FINAL REPORT

MCDONNELL DOUGLAS MD-11 REGISTRATION N413LT

CENTRE LANDING GEAR DAMAGE DURING LANDING

SINGAPORE CHANGI AIRPORT

7 APRIL 2005

AIB/AAI/CAS.023

Air Accident Investigation Bureau of Singapore
Ministry of Transport
Singapore

08 May 2009

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> *"The sole objective of the investigation of an accident or incident shall be the prevention of accidents and incidents. It is not the purpose of this activity to apportion blame or liability."*

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SYNOPSIS

On 7 April 2005, a McDonnell-Douglas MD-11 aircraft carried out a series of test flights after a passenger-to-freighter (PTF) conversion in a maintenance facility in Singapore. The aircraft was scheduled to perform three landings and one go-around at Changi Airport on the day of the flight tests. The flights were normal for the first two landings. During the third landing, the centre landing gear (CLG) lower drag brace link forward attachment point and the gear retract actuator end broke loose from the aircraft structure.

There was no injury in this incident.

The occurrence was classified as an incident by the Air Accident Investigation Bureau of Singapore.

AIRCRAFT DETAILS

Aircraft type	:	McDonnell Douglas MD-11
Registration	:	N413LT
Number and Type of Engines	:	Three, General Electric CF6-80C2
Place	:	Singapore Changi Airport
Date and Time (Local Time)	:	7 April 2005, 1110 hours
Type of Flight	:	Test flight after passenger-to-freighter conversion
Persons on Board	:	Five

GLOSSARY OF ABBREVIATIONS

ACU	Autobrake control unit
AMM	Aircraft maintenance manual
ASCU	Antiskid control unit
ATC	Air traffic control
BMT/TPI	Brake Temperature Monitoring/Tyre Pressure Indicator
CLG	Centre landing gear
CVR	Cockpit voice recorder
FDR	Flight data recorder
FO	First Officer
IBCV	Integrated brake control valve
MAX	Maximum
MED	Medium
MIN	Minimum
MLG	Main landing gear
NLG	Nose landing gear
PF	Pilot flying
PIC	Pilot-in-command
psi	Pound per square inch
PTF	Passenger-to-freighter
RTO	Rejected take-off
SB	Service bulletin

1 FACTUAL INFORMATION

All times used in this report are Singapore times. Singapore time is eight hours ahead of Coordinated Universal Time (UTC).

1.1 History of flight

1.1.1 On 7 April 2005, the MD-11 aircraft carried out a series of test flights after a passenger-to-freighter (PTF) conversion in a maintenance facility in Paya Lebar Airport, Singapore. The test flights involved the aircraft flying from Paya Lebar Airport to Changi Airport, and one of the flight test items was the performance of the autoland system. The aircraft was scheduled to perform three landings and one go-around at Changi Airport. The flights were normal for the first two landings. The incident took place on the third landing of the flight test.

1.1.2 Prior to the take-off from Paya Lebar Airport on 7 April 2005, two braking tests were carried out at about 0730 hours: first a low speed autobrake rejected take-off (RTO) and then a high speed autobrake RTO. For both the braking tests, the flight crew recorded in the test sheet that the braking operation was satisfactory. (Refer to 1.7.2.2 for some parameters recorded for the two braking tests.) It was noted after the incident that, during the high speed autobrake RTO, the autobrake was disarmed at about 115 knots when brake pedals were pressed. The Flight Test Manual (FTM) recommended disarming at 70 knots.

1.1.3 A post-incident review of the Brake Temperature Monitoring/Tyre Pressure Indicator (BTM/TPI) log showed that, about five minutes after the high speed RTO, there was a brake #5 (on left main landing gear (MLG)) overheat alert with a peak temperature of 629℃. About two minutes later, a brake #10 (on centre landing gear (CLG)) overheat alert was also recorded, with a peak temperature of 603℃. The FTM indicated that the overheat threshold was 550℃ and that the brake temperature should peak at about 10 to 15 minutes after brake application.

1.1.4 The BTM/TPI log also recorded a fault of simultaneous failure of the two CLG tyres (#9 and #10) after the high speed RTO. However, the two tyres appeared inflated and intact immediately after the incident.

1.1.5 The aircraft took off from Paya Lebar Airport on 7 April 2005 at about 0800 hours. The aircraft flew for about 2½ hours before landing on Runway 02C at Changi Airport. This first landing was carried out with Autopilots 1 and 2, 50° flap and autobrake set at MIN[1] (minimum). No problems were reported.

