Accident

Aircraft Type and Registration:	Boeing 737-4Q8, G-JMCY
No & Type of Engines:	2 CFM56-3C1 turbofan engines
Year of Manufacture:	1994 (Serial no: 25114)
Date & Time (UTC):	19 January 2021 at 0237 hrs
Location:	Exeter Airport, Devon
Type of Flight:	Commercial Air Transport
Persons on Board:	Crew - 2 Passengers - None
Injuries:	Crew - None Passengers - N/A
Nature of Damage:	Damaged beyond economical repair
Commander's Licence:	Air Transport Pilot's Licence
Commander's Age:	56 years
Commander's Flying Experience:	15,218 hours (of which 9,000 were on type) Last 90 days - 25 hours Last 28 days - 14 hours
Information Source:	Field Investigation

Synopsis

During an ILS approach at Exeter Airport, the aircraft became unstable after the point where the crew had declared it stable and continued with the approach. During the final 500 ft the rate of descent exceeded the required 500 ft stable approach maximum on four occasions. All bar the first of these excursions were accompanied by GPWS "SINK RATE" alert. The subsequent hard landing resulted in extensive damage to the aircraft. There were no injuries.

The operator has taken safety action to reinforce its operating procedures with regards to the criteria for a stable approach.

History of the flight

Background information

The crew were scheduled to operate two cargo flights from Exeter Airport (EXT), Devon, to East Midlands Airport (EMA), Leicestershire, and return. The co-pilot was the PF for both sectors, and it was night.

The sector from EXT to EMA was uneventful with the crew electing to landed with FLAP 40[1].

Footnote

1 FLAP 40 is the recommended landing configuration for performance limiting runways and in poor weather.

Accident flight

The subsequent takeoff and climb from EMA to EXT proceeded without event.

During the cruise the crew independently calculated the landing performance, using the aircraft manufacturer's software, on their portable electronic devices. Runway 26 was forecast to be wet, so they planned to use FLAP 40 for the landing on Runway 26, with AUTOBRAKE 3[2]. With both pilots being familiar with EXT the PF conducted a short brief of the pertinent points for the approach. However, while they did mention that the ILS had a 3.5° glideslope (GS), they did not mention that the stabilised approach criteria differed from that on a 3° GS[3]. From the ATIS they noted that the weather seemed to be better than forecast and the surface wind was from 230° at 11 kt.

The ATC provided the flight crew with radar vectors from ATC to the ILS on Runway 26 at EXT, Figure 2. The landing gear was lowered and FLAP 25 selected before the aircraft intercepted the GS. FLAP 40 (the landing flap) was selected on the GS just below 2,000 ft amsl. With a calculated V_{REF} of 134 kt and a surface wind of 10 kt the PF planned to fly the approach with a V_{APP} of 140 kt. At about 10 nm finals, upon looking at the flight management computer, the PM noticed there was a 30 kt headwind, so a V_{APP} of 144 kt was selected on the Mode Control Panel (MCP). The crew became visual with the runway at about 1,000 ft aal. The PF then disconnected the Auto Pilot and Auto Throttle; the Flight Directors remained on. As the wind was now starting to decrease, the V_{APP} was then reduced from 142 to 140 kt at about 600 ft aal.

As the wind reduced, towards the 10 kt surface wind, the PF made small adjustments to the power to maintain the IAS at or close to V_{APP}. At 500 ft radio altimeter (RA) the approach was declared stable by the crew, as per their standard operating procedures. At this point the aircraft had a pitch attitude of 2.5° nose down, the IAS was 143 kt, the rate of descent (ROD) was about 860 ft/min, the engines were operating at about 68% N_1 and the aircraft was 0.4 dots above the GS. However, the ROD was increasing and soon thereafter was in excess of 1,150 ft/min. This was reduced to about 300 ft/min but soon increased again.

At 320 ft RA, the aircraft went below the GS for about 8 seconds and, with a ROD of 1,700 ft/min, a "SINK RATE" GPWS alert was enunciated. The PF acknowledged this and corrected the flightpath to bring the aircraft back to the GS before stabilizing slightly above the GS; the PM called this deviation too. As the PF was correcting back to the GS the PM did not feel there was a need to take control. During this period the maximum recorded deviation was ¾ of a dot below the GS.

At about 150 ft RA, with a ROD of 1,300 ft/min, there was a further "SINK RATE" GPWS alert, to which the PM said, "WATCH THAT SINK RATE", followed by another "SINK RATE" alert, which the PF responded by saying "AND BACK…"

Footnote

[2] The manufacturer's Flight Crew Training Manual states that Autobrake 3 '*Should be used for wet or slippery runways or when landing rollout distance is limited.*'

[3] See '*Operator's operations manual*' for more detail.

The commander recalled that as the aircraft crossed the threshold, at about 100 ft, the PF retarded the throttles, pitched the aircraft nose down, from about 5° nose up to 4° nose down, and then applied some power in the last few feet. During these final moments before the landing, there was another “SINK RATE” alert. The result was a hard landing. A “PULL UP” warning was also triggered by the GPWS, but it was not audible on the CVR.

