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

09-29-2011

SYSTEMS GROUP CHAIRMAN'S FACTUAL REPORT

NTSB ID No.: DCA11IA015

A. ACCIDENT:

Location:	Jackson Hole Airport (JAC), Jackson Hole, Wyoming
Date:	December 29, 2010
Time:	About 1138 Mountain Standard Time (MST)
Aircraft:	Boeing 757-200
Registration Number:	N668AA
Serial Number:	25333

B. SYSTEMS GROUP:

Chairman:	Mike Hauf National Transportation Safety Board Washington, D.C.
Member:	Doug Hippe Boeing Aircraft Company
Member:	Paul Mackey Allied Pilots Association
Member:	Kenneth Frey Federal Aviation Administration
Member:	Aubrey Fulcher Transport Workers Union of America

C. <u>SUMMARY:</u>

On December 29, 2010, at approximately 11:38 am mountain standard time (MST), American Airlines flight 2253, a Boeing 757-200, registration N668AA, overran runway 19 upon landing at Jackson Hole Airport (JAC), Jackson Hole, Wyoming. The airplane came to rest approximately 730 feet past the runway overrun area in deep snow. There were no injuries to the 179 passengers and 6 crew members on board and the airplane received minor damage. The 14 Code of Federal Regulations Part 121 regularly scheduled passenger flight had originated from Chicago O'Hare International Airport, Chicago, Illinois.

During the period of December 31, 2010 through January 6, 2011, an investigator from the NTSB witnessed and documented testing conducted on the airplane’s air/ground system, auto speedbrake control system, autobrake control system and the thrust reverser system in Jackson Hole, Wyoming. Upon arriving in Jackson Hole on December 31, 2010, the NTSB observed that the airplane had been moved from its final resting position to an area located at the Southeast corner of the airport. Other than the removal and the replacement of the flight data recorder (FDR) and the cockpit voice recorder (CVR), no additional maintenance work had been accomplished on the airplane and it had not been de-iced.

After the NTSB inspections were completed, American Airlines re-located the airplane to their maintenance facility based at the Tulsa, Oklahoma International Airport to complete additional maintenance inspections. The airplane was then put back into revenue service.

On March 31, 2011, American Airlines reported to the NTSB that the incident airplane experienced an auto speedbrake system failure upon touchdown at the San Francisco (SFO) international airport. According to American Airlines, the auto speedbrake system failed to automatically deploy the speedbrake lever upon touchdown resulting in the flight crew having to manually extend the speedbrake lever to deploy to the ground spoilers. The airplane was re-located from SFO to American’s maintenance facility based at the Tulsa, Oklahoma International Airport to troubleshoot the auto speedbrake control system and the air/ground sensing system. According to American Airlines, no anomalies were discovered within the air/ground sensing system. American Airlines replaced the speedbrake mechanism (structural assembly containing the auto speedbrake actuator, no-back clutch, switches and wiring) to address the maintenance discrepancy. The airplane was then put back into revenue service.

D. <u>DETAILS OF THE INVESTIGATION:</u>

D.1 Airplane Systems Documented:

Based on a review of FDR data from the December 29, 2010 incident, the systems group documented the following control systems:

1. <u>Air/Ground Sensing System</u>:
   FDR data indicates that upon touchdown in Jackson Hole, Wyoming, the airplane's air/ground sensing system did not indicate a smooth transition from "Air" to "Ground". At touchdown, the system initially indicated "Ground", then briefly transitioned back to "Air" and then indicated "Ground" for the remainder of the landing. Therefore, the investigation reviewed the air/ground system design, conducted testing on the incident airplane and made a request to Boeing to review FDR data from other 757 landings to determine what events or conditions could lead to the air/ground discrete characteristics observed during the incident landing.

2. <u>Auto-Brake System</u>:
   FDR data indicated that during the landing rollout in Jackson Hole, the autobrake disarm discrete changed from "armed" to "disarmed" (The discrete is recorded once every four seconds). Therefore, the investigation reviewed the autobrake control system design, conducted autobrake/antiskid system testing and visual inspections of the tire and brakes on the airplane to determine why the autobrake disarm discrete changed from "armed" to "disarmed".

3. <u>Auto Speedbrake Control System</u>:
   FDR data indicates that the speedbrake lever did not automatically deploy (extend aft) from its "armed" detent during the landing. The investigation reviewed the auto speedbrake control system design, conducted system testing on the airplane, and conducted an examination of the speedbrake arming switch and the speedbrake mechanism assembly to determine the reason why the speedbrake lever failed to extend out of its "armed" detent during these two landings.

4. <u>Thrust Reverser System</u>:
   During the landing in Jackson Hole, Wyoming, the thrust reversers (T/R) indicated "in-transit" upon touchdown and remained "in-transit" until approximately eleven seconds after touchdown. At this time, the T/R "in transit" discrete indicated "not in transit," for about 1 second and then again transitioned to "in transit." About six seconds later, the T/R's fully deployed. A review of FDR data indicates that the thrust reverser system operated as intended on landings before and after the landing in Jackson Hole. The investigation reviewed the thrust reverser control system design to determine why the thrust reversers behaved as they did during the landing in Jackson Hole.

D.2 Documentation of the Flight Deck:

On December 31, 2010, the instruments, controls and displays in the flight deck were visually inspected and documented after electrical power was applied to the airplane. The following are the results of the inspection:

1. Messages remaining displayed on the Engine Indication and Crew Alerting System (EICAS) maintenance status page:
   a. L FLT CONT ELEC
   b. SPOILERS
   c. L REV ISLN VAL
   d. L ENG SURGE BITE
   e. YAW DAMPER

2. A review of the instruments and controls found that the following:

a.	Speedbrake lever:	Full Forward in its down detent
b.	Flap lever:	Flaps 30 detent
c.	Parking brake:	Set
d.	Autobrake switch:	Off
e.	Landing gear selector lever:	Down
f.	Engine and APU fire handles:	Not pulled
g.	Fuel control switches:	In cutoff position
h.	Rudder trim:	Zero units
i.	Aileron trim:	Zero units
j.	Circuit breakers	Found not pulled (including FDR and CVR)[1].

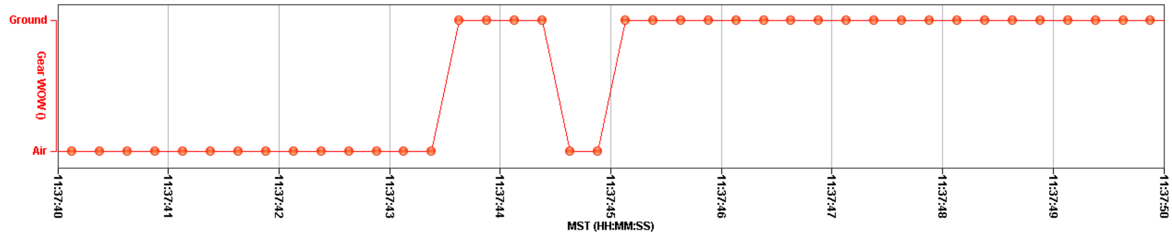
D.3 Air/Ground Sensing System:

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 reverser and autobrake control systems. The air/ground sensing system comprises multiple air/ground relays, proximity switch electronic unit (PSEU), gear tilt pressure switches and two proximity sensors located on each gear assembly. The PSEU converts signals from the proximity sensors and switches to energize or de-energize the air/ground system relays.

A review of FDR data revealed that upon touchdown in Jackson Hole, Wyoming, the air/ground discrete “Gear weight-On-Wheels (WOW)” transitioned from “Air” to “Ground” and remained on “Ground” for about one second. The air/ground discrete briefly transitioned back to “Air” for about 0.5 seconds and then back to “Ground” for the remainder of the landing. Figure 1 provides a graph showing the air/ground data from the event landing.

[1] Prior to the arrival of the NTSB, American Airlines had already removed and replaced the FDR and the CVR.

Figure 1 Weight-On-Wheels data from the December 31, 2010 landing



Air/ground system number 1 & 2 relays are designed to be energized and will provide a "Ground" signal to the auto speedbrake control system, thrust reverser control system and the autobrake control system when the PSEU receives the following signals:

1. The system 1 & 2 proximity sensors have detected and are indicating that both main landing gear (MLG) trucks are not tilted.

   Each MLG truck contains two proximity sensors, a system 1 sensor and a system 2 sensor, that provide air/ground signals to the PSEU; the sensors are located on the outboard side of the truck beam, aft of the main gear shock strut.

   When the airplane is in the air and the landing gear is extended, a truck position actuator on each MLG positions its respective truck to about 9.6 degrees rear wheels down. Upon touchdown, the truck tilt sensor will indicate that the truck is not tilted and provide a "Ground" signal to the PSEU when the truck tilt angle reduces to about 5.4 degrees rear wheels down. Upon takeoff, the system transitions to air mode at about 7.0 degrees rear wheels down. This results in an average air/ground transition at about 6.2 degrees with a hysteresis of about +/-0.8 degrees. Note that the above truck angles are measured relative to airplane waterline.

2. The left and the right truck tilt pressure switches indicate that they have detected hydraulic pressure.

   Each MLG contains a "gear tilt" pressure switch that is installed on the truck position shuttle valve, which is mounted on the ceiling of each main gear wheel well. The purpose of the switch is to validate "Ground" inputs to the auto-speedbrake control system. The switches are actuated by the left hydraulic system pressure. When the landing gear selector lever is positioned down, left hydraulic system pressure is applied through the truck tilt pressure switch to the truck tilt actuators. A relay, K550, in the auto speedbrake actuation control circuit monitors the left and right gear tilt pressure switches to provide fault annunciation when it detects a disagreement between the two sensors. The relay is energized when the left tilt pressure switch detects high pressure. In the event the relay is de-energized, due to low left tilt pressure, when the right tilt pressure switch detects high pressure and the speedbrake lever is armed, an AUTO SPEEDBRAKE fault annunciation will be provided to the flight crew.

One of the "Ground" signals from system 1 and system 2 goes to the left and right EICAS computers for air/ground output comparison. If the "Ground" signal outputs from systems 1 and 2 do not agree, the computers will provide an AIR/GND DISAGREE message on the EICAS status/maintenance display screen. If the nose gear not compressed signal outputs from systems 1 and 2 do not agree, the computers will provide a NOSE A/G DISAGREE message on the EICAS status/maintenance display.

D.3.1 PSEU BITE Troubleshooting:

The PSEU contains built-in-test equipment (BITE) that provides a maintenance technician with the capability to perform a complete air/ground sensing system checkout and an indication of the sensor to target status (near or far).

On Friday December 31, an American Airlines maintenance technician (in the presence of the NTSB) performed BITE testing on the PSEU. The results of the testing showed that the PSEU was functional and that it had not detected or stored any faults within its memory. BITE testing also found that, at the time of the test, the PSEU detected that the proximity sensors on the left and right MLG were correctly sensing that the trucks were not tilted and that the sensors on the nose gear were sensing that the NLG was compressed.

D.3.2 Landing Gear Proximity Sensor Inspections:

Visual inspection of the proximity sensors installed on the MLG trucks and the NLG did not find any physical anomalies with the sensors or their respective targets.

A proximity sensor "health" check was conducted on the system 1 and the system 2 air/ground system proximity sensors located on the MLG trucks. The "health" check measures the resistance and inductance of each proximity sensor and its associated aircraft wiring. The measurements were taken with each sensor's respective target in a "NEAR" condition (target placed on sensor face) and a "FAR" condition (target removed). A de-targeting tool was used to induce a far condition. Using the de-targeting tool can result in inductance numbers smaller than the requirements. Refer to Table 1 for the test results.

Table 1 Proximity sensor measurements

Sensor	Near		FAR	
	Inductance Millihenries (5.2 to 6.5 mH)	Resistance (Ohms) (Max 20 Ohms)	Inductance Millihenries (4.7 to 4.9 mH)	Resistance (Ohms) (Max 20 Ohms)
R MLG System 1 S10060	5.9	14.2	4.4	18.6
L MLG System 1 S10062	5.7	13.5	4.3	18.3
R MLG System 2 S10059	5.8	14.1	4.3	18.9
L MLG System 2 S10064	5.5	13.1	4.5	17.5

D.3.2.1 MLG Tilt Pressure Switches:

On Saturday January 1, 2011, an American Airlines maintenance technician (in the presence of the NTSB) checked the functionality of the left MLG tilt pressure switch (S452) and the right MLG tilt pressure switch (S453) and their associated wiring. The following checks were conducted:

1. Visual inspection of the switch installation.
2. Electrical continuity check of the wiring from the PSEU to the left and right MLG tilt pressure switches.
3. Electrical continuity check of each switch in its non-pressurized state.
4. Electrical continuity check of each switch in its pressurized state.

The results from the electrical continuity checks indicated that both the left switch (S452) and the right switch (S453) correctly switched states when hydraulic pressure was applied and removed from the switch. Continuity checks of the wiring from the PSEU to both switches found that the wiring was electrically intact; no open circuits or shorts to ground were noted.

The only anomaly noted during the visual inspection was the right MLG switch (S453) connector was found in a clocked position that stressed the wiring. After the continuity checks, the connector was re-clocked to relieve the stress in the wiring. The left MLG switch connector was found positioned such that the wiring was not stressed.

D.3.3 Boeing Database Query:

Boeing queried their database of FDR data that had been received from various operators since the beginning of 2010 for all 757 events in which the airplane exhibited gear unloading ("bounces") during landing. The search of the database revealed a total 16 Boeing 757 landings. Of those 16 landings, five exhibited gear unloading ("bounces") during landing. Each of the five "bounce" events contained a similar air/ground signature in the Weight-on-Wheels discrete as the Jackson Hole landing indicating that gear un-loadings events during touchdown are relatively common occurrences and should not be interpreted as a problem with the aircraft air/ground system.