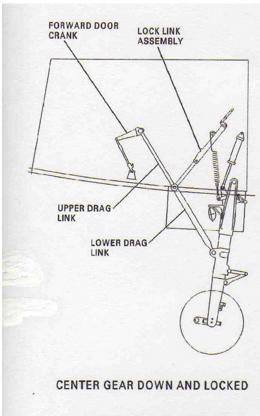
[1] The MIN setting would apply sufficient brake system pressure to achieve a deceleration rate of 6.5 feet/sec^2.

1.1.6 The aircraft took off again and landed on Runway 02C at about 1048 hours using Autopilot 2, 35° flap and manual braking. No problems were reported.

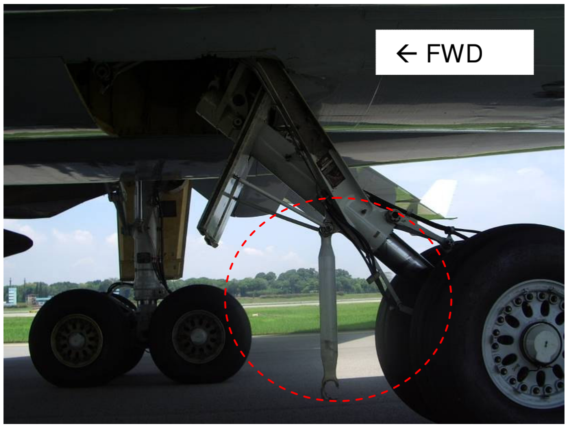
1.1.7 The third take-off was normal and the aircraft landed on Runway 02L at about 1110 hours. The landing was carried out using Autopilot 1, 35° flap and autobrake set at MED[2] (medium). The landing weight was about 155,000 kg (maximum landing weight was 222,941 kg with CLG extended) and approach speed 142 knots.

1.1.8 The pilot-in-command (PIC) was the pilot flying (PF). The crew described that the touchdown was normal but heavy vibrations were felt immediately after the landing. During roll out, the PF disarmed the autobrake manually by pressing the brake pedals. At about the same time, the crew noticed that the CLG "Gear Unsafe" red indication on the primary and secondary flight information displays. The aircraft vacated the runway via Taxiway W3 and stopped on Taxiway WA for the ground engineer to inspect.

1.1.9 The inspection revealed that the CLG, which was normally at an angle of 15° forward of vertical, was angled at about 45° aft of vertical.



Normal CLG geometry



CLG angled at about 45° aft of vertical with the broken lower drag link dangling

The forward lugs of the lower drag brace link, which attached the link (CLG) to the aircraft structure, were broken.

[2] The MED setting would apply sufficient brake system pressure to achieve a deceleration rate of 9 feet/sec^2.

The lugs on the CLG gear retraction actuator were also broken.

1.1.10 The aircraft was towed back to a maintenance facility, with its CLG gear strut depressurised. The CLG's strut inner cylinder was retracted and tied to the upper cylinder. This raised the CLG clear of the ground to prevent further damage. The depressurisation entailed squeezing out some of the damping fluid in the inner cylinder. Thus, it was not possible to determine the correct strut servicing (e.g. correct oil volume and strut pressure versus extension)

1.1.11 An earlier test flight was carried out on 4 April 2005, which was the first test flight after the PTF conversion. Owing to wet runway, only the low speed braking test was carried out before the take-off on that day. No high speed RTO test was carried out. The test prescribed single brake system braking (i.e. using only one of the aircraft's two brake systems) from 35-40 knots down to a full stop. There was no report of any braking problems during the low speed test or the subsequent roll out. (See paragraph 1.8.4.1 for a brief description of the brake system.)

1.2 Injuries to persons

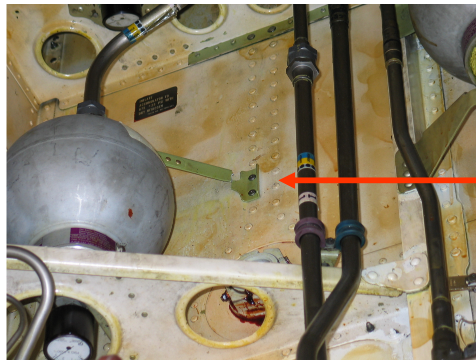
Nil

1.3 Damage to aircraft

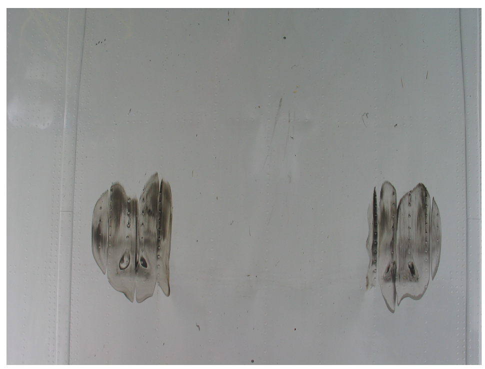
1.3.1 Damages other than those described in paragraph 1.1.9 include the following:

- The aft side of the CLG was pushed against the aft bulkhead of the CLG wheel well, resulting in deformation and failure of metal structure of the bulkhead.
- One CLG door was dislodged and dropped on the runway.
- In the right MLG wheel well, an electrical terminal strip located on the sidewall near the CLG trunnion had shattered and a proximity target located at the end of the CLG trunnion bolt head was found bent away from the bolt.

- In the left MLG wheel well, an accumulator bracket was broken.



- Two dents with tyre marks were found on the aft fuselage above the CLG tyres. They were caused by the backswing of the CLG after the detachment of the lower drag brace link and retract actuator.



- Several dents on fuselage aft of CLG were caused by debris.
- A number of flat spots were found on the two CLG tyres.

1.4 **Personnel Information**

1.4.1 Pilot-in-command

Age	:	49 years (Male)
Licence	:	Airline Transport Pilot Licence issued by the Federal Republic of Germany
Aircraft ratings	:	MD-11
Total flying experience	:	9,500 hours
Flying experience on type	:	3,600 hours
Last Base Check	:	29 August 2004
Last line check	:	1 October 2004
Last simulator check	:	29 August 2004
Last medical check	:	1 March 2005
Flight time (last 24 hours)	:	Nil
Flight time (last 30 days)	:	3 hours
Flight time (last 90 days)	:	90 hours

1.4.2 First Officer

Age	:	58 years (Male)
Licence	:	Airline Transport Pilot Licence issued by the Federal Republic of Germany
Aircraft ratings	:	MD-11
Total flying experience	:	12,000 hours
Flying experience on type	:	2,700 hours
Last Base Check date	:	20 November 2004
Last line check	:	14 May 2004
Last simulator check	:	20 November 2004
Last medical check	:	14 October 2004
Flight time (last 24 hours)	:	Nil
Flight time (last 30 days)	:	18 hours
Flight time (last 90 days)	:	100 hours

1.5 Aircraft Information

1.5.1 The aircraft was manufactured in 1992 and operated as a passenger aircraft by previous operators. The aircraft had accumulated 50,632 hours and 9,227 cycles since new.

1.5.2 The CLG had accumulated a total of about 52,029 hours and 10,126 cycles since new. It was last overhauled in April 2000 before fitted on this aircraft in July 2000, and had accumulated about 18,135 hours and 3,437 cycles since then.

1.5.3 The operator acquired the aircraft in August 2004 and had the PTF conversion and maintenance C check done at the maintenance facility in Singapore in September 2004.

1.5.4 The PTF conversion and C check were completed in March 2005 (after about six months) and the aircraft was ready for test flights in early April 2005.

1.5.5 The aircraft was declared serviceable for test flights and had a valid Export Certificate of Airworthiness issued by the US Federal Aviation Administration to Germany.

1.5.6 The CLG had two wheels, each fitted with a hydraulically operated multi-disc brake unit. Each of the two MLGs had four wheels and each of these wheels was fitted with a hydraulically operated multi-disc brake unit. There were a total of 10 MLG/CLG wheels.

1.5.7 The aircraft brake system comprised the manual brake, autobrake and antiskid systems. The autobrake system was designed to optimise braking performance and reduce tyre wear. There were five autobrake settings (OFF, MIN, MED, MAX and RTO) which provided different deceleration rates. The RTO setting was only used during the take-off roll. The MIN setting provided the least hydraulic pressure on the brake units thus giving the lowest deceleration to the aircraft, while the MAX setting provided the maximum hydraulic pressure. Manual input of the brake pedal will cancel the autobrake system automatically.

1.5.8 Maintenance records showed no entries related to the antiskid system or the autobrake system. Flight data recorder (FDR) data showed that the autobrake pressure increased normally following touchdown.

1.5.9 Autobrake System

1.5.9.1 The flight crew used manual braking procedures when braking was necessary and when the automatic braking system did not operate or was disarmed. When the system was not serviceable, a message would be given by the automatic braking system to the flight information displays.

1.5.9.2 The autobrake control unit (ACU) obtained aircraft acceleration and ground speed data from the inertial reference units. The ACU sent electrical signals to the integrated brake control valves (IBCV) which would operate to achieve the necessary deceleration rate.