The last surface wind transmitted by ATC, just before the landing, was from 230° at 10 kt.

During the rollout the commander took control, selected the thrust reversers and slowed down to taxi speed. After the aircraft had vacated the runway at Taxiway Bravo it became apparent the aircraft was listing to the left. During the After Landing checks the co-pilot tried to select FLAPS UP, but they would not move. There was then a HYDRAULIC LP caution. As there was still brake accumulator pressure the crew were content to taxi the aircraft slowly the short distance onto Stand 10 (Figure 1). Once on stand the listing became more obvious. It was then that the crew realised there was something “seriously wrong” with the aircraft.

After they had shut the aircraft down, the flight crew requested that the wheels were chocked, and the aircraft be connected to ground power before going outside to inspect the aircraft. Once outside a hydraulic leak was found and the airport RFFS, who were present to unload the aircraft, were informed.

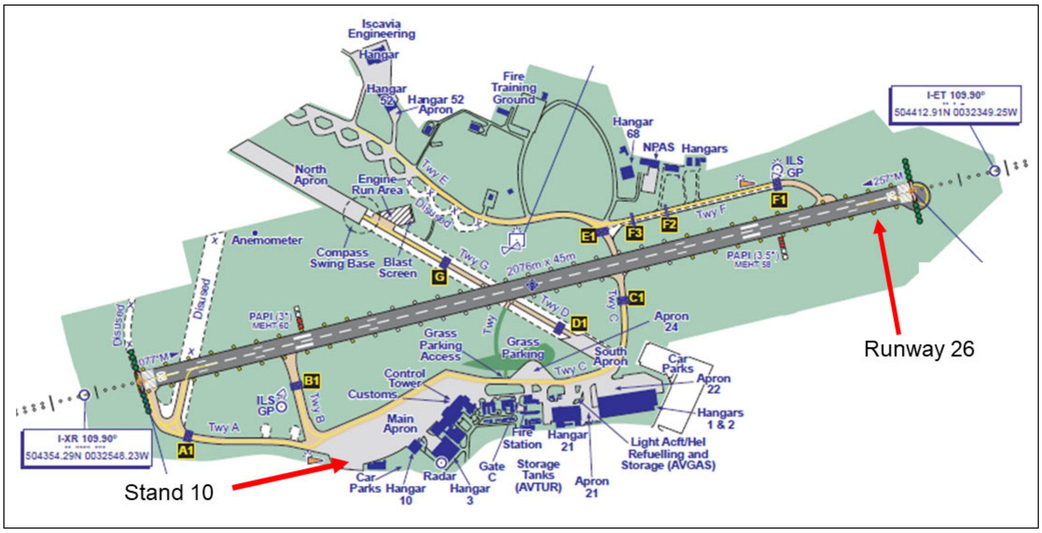

Figure 1

Exeter Airport from UK Aeronautical Information Publication

Airport information

Exeter Airport has one runway orientated 08/26. Runway 26 has a landing distance available of 2,036 m, PAPIs[4] set to 3.5° and an ILS with a 3.5° GS. The approach chart, from the Aeronautical Information Publication, for the ILS/DME to Runway 26 is at Figure 2.

Footnote

4 PAPIs are a visual aid that provides guidance information to help a pilot acquire and maintain the correct approach (in the vertical plane) to an airport.

