ACCIDENT

Aircraft Type and Registration:	Boeing 737-4Q8, OE-IAG
No & Type of Engines:	2 CFM56-3C1 turbofan engines
Year of Manufacture:	1992 (s/n 25168)
Date & Time (UTC):	4 October 2016 at 0455 hrs
Location:	Runway 25, Belfast International (Aldergrove) Airport
Type of Flight:	Commercial Air Transport (Cargo)
Persons on Board:	Crew - 2 Passengers - None
Injuries:	Crew - None Passengers - N/A
Nature of Damage:	Fractured lower torsion link on right main gear leg
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	45 years
Commander's Flying Experience:	5,900 hours (of which 900 were on type) Last 90 days - n/k hours Last 28 days - n/k hours
Information Source:	AAIB Field Investigation

Synopsis

On landing, an intense vibration developed, the crew cancelled the automatic brakes and thrust reversers, as there was sufficient runway, and the aircraft came to a stop. The lower torsion link was found to have fractured on the right main landing gear (MLG) possibly due to excessive MLG vibration (shimmy). The cause of the vibration could not be established but may have been related to the speed of the aircraft on landing, and possibly a problem with the shimmy damper or freeplay within the joints associated with the upper and lower torsion links.

History of the flight

The aircraft had taken off from East Midlands Airport carrying 16 tonnes of cargo. It landed at Belfast International Airport at a weight of 54,900 kg (98% of the maximum landing weight) with a forward, but within-limits, centre of gravity. At the time of the landing there was a tailwind component of 5 kt and a crosswind component of 10 kt from the left.

The aircraft touched down about 250 m beyond the threshold of Runway 25. The crew did not recall anything unusual about the touchdown. The speedbrakes were deployed, and subsequently the thrust reversers and the brakes were selected. The crew felt a vibration that started to increase in intensity and they suspected a tyre failure. The anti-skid fail warning illuminated, and the crew cancelled the thrust reversers and automatic braking as

sufficient runway remained in which to stop. The aircraft track continued to oscillate close to the runway centreline before stopping 2,170 m beyond the threshold of Runway 25 at its intersection with Runway 17/35. There were no injuries and the aircraft was moved from the runway at approximately 1800 hrs.

Aerodrome information

Belfast International Airport, also known as Aldergrove, has two intersecting runways: Runway 07/25, 2,780 m long and Runway 17/35, 1,891 m long (Figure 1).