D.4 Tires and Brakes:

On December 31, 2010, an inspection of the MLG tires was conducted to document their condition. None of the eight MLG tires exhibited evidence of skidding; each tire exhibited normal wear such as chevrons, minor nicks, and scrapes; no dry or wet braking flat spots were noted on any of the tire treads. An American Airlines maintenance technician checked and recorded the tire pressure for each of the MLG and nose landing gear (NLG) tires. At the time of the measurement, the outside air temperature was about 10 degrees Fahrenheit. A review of Boeing Aircraft Maintenance Manual (AMM) 12-15-03 titled "Landing Gear Tires – Servicing", dated January 20, 2011, states that the standardized pressure for the MLG tires is 185 $\pm$ 5 psi and the standardized pressure for the NLG tires is 155 $\pm$ 5 psi. The results of the tire pressure measurements are shown in Table 2:

Table 2 Measured Tire Pressures

Gear Assembly	Location of Tire	Measured Pressure (PSI)
Left MLG	Outboard Forward	180
	Outboard Aft	179
	Inboard Forward	175
	Inboard Aft	175
Right MLG	Outboard Forward	190
	Outboard Aft	190
	Inboard Forward	183
	Inboard Aft	186
NLG	Left	155
	Right	160

Two wear pins are installed in each MLG brake assembly; the pins provide an indication of when the brakes require replacement. The pins attach to the pressure plate and protrude through a brake housing bracket at grommet locations. The wear pins on new brakes initially protrude about 1-3/8 inches past the grommets with brakes applied. When the protrusion is zero, the brakes need replacing. With the brakes applied, a measurement of wear pin protrusion was conducted by an American Airlines maintenance technician on each of the eight MLG brakes. The results of the measurements are shown in Table 3.

Table 3 Brake wear pin measurements

Gear Assembly	Location of Brake	Measured Length (inch)
Left MLG	Outboard Forward	29/32
	Outboard Aft	10/32
	Inboard Forward	16/32
	Inboard Aft	16/32
Right MLG	Outboard Forward	26/32
	Outboard Aft	24/32
	Inboard Forward	6/32
	Inboard Aft	4/32

D.5 Brake and Autobrake Control System:

The brake control system provides a way to slowdown and/or stop the airplane after landing and during taxi operations. Brakes installed in each of the MLG wheels are actuated hydraulically by manual brake pedal movement or automatically through the autobrake control system. In the manual mode of operation, the four brakes on the left gear are operated by the pilot's left pedal(s) and the four brakes on the right gear are operated by the 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 automatically releases the brakes to prevent skids or loss of control during braking.

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 only brake and auto brake system data that was recorded on the incident flight recorder was the “autobrake” discrete. The FDR was not set up to record brake pedal positions, brake pressures, or main landing gear wheel speeds. The data indicates that during the landing rollout, the autobrake discrete changed from “ok” to “fault” between 11 and 15 seconds after touchdown. The discrete was recorded once every four seconds. The FDR “autobrake” discrete monitors the position of the autobrake selector switch through the EICAS computer busses. When the switch is in the “disarm” position, the discrete will change from “ok” to “fault”.

The autobrake control system comprises an AUTOBRAKES selector switch, AUTOBRAKE light and an antiskid/autobrake control unit. The AUTOBRAKES selector switch and light are located on the center instrument panel in the cockpit. The switch is a rotary, magnetic-latching eight position switch that can be selected to five automatic braking levels (1, 2, 3, 4, and MAX AUTO) and one refused takeoff (RTO) mode of automatic braking. When rotated from the off position to an automatic braking level, the switch provides power to the autobrake section of the antiskid/autobrake control unit. The selector switch also provides a ground to illuminate the AUTOBRAKES light when the selector switch is in the DISARM position. The light will also illuminate when the switch is positioned to OFF and the autobrake module solenoid valve output pressure switch detects high pressure.

During the initial inspection of the airplane on Friday, December 31, 2010, the AUTOBRAKES selector switch was found in the OFF position. However, this inspection was conducted approximately two days after the overrun event and the airplane had been moved from its final resting position to another location at the airport.

When power is removed from the selector switch latch, the selector switch will automatically move from its selected position (1, 2, 3, 4, or MAX AUTO) to DISARM. In the DISARM position, the autobrake control system releases the autobrake pressure, the AUTOBRAKES light comes on, the EICAS display will show the AUTOBRAKES advisory message and a signal is sent to the flight data recorder indicating that the autobrake system is disarmed.

The antiskid/autobrake control (AACU) unit provides arming, disarming, control and monitoring of the antiskid/autobrake control system. Extensive BITE on the AACU provides the system with both in-flight and on-ground testing. The autobrake control system arms and latches with a magnetic latching switch within 100 milliseconds when all of the following conditions are met:

1. A deceleration level of (1, 2, 3, 4, or MAX AUTO) has been selected.
2. No autobrake system failures have been detected.
3. No antiskid system failures have been detected.
4. All thrust lever switches show that the thrust levers are not advanced above 4.86 degrees forward of the idle stop.
5. Inertial Reference System (IRS) signal available.
6. Brake pressure switches (both left and right) show low pressure.

An autobrake module (ABM) is connected to the normal brake lines, and is located on the forward bulkhead of the left main gear wheel well. The ABM develops brake pressure in response to selected deceleration for all required autobrake functions. The solenoid valve provides on-off control of hydraulic power to the valve module, and the pressure control valve controls output pressure from the module as commanded by the control unit. Pressure switches on the module monitor the pressure outputs from the solenoid valve and the pressure control valve and provide the logic to the control unit.

The autobrake control system will command brake pressure through the ABM as required when the following conditions are satisfied:
1. Autobrake control system is armed.
2. All thrust lever switches show that the thrust levers are not advanced above 4.86 degrees forward of the idle stop.
3. Airplane is on the ground as indicated by one air/ground signal continuously indicating “Ground” for 0.2 seconds.
4. Wheel spin-up circuit activated and the wheel speed reaches 60 knots.

Note: A loss of conditions 3 or 4 above after autobrake application causes auto braking to be removed but not disarmed and the time delay resets.

Once activated, hydraulic pressure will be metered to the brakes, establishing an initial low pressure level. The autobrake system will hold the brake pressure at this level until the pitch angle of the airplane is reduced to approximately one degree, as measured by the IRS. As the airplane de-rotates through the one degree reference attitude, brake pressure is increased to achieve the deceleration level which corresponds to the chosen autobrake setting (MAX AUTO for this incident). If airplane de-rotation is delayed, the system will still command brake application. However, the system will pause before transition to the selected deceleration rate. With an autobrake setting of “MAX AUTO”, transition to the selected deceleration rate will commence when 8.0 seconds have elapsed from main gear touchdown. However, this time delay will be overridden when the pitch attitude reaches one degree. When the autobrake switch is positioned at “MAX AUTO”, the autobrake system targets a deceleration rate of 11 feet per second squared, which it attempts to achieve by commanding up to full braking authority of 3000 psi. The system will maintain this deceleration level throughout the landing roll.

Because the FDR data indicated that the autobrake fault discrete changed from “armed” to “disarmed” between 11 and 15 seconds after touchdown, the investigation reviewed a list of events that could automatically disarm the autobrake control system. The review indicated that the system will disarm and remove the power from the autobrake module solenoid and from the selector switch latch when any of the following events occur:
1. The autobrake control system is manually selected off.
2. Either the left or the right metered pressure switch indicates a pressure (manual brake application) of 750 psi or greater.
3. Any thrust lever switch indicates advanced on the ground.
4. Autobrake system failure detected, including failure to apply pressure (indicated by the pressure control switch) when application conditions are met and the commanded deceleration exceeds the actual airplane deceleration by more than one foot per second square for more than three seconds.

5. Antiskid failure on normal system detected except for failures on a wheel whose indication has been deactivated by the control unit selector switch.
6. Spoilers stowed after having been deployed on the ground.
7. IRS signal not present or faulty.

On December 31, 2010, an American Airlines maintenance technician performed a BITE check on the AACU to check for any fault indications. BITE testing indicated the system was functional and no faults were stored within the units memory.

On January 3, 2011, an American Airlines maintenance technician performed, under NTSB oversight, the "autobrake control test, speedbrake switch test, and the landing gear down and locked test' (task 32-42-00-715-044) contained within Boeing AMM 32-42-00/501, titled "Antiskid/Autobrake System – Adjustment/Test" dated Feb 20, 2010. The tests were completed with no discrepancies; the autobrake system functioned per all AMM test requirements.

D.6 Spoiler and Auto Speedbrake Control System:

D.6.1 System Description:

The airplane's spoiler/speedbrake system comprised a total of twelve spoiler panels that are numbered 1 through 12 consecutively from the left wing outboard to the right wing outboard. Spoiler panels Number 4 and 9 are only used for ground speedbrakes and are not actuated during flight under any circumstances. The spoiler/speedbrake system, which is electrically controlled and hydraulically powered, uses the same flight control surfaces to perform two functions. The system deploys the flight spoilers to assist the ailerons in lateral control of the airplane and also operates the same surfaces as speedbrakes to increase drag and reduce lift in flight.

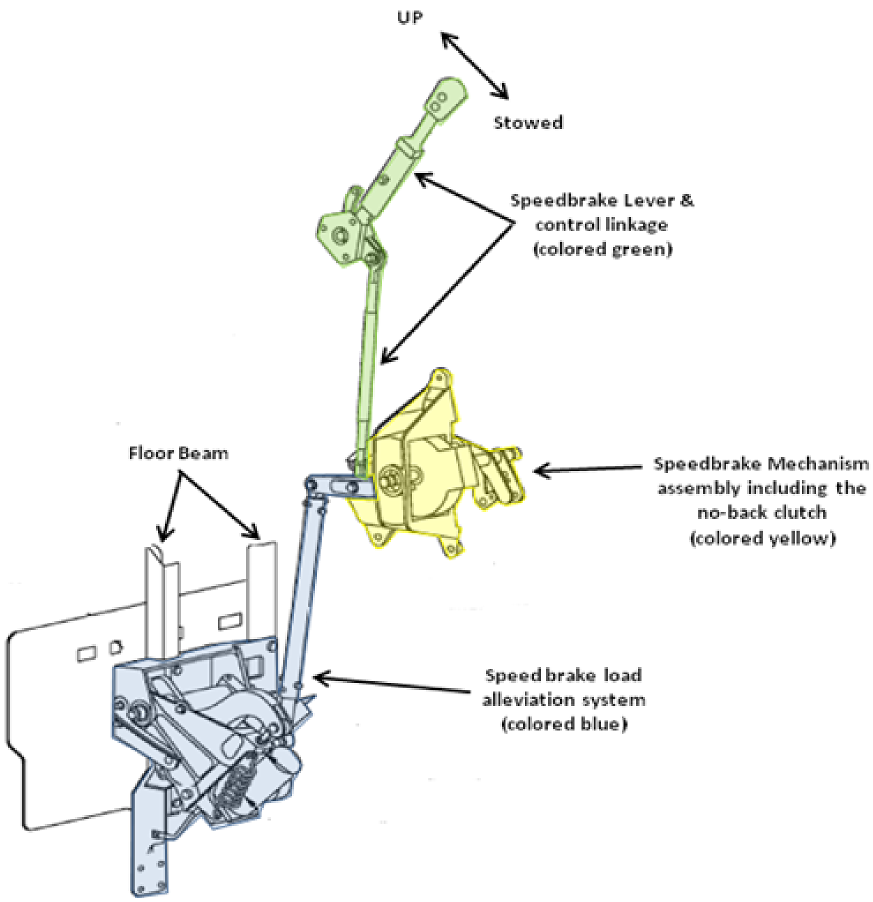
The flight spoilers are electrically operated through the aileron control system through the control wheel or by the speedbrake system through the position of the speedbrake lever. Six linear variable differential transformers (LVDTs), attached to the speedbrake mechanism, translate speedbrake lever position into electrical signals that are transmitted to each of the six SCMs to extend the flight spoilers symmetrically on both wings. As flight speedbrakes, spoilers 1, 2, 3, 10, 11, and 12 extend 30 degrees; spoilers 5 and 8 extend 20 degrees; and spoilers 6 and 7 extend 15 degrees. Spoilers 4 and 9 are ground speedbrakes only.

The speedbrake lever is located on the control stand between the stabilizer trim switches and the engine thrust levers. There are three speedbrake lever positions marked on the control stand, Down, Armed, and Up. When the lever is "Down", the speedbrake system does not provide an input to the spoiler system. Pulling up on the lever and moving it aft to the "Armed" detent prepares the speedbrake system for automatic deployment on landing. Pulling the lever all the way back to the "up" position will raise the spoilers to their full extension.

The airplane's speedbrake control system was modified on September 24, 2007 as part of the winglet installation per Supplemental Type Certificate (STC) number ST01518SE, dated March

25, 2005. STC ST01518SE includes modification to the wing structure, installation of a wing transition plug, blended winglets, and the installation of a speed brake load alleviation system per Aviation Partners Boeing Master Drawing List AP57.2-0609, Revision B, dated April 25, 2005 or a later FAA approved revision. Modifications to the speedbrake system include the addition of a mechanism that can automatically partially retract the speed brake lever and the installation of a speedbrake autostow control (SAC) module to control the operation of the mechanism as a function of aircraft velocity, weight and flap position (Figure 2).

Figure 2 Schematic of how the auto stow system connects to the speedbrake mechanism



The speedbrake load alleviation system (LAS) contains a single direction cam/electric motor mechanism, which is located below the control stand. This mechanism interfaces with the speedbrake lever linkage. When the motor is activated, a deployed speedbrake lever will be pushed toward the stowed position. This action only occurs during high airspeed and heavy gross weight flight conditions.

D.6.2   Auto-Speedbrake Control System:

The auto-speedbrake system automatically drives the speedbrake lever to deploy all of the spoiler panels at touchdown or during a refused takeoff (RTO). The system will also retract the spoilers when a go-around is initiated after touchdown or when either throttle lever is advanced beyond 20 percent of thrust lever travel forward of the idle stop. To use the auto-speedbrake system for landing, a pilot raises the speedbrake lever out of its down detent and moves it aft (about 8 degrees) to its "armed" detent before touchdown. In this position, an indicator (black arrow) on the aft end of the speedbrake lever aligns with a gray stripe labeled ARMED on the pedestal as a visual cue to the flight crew. The detent also provides a tactile indication to the flight crew that the lever is in the "armed" position. The speedbrake lever can also be moved manually to its full extend position by the pilot. When the airplane is on the ground and the speedbrake lever is fully extended to its UP position, spoilers 1, 2, 3, 5,8,10, 11, and 12 will extend 45 degrees; spoilers 6 and 7 extend 30 degrees; and spoilers 4 and 9 extend 55 degrees.

The auto-speedbrake system comprises a speedbrake lever, no-back clutch mechanism, auto-speedbrake actuator, six LVDTs, six SCM's, air/ground relays, truck tilt pressure switches and relays, speedbrake lever arming switch, thrust reverse switch and thrust lever position switches. When the speedbrake lever is in the "armed" detent and both thrust levers are positioned to their forward idle stop, power will be supplied through the arming switch to a set of contacts contained within the air/ground relays[2]. Once energized[3], the relays allow the power from the arming switch to be directed, through an extend relay, to the extend circuit of the auto-speedbrake actuator. Operation (extension) of the auto-speedbrake actuator drives (through the no-back clutch mechanism) the speedbrake lever, LAS mechanism, the multi-faced cam and the six LVDTs. The actuator will extend to its full extend position, resulting in the speedbrake lever being driven to its full UP position.

