FINAL INVESTIGATION REPORT

SERIOUS INCIDENT OF SHAHEEN AIR INTERNATIONAL (SAI) FLIGHT NL-151 (SECTOR ISB – UET), B737-400 AIRCRAFT REG # AP-BJT AT QUETTA ON 16TH JULY, 2015

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Synopsis

The serious incident was reported to Safety Investigation Board (SIB), Pakistan by operator **(Appendix 'A')** and was notified in accordance with ICAO Annex-13 by SIB **(Appendix 'B')**. Accredited Representative (ACCREP) was appointed by United States of America (USA), the state of design, and investigation was conducted by SIB, Pakistan, the state of registry and occurrence. Director General of Pakistan Civil Aviation Authority (CAA), issued Memorandum vide letter no. HQCAA/1901/370/SIB/636 dated 2nd November, 2015 **(Appendix 'C')** authorizing SIB, CAA Pakistan to investigate the incident.

The aircraft experienced failure of Upper Torsion Link of Left Main Landing Gear (LMLG) after landing due to shimmy (excessive vibrations) and was stopped on the runway. The cause of the occurrence was high ground speed, low sink rate landing combined with excessive play present at the linkages of shimmy damper mechanism.

1. FACTUAL INFORMATION

1.1. **History of the flight**. Shaheen Air International (SAI) Flight NL-151, Boeing 737-400 aircraft Registration No. AP-BJT was operating a routine passenger flight from Islamabad to Quetta on 16th July, 2015. The flight remained uneventful till landing at 0547 UTC (day light conditions). Approximately 2-3 seconds after touchdown, the cockpit crew experienced vibrations which increased in intensity. The directional control was maintained through rudder and aircraft was stopped on the runway. On post flight inspection, Left Main Landing Gear (LMLG) Upper Torsion Link was found broken.

1.2. **Injuries to persons**. There were no injuries to the any person on board.

1.3. **Damage to aircraft.** The LMLG Upper Torsion Link Pt No. 65-67963-4 S No. 2088 was found fractured.

Fractured LMLG Upper Torsion Link

Close up view

1.4. **Other damages.** Not applicable.

1.5. **Personnel Information.**

Captain

Date of Birth	:	01 April, 1954
Type of License held & No.	:	ATPL-751(A)
Medical Status	:	Class One, Valid upto 30th November, 2015
Type Rating	:	Boeing 737- 400
Type Current	:	Boeing 737- 400
Flying Experience (on B737)	:	1093:00 hrs
Grand Total	:	20500:00 hrs approx
Total in Command	:	13085:00 hrs as on
Total in Command on B-737 when incident occurred	:	1093:00 hrs.

First Officer

Date of Birth	:	1st June, 1956
Type of License held & No.	:	CPL No. 2840
Medical Status	:	Class One, Valid upto 31st October, 2015
Type Rating	:	Boeing 737- 400
Type Current	:	Boeing 737- 400
Flying Experience (on B-737)	:	310:00 hrs
Grand Total	:	2400.00 hrs
Total on B-737 when incident occurred	:	1200 hrs (P-2)

1.6. **Aircraft Information**. The aircraft was maintained by the operator in accordance with the regulations of CAA, Pakistan. The Certificate of Airworthiness was valid till 30th May, 2016. Last maintenance review was carried out on 3rd June, 2015 and next review was due on 2nd December, 2015. Daily inspection was conducted on 15th July, 2015 at Islamabad. Transit check was carried out on 16th July, 2015 at Islamabad. There was no carried forward defect related to the incident. The aircraft used Jet-A1 fuel. Pertinent maintenance and component life information are presented below:

1.6.1. **Aircraft**

Aircraft Make & Model	Boeing 737-400
Registration Marking	AP-BJT
Manufacture's Serial No.	25740
Year of Manufacture	1993
Total Aircraft Hours	52331
Total Cycles	33133
Total Landings	33133
Last C-check, Date, Place, Hrs / Cycles	Check-C3, on 10th March, 2015, by Turkish Habon-Turkey-51406 / 32630
Last A-check, Date, Place, Hrs / Cycles	Check-A4, on 3rd July, 2015 by SEAMS Karachi-52248 / 33087

