INCIDENT

Aircraft Type and Registration:	Jetstream 4100, G-MAJA
No & Type of Engines:	2 Garrett Airesearch (Honeywell) TPE331-14HR-802H Turboprop engines
Year of Manufacture:	1994
Date & Time (UTC):	29 June 2005 at 1523 hrs
Location:	Manchester Airport, Manchester
Type of Flight:	Public Transport (Passenger)
Persons on Board:	Crew - 3 Passengers - 10
Injuries:	Crew - None Passengers - None
Nature of Damage:	Nil
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	50 years
Commander's Flying Experience:	3,270 hours (of which 1,310 were on type) Last 90 days - 275 hours Last 28 days - 52 hours
Information Source:	AAIB Field Investigation

Synopsis

The aircraft departed from Hamburg Airport with an overloaded baggage compartment and with the centre of gravity outside the aft limit of the operating company's approved aircraft flight envelope, although it was within the manufacturer's less restrictive envelope. On landing at Manchester Airport in benign weather conditions, an oscillation in yaw developed which the pilot was unable to correct through use of the rudder or nose wheel steering (NWS). After several cycles the oscillations rapidly became divergent and the aircraft veered off the runway, coming to a halt on the grass approximately 80 m from the runway centreline.

History of the flight

On the morning of the incident, the commander and first officer flew the aircraft from Humberside Airport to Hamburg Airport with a cabin attendant on board, but with no passengers or cargo. Whilst taxiing prior to departure the commander noted that the aircraft had a tendency to meander about the taxiway centreline without any associated crew NWS input. The aircraft arrived at 1029 hrs and was scheduled to depart with 10 passengers and their associated luggage at 1200 hrs, for a chartered flight to Manchester. After the aircraft had been catered and refuelled, the passenger baggage arrived at the aircraft. The commander noted that there were several large and heavy bags and enquired as to whether they had been weighed. He was told by the handling agent they had not been weighed and that they were not planning to weigh them. The bags were then loaded into the two baggage compartments; Holds 4 and 6 (see Figure 1). These were both filled to volumetric capacity and the remaining bags (approximately five) were stored in the passenger cabin. The commander appreciated that the centre of gravity would be positioned significantly aft as a result of the full baggage compartments and asked the cabin attendant to seat the passengers in the forward seats. All the loading information was then passed to the first officer who completed the manual loadsheet which the commander then signed. Throughout this period the first officer had remained on the flight deck. The passengers then boarded the aircraft and it was noted by the commander that they possessed a significant amount of hand baggage.

After a normal start, the commander, who was the handling pilot for this sector, taxied the aircraft to Runway 33 for departure; there was no tendency for the aircraft to meander whilst operating on the ground and the NWS operation was normal. During the taxi the ANTI-SKID caption on the central annunciator panel illuminated. The anti-skid switch was recycled two or three times before the light extinguished and the taxying proceeded as normal. The flight then continued without incident until it arrived at Manchester Airport An ILS was flown to Runway 06R in benign weather conditions; a light and variable surface wind, 10 km visibility, a cloudbase of 2,000 ft and a temperature of +16°C. Following the ILS approach the autopilot was disengaged and a reportedly smooth touchdown achieved on the runway centreline. The spoilers, which had been pre-armed, deployed and, after confirmation of power in the 'beta' range, reverse power was selected.

The commander reported that almost immediately the aircraft touched down it began to meander about the runway centreline, and this rapidly became more progressive. He initially attempted to control this instability with rudder but as this had no noticeable effect, he resorted to using NWS through the tiller. Although the tiller handle moved freely, he was unable to control the aircraft's heading and shortly afterwards the aircraft yawed rapidly to the left and departed off the side of the runway. At this point full wheel braking was being applied and the rudder was used in addition to the tiller in an attempt to keep straight.