The speedbrake lever can also be automatically deployed from its down detent (or just aft of down, but not yet in its electrically "armed" position) by the action of manually moving either reverse thrust lever up and rearward to its interlock position. Movement of either reverse thrust lever results in two actions:

1. The speedbrake lever is automatically lifted up out of its down detent.
2. The reverse thrust switch is closed (activated to "reverse"). The thrust reverse switch bypasses the auto-speedbrake arming switch to provide energizing power to the air/ground relays to command the auto-speedbrake actuator to extend.

The auto speedbrake control system incorporates a no-back clutch mechanism that provides two main functions: 1) it allows the speedbrake lever to be manually moved without driving the auto speedbrake lever actuator, and 2) allows the auto speedbrake lever actuator to drive the speedbrake lever and speedbrake control mechanism. The no-back clutch mechanism is positioned between the speedbrake lever and the auto speedbrake actuator; it has two separate inputs and one single output (Figure 3). The clutch is designed to receive an input (rotational motion) from either the speedbrake lever linkage assembly[4] or from the auto speedbrake actuator. During normal operation, these inputs will result in the rotation of a shaft (inner shaft), which is connected to a multi-faced cam and the six LVDTs. When rotated, the multi-

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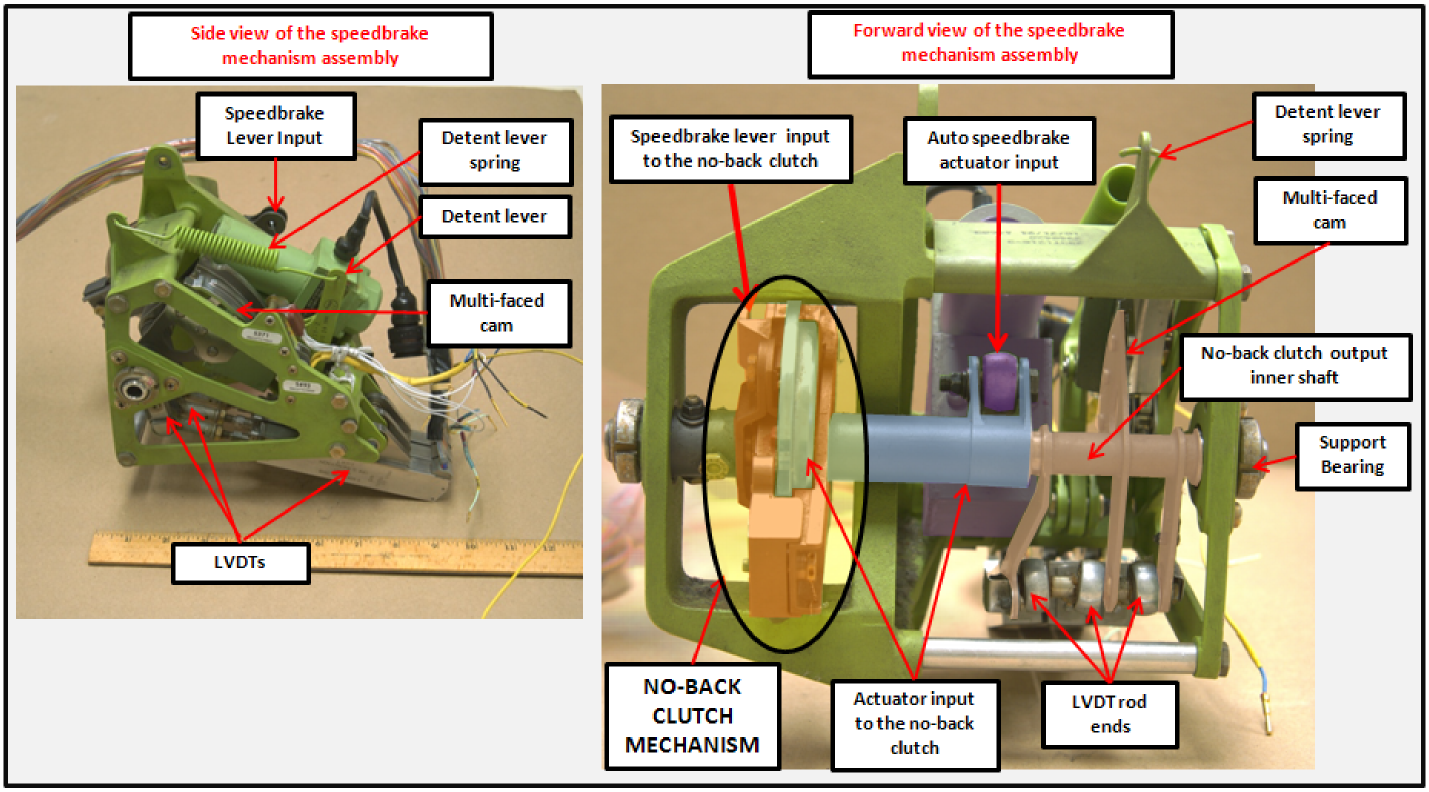
[2] The K87 relay is the speedbrake air/ground relay for system 1and the K88 relay is the speedbrake air/ground relay for system 2.

[3] The relays are energized when they receive a "Ground" signal from the air/ground system and when both left and right MLG tilt pressure switches are activated (high pressure)

[4] The speedbrake linkage assembly comprises the speedbrake lever linkage and the load alleviation system linkage.

faced cam mechanically actuates the auto-speedbrake arming switch and other switches, and provides an armed detent for the speedbrake lever.

Figure 3 Speedbrake mechanism assembly



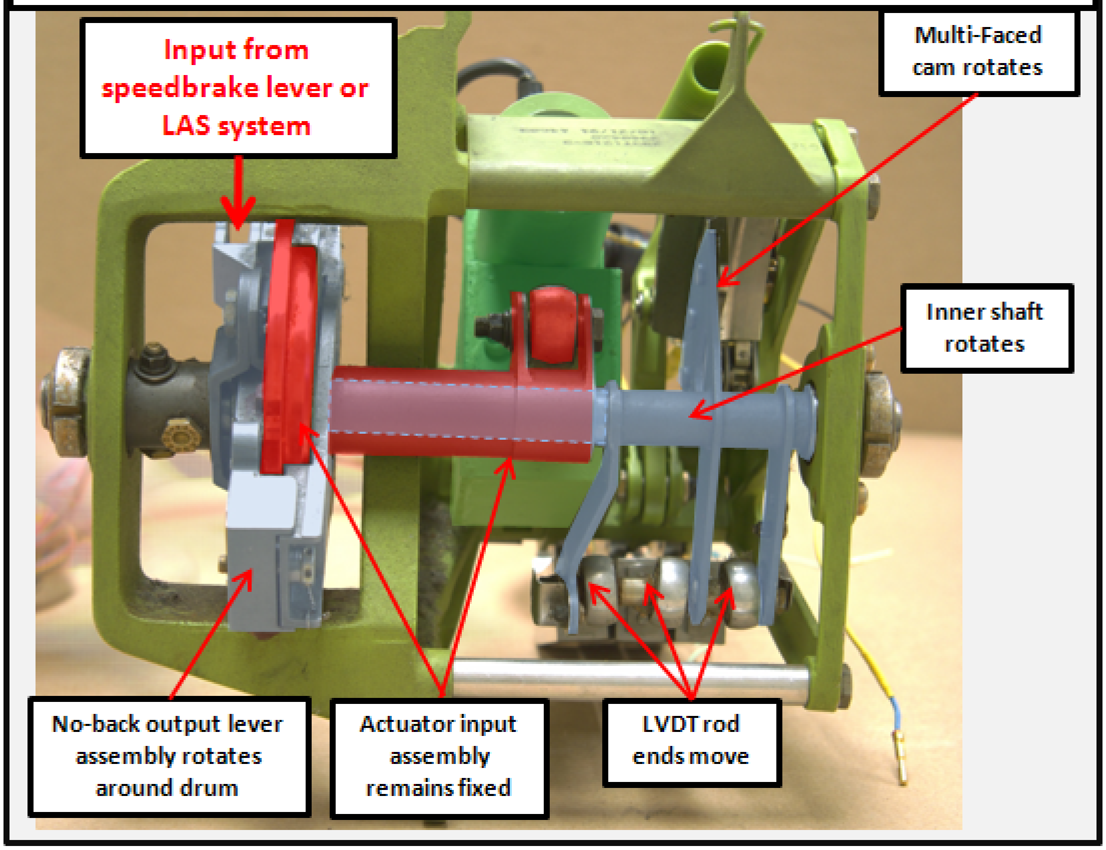
Because the no-back clutch mechanism is positioned between the speedbrake lever and the auto speedbrake actuator, the speedbrake lever is allowed to move independently from the speedbrake actuator to provide a rotational input directly to the inner shaft, LVDTs and the multi-faced cam. For this operational condition, the auto speedbrake actuator acts as a ground point for the no-back clutch resulting in the actuator assembly remaining stationary. In order to move the speedbrake lever, a force must be applied to the lever in the direction of desired movement. The applied force is transferred through linkages to the speedbrake lever input side of the no-back clutch mechanism. When a sufficient amount of force is applied to the lever, (about 3 to 4 pounds), it will override a set of friction pads within the no-back clutch mechanism resulting in the movement (rotation) of the output lever assembly around the actuator input assembly drum. This action will result in the rotation of the inner shaft, multi-faced cam and LVDTs. Refer to Figure 4.

Figure 4 Input from the speedbrake lever

Condition 1: Manual input from speedbrake lever or LAS system

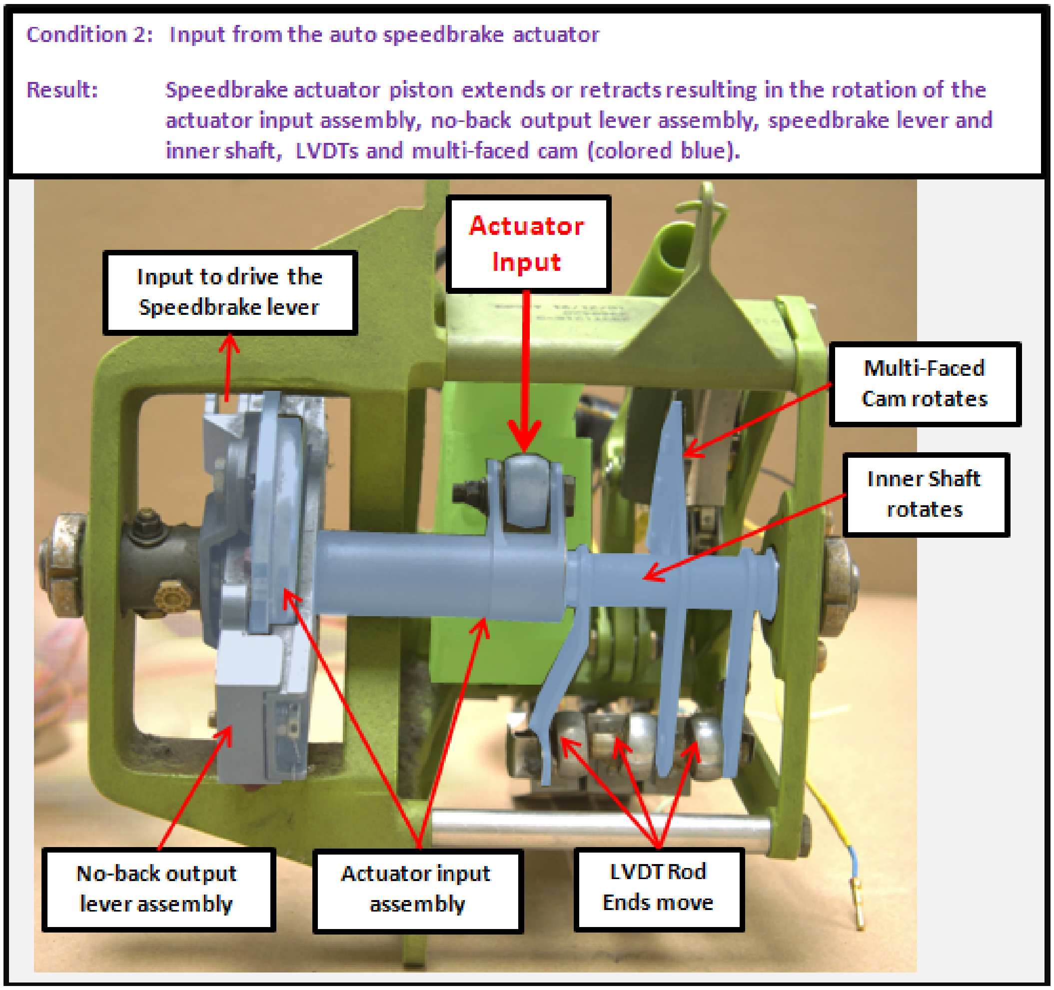
Result: Auto speedbrake actuator acts as a ground point preventing the actuator input assembly from rotating (colored red).

Lever input overrides the no-back clutch allowing the no-back output lever assembly to rotate around the actuator input assembly (drum) resulting in the rotation of the inner shaft, LVDTs and cam (colored blue).



