INCIDENT

Aircraft Type and Registration:	Boeing 747-2D7B, N523MC
No & Type of Engines:	4 General Electric CF6-50 turbofan engines
Year of Manufacture:	1979
Date & Time (UTC):	12 December 2004 at 1611 hrs
Location:	On approach to Runway 05 at London Stansted Airport, Essex
Type of Flight:	Public Transport (Cargo)
Persons on Board:	Crew - 3 Passengers - None
Injuries:	Crew - None Passengers - N/A
Nature of Damage:	None
Commander's Licence:	FAA Airline Transport Pilot Certificate
Commander's Age:	56 years
Commander's Flying Experience:	Approximately 14,000 hours (of which 6,000 were on type) Last 90 days - 196 hours Last 28 days - 66 hours
Information Source:	AAIB Field Investigation and operating company report

Synopsis

The incident occurred when the crew became involved with an apparent unserviceability, which resulted in no-one in the cockpit monitoring the flight path of the aircraft during an ILS approach. The aircraft broke cloud at 900 feet amsl just over 6 nm from the threshold. The commander then disconnected the autopilots and manually flew the aircraft to acquire the proper glideslope. Subsequent to the incident, the crew did not report the incident to the airport authority nor to their company. The incident and subsequent lack of proper reporting procedures by the crew indicated a serious breakdown in crew effectiveness.

History of the flight

The aircraft, with three crew members on board, departed Chicago International Airport at 0909 hrs for a flight to London Stansted International Airport. Departure had been delayed more than three hours due to loading problems. There were some minor unserviceabilities noted in the Technical Log but the crew considered that the aircraft was fully serviceable during the transit.

As the handling pilot in the left cockpit seat, the commander briefed for a practice Category II approach and automatic landing on Runway 05 at Stansted. By 1600 hrs, the aircraft was at Flight Level 75 and overhead Barkway (BKY) VOR/DME. Then, following instructions from Essex Radar on frequency 126.95 MHz, the commander established the aircraft on a heading of 050ºM from BKY and commenced a descent to 6,000 feet on the QNH of 1027 mb; he was controlling the aircraft with autopilot 'A' selected. Over the next few minutes, the aircraft was given further instructions by ATC and, by 1605 hrs it was at 3,000 feet amsl and heading 180ºM. Then, at 1607 hrs, the ATC controller apologised for a late turn and instructed the aircraft to turn left onto 020ºM and to report established on the ILS. While the aircraft was still in the turn, the controller cleared the aircraft to "DESCEND TO 2,000 FEET AND FURTHER WITH THE ILS"; this instruction was correctly acknowledged by the crew of N523MC. At 1609 hrs, the crew reported that they were "ESTABLISHED ON LOCALISER FOR 5". The controller again apologised for the late turn, cleared the aircraft to descend on the ILS and instructed the crew to call 'Stansted Tower' on frequency 123.8 MHz. After acknowledging this instruction, the crew then checked in with 'Stansted Tower' and reported "ON ILS 5". The controller acknowledged with "CONTINUE AS NUMBER ONE WITH ONE AIRCRAFT DEPARTING AHEAD". At 1610 hrs, the controller cleared the aircraft to land. After landing, N523MC cleared the runway using the normal rapid exit taxiway.

Within the aircraft, the commander had configured with Flap 20 and with the gear still retracted for the descent from 3,000 to 2,000 feet amsl. By this time, both autopilots had been selected. During the descent, the co-pilot noted 'flags' on his instruments indicating that the localiser and glideslope were not being received. The commander had indications from his instruments that they were established on the localiser and all three crew members then discussed the problem and attempted to identify the cause. Shortly afterwards the aircraft broke cloud at approximately 900 feet amsl. With the ground and PAPIs in visual contact, the commander immediately disconnected the autopilots and levelled the aircraft. He maintained the aircraft on the localiser and entered a gentle climb to intercept the normal glideslope from below. The crew completed the normal pre-landing checks and made an uneventful landing.

After shutdown, entries were made in the aircraft's Technical Log. These included a statement that the autoland was unsuccessful and that the co-pilot's 'G/S and LOC' flags were in view until 800 feet on the approach. Ground engineers carried out a BITE check in accordance with the maintenance manual but were unable to replicate the fault. The aircraft was cleared for flight with a request for airborne reports on the next sector.

The commander did not submit any reports about the incident. The co-pilot reported the incident using both the confidential 'National Aeronautics and Space Administration (NASA) Aviation Safety Reporting System' and the confidential 'Aviation Safety Action Program (ASAP)'. The flight engineer submitted a 'NASA' report. The airport authority had no indication of the occurrence until a number of noise complaints resulted in an examination of the radar recording. Subsequently, the AAIB were advised of the incident by the airport authority on 15 December and initiated an investigation the same day. The aircraft operating company also initiated an internal inquiry, in collaboration with the Federal Aviation Administration (FAA) and the National Transportation Safety Board (NTSB), and provided full support to the AAIB investigation.

Weather information

The Terminal Aerodrome Forecast (TAF) at Stansted on 12 December from 1300 to 2200 hrs indicated the following conditions: Surface wind 100º/08 kt, visibility 8,000 metres and cloud broken at 600 feet agl; temporarily throughout the period visibility could reduce to 4,000 metres and the broken cloud base could reduce to 400 feet agl; there was also a 40% chance of a temporary reduction between 1800 and 2200 hrs of 400 metres visibility in fog and a cloud base of less than 100 feet agl.

The actual weather at Stansted at 1550 hrs was as follows: Surface wind 100º/9 kt, visibility of 8,000 metres, cloud scattered at 700 feet agl and broken at 900 feet agl. At 1620 hrs, the surface wind was reported as 100º/8 kt, the visibility was 8,000 metres, cloud was scattered at 800 feet agl and broken at 900 feet agl. The QNH was steady at 1027 Mb.

ATC information

Examination of the ATC radio recordings show that all appropriate clearances were correctly acknowledged and there was no indication of any confusion between the controllers and crew.

The 'Tower' controller at Stansted had both landing and departing aircraft on frequency. On initial check-in by the crew of N523MC, she recalled that she looked at the aircraft label on her radar display and noted the displayed altitude as not being unusual; thereafter, she could not recall looking at the altitude information. As a 'Tower' controller, her priorities were visually to monitor the movement of departing and landing aircraft. She obtained visual contact with N523MC at about 3 nm from touchdown.

Stansted Tower, in common with other UK major airports is equipped with an Approach Monitoring Aid (AMA). This system monitors the lateral position of aircraft on approach relative to the runway centre-line and activates audible and visual alarms if the aircraft goes outside certain parameters within a range of 4 nm from touchdown. The system does not monitor vertical deviation.

Controllers at Essex Radar have an instruction within the Manual of Air Traffic Services (MATS) Part 2 to monitor the altitude of aircraft on approach to Stansted Airport after they have been transferred to 'Tower'. The controller omitted to do so in the incident involving N523MC; at the time, he assessed his work load as low to medium.

The crew of N523MC were using current Jeppesen approach charts. The relevant approach chart for Runway 05 shows the Final Approach Fix at 6.6 DME, based on the ILS, at an altitude of 2,500 feet amsl; the runway elevation is 324 feet. Enquiries with Stansted controllers indicate that it is not unusual for aircraft to be vectored towards the ILS at 2,000 feet amsl.

Recorded information

Due to the late notification of the incident, both the Cockpit Voice Recorder (CVR) and the Flight Data Recorder (FDR) had overrun and so no relevant information was available.

The radar recording, based on Stansted Radar was evaluated by the AAIB. This indicated that the descent from 3,000 feet amsl was at an average descent angle of 5.4º. The rate of descent was fairly constant at 1,570 feet per minute until the level off at approximately 900 feet amsl; Stansted Airfield elevation is 348 feet amsl. Figure 1 shows the recorded descent path of the aircraft relative to the normal glideslope together with the range from touchdown and the ground elevation.

Ground Proximity Warning System (GPWS) evaluation

The aircraft was equipped with a Honeywell Mk VII GPWS. The crew reported that the GPWS had not activated during the incident. The crew actions effectively pre-empted any GPWS warning. An evaluation by the AAIB indicated that, if the crew had not taken remedial action, the first warning (Mode 4 alert: "Too Low Gear") by the GPWS would have activated within a further 6 to 10 seconds.

Crew information

When the operating company initially became aware of the incident, the commander was immediately recalled to the USA. The other two crew members continued one further sector under the command of a company check pilot but, once the serious nature of the incident was realised, they were also recalled to the USA. All three crew members were individually interviewed on 20 December 2004. The interviews revealed the following information:

1. Both the commander and flight engineer had been off-duty for six and five days respectively before positioning to Chicago on 11 December, arriving at 1611 hrs. The co-pilot had been on simulator duties on 10 December and positioned to Chicago on 11 December, arriving there at 1859 hrs. On 12 December 2004, the crew were woken at 0330 hrs (2130 hrs local) for an on-duty time of 0430 hrs based on a planned departure of 0600 hrs.

2. Pre-flight checks were normal including a successful check of the GPWS and its associated radar altimeter.

3. An aircraft requirement for a Category II autoland evaluation was due shortly and the commander decided to carry one out at Stansted. The crew agreed that some briefing was completed but that individual crew duties were not reviewed. The radar altimeters were 'bugged' at 107 feet. ATC were not informed of the intention to complete an autoland.

4. The flight engineer was facing forward during the approach and the ILS was correctly identified.

5. The crew could not all positively recall that the aircraft was cleared to 2,000 feet during the final turn. The commander stated that he had selected 500 feet per minute vertical speed for this descent and had selected the cleared altitude on the Mode Control Panel (MCP).

6. The commander thought that the standard company calls had been made regarding the localiser interception and altitude checks. The co-pilot had no recollection of any altitude calls being made and the flight engineer could not be certain either way. The crew considered that the localiser capture was smooth.

7. The commander and co-pilot confirmed that both autopilots were engaged and that 'LAND' was selected. No-one recalled hearing any altitude alert sound after the descent from 3,000 feet.

8. All three crew members recalled seeing warning flags on the co-pilot's instruments when the aircraft was established on the localiser and between 3,000 and 2,500 feet. During the crew interviews, there were some differences in recollection as to which flags were in view.

9. All three crew members confirmed that they were all involved in troubleshooting the problem.

10. The commander stated that he disconnected both auto-pilots, added power and levelled off immediately he became visual with the ground at about 900 feet altitude.

11. The aircraft was configured with Flap 20, but with gear still retracted, at localiser capture and the configuration was unchanged at the time the commander levelled the aircraft below cloud.

12. When level, the commander was visual with the runway PAPIs and felt comfortable continuing with the approach. He was also reluctant to re-enter cloud because of the flag indications. All crew members considered that they subsequently remained visual with the runway although the aircraft may have climbed slightly.

13. At about 3 nm range, the ILS glideslope was captured and the 'G/S' and 'LOC' flags on the co-pilot's instruments retracted at about 800 feet altitude.

14. The gear was selected down and landing checks completed at between 3 and 5 nm range from touchdown.

15. The subsequent landing was uneventful.

16. During the last 10 minutes of flight, all crew members considered that the atmosphere on the flight deck was normal although the commander considered that he was tired.

17. The commander completed the Technical Log after landing and wrote that the autoland was unsuccessful and that the co-pilot's 'G/S' and 'LOC' flags were visible until 800 feet altitude.

Company information

The company operates 10 'classic' Boeing 747s (models earlier than the 747-400). Within this total, there are differences in equipment and therefore operating procedures; these differences are detailed in the company Flight Hand Book (FHB) 20.06.1. Because of this variety, it is a company requirement for the commander to brief the crew on the differences prior to the first of any series of flights. The crew could not recall completing this briefing before the flight from Chicago. However, one of the company simulators is based on the same standard as N523MC and all the crew members had completed their most recent simulator flights on that model. The crew was also required to operate in accordance with the company Flight Operations Manual (FOM). The following is a selection of relevant instructions and information from the FHB and FOM:

1. '*The priority is to fly the aircraft when an emergency or abnormal condition arises.*' Reference FHB 3.01.2.

2. '*A stabilised approach must be established before descending below 1,000 feet above the airport touchdown zone elevation (TDZE) during an instrument approach or*

a go-around is required. A stabilised approach is defined as being in an approved landing configuration, on the proper flight path, at approach speed with engines spooled-up.' Reference FOM 6.8.4 and FHB 2.19.3.

3. The standard call outs and commands are detailed in FHB 2.01.1 through to FHB 2.01.4.

4. *'For a Category II autoland, both ILS Glideslope and Localiser must be operating.'* Reference FHB 4.01.7.

5. *'Below 800 feet above TDZE, any failure requires an immediate go-around.'* Reference FHB 2.19.19.

6. On N523MC, the Altitude Mode switch will trip to 'OFF' as the glideslope is captured when in 'ILS' or 'Land' mode. Reference FHB 22.01.06.

7. Flight Crew Reports are required to be submitted if there has been a '*significant deviation from normal operating practice, whether caused by mechanical systems, weather or personnel'*. Reference FOM 2.2.3.

Company records indicate that no fault was identified with the aircraft systems and, following the incident a Category II autoland was successfully completed on 17 December 2004. Between the incident and the autoland, no rectification was carried out on N523MC.

The crew and aircraft were operating on behalf of a UK airline and the crew were therefore subject to the appropriate UK Flight Time Limitations which were stipulated in the company's FOM. With an on-duty time of 2230 hrs local, the crew were restricted to a maximum Flight Duty Period (FDP) of 10¼ hours. The commander had the authority to extend this FDP by up to 3 hours for a single sector duty. The total duty in the incident involving N523MC was just under 12 hours. The UK Flight Time Limitations are more stringent than those established by the FAA.

The three crew members had previously flown together. All three had complied with the company qualifications and recurrent training required by the FOM and the company 'Training Program Manual'.

Discussion

The crew were approaching the end of an uneventful flight in a serviceable aircraft. The flight had been subject to a three hour delay before departure, which resulted in the crew operating for longer than the normal maximum FDP. However, the extension was within the authority of the commander. Although the commander was tired, all the crew considered that they were operating normally.

As the handling pilot, the commander had decided that he would complete a practice Category II autoland. For an experienced crew, this would not be an unusual event and the approach was briefed, although not specifically covering individual duties. Additionally, the crew omitted to notify ATC that they would be carrying out an autoland. This omission had no effect on the incident as there were no aircraft or vehicles within the ILS protected area during the approach.

The initial approach was uneventful except that the final turn to intercept the localiser was late. This did not appear to be of concern to the crew and the controller's apology was readily accepted. During this final turn, the aircraft was cleared to descend from 3,000 to 2,000 feet and further with the ILS. During subsequent crew interviews, there appeared to be some confusion about the cleared altitude but, at the time the crew correctly acknowledged the clearance. At this point, the aircraft was configured with gear up and Flap 20 and the normal procedure would be for the handling pilot to select the cleared altitude and then 'ALT SEL' on the MCP. The commander recalled that he controlled the descent using vertical speed at 500 feet per minute. However, as indicated on Figure 1, the rate of descent was fairly constant at 1,570 feet per minute. Furthermore, there was no indication of any change in rate of descent as the aircraft approached its cleared altitude of 2,000 feet. This meant that the cleared altitude had either not been selected or had deselected early in the descent, possibly due to a technical unserviceability or at an apparent glideslope capture. After the incident, no faults were identified with the ground or aircraft systems. The lack of FDR and CVR information meant that this apparent anomaly could not be resolved. Nevertheless, the primary role of the crew was to monitor the aircraft manoeuvres to ensure that it remained on the required flight path. At about this time, the crew became aware of flags on the co-pilot's instruments indicating a failure to display the ILS. This appeared to be a trigger for all three crew members to start troubleshooting the problem. The result was that no-one was actively controlling or monitoring the aircraft. This was a clear breakdown in crew effectiveness. While the commander has overall responsibility for the safety of any flight, the other crew members also have a responsibility to ensure that safety is not compromised. Once the crew became distracted, the situation was reliant on safety back-up systems to recognise the potential danger.