The aircraft decelerated rapidly on the furrowed grass and came to a stop after approximately 10 seconds. The commander made a public address announcement to the passengers to let them know that the situation was under control and to remain in their seats. He also opened the flight deck door to check on the situation in the cabin and received a 'thumbs up' from the cabin attendant. After the AFRS arrived at the scene the engines were shut down and the commander, having established that there were no hazards outside the aircraft, released the passengers. There was no smoke, fire or apparent damage to the aircraft.

Aircraft layout (Refer to Figure 1)

This particular variant of the Jetstream 4100 has a passenger cabin comprising nine rows of three seats and a tenth row of two seats. The cabin attendant's seat is immediately behind the tenth row, adjacent to the galley and a wardrobe is situated behind the first officer's seat. For loading purposes, the cabin is divided into three bays; Bay A contains seat rows 1-3, Bay B contains Rows 4-6 and Bay C contains rows 7-10. There are two cargo holds; Hold 4 just aft of the wing and Hold 6 towards the rear of the fuselage. The wardrobe, Bay A and Bay B all have a forward effect on centre of gravity whilst Bay C, both holds and the fuel load have an aft effect.

Baggage loading

The commander, having filled both baggage holds to volumetric capacity at Hamburg, estimated their contents weight as the maximum allowed in each hold; that is 330 kg in Hold 6 and 158 kg in Hold 4, and these were the figures that were entered onto the loadsheet.

After the incident at Manchester, the company's handling agents were asked to assist with offloading the hold baggage. On opening the door to Hold 6, the ramp supervisor was surprised by the volume of bags in the hold and decided to weigh the contents. An engineer from the aircraft's operating company unloaded Hold 4 and these bags were added to those in Hold 6 prior to weighing, with the exception of two crew bags. The engineer could not recall exactly how many bags were in Hold 4 but thought that there were probably 4 or 5 large bags, a guitar and 6 smaller bags in addition to the crew baggage. The crew baggage along with the internal cabin bags were taken separately to be reunited with the passengers and crew.

Thirty items of baggage were weighed giving a total weight of 610.9 kg which is 122.9 kg greater than the maximum allowed combined hold weights. The exact distribution of weight between the holds is not known but from the engineer's recollection it appears likely that Hold 4 was close to its weight capacity of 158 kg. Hold 6 is thus likely to have contained approximately 453 kg.

The hold baggage that was taken into the passenger cabin and strapped onto the passenger seats was not shown on the loadsheet as it was considered part of the allowed passenger hand baggage of 6 kg per person. There was one bag of approximately 5 kg placed in the wardrobe behind the first officer's seat.

Passenger loading

Prior to the boarding of the passengers the commander asked the cabin attendant to seat them in the forward seats. As a result of this request, the loadsheet was completed showing nine passengers sat in Bay A and one passenger sat in Bay B. However the cabin attendant did not seat any passengers in Row 1 due to its unpopularity; the seats being close to the forward bulkhead. Excess baggage from the hold had already been strapped into some of the seats in Rows 2 and 3 which meant that Bay A actually contained just two passengers, Bay B contained seven passengers and Bay C contained one passenger. This difference, particularly the number of passengers sat in Bay A, had a significant impact on the actual position of the centre of gravity. The loadsheet compiled by the crew is shown at Figure 1 whilst the loadsheet detailing the actual load positions is shown at Figure 2. It can be seen that the actual load positions placed the aircraft's centre of gravity aft of the operating company's flight envelope and into the 'unsafe' region for both takeoff and landing. The manufacturer's flight envelope is less restrictive and using their envelope the centre of gravity fell within the aft limit for both takeoff and landing.