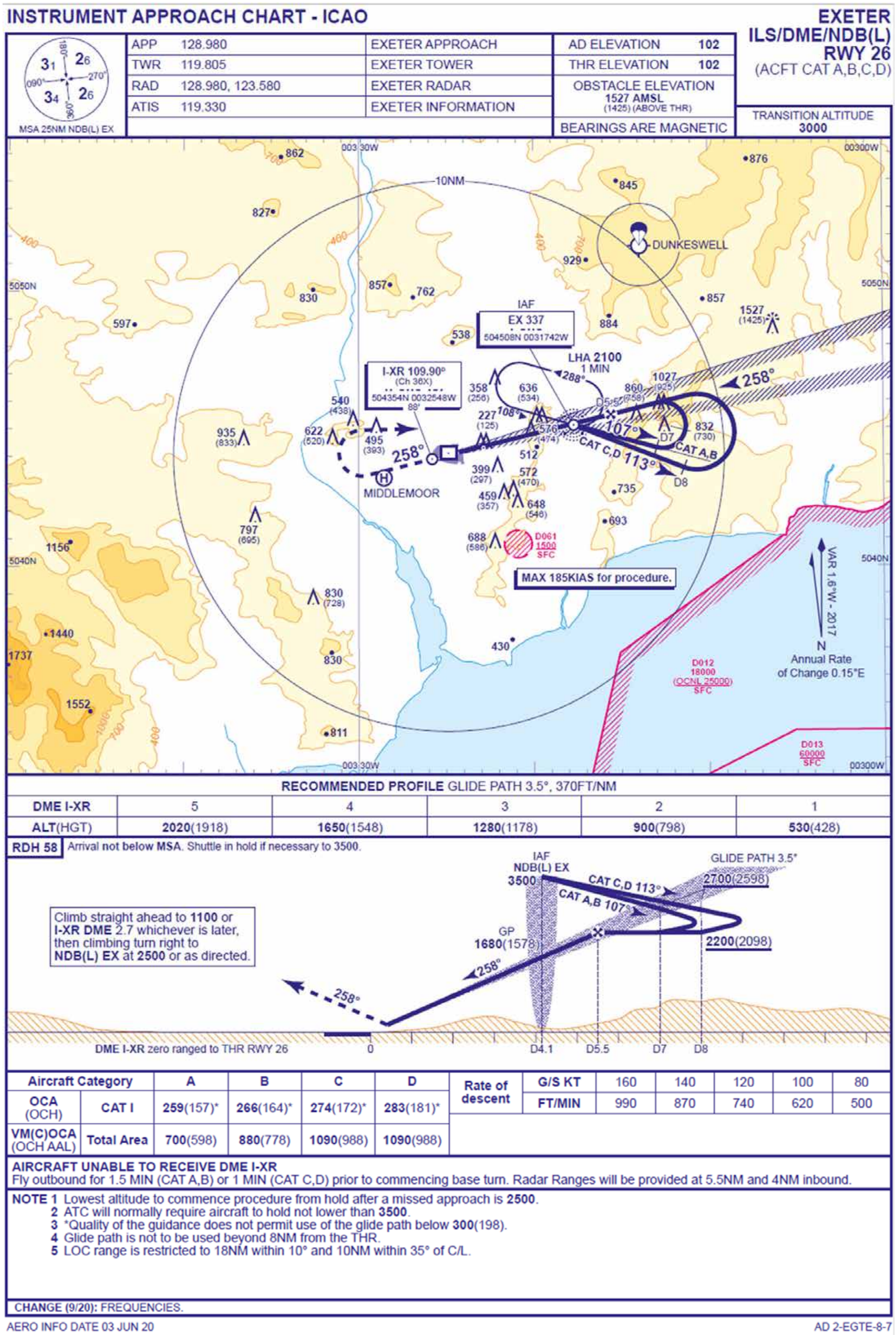

Figure 2

Approach Chart for ILS/DME to Runway 26 at Exeter Airport

The ILS chart stated that for a ground speed of 140 kt the ROD would be about 870 ft/min and 740 ft/min for 120 kt while maintaining the GS (Figure 3). By interpolation this gives a ROD of about 805 ft/min at a ground speed of 130 kt, ie close to that during the final stages of the approach.

Rate of descent	G/S KT	160	140	120	100	80
	FT/MIN	990	870	740	620	500

Figure 3

ROD from ILS/DME to Runway 26

After the accident the airport operator checked the runway lights, ILS, DME, PAPI's and pressure sensors and all were confirmed serviceable.

Crew's comments

Commander's comments

The commander stated that if the thrust is reduced to IDLE quickly, with FLAP 40, the "aircraft stops flying" due to the large amount of drag from the flaps. While the possibility of conducting a GA just before the landing was always in his mind, it was not considered as the aircraft "stopped flying" and "dropped" onto the runway so quicky he felt it was too late for him to call go-around or take control. He added that in hindsight one should have been initiated at that point, but the aircraft would have more than likely touched down during the manoeuvre.

Co-pilot's comments

The co-pilot commented that she did not know what caused the hard landing but did not believe there was a technical issue. She had no issues with operating into Exeter in the past and operating into Exeter was not a rarity. She added that she did not consider a 3.5° GS to present any additional difficulty and was comfortable and familiar with the airport.

Crews' experience

Commander's experience

The commander had a total of 15,218 flying hours, of which 9,000 were on the Boeing 737 (B737). He had been with the operator since 2014.

During his OPC on 8 January 2021 he was assessed as *Surpasses Company Standard* in six of the pilot competencies, *Expected Company Standard* in two and *Baseline Minimum Standard* in *Applied Knowledge*, where the training captain commented that "Few gaps observed and debriefed."

Co-pilot's experience

The co-pilot had a total of 19,350 flying hours, of which 5,637 were on the B737. She had been with the operator since 2015.

Prior to this accident the co-pilot had previously landed at Exeter on Runway 26, in a B737-400 on 24, 26 and 28 November 2020. These were also night sectors. During the approaches there was a 20-25 kt tailwind, at height, that reduced to about a 2 kt tailwind over the threshold.

The commander for these sectors stated all the approaches and landings were all flown well bar the last one on 28 November 2020. On the last approach, at about 200 ft aal, while manually flying, there was a "SINK RATE" GPWS alert. The co-pilot quickly adjusted the flight path and the approach remained stable. However, the aircraft drifted up into three whites on the PAPIs, due to an increase in thrust, which was corrected. The aircraft landed "a bit deep" but inside the touchdown zone. The co-pilot attributed the event to the tailwind. However, the commander at the time believed she made a momentary forward input on the control column, and, as the vertical speed indicator was fed by the aircraft's inertial reference system[5], this shortlived increase in the ROD triggered the GPWS alert.

