INCIDENT

Aircraft Type and Registration:	Avro 146-RJ100, G-CFAH
No & Type of Engines:	4 Lycoming LF507-1H turbofan engines
Year of Manufacture:	2001
Date & Time (UTC):	29 March 2005 at 1819 hrs
Location:	London (City) Airport
Type of Flight:	Public Transport (Passenger)
Persons on Board:	Crew - 5 Passengers - 104
Injuries:	Crew - None Passengers - None
Nature of Damage:	Tail scrape protection strip damaged
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	34 years
Commander's Flying Experience:	5,725 hours (of which 2,549 were on type) Last 90 days - 167 hours Last 28 days - 66 hours
Information Source:	AAIB Field Investigation

Synopsis

The first officer had stabilised the aircraft on an ILS approach, at night, to Runway 10. At 400 ft the commander sighted the runway lights, took control in accordance with the Operator's procedures and disconnected the autopilot and autothrottle. During the landing flare the rate of descent appeared to be high and the commander corrected this by increasing the pitch attitude. The aircraft touched down at a body angle that exceeded the safe limit, causing the underside of the rear fuselage to contact the runway surface.

History of the flight

The crew had rested for 14 hours and 20 minutes before reporting for duty. The aircraft departed Geneva at 1650 hrs and the transit to London (City) Airport was uneventful. This was the crew's third sector of the day and was to be their second landing that day at London (City) Airport.

The forecast weather was poor and the crew loaded additional fuel. They briefed for a monitored ILS approach to Runway 10, with the first officer (FO) as the pilot flying (PF); the briefing considered the actions to be taken in the event of a go around at decision altitude. The aircraft operator's procedures required that landings by 146-RJ100s, at London (City), were to be flown by the aircraft commander. He should take control of the aircraft when he had acquired sufficient visual references to land.

The crew expected to land at a weight slightly above 39 tonnes and used the associated V_{ref} of 122 kt; 5 kt was then added to this to give an approach speed of 127 kt. In accordance with the manufacturer's landing profile, this should result in a predicted touchdown speed of 115 kt ieV_{ref} -7 kt.[1] The centre of gravity was at a mid position.

ATC radar vectored the aircraft onto an intercept heading to establish on the ILS localiser for Runway 10. The aircraft intercepted the localiser with the autopilot and autothrottle both engaged, the landing gear DOWN and the flaps set at 33º. As the aircraft intercepted the 5.5º glideslope, the airbrake was selected and the aircraft commenced the descent. At 500 ft on the Radio Altimeter (RA), the approach was confirmed as stable and at 400 ft RA the commander saw the runway lights through the rain, took control, and disconnected the autopilot and autothrottle. The decision altitude for the approach was 360 ft.

The speed remained stable at 127 kt until 200 ft RA when the FO noted an increasing speed trend. The commander reduced thrust by approximately 1% N1: this was in addition to the automatic 2% reduction, applied by the engines' full authority digital engine control system (FADEC), when the autothrottle had been disconnected.

Indications from the PAPIs confirmed that the aircraft was on the correct glide slope and, two to three seconds after the automatic call of "100 ft" (RA), the commander reduced thrust to achieve a touch down speed of 115 kt. The FO, who had been monitoring the flight instruments, saw that the IAS had decreased at one point to 120 kt, but this had been corrected immediately and the speed accelerated through 122 kt. At about 60-70 ft RA the commander noticed that the rate of descent was high and at about 40-50 ft RA he commenced the landing flare. The FO saw an IAS of 117 kt during the flare, but with a higher than normal rate of descent and almost immediately sensed the 'ground-rush'.

The touchdown was heavier than normal but the aircraft was able to stop well within the available runway length. ATC considered that a possible tail scrape had occurred and initiated a runway inspection. An external inspection of the aircraft revealed that the tail protection strip had contacted the runway surface causing light damage to the protector plate; the flight crew were unaware that this damage had occurred.

Weather conditions

The synoptic situation at 1800 hrs on the day of the incident, showed an area of low pressure, and its associated frontal systems, moving slowly east along the English Channel. The weather in the area was light rain which reduced the surface visibility to 2,000 m, with an overcast cloudbase of 400 ft and a mean sea level pressure of 1011 hPa.

The relevant TAF for London (City) Airport forecast the following conditions between 1600 hrs and 2200 hrs:

> *Surface wind from 070º at 10 kt, visibility 2,000 m in mist, cloud overcast at 500 ft, temporarily lowering to 400 ft, with temporary rain between 1800 hrs and 2200 hrs.*

The METAR at London (City) Airport, issued at 1820, contained the following information:

Footnote

[1] Radar vectoring resulted in more fuel being used and the aircraft eventually landed at a weight of 38.7 tonnes; the correct V_{ref} for this weight is 121 kt. However, the V_{ref} of 122 kt calculated by the crew is used throughout the report.