Flight testing of this series of Jetstream aircraft included assessment of handling characteristics with a centre of gravity up to two inches outside the manufacturer's certified aft limit in the takeoff and landing configurations and four inches outside the aft limit in the en-route configuration. The aerodynamics department's flight test report concluded that:

> *'At no time during any of these tests were any adverse or undesirable handling characteristics encountered. Positive longitudinal stability was demonstrated and the aircraft was easily controlled, requiring no exceptional pilot skills.'*

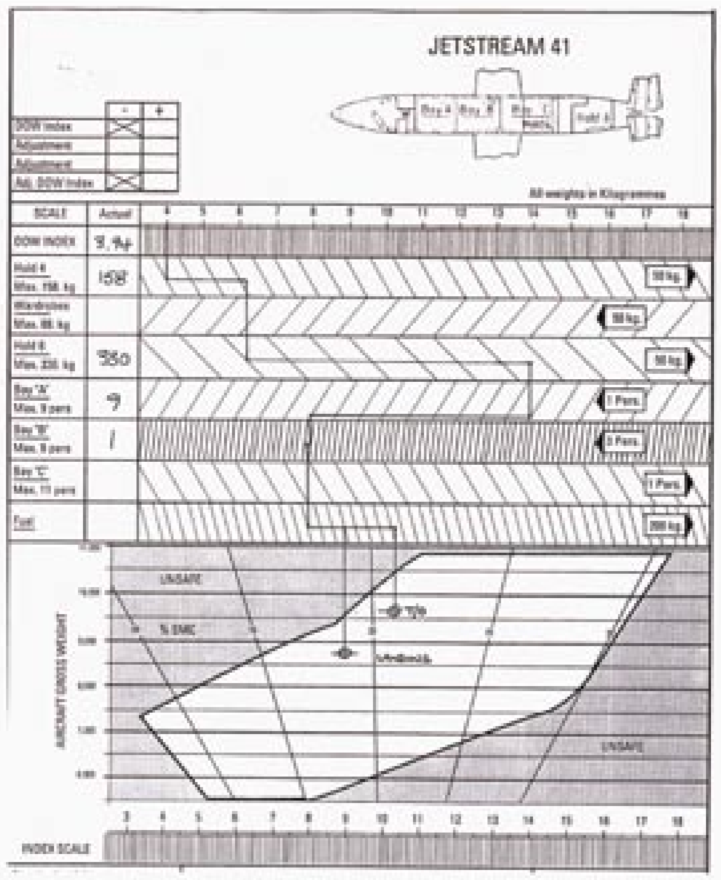

Figure 1 (Left)

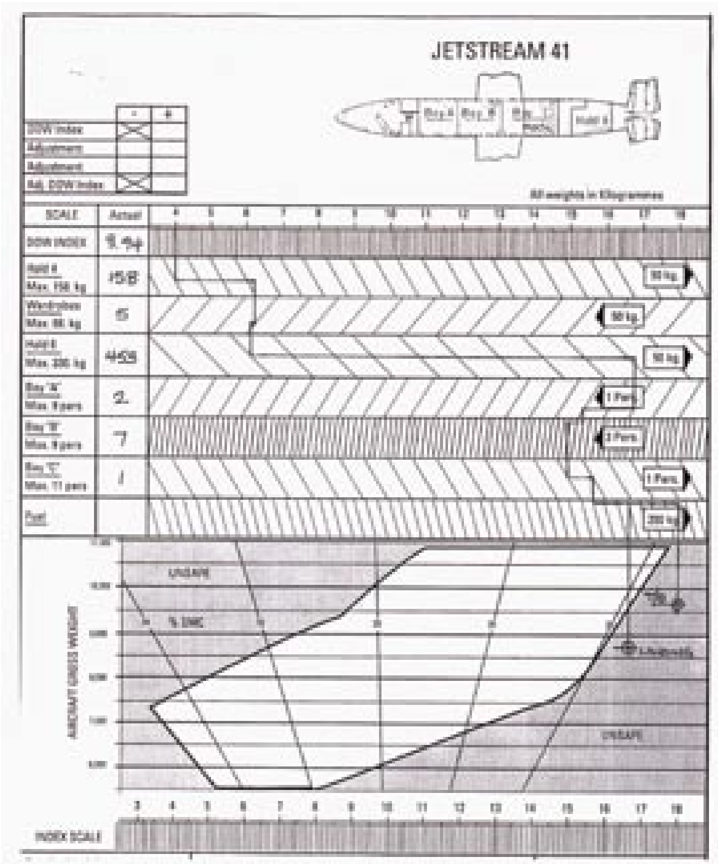

Figure 2 (Right)

