ACCIDENT

Aircraft Type and Registration:	Airbus A321-231, G-EUXF	
No & Type of Engines:	2 International Aero Engine V2533-A5 turbofan engines	
Year of Manufacture:	2004 (Serial no: 2324)	
Date & Time (UTC):	19 July 2015 at 2122 hrs	
Location:	Glasgow Airport	
Type of Flight:	Commercial Air Transport (Passenger)	
Persons on Board:	Crew - 7	Passengers - 200
Injuries:	Crew - None	Passengers - None
Nature of Damage:	Damage to underside of aft fuselage and drain mast	
Commander's Licence:	Airline Transport Pilot's Licence	
Commander's Age:	54 years	
Commander's Flying Experience:	10,980 hours (of which 6,864 were on type) Last 90 days - 143 hours Last 28 days - 57 hours	
Information Source:	AAIB Field Investigation	

Synopsis

The aircraft landed on Runway 23 at Glasgow in calm weather conditions. During the flare there was a continuous progressive aft sidestick control input, which was maintained after touchdown. The aircraft bounced slightly and the nose-up pitch continued to increase, reaching a maximum recorded value of 9.5° at the second touchdown. The aft fuselage and aft galley drain mast contacted the runway surface. The flight crew were not aware there had been a tailstrike until after their arrival on stand, when the damage was reported by a ground crew member.

History of the flight

The flight crew reported at 1325 hrs for a three-sector flight duty. The commander was the pilot flying (PF) for the first two sectors, from London Heathrow to Hamburg and return. These two sectors were operated with an Airbus A319.

The operator's Standard Operating Procedure (SOP) is for the Pilot Monitoring (PM) for the sector to act as the handling pilot from top of descent until below 1,000 ft aal on the approach. The PF then takes control for the landing when visual contact is achieved. On the second sector to Heathrow, the arrival route, flown by the co-pilot, was abbreviated when ATC offered a straight-in approach to Runway 27L. The commander noted that the increase in workload was well managed by the co-pilot.

The third sector of the day, to Glasgow, was operated on a different aircraft, an Airbus A321, G-EUXF. The sector involved tankering fuel, with a planned landing weight of 74,600 kg; the maximum landing weight for this aircraft was 75,500 kg. The co-pilot was the PF for this northbound sector.

The pilots reported that the approach briefing was carried out before the top of descent and that it included a review of the greater potential for a tailstrike on the A321. The descent and approach for Runway 23 proceeded uneventfully, with the aircraft being vectored for a CAT 1 ILS approach in visual flight conditions. At 1,000 ft aal the aircraft was fully configured for landing, stable, with flap FULL and the autopilot engaged. The V_{LS}[1] (lowest selectable speed), based on the weight data for the aircraft, was 140 kt and the corresponding V_{APP} (approach speed) was 145 kt.

The co-pilot took control, disconnected the autopilot and flew the final approach manually with the autothrust engaged. At 50 ft agl the flare was initiated, using a progressive aft sidestick input, and at 25 ft agl the thrust levers were closed. Sensing that the pitch attitude had not increased enough and that the flare was a bit "flat", the co-pilot continued to pull further back on the sidestick.

After touchdown the operator's SOP requires the commander, as the PM, to select reverse thrust. He reported that, on touchdown, he looked down to locate the thrust levers, prior to making the selection, and this may have diverted his attention from monitoring the landing attitude.

The recorded data showed an initial touchdown at 138 kt, with a pitch attitude of 7.4° and a normal acceleration of 1.5 g; the ground spoilers deployed. The aft sidestick input was reduced but a net nose-up pitch command was maintained. The aircraft lifted off the ground for a short time before making a second touchdown, recorded at a pitch attitude of 9.5° and normal acceleration of 1.7g. The operator's SOP requires the PM to announce 'PITCH' if the nose-up pitch attitude exceeds 7.5°. At some stage the commander said 'OK PUSH THE NOSE DOWN' but it was too late to prevent the tailstrike. Reverse thrust was selected 4 seconds after the second touchdown.