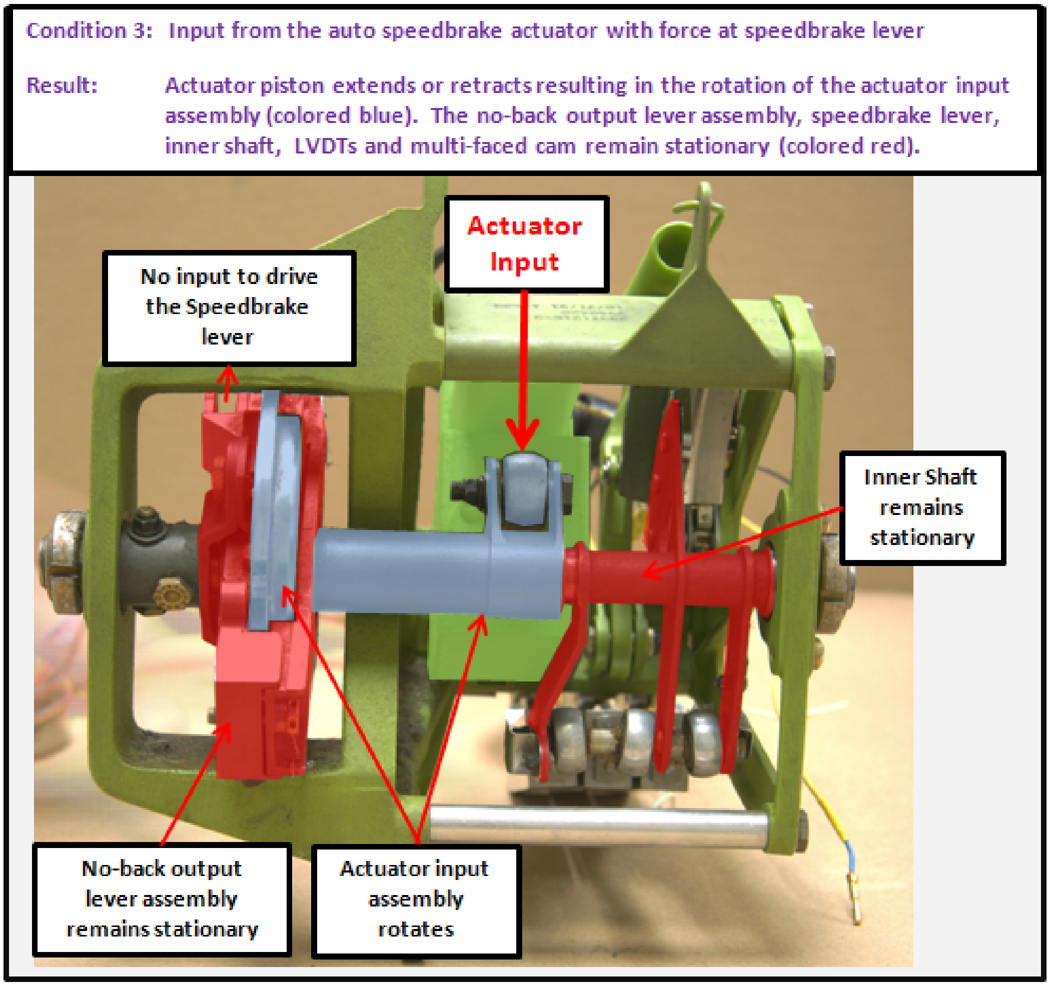
Because of the no-back clutch mechanism, the auto speedbrake actuator is allowed to fully extend or retract. When the auto speedbrake control system electrically commands the auto speedbrake actuator to drive the speedbrake lever, the actuator's piston will either extend or retract, providing a rotational input to the actuator input assembly portion of the no-back clutch mechanism. If there is not a force applied to the speedbrake lever and the friction in the speedbrake lever linkage, including the lever's drag friction and the LAS mechanism, is less than the capability of the pin locking mechanisms inside the no back clutch, the actuator's input will be transferred through the no-back clutch to drive the speedbrake lever and inner shaft, multi-faced cam and LVDTs (Figure 5).

Figure 5 Input from the auto speedbrake actuator – no force applied to the speedbrake lever



However, if a force is applied to the speedbrake lever or the friction in the speedbrake lever linkage, including the lever's drag friction and the LAS mechanism, exceeds the 3 or 4 pounds (equivalent force at the speedbrake lever), the actuator input assembly will decouple from the no-back clutch mechanism. When this occurs, the speedbrake actuator will continue to fully extend or retract without a corresponding movement of the no-back output lever assembly, speedbrake lever and LAS linkage, inner shaft, LVDTs or multi-faced cam. Refer to Figure 6.

Figure 6 Input from the auto speedbrake actuator –force applied to the speedbrake lever



The "AUTO SPDBRK" light illuminates along with an EICAS advisory message "AUTO SPEEDBRAKE" to indicate that a fault is detected in the automatic speedbrake system which may result in the loss of automatic speedbrake extension. The speedbrakes can still be operated manually. The "AUTO SPDBRK" light may illuminate and the EICAS advisory message "AUTO SPEEDBRAKE" may display momentarily when the speedbrake lever is moved to the Down position after the speedbrakes have been deployed automatically. Both the light and the message will extinguish when the panels are retracted. The "SPOILERS" Light illuminates and the EICAS advisory message "SPOILERS" displays to indicate that one or more spoiler pairs are inoperative.

The AUTO SPEEDBRAKE message can be generated for the following conditions:

1. Speedbrake lever positioned in "armed" or greater and there is a disagreement between the right and left MLG tilt pressure switches.
2. Speedbrake lever positioned to down and the auto-speedbrake actuator is not fully retracted.
3. Certain disagreement conditions between air/ground System 1 and System 2 relays.
4. Auto speedbrake actuator control relay disagreements.

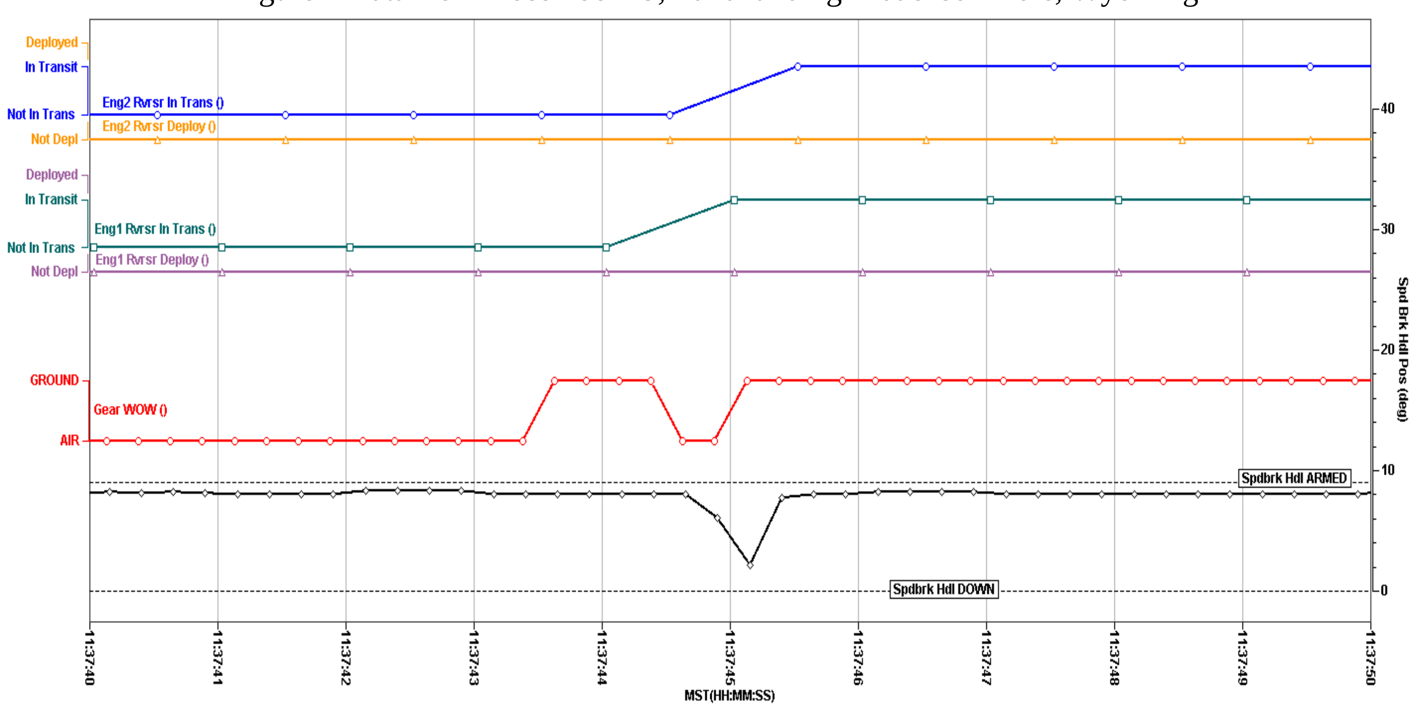
D.6.3 Investigative Findings:

D.6.3.1 Review of FDR Data:

After the incident in Jackson Hole, Wyoming, the FDR was removed from the airplane and sent to the NTSB for readout. This FDR contained data for a total of fourteen landings. A review of this data identified a total of three landings (including the incident landing) in which the speedbrake lever did not move (extend) out of its "armed" position within one second of the initial touchdown. This can be observed in the data by noting that the value of the speedbrake handle position parameter did not immediately increase from about 8 degrees "armed" to a position greater than 78 degrees "up" when the air/ground discrete transitioned to "Ground" upon touchdown.

A review of the data from the fourteenth landing (Jackson Hole) indicates that the airplane touched down at 11:37:36 MST. Upon touchdown, the air/ground discrete transitioned to "Ground" for about one second (Figure 7). While indicating "Ground", the speedbrake lever position remained at about 8 degrees. Approximately one second later, the air/ground discrete indicated "Air" for about 0.5 seconds before transitioning back to "Ground" for the remainder of the landing. During the momentary transition to "Air", the speedbrake lever retracted from about 8 degrees to about 2 degrees. When the air/ground discrete indicated "Ground" a second time, the engine 1 (left) thrust reverser discrete indicated "in-transit" followed by the engine 2 (right) thrust reverser discrete indicating "in-transit" and the speedbrake lever extended from about 2 degrees to about eight degrees "armed" and remained at eight degrees throughout the remainder of the landing.

Figure 7 Data from December 29, 2010 landing in Jackson Hole, Wyoming



A review of speedbrake lever position data from the eleven other landings revealed that the speedbrake lever typically began movement (extended) about 0.6 to 0.8 seconds after touchdown. Once movement began, the data indicates that it typically took about 1.2 seconds for the speedbrake handle to travel from about 8 degrees to about 78 degrees.

In addition to the landing at Jackson Hole, there was another landing[5] in which the speedbrake lever failed to extend out of its "armed" position upon touchdown within the typical period of 0.6 to 0.8 seconds. For this landing, the signals provided from the air/ground system were similar to the air/ground signal characteristics during the Jackson Hole landing. Upon initial touchdown, the air/ground system provided a "Ground" signal to the auto speedbrake system for a period of about 1.25 seconds. However, instead of extending, the speedbrake lever remained in its "armed" position. About 1.5 second after touchdown, the air/ground system indicated "Air" for about one second before indicating "Ground" for the remainder of the landing. During this momentary transition to "Air", the speedbrake lever automatically retracted from "armed" to a "non-armed" position of about five degrees. Upon returning to "Ground", the speedbrake lever remained at five degrees. After an additional six seconds, the reverse thrust levers were moved to their interlock position and the speedbrake lever extended to "up".

The airplane experienced another failure with the auto speedbrake system to automatically deploy the spoilers while landing in San Francisco on March 31, 2011. A review of the FDR data from this landing found that the speedbrake lever had been selected to its "armed" position before touchdown. Upon touchdown, the air/ground system detected that the airplane had transitioned from "Air" to "Ground" and provided a "Ground" signal for the entire landing. The speedbrake lever remained in "armed" for approximately four seconds after touchdown, at which time it extended to its full "up" position at a rate consistent with a manual deployment by a flight crew member.

D.6.3.2 Auto Speedbrake System Functional Testing:

On Monday January 3, 2011, an American Airlines maintenance technician (in the presence of the NTSB) conducted the "Operational Test – Auto-Speedbrake System" test per AMM 27-62-00/501, titled "Auto-speedbrake Control System Adjustment/Test" dated February 20, 2010. The test was completed and no discrepancies were noted with the airplanes auto speedbrake system.

In an attempt to duplicate the December 29, 2010 condition (speedbrake lever did not move out of its "armed" position upon transition to "Ground"), the following test was conducted.

[5] This event occurred on the twelfth landing on the incident recorder.

1. Simulation - Landing Event:
    a. The airplane was put into a simulated “approach” or “Air” mode by pulling the C30 circuit breaker (Landing Gear Air/Gnd Sys 1[6]) and the speedbrake lever was manually positioned to “armed”.
    b. Both NLG proximity sensors were “slugged” to simulate the NLG in a non-compressed state (air mode).
    c. The airplane was put into a simulated “touchdown” or “Ground” mode by pushing in the C30 circuit breaker. This action resulted in the speedbrake lever automatically moving out of its “armed” position to its full aft “up” position.
    d. After approximately 1 second, the airplane was put into a simulated “bounce” or “Air” mode by pulling the C30 circuit breaker. This action resulted in the speedbrake lever automatically “retracting” moving forward to its down and locked position.
    e. The airplane was put back into “Ground” mode by pushing in the C30 circuit breaker. This action had no effect on the speedbrake lever; it remained in its down position.
    f. Both reverse thrust levers were moved up and aft to their interlock position. This action resulted in the speedbrake lever automatically moving out of its down detent and then to full aft.
    g. With the speedbrake lever in its down detent, and when either thrust reverse lever was moved aft, the speedbrake lever would move out of its down detent and then to the full aft position when the airplane was configured in “Ground” mode.

D.6.3.3 Speedbrake Lever Force Testing:

A review of the “Speedbrake Lever Force Test” contained within the “auto-speedbrake control system adjustment/test” Boeing AMM 27-62-00, dated September 20, 2010, found that the force required to move the speedbrake lever from a position just aft of “armed” to its full UP position must be less than 6 pounds. The AMM does not contain a procedure to check the force required to move the lever out of the “armed” detent position. The 6 lb maximum lever force (out of “armed” detent) ensures that the mechanical friction is not too high. If the force to move the lever exceeds the AMM limits, it could affect the auto speedbrake systems capability to drive the speedbrake lever.

Using a hand held force gauge, the force required to move the speedbrake lever was checked in the presence of the NTSB and while the airplane was in Jackson Hole. Prior to checking the force, the speedbrake lever was moved from its down detent to a position just aft of “armed”. The force gauge was then connected to the lever and the force required to move the lever[7] aft to its full up position was measured and found to be 5 pounds. The force required to move the lever forward from its full up position was also found to be 5 pounds. This 5 lb force is the sum of the forces (at the lever) to override the no-back clutch mechanism and rotate the inner pivot shaft, which is connected to the multi-faced cam and the six LVDTs, and back drive the LAS linkage.

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[6] Opening circuit breaker Landing Gear Air/Gnd Pos Sys 1 or Landing Gear Air/Gnd Pos Sys 2 will de-energize its respective air/ground relay (K167/K211) causing the K87 or K88 relay to de-energize and thus providing power to the auto speedbrake retract relay (K218) and removing power from the extend relay (K217).

[7] When the force was being measured, the hand held force scale was held perpendicular to the speedbrake lever.

Even though the AMM did not require a check of the force to move the lever out of its "armed" detent, this check was conducted. The force required to move the lever out of its "armed" position to a position just aft of "armed" was measured and found to be 12 pounds.

