FINAL REPORT

BOEING 737-400, REGISTRATION HS-KMC

MAIN LANDING GEAR TORSION LINK DAMAGE DURING LANDING

5 June 2019

AIB/AAI/CAS.180

Transport Safety Investigation Bureau
Ministry of Transport
Singapore

19 October 2020

The Transport Safety Investigation Bureau of Singapore

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GLOSSARY OF ABBREVIATIONS

AMM	Aircraft Maintenance Manual
CVR	Cockpit Voice Recorder
FDR	Flight Data Recorder
FO	First Officer
FOD	Foreign Object Debris
ICAO	International Civil Aviation Organization
LH MLG	Left-hand Main Landing Gear
LT	Local Time
MLG	Main Landing Gear
MRO	Maintenance, Repair and Overhaul
RH MLG	Right-hand Main Landing Gear
T-LAME	Travelling Licensed Aircraft Maintenance Engineer

SYNOPSIS

On 5 June 2019, a B737-400 cargo aircraft landed at Singapore Changi Airport. During the landing roll, the flight crew experienced vibrations in the aircraft and the aircraft deviated to the left of the runway centreline. The flight crew managed to maintain the aircraft on the runway centerline and taxi to the parking bay.

After arrival at the parking bay, the right main landing gear upper torsion link was found broken. The main landing gear damper manfold and the hydraulic line guide were recovered from the taxiway along the taxi route to the parking bay. No one was injured in the occurrence.

The Transport Safety Investigation Bureau classified this occurrence as a serious incident.

AIRCRAFT DETAILS

Aircraft type	:	B737-400
Operator	:	K-Mile
Aircraft registration	:	HS-KMC
Numbers and type of engines	:	2 x CFM56-3C1
Date and time of occurrence	:	5 June 2019, 0407LT
Location of occurrence	:	Changi Airport
Type of flight	:	Scheduled flight
Persons on board	:	3

1 FACTUAL INFORMATION

All times used in this report are Singapore Local Time (LT) unless otherwise stated. Singapore Local Time is eight hours ahead of Coordinated Universal Time (UTC).

1.1 History of the flight

1.1.1 The B737-400 cargo aircraft involved in this incident had all the three landing gears recently replaced by a maintenance, repair and overhaul organisation in Jakarta, Indonesia (hereinafter referred to as MRO-I)[1]. The set of replacement landing gears was sourced by the aircraft operator from a maintenance, repair and overhaul organisation in the United States (hereinafter referred to as MRO-US) and was shipped by MRO-US direct to MRO-I. The aircraft returned to service on 3 June 2019.

1.1.2 On 5 June 2019, the aircraft flew from Bangkok, Thailand, to Singapore. This was the aircraft's fifth flight after the landing gears replacement at MRO-I. The flight crew, consisting of a Captain and a First Officer (FO), were accompanied by a travelling Licensed Aircraft Maintenance Engineer (T-LAME) who would perform maintenance checks during the transit in Singapore. For the approach to and landing at Singapore, the FO was the Pilot Flying and the Captain the Pilot Monitoring.

1.1.3 The aircraft landed on Runway 20R at Singapore Changi Airport at about 0407LT. During the landing roll, the flight crew experienced unusual vibrations[2] when the thrust reversers were deployed. At the same time, the aircraft deviated to the left of the runway centreline. According to the FO, he had to apply greater than normal right rudder pedal input to keep the aircraft on the runway centreline. The Captain then took over control of the aircraft and applied brakes to slow down the aircraft. The vibrations subsided by the time the aircraft was slowed to about 60 knots on the runway. The aircraft left the runway via Taxiway W7 and taxied on Taxiways WP and NC2 to reach the parking bay 308 (see **Figure 1**).

[1] MRO-I had been contracted by the aircraft operator since 2017 for aircraft maintenance.

[2] The flight crew described the vibrations as similar to those resulting from a flat tyre. However, the vibrations did not appear to the flight crew to be disconcerting.

Figure 1: Aircraft taxi route

1.1.4 The aircraft arrived at parking bay 308 at 0415LT. It was received by a team from a ground handling agent at Singapore Changi Airport which provided ramp services (e.g. aircraft marshalling, cargo handling). After the aircraft was parked, the T-LAME exited the aircraft and carried out a post-flight inspection. He found that the upper torsion link of the right-hand main landing gear (RH MLG) was broken and the RH MLG damper manifold (which was a part of the RH MLG damper[3]) was missing (see **Figure 2**). There was also a hydraulic leak[4] from the RH MLG because the hydraulic return line connecting the aircraft hydraulic system to the damper manifold was disconnected.

[3] The function of the MLG damper is to prevent excessive vibration build-up in the MLG during landing, high speed taxiing and heavy braking.

[4] Estimated hydraulic fluid loss was about 11 litres.