Surface wind from 060º at 09 kt, visibility 2,000 m in light rain, overcast cloud at 400 ft, temperature 7ºC, dewpoint 7ºC and pressure 1,011 hPa.

London (City) Airport

London City airport has a single, concrete runway, orientated 28/10, which is 1,508 m long and 30 m wide. The Landing Distance Available (LDA) for Runway 10 is 1,319 m and the threshold elevation is 16 ft. The end of the touchdown zone is defined by two pairs of white, high-intensity lights, either side of the runway centreline and positioned 360 m from the runway threshold. The PAPIs are set to an approach angle of 5.5º, coincident with the ILS glideslope.

Steep approach, Standard Operating Procedures (SOPs)

The aircraft flight Manual sets out the procedures to be followed when conducting steep approaches. The steep approach mode is available for airports with a glideslope between 4.5º and 6º.

On intercepting the glideslope the airbrake should be selected OUT and the approach speed (V_{ref} + 5 kt) maintained. The approach must be made with the flaps at 33°, the airbrake must be operative and visual precision approach path guidance (PAPI or cockpit display of ILS) appropriate to the steep approach angle must be used. The decision height must not be less than 200 ft above the runway threshold elevation or the obstacle clearance altitude/height (OCA/H), whichever is the greater. When a coupled ILS approach is carried out, the autopilot and autothrottle may remain engaged down to 160 ft above the runway threshold elevation. When approaching the runway, speed should be reduced to cross the threshold screen height of 50 ft at the threshold speed (V_{ref}).

The aircraft is fitted with a steep approach system which desensitises the altitude rate warning from the GPWS. This is selected ON before the steep approach is commenced.

Manufacture's Flight Operations Bulletin

In June 1989 the manufacturer issued a Flight Operations Bulletin covering 'the risk of tail strikes'. The bulletin related to the 146-300 but applies equally to the RJ100 variant and mainly covered the takeoff phase of flight.

The final paragraph of the bulletin addresses the landing phase of flight and states:

'With regard to the possibility of a tail strike occurring on landing, it is our opinion that this can only occur if a late flare is made from a high sink rate which would result in a heavy landing. On the -300 this implies a pitch incidence of about 8° at touch-down and a rate of decent in excess of 10 ft/sec. This is not a normal landing and cannot be considered to be typical of an in-service approach and landing'.

Operator's Flight Operations Manual

The operator's Flight Operations Manual, Part B, contains guidance on the conduct of the steep approach and landing and considers the most likely causes of tail strikes. The guidance is as follows:

'Speed control is crucial during the approach and a high speed approach must be avoided as it results in the thrust levers being retarded to a position from which a rapid engine response cannot be guaranteed.

The engine air switches must be selected OFF before 200 ft on the final approach to guarantee the Go-Around performance from the steep approach. The autopilot must also be deselected not later than 160 ft above touchdown, no Cat 2 or 3 is available from a steep approach.

Aircraft handover from P2 to P1 occurs whenever *the P1 is satisfied that a successful landing can be completed. Due to the higher descent rate start to retard the thrust levers at approximately 100 ft AAL at a rate to achieve flight idle on touchdown. The steeper approach attitude requires a greater attitude change to achieve the landing attitude; it is this greater flare that can lead to the increased possibility of a tail strike.*

The most common cause of a tail strike on landing is a fast approach. This leads to a prolonged time in the flare, followed by a rapidly increasing ground closure rate. It is then very tempting to reduce the rate of descent by additional flaring. This technique will NOT reduce the rate of descent - at best it will cause a heavier landing than anticipated by rotating the main wheels into the ground; however it will also be very likely to cause a tail strike. The second most likely cause is an approach where, because of higher than expected ground closure rate, – (as in a steep approach) – the pilot either flares too early (causing subsequent 'sink' in the flare) or again prolongs the flare with a similar eventual effect. The 'sink' or rapid ground closure can provoke or tempt a further flare or over rotation, again causing a heavy landing with a likely tail strike.

There is no fixed advice on pitch angles for a correct landing, indeed, the pilot should be looking out at this point rather than at the PFD. For guidance, it is rather unusual to require more than four degrees pitch up in a correctly executed flare-to-land, this flare should not be increased even if it is felt that the ground closure rate is too high. A high rate of descent at this point may be checked by the application of power – always provided the runway performance permits. The technique of 'feeling' for the runway, by continuing to increase the body angle to try and achieve a smooth landing should never be used. A landing from a steep approach should be firm, as the runways are usually fairly short.