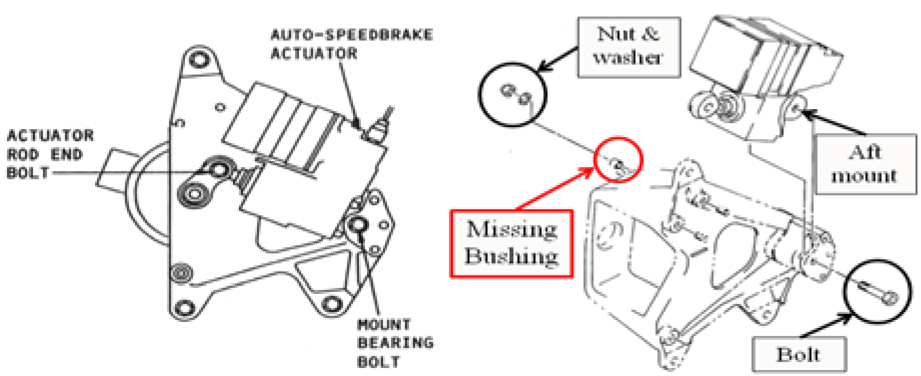
At the request of the NTSB, Boeing performed an analytical analysis to estimate the amount of force required to move the speedbrake lever out of the armed detent. According to their analysis, it may take between 9.5 to 11.5 pounds, at the lever, to move it out of the armed detent position, without counting other miscellaneous sources of friction from items such as bearings and seals. This force is the sum of the forces (at the lever) to override the no-back clutch mechanism; rotate the inner pivot shaft, which is connected to the multi-faced cam and the six LVDTs and the force to overcome the armed detent and to back drive the LAS linkage.

D.6.3.4 Speedbrake Mechanism Observations:

On January 4, 2011, the speedbrake lever was moved aft out of its down detent to a position that "visually" appeared to be "armed". However, a visual inspection of the speedbrake actuation mechanism showed that the detent lever roller was not in its fully engaged position within the switch operating cam detent; the roller was found positioned on the down side of the roller detent. It was noted that when the speedbrake lever was cycled, the lever roller and the notch in the cam did not always align the same.

Troubleshooting found that when a rotational force (by hand) was applied to the auto speedbrake actuator output, the entire speedbrake mechanism assembly (inner shaft, outer shaft, and actuator) could be moved. The auto speedbrake actuator was not providing a solid ground point. Further inspection revealed that the motion was possible because the rear attachment hardware for the auto speedbrake actuator was loose. The actuator's aft mount bearing bolt and the attachment hardware (nut and one washer) were removed from the actuator's attachment point. A review of Boeing IPC 27-62-51-02, "Lever installation-speed brake control and actuator", dated May 28, 2007, indicated that a bushing should have been present in the installation (Figure 8). According to American Airlines maintenance records, the actuator, S/N 1543, was installed on January 31, 2008 in John F. Kennedy International Airport (JFK), Queens, New York.

Figure 8 Schematic showing the location of the missing bushing



The actuator's aft mount bearing bolt and the attachment hardware were then reassembled with the required bushing. The installation of the bushing fixed the discrepancy.

D.6.3.5 Auto Speedbrake Arming Switch (S371):

At the request of the NTSB, on January 6, 2011, an American Airlines maintenance technician removed the arming switch from the airplane and provided it to the NTSB for further investigation. A representative from the NTSB packaged and hand carried the switch having part number 63746-1 and serial number 064 to the Boeing Equipment Quality Analysis (EQA) Laboratory located in Seattle, Washington for examination.

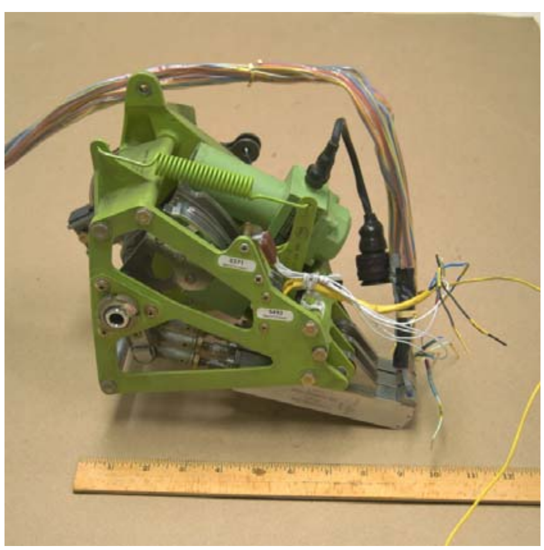
Examination of the arming switch was conducted on February 1, 2011 at the Boeing EQA laboratory. In attendance were representatives from the NTSB, the Federal Aviation Administration (FAA), Boeing Air Safety Investigation (ASI), and Allied Pilots Association (APA).

The examination found no faults with the electrical characteristics of the switch. The switch met the electrical specifications in the Haydon Switch & Instrument/Ametek (HSI) drawing 63746-1 and inspection document in every respect. The subject switch's parameters were also compared to a new, exemplar switch's parameters without any apparent disparities.

D.6.3.6 Speedbrake Mechanism Assembly:

On April 2, 2011, (after the event on March 31,2011) American Airlines removed and replaced the speedbrake mechanism (structural assembly containing the auto speedbrake actuator, no-back clutch, switches and wiring) to address the failure of the speedbrake lever to deploy upon landing in San Francisco. Refer to Figure 9. American Airlines sent the speedbrake mechanism (P/N 254N1053-5) to the FAA to be held for further investigation. A representative from the FAA hand carried the Mechanism to the Boeing EQA Laboratory located in Seattle, Washington for examination.

Figure 9 Speedbrake mechanism

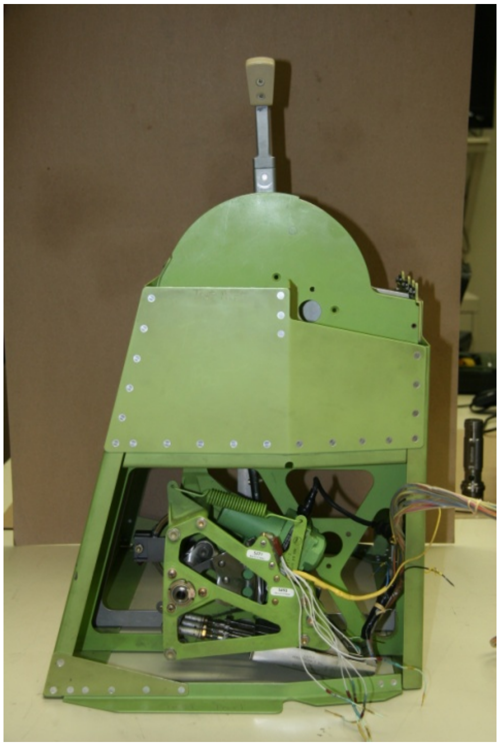


Examination of the speedbrake mechanism was conducted on May 10, 2011 at the Boeing EQA laboratory. In attendance were representatives from the NTSB, the FAA, Boeing Air Safety Investigation (ASI), Adams Rite Aerospace, and Allied Pilots Association (APA).

A general visual inspection found that, other than a slight amount of dust and/or oil on the speedbrake mechanism arming detent cam, all mechanisms appeared in good condition. No flat spots were noted on the detent lever roller and it rotated freely. There was no visual or cosmetic damage or excessive wear noted on the exterior of the entire no back assembly.

The speedbrake mechanism was installed into a control stand fixture that replicates a 757 center console assembly including a speedbrake lever and its associated linkage. The test stand was provided by Adams Rite Aerospace. Refer to Figure 10.

Figure 10 Speedbrake mechanism installed in test stand



Using a hand held force gauge, the force required to move the speedbrake lever was checked. Prior to checking the force, the speedbrake lever was moved from its down detent to a vertical position just aft of “armed”. A hand held force gauge was then positioned against the lever. The breakout force required to move the lever[8] forward was measured three times and found to be 5.35 pounds on average. The breakout force required to move the lever aft from its vertical position was measured two times and found to be 5.5 pounds on average. The running force to move the lever from its full aft position to its “armed” detent was ranged from 4.5 pounds to 4.0 pounds. The running force to move the lever aft from a position just aft of “armed” detent to full aft ranged from 4.6 pounds to 4.0 pounds. The measured force to move speedbrake

[8] When the force was being measured, the hand held force scale was held perpendicular to the speedbrake lever.

lever out of armed detent going aft was measured three times and found to be 13.5 pounds on average.

To test the functionality of the auto speedbrake actuator's ability to extend/retract and drive the speedbrake lever, power was applied to the extend and retract circuits of the actuator. Whenever the speedbrake lever was placed in its "armed" detent, the actuator was always able to drive the lever to its full aft position as long as an external force was not applied to the speedbrake lever. The actuator was also able to drive the speedbrake lever from its full aft position to its down detent.

A test was conducted to partially extend the auto speedbrake actuator while maintaining the speedbrake lever in its "armed" detent and then retract the actuator to determine if the speedbrake lever would also retract. While electrically operating the actuator in the extend direction, the speedbrake lever was manually restrained in its "armed" detent. As the actuator was extending power was interrupted to stop the actuator in a partially extended position. With the speedbrake lever remaining in its "armed" detent, the restraint was removed and a retract command was supplied to the actuator. The actuator fully retracted and the speedbrake lever was driven forward to its down detent.

A test was conducted to determine if the actuator, in a partially extended position, could drive the speedbrake lever out of its "armed" detent. While electrically operating the actuator in the extend direction, the speedbrake lever was manually restrained in its "armed" detent. The actuator began extending. Power was then interrupted to stop the actuator in a partially extended position. With the speedbrake lever in the armed detent, the restraint was removed and an extend command was re-supplied to the actuator. The actuator fully extended but the speedbrake lever did not move; it remained in the "armed" position. This test was repeated 3 times with similar results. Subsequent attempts to duplicate this phenomenon (7 repetitions) failed, indicating that the potential deficiency has an intermittent character.

The incident speedbrake mechanism was removed from the test stand and an exemplar speedbrake mechanism having a newly overhauled no-back clutch mechanism was re-installed. While electrically operating the actuator in the extend direction, the speedbrake lever was manually restrained in the "armed" detent. The actuator began extending. Power was then interrupted to stop the actuator in a partial travel position. With the speedbrake lever in the armed detent, the restraint was removed and an extend command was re-supplied to the actuator. The actuator fully extended and the speedbrake lever was also driven aft. This test was repeated several times and the actuator was always able to drive the speedbrake lever aft.

Troubleshooting was performed on the incident speedbrake mechanism. Using a force gauge, the force needed to backdrive the output shaft (applied at the LVDT input cranks) to slip the no back was measured. The requirement is a minimum of 150 in-lbs at the no-back mechanism's output shaft (74 lbs at LVDT input crank).

With the actuator still connected and the detent spring removed, no slippage of the no back mechanism was observed when a force of 100 pounds was applied to the LVDT input crank in the spoiler extend direction. (This measurement technique identified no potential no back slippage during the auto speedbrake retraction.)

Slippage of the no back mechanism was observed when a force of 50-58 pounds was applied to the LVDT input crank in the spoiler retract direction. (This measurement technique identified potential no back slippage during the auto speedbrake extension.)

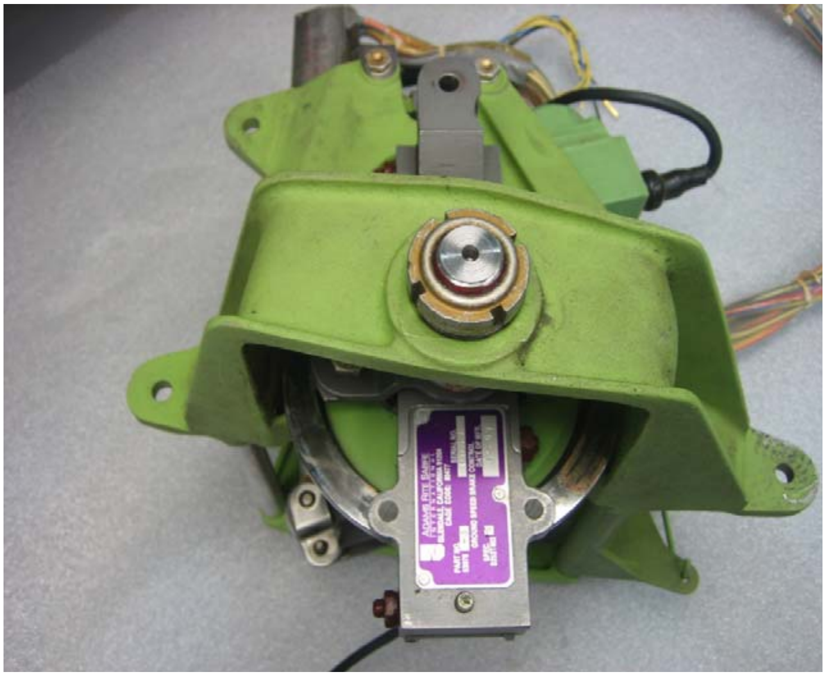
D.6.3.7 Ground Speed Brake Control Assembly (GSBCA):

Examination of the GSBCA, part number 53078-3, serial number 1737 was conducted on July 7, 2011 at the facilities of Adams Rite Aerospace at 4141 North Palm Street, Fullerton, California. In attendance were representatives from the NTSB, Boeing Air Safety Investigation (ASI), and Adams Rite Aerospace.

The speedbrake mechanism assembly (structural assembly containing the auto speedbrake actuator, GSBCA, switches and wiring) was delivered to the Adams Rite facility by a NTSB representative. Refer to Figure 12. The entire assembly was visually examined, and appeared free of shipping damage.

The speed brake mechanism assembly was dismantled to remove the GSBCA from the assembly. Refer to Figure 11. Once removed, an external inspection of the GSBCA revealed that it remained sealed with its original lock wire and anti-tamper compound. Adams Rite records indicated that the GSBCA was manufactured in September 1997, and had not been returned to Adams Rite Aerospace since that date.