It was the commander who first recognised the danger as the aircraft broke cloud at 900 feet altitude and he immediately resumed positive control of the aircraft. In addition to active crew monitoring, back-up systems, which may also have identified the potential danger, were aircraft systems (GPWS) and monitoring by ATC. ATC was evaluated to see what safeguards were in place. There was a requirement for the radar controller to monitor the altitude of the aircraft even after it had been transferred to 'Tower' and the controller omitted to carry out this task. Following the incident, London Control issued a Supplementary Instruction, SI 21/05 TC, which clarified the responsibilities of controllers with regard to radar monitoring of aircraft on ILS approaches. The 'Tower' controller had no specific requirement to monitor the altitude of aircraft on approach and her primary responsibilities were runway occupancy of both departing and landing aircraft

Following the recovery of the aircraft from the descent, the commander decided to continue his approach with the PAPIs in sight. In accordance with company regulations, the approach should have been discontinued since the aircraft was neither stabilised on approach nor configured for landing. The commander's decision was based on his visual acquisition of the PAPIs, and the unresolved instrument problem, which made him reluctant to climb back into cloud. The glideslope was captured at about three miles range and with normal landing configuration achieved, the commander made an uneventful landing.

Following such an incident, the crew had a clear duty to report it to their company. The commander decided not to do so but the other two crew members did report the incident but as individuals and in different ways. The result was that the reporting was late and the airport authority was not aware of the incident until it was brought to their attention by other means. The lack of reporting was another indication of a breakdown in crew effectiveness. The normal procedure should have been to discuss the incident as a crew and report the incident to the airport and to their company.

Subsequent company action

Following notification of the incident, the aircraft operator instituted a full investigation in collaboration with the FAA and NTSB. Full assistance was provided to the AAIB.

The company procedures were clear and comprehensive, both in cockpit duties and for incident reporting. The investigation concluded that there was a serious breakdown in crew procedures during N523MC's approach to Stansted. Accordingly, the crew members undertook subsequent training with a human factor specialist, before further ground and simulator training. At the completion of this training, each crew member was to be evaluated before any return to normal duties.

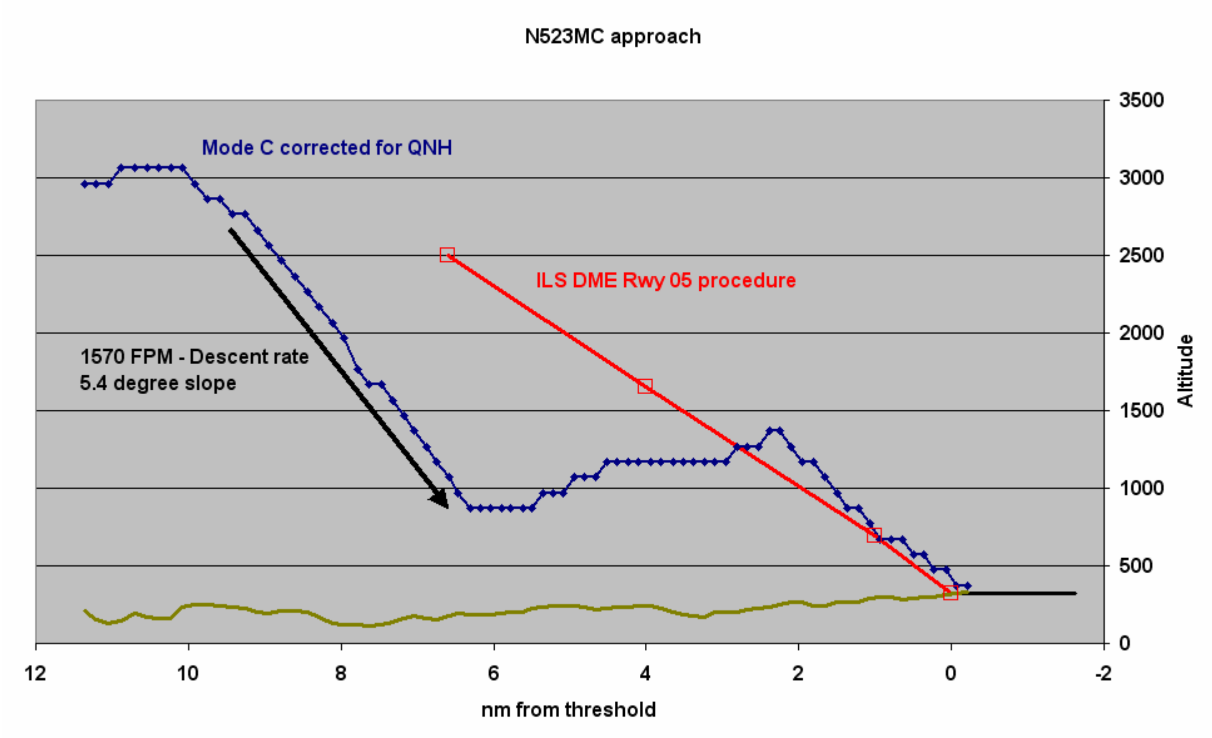

Figure 1 N523MC Approach and normal glideslope

INCIDENT

Aircraft Type and Registration:	Boeing 757-236, G-BPEE
No & Type of Engines:	2 Rolls-Royce RB211-535E4-37 turbofan engines
Year of Manufacture:	1991
Date & Time (UTC):	12, 16 and 23 November 2004
Location:	En-route, various sectors
Type of Flight:	Public Transport (Passenger)
Persons on Board:	Crew - Not known Passengers - Not known
Injuries:	Crew - 3 (Minor) Passengers - None
Nature of Damage:	None to aircraft
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	43 years
Commander's Flying Experience:	12,000 hours (of which 6,000 were on type) Last 90 days - 155 hours Last 28 days - 65 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot and subsequent enquiries by the AAIB

Synopsis

The aircraft experienced several incidents, on different flights, of fumes in the cockpit and cabin and in some cases this produced symptoms in the flight and cabin crew. Although evidence was found of leaking hydraulic fluid having migrated inside a bleed air supply duct, the various investigations failed to definitively establish if this was the source of the fumes.

History of flight

Incident of 12 November 2004

This was the aircraft's first flight following a major maintenance check. On the outbound sector of a return flight from London Heathrow to Nice, the flight crew detected fumes in the cockpit. Passengers in the forward cabin and cabin crew in the rear galley also reported smelling fumes.

After landing, the flight crew contacted the company's Flight Operations department for advice before deciding to operate the return sector to London Heathrow. After engine start, they smelt a "strong but short burst" of "contaminated air" in the cockpit when the left air-conditioning pack was selected on, but this quickly cleared. Once airborne, they experienced four or five further occasional "sharp bursts" of contaminated air in the cockpit, but as these also cleared quickly, they did not consider it necessary to don their oxygen masks. The problem appeared to be associated with the left air-conditioning pack, which tripped on and off line occasionally during the flight, the contaminated air seeming to coincide with the left air-conditioning pack coming back on line.

During the descent into London Heathrow, both flight crew members became aware of a stronger and more persistent smell in the cockpit. At this point the commander had considered going onto oxygen as he was feeling a little unwell and "a bit spacey", but did not do so. The Cabin Services Director was asked to visit the cockpit to provide an independent opinion on the fumes and confirmed the presence of the odours. Both flight crew members then donned oxygen masks before declaring a 'PAN' and carrying out the relevant Quick Reference Handbook (QRH) drills. The approach and landing were uneventful. The odours were confirmed by a fireman from the Airport Fire Service who attended the cockpit after landing. The captain reported feeling slightly unwell for three days after the flight, causing him to consult his doctor.

Incident of 16 November 2004

This was the aircraft's first flight since the incident of 12 November. When boarding the aircraft for a flight from London Heathrow to Stockholm Arlanda, the crew commented on a strong smell inside the cabin. The APU was not running at the time. On takeoff a "warm aromatic" smell was present in the cockpit. The QRH procedure for '*SMOKE OR FUMES AIR CONDITIONING*' was actioned after flap retraction, with the flight crew donning their oxygen masks. When the right air-conditioning pack was selected off, the air cleared, allowing the crew to remove their oxygen masks. Given that there were no reported symptoms amongst any of the crew or passengers, the flight was continued, although the possibility of a return to Heathrow was discussed.

In the early part of the cruise, odours were again detected in the cockpit, prompting the flight crew to don their oxygen masks again. The Cabin Services Director confirmed the smell and advised that it could be detected faintly throughout the cabin. The captain described the odour as being a "warm sweet smell, but slightly burnt". Suspecting that the source of the smell might be the left air-conditioning pack, this was turned off and the right-hand pack was switched back on. Within seven minutes, the smell had cleared from inside the cockpit and, with no symptoms amongst the crew, the flight was continued.

Approximately 80 minutes into the flight, the Purser at the Door 4 station reported that she and a colleague had sore throats. The Cabin Services Director investigated and reported that the air seemed to be irritant at the rear galley only. This was confirmed later by the captain who visited the area.

During the descent the co-pilot started to get a "buzzy head and body", although he did not report it at the time. At 3,000 feet in the descent, both flight crew members noted an "oily-sewage" smell and the co-pilot voiced his feeling of buzziness. At 2,000 feet, the captain felt "slightly spaced" and found it an effort to concentrate, although he reported his breathing was normal. The aircraft was configured for a triple-channel autopilot approach and a manual landing was completed without further incident.

After the flight, the flight and cabin crew visited a paramedic at Stockholm Airport with their symptoms being recorded as including headaches, a sore throat, coughing, nausea, burning sensation in the lungs, and a "slightly spaced" feeling. On the advice of the paramedic the crew saw a doctor, who gave them the 'all clear' to return to the UK. The aircraft was ferried back to London Heathrow on completion of troubleshooting at Stockholm.

Incident of 23 November 2004

A further occurrence of fumes in the air supply on this aircraft was reported on 23 November, whilst en-route from London Heathrow to Milan Malpensa. During the flight the flight crew were aware of an unusual background smell, which was confined to the cockpit. The smell came and went during the descent. No unusual smells were noted during climb and cruise on the return sector but the smell returned in the descent, this time more strongly. Selecting the left air-conditioning pack and bleed-air sources off caused the smell to dissipate. The smell returned when the left pack and bleed-air were selected on again for the approach. Cross-feeding the left pack from the right bleed supply during taxi-in did not cause the smell to dissipate.

Two further event of oil fumes were recorded, one on 9 December 2004, but no definitive cause was identified, the other on 16 January 2005.

Boeing 757 pneumatic and air conditioning systems

The cabin pressurisation, air conditioning and various other systems require pressurized air, which is sourced from the engines. Depending on the engine power setting, high pressure air is bled from either the second or the sixth stage of the High Pressure Compressor (HPC) of each engine, denoted HP2 or HP6, to supply the pneumatic system. The bleed air is cooled by precoolers and pressure-regulated prior to being fed to the various user systems.

There are two air conditioning packs, a left and a right unit. These are supplied with air from the pneumatic system and their function is to provide pressurised air for the cabin which has been cooled and conditioned for passenger comfort. The left pack receives pneumatic air supplied by the left engine and the right pack receives air from the right engine. The conditioned air from both packs is combined within a mix manifold, together with a certain amount of recirculated air from the cabin, before being supplied to the cabin. The cockpit receives its own dedicated supply of conditioned air which is tapped off the supply duct between the left air-conditioning pack and the mix manifold. The aircraft is normally operated with both air conditioning packs selected on although it is permissible to operate with either pack inoperative, subject to some operational restrictions.

Service experience shows that, mostly, on aircraft types fitted with turbine engines, because the conditioned air is sourced from the engine compressors, it is vulnerable to contamination from engine oil leaks that allow oil to enter the compressor air path.

Engine oil servicing

The AAIB is investigating an event of fumes in cockpit/cabin on another Boeing 757, G-CPER, from the same operator that occurred on 7 September 2003. During this investigation it was found that maintenance engineers were not servicing the engine oils consistently in accordance with the Aircraft Maintenance Manual (AMM) procedure. Failure to comply with the specified time limits for checking the oil level can result in an incorrect level indication on the oil tank sight glass. This is so as there is a tendency with time for oil in the tank to slowly drain down into the engine gearbox, causing the oil level on the sight glass to drop. If the oil level is not checked within the specified time period, there is a danger that too much oil may be added.

Overfilling the engine with oil can cause the oil separator in the vent system to become partially blocked with oil, causing an increase in the air pressure in the bearing chambers. Oil may then be forced out past the compressor seals, and centrifuged outwards in the compressor drum. If the leak is sufficiently large, an oil mist is released into the compressor air path. This may be ingested into the HP2 and HP6 bleed-air off-takes, resulting in oil fumes entering the cabin air supply.

Following the G-CPER incident, the operator amended their engine oil servicing procedures to ensure compliance with the AMM requirements and specific training was given to maintenance staff on the correct procedure for servicing the engine oils. There has been a significant reduction in the rate of reporting of air contamination events since these changes were implemented.

Engineering investigation

After the incident of 12 November, a standard troubleshooting procedure was carried out, involving checking various areas of the aircraft where oil might leak into the bleed air supply path and contaminate the air supply. The engine oil quantities were checked and found to be acceptable, with 17 and 18 litres in the left and right engines respectively. (The full graduation on the oil tank represents a quantity of 20 litres; however the operator fills to below this level to reduce the chances of overfilling.) The fan blades were inspected for oil that might indicate a leak from the front bearing housing, but none was found. The APU was inspected and, although the area was found to be oily, no leaks were found. Some evidence of hydraulic fluid seepage was found at the base of the rudder, but this was remote from the APU air intake and no leaks were found in any of the rudder hydraulic components. When engine ground runs were performed, no unusual smells were noted inside the aircraft. The left air-conditioning pack control valve was replaced to correct the problem of the left pack tripping off line.

During troubleshooting after the incident of 16 November, a slight odour was detected inside the aircraft when the left air-conditioning pack was supplied with bleed air from the right engine. The oil pump assembly from the right engine was replaced as a precaution, as poor oil scavenging due to a faulty pump is a potential cause of oil contamination of the air supply. Examination of the APU and engines, including boroscope inspections of the engine compressors did not reveal any oil leaks, although chemical analysis of swabs taken from the right-hand engine compressor identified traces of Mobil Jet II engine oil.