1.6.2. **Left Main Landing Gear**

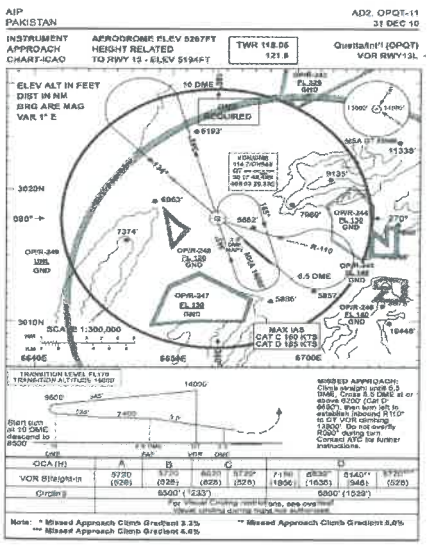
Cycles Since New (CSN)	33133
Cycles Since Overhaul (CSO)	6555
Overhaul due Date	30th March, 2018
Upper Torsion Link (S.No 2088) CSN / CSO	35261 / 4721
Upper Torsion Link remaining life	39729 Cycles

1.7. **Metrological information.** All weather parameters were within limits at departure, enroute and destination aerodrome to undertake and safely land the flight.

1.8. **Aids to Navigation**. All required onboard navigation aids and at the destination airport were available and serviceable.

1.9. **Communications**. All required onboard communication equipment and at the destination airport were serviceable.

1.10. **Aerodrome Information**. The pertinent aerodrome information is appended below:



OPQT AD 2.12 RUNWAY PHYSICAL CHARACTERISTICS

Designations RWY NR	True bearing	Dimensions of RWY (M)	Strength (PCN) and surface of RWY and SWY	THR coordinates	THR elevation and highest elevation of TDZ of precision APP RWY
1	2	3	4	5	6
13L	136°	3658 x 46	52/F/A/X/T Bitumen	30 15 50.76N 066 55 32.12E	THR 1583 M / 5194 FT
31R	316°			30 14 24.89N 066 57 06.38E	THR 1605 M / 5267 FT

Note: Parallel taxi track / RWY (12000ft x 110ft) direction 13R / 31L is in use by military aircraft only. The same is painted with RWY designator, centre line and threshold marking.

Designations RWY NR	Slope of RWY / SWY	SWY dimension (M)	CWY dimension (M)	Strip dimension (M)	Obstacle Free Zone
7	8	9	10	11	12
13L	0.442% UP	287	-	-	-
31R	1.014 % UP	274	-	-	-

OPQT AD 2.13 DECLARED DISTANCES (M)

Designations RWY NR	TORA	ASDA	TODA	LDA	Remarks
1	2	3	4	5	6
13L	3658	3925	3658	3658	-
31R	3658	3932	3658	3658	-

OPQT AD 2.14 APPROACH AND RUNWAY LIGHTS

Designations RWY NR	APCH LGT type LEN INTST	THR LGT colour WBAR	VASIS (MEHI) PAPI	TDZM LGT LEN	RWY Centre line LGT Length, spacing, colour, INTST	RWY EDGE line LGT Length, spacing, colour, INTST	RWY End LGT spacing colour WBAR	SWY LGT LEN (M) colour	Remarks
1	2	3	4	5	6	7	8	9	10
13L	PALS CAT-I LIH	GREEN	PAPI Left 2.75°	-	-	3658 M, 30 M, WHITE, LIL	RED	-	Strobe LGT
31R	PALS CAT-I LIH	GREEN	PAPI Left 3°	-	-		RED	-	

1.11. **Flight Recorders**. The aircraft was equipped with Cockpit Voice Recorder (CVR) and Flight Data Recorder (FDR). The data from (FDR) was successfully retrieved and sent to ACCREP for analysis. The Boeing FDR analysis report **(Appendix 'D')** was received through ACCREP and was effectively utilized for the investigation.

1.12. **Wreckage and Impact Information**. The aircraft was stopped on the runway. There was no other structural damage except failure of LMLG Upper Torsion Link.

