**AAIB Bulletin No: 2/96** **Ref: EW/C95/9/3** **Category: 1.1**

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| **Aircraft Type and Registration:** | Airbus A340-311, G-VBUS |
| **No & Type of Engines:** | 4 CFM56-5C2 turbofan engines |
| **Year of Manufacture:** | 1993 |
| **Date & Time (UTC):** | 19 September 1995 at 1239 hrs |
| **Location:** | Runway 09R at London Heathrow Airport |
| **Type of Flight:** | Public Transport |
| **Persons on Board:** | Crew - 16 Passengers - 249 |
| **Injuries:** | Crew - None Passengers - None |
| **Nature of Damage:** | Damage to lower fuselage skins between frames 71 and 76 from scraping of tail at rotation |
| **Commander's Licence:** | Airline Transport Pilot's Licence |
| **Commander's Age:** | 47 years |
| **Commander's Flying Experience:** | 12,160 hours (of which 1,113 were on type)<br>Last 90 days - 120 hours<br>Last 28 days - 43 hours |
| **Information Source:** | AAIB Field Investigation |

## History of flight

The aircraft was loaded almost to the maximum structural take-off weight for a 12 hour scheduled flight. The pushback, engine start and taxi phases of the flight were normal except for a transient fault within number one primary flight control computer. This fault was subsequently cleared and no other faults of significance were indicated to the flight crew on the ECAM (Electronic Centralized Aircraft Monitoring) displays.

The ATIS broadcast weather conditions for takeoff were: QNH 1017 HPa, temperature 16°C, visibility 9 km and overcast cloud at 1,600 feet; the average wind was 020°/11 kt with the direction varying between 330° and 060°. Although the airline's fleet policy was normally to use CONFIG 2 (24° slat and 22° flap) for departures which were not climb performance limited, on this occasion the commander decided to takeoff in CONFIG 1+F (21° slat and 17° flap) for training purposes with the first officer handling. The flight crew opted to takeoff with reduced engine power by using a FLEX temperature of 38°C and assuming no headwind component. The scheduled speeds were: $V_1$ 144 kt, $V_R$ 153 kt and $V_2$ 160 kt. For performance purposes these figures were valid for a take-off weight of 258.2 tonnes which was 1.8 tonnes more than the calculated take-off weight given in the loadsheet, and above the structural limit of 257 tonnes.

The flight was cleared to takeoff and informed that the surface wind was 030°/12 kt. Initially the take-off roll proceeded normally. The first officer applied nose down sidestick with negligible into-wind sidestick and he relaxed the forward pressure at about 100 KIAS. As the airspeed approached $V_R$, the trend became slightly erratic due to the varying crosswind and the commander inadvertently called "rotate" about one second early (149 KIAS). At the same time the first officer, who noticed the commander's slightly early call, applied gentle back stick pressure followed by almost full back stick as the IAS reached $V_R$. The nose gear lifted off the runway during the next second and the first officer continued the rotation manoeuvre at a rate which he considered to be slightly less than 3°/sec. As the aircraft rotated, he also applied a little more than half into-wind sidestick to oppose the tendency of the aircraft to roll to the right due to the crosswind from the left. During this phase the flight deck crew felt the aircraft jerk laterally and the cabin crew at the rear of the aircraft heard and felt the underside of the fuselage touch the runway.

Within seconds of becoming airborne, the flight crew were informed by ATC that the aircraft had scraped its tail on takeoff. The commander acknowledged the report and the aircraft continued with the standard instrument departure but unpressurised and not above 6,000 feet altitude. Once over the sea, the crew attempted to jettison fuel down to maximum landing weight before returning to Heathrow. However, despite exhaustive efforts and technical advice from the company's engineers, fuel could not be jettisoned. Meanwhile, conditions in the passenger cabin were becoming hot and stuffy so the commander decided to use ram air to condition the cabin. This was only partially successful and faced with the choice of landing overweight or burning off fuel for 10 hours, the commander decided to return to Heathrow where conditions were suitable for the overweight landing. He took control from the first officer for the approach and landed softly on Runway 09L at 1402 hrs from a CONFIG 3 approach using a final approach speed of 163 kt. Full reverse thrust and pedal braking were employed to decelerate the aircraft with the intention of using most of the runway length. The fire service were waiting and attended the aircraft which was able to taxi to the Terminal.

## Damage to aircraft

Examination of the aircraft that evening showed that the fuselage skins on the lower aft fuselage had been damaged by their abrasive contact with the runway surface. The abrasion was over a distance of some 2.5 metres and was more extensive in those areas of skin supported by the fuselage frames. Just aft of the Waste Service door, for example, a small area of the skin at frame 75 had been worn to the point where the internal airframe structure was exposed. The damage was very similar to that documented from a previous A340 tailscrape accident in Hong Kong.