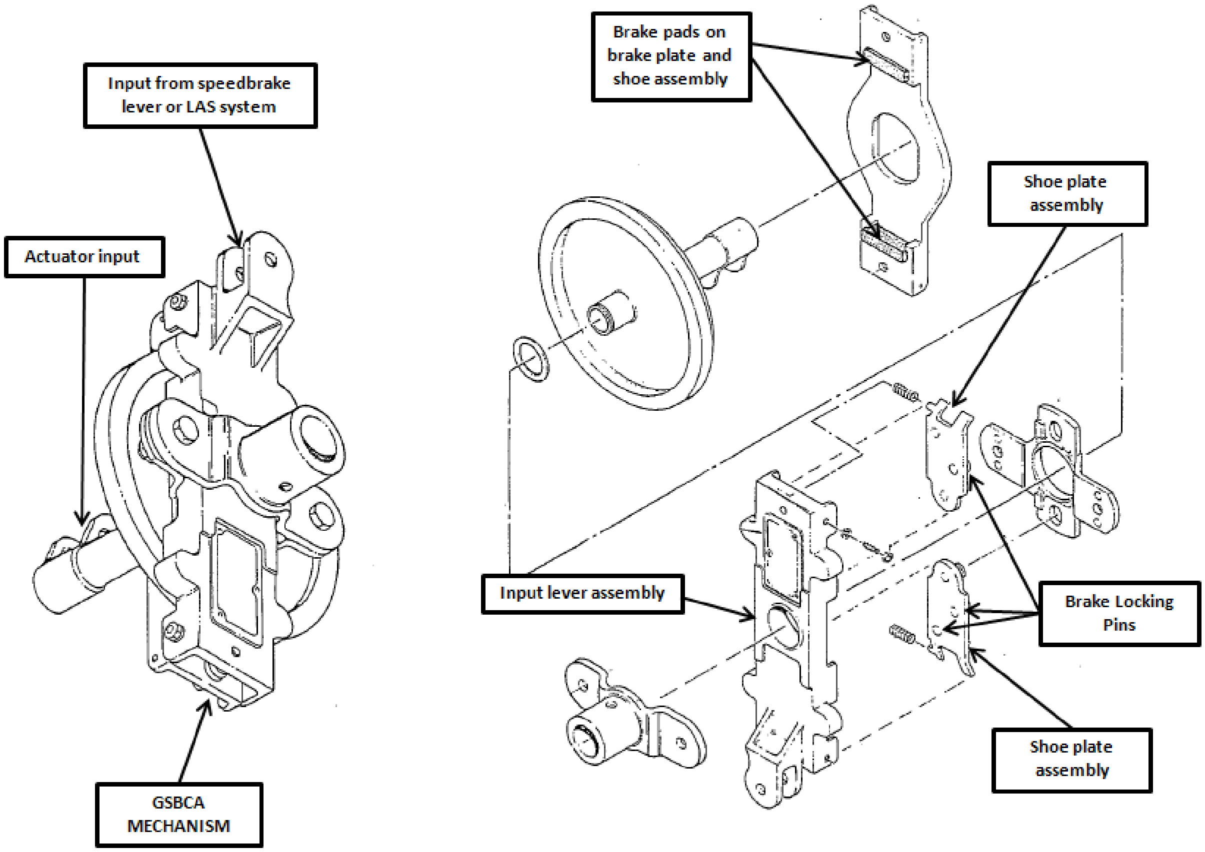
Figure 11 The GSBCA after removal from the speedbrake assembly



The outer coupling was then removed, revealing the center bronze bushings. The bushings displayed light rotational burnishing, which according to Adams Rite representatives is consistent with normal operation and wear. The pilot-controlled flat race upper and lower friction plate surfaces displayed light radial burnishing consistent with normal operation. Light oil residue was noted on all friction surfaces. The GSBCA was then tested in accordance with acceptance test procedure (ATP) Number 2115, revision F. This revision was current at the time of manufacture of the subject mechanism. All tests were found to be within acceptable limits.

The GSBCA was then dissembled and its internal components were examined. Refer to figure 12 for a schematic showing the internal components.

Figure 12 Schematic of the GSBCA



Radial burnishing was noted on the semi-circular brake pads, with a light oil-like film present on all friction surfaces. Refer to figure 13 for a view of the brake pads. Removal of the input lever assembly revealed the four circular brake pads, which displayed similar burnish markings as the brake pads on the brake plate and shoe assembly. Refer to figure 14 for a view of the brake pads.

Figure 13 Brake plate assembly

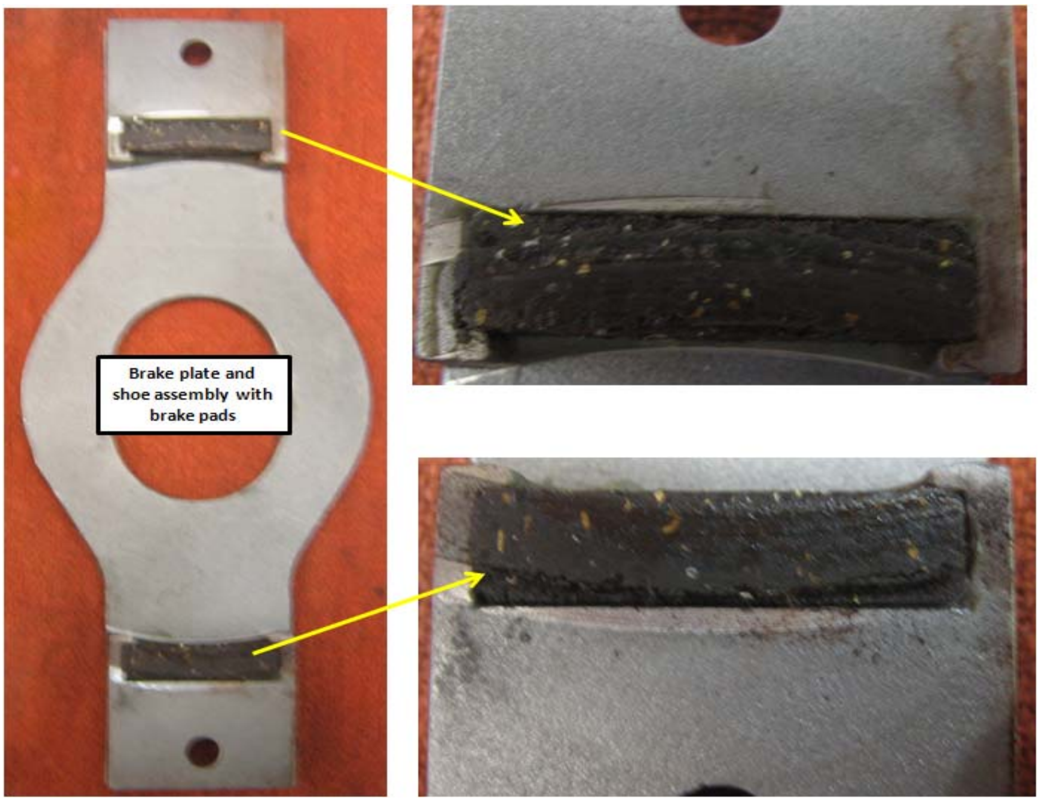
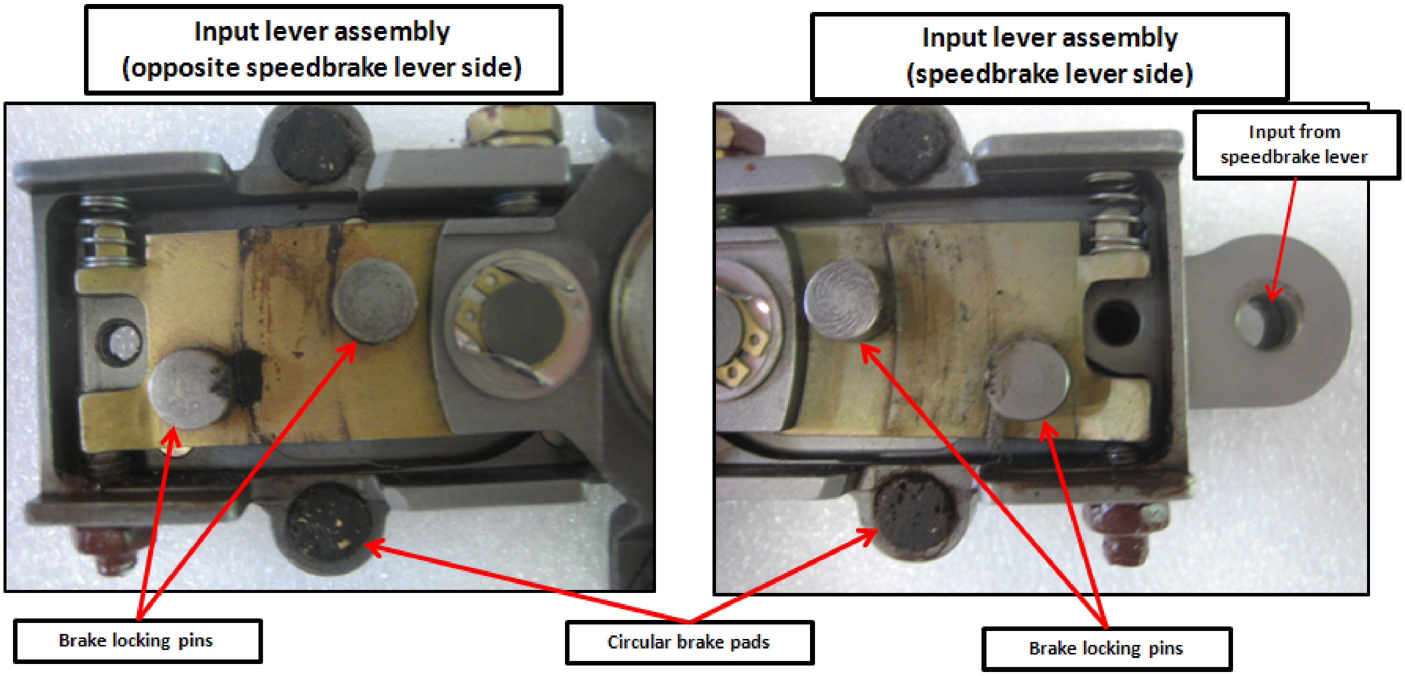
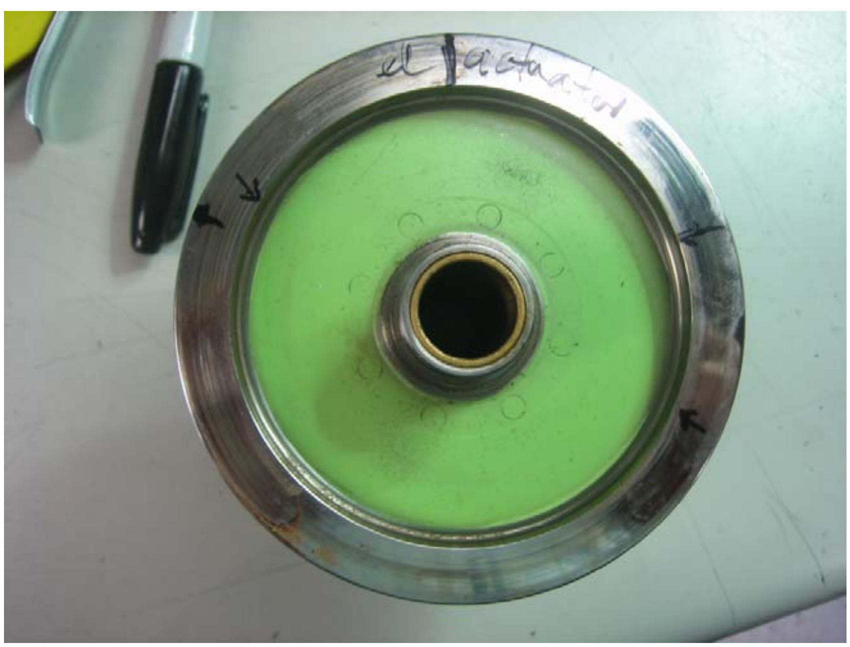


Figure 14 Input lever assembly



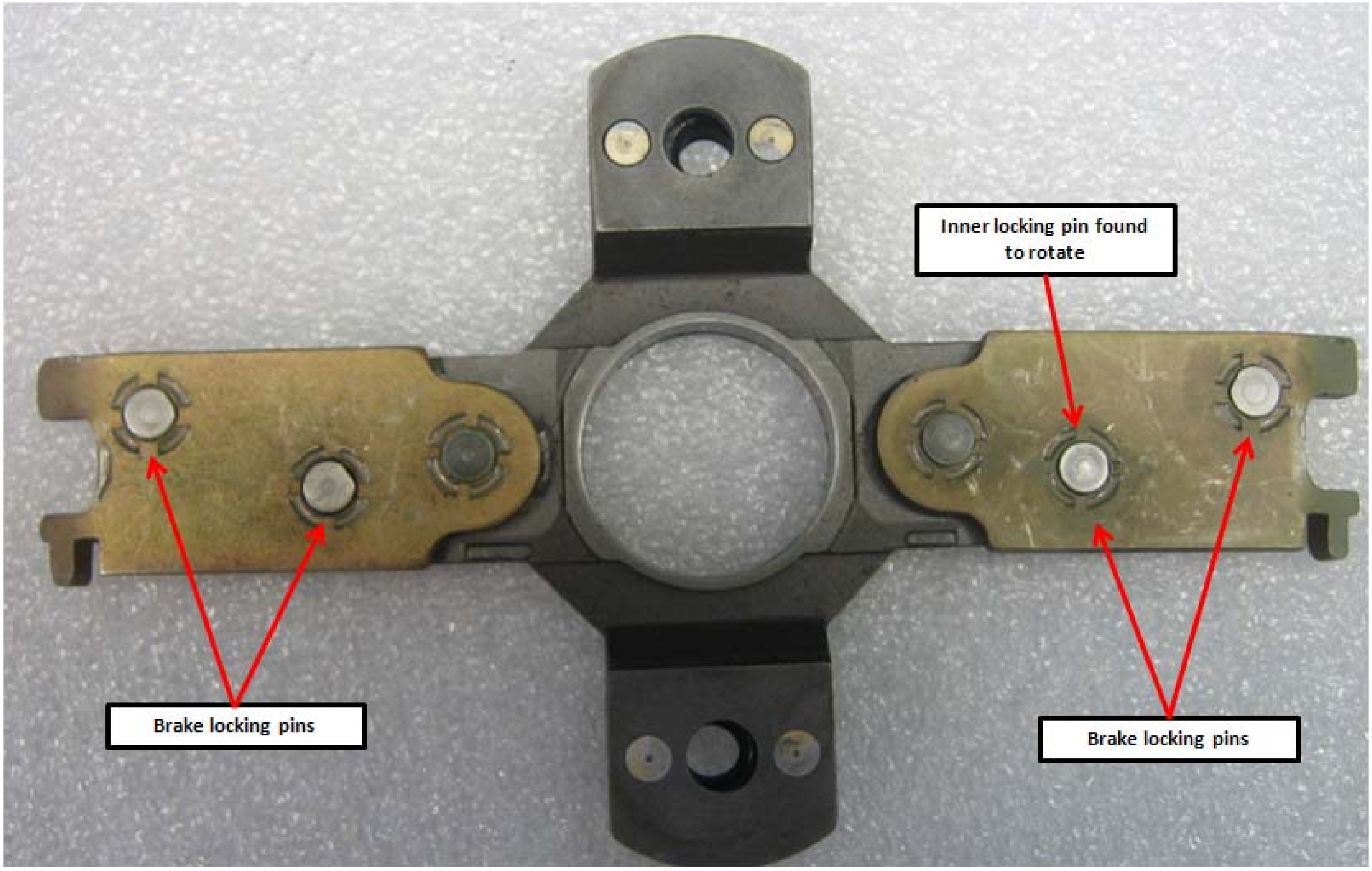
Three flat spots were noted on the inner race of the hub assembly with one flat spot noted on the outer race. The flat spot positions were measured from an index line (center of hub assembly through the center of the clevis). The inner wear points measured clockwise at the 75, 118, and counterclockwise 56 degrees point relative to the index. The outer race spot was measured counterclockwise 65.3 degrees relative to the index. Refer to Figure 15. The output assembly appeared free of damage.