During this examination, evidence of burnt hydraulic fluid was found on the exterior of a bleed air duct (Part Number 312N5306-1) on the left engine. This duct supplies HP2 compressor bleed air to the pneumatic system, which provides air for the cabin air supply system. A leak was found in a hydraulic pipe in the thrust reverser retract line (Item 205 in 757 Illustrated Parts Catalogue Chapter 78-31-01-01), which is located above the HP2 duct. Chemical analysis of swabs taken from the inside of the HP2 duct suggested that hydraulic fluid had migrated inside the duct. According to the aircraft manufacturer, the most likely leak path would have been through the carbon seals in the spherical flex joint in the duct. The duct is pressurised with air when the engine is running. The thrust reverser hydraulic pipes in the pylon area are located within tubes or shrouds, which provide cooling air for the hydraulic pipes and are also designed to allow any leaking fluid to drain out of the pylon area safely. The removed hydraulic pipe and shroud were not available for examination and so their condition could not be determined.

A flight test was completed with no reports of fumes and the aircraft was released for service.

Following the incident of 23 November, the engine oil levels, when checked within 20 minutes of engine shutdown, were noted to be 17 and 18 litres in the left and right engines respectively. Chemical analysis of swabs taken from the compressors on both engines revealed traces of Mobil Jet II engine oil in one of the swabs from the left engine. Traces of Skydrol LD4 hydraulic fluid were found in both engines. The left engine, serial number 31207, was removed for strip examination at Rolls-Royce Derby. It had completed 7,237 hours and 5,473 cycles since the previous shop visit. During this examination, no evidence was found of any leaks that might have allowed oil to enter the bleed air system.

Discussion

There have been numerous other reports of oil smells in the cockpit and/or cabin of the Boeing 757 and some of these events have been the result of genuine oil leaks from the engine or APU compressor oil seals. In other cases, no definitive source of the fumes could be identified. However, service experience shows that overfilling the engines with oil can produce fumes in the aircraft interior. Since the G-CPER incident, the operator has taken extensive measures to ensure that the engine oil is serviced correctly and, in the particular case of G-BPEE, no evidence was found to suggest that the engines had been over-serviced.

It was possible that the fumes may have been caused by contamination of the HP2 bleed air duct by hydraulic fluid from a leak in a thrust reverser hydraulic pipe, as evidenced by the presence of burnt hydraulic fluid on the outside of the duct and the analysis of the swabs from its interior. However, given that the thrust reverser hydraulic pipes are enclosed in tubes or shrouds designed to contain any leak and allow fluid to drain away safely, and that the HP2 duct is pressurised with bleed air when the engine is running, the amount of hydraulic fluid that could have found its way inside the duct would probably have been small. What is not known, however, is how much hydraulic fluid would be required to leak into the duct to produce fumes inside the aircraft.

Hydraulic fluid has a characteristic sharp, acrid, chemical smell, but different crews described the contamination as "warm aromatic", "warm sweet….. but slightly burnt" or like "oily-sewage". This seems inconsistent with the characteristics of hydraulic fluid. Although the hydraulic leak cannot be ruled as insignificant, there remains doubt as to whether it was the source of the fumes.

The problem of fumes in the cabin is not new and is currently the subject of much industry discussion. AAIB Formal Report 1/2004 presents the findings of an extensive investigation into the problem of contamination of cockpit/cabin air supply by engine oil fumes and includes the results of studies into the physiological effects of such fumes. In December 2000, The UK CAA issued Flight Operations Department Communication (FODCOM), number 17/2000, providing valuable safety advice on the use of flight crew oxygen masks in the event of smoke or fumes entering the cockpit. Further updated safety advice was provided in FODCOM's 14/2001 and 21/2002.

INCIDENT

Aircraft Type and Registration:	Boeing 767-200, EI-DBW
No & Type of Engines:	2 General Electric CF6-80C2 turbofan engines
Year of Manufacture:	1987
Date & Time (UTC):	12 April 2005 at 1015 hrs
Location:	London Gatwick Airport, West Sussex
Type of Flight:	Public Transport (Passenger)
Persons on Board:	Crew - 10 Passengers - 224
Injuries:	Crew - None Passengers - None
Nature of Damage:	Left wing leading edge and motorised passenger steps damaged
Commander's Licence:	Air Transport Pilot's Licence
Commander's Age:	53 years
Commander's Flying Experience:	15,850 hours (of which 2,200 were on type) Last 90 days - 65 hours Last 28 days - 60 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot

The aircraft had recently arrived at Gatwick, following an uneventful scheduled flight from Moscow, and it was assigned to Stand 32M. Stand 32 at Gatwick's South Terminal consists of three possible parking positions 32 left (32L), 32 (32M) and 32 right (32R). In preparation for the arrival of the aircraft, a set of motorised passenger steps had been positioned in the inter stand clearway to the left of Stand 32, leaving enough clearance for the aircraft to taxi onto Stand 32M. The driver of the motorised steps also noticed that the parking aids were set for the aircraft to taxi onto, and park on, Stand 32M.

When the aircraft arrived, it was observed, by the ground staff, to turn onto Stand 32L, instead of Stand 32M. Upon seeing the aircraft turn onto Stand 32L, a member of the ground support staff then switched the stand parking aids from Stand 32M to Stand 32L, thinking they had been initially set incorrectly.

With the aircraft now approaching Stand 32L, the aircraft's left wing was overhanging the inter stand clearway on which the motorised steps were parked. The driver of the steps realised that the aircraft was approaching the wrong stand; he moved away from the steps and attempted to try to attract the pilot's attention, without success. The pilot continued to park on the stand, guided by the parking aids now set on 32L. The leading edge of the left wing then came in contact with the handrail of the motorised passenger steps.

Each parking stand has a stop button which allows ground staff to immediately indicate to the flight crew of the parking aircraft to stop. At no point during the incident was the stop button utilised.

Since this incident the ground handling agent has issued a notice to its entire staff about the use of the stop button.

INCIDENT

Aircraft Type and Registration:	Jetstream 3202, G-BYRA	
No & Type of Engines:	2 Garrett TPE331 turboprop engines	
Year of Manufacture:	1989	
Date & Time (UTC):	10 January 2004 at 1930 hrs	
Location:	Near Farnborough, Hampshire	
Type of Flight:	Public Transport (Passenger)	
Persons on Board:	Crew - 3	Passengers - 17
Injuries:	Crew - None	Passengers - N/A
Nature of Damage:	Mechanical failure of the right engine propeller reduction gearbox	
Commander's Licence:	Airline Transport Pilot's Licence	
Commander's Age:	64 years	
Commander's Flying Experience:	30,000 hours (of which 2,000 were on type) Last 90 days - 97 hours Last 28 days - 50 hours	
Information Source:	AAIB Field Investigation	

Synopsis

The incident occurred during a charter flight from Southampton Airport to Manchester Airport. The aircraft was passing FL120 in the climb when there was a loud bang from the area of the right engine. High levels of vibration did not permit reading of the engine instruments and control of the aircraft was difficult due to unexpectedly strong tendencies to yaw and roll. The right engine was identified as not producing power and an emergency checklist shutdown carried out. After the right propeller feathered a single-engine diversion to Farnborough was safely accomplished.

History of the flight

The aircraft was carrying out a charter flight to take a private party of 17 passengers from Manchester Airport to Southampton Airport. The party was then to return to Manchester that evening on the same aircraft.

In order to undertake the charter the aircraft was positioned that morning from Leeds Bradford Airport by a flight crew of two pilots. The aircraft was not fitted with an autopilot (AP) but it had a serviceable yaw damper; the only unserviceable item was the left engine Single Red Line Computer (SRLC). The company procedure was for the co-pilot to carry out the pre-flight inspection whilst the aircraft commander completed the internal cabin and cockpit checks.

Having completed their preparations, the aircraft departed Leeds Bradford and, following an uneventful flight, arrived at Manchester. The flight crew met the cabin attendant who was to accompany them for the next two sectors on which the passengers were to be carried and, following a briefing, crew and passengers boarded the aircraft. Departure from Manchester was normal and an uneventful transit to Southampton was made at FL170 in good weather arriving at 1241 hrs.

Whilst the passengers attended their function, the crew rested at the airport. Prior to the scheduled departure time of 1845 hrs, they prepared the aircraft for the return flight to Manchester. The crew adopted the same procedure as before with the co-pilot carrying out the pre-flight inspection, which included checking the engine oil levels. The passengers were delayed arriving at the aircraft but as soon as they were boarded, the aircraft's engines were started. Both engines started normally and the aircraft was taxied for Runway 20. With the cabin secure and all checks completed, the aircraft departed Southampton at 1905 hrs.

The takeoff was carried out with the commander as the pilot flying (PF) and the co-pilot as the pilot non-flying (PNF). The PNF set the propeller RPM levers to 100% and the PF then set the engine torque to 100% on both engines. The right engine achieved 100% slightly before the left but both were matched at 100% torque. The aircraft accelerated normally with the PNF calling the airspeeds in accordance with normal company procedures. The commander followed the Standard Instrument Departure (SID) which required a climb to 2,000 feet with a right turn onto a track of 360º climbing to 4,000 feet. Landing gear and flaps were retracted and power and propeller RPM set for the climb. During the climb the aircraft passed through a layer of stratus cloud but no airframe icing was encountered; the engine anti icing system had been selected on prior to departure. The behaviour of the aircraft, including the rate of climb, all appeared normal. Radar control of the aircraft was passed from Solent Radar to the London Terminal Control Centre (LTCC) and the aircraft cleared to the requested cruising level of FL160 as they proceeded under their own navigation direct to NORRY (a virtual waypoint near Pangbourne) In the darkness, there was no clearly defined horizon or external references such as ground illumination or stars, and so the aircraft was being flown by sole reference to the flight instruments.

Immediately before the incident, the PF had both his hands on the control column and his feet on the floor. As the aircraft passed FL120, there was a loud bang from the area of the right engine.

Simultaneously, the red Central Annunciator Panel (CAP) warning light illuminated and the aircraft decelerated, yawing and rolling rapidly to the right. Some passengers saw a shower of sparks from the right engine, swept aft by the slipstream. The PF immediately placed both feet on the rudder pedals and attempted to oppose the yaw and roll to the right with large amounts of opposite rudder and aileron. The bang had been accompanied by a severe high frequency vibration which made reading the engine instruments very difficult, and confirmation of the right engine problem was not possible at that stage. With the IAS decaying rapidly, and the aircraft still yawing and rolling, in order to maintain control the PF reduced both engine power levers to idle and lowered the aircraft's nose to ensure a safe airspeed was maintained. The PNF was instructed to transmit a MAYDAY distress on the operating frequency informing them of the situation and to ask for radar vectors to the nearest airfield; this was acknowledged by London Control, who passed a heading of 080° to vector the aircraft towards London Heathrow Airport.

With the aircraft under control, but with the vibration still present, the pilot advanced each power lever individually to identify the vibrating powerplant and shortly after the failure the right engine OIL caption, right generator failure and bus tie lights illuminated. Having positively identified the right engine as the failed engine, the PF had his diagnosis confirmed by the PNF. The PNF completed the memory items of the "ENGINE FAILURE OR IN FLIGHT SHUTDOWN" emergency drill with the PF confirming the correct selection of operating controls prior to them being moved. Having placed the right power lever to idle and the left propeller RPM lever to 100%, the PNF turned and pulled the right engine propeller feathering lever and heard the distinct sound of the propeller feathering. He then visually confirmed that the propeller had stopped, and that the engine fuel cocks for the right engine had closed. The PF considered that this activity led to a loss of some 2,000 feet altitude before the aircraft levelled off. The aircraft was re-trimmed for the asymmetric condition using rudder and aileron trim.

The secondary checklist items were commenced with the PF monitoring the PNF actions. LTCC offered Farnborough Airport as a closer diversion which was accepted with a request from the PF to be vectored for an 8 mile final approach.

The cabin attendant who had been serving a light meal at the time of the engine failure moved to the flight deck. She was aware of the high level of activity being undertaken by the two pilots, and was careful to choose an appropriate moment to talk to the PNF. She was asked to brief the passengers of their intended diversion to Farnborough and she informed the flight crew that there had been some misty vapour and a smell of burning at the forward part of the cabin. All the passengers had their seat belts fastened at the time of the incident and although understandably alarmed by the incident, they were calm. The cabin attendant informed the passengers of the situation and secured the cabin for landing.

The PNF tried to complete the emergency drills but had to respond to ATC messages and make a written note of the Farnborough weather. He then extracted the Farnborough Approach charts from the Aerad book and set the ILS frequency and course bar for Runway 24 for both pilots. The approach minima were checked and the PF briefed for the approach. The PNF then completed the emergency checklist followed by the descent and approach checks. During this time the aircraft heading increased by some 90º, which, when noticed by the crew, was corrected although the PF was having difficulty in holding the heading. Air traffic control of the aircraft was transferred to Farnborough Approach, who requested which direction of turn the pilot would prefer. Left turns were requested, towards the live engine, which took the aircraft onto the ILS localiser. An accurate ILS approach was then flown, during which the landing gear and two stages of flap were lowered. The PF maintained a higher than normal approach speed at 150 kt, some 20 kt faster than the 130 kt required for the weight, and he first saw the runway lights at a height of about 400 feet. After touch down a lower than normal amount of reverse thrust was used on the live engine together with moderate wheel braking to bring the aircraft to a stop. The aircraft was then taxied to the allocated parking stand, attended by the airfield Rescue and Fire Fighting Service (RFFS), where the crew and passengers disembarked.

Weather

The synoptic situation at 1900 hrs showed a warm sector covering southern England with a light or moderate south-westerly flow over the initial part of the route from Southampton to Manchester. The surface weather was overcast with mist and some outbreaks of drizzle from extensive, low-altitude stratus cloud. The METAR's for Southampton and Farnborough airports covering the departure and landing were as follows:

Southampton: EGHI 101850Z 24007KT 5000 –RADZ SCT003 BKN004 11/09 Q1010=
Farnborough: EGLF 101920Z 22012KT 8000 DZ OVC005 11/11 Q1008=

Powerplant details

The engine involved was a Garrett TPE 331-12UHR-703H, built in 1989 as a model TPE331-12UAR-705H but modified and redesignated as a –12UHR-703H in July 1998. It was rated at 1,100 shaft horsepower (SHP) for takeoff, with a continuous rating of 1,050 SHP. The engine had been owned by the engine manufacturer from new, and had been used as a loan unit throughout its life.

At the time of the incident the engine had accumulated a total of 10,154 hours from new. It was installed on the right wing of G-BYRA on 25 November 2003, having accumulated 10,046 total hours. Previously, in December 2000, the engine had been removed from a sister aircraft of the operator's fleet and returned to the manufacturer's overhaul facility in Germany for inspection following a birdstrike. Between completion of the birdstrike inspection in January 2001 and its installation on G-BYRA in November 2003, it is understood to have remained in storage at the manufacturer's overhaul facility in Germany.

The engine's last overhaul was in April 2000, some 525 hours prior to the incident, at which time the reduction gearbox high-speed pinion, bull gear, and the sun gear forward bearing were replaced with new components. The engine logbook contained no entries of significance to the investigation. The records showed that the engine had been subject to spectrographic oil sample analyses (SOAP checks) at the intervals specified by the manufacturer to provide warning of impending gear failures. The SOAP trends showed no anomalies.

The engine was driving a Dowty Rotol variable pitch propeller.

Examination of right powerplant in situ

Oil was visible externally on the upper surface of the wing in the vicinity of the engine, and ground staff at Farnborough reported that oil could be seen dripping from the engine cowlings immediately after the aircraft had landed.

The propeller blades were fully feathered, but the propeller itself could not be turned beyond a very small amount, comparable to the backlash which would normally be expected in the splined coupling and second-stage reduction gears. It was apparent that the gearbox was effectively locked by some form of internal obstruction.