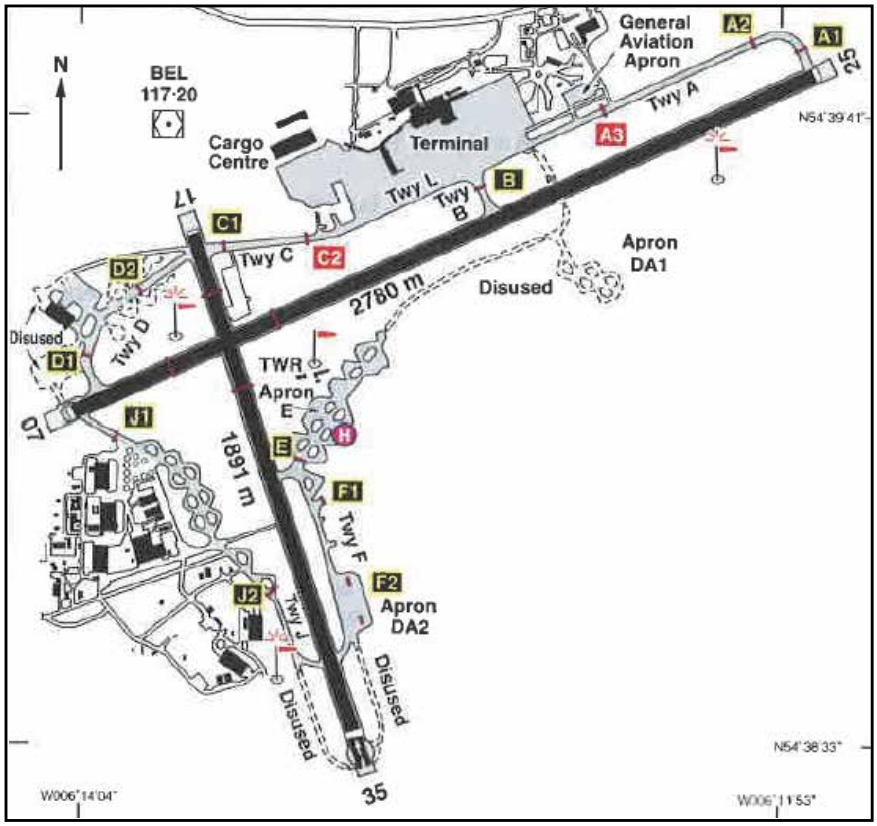

Figure 1

Plan of Belfast International Airport (courtesy of Pooleys)

Meteorological information

The METARs at Belfast International Airport around the time of the accident were:

EGAA, Belfast / Aldergrove Airport (United Kingdom)
Latitude 54-39N. Longitude 006-13W. Altitude 81 m.

201610040420 METAR EGAA 040420Z 13011KT 090V150 CAVOK 12/09 Q1026=
201610040450 METAR EGAA 040450Z 13009KT CAVOK 12/09 Q1027=
201610040520 METAR EGAA 040520Z NIL=
201610040550 METAR EGAA 040550Z 13009KT 090V150 9999 FEW010 12/09 Q1027=

A surface wind of 130° at between 9 and 11 kt equates to a tailwind component of around 5 kt and a crosswind component of about 10 kt from the left for Runway 25.

The Met Office commented that:

> *'If the 2000FT wind is assumed to have been a conservative 35 KT the vertical wind shear was 12KT/1000FT which meets the requirements for severe turbulence.'*

The aircraft manufacturer calculated a tailwind component of 5 kt from 1,000 ft agl to touchdown and a crosswind of 30 kt from the left at 1,000 ft, dropping to about 10 kt from the left at touchdown.

On-site investigation

The aircraft stopped on Runway 25 at its intersection with Runway 17/35 (Figure 2).

Figure 2

Image showing aircraft stopped at intersection of the two runways

A pair of parallel tyre marks to the right of the centre line on Runway 25 had a distinctive 'S-shaped' pattern, and started approximately 900 m from the threshold of Runway 25. They continued to the main wheels on the right MLG leg; however for the last 60 m the two marks became straight (Figures 2, 3 and 4).

Figure 3

Image showing tyre marks close to the aircraft

Figure 4

Image looking approximately east showing tyre marks

When inspected, both wheels of the right MLG were skewed to one side and there was significant damage to both wheel hubs and both tyres (Figure 5). Both tyres had remained inflated.

The lower torsion link on the right MLG had fractured. Several pieces of debris were recovered from the runway, including pieces of the bushings from the apex where the upper and lower torsion links join. It was not possible to make an accurate assessment of the shimmy damper link condition due to the high level of damage.

Figure 5
Image of right MLG showing torsion link

Recorded information

The aircraft's flight data recorder (FDR) and cockpit voice recorder (CVR) were downloaded and their recorded data analysed.

Descent into Belfast International Airport

The FDR data showed that as the aircraft descended through 1,000 ft it was configured with flaps 30, and autopilot and auto throttle disengaged. The calibrated airspeed was about 148 kt (V_{REF} + 7), with a tailwind component of approximately 5 kt and crosswind component of approximately 30 kt from the left.

As the aircraft descended below 500 ft, the descent rate was a nominal 800 fpm. This was maintained until about 40 ft agl when the landing flare was initiated, reducing to about 600 fpm (10 fps) at touchdown. The aircraft touched down with 1.7º of left bank and a drift angle of 3º to the right, at about 148 kt CAS (V_{REF} + 7) and a peak recorded normal acceleration of 1.65 g.