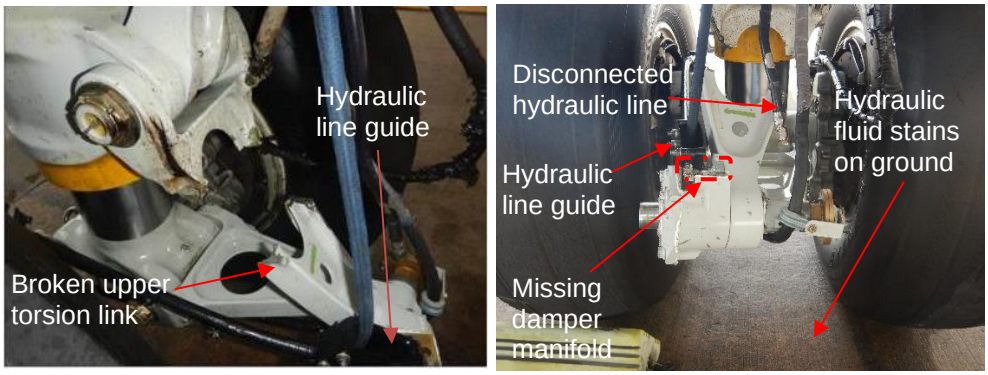

Figure 2: Damaged RH MLG torsion link assembly

1.1.5 The T-LAME called the aircraft operator's headquarters[5] in Bangkok to report the situation and asked for further advice. The headquarters asked the T-LAME to seek ad-hoc technical assistance from the maintenance, repair and overhaul organisation which was contracted to provide refuelling operation for the aircraft (hereinafter referred to as the MRO-S). The T-LAME approached an MRO-S technician who was then onsite supporting the aircraft refuelling operation and asked for an engineer to assist him. A Duty Engineer from MRO-S (MRO-S Duty Engineer) arrived at about 0600LT.

1.1.6 The MRO-S Duty Engineer performed a walk around inspection with T-LAME. They assessed that the aircraft could not be repaired in time for the 0800LT scheduled departure. Having discovered that the damage[6] was serious, the MRO-S Duty Engineer reported the incident to the aerodrome operator at about 0755LT. At about 0800LT, the aerodrome operator was informed by an aircraft towing team that the team had picked up a foreign object debris (FOD) from Taxiway NC2 between bays 303 and 304, about 300 metres away from bay 308. In response, the aerodrome operator despatched a vehicle to collect the FOD from the towing team and the FOD was eventually collected at 0805LT, which was the damper manifold (see **Figure 3**). At the same time, the aerodrome operator also despatched another vehicle to inspect for FOD and fluid leaks along the taxiing route taken by the aircraft. At about 0820LT, this vehicle recovered a another FOD from Taxiway NC2 between bays 303 and 304, which was a hydraulic line guide (see **Figure 4**). The T-LAME realised that the missing parts were a FOD hazard when the FODs were brought to him for identification.

[5] The T-LAME informed the headquarters as per the aircraft operator's procedures. The aircraft operator did not have a contract with any maintenance engineering service provider in Singapore but would use such a service provider on an ad-hoc basis.

[6] The MRO-S Duty Engineer assessed that the missing damper manifold would pose a danger to other aircraft if it had dropped on the runway or taxiway.

Figure 3: Damper manifold

Figure 4: Hydraulic line guide

1.1.7 The aerodrome inspection team did not find any trace of hydraulic fluid nor any other FOD on the runway and taxiways.

1.2 Injuries to persons

1.2.1 No one was injured in the occurrence.

1.3 Damage to aircraft

1.3.1 The damage to the RH MLG included the following (see **Figures 5** and **6**):

(a) The upper torsion link[7] of the RH MLG was broken and its bushings were out of position and no longer parallel to each other.
(b) The lower torsion link was distorted and one of its bushings at the end of the link, which connected to the apex joint[8], was fractured.
(c) The damper manifold was detached from its mount.
(d) The outer sleeves of the hydraulic return line (connecting the hydraulic system and damper) and other hydraulic lines of RH MLG were torn resulting in a hydraulic fluid leak.
(e) The damper piston was bent.
(f) Scuffs and score marks were found on the two tyres of the RH MLG.

[7] The MLG torsion link assembly consisted of the upper and lower links connecting the outer and inner cylinders of the MLG shock strut. Its function is to prevent rotation of the cylinders about the vertical axis, to maintain the wheels pointing in the direction of travel.

[8] The apex joint is where the damper piston meets the lower torsion link and thrust washers.