The engine cowls were intact but a large number of the cowl fasteners had loosened off, or were missing. Removal of the cowlings revealed widespread damage to ancillary components mounted on the engine, consistent with exposure to severe vibration. A detailed description of this damage is at Appendix A.

The engine/gearbox and propeller were removed from the wing in preparation for detailed strip examination, with no further damage being noted. In particular, the rubber engine mount blocks exhibited no signs of damage.

In summary, examination of the powerplant in situ suggested that a major failure of the input stage to the reduction gearbox had occurred, resulting in a severe vibration which lasted for a period sufficient to cause widespread secondary damage including disruption of fuel, oil, and electrical systems.

Engine and gearbox configuration

The Honeywell (Garrett) TPE 331 series powerplants comprise a range of single-shaft turbine engines which drive the propeller via an integral reduction gearbox, the casing of which also incorporates the engine intake duct. The gas generator comprises a two stage centrifugal compressor supplying air to a reverse (forward) flow annular combustor, which surrounds the three-stage axial turbine section. The combustion gasses are turned back through 180º at the inlet to the turbine section, and after passing through the turbine, discharge rearward into a conventional exhaust duct. The engine can be installed either erect (with the intake below the engine axis) or inverted (intake above). On the Jetstream, the engine is mounted inverted.

The –12 engine, as installed on G-BYRA, was introduced in 1988 as a development of the –11, providing an increased power margin for hot and high conditions. Although there are significant variations in the detailed design of components across the full range of the TPE 331 format, the –11 and 12 variants are, for all practical purposes, identical.

Figure 1 is a cut-away view of the TPE 331 series engine and gearbox of the type installed in G-BYRA. The 41,750 RPM rotational speed of the gas generator is reduced to 1,591 RPM at the propeller in two stages. The first stage reduction is achieved via a simple pair of straight-cut gears, comprising a high-speed (input) pinion mounted on the engine shaft driving a large bull gear. The second (epicyclic) stage reduction comprises a sun gear, formed integrally with the forward face of the bull gear, driving a set of planet gears which in turn drive the propeller shaft directly via a splined coupling to the planet gear carrier.

Figure 2 shows a schematic sectional view through the reduction gearbox. The input pinion (coloured dark blue) and bull gear (coloured red) are supported within a split aluminium housing within the gear casing known as the diaphragm; the two halves are manufactured as a matched set. The epicyclic second stage occupies the front half of the gear case cavity, formed by the nose casing. The ring gear of the epicyclic stage is anchored to the forward face of the diaphragm.

Negative torque sensing

Because the power absorbed by a windmilling powerplant could potentially result in very high drag being developed, and attendant aircraft control problems, a negative torque sensing (NTS) system is provided which automatically adjusts the propeller pitch to minimise drag in the event of power loss. It should be noted that the NTS system is a drag reduction system not a drag elimination system; it cannot drive the propeller into the feathered position. Feathering per se is achieved solely under the control of the pilot, by pulling the feathering handle to manually open the feathering valve. Until the propeller is feathered and as long as the propeller rotates, there will be some windmilling drag.

To accommodate the NTS system, the attachment of the epicyclic ring gear to the diaphragm incorporates a sloppy link, which permits a very small amount of rotational movement of the ring gear to occur in either direction, before coming up against a hard stop and reacting any torque being developed by the gear. The slight movement of the ring gear (within the sloppy link regime) arising from a negative torque condition moves a linkage which causes the NTS dump valve to close, creating an accompanying rise in NTS oil pressure. The increasing NTS pressure acts on an internal portion of the feather valve, opening a bleed path in the oil circuit to the propeller dome, and coarsening off the blade pitch toward the feather position. When a stage is reached where the propeller is no longer back-driving the engine and a positive torque is sensed by the torque sensing system, the change in torque produces an opposite movement of the ring gear within the sloppy link regime, causing the bleed path to close and allowing oil back into the propeller to reduce blade pitch. Thereafter, whilst the engine remains unable to drive the propeller normally, the torque tends to cycle between positive and negative as the NTS system endeavours to maintain the propeller in a minimum drag condition.

Detailed examination of the engine

Bulk teardown inspection

The engine was strip examined under the direction of the AAIB investigator at the manufacturer's plant in the USA.

Preliminary external inspection revealed evidence of additional external damage, over and above that detailed at Appendix A, consistent with heavy vibration comprising:

1. Deformation of the bearing plate on the accessory case which supports the hydraulic pump take-off shaft.
2. Partial loosening of the feathering valve housing at its attachment to the engine case.

Removal of the nose casing, with the propeller shaft in-situ, revealed that the epicyclic reduction stage was intact. The sun, planet, and ring gears displayed no overt signs of significant damage or deterioration, and the mechanism which provided the mechanical signal to the NTS system was undamaged. The crushed remains of a threaded bolt shank were found inside the nose casing together with a quantity of metallic shards, and numerous internal casing screws were also loose or missing.

When the diaphragm plate was split from the rear section of the gear case, it was evident that a major failure of the first stage gears had occurred, see Figure 3. The debris thus exposed included: broken pieces of gear tooth; crushed remains of various bolts and studs; fragments of the subsidiary housing which enclosed the input gears; and a large quantity of general debris.

A large segment of the bull gear rim, comprising approximately one third of the gear's circumference, had separated and burst out through the side of the subsidiary housing and had become jammed hard up against the starter generator shaft, fracturing and crushing the hollow shaft, see Figure 4.

Although debris restricted movement of the remaining part of the bull gear, a small range of movement was possible: sufficient to show that it was able to turn freely in its bearings.

Amongst the debris which fell clear during disassembly of the diaphragm were:

- A third, much smaller, fragment of bull gear rim encompassing four gear teeth.
- A small segment of the bull gear web, from a region adjoining the juncture of the fractures associated with the large and small rim segments.
- Pieces of shattered subsidiary housing, from where the large bull gear segment had broken through.
- Numerous miscellaneous fragments comprising broken and/or crushed remains of components originating from the input stage gear casing.

The subsidiary housing was removed from the diaphragm, allowing removal of the remaining part of the bull gear and the input (high speed) pinion. The input pinion was intact but all of the teeth had been stripped, leaving just the remains of the tooth roots, see Figure 5. The drive shaft had sheared from the pinion at the reduced section, which effectively formed a weak point shear neck.

Gear fracture details

Close inspection of the fractured pieces of bull gear revealed clear indications of fatigue consistent with propagation from an origin region in the web at approximately 60% radius. Figure 6 shows the fractured bull gear, with the principal separated fragments held in position to illustrate the fracture paths and position of the origin region, from which two primary crack fronts propagated, labelled 'A' and 'B' respectively.

The shorter of the two primary cracks ('A' in Figure 6) propagated radially outwards for a short distance until it met the thicker section of the rim, where it turned and ran circumferentially for a short distance before reverting back to a radial direction and intercepting the free edge of the wheel at the root of a tooth. The much larger primary crack ('B') propagated radially inwards initially, in opposition to crack 'A', then turned briefly in a circumferential direction (also away from crack 'A') before turning back inward again to follow an oblique path towards the centre of the wheel. As it approached the blend radius marking the transition from the web into the hub, the crack was deflected again and thereafter it followed an oblique path back outwards towards the rim of the wheel, where it intercepted the free edge at the root of a tooth. During the course of its progress, numerous secondary cracks branched off crack 'B' to form a network of fractures in the adjoining web. The consequence of this multiplicity of cracks was the separation and detachment of:

1. The large rim segment comprising approximately ⅓ of the wheel circumference, with vestigial web attached.
2. The small rim segment comprising four teeth.
3. Numerous fragments of the inner web from within the region of secondary cracking, identified in Figure 6, of which four pieces in total were eventually recovered and positively identified. (Figure 6 shows only the largest of the recovered pieces.)

Significant heat discolouration was evident in the region of secondary cracking around the hub blend radius, consistent with large-scale cyclic deformations of the material in these areas at a late stage in the fracture process, prior to rim separation.

Tooth condition

The condition of the teeth on the main section of the fractured bull gear varied progressively from completely stripped at 'X' in Figure 7 (adjacent to the large segment) through to a substantially undamaged state at 'Y' (adjacent to the small separated rim segment). This pattern of damage, together with the completely stripped condition of the high-speed pinion, was consistent with the main segment of the fractured bull gear attempting to re-mesh with the high-speed pinion following separation of the rim segments.

Metallurgical examination of the failed gear wheel

The fractured bull gear was subjected to detailed metallurgical examination at the manufacturer's materials laboratory. This confirmed the provisional assessment of crack propagation made during the teardown, and established that the fracture origins were on the aft face of the web approximately 3.7 inches from the rotational axis.

The failure characteristics were broadly comparable to those seen previously by the manufacturer during post-failure investigations of fractured bull gears from TPE 331 –11 and –12 series engines, extending over many years.

History of gearbox failures on TPE 331 series reduction gears

The –12 series bull gear is reportedly the most highly loaded of any gear in the Honeywell series of propulsion engines, and the bull gear itself and/or its associated components have suffered a number of failures since the type's introduction into service in 1983. Some of these failures resulted in the ejection of uncontained debris, either from the gear case directly or via the air intake duct. Of the latter, a number resulted in ejected debris being struck by the propeller and forcibly projected against the fuselage side, in one instance resulting in penetration into the cabin. The manufacturer identified imperfect tooth contact as being a significant causal, or contributory, factor in a majority of these failures, giving rise to:

- Load pulses in the bull gear which excited a resonance mode leading ultimately to the initiation of a fatigue crack in the web of the bull gear, and consequent separation of segments of rim.
- Initiation of fatigue cracks in the roots of the teeth, which propagated into the rim and web of the bull gear, resulting in separation of rim segments.

Factors previously identified as contributing, or potentially contributing, to contact pattern degradation included:

- Changes to manufacturing methods, which had tended to produce an involute profile with inadequate tip and/or root relief, leading to increased tooth loading (on an already very highly loaded gear).
- Distortion, over time, of the housings in the diaphragm plate which supports the bull gear and high-speed pinion bearings, resulting in displacement of the centres of rotation of the support bearings by as much as 0.006" from their correct positions; giving rise to associated tooth misalignment and increased wear.
- Re-dressing of gear teeth profiles during overhaul.
- Installation of gears in unmatched sets.

Remedial measures taken to date

In an effort to address the problem of bull gear system failures, the manufacturer implemented a number of remedial measures, with variable success, which are summarised together with their outcomes below.

Service Bulletin TPE331-A72-2011

A design change to the bull gear was introduced in 1997 via Service Bulletin (SB) TPE331-A72-2011, which comprised:

1. The introduction of a Metco spray coating on the web adjacent to the rim, intended to increase the damping inherent in the gear itself thereby reducing the potential for damaging amplitudes to occur within the various flexural modes of the gear.

2. Shot peening of the tooth roots, to locally increase resistance to fatigue initiation in those areas.

Testing of this revised design showed that it potentially cured the resonance and related fatigue initiation problems within the bull gear, but the manner in which the revised gear was introduced into service threw up a range of new, but related, failures affecting the high-speed pinion. Specifically:

- Production of the revised bull gear included reworks of the original pattern gear (P/N 3102585). Re-working of the gear teeth, a consequence of which tended to be a further reduction in the amount of involute tip/root relief.
- Mixing of existing (used) high speed pinions with reworked/new-manufacture revised pattern bull gears occurred, with consequent deleterious implications for tooth contact pattern.

The outcome was that whilst the revised bull gear was successful in reducing the incidence of resonance-induced failures and rim separations specifically, the (unhardened) splines on the high speed torque shaft, which transmitted torque from the engine to the high speed pinion, started to wear. As a consequence of this wear, high cycle fatigue cracks initiated in the non working splines which in turn led ultimately to failures of the high speed torque shaft.

Compared with bull gears which had been reworked from the original pattern to incorporate the changed design, those gears manufactured as new components to the revised design (allocated P/N 3108197) appeared relatively immune to these problems.

The issue of diaphragm distortion, and attendant alignment problems, remained unaddressed.

Service Bulletin TPE331-A72-2062

SB TPE331-A72-2062 was introduced in 1999 removing the Metco coating, on the assumption that in-service failures would return to a pattern similar to that associated with the original design of bull gear. The shot peen element of the revised design was retained, however.

The situation did indeed revert partially to the original failure pattern: all of the previously identified initiating factors were present including gears with re-worked teeth; gears installed on a mix and match basis; and diaphragm distortion. Moreover, without the damping provided by the Metco coating, resonance-induced failures returned, including some rim separations. Mostly the failures affected re-worked gears, but some new gears also failed; these were all associated with heavily deformed diaphragms, which the manufacturer estimated caused potential increases of up to 40% in the dynamic loading of the gear teeth.

The shot peening of the teeth, which had been retained from Service Bulletin TPE331-A72-2011, appeared to be effective in reducing crack initiations in the tooth roots; instead, failures were tending to originate in the web.

Diaphragm inspection & matched-pair gears

Revised interim measures were introduced in 2001 pending a complete redesign of the bull gear. These measures comprised:

1. Inspection of the diaphragm bearing housing positions to detect and reject housings which had suffered displacement beyond acceptable limits.

2. Introduction of matched-pair gear sets, incorporating:

   - Shot-peened tooth roots.

   - Improved tip relief.

   - Reduction in life to 3,500 hours (previously on condition).

Introduction of SOAP checks at 100 hr intervals

Because sub-optimal tooth contact patterns had been established as a factor contributing to the failures, and such tooth contacts invariably result in abnormal tooth wear, the manufacturer considered that monitoring the rate of accumulation of tooth wear-product in the lubricating oil could provide prior warning of impending failure. Accordingly, a requirement was introduced for regular spectrographic analysis of oil samples taken when the oil filter was changed. The interval between filter changes (and hence SOAP checks) was specified at 200 hrs when the requirement was first introduced in 1999, later reduced to 100 hr intervals in October 2001.

Re-designed gear sets

A permanent solution to the problem was sought through a total re-design of the high-speed pinion and the bull gear. The revised gear sets, which incorporate a helical tooth form, thicker web, thicker rim, and improved cooling, was implemented by SB TPE331-A72-2114 in August 2004.

Recorded data

Data sources

The aircraft was fitted with a 30 minute Fairchild A100A Cockpit Voice Recorder (CVR) and a 25 hour, 5 parameter Honeywell UFDR Flight Data Recorder (FDR). The CVR had been left running after the incident so did not yield any useful information. The FDR recorded altitude, normal acceleration, indicated air speed, heading and the VHF transmission key.

Other sources of recorded information included radar data, weather data and ATC recordings from five ATC centres including Southampton and Farnborough.

The radar provided track data from a point shortly before the failure event until shortly before touch down. The altitudes recorded were consistent with the FDR record, and provided a common reference allowing UTC time stamping of the FDR record. The radar track was also found to correlate well with the FDR heading and speed parameters. The weather data correlated approximately with the difference between radar-recorded ground speed and FDR-recorded indicated airspeed.

The quality of ATC data varied by source with some of the 60 second stamped periods taking 64 seconds to replay. The ATC data was correlated with the radar and FDR data by matching the VHF transmission key FDR parameter with the ATC recorded transmissions.