Operator's Charter Brief

The aircraft's operator, whose normal business involves scheduled public transport operations, uses a Crew Flight Aide Memoir form to facilitate pre-flight planning for charter flights; flight crews generally being less familiar with this side of the operation. This form consists of a series of tick boxes for various elements of the charter flight such as performance, aircraft defects and passenger numbers. A company operations officer prepares this form in advance of the flight and initialises the relevant boxes when they have each been checked. The commander is then required to brief and tick each relevant box or contact operations for further clarification. The boxes marked *'pax nos'* and *'estimated baggage weight'* had not been ticked by either the operations officer or the commander for this particular charter flight. This is apparently not unusual as passenger numbers and baggage weights are often only finalised at the very last minute.

Flight Recorders

The aircraft was fitted with a Solid State Flight Data Recorder (FDR)[1] capable of recording a range of flight parameters[2] into solid state memory when power was applied to the aircraft. The aircraft was also fitted with a Cockpit Voice Recorder (CVR), however, these recordings from the incident landing were over written with more recent information whilst the aircraft was on the ground after the landing.

A time-history of the relevant parameters during the incident landing is shown at Figure 3. The data presented starts just over 30 seconds before the touchdown, with the aircraft established on the glideslope at 295 ft agl, with the autopilot engaged, flaps at 25º, at 121 kt IAS (ie V_{ref} +14 kt) and with a descent rate of about 670 ft/minute. Vref is the target airspeed at 50 ft on the approach.

At approximately 80 ft agl the autopilot[3] was disconnected. Coincident with the autopilot disconnect, and about 12 seconds before touchdown, the aircraft pitched nose down from -5º to -7º. Following an application of nose up elevator the pitch angle increased by 6º to -1º. Two further pitch oscillations were recorded prior to the flare. These pitch oscillations are indicated by Point A at Figure 3.

Just before touchdown the aircraft had a yaw rate to the left of approximately 0.5º/s. The aircraft then banked to the right with a 2.5º roll attitude recorded at touchdown as the yaw rate reduced to zero. At touchdown, the pitch attitude was +2.5º, the airspeed was 107 kt IAS (ie V_{ref}), and the normal acceleration peaked at 1.25 g. Immediately after touchdown the aircraft pitched nose-down to -4º.

Landing gear squat switches indicated that the nose gear and right main gear were the first to contact the ground with the right main gear almost immediately bouncing back up to disconnect the squat switch. The aircraft then commenced a yaw to the right at a rate of approximately 0.5º/s. The left main gear followed shortly by the right main gear (for the second time) finally made contact with the ground three seconds after the initial contact, as the aircraft pitch increased from about -4º to -1º. The

Footnotes

[1] LORAL Fairchild Model F1000 FDR: which contains memory capable of recording at least 25 hours of data at 64 words per second data rate.

[2] The range of parameters included aircraft control surface deflections but none of the associated control inputs. Also not recorded are nose wheel steering, tiller angle and braking.

Footnote

[3] Discrete parameters (for example autopilot disconnect, landing gear squat switches, reverse thrust selection) are recorded with a one second sample rate that could result in a delay of up to one second between when an event is sensed and when the event is recorded on the FDR.

air/ground landing gear squat switch positions after touchdown are indicated by Point B at Figure 3. Revere thrust from the propeller blades was selected shortly after this without any noticeable change in aircraft pitch or heading.