Flight Recorders

The aircraft was fitted with a Solid State Flight Data Recorder (FDR) and a Cockpit Voice Recorder (CVR). Both recorded details of the approach and touchdown.

A time-history of the relevant parameters during the incident is shown in Figure 1 as a solid line. For comparison, data is also presented in Figure 1 for a normal landing carried out earlier that day by the same crew at London City Airport in G-CFAH (time-aligned for main-wheel touchdown), this is depicted as a dashed line.

The final descent into London (City) Airport commenced from 2,000 ft RA, two minutes before touchdown, with the flaps at 33º, landing gear DOWN and the airbrake deployed. The speed during the descent varied between V_{ref} and V_{ref} +5 kt calibrated airspeed (CAS).

The data presented for the incident landing starts just over 18 seconds before the touchdown with the aircraft on the glideslope at 320 ft RA, 127 kt CAS (ie V_{ref} +5); descending at about 1,200 ft/min, with about 58% N1 on each engine[2]. Autothrottle was engaged throughout the descent until 300 ft, 17 seconds before touchdown.

Immediately after the disengagement of the autothrottle, the N1 for each engine reduced by about 3%, consistent with the FADEC synchronisation of the N1s to that of engine No 2 (the default master engine for such

Footnote

[2] For clarity, only the Power Lever Angle (PLA) and N1 for engine No 4 are shown. These are, however, representative of the other three engines.