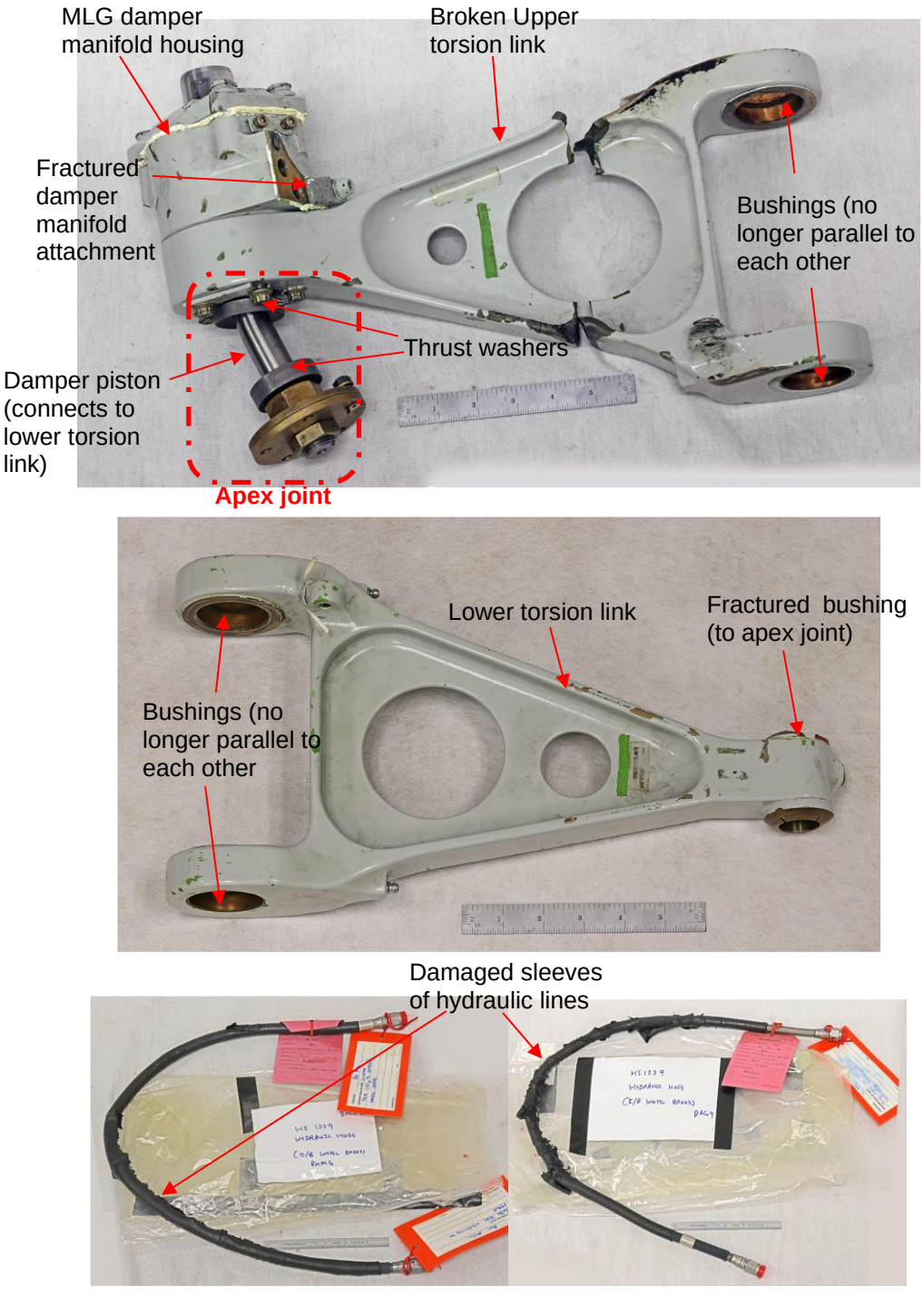

Figure 5: Damaged components of RH MLG torsion link assembly

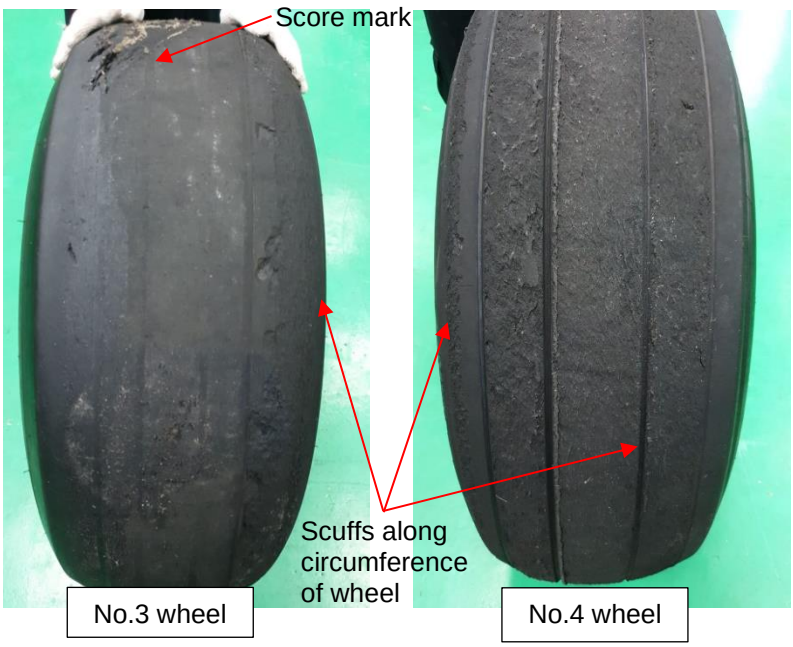

Figure 6: Damage on tyres of RH MLG

1.4 Personnel information

1.4.1 Captain

Age	42
Gender	Male
Licence Type	Airline Transport Pilot Licence
Aircraft rating	B737-400
Medical certificate date	Valid from 18 February 2019 until 17 August 2019
Last base check	Pilot Proficiency Check on 23 May 2019
Last line check	3 July 2019
Rest period before flight	About 18 hours
Duty time before occurrence	About 7 hours
Total flying time	12,250 hours
Total flying time on this type	7,250 hours
Flying time in last 90 days	About 155 hours
Flying time in last 28 days	About 44 hours
Flying time in last 24 hours	About 4 hours

1.4.2 First Officer

Age	32
Gender	Male
Licence Type	Commercial Pilot Licence
Aircraft rating	B737-400
Medical certificate date	Valid from 27 April 2019 until 26 April 2020
Last base check	Pilot Proficiency Check on 25-26 March 2019
Last line check	4 March 2019
Rest period before flight	2 days off before flight
Duty time before occurrence	About 3.5 hours
Total flying time	About 2624 hours
Total flying time on this type	About 1509 hours
Flying time in last 90 days	About 95 hours
Flying time in last 28 days	About 39 hours
Flying time in last 24 hours	-

1.5 Aircraft information

1.5.1 The occurrence aircraft was converted to a freighter aircraft and started operations with the operator[9] in September 2016.

1.5.2 In May 2019, the landing gears were reaching their service life limits and needed to be replaced. The replacement was carried out by MRO-I and the aircraft was returned to service on 3 June 2019. The set of replacement landing gears had been overhauled by MRO-US. It was sourced by the aircraft operator from MRO-US and shipped by MRO-US direct to MRO-I.

1.5.3 The replacement landing gears from MRO-US were fully assembled and shipped with the MLG dampers installed and painted. The part number of the RH MLG damper was 65-44771-4 and the serial number was TSC3149. MRO-I did a receiving inspection of the set of replacement landing gears before accepting the landing gears into its store. After that, representatives of the aircraft operator were also at MRO-I to verify that the components of the landing gears tallied with what it had ordered from MRO-US. In particular, the serial number of the RH MLG damper was verified by the aircraft operator to be TSC3149. Following the incident at Changi Airport, the serial number of