The co-pilot reported that the touchdown seemed heavier than normal and the pitch attitude rather high but, because no 'PITCH' callout was heard, the co-pilot was not overly concerned. Neither pilot perceived that the aircraft had bounced or that a tailstrike might have occurred. The landing was completed and the aircraft was taxied clear of the runway and onto a parking stand.

After the aircraft parked on stand, a post-flight report (PFR) printout was generated. The commander checked it and noted that there had been a pitch exceedence on landing. Several of the cabin crew had noticed an unusual noise during the landing and the senior cabin crew member reported this to the commander. A ground maintenance engineer then came on board and advised the commander that there was damage to the aircraft. They

Footnote

[1] A description of the 'characteristic speed', $V_{LS,}$ is provided later in this report.

both disembarked to carry out an inspection and observed scrape marks on the aft lower fuselage area and the aft galley drain mast.

Air Traffic Control (ATC) were contacted by a member of the public who had seen sparks coming from the aircraft as it landed. On receipt of this information, a runway inspection was ordered and carried out. A scrape mark was seen on the runway surface but there was no sign of any debris.

Recorded information

The aircraft's flight data recorder (FDR) and cockpit voice recorder (CVR) were downloaded and their recorded information was analysed. The salient FDR data for the tailstrike event is presented at Figure 1.

Figure 1 starts with the aircraft descending through 180 ft agl, at 145 KIAS (V_{APP}), just under 15 seconds before touchdown. At about 50 ft agl, nose-up pitch inputs were made by the co-pilot to commence the flare. The aircraft responded and started to pitch up (from a nominal 4° nose-up) at a rate of 1.5°/sec. The sidestick was progressively pulled further back throughout the flare and the thrust levers closed at about 25 ft agl. There was a small check in the aft-stick at -10° input[2] before reaching a recorded peak value of 12° prior to touchdown. The aircraft pitch attitude levelled off at 7.4° nose up for 1 second during which the aircraft touched down, at 138 KIAS, with a maximum recorded normal acceleration of 1.5g.

The aft-stick input was maintained but reduced to -6.5° just as the ground spoilers deployed. The aircraft continued to pitch nose-up and became airborne again, before touching down at 134 KIAS with a nose-up pitch attitude of 9.5° (the PFR recorded a maximum pitch attitude of 9.8° at touchdown[3]) and a maximum recorded normal acceleration of 1.7g. It remained at this pitch attitude for about 0.5 s before reducing as the aircraft was de-rotated. The nosewheel touched down 3 seconds later.

Comparison with previous landings recorded on FDR

For comparison, Figure 1 also shows the pilot pitch input, aircraft pitch attitude and aircraft radio altimeter height for ten previous landings recorded on the FDR. These are aligned in time at the point when the aircraft descended through 30 ft agl. The recorded minimum (nose-up) pitch attitude at touchdown was 3.9° and the maximum was 6.3°, giving an average of about 5°. The range of aft-stick inputs on these landings vary considerably compared with the control inputs on the tailstrike event. Similar peak aft inputs are evident; however, these appear transient.

Footnote

[2] The maximum aft-stick position is -16°.

[3] The difference between the FDR and PFR recorded value is due to the fact that the FDR records at a lower resolution (0.35°) as well as temporal differences in sampling. Note, however, that the accuracy of the pitch attitude sensor is ±0.3°.