Interpretation of the data

At 1910 hrs UTC the aircraft started climbing out of Southampton Airport in a southerly direction before turning onto a northerly heading and starting its climb towards FL70 in accordance with ATC directions. This climb profile was maintained in accordance with ATC instructions through various ATC hand overs.

At 1920 hrs the aircraft was at FL120 climbing for FL140 and still heading north when the normal acceleration trace 'spiked' down to 0.28g and became very noisy, accompanied by a heading change to the right. These events, which were consistent with the sudden loss of thrust which was caused by the No 2 engine gearbox failure, were accompanied by a reduction in altitude of approximately 130 feet, followed by a brief recovery; then a reducing altitude once more. Thereafter, the 'noise' in the normal acceleration parameter remained for approximately two minutes before abruptly disappearing. During that time the right hand turn continued accompanied by reducing altitude. The turn continued for approximately one minute after the 'noise' in the normal acceleration trace ceased; after that the flight path was consistent with ATC instructions to descend and divert to Farnborough. During the period between the failure event and the aircraft reverting to follow ATC instructions for the descent into Farnborough, the aircraft had turned through approximately 180º from its heading at the time of the event.

An audio analysis was undertaken of those parts of the ATC tapes containing transmissions from the aircraft, in order to check for anomalies before, during or after the vibration period. However, the analysis was hampered by the variable quality of the recordings and the fact that the aircraft signal would have undergone a number of processes before finally being recorded. The ATC tape captured a configuration alert when the aircraft lined up with the Farnborough runway centre line but nothing further of significance was found.

Analysis

The gearbox failure

In light of the extensive prior history of bull gear failures and the program of implemented and planned activity by the manufacturer to address the issue, the focus of the technical investigation was directed primarily towards:

1. Establishing whether this failure exhibited features which suggested that new and previously unidentified causal factors might have come into play.
2. Studying the implications of the gear failure so far as they affected aircraft handling, and in particular the crew's ability to retain full control of the aircraft and subsequently to execute a safe landing.

The widespread damage within the gearbox was such that it was not possible to determine in every detail the sequence of failure, but it was clear that most of the damage was secondary and that it had been sustained as a direct consequence of a fatigue failure of the bull gear, which resulted in the release of large segments of the gear rim into the gear housing and adjacent rotating components. Detailed visual and metallurgical examination of the failed bull gear showed that its mode of failure fell within the ambit of the modes identified in previously studied instances of bull gear failure. There was little doubt too that the underlying causal factors associated with these previous failures would have been applicable to G-BYRA, such as uneven tooth wear causing increased tooth loading and the excitation of resonance modes leading to fatigue failure from origins in the web of the gear. Whilst the full range of contributory factors in this case could not be identified, due to secondary damage, these would have been likely to fall within the range of factors identified previously, and summarised earlier in this report.

Whilst the failure of the bull gear undoubtedly fell within the known pattern of crack propagation and rim separation, the consequences of the failure in this case was not typical insofar as it set in train a sequence of events which compounded significantly the problems faced by the crew in their efforts to deal with the resulting emergency. The following technical analysis will therefore focus primarily on the implications of the failure for the continued safety of the flight.

Flight safety implications

Whilst in the case of G-BYRA no debris was ejected through the gear case or from the engine intake, and consequently there was no direct risk to the occupants arising from potential penetrations of the fuselage by debris, the engine was subjected to extreme levels of vibration as a consequence of the gear failure which, indirectly, did hazard the aircraft. Specifically:

1. The level of vibration was such as to fracture, or compromise the integrity of, both fuel and oil supply lines together with proximate electrical systems, creating a potential fire hazard.
2. Substantial numbers of stiff-nuts and studs on the gear case itself, and on associated components mounted on the forward end of the engine casing, were vibrated off or otherwise compromised in a manner which suggested that, had the vibration persisted and the damage accumulated, it could have threatened the structural integrity of the gear case; with an attendant potential for the nose housing, and propeller, to separate from the aircraft.
3. The heavy vibration associated with the failure rendered critical flight deck instruments unreadable, adding to the difficulties faced by the flight crew in retaining control of the aircraft.

It is clear, therefore, that the vibration which followed as a direct consequence of the bull gear failure was an important factor in terms of flight safety, and both its cause and its effects require further analysis to determine its significance in terms of the continued safety of the flight.

Source of the vibration

If the bull gear had continued to rotate post-failure, whether driven from the engine or back-driven from the propeller, then the resulting rotational imbalance would have generated a high-frequency forced vibration of the whole engine installation, capable potentially of causing both the observed secondary damage and the vibration of the instrument panel on the flight deck. No other potential source of the vibration could be identified but for such a condition to have occurred, it would have required the bull gear to remain clear of obstruction.

Based on a visual assessment alone, it was not possible to determine with confidence whether the separated rim segment, which had burst through the side of the subsidiary housing and become jammed against the starter generator connecting shaft, would have obstructed the remaining part of the bull gear and thus prevented its rotation in the post-failure period.

In order to resolve this issue a simple 3-D CAD model was constructed of the detached rim segment, together with the remains of the fractured gear and relevant parts of the adjacent gearbox casing. After setting up the model to match the observed position of the jammed rim segment, (see Figure 8), it was evident that the combination of its radial position, and tilted orientation relative to the surviving part of the gear, was such that it would not have interfered. Consequently, it would have been possible for post failure rotation of the bull gear to have taken place, and thus for it to have been the source of the severe vibration, provided the drive line from the engine, or alternatively from the propeller shaft, had remained intact following gear fracture.

Based on the distribution of secondary damage within the gearbox, it is very unlikely that the engine would have been capable of driving the fractured bull gear. The stripped condition of the high-speed pinion is consistent with its forced re-engagement with the disrupted rim of the bull gear in the instant following separation of the detached section of the rim. This process is likely to have been virtually instantaneous – due to the rapid acceleration of the gas generator shaft in the interval between the shaft becoming unloaded, as the pinion disengaged momentarily from the fractured bull gear, before attempting to re-engage again as it came into contact with the far side of the missing section of rim. Indeed, the distribution of tooth damage on the bull gear indicates that all of the pinion's teeth were effectively wiped off within about half a revolution of the bull gear, and there is little doubt that the pinion coupling sheared at some point during this sequence. From that stage onwards the engine would have been disconnected from the gearbox input and, assuming that the fuel delivery side of the system was still operable, it would have accelerated rapidly until constrained by the overspeed governor. Continued operation of the engine, however, would not have been possible because of collateral damage from the gear failure, which disrupted the drive to the fuel control unit thus rendering the gas producer inoperative. In summary, therefore, it is evident that any post-fracture rotation of the bull gear, and the attendant vibration, must have been the result of it being back-driven by the propeller.

The FDR data provides further evidence in support of the contention that the severe vibration was associated with continued rotation of the propeller. Examination of the normal acceleration trace showed the onset of an apparently high frequency vibration, manifesting as noise on the data trace, at a point when other recorded parameters showed changes consistent with the gear-failure event. Because of the poor frequency response of the recording system, the true frequency and amplitude of this vibration could not be established and so it was not possible to educe its source from the frequency content of the recorded signal. However, not only does the vibration begin coincident with the gear failure but it also ends approximately two minutes later at about the time, based on the crew's testimony, when the propeller was feathered. Assuming that the noise on the FDR signal is indeed a reflection of the very heavy level of high-frequency vibration evidenced by the engine damage and the crew's account of unreadable flight deck instruments, then it was undoubtedly significant. Also, it appears to correlate with the period between gear failure and the propeller eventually being feathered – suggesting strongly that the vibration was associated with a windmilling right propeller. Furthermore, the mere fact of its detection by the aircraft's normal 'g' transducer (which is mounted in the fuselage and not sensitive to high-frequency vibrations) implies that the level of vibration at its source, significantly remote from the transducer, must have been severe indeed.

Normally, the NTS system will modulate blade pitch to minimise the drag caused by a windmilling propeller, but in this case the effective disconnection of the bull gear from the input pinion would have compromised the system's ability to function as intended and as flight tested. The drive train to the propeller governor arguably remained intact during the period that the propeller apparently continued to rotate post gear failure, and during this period it potentially would have had the capability to modulate propeller pitch in an effort to hold the selected propeller RPM. However, the governor's oil supply would potentially have been compromised at an early stage, because of the early failure of the input pinion from which the engine oil lubricating pump is driven, and the attendant cessation of a pumped supply of oil to the oil gallery feeding the governor. Whilst the behaviour of both the NTS and propeller governing systems under these abnormal conditions cannot be predicted with any degree of confidence, it is evident from the FDR traces and from the crew testimony that sufficient propeller pitch was maintained to cause the propeller to back-drive the broken bull gear, causing the severe vibration reported by the crew. It is also possible that, until the feathering valve was operated manually by the crew and the propeller actually achieved a feathered state, the compromised propeller pitch control system may have caused abnormal blade-pitch variations to occur, with attendant yawing moments being imposed on the aircraft.

Summary of findings arising out of the technical investigation

The failure of the bull gear system occurred as a result of a fatigue failure initiating in the web of the bull gear, which propagated on two fronts leading ultimately to the separation of a large segment of outer web and rim comprising approximately one-third of the gear's circumference. In terms of both its overall characteristics and underlying causal factors, the failure fell within the ambit of previous failures which have been studied in detail by the manufacturer and addressed by a series of remedial measures, culminating in a total redesign of the bull gear and related components, implemented under SB TPE331-A72-2114 in August 2004.

Following the gearbox failure and associated disconnection of the engine input, the fractured bull gear was back-driven at speed by the windmilling propeller for approximately two minutes before the crew was able to identify the source of the problem and feather the No 2 propeller. During this period, the resulting rotational imbalance caused a severe vibration which resulted in extensive and potentially hazardous secondary damage to oil, fuel, and electrical components mounted on the engine, and to the gearbox casing. The vibration also: rendered the flight deck instruments unreadable, seriously compromising the crew's ability to identify which powerplant was affected and frustrated their efforts to deal with the emergency. Any oscillations in propeller pitch which may have occurred during this period, due to abnormal operation of the NTS and/or propeller governor systems, could have given rise to oscillatory yawing moments producing an associated dutch-roll like motion of the kind reported by the crew. This would not only have added to their control problems, but also made it more difficult for them to identify promptly which powerplant was malfunctioning.

Handling of the emergency

At the time of the gearbox failure, the aircraft was in the climb on a heading 360º, with the yaw damper engaged. The loss of power from the right engine would have caused the aircraft to yaw to the right with an associated roll to the right. The yaw damper will disengage when the rate of roll exceeds 7º sec or at bank angles greater than 45º; consequently it is not likely to have made any significant contribution to the crew's efforts to retain control of the aircraft.

Illumination of the oil pressure, generator fail and bus tie warning lights was indicative of the engine having stopped and not just run down to idle yet the pilot experienced great difficulty, not only in correcting the departures, but also in preventing himself from over-controlling as if the aircraft yaw to the right was not constant but varying as if power was fluctuating. For reasons discussed earlier in the technical analysis, the yawing and rolling oscillations are likely to have been caused by fluctuations in blade pitch on the right propeller associated with either the governor's attempts to control the RPM on the disconnected and windmilling propeller, or erratic intervention of the NTS system. This is not a condition which would normally accompany a loss of thrust engine failure and it would have presented significant handling difficulties, both directly and indirectly by masking the underlying problem, thus compromising the crew's ability to take appropriate corrective action.

With no external horizon, all flight was by sole reference to instruments, which were being shaken by the severe vibration. It was not possible to read the engine instruments and in order to try and stabilise the aircraft the pilot brought back to the idle position the two engine power levers. His plan was to accept a loss of altitude whilst maintaining a safe IAS in order to maintain control of the aircraft and give him and the PNF time to properly analyse the situation. However, whilst this was an entirely appropriate action in the circumstances, and one that would have reduced the steady-state component of the thrust asymmetry, it would not have eliminated any yawing oscillations associated with blade-pitch oscillations of the right propeller. As the instruments were still not readable, but being aware that some form of engine problem was present, the PF advanced each engine power lever in turn and, on finding a positive power increase on the left and none on the right, confirmed the right engine was malfunctioning. The shut down and feathering drills were then accomplished using the abnormal checklist, and once the right propeller was feathered the vibration ceased and the pilot was able to continue the flight using the left engine with the flight controls trimmed for the asymmetric condition. By the time that this process was complete and the crew were in a position to begin their recovery to Farnborough, some three minutes after the initial failure event, the aircraft had gently turned through 180º; this was probably due to a break-down in instrument scan, due to the concentration required to maintain wings level and to maintain the desired IAS attitude.

The increase in the approach speed of 20 kt was to ensure that in the event of a go-around and any re-emergence of handling difficulties, an increased safety margin above V_{MCA} was available. The increase still permitted a safe landing to be made in the landing distance available.

Conclusion

This serious incident was the result of a major failure of the propeller gearbox which led to the aircraft yawing and rolling to the right and left. The crew were unable easily to identify the nature of the problem but with some difficulty they maintained control of the aircraft. Through a process of elimination, the crew correctly identified the right powerplant as the source of the problem. When the engine was shut down and the propeller feathered, the aircraft's handling qualities were restored to normal single-engine flight.

Safety action

The technical analysis has shown that the gear failure on G-BYRA fitted a pattern of failure already identified by the manufacturer as a result of its investigations of previous gear failures. The factors contributing to the failure on G-BYRA also fell within the ambit of factors identified previously as having contributed to these earlier failures, which have themselves been the subject of a range of remedial measures already implemented by the engine manufacturer. The culmination of these actions by the engine manufacturer, comprising the introduction in August 2004 (via SB TPE331-A72-2114) of a completely redesigned bull gear assembly, renders moot any recommendations arising out of this investigation which might otherwise have been made.