[9] The aircraft operator started operations in 2004. It had been operating B737-400 since 2014.

the RH MLG damper was verified to be TSC3149[10].

1.5.4 Following the installation of the set of landing gears sourced from MRO-US onto the aircraft, MRO-I connected the necessary hydraulic lines. According to MRO-I, the hydraulic lines were bled[11] as required by the Aircraft Maintenance Manual (AMM).

1.6 Meteorological information

1.6.1 There was no significant weather and the wind was calm. The wind was coming from 140 degrees at about three to four knots.

1.7 Aerodrome information

1.7.1 The gradients of runway and taxiways were within ICAO[12] requirements. The runway and taxiway surfaces were dry at the time of the incident.

1.8 Flight recorders

1.8.1 The flight data recorder (FDR) and cockpit voice recorder (CVR) were available for readout by the investigation team. The reading out of the recorders was successful.

1.8.2 The FDR had 25 hours of recording. The following information was gleamed from the FDR:

(a) There were no anomalies observed in the flight data for the five flights after the landing gears replacement by MRO-I, except for the unusual vibrations that occurred after the touchdown on the incident flight.
(b) There was no instance of low sink rate (i.e. low descent rate).
(c) There was no evidence of low hydraulic pressure or low hydraulic quantity. Thus, there was unlikely that the main landing gear damper and its associated hydraulic lines had a hydraulic leak prior to touchdown.

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[10] Inexplicably, MRO-I indicated that the RH MLG assembly from MRO-US did not come with the damper installed, and that it had the agreement of the aircraft operator to reuse the damper of the RH MLG that had been removed from the aircraft. However, MRO-I was not able to produce work documents related to its installation of the reused damper and the aircraft operator denied that it had been approached by MRO-I regarding the reusing of any damper from the set of removed landing gears.

[11] Bleeding means to remove air in the hydraulic line. Air in the hydraulic line will render the damping action ineffective.