Ground track

Figure 6 shows the pertinent data for OE-IAG during the landing rollout and the resulting ground track. The distance on the x-axis (CALCULATED DISTANCE FROM RUNWAY THRESHOLD) is based on an integration of the groundspeed, then working back along Runway 25 from the crossing with Runway 17/35 where the aircraft came to a stop and runway information published in the UK Integrated Aeronautical Information Package. The lateral distance of the aircraft from the runway centreline (CALCULATED LATERAL DEVIATION FROM RUNWAY CENTRELINE) is based on localiser deviation.

An analysis of the data indicates that the aircraft touched down about 250 metres beyond the threshold to Runway 25. The speed brakes deployed on touchdown and the thrust reversers were fully deployed by 530 m beyond the threshold. At about 690 m beyond the

threshold, the air/ground discrete erroneously changed to AIR, followed by oscillations in lateral acceleration.

At 950 m beyond the threshold, the brakes were applied. They were released temporarily after about 600 m when the thrust reversers were re-stowed. The aircraft then oscillated from the runway centreline before stopping 2,170 m beyond the threshold.

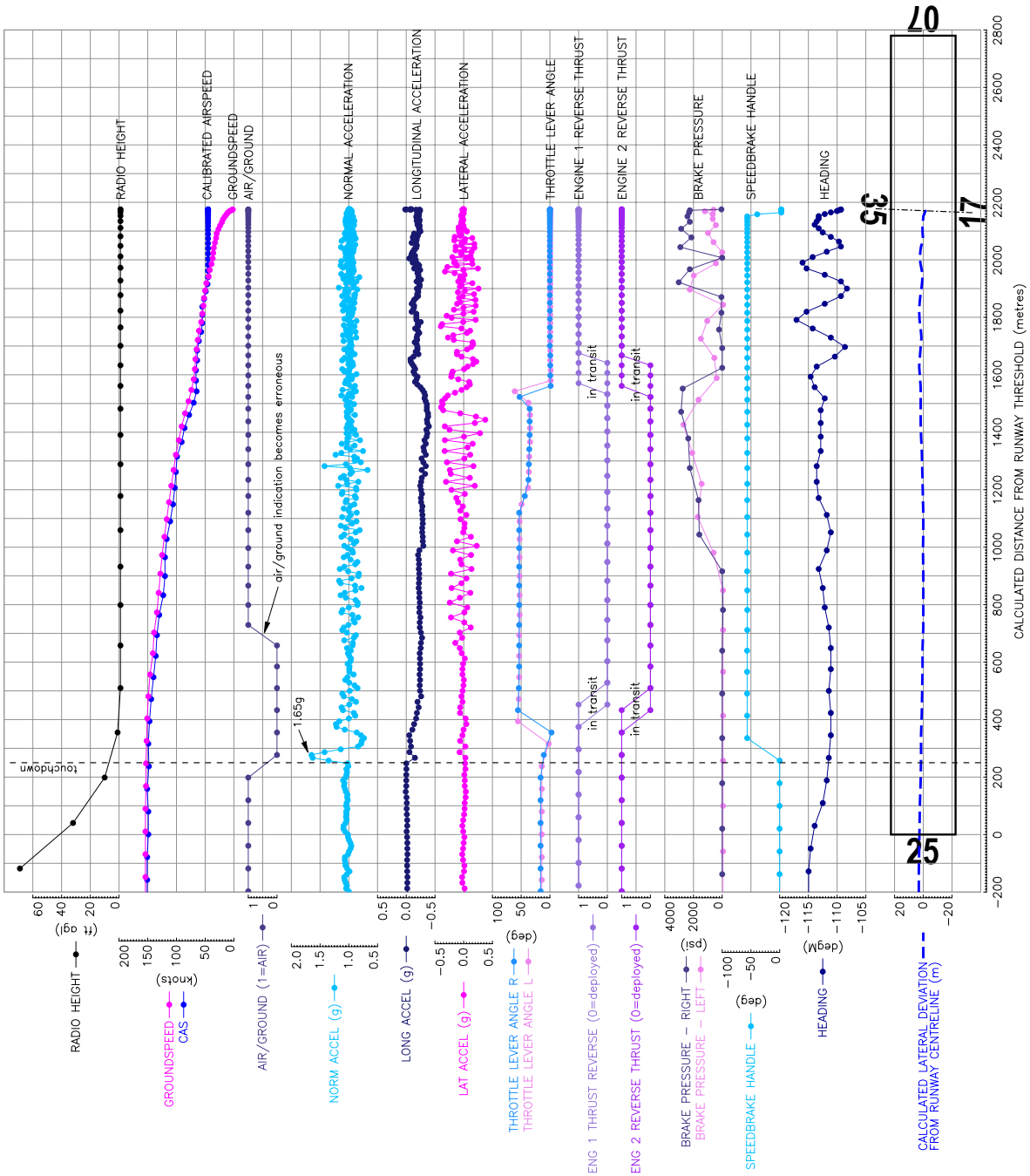

Figure 6

Pertinent FDR data and ground track on landing

Aircraft information

The Boeing 737 MLG leg consists of a cylinder/piston type shock-strut, with the outer cylinder attached to the wing structure, and the lower end of the inner piston carrying an axle with two main wheels. The axle centreline is located 9 cm behind the shock-strut centreline to provide a castoring effect.

A scissor linkage, made up of an upper and lower torsion link, is intended to prevent rotation of the inner piston relative to the outer cylinder, while allowing axial movement to provide shock absorption (Figure 7). The upper torsion link is attached to the outer cylinder via a horizontal pivot joint and the lower torsion link is similarly attached at the inner piston.