During her previous licence proficiency check on 15 July 2020, during a single engine approach, if was noted that the aircraft produced a "SINK RATE" alert on short finals. There were also some deviations on the GA that was subsequently flown. The training captain recorded this element as passed at second attempt and assessed her *Flight Path Management* as *Baseline Minimum Standard*.

Since this accident, the operator recognised that there was no robust mechanism to monitor trends in pilots' performance across recurrent checks, therefore persistent/repetitive under performance in technical skill areas were not always identified. The operator has since introduced a number of new procedures to rectify this.

Fatigue

Given this accident happened at about 0230 hrs, the crew's sleep history was assessed to see if tiredness and/or fatigue could have been a contributory factor. It was found not to be a factor.

Aircraft information

Weight and balance

The aircraft's weight and balance were within limits. It departed with 8,400 kg of fuel. The trip fuel was expected to be about 1,800 kg.

The aircraft landed with 6,600 kg of fuel, giving it a landing weight of approximately 52,900 kg. Its planned minimum diversion fuel was 3,118 kg. The nominated diversion was EMA.

The operator commented that a B737 would use about 1,000 kg of fuel during a GA and another approach.

Footnote

[5] The inertial reference system provides inertial navigation data to aircraft systems. It uses a ring laser gyro instead of the conventional rate gyro to sense angular rate about the roll, pitch and yaw axes.

Aircraft attitude on approach

The aircraft manufacturer stated that the approximate pitch attitude at 52,900 kg, FLAPS 40 with V_{REF}+5 kt, on a 3.5° glideslope was about 1° nose up.

Meteorological information

The METAR issued at 0220 hrs stated that the surface wind was from 230° at 10 kt, visibility of 9 km, light rain, SCATTERED clouds at 1,200 ft aal, BROKEN clouds at 4,000 ft aal, temperature 12°C dew point 10°C, QNH 1009 hPa.

Operations Manual

The operator's Operations Manual (OM) Part B stated:

> *'2.1.14 Stabilised Approach*
>
> *It should be clearly understood that an unstable approach is more likely to result in a hazardous landing with the resultant high risk of an accident. The majority of unstable approaches result from a lack of appreciation of the aircraft energy level at an early part of the approach and the resultant failure to slow the aircraft in a controlled manner.*
>
> *…*
>
> *The criteria for a stabilised approach are:*
>
> *a) Aircraft in landing configuration (Note 1);*
>
> *b) Final approach speed [V_{APP}] +10/-5 kt;*
>
> *c) Rate of descent less than 1,000 ft per minute (Note 2) [1,150 ft/min for a 3.5° glideslope];*
>
> *d) ILS: Aircraft within +/- 1 dot of glideslope/LOC [localiser];*
>
> *…*
>
> *g) Normal approach thrust set.*
>
> *…*
>
> *Note 2: Rate of descent limit may be increased by 150 fpm per 0.5 degree that the published approach path exceeds 3 degrees.*
>
> *All approaches must be stable:*
>
> *a) in IMC by 1,000ft above TDZE [touchdown zone elevation];*
>
> *b) in VMC by 500ft above TDZE (Note 1)...*
>
> *Note 1: All approaches in VMC should be stable by 1,000ft above TDZE*
>
> *…*

If the Commander is in any doubt as to whether a stabilised approach can be achieved, he should review the need for a go-around at an early stage. If a stabilised approach cannot be achieved, he must ensure that a go-around is carried out.

If the parameters of a stabilised approach are not achieved at 500 feet a go around must be initiated.'

2.1.17.5 Deviations

PM should use the following calls to alert the PF at any time there is a deviation from the intended condition.

An uncorrected significant trend towards a deviation should trigger a call in a timely manner to help avoid a significant exceedance.

…If the PM notices that the PF is already correcting, a call might not be necessary.

Should there be no correction from a deviation call, the PM must call again adding appropriate describing words, such as "SPEED TOO LOW"…

Phase of Flight	***Deviation***	***PM Call***
…	…	…
Final Approach	*>1000 fpm ROD unless a greater ROD has been briefed*	*"SINK RATE"*

2.2.14 Landing Procedure - ILS

…

2.2.14.1 Allocation of Duties and Standard Calls

This table assumes a CAT I ILS approach, …

Event	***PF***	***PM***
…	…	…
500ft RA[6]	*If stable:* *"CHECK"* *If unstable:* *"GO-AROUND, FLAP 15"*	*If unstable:* *"UNSTABLE, GO AROUND"*

…

Footnote

6 An amendment to OMB after the accident added a note to this section that states: '*For approach stability requirements, see OMB 2.1.14. Note specifically that approach stability requirements are with respect to TDZE, not Radio Altimeter height.'*

Note 3: Wind corrected final approach speed [V_{APP}] is calculated by adding half of the reported steady headwind component plus the full gust increment to the reference speed. The minimum final approach speed setting is VREF +5kts…

...All further callouts by the PM may be omitted, except for the relevant callout at 500 ft RA and any deviations.'