[12] International Civil Aviation Organization

1.9 Tests and research

1.9.1 The aircraft's maintenance records showed that the shock strut extension and pressure were last checked at MRO-I on 2 June 2019 after the landing gears replacement. The readings were about six inches and 600 psi[13] for both LH and RH MLGs and were within the operating band prescribed by the aircraft manufacturer.

1.9.2 The damaged upper and lower torsion links and other RH MLG components[14] were subsequently sent to the aircraft manufacturer for metallurgical examination.

1.9.3 The conclusions of the aircraft manufacturer's failure analysis were as follows:

(a) The parts were genuine parts from the aircraft manufacturer.
(b) The upper torsion link broke into two segments mid span. The outboard fracture surface was consistent with ductile separation due to tensile loading. The inboard fracture surface was consistent with ductile separation due to shear loading (see **Figure 11**). There was no evidence of corrosion or fatigue.
(c) The manifold attachment lug on damper manifold housing[15] fractured under ductile/tensile loading (see **Figure 11**).
(d) There was galling/wear[16] and a shear crack on the damper piston just outside the housing where the thrust washer was normally seated. The damper piston shaft was bent under ductile/tensile loading.
(e) No unusual metallurgical defects were observed on the fracture surfaces of the above components.
(f) The torsion link pins (upper and lower) connecting the upper and lower torsion links to the shock strut showed no signs of abnormal wear or damage.
(g) Deformations found on the bushings in the upper and lower torsion links and there was material transfer to the thrust washers. The thrust washers also showed signs of deformation.

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[13] According to the aircraft operator, re-servicing of the MLG shock strut is required:
- after certain maintenance activities that require releasing the shock strut pressure to perform part replacement or inspection; or
- when the measured shock strut extension and pressure readings are out of the operating band prescribed by the aircraft manufacturer.

[14] Torsion link pins, hydraulic lines, thrust washers, apex washer, damper manifold housing, damper piston, and torsion link bushing

[15] The manifold attachment lug is the interface where the damper manifold is attached to the manifold housing.

[16] Galling is a form of severe wear when there is adhesion between sliding surfaces under a large amount of force. It occurs quickly and material from sliding surfaces spread rapidly; it is not a gradual process.

(h) Although the outer sleeves of the hydraulic lines were torn, there was no damage to the steel braided lines under the sleeves.

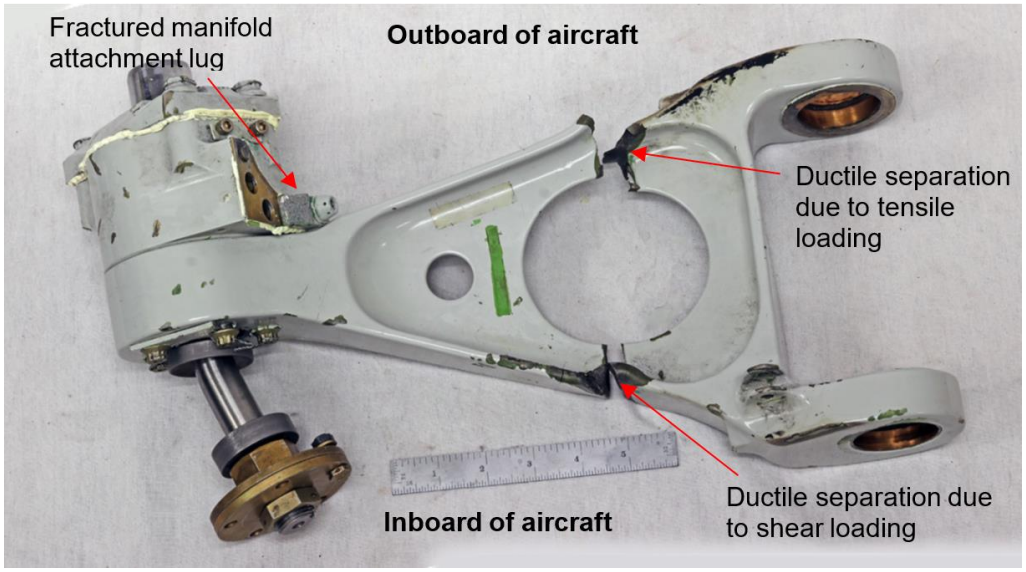

Figure 7: Damages on the upper torsion link

1.9.4 According to the aircraft manufacturer's failure analysis report, there were no metallurgical defects found in the damaged components that would suggest any issues related to the overhaul of the RH MLG by MRO-US. The parts used, including the damper, were genuine and were the correct parts for the RH MLG installation. The damage observed on the components in **Figures 5** and **6** were incurred after the aircraft landing.