1.5.9.3 Each of the 10 brake units of the MLG/CLG wheels had eight pistons and two IBCVs. Each IBCV controlled four of the eight pistons in each brake unit.

1.5.10 Antiskid system

1.5.10.1 The antiskid system monitored and provided skid protection to all wheels during ground operations. The antiskid control unit (ASCU) is the main component in the antiskid system. The ASCU provided skid protection, locked wheel protection function and taxi brake selection function.

1.5.10.2 The aircraft was also equipped with a 15-second touchdown protection timer on the CLG brakes. The touchdown protection timer was to delay brake pressure to the CLG before the nose landing gear (NLG) touchdown. This is to prevent overloading of the CLG during landing operation.

1.5.10.3 The aircraft had incorporated Service Bulletin MD11-32-30 issued in March 1993. Its ASCU part number was 6005304-3. (See paragraph 1.9.2.3)

1.6 Meteorological Information

1.6.1 The weather on the day of incident was fine with no rain. Surface wind was 5 knots at 340°.

1.7 **Flight Recorders**

1.7.1 Cockpit Voice Recorder (CVR)

1.7.1.1 The aircraft was equipped with a Honeywell solid state CVR (part number 980-6022-001, serial number CVR120-07053) with a recording length of two hours.

1.7.1.2 The four tracks of the CVR recorded separately the microphone inputs of the PIC, co-pilot, observer and the cockpit area. The quality of the recording was satisfactory.

1.7.1.3 As the conversation in the cockpit was in German, the CVR was removed and sent to the German Federal Bureau of Aircraft Accident Investigation (BFU) for downloading as well as translation into English. An English translation of the relevant CVR transcript was provided by the BFU to the investigation team.

1.7.2 Flight Data Recorder (FDR)

1.7.2.1 The aircraft was equipped with a Honeywell solid state FDR (part number 980- 4700-042, serial number 08735). The data was read out by the operator and provided to the investigation team for analysis.

1.7.2.2 The FDR data showed the following parameters for the low and high speed autobrake RTO tests on 7 April 2005:

	Low speed RTO	High Speed RTO
Peak air speed before braking	64 knots (prescribed 50-55 knots)	116 knots (prescribed 110 knots)
Type of brake application	Auto-brake with average deceleration of about 6.5 ft/sec^2 (The test is prescribed with spoilers armed and Auto-brake set to RTO; accelerate the aircraft to 50-55 kts and retard the throttles and move levers to reverse idle position. The automatic spoiler handle movement triggers the Auto-brake to MIN braking of 6.5 ft/sec/sec deceleration. The spoilers are to be retracted at 25kts causing Auto-brake to cease braking action.)	Auto-brake and manual brake application with peak deceleration of about 10.8 ft/sec^2 (This test is prescribed with spoilers armed and Auto-brake set to RTO; accelerate to 110 kts and retard the throttles and move levers to reverse idle position. The automatic spoiler handle movement triggers the Auto-brake to MIN braking of 6.5 ft/sec/sec deceleration and maintain the RTO with Auto-brake down to approx. 70 kts before disarming the Auto-brake by pressing brake pedals.)
Braking pressure	About 550 psi to bring aircraft to low speed	Between 1000-2000 psi to bring aircraft to low speed

1.7.2.3 As the FDR data did not include the weight-on-wheel parameter, the touchdown point of the landing when the incident happened was estimated by the change in vertical acceleration.

1.7.2.4 In respect of the landing incident, the FDR data showed that brake pressure to the MLG brakes started to increase about 2.5 seconds after the MLG touchdown. The nose gear strut began to be compressed about 5.8 seconds after the MLG touchdown.

1.7.2.5 About 8.5 seconds after the MLG touchdown, the lateral acceleration showed a single high G recording of +0.312g. The longitudinal acceleration, which had decreased to -0.276g and momentarily increased to -0.005g, then decreased again to -0.383g about 2.8 seconds after the lateral G peak of +0.312g.

1.7.2.6 As the accelerometer sensor was mounted in the MLG wheel well on the same bulkhead as the CLG drag brace upper link assembly and thus would be sensitive to the effect of a tension failure of the lower drag brace link, it is estimated that the lower drag brace link failed at this moment of high lateral G load. At this point, the aircraft speed was about 121 knots and deceleration rate 8.8 ft/sec^2.

1.7.2.7 About 1.7 seconds after the peak longitudinal G load of -0.383g, the “Gear Unsafe” indication was recorded by FDR. (Gear Not Unsafe/ Unsafe parameter was recorded once every four seconds.)