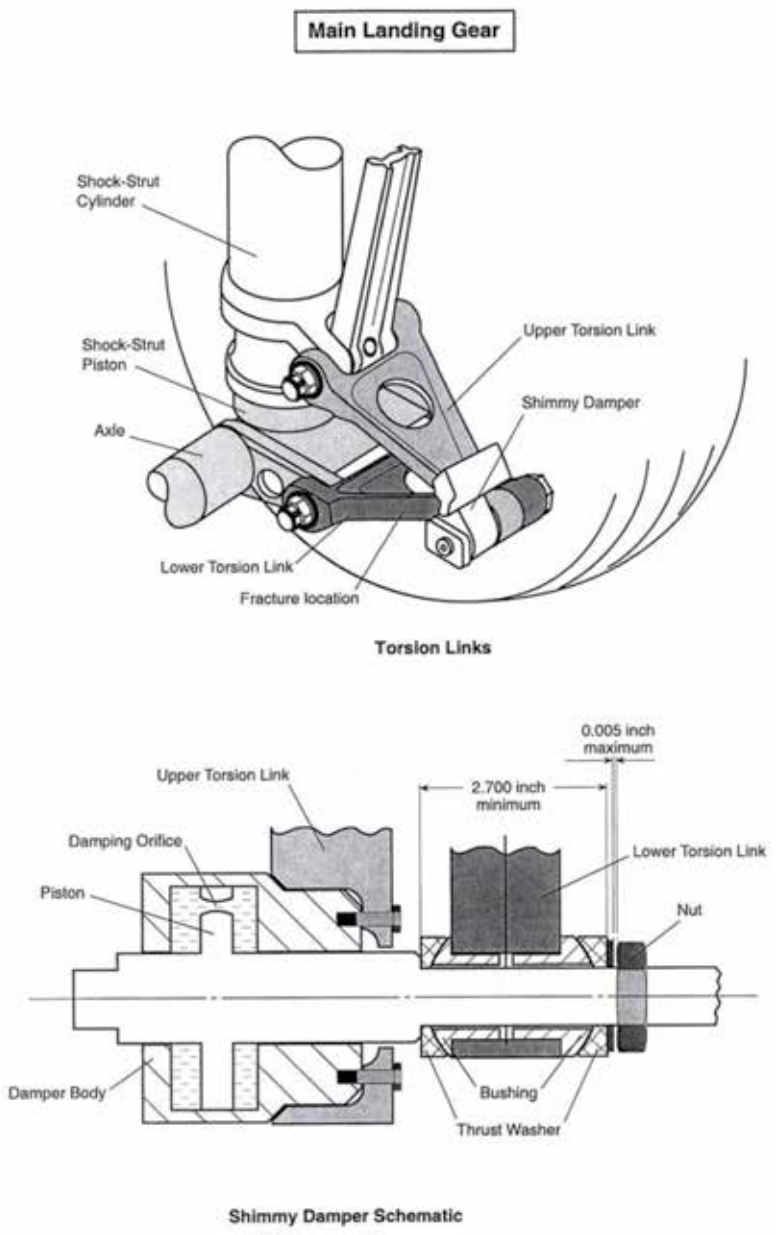

Figure 7

Schematic of MLG and shimmy damper

A shimmy damper is connected between the apexes of the upper and lower torsion links in order to control the rotary oscillation of the shock-strut inner piston relative to the outer cylinder and thereby prevent excessive MLG vibration (shimmy) during high-speed taxi and under heavy braking. The apex of the upper torsion link is bolted to the damper body and the apex of the lower torsion link is connected to the damper piston rod via a bearing assembly. This consists of spherical bushes sandwiched between two thrust washers and is clamped against a shoulder on the rod by an end nut. The torsion links can pivot relative to each other but horizontal displacement between their apexes is controlled by the damper action (Figure 7).

Previous shimmy events

The phenomenon of shimmy, which is an abnormal wheel vibration, is a known issue for the MLG on this aircraft type and typically has a frequency of approximately 15 Hz. To reduce the possibility of shimmy not being damped out due to wear in the apex joint, the applicable issue of the Aircraft Maintenance Manual specifies a number of checks and maintenance operations related to the MLG torsion links and the shimmy damper to replace worn, fractured or cracked apex bushings or apex thrust washers.

The manufacturer provided advice in a quarterly publication in 2013 entitled '*Preventing Main Landing Gear Shimmy Events*', which is applicable to the Boeing 737-100, -200, -300, -400 and -500 models:

> *'…(the manufacturer) recommends pilots strive for a landing with normal sink rates with particular emphasis on ensuring that the auto speedbrakes are armed and deploy promptly on touchdown. An overly soft landing, or a landing which the speedbrakes do not deploy promptly, allows the landing gears to remain in the air mode longer, which makes them more vulnerable to shimmy. This is especially true when landing at airports at higher elevations, where the touchdown speed is increased.'*

Later variants of Boeing 737 have a different design and are less susceptible to shimmy.

The manufacturer has also published the following information for the 737 fleet:

- Multi Operator Message MOM-MOM-15-0853, Boeing participation in 737CL Main Landing Gear collapse events under investigation on 15 December 2015
- Service Letter 737-SL-32-057E, Main Landing Gear Lower Torsion Link Fractures on 22 December 2015
- Fleet Team Digest Article 737-FTD-32-11001, Main Landing Gear Shimmy on 15 December 2015.
- Flight Operations Technical Bulletin 737-15-2, Main Landing Gear Shimmy on 14 December 2015.

Assessment of the wear in the bushings

The torsion link exhibited some evidence of wear in the bushings. However, the manufacturer, having compared the wear with bushings which had been causal in previous events, did not consider that the wear in the bushings on OE-IAG was significant.

Assessment of fractured torsion link

The two pieces of the fractured lower torsion link (Figure 8) were sent to a metallurgical laboratory for an assessment of the fracture surfaces (note the inboard lug at the top left of the image was cut during removal from the aircraft).

The assessment concluded that the torsion link had failed in overload. There was no evidence of fatigue. It was concluded that the failure of the torsion link was caused by shimmy.