There was no stated requirement in the OM for both pilots to monitor that the stable approach criteria were maintained below 500 ft, with the aim of delivering the aircraft to the point in space above the runway from which a flare manoeuvre will result in touchdown at the right speed and attitude, and within the touchdown zone. This is something other operators are known to have in their OM, with a requirement to conduct a GA if the stable approach criteria are not maintained to the landing.

B737 Flight Crew Training Manual

The manufacturer's *Flight Crew Training Manual* (FCTM) also stated the same criteria for an approach to be stable as those in the OM. However, it has the following additional statement:

'*Stabilized Approach Recommendations*

…

These conditions should be maintained throughout the rest of the approach for it to be considered a stabilized approach. If the above criteria cannot be established and maintained until approaching the flare, initiate a go-around.'

It also has the following guidance:

'Rejected Landing

A rejected landing maneuver is trained and evaluated by some operators and regulatory agencies. Although the FCOM/QRH does not contain a procedure or maneuver titled Rejected Landing, the requirements of this maneuver can be accomplished by doing the Go-Around Procedure if it is initiated before touchdown. Refer to Chapter 5, Go-Around after Touchdown, for more information on this subject.

Go-Around after Touchdown

If a go-around is initiated before touchdown and touchdown occurs, continue with normal go-around procedures…

If a go-around is initiated after touchdown but before thrust reverser selection, continue with normal go-around procedures…

Flap Setting for Landing

For normal landings, use flaps 15, 30, or flaps 40…When performance criteria are met, use flaps 40 to minimize landing speed, and landing distance.'

B737 Quick Reference Handbook

The B737 Quick Reference Handbook states in MAN1.4:

'Ground Proximity Warning System (GPWS) Response

GPWS Caution

Do the following man[o]euver for any of these aural alerts:

• *SINK RATE*

…

Pilot Flying	*Pilot Monitoring*
Correct the flight path, airplane configuration, or airspeed.	

…'

Operator's comments

The operator stated that during their pilots' recurrent training, prior to this event, they had conducted rejected landings/GA from different altitudes and configurations, but not from a touchdown; this practise will continue.

While OMB did not have specific guidance as to what to do in the event of an approach becoming unstable, on an ILS, below 500 ft aal, they believed that the expectation was that if an approach went unstable after 500 ft, it would lead to a GA being initiated. However, the operator believed there could be a perception amongst some of its pilots that the stable criteria applied to a single point in space rather than for the remainder of an approach.

After this accident the operator noted that there was no robust mechanism for tracking an individual pilot's performance during a recurrent check and no formal process in which to manage underperformance or individual trends identified over a series of checks or poor operational performance. They have subsequently introduced a number of procedures to rectify this. They also included stabilised approach criteria as a feature in their pilots' ground based recurrent training.

Recorded information

Recordings were recovered from the onboard FDR, CVR, Quick Access Recorder (QAR) and the Terrain Awareness and Warning System (TAWS) computer.

External sources of data included CCTV, wind data from airfield sensors, radar and ATC recordings, runway lighting data and QAR data from previous flights. These did not highlight any anomalies over and above those identified in the aircraft recordings.

The FDR recorded over 108 hours of flight data. No issues were identified with the aircraft systems prior to touchdown. While the FD was known to be on, its computed pitch and bank angles were not recorded on the FDR.

The QAR and TAWS recordings corroborated the FDR recordings. The TAWS recordings provided additional parameters not recorded by the FDR, including altitude rate. The TAWS did not record continuously, but gathered data associated with alerts that had been triggered. In this case TAWS recordings were triggered by three GPWS Mode 1 events. Mode 1 alerts are generated when the descent rate is too high for the given radio height. The alerts were recorded between data samples, at radio heights of approximately 280 ft, 150 ft and below 20 ft. Each trigger was associated with "SINK RATE, SINK RATE" cautions. The last of these also triggered a GPWS Mode 1 alert just prior to touch down. The associated "PULL UP" aural was not evident on the CVR; by the time the preceding "SINK RATE" aural had been issued, the aircraft had touched down.

Figure 4 shows the pertinent parameters associated with the approach and landing.

The recorded wind data and aircraft manufacturer calculated values based on recorded aircraft motion, indicate decreasing overall wind speeds during the descent, slowly backing to about 10 kt, 30° to the left of heading on touchdown. Wind fluctuations were also decreasing during the descent.

The data indicates that the aircraft did not stall. The maximum vertical acceleration recorded by the FDR on touchdown was 3.8g, at this point there was 3° of left roll. However, FDR sample rates and sensor locations are not ideally placed to determine peak forces on touch down. Altitude rate parameters are smoothed and so lag the aircraft dynamic behaviour. The descent rate values were decreasing on touchdown, but more detailed aircraft modelling was required to better understand the descent rate at touchdown. The airframe manufacturer assessment of the data indicates a calculated descent rate of approximately 24 ft/second. This is consistent with the trends of the combined recordings of the left and right radio heights.