### Landing gear

Measurements taken after the accident showed that, with the landing fuel still on board the aircraft but with the passengers and baggage containers removed, the static angle between the fuselage datum and the line at which tail contact would occur was approximately 12° to 12.5°. This is consistent with the Flight Crew Operating Manual which gives this tail contact angle as ranging between 10.5° (oleos fully compressed) and 14.7° (oleos fully extended).

While the aircraft was being repaired, the 'weight on wheels' static extensions of the main landing gear (MLG) oleo legs were measured. These extensions were then compared with the Maintenance Manual figures for the ambient temperature and nitrogen charging pressure. The extensions showed the main landing gear legs to be 42 mm (left) and 69 mm (right) more compressed than the table indicated for the nominal case. These differences would reduce the tail contact angle by some 0.2° in the static case. Analysis by Airbus Industrie, however, suggests that this reduction in nitrogen charging pressure results in a greater reduction in the tail clearance margin during aircraft rotation than the 50 to 60 mm reduction for the static case. This is, in part, due to the action of the 'bogie pitch trimmer' which, with extension of the MLG oleo, tilts the bogie beam aft. Under-inflation of the oleo would, therefore, result in a delay in full extension of the oleo, giving, according to this analysis, a reduction in the tail clearance margin of some 260 to 300 mm. This corresponds to a reduction in the tail contact angle of some 1°.

### Fuel Jettison

Following the accident flight, the Post Flight Maintenance Report was printed from the CMC (Central Maintenance Computer). This showed intermittent occurrence of the FUEL INR TK LO LVL1 message from the FCMC1 (Fuel Control and Monitoring Computer), indicating malfunction of one of the two fuel low-level sensors in one of the two inner tanks. The design of the fuel jettison system in the A340 is such that the jettison operation is terminated manually or automatically. One of the conditions for automatic termination is achieved when any of the inner tank low-level sensors becomes dry and thus, if this condition exists, jettison will not commence. This information is not displayed to the flight deck crew.

During the period of airframe repair, the faulty low level sensor was removed from its inner tank and returned to its manufacturer for investigation. The sensor is a moulded probe, incorporating a thermistor, and the sensor had clearly suffered extensive damage to the sealant, resulting in corrosion and loss of electrical continuity. The design logic of the level sensing system is that the failure state of any of the low level sensors is 'dry'; thus the failure of this inner tank low level sensor, first noted by the CMC in the 'Engine Start' phase, prevented the fuel jettison operation.

Despite extensive laboratory work by the manufacturers involving both the sensor itself and the 'potting' compound used as sealant, the cause of the breakdown of the sealant could not be determined. However, this sensor is used in a range of aircraft types and this particular failure appears to have been an isolated instance.

## Flight Recorders

The Solid State Flight Data Recorder (SSFDR), a Loral F1000, was removed from the aircraft and returned to the AAIB for replay. The Cockpit Voice Recorder (CVR), which was not removed, had a recording duration of half an hour and had overrun.

The SSFDR contained data from the flight before the accident, data recorded during ground running and all of the accident flight. The data indicate that just prior to the accident takeoff, the flap configuration was 1+F as indicated by the flap lever (position 1) and the position of the flaps (17.2°) and slats (20.7°).

During rotation the recorded Indicated Airspeed (IAS) appeared to drop but this was partly due to a variation in the angle of attack of the static port on the front side of the aircraft. Corrected airspeed values to account for this position error are shown in brackets after the SSFDR recorded value and are calculated from the variation in barometric pressure altitude observed during the rotation together with the increase in static port height above the runway as the aircraft pitched-up.

The first officer was in control of the aircraft during the takeoff and no movements of the commander's sidestick were recorded during this period.

The selected flight trace printout shown in Figure 1 shows that at an IAS of 148 kt ($V_R$-5 kt) the first officer began to pull on his sidestick and reached 14.8° of back stick over a period of 2 seconds (full aft sidestick deflection is 16°). The aircraft started to pitch-up and the first officer eased forward on the sidestick to a position of 12° aft. The nosewheel left the ground at a recorded IAS of 151 kt (154 kt corrected).

Over the subsequent 3 seconds the aircraft pitch rate stabilised at an average of 2.8°/sec and the aircraft achieved a pitch-up of 8° at a recorded IAS of 152 kt ( 158 kt corrected). During this period, the first officer applied up to 8° of left sidestick which resulted in the number 5 and 6 spoilers on the port side deploying to 7° and the aircraft rolled from 1.5° right wing down to 0.5° left wing down.

The first officer then pulled the sidestick back to 14° aft for a period of 0.75 seconds at the end of which the aircraft had reached a pitch of 10° and an IAS of 152 kt (158 kt corrected). The main centre gear fully extended at this time.