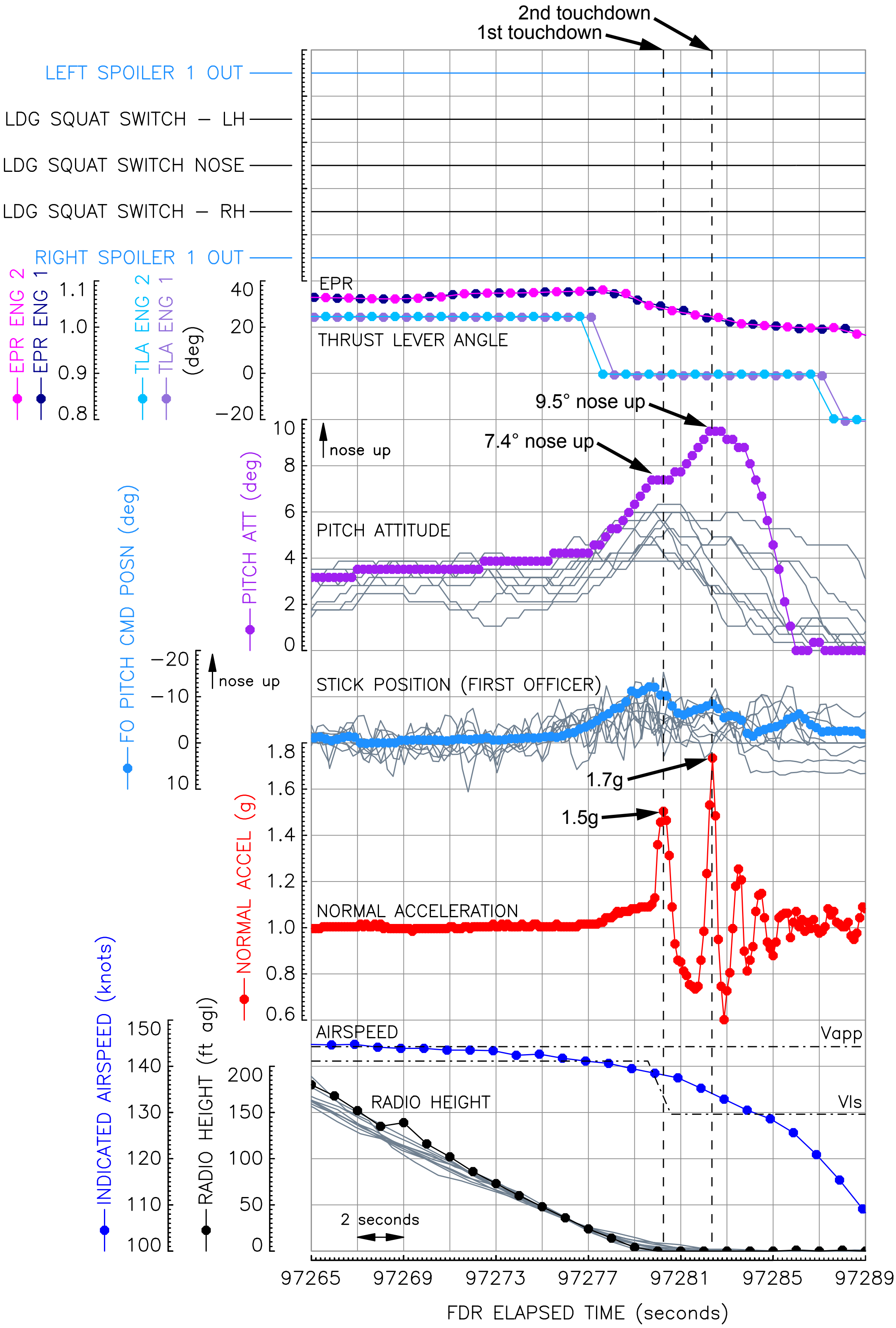

Figure 1

FDR data for the tailstrike event and elements of ten previous landings (grey traces)

Figure 2 compares the tailstrike event with one of the previous landings (light blue traces), also aligned in time at 30 ft agl. The flight profile and aircraft attitudes are similar until about 50 ft agl when the flare is initiated. The earlier flight shows a positive aft sidestick input to a maximum of 7° over 3 seconds, without any loss in airspeed. However, for the tailstrike event, the aft stick input is initially slower but reaches a maximum of 12° aft over a period of 4 seconds, just prior to touchdown, during which the airspeed decays by about 4 kt. For both landings, the thrust levers are reduced to idle at 25 ft RA. However, the airspeed decays more gradually on the earlier flight and touchdown occurs 5 seconds later than on the tailstrike event.