Three seconds after touchdown, the aircraft yawed more sharply to the right (at just under 3º/s) before reversing the direction of yaw to the left. The aircraft yawed right then left another three times, each directional-oscillation growing in amplitude, before coming to a rest off to the left of the runway on a heading of 358ºM. These oscillations in yaw are indicated by Point C at Figure 3. Increasing rudder deflections to a maximum of +24° were recorded (where positive indicates yaw to the right and ± 24° is full deflection); these rudder deflections commenced about 10 seconds after touchdown and were in phase with, but slightly lagging the oscillations, and in the same sense (ie driving the oscillation).

Examination of the runway

The aircraft had left skid marks from all six tyres as the final left turn commenced, and which continued across the grass until it came to rest. There were no other marks discernible prior to the point at which the right mainwheel tyres, on the right side of the centreline and heading slightly to the right, changed direction in a turn to the left. Almost immediately, the left main and nosewheel tyres also started to produce marks. Several conclusions were drawn from observations and measurements of these marks:

- The aircraft left the paved surface approximately 1,400 m from the runway threshold, coming to a halt on the grass 81 m from the runway centreline and on a heading of about 360°.
- All six tyres were skidding sideways to produce the marks.
- The change of direction from right to left was consistent with a divergent oscillatory behaviour.
- The fact that the nosewheel marks were some 2.4 m closer to the left mainwheels than the right indicates that the aircraft was yawed about 7-8º to the left.
- Braking was being applied as the aircraft left the paved surface and the distinctive 'dashed' appearance of the left mainwheel marks just prior to this showed that the anti-skid system was operating (this was not the case with the right mainwheels, almost certainly because the weight distribution was being transferred from the left wheels to the right under the action of cornering).
- The aircraft was not being steered by the nosewheel but subjected to other forces being applied to change its path across the ground.

Examination of the aircraft

The aircraft was examined by the AAIB and a senior engineer from the operating company the day after the incident; the baggage had been off-loaded. After a visual inspection of the landing gears, during which no abnormalities were noticed, it was towed onto a 'grease plate' which enables the nosewheel steering to be exercised under power with the normal weight of the aircraft on the wheels. Both engines were then started, hydraulic power applied to the system and the steering exercised several times throughout its operating range using the tiller on the captain's side console. The nosewheel steering functioned correctly and the 'feel' of the tiller was normal.