1.8 Test and Research

1.8.1 The CLG components were examined by Boeing and Hawker Pacific Aerospace, California. The damage to the CLG components was determined to be the result of the incident and not a pre-existing condition.

1.8.2 The CLG lower drag brace link and retract actuator were sent for metallurgical examinations. Tests were also carried out on the aircraft brake/antiskid systems and on a number of components removed from the brake/antiskid systems.

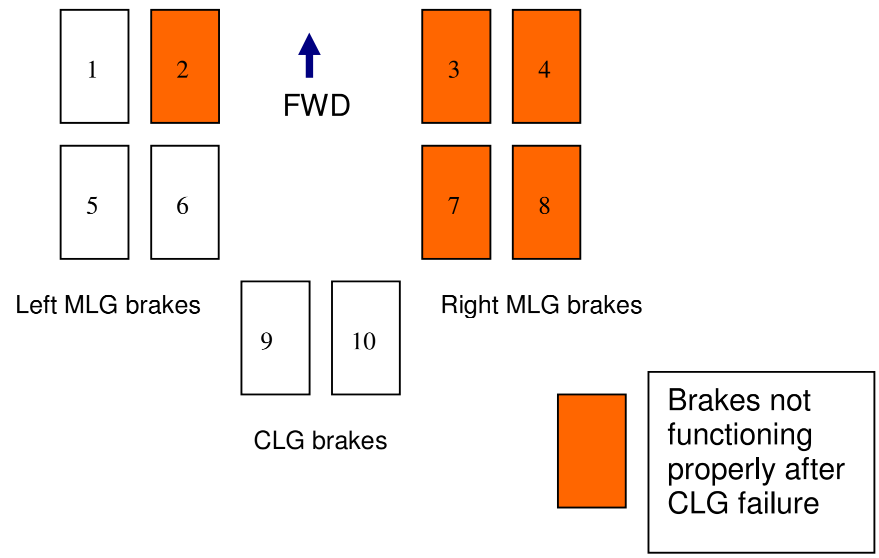
1.8.3 <u>CLG lower drag brace link and retract actuator</u>

1.8.3.1 Metallurgical examinations revealed that the CLG lower drag brace link and retract actuator had fractured under overload.

1.8.4 <u>Brake/antiskid system</u>

1.8.4.1 The eight pistons in each brake unit were operated by two different brake systems, with each brake system operating 4 pistons. Brake system #1 was operated by hydraulic system #1 and brake system #2 was operated by hydraulic system #3.

1.8.4.2 The operator performed a spin check of the antiskid system after the aircraft was towed back to the maintenance facility following the incident. It was noted that brake #2 (in left MLG), #3, #4, #7 and #8 (in right MLG) did not function properly. In each of these five brake units, the four pistons that were powered by brake system #2 did not operate, whereas the four pistons powered by brake system #1 operated normally. The two brake units in the CLG (#9 and #10) functioned properly. The aircraft manufacturer could not determine the cause of the malfunction. It commented that if the brakes #2, #3, #4, #7 and #8 did not function properly during the autobrake RTO tests on 7 April 2005, their energy absorption effectiveness could be reduced by about 40%.



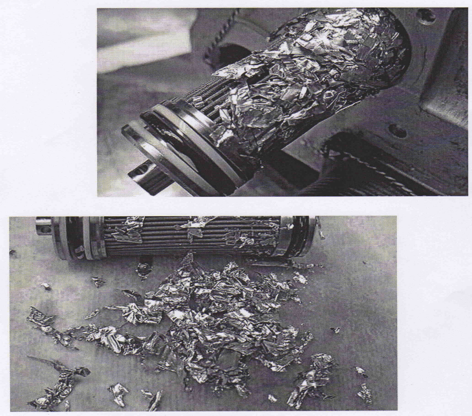
1.8.4.3 The investigation team and engineers from the aircraft manufacturer performed a similar spin check on 15 April 2005. Brake #2 and #8 showed the same problem, i.e. pistons powered by brake system #2 did not operate. After additional spin checks, brake #8 pistons began to function correctly. Brake #2 only began to function properly on the next day in a subsequent check. An oil sample from hydraulic system #3 (which powered brake system #2) was checked for contamination but no contamination was found. The cause of the irregular brake systems operation could not be determined.

1.8.4.4 A test on the antiskid system's 15-second touchdown protection timer (see paragraph 1.5.10.2) was also carried out. The elapsed time from moving the nose gear air/ground input link from AIR to GND (ground) was about 17 seconds.