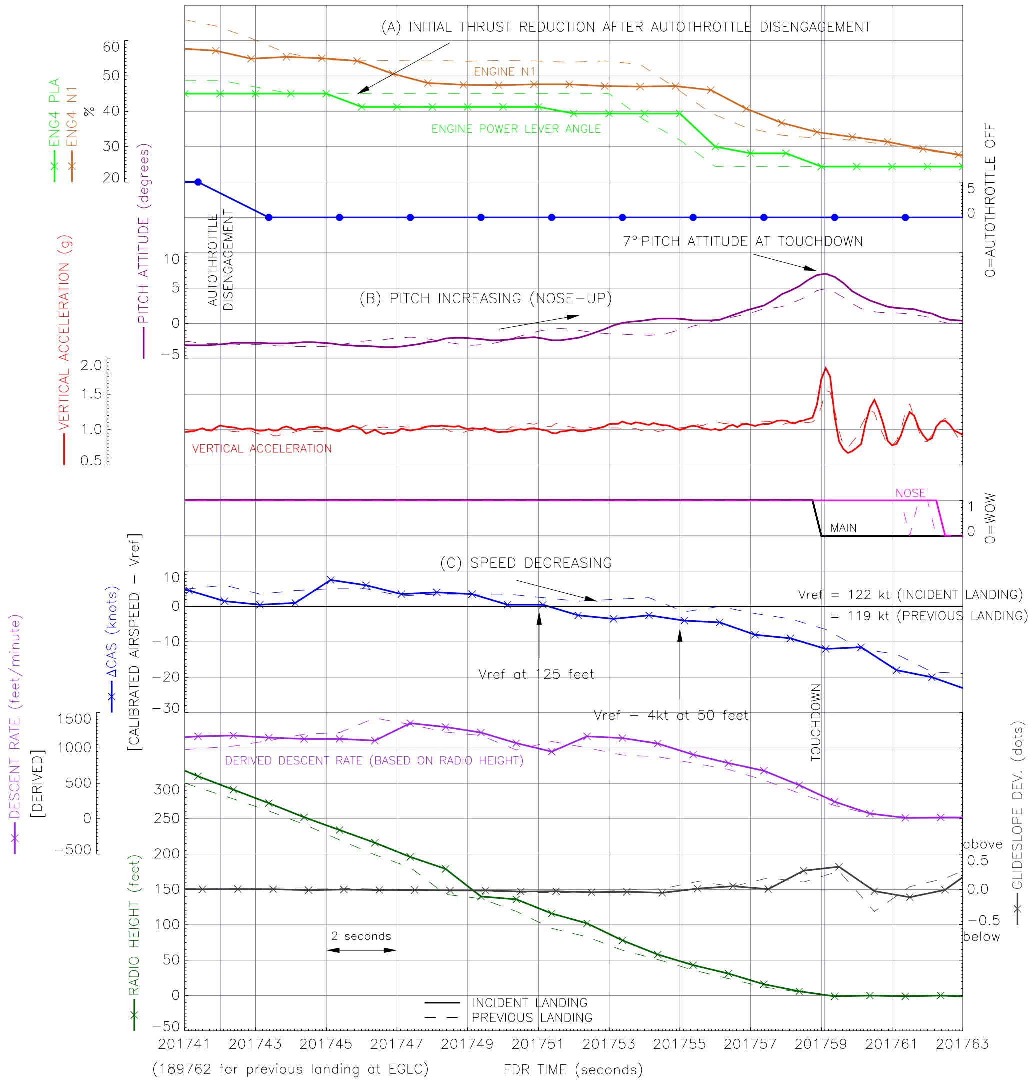

Figure 1

Salient FDR Parameters
(Incident to G-CFAH on 29 March 2005)

synchronisation) as engine control reverted back to manual control (or Thrust Modulation mode).

Three seconds after the disengagement of the autothrottle, the power levers for all four engines were retarded slightly, reducing N1 to 48% two seconds later (Point A of Figure 1). As the aircraft descended, its pitch began to increase (Point B of Figure 1) and the airspeed began to decrease (Point C of Figure 1) while maintaining the 5.5º glideslope. At 125 ft, with the airspeed at V_{ref}, the power levers were further retarded causing a slight reduction in N1. At 50 ft, when the power levers were retarded for the flare, the airspeed had decreased to V_{ref} –4 kt and the descent rate was about 1,060 ft/min (compared with V_{ref} and about 880 ft/min for the previous landing[3]).

Six seconds before touchdown, the aircraft pitch had

Footnote

[3] The derived descent rates are calculated from the rate of change of Radio Height above terrain height. The terrain height below the final part of the glideslope into London City is level (water then runway) and therefore provides an accurate and consistent measure of descent rate for this late stage of the approach.

increased to just above 0º, where it remained for three seconds before increasing steadily until touchdown. At touchdown the pitch attitude was 7º, the airspeed was V_{ref} –11 kt and the descent rate was 480 ft/min (compared with 5º, V_{ref} –6 kt and 360 ft/min respectively for the previous landing).

Aircraft information

The BAe 146 was the first aircraft to be Certificated to the JAR Part 25 requirements. The series 100 & 200 achieved UK Type Certification in February and June 1983 respectively. The Series 300, introduced to accommodate more passengers, was developed in the late eighties and received Type Certification in September 1988. Further significant developments, included: upgraded avionics, a Cat III landing capability and auto-throttle & FADEC controlled engines which were approved in April 92. This modification development was also co-incident with the remarketing of the aircraft as the Avro 146-RJ Series.

The length of the aircraft's fuselage was increased from 85 ft 11 in to 101 ft 8 in during this development. This was achieved by inserting a fuselage plug forward and aft of the wing. This increase in length reduces body angle clearance from 8.3º to 6.9º (with the main landing gear compressed).

Following the manufacturer's own test flights, the certification by the UK CAA of the steep approach profile for the 146 RJ100 was completed in 1995. The flight was made using a BAe146-300 series aircraft which has the same overall length and geometry as the RJ100. The object of the test was to clear the aircraft for steep approaches up to 5.5º glidepath angle. Some steep approach work had been done previously at a glidepath angle of 5º.

The Certification test flight included 11 approaches at a high gross mass with a forward CG. The flight examined a number of 'abuse' cases which represented the aircraft being flown at air speeds greater and less than the approach profile speeds and following a glidepath angle 2º steeper than that being requested. The 5.5º glidepath was flown at V_{ref} ± 5kt and the 7.5º glidepath abuse case was flown at V_{ref} +5 kt. The approaches were made to go-around, to assess the height loss under missed approach conditions. The test concluded that when the aircraft is flown on a 5.5º glidepath at V_{ref} - 5kt it was approaching a pitch limiting attitude (7º with a 10º geometric limit).

Stabilised Approach Criteria

The following stabilised approach criteria are set out in Part B of the operator's Operations Manual:

On all approaches:

At 1,000 ft RA, the aircraft should be in the planned landing configuration and on the correct glidepath. The airspeed should be 155 kt or less. If these criteria are not achieved consideration should be given to discontinuing the approach.

At 500 ft RA, the aircraft must be established in the planned landing configuration, the glideslope or correct vertical profile established, approach power set and indicated airspeed no more than V_{REF}+20 kt. If these criteria are not achieved then an immediate go-around must be carried out.

Analysis

The crew had achieved the required rest period prior to reporting for duty and they did not consider fatigue to be a factor contributing to the incident. The approach speed of 127 kt had been correctly calculated for the expected landing weight of slightly above 39.0 tonnes and the aircraft had been properly configured for the steep approach.