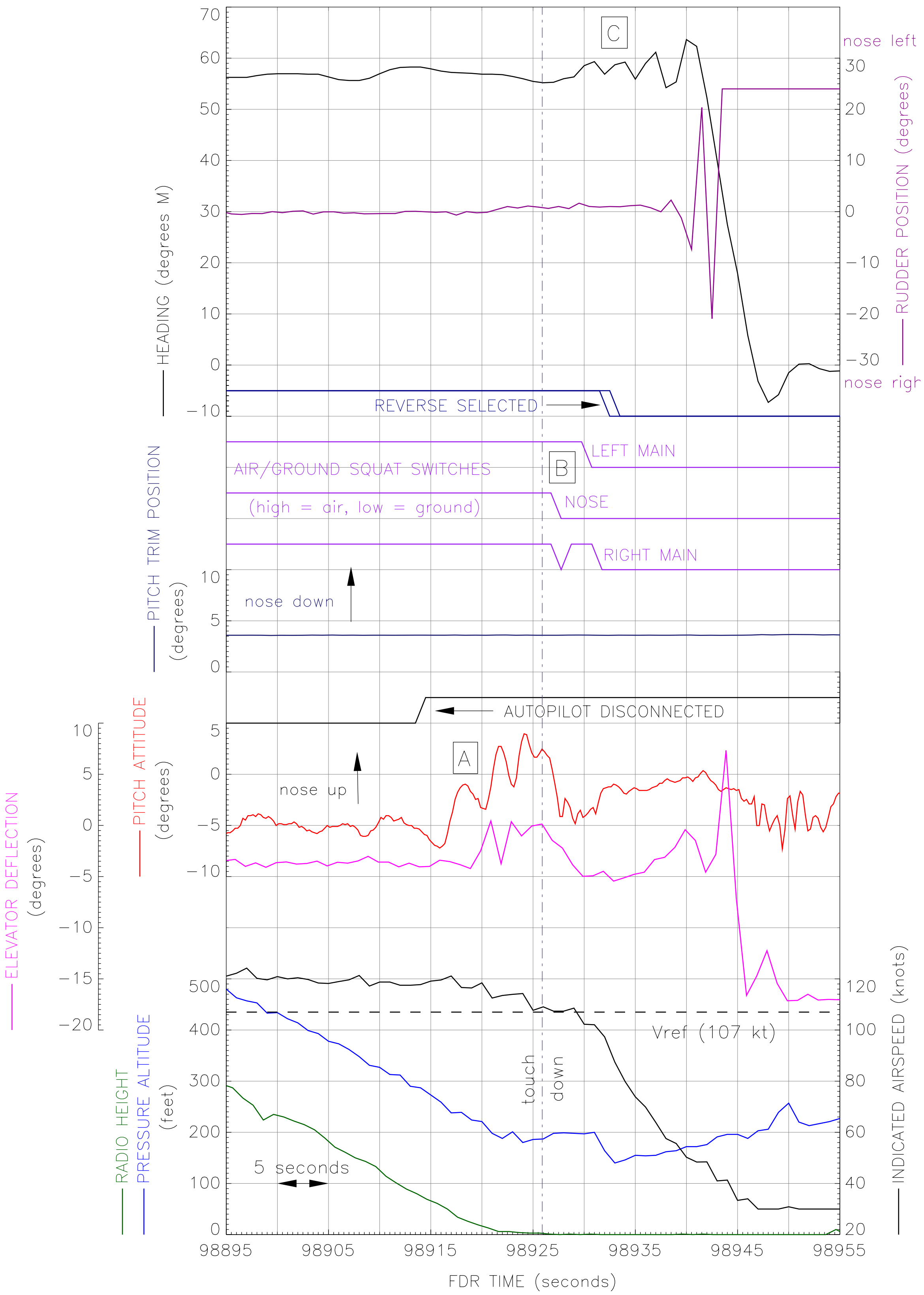

Figure 3

Salient FDR Parameters
(Serious Incident to G-MAJA on 29 June 2005)

The engines and propellers were then exercised through the flight, beta and reverse pitch ranges to check for evidence of differential operation – none was found. Later in the day the aircraft was taxied by a company pilot at high speed along the runway several times to check for normal operation of the steering and brake systems. He reported that the handling was normal and, after some tyre changes, the aircraft was ferried to the operator's maintenance base for further checks. These found no anomalies and the aircraft was returned to service.

A few days later, a captain who had flown G-MAJA on a revenue flight reported an apparent 'over-sensitivity' of the nosewheel steering at high speeds. The aircraft was removed from service and placed on jacks. In this condition, great difficulty was found in moving the nosewheel steering by hand with hydraulic power removed, although operation with power applied was normal (note: there is no maintenance manual procedure requiring manual movement of the steering - the engineer simply felt that G-MAJA's steering resisted his efforts much more than other aircraft in his experience). Upon opening the steering actuator cover plate on the back of the noseleg, a quantity of water spilled out and the grease inside appeared old and hard. After fresh grease was applied and the mechanism exercised, the steering could be turned by hand freely. The aircraft was returned to service and there have been no other reports of abnormalities in the steering system.

Engineering conclusions

The nature of the marks on the runway suggested that the nosewheel steering was not responsible for the aircraft leaving the runway – the presence of clear tracks of the nosewheel tyre indicate that the steering was trying to resist the forces turning the aircraft to the left. Despite this, attention focussed on the serviceability of the steering system since it appeared to have been ineffective at countering the first minor oscillations, according to the pilot. The testing at Manchester did not reveal any functional anomalies and even the later discovery of water in the steering actuator did not appear to impede operation of the system under hydraulic power. Some consideration was given to the possibility that the water could have frozen during the flight but any resistance to tiller movement, if the nosewheel had become seized in the fore-and-aft position, should have been easily sensed by the pilot (he reported tiller 'feel' as normal). The apparent abnormally high forces required to rotate the steering by hand could have been explained by residual hydraulic pressure in the system.