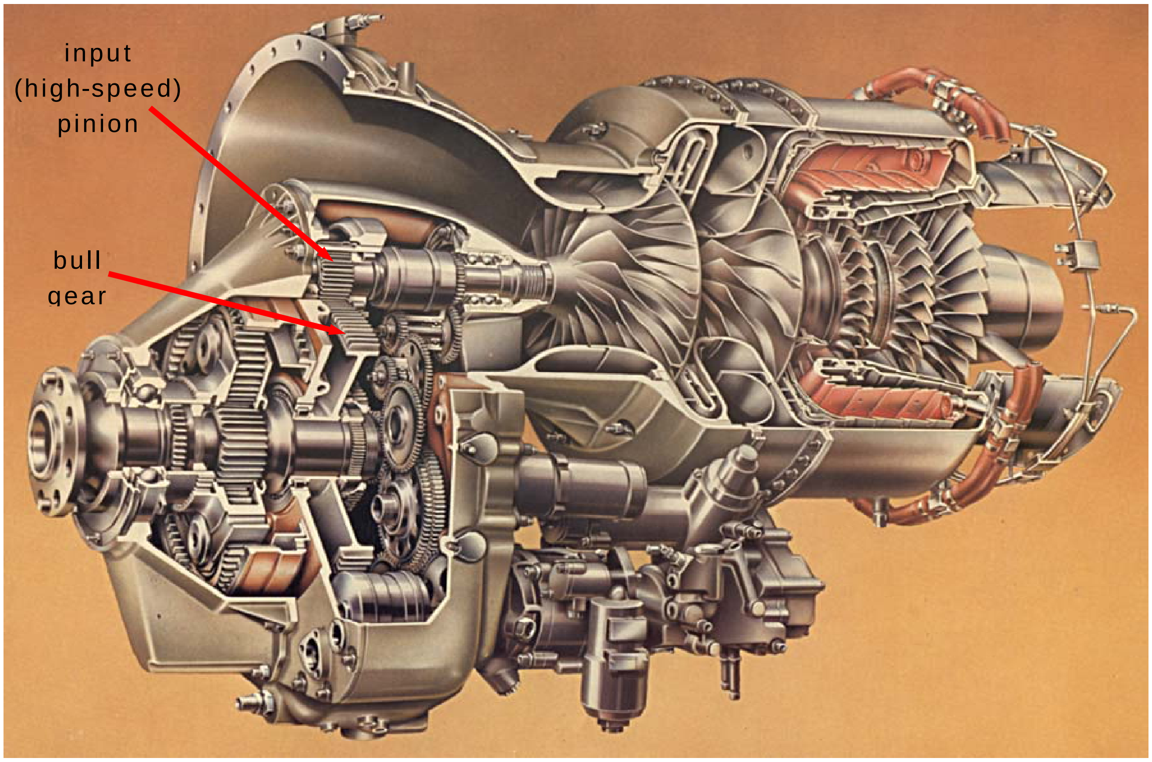

Figure 1:
Configuration of TPE 331 engine as installed on the Jetstream

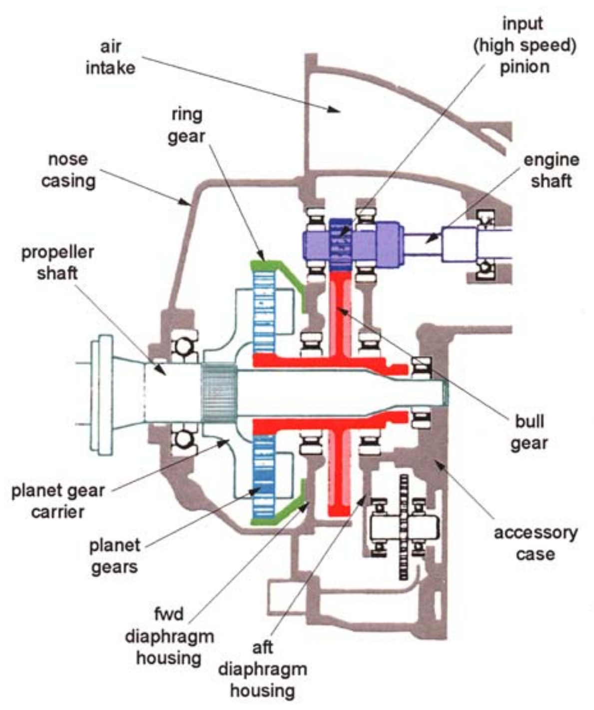

Figure 2:
Sectional view through gearbox (schematic)

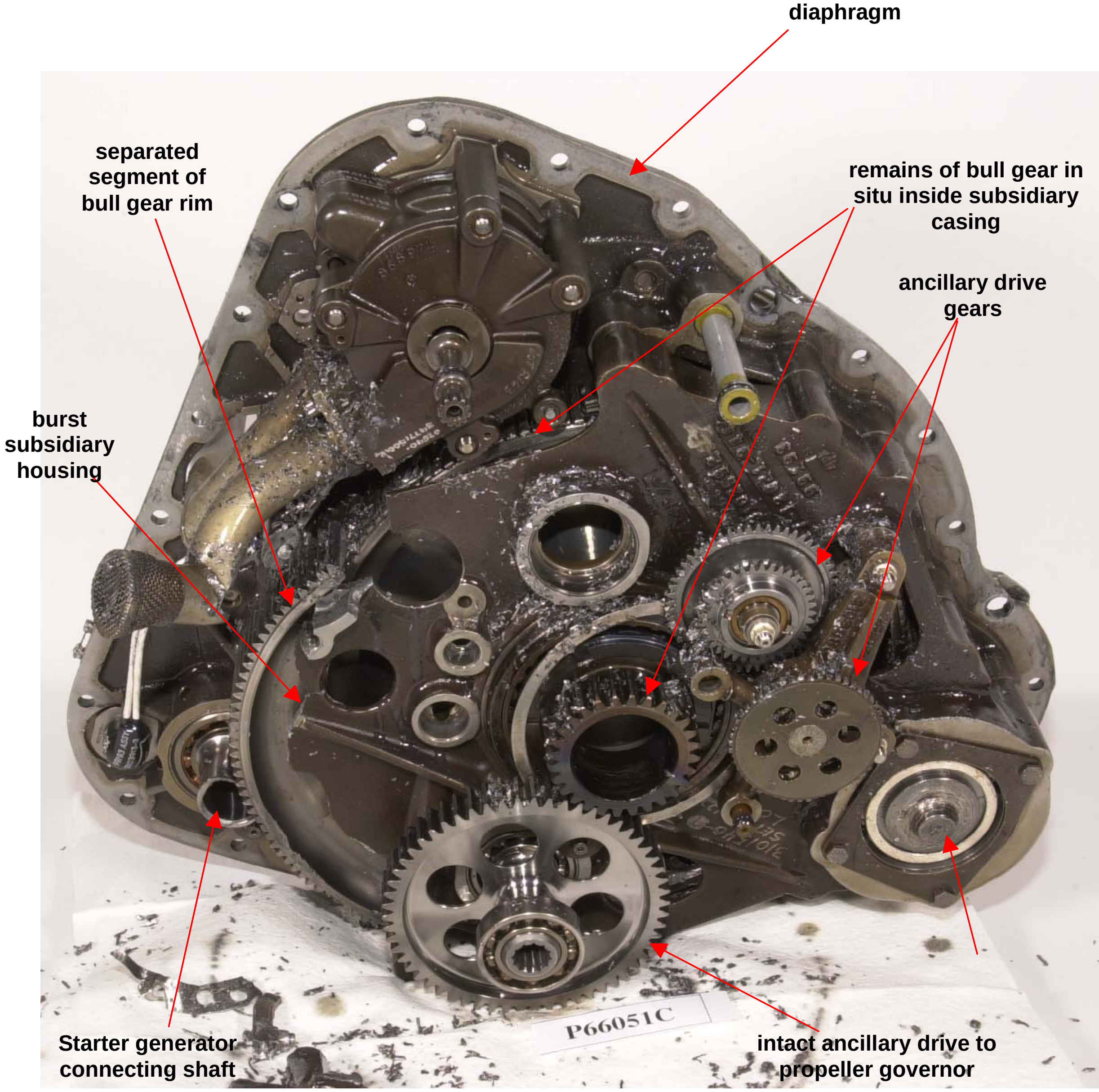

Figure 3:
View onto aft face of diaphragm, with damaged components in situ

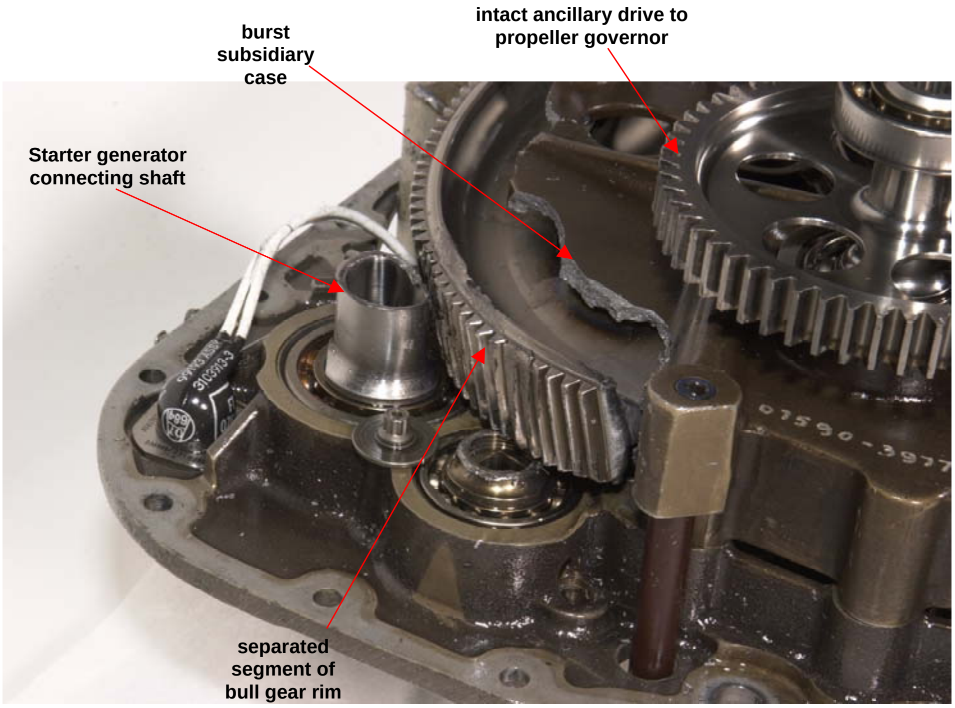

Figure 4:
Detail of separated segment of bull bear

Figure 5
Input (high speed) pinion, showing sheared drive neck

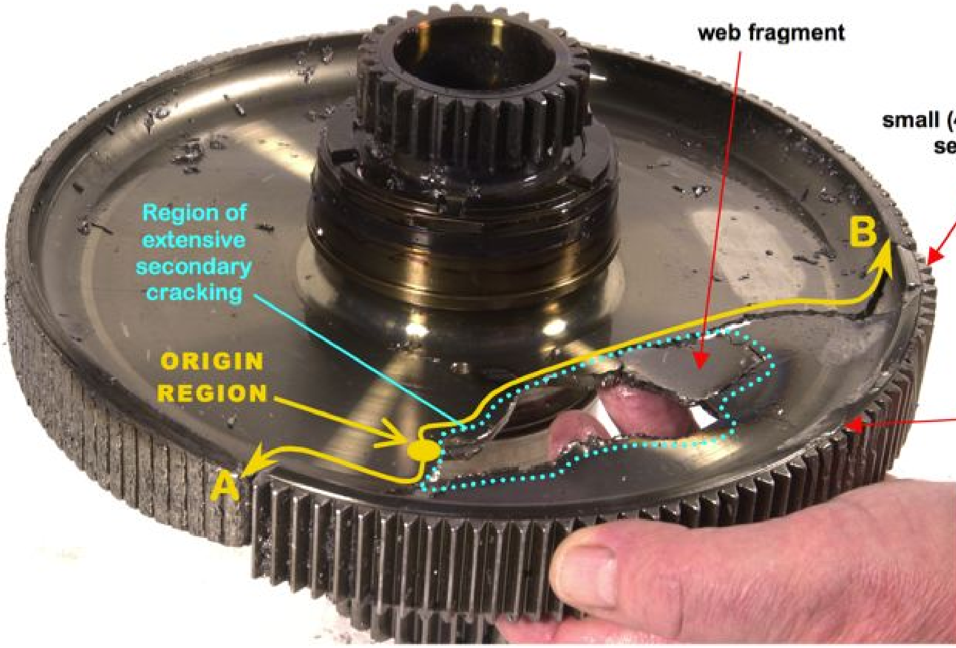

Figure 6
Fractured bull gear, showing principal fracture paths

Figure 7
Pattern of post-fracture tooth damage

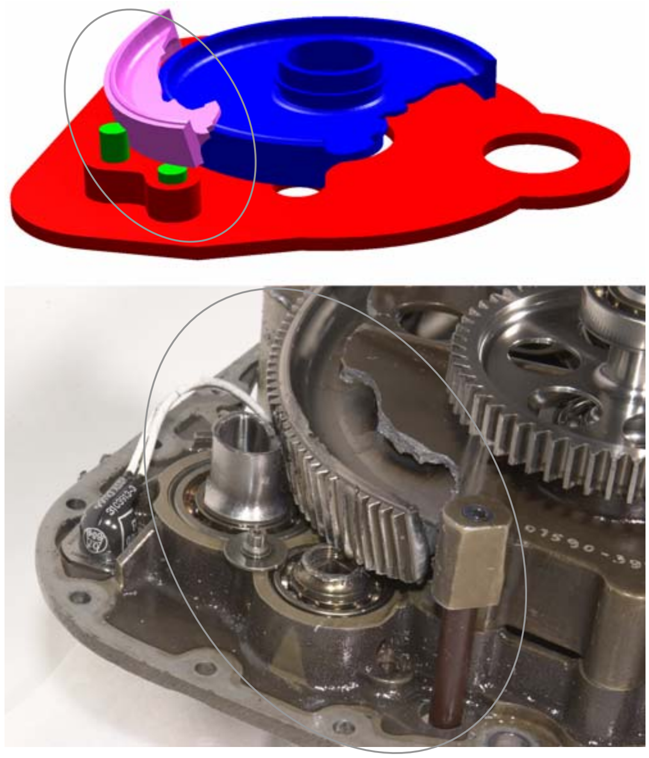

Figure 8:
CAD model showing relative positions of separated rim segment and remains of bull gear

DETAILED DESCRIPTION OF ENGINE DAMAGE

1. Fracture and break-up of the mounting brackets supporting the igniter control box, leaving the box loose and supported only its connecting cables.

2. Fracture of the air-bleed pipe supplying the intake de-icer, at a point adjacent to the off-take boss on the compressor case, together with cracking of the boss itself.

3. Loosening and separation of a 'B nut' securing a main lubrication pipe to a 'T' connector on the right side of the engine, just below the fractured air-bleed pipe.

4. Fracture of the main fuel feed pipe adjacent to its connection to the fuel flow transducer.

5. Loosening of the fuel flow transducer body in its mounting clamp, and partial migration of the unit out of the clamp.

6. Numerous loose and missing stiff-nuts, studs, and bolts securing the gearbox nose-cone to the diaphragm plate, and the diaphragm plate to the main gear case.

7. Several fractured studs and missing nuts on the fuel control housing, primarily at a flanged joint between the inner and outer ends of the housing immediately aft the unit's fixture to the accessories case, resulting in springing of the affected joint and partial expulsion of the associated O ring seal.

8. Deformation of the firewall ring-seal diaphragm at the jet pipe connection, consistent with violent oscillation of the entire powerplant on its rubber mounts.

9. Fracture of studs attaching the fuel-cooled oil cooler to the gearbox case.

10. Fracture of the shear neck coupling to the starter generator, and deformation of the associated transfer shaft bearing-retainer in the accessory case.

The engine oil tank was empty. Significant quantities of metallic shards were present in the oil filter housing, but its impending bypass tell-tale button was in its normal (flush) position.

There was no evidence of fire or elevated temperatures anywhere within the engine nacelle.

A visual inspection of the turbine via the jet pipe revealed that the pair of studs securing the turbine rear bearing cover had fractured, and the cover plate was missing. The turbine itself appeared to be intact but slight metal spatter was visible on the final-stage guide vanes. Manual rotation of the turbine was possible, and produced comparable rotation of the compressor confirming that the main shaft was intact between the compressor and the turbine sections; however, substantial roughness was apparent in the bearings. Examination of the compressor face, via the inlet duct, showed that the first stage impeller was intact but there was evidence of severe tip rubbing which, together with the roughness of rotation, was indicative of front bearing failure. With the exception of the missing rear bearing cover, there was no evidence of separation or non-containment of the engine core.