1.8.5 <u>Aircraft components</u>

1.8.5.1 Two IBCVs (S/N 221 from brake system #1 and S/N 363 from brake system #2) were removed after the incident for disassembly and tests at the IBCV manufacturer. They failed some of the tests carried out on them. S/N 221 was found to have excessive aluminium shavings at the inlet filter. No shavings were found in S/N 363.

1.8.5.2 IBCV S/N 363 was installed in place of SN 219 before the incident. S/N 219 had been sent to the IBCV manufacturer before the incident and was found to have excessive aluminium shavings at the inlet filter.



Aluminium metal shavings found at the inlet filters of IBCV S/N 219 and 221

1.8.5.3 The aircraft manufacturer informed all the operators of this finding, requesting them to check for IBCV filter contamination and to provide feedback when IBCV filter is found contaminated.

1.8.5.4 Basing on the operators' feedback, the aircraft manufacturer identified that a laminated aluminium shim in the Brake Check Valve Manifold Assembly (part number 296200-50XX) was the source of the aluminium shavings found at the inlet filter of the IBCV.

1.8.5.5 This shim was the subject of three similar Service Bulletins (SB) issued to address a parking brake pressure decay problem on DC-10/MD-11 aircraft (SB DC10-32-247 dated 1 December 1997, SB MD11-32-073 dated 1 December 2007, and Parker Hannifin SB 206200-32-92 Revision 1 dated 23 June 1998). These SBs called for modification of the Brake Check Valve Manifold Assembly by replacing the aluminium shim with a solid steel washer and an adjustable steel shim. However, these SBs did not call for the inspection of the IBCV inlet filter. These SBs were subsequently revised to include an inspection of the inlet filter for contamination.

1.8.5.6 The IBCV with contaminated inlet filter (S/N 221) was part of brake system #1 and the brake pistons in all the brake units controlled by this brake system were observed to be working properly during the post-incident test. The contaminated inlet filter did not seem to have affected the functioning of the pistons in brakes #2, #3, #4, #7 and #8.

1.8.5.7 The aircraft manufacturer performed a series of system level tests to compare the performance of the brake system with and without a contaminated IBCV inlet filter and to assess the effects that a contaminated IBCV inlet filter may have on overall braking system performance and on the stability of MD-11 CLG during antiskid braking. The tests were conducted using a hydraulic brake control system simulator complete with all the MD-11 brake system components and piping. The aircraft manufacturer concluded from the test data that there was no degraded performance of brake system with a heavily contaminated IBCV inlet filter.

1.9 Additional information

1.9.1 Maintenance work during PTF modification

1.9.1.1 According to the operator's maintenance records, the following jobs related to the hydraulic systems, CLG, and brake systems were performed during the maintenance C check in Singapore:

(a) All three hydraulic systems were drained and refilled with Skydrol hydraulic fluid. New hydraulic system filters were installed. The hydraulic reservoirs fill filters were also replaced.

(b) The CLG was de-pressurised and the bearing was rotated 90° to compensate for localised wear. The gear was not oil serviced after that. It was re-pressurised in accordance with the maintenance manual.

(c) Anti-skid control unit P/N 6005304-3 was installed.

(d) The CLG's #9 wheel/tyre assembly was replaced due to a deep cut in the tyre.

(e) The CLG wire harness for the antiskid wheel speed transducers and the tyre pressure transducers were replaced due to external damage. An antiskid check was performed per aircraft maintenance manual (AMM) 32-45-00 Revision 50 and found satisfactory.

(f) One brake hose on the CLG was removed for leak inspection. It was subsequently replaced by another hose.

(g) During pre-flight check on 30 March 2005, the autobrake in RTO setting would incorrectly disarm when the spoiler handle was moved one inch out of position. IBCV S/N 219 was replaced by S/N 363 to fix the problem.

1.9.1.2 There was no maintenance record on inspection/servicing done on the CLG lower drag brace link attachment lugs prior to the incident as there was no requirement for in-service inspection of the attachment lugs.

1.9.2 Similar occurrences

1.9.2.1 Since its entry into service, MD-11 had experienced seven other CLG failures similar to N413LT's.

1.9.2.2 The first three failures were in-service events while the fourth and fifth occurred on instrumented aircraft used to investigate the first three events. The sixth happened on 5 October 1999 during landing roll at Newark International Airport in the United States and was investigated by the US National Transportation Safety Board (NTSB). The seventh happened in Paris in November 2006.