Some consideration was also given to the possibility that the extreme aft centre of gravity at touchdown could have resulted in such light loads on the nose leg that the steering became ineffective due to lack of friction. Information from BAE Systems indicated that, even with the centre of gravity at its most probable position, there would still have been significant, if reduced, loading on the nose landing gear.

The AAIB have investigated another incident in which a Jetstream 31 aircraft left the side of the runway whilst taking off from London Stansted Airport (G-LOVA, AAIB Bulletin 1/2000). The Jetstream 31 and 41 series of aircraft employ a very similar nosewheel steering system. In the case of G-LOVA, the cause of the loss of directional control was considered to be a worn spring plunger in the steering valve which put a small 'steer left' hydraulic flow into the steering actuator, after the pilot had released his hand from the tiller. In this case, however, there no suggestion of any oscillatory motion of the aircraft.

Discussion

The chain of events that led to this incident began with an incomplete charter brief. A provisional baggage weight estimate at this stage may have highlighted a potential loading issue. However, the nature of the charter business invariably means significant last minute changes and commanders would be expected to safely handle whatever loading issues they are presented with. During the turnaround at Hamburg Airport the commander had to decide whether to delay the flight in order to allow the baggage to be weighed. Although in hindsight this would have been the sensible option there was pressure, possibly self-imposed, to depart on schedule in order to meet the passengers expectations, and consequently, the bags were not weighed. Having loaded the baggage, the commander estimated the weights as the maximum allowable for each hold which, considering both holds were full and no actual weights were known, was his only realistic option. The fact that the baggage, particularly in Hold 6, was tightly packed in might have been an indication at this stage that there was an overloading issue. The commander obviously realised the implication of the full baggage holds on the position of the centre of gravity, in that he instructed the cabin attendant to sit the passengers in the forward seats. However the full significance of this instruction was not understood by the cabin attendant as she did not use the front row of seats that are known to be unpopular with the passengers. This misunderstanding may have arisen because the instruction was not clear or significantly emphasised or because the cabin attendant did not understand the implication of what she was being asked to do. Either way, the loadsheet did not accurately reflect the actual passenger seating positions, and this led to an incorrectly calculated centre of gravity and trim position. At the time of this incident there was no company procedure for a final check of loadsheet seating accuracy other than the commander physically checking the seating positions.

During the final approach, the aircraft was being flown through the autopilot which would have automatically trimmed the aircraft. As it is not normal procedure to check the trim indicator position at this stage of flight the flight crew were unlikely to be aware that it was in an unusually nose down position. When the commander took control manually, at 80 ft agl, the aircraft was correctly positioned and stabilised on the approach path, and in the landing configuration. During the landing flare several pitch oscillations were identified from the flight data recordings, although none of the flight crew recall anything problematic with the approach. With a centre of gravity further aft than normal the aircraft would have been more responsive to control input than anticipated; however, flight tests have indicated that with the CG 2 inches outside of the manufacturers limit the stick forces are acceptable and that there are no adverse or undesirable handling characteristics.

The approach speed was close to the maximum allowable of V_{ref} +15 kt and as such resulted in a more pronounced nose down attitude during the approach. A combination of landing at V_{ref} and the oscillatory nature of the flare led to the nose wheel contacting the ground almost coincidentally with the right main wheel followed by a period with just the nose wheel in contact with the ground. During this period the aircraft was yawing to the right, a motion that would have been difficult to correct until all main landing wheels were in ground contact and restoring forces were then available. There was no noticeable rudder activity for 10 seconds after touchdown during which time directional oscillations developed. Thereafter, significant alternating and increasing rudder deflections occurred coincident with rapidly diverging directional oscillations until the aircraft departed the runway.