Aircraft after final stop

1.13. **Medical and Pathological Information**. Not applicable.

1.14. **Fire**. Not applicable.

1.15. **Survival Aspects**. After landing, passengers were disembarked through normal procedure using steps.

1.16. **Tests and Research.** The fractographic analysis of failed upper torsion link and shop check along with tear down examination of the shimmy damper was carried out.

1.17. **Organizational and Management Information**. Not applicable.

1.18. **Additional Information**. Not applicable.

1.19. **Useful and Effective Investigation Techniques**. Standard investigation techniques were used.

2. ANALYSIS

2.1. The following paragraphs present analysis of the relevant FDR parameters for the purpose of this investigation.

2.1.1. The landing reference speed for the airplane's configuration was 139 knots. The airplane's computed airspeed reached as high as 150 knots during flare. The maximum permissible speed for a stabilized approach should be +10 knots (if tending towards planned speed), which in this case was 149 knots. Thus the approach was unstable (as per Boeing criteria), warranting a go around. The cockpit crew continued for landing instead of initiating a go around.

2.1.2. A distinct flare initiation was not obvious in the FDR data, but flare was determined to have been initiated with a nose up column input at approximately 4038 seconds at a radio altitude of around 45 feet which is higher than the recommended 20 feet. Touchdown occurred at 4044.4 seconds at computed airspeed of 150 knots (VREF+11), a ground speed of 177 knots, and at an approximate 1° left bank angle.

2.1.3. After touchdown, speed brakes were automatically deployed and wheel brakes were also applied, however, distinction could not be made between auto braking or manual braking from the FDR data. Thrust reversers were commanded approximately 4 seconds after touchdown.

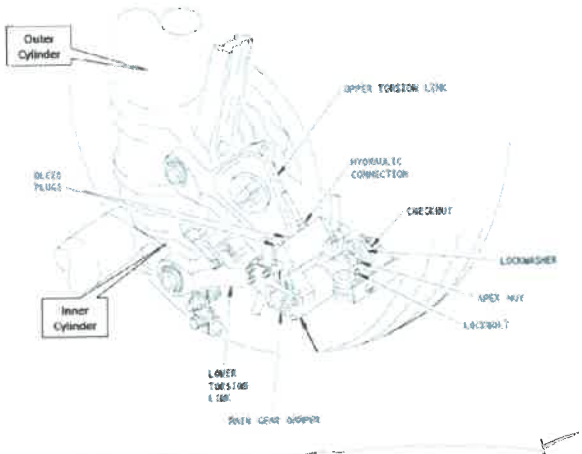
2.1.4. Approximately after 4 seconds of touch down oscillations were recorded in the lateral acceleration data. The oscillations in lateral accelerations indicate presence of shimmy event. The presence of shimmy event of the LMLG was also corroborated by tyre marks on the runway. The aircraft came to a stop approximately 50 seconds after touchdown. The zigzag tyre marks on the runway are characteristic indication of the shimmy event.

LMLG tyre marks on runway-viewing backward from aircraft final position

2.1.5. The calculated sink rate (negative vertical speed) at touchdown was around 1.4 feet / second with a normal load factor of 1.2 G's. The calculated closure rate (change of distance between landing gear and local terrain) was approximately 3.4 feet / second.

2.1.6. The airplane touched down at high ground speed and low sink rate, and the AIR / GROUND transition of the landing gear squat switches to the GROUND occurred approximately two seconds after touchdown which means the landing gear struts remained extended for about two seconds after the touchdown. In this position the torsion links of the shimmy damper have less mechanical advantage and therefore, shimmy damping mechanism effectiveness is reduced.

2.1.7. The axle of the wheels is mounted on the inner cylinder. The torsion links and shimmy damper assembly prevents pivot of the inner cylinder inside the outer cylinder (torsional movement). The torsional vibrations are prevented by the shimmy damper. It is pertinent to mention that clearance / play at the attachment points of shimmy damper and torsion links are detrimental in effectiveness and efficiency of the whole mechanism to prevent torsional vibrations of the wheel assembly.