1.9.5 The aircraft manufacturer had shared with B737 operators that there were sporadic reports from operators of B737-100/200/300/400/500[17] aircraft of aircraft MLG vibrations[18] following touchdown and that such vibrations might last for several seconds during the landing roll and might result in broken torsion links, damaged MLG dampers and even MLG collapses in severe cases. **Appendix A** is a list of possible factors according to the aircraft manufacturer. These factors are recapitulated below, in the approximate order of decreasing likelihood:

(a) Excessive wear or free play in the apex joint
(b) Wear or free play in the torsion link bushings (e.g. where the torsion links connected to the outer and inner cylinder of the MLG strut)
(c) Landing with extremely low sink rates
(d) Presence of air in the MLG damper

[17] These aircraft models are collectively known as B737 Classic models.
[18] An MLG vibration is also known as an MLG shimmy.

(e) Damper piston fractures
(f) Over serviced shock strut
(g) Incorrect damper installation
(h) Unconnected hydraulic tube

2 ANALYSIS

The investigation team looked into the following:

(a) Cause of aircraft MLG vibrations following touchdown

(b) Notification of foreign object debris hazard or occurrence

2.1 Cause of aircraft MLG vibrations following touchdown

2.1.1 According to the FDR data, there were no anomalies during the five flights after the landing gears replacement by MRO-I, except for the unusual vibrations that occurred after the touchdown on the incident flight. The investigation team believed that the the RH MLG torsion link assembly broke shortly after the unusual vibrations had come about. Paragraph 1.9.5 lists the possible factors of aircraft MLG vibrations following touchdown. The factor of "presence of air in the MLG damper" (i.e. item (d) in paragraph 1.9.5 and item (d) in paragraph A.2 in Appendix A) appeared to match the circumstances of this occurrence. As explained in item (d) in paragraph A.2 of Appendix A, MLG vibrations could occur within a few flights after a new or overhauled damper was installed. In these cases, a reason for the MLG vibrations could be that a thorough bleeding of air from the damper was not performed. This prevented proper damper operation. An ineffective damper would be unable to reduce the MLG torsional vibrations during landing.

2.1.2 The investigation team considered the other possible factors listed in paragraph 1.9.5 but concluded that these possibilities could be eliminated having taken into account the following:

(a) It was unlikely that wear or free play was a factor given that the RH MLG had been recently overhauled, and the aircraft had only made five flights after the installation of the overhauled RH MLG.
(b) FDR data showed no instance of extremely low sink rate.
(c) The damper piston was bent as a result of the vibration event. There is no evidence of pre-existing damper piston fracture.
(d) Shock strut pressure and extension readings were within the operating band.
(e) There is no evidence of wrong components or wrong part number having been used in the damper installation.
(f) There was no evidence of hydraulic fluid leak or loss prior to the occurrence.

2.1.3 In view of paragraphs 2.1.1 and 2.1.2 above, the investigation team concluded that a probable cause of the aircraft MLG vibrations following touchdown was the presence of air in the RH MLG damper which likely affected the damper's effectiveness and resulted in the breaking of the torsion

link assembly. However the investigation team was not able to ascertain if the bleeding was done satisfactory.

2.2 Notification of foreign object debris hazard or occurrence

2.2.1 After touchdown, the flight crew felt vibrations but they did not feel the need to inform Air Traffic Control as the vibrations were not disconcerting. After the aircraft arrived at bay 308 at about 0415LT, the T-LAME inspected the aircraft and found that the upper torsion link of the RH MLG was broken, and that the RH MLG damper manifold was missing. However, the aerodrome operator was only informed of the event at about 0755LT and it was only after then that the missing parts were recovered. Thus, these aircraft parts had been lying on the taxiway for about four hours which obviously constituted a hazard for taxiing aircraft.

2.2.2 The T-LAME and the aircraft operator would be expected to appreciate that any aircraft missing parts constituted potentially an FOD situation and such cases should be reported to the aerodrome operator. However, there was a delay in reporting the potential FOD situation to the aerodrome operator. The T-LAME was preoccupied with reporting the situation to the aircraft operator's headquarters and the follow-up repair actions and was not aware of the need nor the avenues to report the situation to the aerodrome operator. The aircraft operator did not seem to have a system that could ensure its flight personnel know how to contact the aerodrome operator at a destination or transit airport immediately and directly.

2.2.3 The MRO-S Duty Engineer would also be expected to appreciate that any missing parts from an aircraft constituted potentially an FOD situation and such cases should be reported to the aerodrome operator. Yet the aerodrome operator was only informed by the MRO-S Duty Engineer about two hours after the MRO-S Duty Engineer arrived at the aircraft and assessed the damage. The MRO-S Duty Engineer did not alert the aerodrome operator immediately once he realised that aircraft parts were missing.