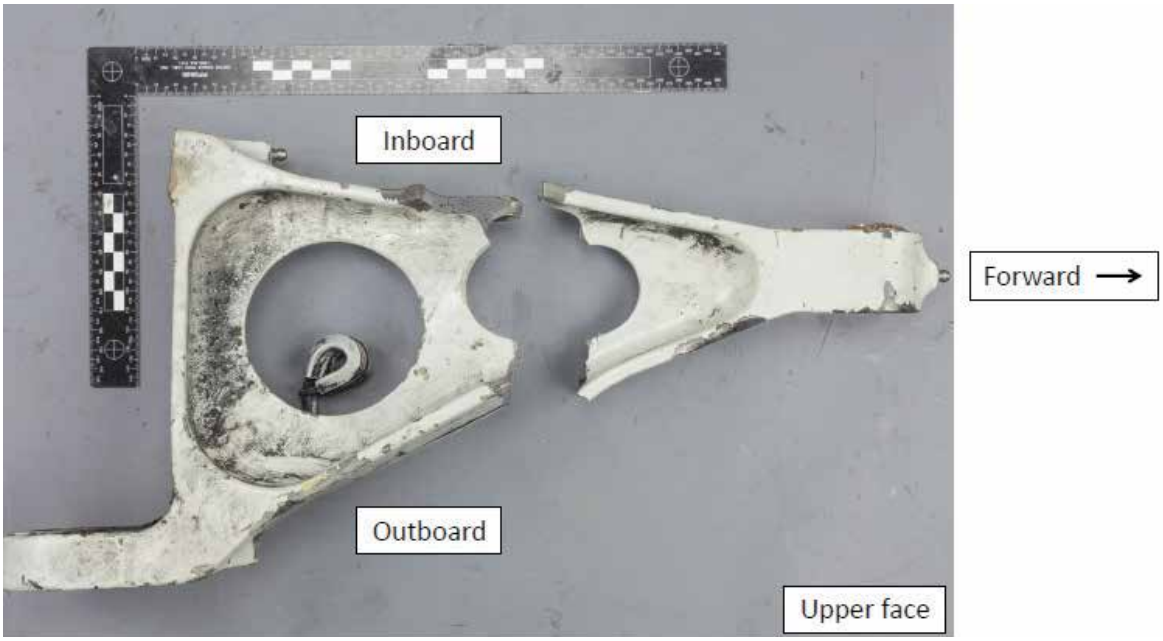

Figure 8

Image of fractured torsion link (courtesy of QinetiQ)

Aircraft maintenance records

Maintenance records indicated that the torsional free play check between the inner and outer cylinder, and therefore an indication of wear at the torsion link apex, had last been successfully carried out on the right MLG in January 2015, with a visual check of the torsion links for security and damage in November 2015; nothing significant was found.

Manufacturer's analysis of FDR data

The manufacturer noted that high-speed landings have been shown to elevate the risk of landing gear shimmy. It noted that the:

> *'Flight Crew Reference Manual[1] recommends an approach with a tailwind be flown at Vref+5, with the 5 knot additive being bled off during flare. In this case, the airplane touched down at a computed airspeed of 148 kt (Vref+7). In addition the tailwind increased the groundspeed at touchdown to 153 knots'*

Analysis

The physical and recorded evidence indicate that the fracture to the lower torsion link on the right MLG leg was most likely caused by shimmy. This and previous occurrences show that the Boeing 737 MLG is susceptible to shimmy, particularly at higher landing speeds and for softer landings.

The manufacturer has a mature and well-documented list of probable causal factors for shimmy on this aircraft type. There was no evidence of a pre-existing defect in the failed torsion link or the apex joint which would have caused the shimmy. It was not possible to assess the condition of the shimmy damper or determine if there was any freeplay in the joints associated with the torsion links. Accordingly it is possible that there was a failure of the damper or excessive freeplay in the joints, which combined with the high-speed landing may have induced shimmy.

Whilst there was no evidence to suggest that maintenance was a causal or contributory factor, the manufacturer is currently working with the operator to assess the maintenance requirements to ensure they are appropriate for its operations.

Footnote

[1] 737 Classic Flight Crew Training Manual (FCTM) The Boeing Company, Revision date June 30, 2016