Torsion Links and Shimmy Damper Assembly

2.1.8. Ineffectiveness of shimmy damper mechanisms results in torsional vibrations, which is termed a shimmy event. If the vibrations approach the natural frequency of assembly then resonance phenomenon is excited which results into very large amplitude vibrations. The large amplitude vibrations exert excessive load on associated linkages, resulting into failure of the torsion links/shimmy damper

2.1.9. The shimmy damper mechanism efficiency is adversely affected due to trapped air, fluid leaks, and mechanical failures of the damper, excessive strut pressure, very low sink rate touchdown and excessive play / wear of the associated linkages.

2.1.10. The failure mode analysis of the upper torsion link was performed at Institute of Space Technology (IST), Failure Analysis Center (FAC), Pakistan. The FAC analysis report **(Appendix 'E')** concluded that part failed due to bending overload. There was no evidence of fatigue, stress corrosion cracking and no deviation of chemical composition or microstructure of the material of the failed part was reported.

2.1.11. Boeing maintenance instructions in Maintenance Planning Document (MPD) and Aircraft Maintenance Manual (AMM) specify inspection and adjustment of Shimmy Damper Linkages mostly in C-check. In order to address the problem of shimmy events the latest Service Letter (SL 737-SL-32-057-D) dated 16th September, 2014 recommends more frequent checks, summarized as follows:

2.1.11.1. Adjust MLG Torsion Link Apex Joint in accordance with "AMM 32-11-81, Page 501, Main Landing Gear Damper Adjustment" starting at A-check and escalating incrementally up to every C-check or annually as service experience with the damper is attained.

2.1.11.2. After performing the above adjustment, measure across the faces of the thrust washers. If dimension is more than 2.7 inches, disassemble the joint and replace worn parts.

2.1.11.3. Disassemble the Apex Joint and inspect spherical cup washers, the damper piston, and the spherical bushings in the torsion link for wear annually, escalating incrementally to every C-check as service experience with the damper is attained. Worn parts are to be replaced if measurable wear is detected.

2.1.11.4. Bleed the air from the damper as per AMM 32-11-81, Page 401, Main Gear Damper Installation annually, escalating incrementally up to every C-check as service experience with damper is attained.

2.1.12. The technical review of the Service Letter SL 737-SL-32-057-D was not performed by the operator and shimmy damper mechanism maintenance was being performed during C-check as specified in MPD/AMM.

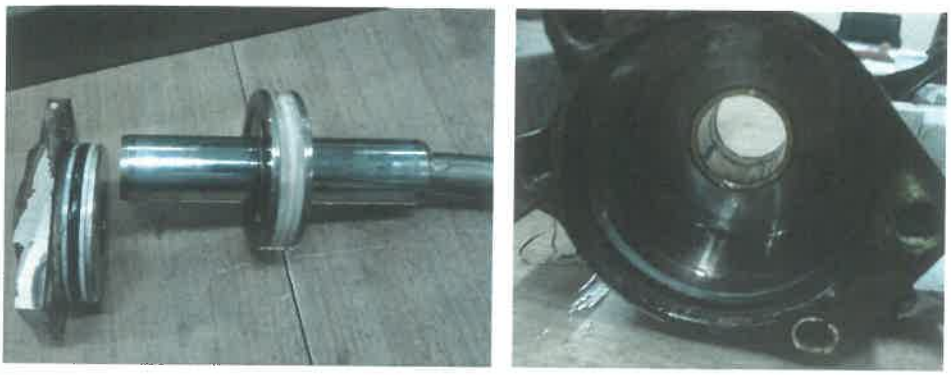
2.1.13. The assembled landing gear checks like "Main Gear Damper Test" with the help of a feeler gage (Task 32-11-81-705-014) and "Torsional Free Play Check" with the help of dial indicator (Task 32-11-00-206-001) in accordance with the applicable AMM, are effective indicators of wear of the linkages of shimmy damper mechanism. Since the related parts got damaged during the occurrence, therefore, these checks were not possible.