INCIDENT

Aircraft Type and Registration:	Jetstream 4100, G-MAJM
No & Type of Engines:	2 Garrett Airesearch TPE331-14GR-805H turboprop engines
Year of Manufacture:	1996
Date & Time (UTC):	23 February 2005 at 1245 hrs
Location:	Climbing to cruising level from Aberdeen, Scotland
Type of Flight:	Public Transport (Passenger)
Persons on Board:	Crew - 3 Passengers - 7
Injuries:	Crew - None Passengers - None
Nature of Damage:	None
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	37 years
Commander's Flying Experience:	7,100 hours (of which 200 were on type) Last 90 days - 160 hours Last 28 days - 71 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot

Synopsis

While climbing through 9,000 feet on a scheduled passenger flight from Aberdeen to Newcastle, the aircraft experienced a sharp pitch change as the autopilot was engaged. When the autopilot was disengaged, pitch control was found to be very limited. Control improved during the descent for a precautionary landing at Aberdeen, and was completely restored upon touchdown. The captain believes that failure to ensure proper de-icing prior to departure had permitted ice to remain on the horizontal tail surfaces and that a further accumulation in flight caused the elevator to become jammed.

History of the flight

The aircraft had been parked outside throughout the previous night, during which snow had fallen. Visible accumulations of ice were removed from the aircraft in the morning, but no de-icing fluid was applied and the horizontal tail surfaces were not inspected or treated for ice by any other means.

The captain stated that he made a visual pre-flight inspection of the aircraft, but was not able to see the top surface of the tailplane. Nevertheless, the flying controls were found to have full and free movement in all axes when checked prior to departure in accordance with normal procedures.

The airfield weather report at the time of departure indicated cloud scattered at 1,500 and 2,500 feet, with a surface temperature of 1ºC and dew point -3ºC. The runway was dry. The takeoff, with ice protection systems selected OFF, was uneventful. All ice protection systems were then selected ON as the aircraft entered cloud at approximately 2,000 feet, and ice was detected as the aircraft climbed though 7,500 feet. The aircraft climbed clear of cloud as it passed 8,000 feet, and the first officer continued to fly it manually until passing 9,000 feet, without encountering any unusual handling characteristics. However, when the autopilot was engaged, the aircraft made a sharp pitch change. The first officer disengaged the autopilot and attempted to control the aircraft manually, but found that the control column was severely restricted in pitch, with only limited nose-up control. When the captain attempted to fly the aircraft, he discovered that he had slightly more control, possibly because he was physically stronger than the first officer.

Elevator control

Each half of the elevator is controlled by an independent cable and rod system connected to its respective control column in the cockpit. In normal operation, the two systems act together because the control columns are mounted on a common torque tube. In the event of restricted movement, the two halves can be disconnected by pulling a manual disconnect handle, enabling each system to operate independently. The pilots decided not to pull the disconnect handle because the captain found that he was able to exercise adequate pitch control by using the elevator trim control. The crew declared a PAN and returned to Aberdeen, requesting radar vectors for a long and shallow approach. The captain regained greater pitch control as the aircraft descended, and full control authority was restored prior to the uneventful landing.

When the aircraft arrived on stand, ice was seen falling from the gap between the elevator leading edge and the fixed portion of the tailplane. A more detailed inspection, carried out when the aircraft was moved into a hangar, revealed that the space between the elevator leading edge and tailplane was filled with ice. No fault was found with the elevator hinge bearings, and no water was evident in the elevator actuating system.

Conclusion

The captain considers that, because no de-icing fluid was applied to the aircraft, ice which was not visible from the ground was present on the tailplane before takeoff. More water and ice accumulated in the gap between the fixed tailplane and the elevator as the aircraft entered cloud, and froze completely as the aircraft climbed, preventing normal elevator operation. Manual disconnection of the two elevator control systems would not have helped to regain control, because both halves of the elevator were similarly affected.

Aircraft Type and Registration:	American General AG-5B, G-BYDX	
No & Type of Engines:	1 Lycoming O-360-A4K piston engine	
Year of Manufacture:	1991	
Date & Time (UTC):	7 May 2005 at 1600 hrs	
Location:	Farley Farm, Hampshire	
Type of Flight:	Private	
Persons on Board:	Crew - 1	Passengers - 1
Injuries:	Crew - None	Passengers - None
Nature of Damage:	Extensive	
Commander's Licence:	Private Pilot's Licence with Instrument Rating	
Commander's Age:	78 years	
Commander's Flying Experience:	3,458 hours (of which 610 were on type) Last 90 days - 8 hours Last 28 days - 1 hour	
Information Source:	Aircraft Accident Report Form submitted by the pilot	

The pilot had flown from a private airstrip at Farley Farm to Lee-on-Solent Aerodrome to collect a passenger and return to the airstrip. Takeoff from Runway 24 at Farley Farm had been uneventful with a surface wind, assessed from the windsock, of north-westerly at 10 kt. The grass airstrip is approximately 700 metres long and is bounded by a hedge at the northern end and by trees at the southern end. There is a downslope from mid runway towards the southern end. With the physical characteristics of the airstrip, the preferred takeoff is from Runway 24 and the preferred landing is on Runway 06. The windsock is located close to the mid-point of the runway.

During his return flight, the pilot had checked the ATIS at Southampton. This broadcast gave the surface wind as 310º/10 to 12 kt but with large variations. On arrival at Farley Farm, the pilot assessed the wind to be similar to that he had experienced on takeoff and his passenger noted the windsock showing the surface wind at right angles to the runway. The pilot decided to land on Runway 06 and subsequently made a normal approach. Touchdown was near the mid-point of the runway and the pilot was unable to stop the aircraft before it struck a gate in the hedge at the end of the runway.

In an honest report, the pilot considered that the wind may have backed and strengthened during the approach and resulted in a tailwind for landing, which he had been too slow to appreciate. He assessed the most likely cause of the accident as "Hubris, leading to nemesis"

Aircraft Type and Registration:	Cessna F172M, G-BCYR
No & Type of Engines:	1 Lycoming O-320-E2D piston engine
Year of Manufacture:	1975
Date & Time (UTC):	29 April 2005 at 1420 hrs
Location:	Inverness Airport, Scotland
Type of Flight:	Private
Persons on Board:	Crew - 1 Passengers - None
Injuries:	Crew - None Passengers - N/A
Nature of Damage:	Nose landing gear, engine bulkhead and propeller blades damaged
Commander's Licence:	Private Pilot's Licence
Commander's Age:	22 years
Commander's Flying Experience:	82 hours (of which 18 were on type) Last 90 days - 30 hours Last 28 days - 14 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot

Synopsis

During a landing at Inverness Airport, a strong gust of wind resulted in the aircraft landing heavily on the nose wheel, the force of which shattered the wheel hub and allowed the propeller blades to strike the runway.

History of the flight

The aircraft was based at Inverness and belonged to the local flying school. On the day of the accident the pilot, who had started flying training six months previous, travelled by train to Dundee Airport in order to collect the aircraft from a maintenance organisation where it had undergone a 50 hour inspection. The pilot noted that the forecast wind was close to the flying school limitation of 30 kt and, therefore, before departing Dundee contacted the flying school to establish what the actual wind was at Inverness. The pilot was advised by an instructor that whilst it was "quite windy", the wind was along Runway 23 and was within the 30 kt limit published in the flying school manual.

The 50 minute flight was uneventful but, just as the aircraft commenced the flare on Runway 23 at Inverness, a strong gust of wind resulted in the aircraft landing with sufficient force to shatter the nose wheel hub and allow the propeller blades to strike the ground. The force through the nose wheel fork was also sufficient to distort the engine bulkhead. All the damage was consistent with the aircraft landing heavily on the nose wheel.

Weather information

The Meteorological Office TAF issued at 0851 hrs on 29 April 2005 forecast the wind at Inverness as 220º/20 kt with gusts of up to 32 kt. The METAR issued at 1320 hrs reported the wind at Inverness as 220º/30 kt and at 1420 hrs as 230º/27 kt. An aerodrome warning advising of a strong wind from the south-west of 22 kt gusting to 35 kt had been issued by the Meteorological Office at Aberdeen. This strong wind warning had been faxed to the flying club; however, it would not have been sent to Dundee Airport. ATC at Inverness use the PAMOS weather recording system, which samples the wind direction and strength every 10 minutes. The records for the period 10 minutes before and after the accident indicate that the wind was approximately 234º, +/- 15º, with a minimum strength of 19 kt, mean strength of 26 kt and gusts of up to 35 kt.

Discussion

The pilot recognised that the wind was close to the flying school operating limits and, therefore, twice contacted the flying school to establish the actual wind conditions at Inverness. Whilst the flying school informed the pilot that the wind was within the aircraft operating limits, they did not tell the pilot that a strong wind warning, forecasting gusts of up to 35 kt, had been issued. The CFI at the flying school stated that strong wind warnings are often received but that, in his opinion, the forecast conditions did not often materialise. Hence the instructors tend to use their experience and local knowledge to decide if conditions are likely to remain favourable. On this occasion the strong wing warning was accurate.

Since this accident, the pilot has undertaken additional training on handling this aircraft type.

Aircraft Type and Registration:	DH82A Tiger Moth, G-ALIW
No & Type of Engines:	1 De Havilland Gipsy Major I piston engine
Year of Manufacture:	1938
Date & Time (UTC):	15 February 2005 at 1330 hrs
Location:	Private Strip at Littlebredy, Dorchester, Dorset
Type of Flight:	Private
Persons on Board:	Crew - 2 Passengers - None
Injuries:	Crew - None Passengers - None
Nature of Damage:	Damage to propeller, underside of lower wing and detached undercarriage strut on right side
Commander's Licence:	Airline Transport Pilot's Licence with Instructor Rating
Commander's Age:	68 years
Commander's Flying Experience:	8,186 hours (of which 568 were on type) Last 90 days - 72 hours Last 28 days - 24 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot

The purpose of the flight was for an instructor to revalidate the pilot's Private Pilot's Licence. The intention was to practice circuits followed by upper air work and a short cross-country with a practice forced-landing. After the instructor had demonstrated a 'three-point' landing, the pilot performed a 'wheeler' landing, intending to allow the tail to settle before applying power to go around. However, before the tailskid touched, the right undercarriage collapsed and the aircraft tipped onto its nose and right wingtip before settling back in an upright attitude. The instructor reported that the touchdown was normal and states that the damage was relatively light due to the low groundspeed at the time of the collapse. Both pilots evacuated the aircraft normally.

The instructor, who is a retired metallurgist, found that the right undercarriage drag strut had detached from the fitting securing it to the fuselage due to failure of the swivel bolt, part number H.22186 (see Figure 1). On a brief visual examination, he diagnosed that the fracture involved a fatigue crack. One half of the fracture was sent to the AAIB for examination: this concurred with his diagnosis with the additional observation that it appeared to be low-cycle fatigue occurring over a relatively short period and that the bolt passing through the strut fork fitting and the swivel bolt appeared to have been excessively tightened at some point. The history of the failed item is unknown but a report was found, dated 1960, in which a De Havilland investigation identified an almost identical failure. The report did not recommend any action as "this is the first recorded defect of this particular nature".

The maintainer of the aircraft has advised that he intends to inspect the swivel bolts during annual inspection of Tiger Moth aircraft in future and it would seem prudent for other maintainers to do likewise. The age and history of these components is scarcely ever recorded and loads experienced can vary greatly with runway conditions and also the effectiveness of lubrication, since the bolt must be free to articulate in the fitting as the undercarriage struts 'spread' under load.

Figure 1

Tiger Moth Main Undercarriage drag strut showing location of failed pin and approximate line of fracture.

Aircraft Type and Registration:	Glasair RG, G-TRUK
No & Type of Engines:	1 Lycoming O-320-D1A piston engine
Year of Manufacture:	1989
Date & Time (UTC):	26 April 2005 at 1216 hrs
Location:	Bembridge Airport, Isle of Wight
Type of Flight:	Private
Persons on Board:	Crew - 1 Passengers - None
Injuries:	Crew - None Passengers - N/A
Nature of Damage:	Damage to lower forward cowling and propeller. Slight damage to nose gear door and spinner
Commander's Licence:	Private Pilot's Licence
Commander's Age:	73 years
Commander's Flying Experience:	1,335 hours (of which 639 on type) Last 90 days - 0 hours Last 28 days - 0 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot and further enquiries by the AAIB

The aircraft was conducting a PFA Annual Permit Renewal Flight Test after completion of repairs following a wheels up landing at Bembridge seven months previous. The pilot had flown all previous annual flight tests since acquiring the aircraft in 1991. The aircraft had been signed off as fit to fly by the PFA Inspector, with a Permit Renewal completed by the inspector up to the point of the test flight. The weather was good with a surface wind of 240º/20 kt. Runway 30 was in use.

All ground checks were satisfied and the takeoff was normal. After selecting the main landing gear up the pilot saw that the nose landing gear light remained green. The pilot asked Bembridge radio if his nose wheel had failed to retract; they reported that all of the landing gear appeared to be fully retracted.

Bembridge radio invited the pilot to do a fly by so that they could take a closer look: this he accepted. However, on the downwind leg, before doing the fly by, the pilot decided to recycle the landing gear down and then up to see if the fault would clear. On doing so the nose gear remained green throughout and both main landing gears functioned correctly.

The pilot then decided that there was little point in doing the fly by so he selected the landing gear down and on obtaining three greens said that he was returning to land. As he had indications of the landing gear being down and locked he did not use the emergency lowering system. The pilot asked Bembridge radio on turning finals and on short finals for a visual confirmation that his landing gear was down. On both occasions they confirmed it appeared to be down.

A normal approach, with full flap, was flown at 90 mph followed by a touchdown on the main gear at 80 mph. On lowering the nose the pilot did not feel weight being taken by the nose gear. The nose continued to drop until the propeller struck the runway. The aircraft slid to a halt on its nose on the runway. There was no fire and the pilot vacated the aircraft uninjured. The resident Rescue and Fire Fighting Service were rapidly on the scene and were able to assist in the recovery of the aircraft.

On examining the aircraft, the resident maintenance organisation found severe abrasion damage to the lower forward cowling and to the nose gear door and damage to the spinner, engine and propeller. Their initial investigation suggested that the nose wheel had failed to make its geometric lock due to the undercarriage pump motor locking out early when the nose wheel indicated green, and had thus folded up under the aircraft when it took the weight of the aircraft. No reason has yet been found as to why the nose gear indication stayed green upon an up selection.

Aircraft Type and Registration:	Jabiru SK, G-BYNL
No & Type of Engines:	1 Jabiru Aircraft Pty 2200A piston engine
Year of Ma°nufacture:	1999
Date & Time (UTC):	22 April 2005 at 1115 hrs
Location:	Slinfold (Welcross Farm) Airstrip, West Sussex
Type of Flight:	Private
Persons on Board:	Crew - 1 Passengers - None
Injuries:	Crew - None Passengers - N/A
Nature of Damage:	Damage to the left side of the fuselage, the left wing and propeller
Commander's Licence:	Private Pilot's Licence
Commander's Age:	47 years
Commander's Flying Experience:	163 hours (of which 26 on type) Last 90 days - 11 hours Last 28 days - 2 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot

History of the flight

The pilot had completed maintenance work on the aircraft's engine and had elected to conduct a short airtest prior to the Permit-to-Fly renewal. The weather was good with a surface wind of 120º/10 kt, visibility of 9 km and a cloud base at 2,500 feet. The airstrip at Slinfold has a single grass runway orientated 22/04, 650 metres long by 40 metres wide with a house located at the north-eastern end near the threshold of Runway 22. A windsock is positioned on the north side of the runway approximately opposite its midpoint.