Earlier in the day, the crew had carried out an approach and landing at London (City) Airport in similar weather conditions to those prevailing at the time of this incident. From the FDR data it was established that the earlier approach and landing had followed the speed and height profile promulgated by the manufacturer. The subsequent approach, whilst initially stabilised at the correct speed, began to deviate from the landing profile when the airspeed reduced from V_{ref} + 5 kt at 150 ft to V_{ref} at 125 ft, instead of at the screen height of 50 ft. Engine thrust was also set lower than that required, the thrust levers having been moved aft when the autothrottle was disengaged. Whilst the pilot maintained the correct 5.5º glidepath, the airspeed decayed to V_{ref} -4 kt at 50 ft, at which point the power levers were retarded for the flare; the rate of descent was now 1,060 ft/min, compared to 880 ft/min at the same height on the previous landing. This high rate of descent may have been the visual cue which prompted the pilot to increase the aircraft pitch attitude in order to reduce that rate of descent.

Whilst surface wind was considered not to be a factor in the incident, the poor weather had been considered by the flight crew. Extra fuel was carried and a full briefing on the actions to be taken in the event of a go around at decision altitude was carried out in accordance with the SOPs. The crew fully expected to have to divert from the approach but obtained the required visual landing reference just above decision altitude.

The Operations Manual guidance on "*the most likely cause of tail strikes",* identifies both "*fast approaches"* and the "*higher than expected ground closure rate"* which results from steep approaches. The need to accurately maintain the target speed and not allow excess speed to develop when landing at London (City) Airport was clearly appreciated by the crew, particularly on the wet runway that night. The decreasing airspeed was noted by the FO just prior to the flare but this appeared to be corrected as he noted the increasing speed trend on the PFD airspeed indication.

Safety Actions

Since the incident, the operator has reviewed the conditions which lead to tail strikes with the BAe 146 RJ100 and has identified preventative measures developed from discussions with the manufacturer and from trials carried out in the training simulator.

An Operations Manual Amendment Notice (OMAN) was issued on 3 June 2005, promulgating the policy for the pilot not flying (PNF) to alert the pilot flying (PF) to an excessive nose up pitch attitude on approach or landing. The policy stated:

> *"For all approaches/landings, if a higher than normal pitch attitude is recognised (5° or above) in the final stages of the approach/flare the PNF must call "Attitude".*
>
> *If "Attitude" is called the PF must not increase the pitch attitude any further but is to either accept the current attitude for landing or conduct a go around".*

In order to support the OMAN, a comprehensive Tail Strike Prevention training package has been developed by the operator for use during each pilot's recurrent simulator training. It follows the normal convention of briefing, simulator demonstration by the instructor and exercises flown by the crew under training, followed by debriefing. The training addresses in detail speed control with thrust, particularly when correcting loss of airspeed, and the amount and duration of the thrust increase required, not only to prevent further loss of airspeed but to re-establish the target airspeed.

Clarification of the effect on landing distance required when applying a gust factor is also covered. An increase in the landing distance required is related to airspeed above the targets stated in the manufacturer's landing profile and specific calculations are applied utilising generalised flight manual landing data.

Throughout the training, the need to execute a go-around where there is a loss of profile target speeds or when a high nose-up pitch angle develops, is emphasised. The time taken from 50 ft to touchdown is approximately five seconds and a demonstration of a go-around from 50 ft with the airspeed at V_{ref} -5 kt is given. Emphasis is placed on the need to ensure that care should be taken not to over rotate the aircraft which might lower the main landing gear wheels onto the runway, causing structural damage. The crew under training then carry out a go-around at least twice from a height of 50 ft or below. The operator has also introduced a requirement for approaches to London (City) to be made at least every three months. Specific training on such approaches is included in the biannual simulator training.

Conclusions

This tail scrape incident occurred because the thrust set, three seconds after the disengagement of the autothrottle, was too low to maintain the required airspeed for the landing profile whilst the commander attempted to maintain the correct glideslope. A high rate of descent developed which the commander attempted to reduce by increasing the flare which caused the aircraft fuselage to exceed the body contact angle of 6.9º causing minor damage to the tail strike protection plate.

The safety actions carried out by the operator in addressing the issue of tail strike prevention provides valuable information for flight crews, in particular the increment of airspeed above V_{ref} that may be carried without increasing the landing distance required.

Safety Recommendation 2006-095

It is recommended that BAE Systems review the work jointly undertaken with the operator regarding tail strike prevention on the Avro 146-RJ100 aircraft with a view to promulgating the information to other operators.