1.9.2.3 Basing on the findings from the first five events, the anti-skid control box was modified to prevent CLG wheel brake application until the nose landing gear was on the ground. In addition, the antiskid cycle rate was modified to avoid the cyclic range related to the natural frequency of the CLG. The aircraft manufacturer issued All Operators Letters to highlight the events. It also issued Service Bulletin MD11-32-30 in March 1993 to suggest replacement of ASCU P/N 6005304-1 by P/N 6005304-2 (or later dash number), aiming at correcting the software timing error which occurred in the earlier antiskid control unit and at minimising the possibility of CLG drag brace link failure by preventing brake pressure application prior to nose gear touchdown.

1.9.2.4 The aircraft involved in the Newark incident was delivered to the operator in 1993 and the CLG had then accumulated 22,055 hours and 5,120 cycles. The aircraft had incorporated Service Bulletin MD11-32-30. The probable cause of the incident as determined by NTSB was a divergent, longitudinal oscillation of undetermined origin on the CLG, which caused a failure of the CLG lower drag brace during landing roll.

1.9.2.5 According to the aircraft manufacturer, the current recommended inspection/overhaul interval of the lower drag brace link is at landing gear overhaul (eight years or 7,500 cycles, whichever is earlier).

1.9.2.6 The cause of the Paris incident is still unknown, but the piston of the CLG was found bowed forward, not aft as would be expected. According to the aircraft manufacturer, permanent deformation in this direction indicates that the bowing condition most likely existed prior to the incident. Some pistons of the CLGs from past failure events (including the N413LT incident) were later found to have the same condition. The cause of the pistons' bending, as well as the effect of the bowing, is the subject of an on-going investigation by the aircraft manufacturer and the NTSB.

2 ANALYSIS

2.1 CLG failure

2.1.1 Metallurgical examinations revealed that both the CLG lower drag brace link and retract actuator had fractured under overloading.

2.1.2 The investigation team attempted to identify possible causes of the overload. The team considered if the following could have been a factor:

(a) Fault recorded in BTM/TPI log concerning CLG tyre failures
(b) Premature application of brake pressure to the CLG brakes
(c) Irregular behaviour of brake system
(d) Contamination of IBCV inlet filters

2.1.3 <u>Fault recorded in BTM/TPI log concerning CLG tyre failures</u>

2.1.3.1 The BTM/TPI log recorded a fault of simultaneous failure of the two CLG tyres (#9 and #10) after the high speed autobrake RTO test on 7 April 2005. However, the fact that the two tyres appeared inflated and intact immediately after the incident suggests that the recorded fault was a spurious message.

2.1.4 <u>Premature application of brake pressure to the CLG brakes</u>

2.1.4.1 As the brake pressure to the CLG brakes was not a parameter to be recorded in the aircraft's recorder systems, it would not be possible to judge by brake pressure figures if there was premature application of brake pressure to the CLG brakes.

2.1.4.2 However, the15-second touchdown protection timer (which delays the porting of brake pressure to the CLG brakes before the nose gear touchdown) was determined to be functioning properly in a post-incident test. Therefore, it is more likely than not that there was no premature application of brake pressure to the CLG.

2.1.5 <u>Irregular behaviour of brake system</u>

2.1.5.1 The brake system behaved irregularly during the post-incident tests. Half of the brake pistons from brake #2 in the left MLG and from brakes #3, #4, #7 and #8 in the right MLG, which pistons being powered by hydraulic system #3, did not function properly. And the functioning of these brakes returned to normal after several more tests. The aircraft manufacturer could not explain the abnormality but commented that such malfunctioning could reduce the brakes' energy absorption effectiveness by about 40%.

2.1.5.2 It cannot be determined whether the brakes #2, #3, #4, #7 and #8 were operating normally or not during the aircraft manoeuvres on 7 April 2005. If they were not operating properly, then the rest of the brake units would have had to work harder (i.e. absorbing more energy) in order to achieve the aircraft deceleration rate targeted by the autobrake setting. This might explain why brakes #5 and #10 attained higher peak temperatures and attained these temperatures faster than usual.

2.1.5.3 During the high speed autobrake RTO test on 7 April 2005, the crew had disarmed the autobrake by applying brake pedals at 115 knots instead of at 70 knots as recommended in the FTM. It is not known how hard the crew applied the brake pedal force and whether this contributed to brakes #5 and #10 attaining higher peak temperatures at a faster rate.

2.1.5.4 The brake system was checked satisfactory by the maintenance personnel after the replacement of CLG wire harness for the antiskid wheel speed transducers and the tyre pressure transducers. There was no report of any braking problems in the subsequent test flight on 4 April 2005. However, it cannot be established whether the pistons powered by hydraulic system #3 for brakes #2, #3, #4, #7 and #8 were operating normally during the check.