After landing, the aircraft maintained a left roll attitude taxiing to the stand, varying between 1.5° and 4.5°. The right trailing edge flap angle had reduced from 40° to 37° on landing, but later in the landing roll this returned to 40°, matching the recorded left flap angle again. The master caution was triggered as the groundspeed reduced through approximately 20 kt. The FDR recorded low pressure states for the hydraulic A and B systems associated with engine 1 and 2 respectively and hydraulic B electrical systems during the taxi to stand.

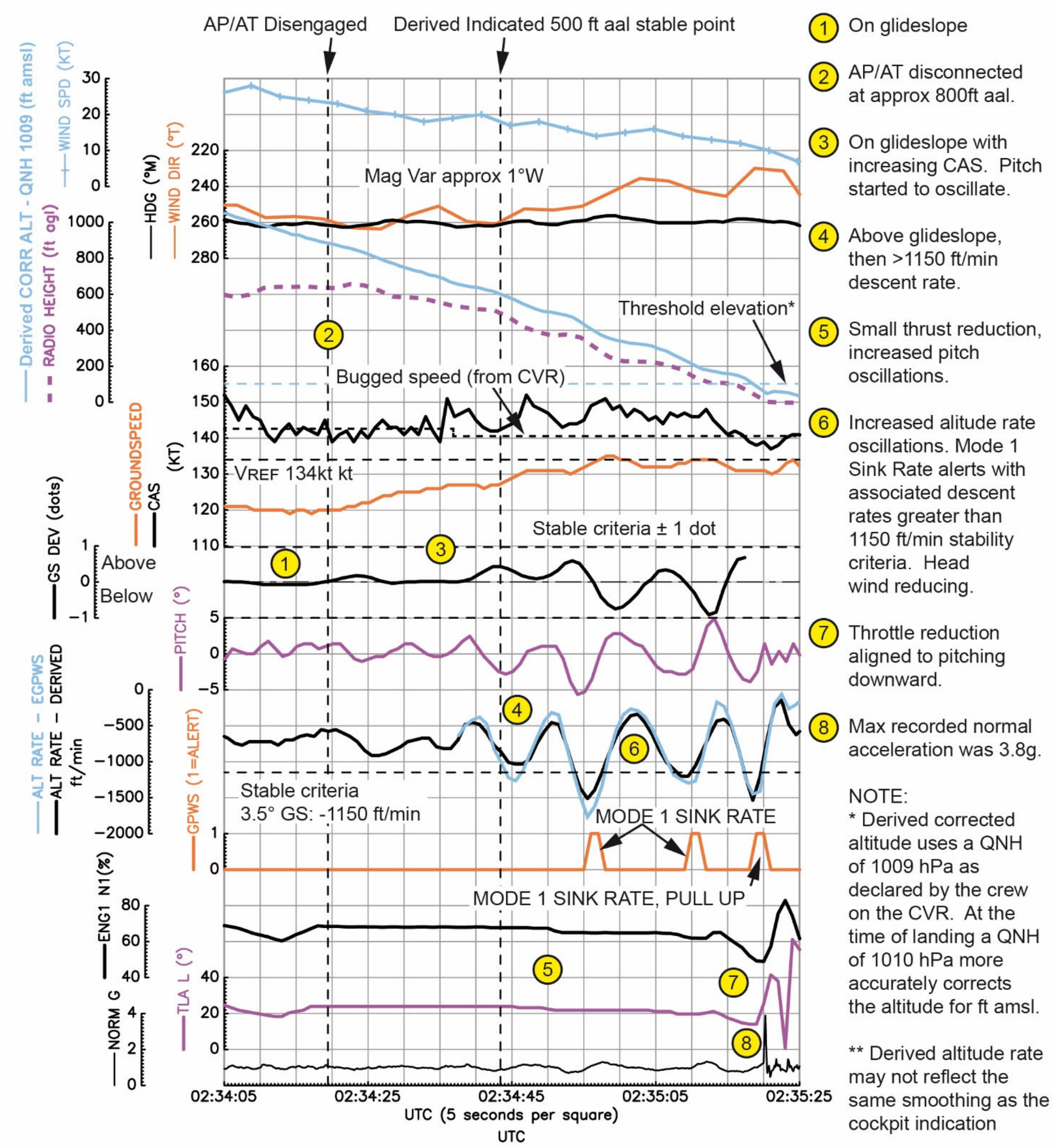

Figure 4

Pertinent parameters from the FDR and TAWS recordings

Airfield wind data

Wind data recovered from the airfield showed instantaneous airfield readings of 12 kt from 230° on touchdown. This was steady for at least the previous two recorded readings, 10 seconds apart, at the airfield sensor location. Gusts of about 5 kt were recorded in the minutes leading up to the landing.

Aircraft information

G-JMCY was manufactured in 1994. It was modified for cargo operations in 2015, which involved the incorporation of several changes under a Supplementary Type Certificate (STC). At the time of this accident, there were no significant deferred defects recorded in the technical log, and the aircraft had accrued almost 38,000 landings and 65,500 flying hours.