During the next half second, the aircraft pitch rate peaked at 3.3°/sec. The first officer applied 13° of left sidestick for half a second and the three outboard port spoilers deployed to 20°. The aircraft rolled from 0.5° to 3.4° left wing down. The sidestick was returned to the neutral roll position and both left and right main gear fully extended at an IAS of 156 kt (161 kt corrected which equals $V_2$+1 kt).

The aircraft achieved a maximum pitch of 13.4° one second after main gear extension. The sidestick was again moved 13° left for 0.5 seconds and the three outboard port spoilers deployed to 20°. The roll attitude of the aircraft remained unchanged at 3.5° left wing down.

The tailscrape occurred just prior to the lift-off with the aircraft pitched-up between 12 and 13° and an indicated airspeed of between 152 kt (158 kt corrected) and 156 kt (161 kt corrected).

**Scheduled Performance**

The A340 was certified in accordance with Joint Airworthiness Requirements (JARs). Takeoffs at high weights in the A340-300 series are always limited by the aircraft's geometry (the tail strike risk). In this respect, JAR 25.107(e) states that:

(1) If lift-off is limited by the geometry of the aeroplane, $V_R$ in terms of calibrated airspeed must not be less than a speed that if the aeroplane is rotated at its maximum practicable rate, will result in a $V_{LOF}$ (lift-off speed) of not less than 108% of $V_{MU}$ (minimum unstick speed) in the all-engines-operating case and 104% $V_{MU}$ in the one-engine-inoperative condition.

(2) A single value of $V_R$ must be used to show compliance with both the all engines operating and the one engine inoperative conditions.

(4) Reasonably expected variations in service from the established take-off procedures for the operation of the aeroplane (such as over-rotation of the aeroplane and out-of-trim conditions) may not result in unsafe flight characteristics or in marked increases in the scheduled take-off distance.

Airbus Industrie assured the AAIB that sufficient flight testing had been conducted to ensure that the A340-300 met all the requirements of JAR 25.107(e). Airbus also stated that for the conditions prevalent at the time of this accident, $V_{MU}$ would have been 150 kt CAS and $V_{LOF}$ 162 kt CAS. However, the Airbus computation of $V_R$ 154 kt and $V_2$ 161 kt CAS were each one knot greater than the figures contained in the operating company's RTOW (Regulated Take-Off Weight) tables. These differences were due to Airbus using updated versions of the 'Octopus' scheduled performance computer program and datafile. These versions contained minor improvements to the versions used by the operator who was under no obligation to use these versions.

### Similar Accidents

The A340 operator involved had suffered an earlier tailscrape during a performance limited take-off out of Hong Kong. This accident is still under investigation by the Hong Kong authorities but it is known that, in common with this accident, the takeoff involved a crosswind component, the use of CONFIG 1+F, and the deployment of upwind spoiler during the rotation manoeuvre. There was also evidence from the DFDR data of a decrease in the headwind component just before and during the rotation manoeuvre. Another A340 operator had also suffered a tailscrape on takeoff but using CONFIG 2. This tailscrape had been attributed by the aircraft manufacturer to the use of full back stick causing a high rotation rate, coupled with a tailwind component of 5 kt which occurred between $V_R$ and lift-off. An apparent loss of about 5 kt airspeed was observed during rotation in all the A340 take-off data recovered from two A340 DFDRs; this was a transient error due to static pressure errors as described above.

### A340 FCOM Bulletin No 06 of May 1995

Following these two earlier tailscrapes, Airbus Industrie issued FCOM (Flight Crew Operating Manual) Bulletin No 06 entitled 'AVOIDING TAILSTRIKES AT TAKE-OFF'. This bulletin informed the reader that under-inflated main gear oleos would delay the start of bogie rotation and reduce tail clearance on takeoff. It also stated that it was important to rotate the aircraft at its nominal rate of 3°/sec with a maximum limit of 4°/sec.

Under the heading 'ROTATION TECHNIQUE' flight crews were informed that the words *'smooth and continuous rotation'* used in the take-off SOPs section of the manual referred to rotation rate and not to sidestick input. In the next paragraph pilots were also informed that *'If the pilot simultaneously increases the rearward sidestick deflection once the rotation rate is established, the risk of tailstrike increases.'* The same section contained the recommendation to pilots to *'Initiate rotation at $V_R$ with a positive rearwards sidestick input (around 2/3 deflection) and hold it constant during the rotation provided the rotation rate achieved be reasonable (about 3°/sec).'*

## Pitch and Roll Control During Takeoff

During the take-off ground roll, the A340's flight controls are in ground mode whereby, for a given airspeed, there is a fixed relationship between sidestick position and control surface position. Once airborne, pitch and roll control change to flight mode whereby the sidestick demands load factor (normal g) and roll rate. In the air the flight controls move sufficiently to satisfy these demands and there is no longer a fixed relationship between sidestick position and control surface position.