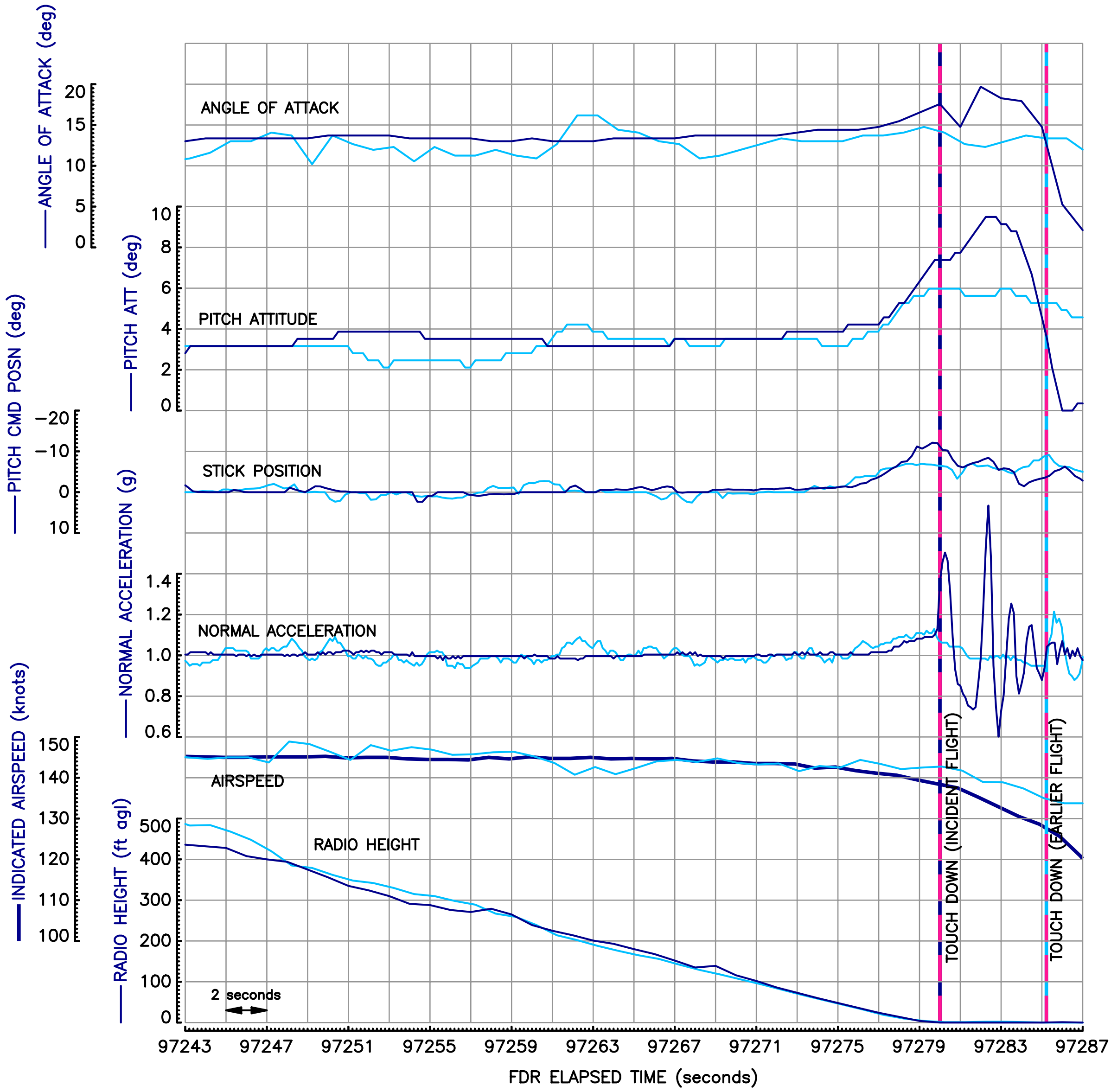

Figure 2

Comparison of data on the tailstrike event (dark blue)
with an earlier landing on G-EUXF (light blue)

Meteorological information

The weather conditions were fine and clear with no reported turbulence. The surface wind was from 250° at 5 kt. Sunset was at 2048 hrs, 34 minutes before landing.