Aircraft examination and description of the damage

Runway

The runway was undamaged, and the touchdown point could not be established because there were no obvious marks caused by the heavy landing. Aircraft debris on the runway consisted of small pieces of composite material, broken fasteners, and a louvre from the right air conditioning pack exhaust. There was visible evidence of fluid contamination on the runway, which was most pronounced where the aircraft had turned off when taxiing to the parking area. The fluid was not analysed but was probably hydraulic oil.

Aircraft

The fuselage skin aft of the wings was cracked and buckled, and the rear fuselage was distorted downward, Figure 5. The crown skin was creased and rippled along most of the fuselage.

Figure 5

Photograph looking aft showing distortion of the rear fuselage and rippling in the skin

Residual hydraulic oil was dripping from several areas but there were no indications of a fuel leak. Both main landing gear shock absorbers were found to be bottomed, and the left main landing gear beam was distorted upwards such that the aircraft was approximately 2° left-wing low (Figure 6).

Figure 6

G-JMCY - left-wing low due to the main landing gear beam damage

There was no obvious tyre damage and the main landing gear drag strut bolts were intact. The engine cowlings were undamaged, so it was apparent that the engines had not touched the runway during the landing. The flap drive mechanism was damaged, and the left-wing inboard driveshaft was bent; the left inboard gearbox casing and its mountings were broken (Figure 7).

Analysis

Conduct of the approach

Both pilots had previously operated into EXT and had no concerns about the ILS approach to Runway 26, despite it having a slightly steeper approach angle. The co-pilot had also conducted a FLAPS 40 landing at EMA, without event, on the previous sector.

During the cruise the crew calculated the landing performance and briefed for the approach. While they noted that there was a 3.5° GS they did not brief that they could increase the SINK RATE deviation call, for the ROD, from 1,000 ft/min to 1,150 ft/min.

The initial part of the ILS approach was flown appropriately, with the aircraft configured for the landing early and crew becoming visual with the runway at about 1,000 ft aal.

Figure 7

View looking inboard under the left-wing. Broken flap gearbox is highlighted

The criteria specified in the operator's OM for an ILS approach to be stable were that the IAS should have been no more than 10 kt above V_{APP} and no slower than 5 kt below, a ROD of less than 1,150 ft/min (on a 3.5° glideslope) and within one dot of the GS and localiser. At 500 ft RA the aircraft was configured for landing, the IAS was V_{APP} +3 kt (143 kt), the ROD was about 860 ft/min and the aircraft was slightly above the GS. In terms of the criteria for a stabilised approach, the aircraft was stable at this point albeit close to the limit of the ROD. However, the ROD was increasing and soon after exceeded the stable approach maximum ROD of 1,150 ft/min. This was reduced to about 300 ft/min but soon increased again. At 320 ft RA the ROD had reached 1,700 ft/min, which was the greatest observed on the approach. While it was reduced again shortly thereafter, the ROD exceeded 1,150 ft/min on two more occasions prior to the landing and the recorded data indicated that 1,700 ft/min was nearly reached again at about 25 ft RA. These variations in the ROD had a corresponding effect on the aircraft's position relative to the GS but while it came close to being one dot below the GS, at about 150 ft RA, it did not exceed it.

During these exceedances of the ROD the PM did not call "SINK RATE" as required by Section 2.1.17.5 of the OM. He did however, say "WATCH THAT SINK RATE", at about 150 ft RA, after the second alert, when the ROD was 1,300 ft/min. The lack of a GA command may have given the PF the impression that the PM was content for the approach to be continued, despite three GPWS "SINK RATE" alerts being generated during the final 30 seconds of the approach. Additionally, while it may not have been explicit in the operator's OM, that a GA should be executed if an approach does not remain stable, the FCTM stated '*If the above criteria* [stable approach criteria] *cannot be established and maintained until approaching the flare, initiate a goaround.*'

While the possibility of conducting a GA just before the landing was always in the commander's mind, it was not considered by him as the aircraft "stopped flying" so quicky he felt it was too late to initiate one. He added that, in hindsight, a GA should have been initiated at that point, even though the aircraft would have more than likely touched down during the manoeuvre. While the aircraft may well have touched down during a late GA, this was a manoeuvre that was described in the FCTM and had been trained for during the pilots' recurrent training.

The commander stated that the aircraft "stopped flying" just before it landed. This was probably a result of the reduction in thrust at about 100 ft RA. There was then an increase in thrust at about 30 ft RA. This was likely to have been an attempt to arrest the ROD of about 1,000 ft/min, just prior to the landing. Had the PF been more positive with her understanding of the situation and elected to GA, even if it was in the final few feet, the extent of the damage may have been reduced. If she felt she had become overwhelmed by the way the approach was progressing she could have handed control to the commander. He too could have taken control, as he recognised he probably should have, albeit in hindsight. The crew may also have been overloaded at the time to think a late GA was a realistic option.

The manufacturer's approximate pitch attitude to maintain the GS was 1° nose up. During the final 500 ft the aircraft's pitch attitude varied between 5° nose up and 6° nose down. While it is not unusual for changes to be made to the aircraft's attitude to remain on a GS, such significant variations suggest there was either an element of over controlling or too great an adjustment to correct a deviation. This probably led to the divergences below the GS and excessive ROD leading to the GPWS alerts and subsequent hard landing. While the FD was on, its computed pitch and bank angles were not recorded on the FDR, but it should have provided appropriate guidance to the crew to allow a stable approach to be maintained.