In order to reduce the likelihood of a tailstrike due to rapid rotation, the rotation rate ($d\theta/dt$) is sensed and fed back to the pitch control computation so that elevator angle may be trimmed accordingly to act as a pitch rate damper. There is, however, no fixed limit to the maximum pitch rate achievable; it is a function of airspeed, mass, centre of gravity and configuration. Of these factors, the maximum achievable rotation rate is greater in CONFIG 1+F than in CONFIG 2. Furthermore, the pitch rate damping function can be temporarily 'beaten' if the sidestick is moved further aft just before the aircraft unsticks. It is now known that movement of the sidestick further aft once the rotation is well developed markedly increases the risk of a tailscrape.

Another significant factor affecting roll control during takeoff is that the changeover between ground mode and flight mode takes place quite rapidly. In pitch, the flight mode is progressively blended in over a period of five seconds which starts when either the aircraft is above 100 feet radio altitude or it has been airborne for 5 seconds and the pitch attitude is above 8°. However, the roll flight mode is blended in over a period of two seconds which begins 0.5 sec after the aircraft becomes airborne. Consequently, lateral sidestick applied during the ground roll phase of a crosswind takeoff may be required to keep the wings level but when the aircraft gets airborne, the corrective input applied to maintain wings-level on the runway will soon turn into a demand for roll into the crosswind (a roll rate). Therefore, unless the handling pilot returns the sidestick to the laterally neutral position during rotation, a brief but undesirable period of roll oscillation may occur close to the ground. Furthermore, if the spoilers deploy during rotation, lift will be reduced and the risk of a tailscrape increased.

## Manufacturer's Analysis

Following this tailscrape Airbus Industrie analysed the event and concluded that it was caused by a combination of four factors:

a. Rotation (aft side stick movement) slightly before the scheduled $V_R$ ,
b. The handling pilot's rotation technique in pitch.
c. Spoiler extension during rotation.
d. Low pressures in the main gear oleos

The AAIB noted the manufacturer's analysis but pointed out that the aircraft's pitch attitude did not change until $V_R$ had been achieved. Moreover, the effect of early aft movement of the sidestick was counterbalanced by the slow average rate of rotation. Throughout the rotation, the pitch rate varied but it was always below the maximum permitted rate of 4°/sec stated in FCOM Bulletin No 06

**Manufacturer's Action**

Following this tailscrape, Airbus Industrie decided to take the following action:

a. Re-issue a revised version of FCOM Bulletin No 6 - AVOIDING TAILSTRIKES AT TAKE-OFF - to all A340 operators with the following significant changes:

   (1) Advising a slightly slower rotation rate of 2.5°/ to 3°/sec.

   (2) Recommending to pilots to *"Initiate rotation at $V_R$ with a positive rearward sidestick input (around 2/3 deflection) and hold the selected position constant during the rotation provided that the rotation rate achieved is reasonable (about 2.5° to 3°/sec)"*

   (3) Advising that during a crosswind take-off, any lateral sidestick input should be returned to neutral during rotation so that the aircraft gets airborne with a zero roll rate demand. (According to Airbus Industrie, this advice is applicable to all the Airbus 'fly-by-wire' aircraft).

   (4) Emphasising that the flight director pitch bar does not command the correct pitch rate during rotation and should be ignored until the aircraft is airborne.

   (5) The addition of advice on the cumulative effects which may contribute to a tailstrike.

b. Ensure that Airbus Training and all A340 Operators receive copies of the recommended training syllabus and revised training notes at no cost.

c. Recommend to all A340 operators that CONFIG 2 or CONFIG 3 should be used for take-off in preference to CONFIG 1+F provided that performance constraints are not limiting.

d. Issue Inspection Service Bulletins for the A340 and A330 types (ISBs A340-32-4032 and A330-32-3018 respectively) to check nitrogen charging pressures in the main landing gear oleos within 500 flight hours. Feedback from the operators of the results of these checks will be collated by the manufacturer by the end of February 1996. The operating company had completed this fleet check by 1 December 1995 with no adverse findings and is reducing the time between checks of nitrogen charging pressure from 15 months to 4 month intervals.

e. Modify the software governing the Flight Warning Computer (FWC) (planned to be certified by the end of January 1996) and the FCMCs (planned for the last quarter of 1996). When embodied, the combined effect of these modifications will provide a new warning of "JETTISON FAULT" and a new status message "INOP SYSTEM JETTISON" on the ECAM. These warnings, available in flight and on the ground, will be activated by a signal from the FCMC. This signal will cover the dry position of one sensor as well as the other conditions leading to the inability to jettison fuel.

In view of the actions taken by Airbus Industrie, the AAIB decided that there was no need to make formal recommendations.

FIGURE 1 - Selected recorder parameters