2.2.4 It was fortunate that the incident occurred during the aerodrome's off-peak period in the early morning. Still, it was a hazard for which the risk could have been minimised if the incident had been duly reported. The aerodrome operator did have a number of initiatives[19] to make airport workers aware of

[19] The aerodrome operator had a number of initiatives to make airport workers aware of the avenues to report hazards, including the following:
- Through Airside Safety Induction Briefing to airport workers prior to the issue or renewal of airport passes
- Publicising the telephone number to call on the aerodrome operator's website

the avenues to report hazards. However, this occurrence showed that, despite its effort, there could still be occasions where foreign flight personnel do not know how to contact the aerodrome operator. There is scope for the aerodrome operator to review its hazard reporting system to ensure that foreign flight personnel know how to contact the aerodrome operator without delay.

- Making available an easy-to-use reporting means in the form of a mobile application known as SWEET, which is compulsory for downloading by airside driving license holders
- Promotion of the airside management centre reporting telephone numbers (+65 6541 2273/2275) on posters placed on all aircraft stands

3 CONCLUSION

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

3.1 There were no anomalies during the five flights after the landing gear replacement by MRO-I, except for the vibrations that occurred after the touchdown on the incident flight. The investigation team believed that the RH MLG torsion link assembly broke shortly after the vibrations had come about.

3.2 A probable cause of the aircraft MLG vibrations following touchdown was the presence of air in the hydraulic line of the RH MLG damper. It could not be established whether the bleeding had been satisfactorily performed when the RH MLG of the aircraft was replaced at MRO-I.

3.3 The missing damper manifold was reported to the aerodrome operator only four hours after the occurrence. During these four hours, the missing parts were lying on a taxiway and constituted an FOD hazard.

4 SAFETY ACTIONS

Arising from discussions with the investigation team, the (organisation(s)) has/have taken the following safety action.

4.1 After the occurrence, the incident aircraft's RH MLG was repaired and both of its dampers were bled at MRO-S. The aircraft operator then checked for proper bleeding of the MLGs dampers on all the remaining B737 Classic aircraft in its fleet.

4.2 The aerodrome operator has disseminated two Airside Safety Notices to all members of its airport community that operate in the aerodrome arising from this occurrence:

(a) Airside Safety Notice No. 13/2020 as a safety reminder to highlight on the importance of prompt reporting on all safety issues related to aircraft operations and the avenues to report such safety issues.
(b) Airside Safety Notice No. 14/2020 on communications measures between the aerodrome operator and aircraft operators/ground handling agents.

5 SAFETY RECOMMENDATIONS

A safety recommendation is for the purpose of preventive action and shall in no case create a presumption of blame or liability.

It is recommended that:

5.1 MRO-I review the main landing gear installation procedure to verify that the bleeding of the main landing gear damper and its hydraulic line connection(s) will not be missed by its maintenance personnel. [TSIB RA-2020-009]

5.2 The aircraft operator ensure that its flight personnel know how to contact the aerodrome operator of the destination or transit airports that they are operating to, for the immediate and direct reporting of FOD hazards that they have become aware of. [TSIB RA-2020-010]

5.3 MRO-S ensure that its personnel know the importance of alerting the aerodrome operator immediately and directly of any real or potential FOD hazard once they realise there are parts missing from aircraft. [TSIB RA-2020-011]

5.4 The aerodrome operator coordinate with the foreign air operators using its aerodromes with a view to ensuring that the flight personnel of these foreign air operators know how to contact them immediately and directly for reporting any real or potential hazard. [TSIB RA-2020-012]

APPENDIX A

AIRCRAFT MLG VIBRATIONS DURING LANDING

A.1 The aircraft manufacturer had shared[20] with B737 operators that there were sporadic reports from operators of B737-100/200/300/400/500 aircraft of aircraft MLG vibrations following touchdown and that such vibrations might last for several seconds during the landing roll and might result in broken torsion links, damaged MLG dampers, and even MLG collapses in severe cases.

A.2 Below is a list of possible factors according to the aircraft manufacturer, in the approximate order of decreasing likelihood:

(a) Excessive wear or free play in the apex joint

- Wear at this location allows undamped torsional free play to exist in the landing gear at the apex joint, which greatly increases the likelihood of shimmy.

(b) Wear or free play in the torsion link bushings (e.g. where the torsion links connect to the outer and inner cylinder of the MLG strut)

- Wear at these locations also allows undamped torsional free play.