Figure 15 Hub assembly showing the location of the flat spots



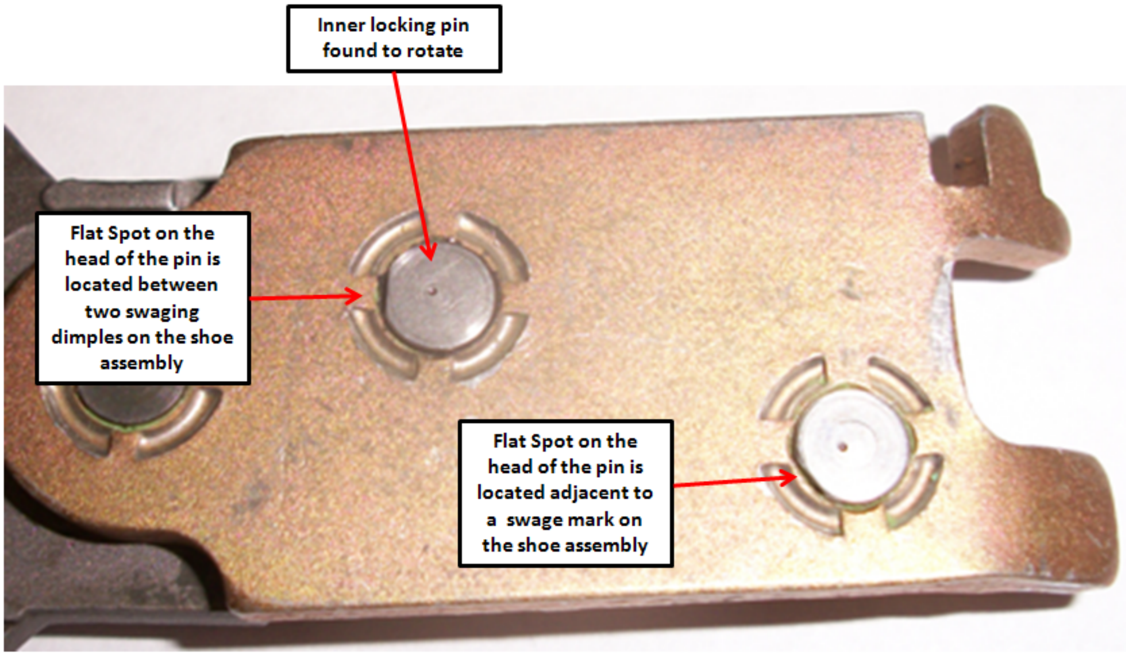
The outer brake locking pins and the inner brake locking pin adjacent to output lever displayed flat spots on their friction surfaces. The inner brake locking pin, located opposite to output lever, displayed no flat spots and was found to rotate within its plate (Figure 17).

Figure 16 Output lever and shoe assembly



Grease was subsequently removed from the surfaces of each brake locking pin and all pins were visually examined. The head of each pin appeared to incorporate anti-rotation flats consistent with design drawings. Examination of the staking area on the shoe plates revealed a segmented 4-tooth staking die had been utilized (Figure 17). A review of the manufacturers drawing for the shoe plate assembly revealed that there was no information denoting the need to orient the anti-rotation flats on the pins with the swage prior to staking. The drawing also indicates that the 4-tooth staking die is an alternate method for attaching the pins to the shoe plate. The fully circular swaging method referenced in early drawing revisions is also acceptable.

Figure 17 Brake pins installed on the GSBCA



The brake unit's component parts were examined utilizing a coordinate measuring machine with no anomalies found.

D.6.3.8 757 Speedbrake System In-Service History:

At the request of the NTSB, Boeing performed a search of their database for all reports indicating that the speedbrakes failed to deploy. The search revealed three reports from operators in which the speedbrakes failed to deploy as expected during landing. None of these events resulted in a landing overrun. Boeing also performed a search of their database for all reports involving no-back clutch mechanism anomalies. The search revealed five events during the period of March 1983 through December 1998. Of the five reports, only one report stated that the speedbrakes failed to deploy. The other four no-back anomalies were discovered during maintenance activities.

D.7 Thrust Reverser System:

A review of the data from the incident landing (Jackson Hole) on the incident recorder indicates that the airplane touched down at 11:37:36 MST. Upon touchdown, the air/ground discrete transitioned to “Ground”. Approximately one second later, the air/ground discrete indicated “Air” for about 0.5 seconds before transitioning back to “Ground” for the remainder of the landing.

At the initial touchdown (air/ground system indicating “Ground”), the left engine’s thrust lever “Equivalent Power Lever Angle (PLA)” parameter indicated a position of about 50.2 degrees and the right PLA parameter indicated a position of about 49.9 degrees.

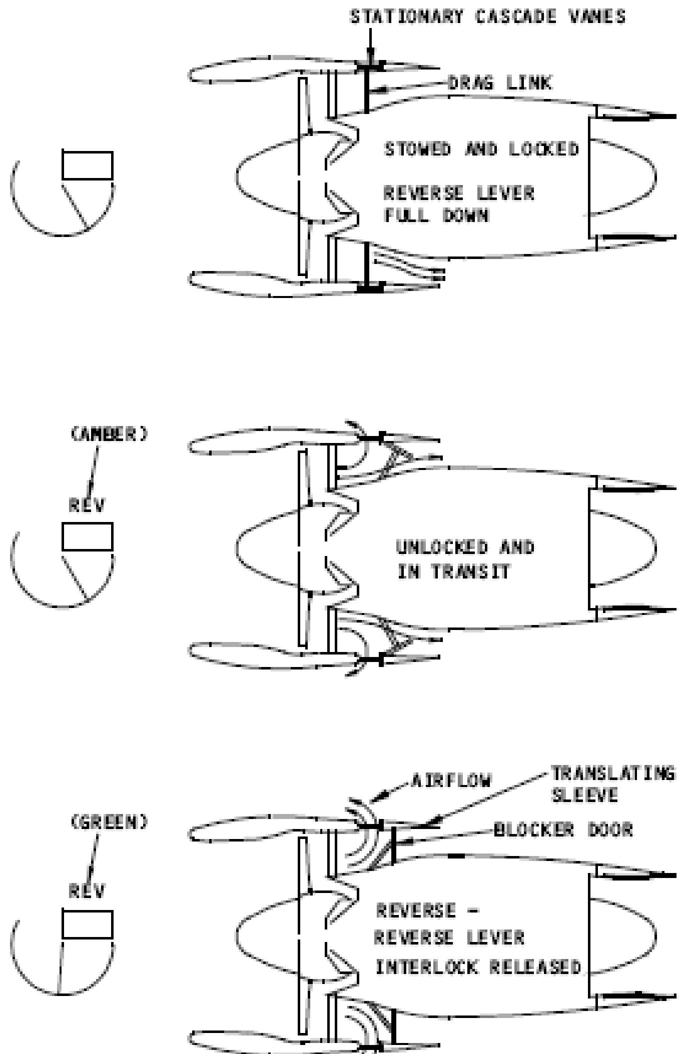
Less than one second after initial touchdown, the value for the right engines PLA indicated a position of about 40 degrees. About 1.5 seconds after touchdown, the value for both the right and the left PLA parameters indicated a position of about 35 degrees and the left thrust reverser “Transit” discrete indicated “in transit”. About 2.0 seconds after touchdown, both the right and the left thrust reverser “Transit” discrete’s indicated “in transit”. Both thrust reverser “Transit” discrete’s continued to indicate “in transit” for about eleven seconds, at which point, they briefly transitioned back to “not in transit” and then back to “in-transit” again. During the time they transitioned back to “not in transit”, the value for the left PLA increased from a value of about 35 degrees PLA up to a value slightly greater than 45 degrees PLA. During the time they transitioned back to “in transit”, the value for the right PLA began decreasing from a value of about 35 degrees PLA to a value of about zero degrees PLA and the value for the left PLA began decreasing from a value of about 45 degrees PLA to a value of about 10 degrees PLA. Both thrust reverser “transit” discrete’s continued to indicate “in transit” for an additional 5 seconds, at which point, they transitioned back to “not in transit” and both thrust reversers indicated “deployed”.

The FDR contained fourteen landings. A review of this data identified that, other than the landing in Jackson Hole, Wyoming the thrust reverser’s deployed without delay when commanded on each of the other landings. A review of the thrust reverser “Transit” discrete and the “Throttle Lever Angle” discrete from the thirteen other landings revealed that the thrust reverser’s were commanded to be deployed anywhere from 1 to 6 seconds after initial touchdown. On three landings, they were commanded between 1 to 2.5 seconds, on six landings, they were commanded between 2 to 4 seconds and on the remainder of the landings, they were commanded after 4 seconds. On the incident landing, the thrust reversers were commanded to be deployed between 0.5 to 1.5 seconds after initial touchdown.

D.7.1 System Description:

The airplane’s thrust reverser system is designed to assist the airplane with deceleration after landing. The thrust reverser utilizes engine power as a decelerating force by reversing the direction of the fan exhaust gas stream. The thrust reverser system responds to the pilot’s positioning of the thrust reverser levers by using cables and micro switches to command reverse thrust functions. Thrust reversal is achieved by means of left and right hand translating sleeves containing blocker doors that block the fan flow redirecting it through fixed deflector vanes (cascades). Refer to figure 18 for a schematic of the thrust reversers. The translating sleeves are hydraulically actuated. Reverse thrust use is restricted to ground operation only, providing additional retarding force on the airplane during landings and refused takeoffs.

Figure 18 Thrust reverser schematic



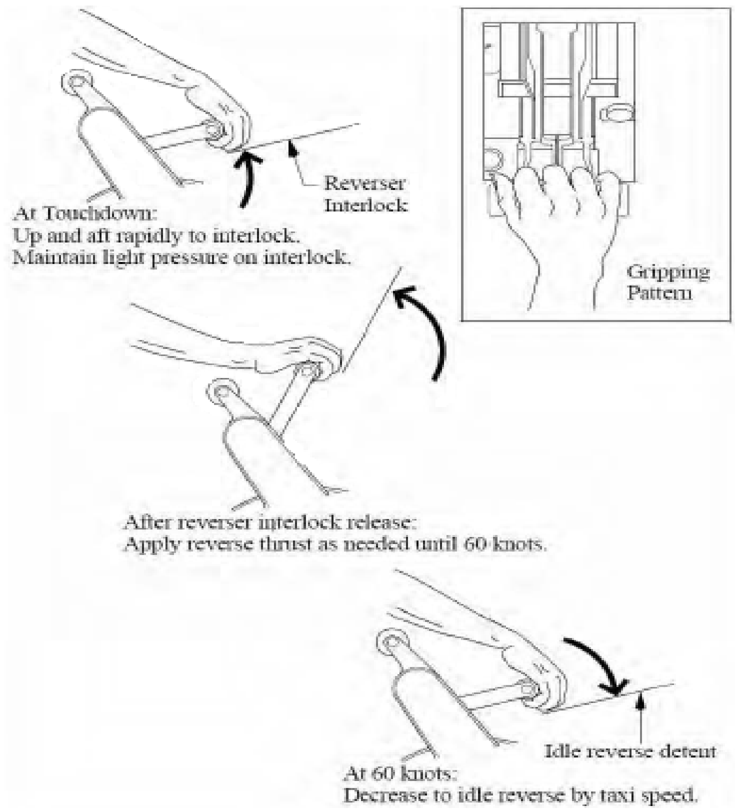
In the forward thrust configuration, the cascades are blocked off by a translating sleeve; the outer sleeve forms the aerodynamic line of the propulsion system and the inner sleeve forms part of the outer wall of the fan stream duct. In the reverse thrust configuration, the sleeve translates rearward to expose the cascades. Blocker doors, attached to the translating sleeve move with the translating sleeve and fold inward to block the fan duct downstream, thus diverting the fan stream gas flow through the cascades. The thrust reverser comprises two C-shaped sections, hinged at the top to provide access to the core engine.

To command reverse thrust, a pilot positions the engine thrust lever(s) to idle[9], and then, after touchdown, lifts the reverse thrust lever(s) up and rearward to their interlock position, and applies reverse thrust as required. Refer to figure 19 for a schematic showing reverse thrust

9 When the thrust levers are at idle power, the equivalent PLA is about 50 degrees.

operation. The pilot monitoring should monitor engine operating limits and call out any engine operational limits being approached or exceeded, any thrust reverser failure, or any other abnormalities[10]. Each reverse thrust lever will be restricted in its interlock position by a baulk mechanism until its respective translating sleeve reaches its mid-travel position (approximately 55% deployed).

Figure 19 Schematic showing reverse thrust operation



When the reverse thrust levers are lifted to their interlock position, the following actions occur within the thrust reverser system: 1) the directional control valve (DCV) is mechanically positioned to extend the reversers, and 2) when the air/ground system indicates "Ground", the sync-lock[11] control switch is activated, and the solenoid valve[12] on the hydraulic isolation valve (HIV) is energized after a 100 millisecond time delay.

