test requirements.

D.3 Autobrake Control System:

The hydraulic brake system is used to provide a means to slow down and/or stop the airplane after landing touchdown and during taxi operations. Brakes installed in each of the main landing gear (MLG) wheels are actuated hydraulically by manual brake pedal movement or automatically through the autobrake control system. In the manual mode of operation, the two brakes on the left gear are operated by each pilot’s left pedal(s) and the two brakes on the right gear are operated by each pilot’s right pedal(s). The captain’s and first officer’s brake pedals are joined together by linkage so that braking force will be the combined force applied to the pedals by both pilots. The antiskid system controls the metered brake pressure from the hydraulic brake system or the autobrake pressure from the autobrake system to prevent wheel skid. This gives maximum brake force to stop the airplane in the presence of any runway condition. The autobrake system automatically applies the brakes after landing to slow the airplane at a deceleration rate selected by the pilots before landing.

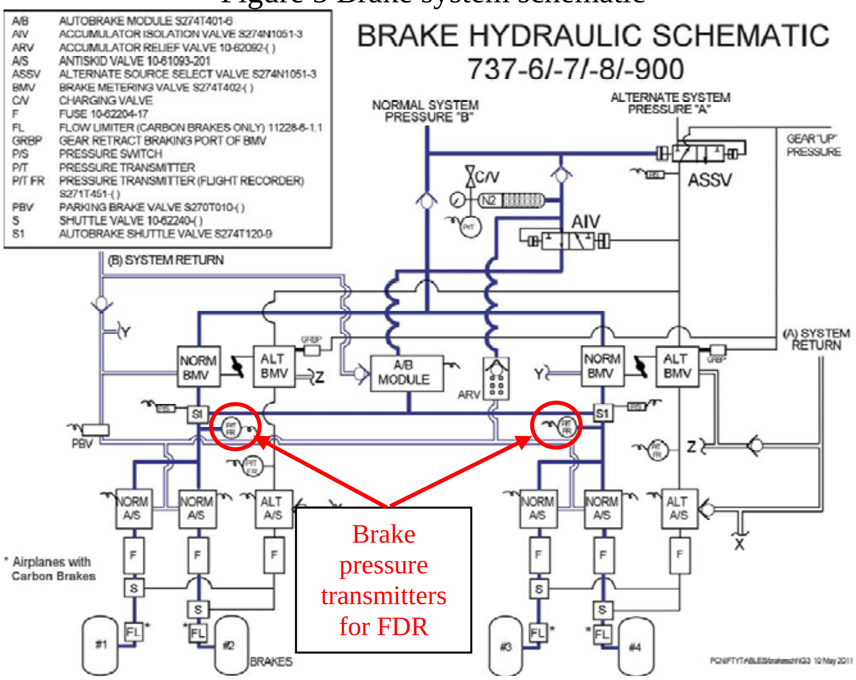
A review of the FDR data revealed that the autobrakes discrete indicated “applied” upon touchdown. Refer to figure 4. The data indicate that the left and right MLG brake pressure also began to increase at this time. After about 1 second, the autobrake discrete indicated “No Auto Brk” while the brake pressure continued to increase (without any fluctuations) up to about 3,000 psi where it remained for the rest of the landing rollout.

Figure 4 Brake pressures upon landing



The autobrake control system comprises an autobrakes selector switch, an autobrake “disarm” light, an antiskid/autobrake control unit (AACU), an autobrake pressure control module and two metered pressure switches (Figure 5). The autobrake selector switch and "disarm" light are located on the center flight compartment instrument panel. The switch is a rotary, six position switch that can be selected to four automatic braking levels (1, 2, 3, and MAX) and one refused takeoff (RTO) mode of automatic braking. When rotated from the off position to an automatic braking level, the switch provides 28 volts direct current (dc) to the AACU. According to the flight crew, the autobrakes had been selected to MAX autobrake[2] for landing.

Figure 5 Brake system schematic



The AACU controls autobrake operation and receives inputs from the following sources: speed brake arming switch, two auto throttle switch packs, two ADIRUs, a proximity sensor control unit (PSEU), autobrake pressure control module (APCM), two autobrake shuttle valves with pressure switches and four wheel speed transducers.