Pilot information

The co-pilot had recorded a total of 302 flying hours, of which 143 hours were on type. It was noted in line-training records that the landings were inconsistent, so an additional simulator training detail was incorporated into the training programme. Following this, the line-training was continued and completed successfully on 13 July 2015. The co-pilot flew a total of 60 sectors during line-training, of which 13 sectors were on an Airbus A321. Ten further line sectors were flown before the accident flight, none of which were on an A321.

The co-pilot was aware of the potential for a tailstrike on the A321 but recalled being advised during training that 11° nose-up was the pitch attitude for ground contact on landing.

Damage to the aircraft

The aircraft suffered abrasion damage to the external fuselage skin panels between frames 63 to 65 and associated internal damage to those frames. There was also abrasion damage to the aft galley drain mast.

Aircraft information

The Airbus A321 entered service in 1994. The aircraft has a longer fuselage than the A320 and different tailstrike geometry. The manufacturer advises that, with the main gear oleo fully compressed and wings level, the pitch attitude limit for the A321 is 9.7° and for the A320 it is 11.7°.

Characteristic speeds

The Airbus Flight Crew Operating Manual (FCOM) description of lowest selectable speed (V_{LS}) is: '*It represents the lowest selectable speed providing an appropriate margin to the stall speed.*' and '*For landing VLS is equivalent to 1.23 VS1G of the selected landing configuration.'* It is represented by the top of an amber strip along the airspeed scale on the Primary Flight Display (PFD) and is derived from aerodynamic data. Another value for $V_{LS,}$ derived from weight data entered by the crew, is displayed on the Multipurpose Control and Display Unit (MCDU).

V_{APP}, the approach speed, is computed by the Flight Management and Guidance System (FMGS) using crew-entered weight data and headwind component. It is displayed on the MCDU and can be modified by the flight crew. The minimum V_{APP} with autothrust engaged is V_{LS} + 5 kt; with manual thrust it is equal to V_{LS}. The FMGS computed speed target for the approach is represented by a magenta triangle; it is variable and moves with the gust variation. It cannot be less than V_{APP}.

The planned landing weight from the loadsheet data was 74,600kg, giving a computed V_{LS} of 140 kt. The V_{LS} displayed on the airspeed scale (derived from aerodynamic data) was recorded as 141.125 kt. The flight crew may modify the V_{APP}, to maintain a 5 kt margin above the displayed V_{LS}, however this was not done for this flight. The recorded target speed (magenta triangle) for the latter stages of the approach was 144.25 kt.

Flare technique

The Airbus Flight Crew Training Manual (FCTM) states that, from stabilised conditions, the flare height is about 30 ft. The following advice is provided: *'Start the flare with positive (or "prompt") backpressure on the sidestick and holding as necessary.'*

Flare mode

Flare Mode is a control law for inducing 'feel' for the pilot during the flare manoeuvre. The system memorises the pitch attitude at 50 ft and that attitude becomes the reference attitude for pitch control. As the aircraft descends through 30 ft the system begins to reduce the pitch attitude to -2° (nose-down) over a period of 8 seconds. This provides the pilot with normal feedback during the flare.

Ground spoilers

The conditions required for the ground spoilers to extend automatically on touchdown are: ground spoilers armed, both main landing gear on the ground and both thrust levers at or below the idle position. On the A321 there is a nose-up pitch effect during ground spoiler deployment, which has to be countered by the pilot.

Reverse thrust

The manufacturer's FCOM procedure is for the PF to select and control reverse thrust.