(c) Landing with extremely low sink rates

- This type of landing is more likely to experience vibrations than a firmer landing because the torsion links remain in an extended, vertical position which gives the damper less mechanical advantage

[20] The related aircraft publications are:
- Multi Operator Message, MOM-MOM-12-0127-01B dated 29 February 2012
- Service Letter 737-SL-32-057-C dated 29 November 2011 for recommended maintenance actions. The last two recent revisions were on 16 September 2014 and 22 December 2015 respectively.
- Quarterly magazine article “Preventing Main Landing Gear Shimmy Events in 3rd quarter of 2013
- Flight Operations Technical Bulletin 737-15-2 dated 14 December 2015 to inform crews about aircraft MLG vibrations on landing and preventive landing techniques
- Fleet Team Digest Article 737-FTD-32-11001 dated 2 November 2011
- AMM 32-11-00/601 for torsional free play Inspection.
- AMM 32-11-81/501 for damper adjustment
- AMM 32-11-51/601 for MLG torsion links inspection/check
- AMM 32-11-81/401 for damper installation
- Maintenance Tip 737-MT-32-008 dated 5 February 2001
- AMM 32-11-51/801 for MLG torsion links approved repair
- Aircraft Maintenance Manual 05-51-68/201 for MLG vibration conditional inspection

to perform its function for a longer time period, especially in an asymmetric wheel spin up situation[21] (see **Figure 12**).

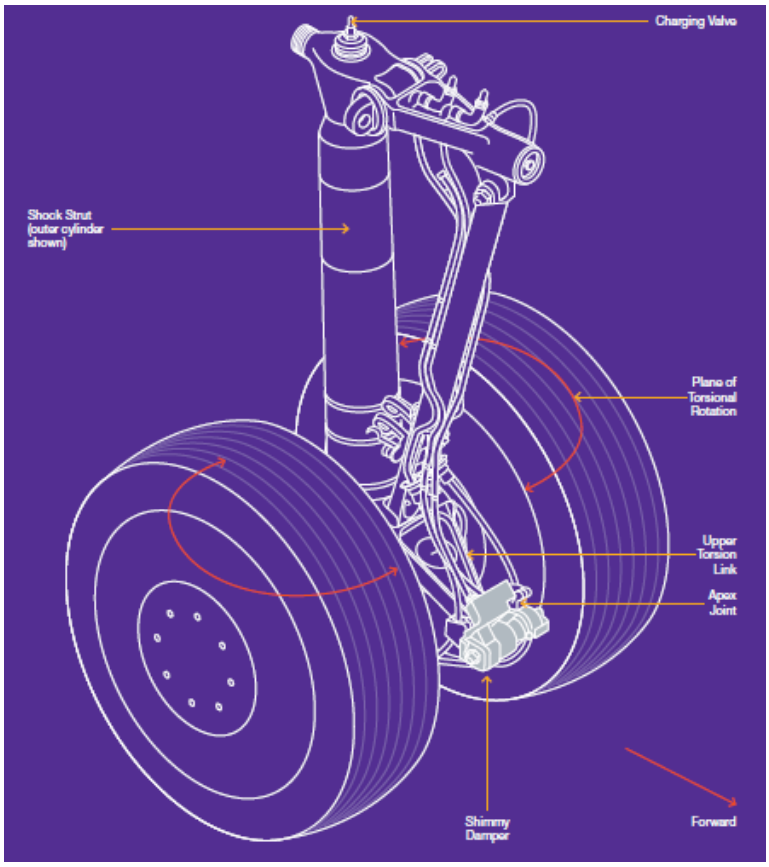

Figure 8: Torsion forces experience by a MLG during landing

(d) Presence of air in the MLG dampers

- Several airplane MLG vibration events occurred within a few flights after a new or overhauled damper was installed. In these cases, it was suspected that a thorough bleeding of air from the damper was not performed, thus preventing proper damper operation.

[21] Asymmetric wheel spin-up in a MLG can happen during low sink rate landings when one of MLGs is on the ground and the second MLG is slowly being lowered to the ground. As the second MLG is being lowered, the asymmetric wheel spin condition may occur when one tire touches down and spins up before the opposite tire touches down. The drag from the ground contact from the first tire torsionally deflects or rotates the strut. When the tire on the same strut touches down, the strut torques in the opposite direction. If the strut continues to be compressed as the aircraft settles, the natural heavy damping of the MLG very quickly suppresses the vibrations. If the strut is not compressed, then the torque effect from the opposite tire touchdown is added to the recovering force and deflection from the first tire touchdown and the resulting vibrations can continue for several seconds.

(e) Damper piston fractures

- In a small number of events, it is suspected that the damper piston fractured due to a pre-existing fault (e.g., a fatigue crack).

(f) Over serviced shock strut

- In several events, an over serviced shock strut has been suspected to have been a contributing factor. A shock strut over serviced with nitrogen allows the torsion links to have a reduced mechanical advantage to react to the torsional motion of the inner cylinder.

(g) Incorrect damper installation

- In one event, a damper designed for a very early B737-200 had inadvertently been installed on a later aircraft that required a more heavy-duty damper.

(h) Unconnected hydraulic tube

- In one event, a hydraulic tube for the damper was inadvertently left unconnected after unrelated maintenance, so there was no hydraulic fluid available to the damper.