2.1.14. The measurement of wear of the bushing of torsional links and of corresponding lugs of inner and outer cylinder is an indirect method of ascertaining the condition of play of the assembled linkages of the shimmy damper system. More than specified wear of the bushings would invariably cause more than specified play in the assembled system. The dimensional check of the distance between the inner faces of the bushings of upper and lower torsion links was carried out and found more than Component Maintenance Manual (CMM) specified wear limits.

2.1.15. It was possible that overload during shimmy event can compress the bushings. In order to verify the condition of shimmy damper linkages, One Time Check (OTC) was performed on three serviceable B737-400 aircraft of the operator for "Torsional

Free Play". The Torsional Free Play was found more than AMM specification on all three aircraft. The next C-check on these aircraft was falling due approximately within next 929 to 2392 hrs. The OTC findings supported the fact that operator's maintenance schedule of inspection of shimmy damper and linkages during C-check was not adequate, and there was a requirement of implementing enhanced frequency checks in light of recommendations of Boeing Service Letter SL 737-SL-32-057-D. The "One Time Check" finding also supports the assumption that wear of the bushings of the mishap aircraft was most probably present prior to the incident and was not solely result of overload during shimmy event. The FAC report also concluded that overload on bushing occurred over period of time and not just during this particular incident.

2.1.16. The internal hydraulic leaks / damaged of shimmy damper can also adversely affect the damping efficiency. The shimmy damper actuator was found bent / deformed after the incident; therefore, complete bench check was not possible. The partial bench check was carried out which confirmed that there was no internal hydraulic leak in the assembly. After the bench check, tear down examination was carried out and internal seals and piston was verified to be intact.



Shimmy damper internal seals and parts were found intact

3. CONCLUSION

3.1. Findings

3.1.1. The initial touchdown was at higher than recommended speed and lower sink rate. The landing was made through an un-stabilized approach without following the correct landing technique as recommended by Boeing.

3.1.2. A smooth touchdown was made which created conditions to reduce the effectiveness of shimmy damping mechanism. The presence of play due to wear / deformation of the bushings in the associated linkages of torsion links further aggravated the situation for onset of shimmy.

3.1.3. The fracture surfaces of the upper torsion link indicated an over load fracture with no evidence of fatigue or material deficiency.

3.1.4. The overload fracture of torsion link was consequence of large amplitude vibrations (resonant vibration) due to shimmy after touchdown.

3.1.5. The shimmy damper internal mechanism was intact and there was no evidence of damage to its seals and piston.

3.1.6. The dimensional check of the distance between the inner faces of the bushings of torsion link indicated wear / deformation of the bushings beyond specifications.

3.1.7. The operator's maintenance schedule of inspection of shimmy damper and linkages during C-check was not adequate, and there was a requirement of implementing enhanced frequency checks in light of recommendations of Boeing Service Letter SL 737-SL-32-057-D.

3.2. **Cause of Occurrence**. The incident took place due high ground speed landing with low sink rate combined with excessive play present at the linkages of shimmy damper mechanism.

4. SAFETY RECOMMENDATIONS

4.1. The operator (SAI) to perform One Time Check of "Main gear damper Test, Task 32-11-81-705-014" and "Torsional Free Play Check, Task 32-11-81-705-014" in accordance with the applicable Aircraft Maintenance Manual (AMM) and perform necessary adjustment / rectification as required. (This recommendation was implemented by operator during process of SIB investigation).

4.2. All operators of Boeing 737-100 / 200 / 300 / 400 / 500 (737 CL) Series, to conduct a review of Boeing Service Letter 737-SL-32-057E, for implementation of the recommended enhanced frequency of check on Shimmy Damper and Associated Linkages.

4.3. Civil Aviation Authority, Pakistan to review its existing airworthiness procedures to ensure that all operators perform necessary technical reviews of non mandatory manufacturer's instructions / service letters, and implement required measures especially if they are facing problems in the area covered by the subject instructions / service letters.

4.4. All Boeing 737-400 operating cockpit crews may be briefed to adhere to Boeing recommended procedures & landing technique especially while landing at higher field elevation airports to ensure effectiveness of shimmy damper mechanism. Boeing's Flight Operations Technical Bulletin Number 737-15-2 provides information related to main landing gear shimmy on landing and preventative landing techniques.