Tailstrike frequency

A manufacturer's report 'Avoiding Tail Strike'[4], which compared the rate of tailstrikes between 1994 and 2001, showed that A321 events on takeoff were at a comparable rate to the A320, between one and two per million departures. However, the rate for tailstrikes while landing, the A321 was 13 to 14 per million arrivals. This was some six times higher than the equivalent A320 rate, which was two to three per million arrivals.

Further data provided by the aircraft manufacturer indicated that, for the years 2010 to 2014, the rate of tailstrikes while landing had reduced to about one event per million cycles on the A320. During the same period, the frequency was about twice this rate on the A321. The manufacturer believed that much of this reduction was as a result of product improvements and raised awareness amongst flight crew. It was also considered that some of the improvement may be due to a better global environment, for example, a greater number of ILS installations and more consistent operational standards.

Footnote

[4] http://www.smartcockpit.com/docs/Avoiding_Tailstrikes_by_Airbus.pdf

Guidance material

The manufacturer has published guidance to address tailstrike occurrences during landings. Flight Operations Briefing Note (2007)[5] entitled: *'Landing Techniques, Preventing Tailstrike at Landing'* cited a number of common reasons for tailstrikes, including the response to a bounced landing. The advice given in the event of a bounce is:

> *'If the bounce results from a firm touchdown associated with a high pitch rate, it is important for the flight crew to control the pitch, so that it does not continue to increase.'*

An additional note includes the information that:

> *'usually, no single factor will result in a tailstrike. However, the combination of several factors significantly reduce the tail clearance margin...'*

Also, in the *Summary of Key Points:*

> *'Avoid increasing the pitch, or letting the pitch increase (e.g. ground spoilers effect) after a bounce.'*

An article entitled '*A320/ Prevention of tailstrikes'*,[6] in the manufacturer's safety magazine '*Safety First*', Issue No 6 July 2008, identified that '*most of the tailstrikes on A320 family aircraft occur during landing in manual mode (Auto Pilot OFF), when the sidestick is maintained in the aft position after touch down.*'

Flight Operations Briefing Note (2007) also includes the following note:

> *'Flight crewmembers may not always be aware that a tailstrike has occurred during landing, because the impact may not be felt. In these cases, a walk-around inspection performed by the flight crew before the next flight will ensure that the marks on the aircraft from the tailstrike are detected, and repaired, if required.*
>
> *However, shallow damage that the flight crew did not detect, and that was therefore not repaired, may result in increased long-term risks (e.g. structural damage in flight, when the aircraft is pressurized).'*

In April 2000[7] the AAIB reported on an investigation into a tailstrike event where damage was sustained to the aircraft which went unnoticed during the turn-around between sectors. The lower fuselage skin had been ruptured and on the subsequent sector the aircraft failed to pressurise.

Footnote

5 http://www.airbus.com/fileadmin/media_gallery/files/safety_library_items/AirbusSafetyLib_-FLT_OPS-LAND-SEQ08.pdf [Accessed 22 July 2015]

6 A320 family aircraft includes A321 http://www.airbus.com/fileadmin/media_gallery/files/safety_library_items/AirbusSafetyLib_-FLT_OPS-LAND-SEQ08.pdf [Accessed 12 December 2015]

7 AAIB Bulletin 4/2000

Modifications

The manufacturer has introduced a number of modifications aimed at tailstrike prevention on the A321. These have included enhancements to the Elevator and Aileron Computer (ELAC) standard and modifications to flight deck indications, to increase pilot awareness of the aircraft's pitch attitude during the landing phase.

The newer ELAC standards (L84 and L93) introduced a control law whereby the maximum commanded pitch attitude on the ground is limited. The values are shown in Table 1. The limitation is triggered by the ground spoiler extension, thus ensuring that it will be active only during a landing.

PITCH RATE CHANGE	< 3°/s	> 3°/s
A320	9°	6°
A321	7°	4°

Table 1

Maximum commanded pitch attitude on ground

Additionally, a pitch limit indicator on the Primary Flight Display, and a 'PITCH PITCH' automatic aural warning were made available. These enhancements were provided as options, dependent upon the modification state of the aircraft. They had not been embodied on G-EUXF.