Prior to the activation of the sync-lock actuator, the sync-lock mechanism prevents the rotation of the rotary flex shafts by engagement of a serrated static disc with a serrated disc that is

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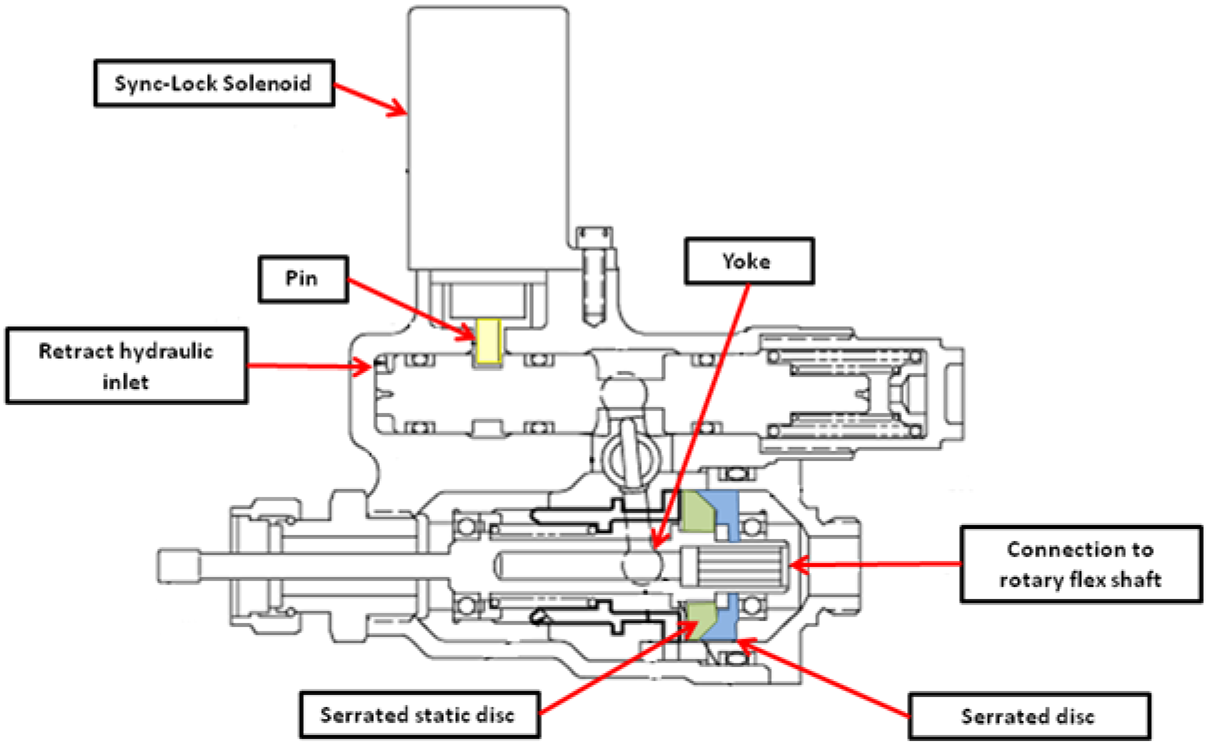
[10] Reference the American Airlines 757/767 Flight Crew Operating Manual section 50.34 "approach – landing-go-around" dated 7-30-2010.

[11] The sync-lock is attached to the lower side of the center hydraulic actuator on each right thrust reverser half. Its purpose is to prevent the translating sleeves from accidental extension because of the failure of or accidental electrical signals to the hydraulic system. This is done by the use of locking elements that prevent the synchronizing flexible drive shafts being turned.

[12] Operation of the reverse thrust lever closes the isolation valve control switch, which is located in the auto throttle switch pack activating the solenoid valve on the isolation valve.

connected to the rotary flex shafts. The activation of the sync-lock control switch completes the circuit that energizes the sync-lock relay to energize the sync-lock solenoid (Figure 20). When energized, the solenoid removes the pin from the piston in the sync-lock actuator unlocking it and allowing hydraulic pressure (when available) to move the piston.

Figure 20 Sync-Lock actuator



After the 100 millisecond time delay, the solenoid valve on the HIV is activated opening the isolation valve to port hydraulic fluid to the DCV. When the DCV is positioned to extend (reverse thrust levers positioned to interlock), it ports hydraulic fluid (from the HIV), at approximately 3000 psi to the sync-lock and to both sides of the piston within each of the six hydraulic actuators. The hydraulic pressure moves the sync-lock “unlock piston” which turns a yoke to disengage the static serrated disc from its mating serrated disc within the sync-lock. This unlocks the sync-lock and permits the rotary flexshafts to turn when commanded.

Because the area on the extend side of the piston, on each of the six actuators, is greater than the retract side, hydraulic pressure will move the actuator piston linearly in the extend direction. Linear movement of the actuator piston produces rotation of the acme screw shaft and worm gear to turn the rotary flexible shafts for synchronized operation thus translating both translating sleeves.

When the reverser system is activated the reverser indication (REV) is displayed above each digital EPR indication in amber when the reverser is in transit and in green when the reverser is fully deployed. Feedback actuators, attached to the translating sleeve, extend as the sleeve moves rearward. This movement, through the feedback cable, releases the baulk mechanism in the strut engine control linkage. The reverse thrust levers cannot be raised to the maximum reverse thrust position until the baulk mechanism releases. Pressing the reverse thrust levers to the full down position retracts the reversers to the stowed and locked position. When the reverser reaches the stowed position, the amber REV annunciation disappears.

The thrust reverser auto restow system comprises a stow-relay and two auto restow proximity sensors. The proximity sensors are located on each section of the translating sleeve and are mounted on the front lower bifurcation of the reverser fixed structure. The target (sensitivity plate), through which the electrical circuit to the auto restow logic card is energized or de-energized, is located on the front edge of the translating sleeve lower outer slider mounting bracket. Whenever one or both thrust reverser translating sleeves are unstowed, its respective proximity sensor will send an electronic signal to the PSEU resulting in the stow-relay being de-energized and it contacts opening, which allows another path for electrical power to be supplied to the HIV. During normal reverse thrust operation, the auto restow system ensures that the HIV remains energized throughout the reverse thrust operating cycle when the system is re-stowed.

To stow the thrust reverser, the reverse thrust lever is returned to its full down position and the DCV is mechanically placed in the stow position, which ports the actuator head end fluid to the return system. Although the HIV switch on the thrust lever is also returned to the off (stow) position, the auto restow sensors for each reverser half result in activation of the auto restow system, which will electrically hold the HIV open until both halves are stowed. When the translating sleeves returns to the stow position, the auto-stow system proximity sensors will send an electronic signal to the PSEU, resulting in the stow-relay being energized and its contacts closing after a 5-second time delay. This action de-energizes the HIV solenoid, shutting off hydraulic power to the thrust reversers.

A malfunction within the thrust reverser control system, results in a (L, R) REV ISLN VAL advisory and/or status message on the EICAS display in the flight compartment. The problems that could cause a REV ISLN VAL indication to be displayed are: Hydraulic pressure switch indicates the HIV is open when not commanded, the stow relay contacts fail closed, an auto-restow proximity sensor problem, or a locking actuator which permits a translating sleeve to extend. On the ground, the L, R REV ISLN VAL advisory and status messages appear when the hydraulic pressure switch indicates the reverser isolation valve is open with the reverse thrust lever in the down position. If this fault is detected above 80 knots during takeoff, or in flight, the advisory message is inhibited, but a status message is recorded in NVM.

D.7.2 Investigative Findings:

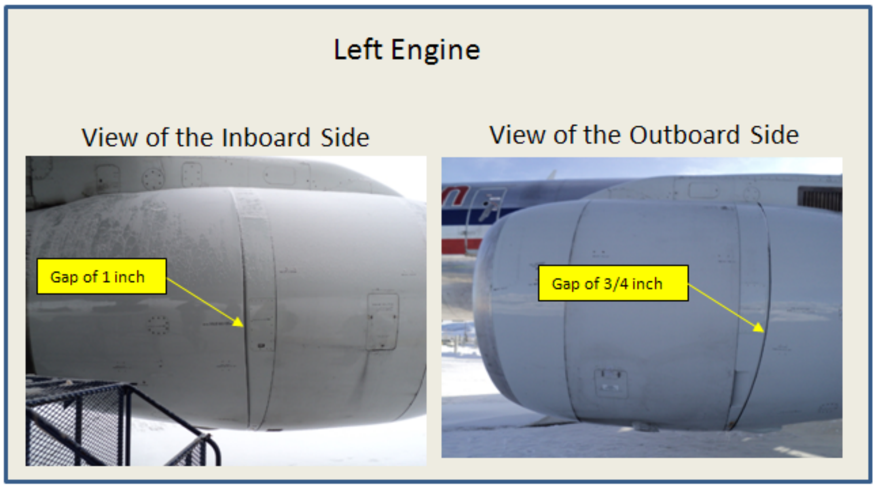
D.7.2.1 Number 1 (Left) Engine:

On December 31, 2010 a review of the EICAS display showed that the message “L REV ISLN VAL” remained displayed on the lower display.

Using the BITE capability of the PSEU, the position of the Number 1 engine’s auto stow sensors indicated a FAR condition, indicating that translating sleeves were not fully stowed. Inspection of the left engine’s translating sleeves confirmed that both the inboard and outboard translating sleeves were not fully stowed (Figure 21).

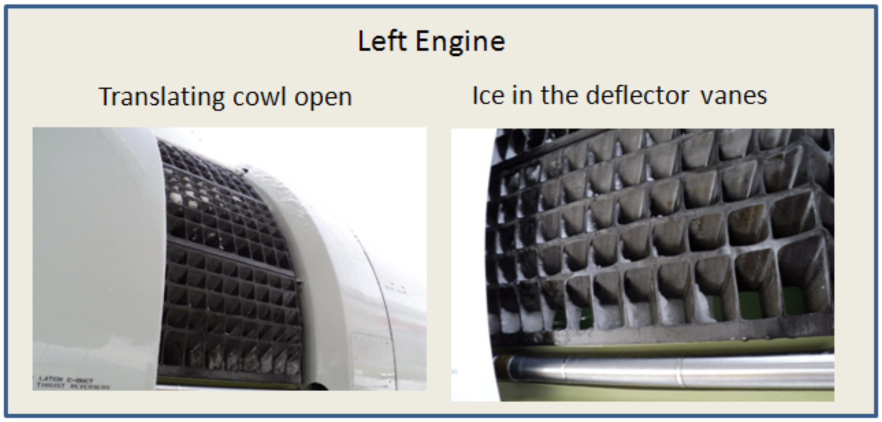
- Inboard side translating sleeve remained open about 1 inch. There was equal distance between the upper and lower leading edge.
- Outboard side translating sleeve remained open about ¾ inch. There was equal distance between the upper and lower leading edge.

Figure 21 Position of the translating sleeves on the left engine



Prior to actuating the translating sleeves hydraulically, a visual inspection (through the gap) was conducted to ensure nothing would restrict their movement. The inspection found a significant amount of ice build-up between the left engine translating sleeves. Using propane heaters, heat was applied to the area around the thrust reversers in an attempt to melt the ice. After approximately 3 hours of applying heat, the translating sleeves could be manually extended using a hand crank at the external drive socket on the left thrust reverser. Once fully opened, inspection found significant quantities of ice within the reverser assembly and cascade elements (Figure 22).

Figure 22 Ice in left engines thrust reversers



Using propane heaters, heat was applied to the area around the thrust reversers to melt the ice within the reverser. Once melted, the reverser was fully closed (stowed) using the left hydraulic system. The reverser was then cycled by moving thrust reverser (piggyback) levers. During this procedure, the speedbrake handle moved fully aft and the ground spoilers deployed when the thrust reverser (piggyback) levers were moved to their interlock position.

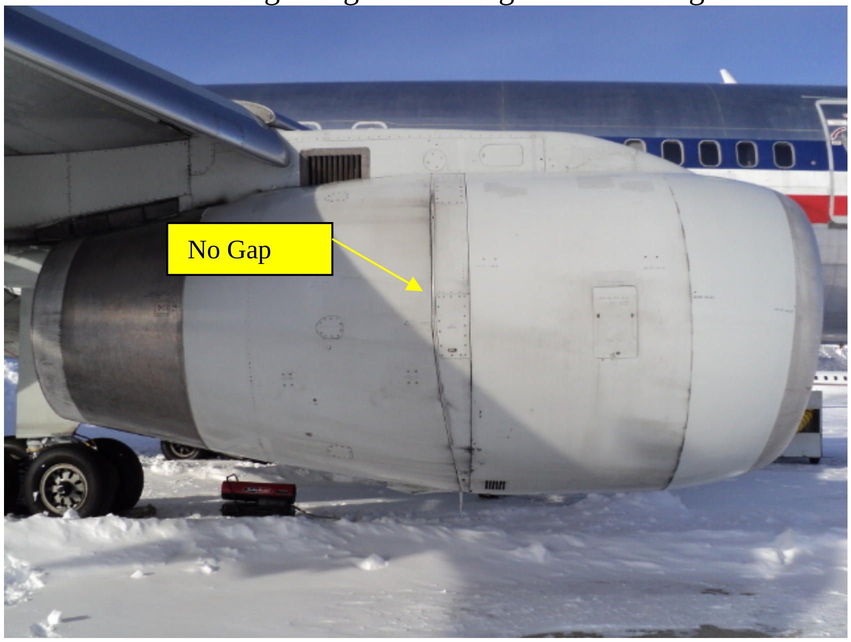
NOTE: After the left engine thrust reversers were closed, both engines were started and ran for about 15 minutes in an attempt to melt the remaining ice.

D.7.2.2 Number 2 (Right) Engine Reverser:

On December 31, 2010 a review of the EICAS display showed no EICAS messages were displayed for the Number 2 Engine.

Using the BITE capability of the PSEU, the position of the Number 2 engine's auto stow sensors indicated a NEAR condition, indicating that translating sleeves were fully stowed. Inspection of the Number 2 engine's translating sleeves found that both the inboard and outboard translating sleeves were fully stowed (Figure 23) and that all three lock indicators were found in their locked position.

Figure 23 View of the right engine showing the translating sleeves closed



The translating sleeves were manually opened about 12 inches using a hand crank. A visual inspection found significant amounts of ice within the reverser assembly similar to the amount of ice found in the left engine. Using propane heaters, heat was applied to the area around the thrust reversers to melt the ice.

D.7.2.3 Thrust Reverser Testing:

On January 3, 2011, a test of the left and right engines thrust reverser system was conducted in accordance with the procedure contained within AMM 78-31-00/501, dated May 20, 2010. The following three tests were performed and no anomalies were noted; the system operated normally and within all specifications:

a. The Usual Operation Test “Task 78-31-00-715-216-R01”.
b. Thrust Reverser - Auto Restow and Sync-lock Test “Task 78-31-00-715-252-R01”.
c. Thrust Reverser - Air/Ground Logic Test “Task 78-31-00-715-226-R01”.

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