The commander recalls using NWS and wheel braking during the landing roll but the lack of FDR data for these parameter prevents analysis as to their effectiveness. If he did utilise these controls the reported 'sensitivity' of this aircraft's NWS system at high speeds would make directional control more prone to pilot induced oscillation. However, the final skid marks from the tyres suggest that the aircraft was not being steered by the nosewheel but subjected to other forces being applied to change its path across the ground.

Conclusion

The aircraft departed Hamburg and arrived at Manchester Airport with its centre of gravity in the unsafe region of the operator's flight envelope due to incorrect loading, although the centre of gravity was within the manufacturer's safe envelope which is less restrictive than the operator's. During the cruise, the autopilot was engaged which would have masked any symptoms of an aft centre of gravity. However, the oscillatory behaviour, in both pitch and yaw, experienced during the final approach after the autopilot was disconnected, was symptomatic of an aft centre of gravity position. After touchdown at Manchester a directional oscillation developed, possibly as a result of a period of time spent with just the nosewheel in contact with the ground. Although directional stability on the ground may have been reduced by an aft centre of gravity, it is unclear as to why these oscillations were not controllable. A rapid increase in rudder deflection occurred at a similar time to a rapid increase in heading change and this quickly led to runway departure. In the absence of mechanical failure it is possible that this was a pilot induced oscillation but without NWS data, a definitive conclusion cannot be drawn.

Operator's findings and recommendations

In response to this incident, the aircraft's operator reviewed its supervision of charter flights and made a number of changes which were issued as Flight Crew Instruction 07/2005 on 8 August, and then re-issued, with minor editorial changes, on 1 September. The changes included the following:

The Charter Manager will receive recurrent guidance and appropriate training in Weight and Balance, Range and Payload, and Aircraft Limitations for each of the aircraft types operated by the company. The baggage capacity and capabilities of the aircraft will be demonstrated to potential charter customers via a simple user guide for each aircraft type, and will be reflected in the Terms and Conditions of Carriage.

Operations staff will be formally trained in Weight and Balance, Range and Payload, Aircraft Performance, Limitations, Meteorology, NOTAMS and FTL. The training will be recurrent and sufficient such that staff are aware of the importance of this information to operational safety.

For those flights identified above, Operations will, using the Flight Aide Memoir, ensure that each element of the planning is completed by initialling the relevant signature box, or filling in the details such as expected baggage weight, aircraft registration, Handling Agent, Fuel Payment method etc. Baggage weighing facilities are particularly important. Guidance notes will be issued to Operations staff so that the requirements for each element of the planning procedure are clear. The completed boxes certify that the particular requirement has been fulfilled by the Operations staff, and subsequently by the commander.

On receipt of the Charter Brief and Aide Memoir from Operations, the aircraft commander is to ensure that the crew are adequately briefed using the aide memoir, and certify as having done so using the certificate at the bottom of Part One of the Aide Memoir. This is to be faxed to Operations before the charter commences. If any element of the planning needs clarification, the aircraft commander is to contact operations or relevant management staff.

Operations staff are to ensure that a faxed copy of Part One of the Aide Memoir is received in Operations and that it has been signed by the commander, prior to the departure of the first flight of that charter.

Crews are reminded of the importance of the safe loading of the aircraft, and the seating of passengers commensurate with Weight and Balance. Prior to closing the main door, the Cabin Attendant is to use a Passenger Seating Proformae to mark the actual seating positions of the passengers. This is to be handed to the Captain, who will confirm that the seating positions are as per the loadsheet. The proformae is to be placed in the 'Ship's Papers' envelope.

All Cabin Attendants are to undergo appropriate training in Weight and Balance to emphasise the importance of correct passenger seating.

Captains are reminded that, despite the process described above, ground staff cannot be expected to have the level of expertise requisite of flight crew. Ultimate responsibility for safe conduct of all flights rests with the aircraft commander and Flight Safety is not to be prejudiced under any circumstances.