Flight Data Monitoring programme

Following this event, the operator reviewed pitch attitudes during landings carried out on their A321 fleet, using information from its Flight Data Monitoring (FDM) programme. This showed a normal distribution curve for pitch attitudes on touchdown in the range of 4.5° to 5.5° pitch-up. The average landing weight was 69,000 kg. A review of high pitch events, 7.5° nose-up or greater, suggested that these events were more likely at above average landing weights.

Analysis

The weather conditions were fine and did not have any influence on the event. The autothrust was engaged for the approach and the target approach speed, V_{APP}, was 145 kt. The displayed target speed (magenta triangle) was recorded as 144 kt and the V_{LS} displayed at the top of the amber strip was 141 kt, thus the 5 kt margin between V_{LS} and V_{APP} was reduced to 3 kt. As the aircraft descended below 150 ft agl the pitch was increased slightly and the airspeed gradually reduced below V_{APP}, reaching a combination of 4° nose-up pitch attitude and 141 kt (V_{LS}) at the flare height. The thrust increased but not by enough to maintain the target airspeed. At the flare height, the aircraft energy state was lower than that seen in a typical previous flight. This was further reduced by the thrust levers being retarded to IDLE.

The pitch attitude of 4° nose-up at 50 ft, before the flare was initiated, was higher than average and consequently the nose-down pitch rate (6° over 8 s) targeted by the flare mode would have been above average. Therefore, the feedback from the initial aft sidestick input by the co-pilot may have felt stronger than usual. The sidestick input was small at first, but progressive, and the pitch attitude correspondingly increased. However, the initial input was not positive enough to check the rate of descent, which did not significantly reduce before touchdown, leading to a firm touchdown.

The aircraft touched down with a nose-up pitch attitude of 7.4°, just less than the 7.5° threshold at which the PM is required announce 'PITCH'. The aft sidestick input was then reduced but some nose-up demand was maintained. The pitch attitude remained at 7.4° for a second then continued to increase. The ground spoilers deployed and the pitch attitude was still increasing as the aircraft briefly lifted off again. The commander looked down at some point to select reverse thrust which may have diverted his attention from the increasing pitch attitude.

The pitch attitude only increased through 7.5° after the first touchdown. Within two seconds, the maximum pitch attitude was reached as the aft fuselage struck the ground. With any rapidly increasing pitch attitude, the SOP monitoring call becomes correspondingly less effective.

The operator's requirement for the PM to select reverse thrust after touchdown is a variation from the manufacturer's procedures. A glance down to locate the thrust levers could have diverted the commander's attention from the visual observation of the landing phase, although during this landing reverse thrust was not selected until after the second touchdown.

The advice from the manufacturer in the event of a bounced landing is that any tendency to pitch up must be controlled. However, in practice it is not necessarily apparent to flight crew when an aircraft has bounced and neither crew member perceived the bounce.

Safety action

> The operator has taken a number of measures since this event to prevent a reoccurrence. These include additional information and training for flight crew on A321 specific differences, together with a review of current landing training guidance and PM actions during the landing phase. The fuel tankering policy is also being reviewed. In addition, the operator is considering introducing an experience restriction for co-pilots performing landings on the A321.

Conclusions

The technical and training measures put in place by the manufacturer have been effective in reducing the tailstrike rate on the global fleet over the last ten years.

It is difficult to pinpoint a precise reason why this tailstrike occurred. As described in the manufacturer's bulletins, it is likely to have been the result of a combination of factors.

These include an airspeed which had reduced below the target towards $V_{LS,}$ and an initial tentative but progressive flare input which did not sufficiently alter the flightpath of the aircraft. Although the initial touchdown was at a high pitch attitude, probably the most significant contributor to the tailstrike was the continued aft sidestick input after touchdown, which resulted in the pitch attitude continuing to increase.