The commander also stated that he felt it was too late for him to take control or call "go around" from about 100 ft RA. While the co-pilot was making adjustments to the aircraft's path, throughout the approach as the wind reduced, SINK RATE alerts at 320 ft RA and 260 ft RA should have alerted them that the approach was not stable and a GA would have been an appropriate thing to do, despite there not being positive guidance in the OM as what to do after the aircraft has passed the stable gate at 500 ft.

The commander had confidence in the co-pilot's ability and had flown with her on many occasions, it is possible this may have led to him to feel that the co-pilot was able to handle the situation and so did not call a GA or take control.

The operator commented that a B737 would use about 1,000 kg of fuel to fly a GA and another ILS approach. With 6,600 kg of fuel on board at the time of the accident, and 3,118 kg required to go back to EMA, there was enough fuel to fly a further three approaches before a decision to divert to EMA was needed to be taken. There was thus no fuel/time pressure to land off the first approach.

Operations Manual

The operator's OM did not specifically state that an approach must remain stable from 500 ft RA (for a VMC approach) to touchdown, even though the FCTM did. Since the accident, the operator has amended the OM to clearly state that an approach '*requires an immediate go-around'* if it becomes unstable after the stable point.

At the time of the accident OM Part B referenced the stable point in 2.1.14, '*Stabilised Approach'*, with regards to the TDZE. However, in Section 2.2.14.1, '*Allocation of duties and standard calls'* it was refenced to 500 ft RA. Since the accident a note has been added to 2.2.14.1 to highlight that '*approach stability requirements are with respect to TDZE, not Radio Altimeter height.'*

Any change in IAS will need an adjustment to the aircraft's pitch attitude to maintain the GS, which will also result in change to the aircraft's ROD as shown in Figure 3. The manufacturer's predicted aircraft attitude for a 3.5° GS was about 1° nose up. Given the wind was decreasing down the GS, the aircraft would not have maintained this attitude all the way to the flare, due to the changing conditions.

Pilot's assessment

During one of the co-pilot's previous licence proficiency checks it was noted that, during a single engine approach, the aircraft produced a "SINK RATE" alert on short finals. The training captain recorded this element as passed at second attempt and assessed her Flight Path Management as Baseline Minimum Standard. Since this event the operator recognised that there was no robust mechanism for tracking an individual pilot's performance during a recurrent check and introduced a number of procedures to rectify this. While these new procedures may not have prevented the accident happening it should enable the operator to screen all of those pilots whose performance may be worthy of monitoring.

Manufacturer's assessment of the airframe damage

As part of the original crashworthiness evaluation of the Boeing 737-400 passenger aircraft, the manufacturer considered a gear-down landing at high sink rate. They concluded that the wing box would remain intact after landing at the maximum permitted weight of 121,000 lb and a sink rate of 18 ft/second.

The manufacturer reviewed the recorded data for G-JMCY and assessed that the landing occurred with mass of approximately 116,700 lb and a sink rate of 24 ft/second. The wing box remained intact, preventing fuel leakage.

If the main landing gear shock absorbers bottom during a landing, the main landing gear beams act as a structural fuse for vertical loading. Correspondingly, the drag strut bolts act as a fuse for drag loading. The left main landing gear beam on G-JMCY was visibly distorted in an upward direction, but it remained intact, as did the drag strut bolts. The manufacturer assessed that this indicated that the landing did not reach the vertical or drag load limits.

Safety margins are lower in the aft fuselage skin, thereby accounting for the damage in this area. Overall, the manufacturer concluded that the damage sustained by G-JMCY was consistent with a hard landing.

Conclusion

The aircraft suffered a hard landing as a result of the approach being continued after it became unstable after the aircraft had passed the point where the crew had declared the approach stable and continued. Despite high rates of descent being observed beyond the stable point, together with associated alerts the crew elected to continue to land. Had the approach been discontinued and a GA flown, even at a low height, while the aircraft may have touched down the damage sustained may have been lessened.

While the OM did not specifically state that an approach was to remain stable beyond the gate on the approach, the FCTM was specific that, if it did not remain stable, a GA should be initiated.

The commander may have given the co-pilot the benefit of doubt and believed she had the ability to correct an approach that became unstable in the final few hundred feet of the approach. However, had there been any doubt, a GA should be executed.

Safety actions

Since the accident the following safety actions have been taken:

> The operator has instructed their crews that, until further notice, only the commander is to conduct the landing at Exeter Airport.
>
> The operator has added a note to Section *2.1.14 Stabilised Approach* of OM B stating, '*An approach that becomes unstabilised below this point* [1,000 ft above TDZE in IMC or 500 ft above TDZE in VMC] *requires an immediate go-around.'*
>
> The operator recognised that there were no robust mechanisms to monitor trends in pilots' performance across recurrent checks. The operator has since introduced a number of new procedures to rectify this.

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