When the autobrake control system applies the brakes, it energizes the valve relay in the AACU. When energized, it sends power to the solenoid valve and control valve on the APCM sending autobrake pressure through the autobrake shuttle valves to the normal brake system. Hydraulic system B supplies pressure to the autobrake pressure control module.

The autobrake control system applies the brakes when all of the following conditions occur:

1. The autobrake control system is armed.
2. All four thrust lever switches show retarded (TRA $\leq$ 44 degrees).

[2] Reference the Operational Group Chairman's factual report for this incident.

3. Either air/ground system provides an "on-ground" signal for 0.2 seconds or longer.
4. At least one wheel on each gear has spun up to 60 knots.

Note: Loss of either of the last two items after pressure has been applied shall cause brake pressure to be removed but not disarmed. Meeting the application logic again will cause the pressure to reapply.

The FDR autobrake discrete monitors the status of the APCM solenoid pressure switch. If this pressure switch reads high, then the AACU sensed that the conditions needed to apply brake pressure were satisfied and started to apply pressure.

A review of the autobrake control system found that the autobrake system will release the autobrakes and disarm the autobrake system when <u>any</u> of these conditions occur:

1. Autobrakes selector switch is selected to the "OFF" or to an invalid switch position. According to the flight crew, they did not select the autobrakes to "OFF" during the landing rollout.

2. Either manual metered brake pressure switch indicates high (>750 psi):

   During autobrake operation, pressure from the APCM is ported simultaneously to two shuttle valves (one for the left brakes and one for the right brakes) and then to their respective brakes. Brake pressure transmitters sense the brake pressure on the output side of each shuttle valve and provide this pressure indication to the FDR. If the brake pedals are depressed during autobrake operation, brake pressure is ported through the normal brake metering valves (one for the left brakes and one for the right brakes) to the shuttle valves. If the normal brake pressure exceeds the autobrake system pressure, the shuttle valve will move to a position that blocks the autobrake system pressure allowing only the normal brake pressure to flow through the valve and to the brakes. The autobrake control system monitors the metered (or normal) brake pressure from pressure switches that are located downstream from the normal brake metering valves. If either of these brake pressure switches read >750 psi, the AACU disarms the autobrake system.

   FDR data indicates that the left brake pressure increased from about 350 to 1,650 psi at the time of the autobrake disengagement. According to the flight crew, they applied the manual brakes almost immediately upon touchdown.

3. Any thrust lever is advanced out of its idle position after the airplane is on the ground for more that 3 seconds (before 3 seconds will cause the brakes to release without disarming the system).

   A review of the FDR data indicates that both thrust levers remained in their forward idle position (TRA = 36 degrees) just prior to landing and for about sixteen seconds after touchdown.

4. The speedbrake lever is moved to the “DOWN” position after having been “armed” via the S276 switch.

   FDR data indicates that the speedbrake lever remained in the “down” position at touchdown and had not been “armed”.

5. Fault in the normal antiskid system of a fault in the autobrake system.

   On April 30, 2011, a Southwest Airlines maintenance technician performed the “Antiskid/Auto Brake Control Unit Functional Test’ (task 32-42-00-720-801) contained within Boeing AMM 32-42-00/501, titled “Antiskid/Auto Brake System-Adjustment/Test” dated February 15, 2011. The tests were completed with no discrepancies; the autobrake system functioned per all AMM test requirements. Maintenance also performed a BITE check on the Antiskid/Autobrake control unit to check for any fault indications. BITE testing indicated an autobrake system fault. Troubleshooting found a discrepant reducer on the right Auto Brake Control Module Valve. Maintenance replaced the Auto Brake Control Module Valve having part number (P/N) 20102060-103 and serial number (S/N) 1122 which cleared the message and the system passed the functional test.

A review of the Southwest Airline’s maintenance records revealed that between February 2, 2011 and April 26, 2011, the airplane had no non-routine write-ups for autobrake control system.

Mike Hauf

Aircraft Systems Engineer