2.1.6 Contamination of IBCV inlet filters

2.1.6.1 Debris in the form of aluminium shavings was found contaminating one inlet filter of an IBCV. The source of the shavings was isolated to aluminium shims originally installed in the Brake Check Valve Manifold Assembly. However, the aircraft manufacturer found no evidence that the presence of the aluminium shavings had contributed to the dynamic instability and subsequent failure of the CLG lower drag brace link.

2.1.7 The investigation team, despite the strong support of the aircraft manufacturer and brake system component manufacturers, was unable to conclude on the nature of the circumstances that led to the overload that caused both the CLG lower drag brace link and retract actuator to fail. Notwithstanding this, the aircraft manufacturer has followed up with safety action (see Section 4).

2.1.8 It was also noted that there is no maintenance requirement to inspect the CLG lower drag brace link attachment lug. Regular inspection of the attachment lug could help detect any elongation or impending failure of the attachment lug.

2.2 Aircraft not in operation for long period

2.2.1 The aircraft was on the ground for quite a long period for PTF conversion and heavy maintenance check. There was no major modification done to the aircraft's brake or antiskid system, although there was some rectification work done. There was no requirement for a full operational check of the brake and antiskid systems before the aircraft was put back into service. It was not known if such a check could have prevented the irregular behaviour of the brake system.

2.2.2 However, after a long grounding period, the operation of some aircraft system components could become sluggish, in particular mechanical parts such as servo valves and contacts of electrical switches. It could be expected that such systems undergo thorough checks and tests before the aircraft took to the air again, even if no modification or rectification work was done on the systems. In this respect, the aircraft manufacturer has followed up with safety action (see paragraph 4.2.2).

3 CONCLUSIONS

From the evidence available, the following findings are made. These findings should not be read as apportioning blame or liability to any particular organisation or individual.

3.1 Findings

3.1.1 The failure of both the CLG lower drag brace link and retract actuator was due to overloading. The cause of the overloading could not be determined.

3.1.2 Brake system #2, which was powered by hydraulic system #3, behaved irregularly in post-incident spin checks. It returned to normal without any rectification after additional spin checks. The cause of the irregular brake systems operation could not be determined.

3.1.3 There is no maintenance requirement to inspect the CLG lower drag brace link attachment lug. Regular inspection of the attachment lug could help detect any elongation or impending failure of the attachment lug.

3.2 Other safety issues

3.2.1 The inlet filters of IBCVs were susceptible to clogging by aluminium shavings from the aluminium shim of pre-modified Brake Control Valve Manifold.

3.2.2 After an aircraft has been on the ground for an extended period, the critical systems should undergo thorough checks or test before the aircraft is put back into service again, even if no modification or rectification work has been done on these systems.

4 SAFETY ACTION

4.1 The aircraft manufacturer informed all MD-11 operators on 15 June 2005 of the N413LT incident as well as the findings regarding the presence of aluminium shavings at the IBCV inlet filters. The aircraft manufacturer issued Service Bulletin MD11-32-073 dated 1 December 1997 and revised on 21 December 2005, which recommends inspection/replacement of the Brake Check Valve Manifold Assembly and IBCV inlet filters on all MD-11 aircraft. Accomplishment of the recommended modification/inspection will minimise the possibility of contamination induced brake system anomalies.

4.2 The aircraft manufacturer issued Service Letter SL-32-113 on 10 January 2007 which recommends operators to perform operational test of the antiskid system and servicing of the CLG shock strut when an aircraft is being returned to service following long term storage and/or while the aircraft is undergoing “1C” Interval Maintenance Check.

4.3 While not the case with N413LT, several MD-11 aircraft have experienced events resulting in extensive damage to the CLG following landing on a dry runway surface using MAX autobrake. The aircraft manufacturer and the NTSB are currently investigating these events. The aircraft manufacturer has issued an Interim Operating Procedure (IOP 2-223 dated 16 November 2007) to the MD-11 Flight Crew Operating Manual. This IOP is intended to minimise the risk of the CLG lower drag brace link failure by suggesting that operators limit the use of MAX autobrake to only those conditions in which it is considered necessary to ensure a safe and successful landing.

4.4 As the root cause of overloading of the CLG lower drag brace link is still unknown, the investigation team has suggested to the aircraft manufacturer that periodic inspections be devised to check the condition of the attachment lug of the CLG lower drag brace link. The aircraft manufacturer is of the view that the current inspection/overhaul interval of the subject line is sufficient and that as the failure was due to overload, a more frequent inspection of the link would not mitigate the overload problem.