Having assessed the wind, the pilot decided to depart from Runway 22, accepting a small tailwind component in order to avoid overflying the house at the upwind end of Runway 04. The takeoff was normal and the aircraft was climbed to 1,500 feet tracking to the west of Brighton before returning to Slinfold. The pilot descended and joined the circuit, establishing on the final approach for Runway 22. The aircraft had the first of the two stages of flap selected down and the approach speed was 60 kt. Grass cutting was in progress and the pilot continued his approach to a height of about 300 feet when he executed a go-around, taking up a left hand circuit at 1,000 feet.

After the grass cutter had cleared the runway and taking into account the crosswind component, the pilot decided to land on Runway 04. He made his approach at 60 kt, again with the first stage of flap lowered but realising he was high, he lowered full flap and tried to correct his approach angle. He also realised that his groundspeed was higher than normal but he was able to touch down at about the mid-point of the runway. The pilot applied the handbrake and the aircraft appeared to be skidding on the newly mown grass and moving towards the left side of the runway whilst still pointing along it.

The left main landing gear wheel dropped into a shallow drainage ditch and at the same time the wing and fuselage struck fence posts positioned adjacent to the runway. The propeller struck the ground and the engine stopped. The pilot was uninjured and having carried out the emergency shut down drills, he vacated the aircraft through the right (passenger) door.

Causal factors

The pilot considered that the accident occurred because he had not checked the wind sock on his return to Slinfold, where the wind had veered by about 30º during his flight. The tail wind component during the second approach had contributed to his landing further along the runway and his attempt to stop before the end of the runway was the reason for his heavy braking. On reflection he considered he should have carried out a second go-around and re-assessed the wind.

Aircraft Type and Registration:	Mooney M20J, N61MF
No & Type of Engines:	1 Lycoming IO-360-A3B60 piston engine
Year of Manufacture:	1979
Date & Time (UTC):	8 May 2005 at 1618 hrs
Location:	Fairoaks Airport, Surrey
Type of Flight:	Private
Persons on Board:	Crew - 1 Passengers - 3
Injuries:	Crew - 1 (Minor) Passengers - 3 (Minor)
Nature of Damage:	Substantial damage to airframe, propeller and engine
Commander's Licence:	Private Pilot's Licence
Commander's Age:	45 years
Commander's Flying Experience:	274 hours (of which 51 were on type) Last 90 days - 10 hours Last 28 days - 5 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot

History of the flight

The pilot and three friends had flown from Fairoaks to Cherbourg before returning to Fairoaks. The weather for the flights was generally good with some rain shower activity over southern England. The 1520 hrs Fairoaks weather was: surface wind 310º/14 kt, CAVOK with Runway 24 in use. A shower had recently passed over the airfield and the runway was wet. Fairoaks has a single asphalt runway orientated 06/24, 813 metres long and 27 metres wide. The landing distance available for Runway 24 is 800 metres.

When established on a wide, left downwind leg the pilot lowered the landing gear and reduced IAS to 100 kt before lowering the first of the two stages of flap. The aircraft descended on the base leg and was turned onto the final approach for Runway 24 at a height of 500 feet. The approach speed was 80 kt IAS and the surface wind was 330º/09 kt. The approach was turbulent with some compensation for the left drift required and the pilot continued the approach. Over the threshold, at a height he estimated between 20 and 30 feet, the pilot was unhappy with his positioning and carried out a go-around. He retracted the flap and landing gear in the climb and carried out a left hand circuit at the normal height of 1,000 feet using set turning points marked by ground features.

Having configured the aircraft with landing gear and two stages of flap lowered, the pilot turned the aircraft onto the final approach for Runway 24. The second approach was less turbulent and was again flown at an approach speed of 80 kt IAS with no drift compensation required. The approach appeared to be normal although, as the aircraft passed over the threshold, the pilot recalled thinking that the approach did not seem to take as long as normal. The pilot flared as normal but the aircraft continued to float just above the runway surface, eventually touching down at or just after the runway mid-point. Realising that insufficient braking distance remained before the end of the runway, the pilot executed a baulked landing procedure by applying maximum engine power but he did not have time to retract the landing gear or the flaps. The aircraft cleared the airfield boundary fence before it impacted a grass field on the runway extended centreline and passed through a wooden fence. During the impact the engine and outboard section of the left wing detached.

The pilot isolated the fuel and electrical services and together with the passengers, he vacated the aircraft through the normal exit. The airfield Rescue and Fire Fighting Services were promptly on the scene and were joined shortly afterwards by other emergency services.

Conclusion

The pilot thought the most likely cause of the accident was that the threshold speed he achieved was higher than the customary 80 kt. This may have been because he had recently been flying a different type of aircraft with a higher approach speed and there may also have been a slight tailwind component on the final approach. He also stated that the low drag characteristics of the Mooney M20 make it susceptible to prolonged 'floating' if the threshold speed is too high; he did not recall the threshold speed but he estimated that it was between 5 and 10 kt too fast. Having applied the brakes after touch down, the pilot also thought he should not have attempted the baulked landing but should have accepted what would have been a low speed overrun.

Aircraft Type and Registration:	Rans S6-ES, G-CBAZ
No & Type of Engines:	1 Rotax 582-48 piston engine
Year of Manufacture:	2001
Date & Time (UTC):	25 March 2005 at 1410 hrs
Location:	Kinderton Lodge Farm, Middlewich, Cheshire
Type of Flight:	Private
Persons on Board:	Crew - 1 Passengers - None
Injuries:	Crew - 1 Passengers - N/A
Nature of Damage:	Extensive
Commander's Licence:	Private Pilot's Licence
Commander's Age:	59 years
Commander's Flying Experience:	206 hours (of which 54 were on type) Last 90 days - 0 hours Last 28 days - 0 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot

History of flight

The aircraft had not been flown for several months and, before commencing takeoff, an engine ground run and two high speed taxis were completed during which maximum engine speed was achieved. Due to the lack of any significant headwind, the pilot elected to use 30º of flap, although he was inexperienced in using flaps for takeoff. After the aircraft became airborne, it momentarily touched down before climbing out. A few seconds later the left wing dropped and, although this was corrected, the right wing then dropped. Thereafter, the left wing dropped again and the aircraft went into a dive and impacted the ground, having turned through approximately 220º from the runway direction.

Local conditions

Kinderton Lodge Farm is an unlicensed grass airfield. The pilot was using Runway 12, which is 354 metres long and has trees located a short distance beyond its far end. The meterological aftercast for the area gave variable winds of three knots, and this agreed with the pilot's report of the local conditions at the time. The condition at the airfield surface at the time of the accident was reported as soft and wet; however, the field was considered viable and had been successfully used that day by other aircraft.

Analysis

As the engine runs prior to takeoff appeared normal, it seems unlikely that the engine was a significant factor in this accident.

The characteristics of the aircraft's behaviour after takeoff indicated that it had approached and then suffered a stall, and hence was flying slowly. In the absence of any reported pre-accident defects with the aircraft or loss of power, possible contributing factors for this lack of speed could have been the pilot's lack of experience in using flaps for takeoff in still conditions, his low level of currency and a lower than normal acceleration on the soft surface.

The pilot suffered a sprained ankle and, in his report, attributed his low level of injury to the correct use of his lap and shoulder harness.

INCIDENT

Aircraft Type and Registration:	Cessna F152, G-BHFC	
No & Type of Engines:	1 Lycoming O-235-L2C piston engine	
Year of Manufacture:	1978	
Date & Time (UTC):	19 April 2005 at 1100 hrs	
Location:	Near Hardwick Airfield, Norfolk	
Type of Flight:	Training	
Persons on Board:	Crew - 1	Passengers - 1
Injuries:	Crew - None	Passengers - None
Nature of Damage:	Significant damage to the engine, minor damage to the airframe structure	
Commander's Licence:	Commercial Pilot's Licence	
Commander's Age:	39 years	
Commander's Flying Experience:	4,451 hours (of which 1,153 were on type) Last 90 days - 133 hours Last 28 days - 36 hours	
Information Source:	Aircraft Accident Report Form submitted by the pilot	

History of flight

The aircraft had completed two stalls without incident as part of a Private Pilot's Licence renewal. On application of full power for a third stall recovery at an altitude of 3,000 feet, the pilot noticed severe airframe vibration which appeared to be coming from the engine. The pilot made a MAYDAY call to Norwich Approach and started to look for a suitable location for a forced landing. Shortly afterwards the pilot reported seeing some pieces of the engine departing the aircraft through the cowling and, a few moments later, there was a loud bang and the propeller stopped rotating.

The pilot subsequently completed a forced landing at Hardwick, a disused American wartime airfield, with no further damage to the aircraft and with no injury to the pilot or the student.

Engine Description

The Lycoming O-235-L2C engine is a flat four engine and has a single camshaft on which there are six cams that drive eight followers (cam Nos 2 and 5 drive two followers each, the remaining cams drive only one follower). This engine was operating on an extension, at some 2,600 hours, to its nominal 2,400 hour engine life.

Engine examination

The engine was removed and the bare engine was returned to the AAIB in Farnborough for detailed strip examination. This revealed several significant areas of damage, the most notable of which was to cylinder No 4 (aft left) which had failed around its base where it attached to the crankcase. The fracture surfaces were heavily damaged in the failure and this precluded their detailed examination. All four of the cylinders had evidence of pitting corrosion but due to the size and pitch of the cooling fins, it was not possible to make an accurate assessment of its extent.

There was extensive damage to the lower portion of piston No 4 below the centre line of the gudgeon pin, the piston had seized inside its cylinder and the connecting rod had failed approximately half way along its length. Both the upper part of the connecting rod and the gudgeon pin were found in the oil sump. The remaining part of the connecting rod (attached to the crankshaft) had been subject to significant abnormal loads and was severely twisted. There was also some damage to cylinder No 3 in the region of its base (this is opposite to cylinder No 4).

The crankcase was cracked over a length of approximately 6 cm and this was approximately 2 cm wide at its widest. There was extensive internal damage to the crankcase over an area of approximately 5 x 15 cm in which most of the crankcase structure that formed the 'roof' of the oil sump had broken away. Both the crack and the internal damage were located opposite cylinder No 4 and were likely to have been caused by the remaining part of the No 4 connecting rod that had become detached from piston No 4.

Inspection of the camshaft, and subsequent measurement of the dimensions of the six cams, revealed that two of the cams were significantly worn and that their respective cam followers were pitted and worn. The height to width ratio for cam Nos 1, 3, 4 and 5 were found to be in the range of 1.30 to 1.32, but the ratios for cam Nos 2 and 6 (the two cams with significant wear) were 1.15 and 1.20 respectively. Whilst such wear is unlikely to have been a major factor in the engine failure, it is likely that the resultant reduction in valve lift would have caused some loss of engine performance.

It was concluded that the most likely cause of the engine failure was the failure of cylinder No 4 due to pitting corrosion induced fatigue cracking around the base of the cylinder, and that this allowed the cylinder to break free and subsequently cause all the observed damage.

The French DGAC have reported a significant number of cylinder barrel failures on Lycoming O-235 engines, including the -L2C mark, and these failures had been initiated by corrosion pits near the base area of the cylinder. As a result of this, Textron Lycoming issued Service Instruction No 1504 in January 2001, in which the replacement of the cylinder assemblies with new assemblies, with improved corrosion resistance, was recommended.

Aircraft Type and Registration:	Team Minimax, G-BYBW	
No & Type of Engines:	1 Rotax 447 piston engine	
Year of Manufacture:	1999	
Date & Time (UTC):	1 May 2005 at 1600 hrs	
Location:	Washington Airstrip, West Sussex	
Type of Flight:	Private	
Persons on Board:	Crew - 1	Passengers - None
Injuries:	Crew - None	Passengers - N/A
Nature of Damage:	Minor damage to nose and wing tip	
Commander's Licence:	Private Pilot's Licence	
Commander's Age:	48 years	
Commander's Flying Experience:	612 hours (of which 8 were on type) Last 90 days - 12 hours Last 28 days - 8 hours	
Information Source:	Aircraft Accident Report Form submitted by the pilot	

Washington Airstrip is a private grass strip located adjacent to the South Downs Way, with a ridge to the east and south. The ridge, and the significant slope of the runway, dictate that takeoffs are normally carried out on Runway 24, and landings on the reciprocal Runway 06. On the day of the accident the slightly damp grass was approximately five inches high and there was a slight tailwind for landing on Runway 06.

The pilot flew a normal approach at 55 kt and touched down in a three point attitude. At a low speed during the landing roll, he felt a yaw to the left and a deceleration. Despite continuous full aft control column deflection, the aircraft's tail rose, the aircraft pitched over onto its nose and rolled to the right until the right wing tip contacted the ground. It eventually came to rest however, in an upright attitude. The pilot exited the aircraft without difficulty and later reported that he believed the aircraft pitched onto its nose as a consequence of, interaction with the long grass, the low-slung straight axle and band brakes of the landing gear, and the tailwind.

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2/2004	Sikorsky S-61N, G-BBHM at Poole, Dorset on 15 July 2002	April 2004
3/2004	AS332L Super Puma, G-BKZE on-board the West Navion Drilling Ship 80 nm to the west of the Shetland Islands on 12 November 2001	June 2004
4/2004	Fokker F27 Mk 500 Friendship, G-CEXF at Jersey Airport, Channels Islands on 5 June 2001	July 2004
5/2004	Bombardier CL600-2B16 Series 604, N90AG at Birmingham International Airport on 4 January 2002	August 2004
1/2005	Sikorsky S-76A+, G-BJVX near the Leman 49/26 Foxtrot platform in the North Sea on 16 July 2002	February 2005

ABBREVIATIONS COMMONLY USED IN AAIB BULLETINS

ADELT	automatically deployable emergency locator transmitter
ADF	automatic direction finding equipment
AFIS(O)	Aerodrome Flight Information Service (Officer)
AFS	Aerodrome Fire Service
agl	above ground level
AIC	Aeronautical Information Circular
amsl	above mean sea level
APU	auxiliary power unit
ASI	airspeed indicator
ATC(C)	Air Traffic Control (Centre)
BMAA	British Microlight Aircraft Association
CAA	Civil Aviation Authority
CG	centre of gravity
°C,F,M,T	Celsius, Fahrenheit, magnetic, true
DGAC	Direction Général à l'Aviation Civile
DME	distance measuring equipment
EGT	exhaust-gas temperature
ETA	estimated time of arrival
ETD	estimated time of departure
FAA	Federal Aviation Administration (USA)
FIR	flight information region
FL	flight level
ft/min	feet per minute
g	normal acceleration
gall imp/US	gallons, imperial or United States
hrs	hours
hPa	hectopascal
IAS	indicated airspeed
IFR	Instrument Flight Rules
ILS	Instrument landing system
IMC	Instrument Meteorological Conditions
IR	Instrument Rating
IRE	Instrument Rating examiner
ISA	international standard atmosphere
kg	kilogram(s)
KIAS	knots indicated airspeed
km	kilometre(s)
kV	kilovolt
kt	knot(s)
lb	pound(s)
LDA	landing distance available
mb	millibar(s)
MDA	Minimum Descent Altitude
mm	millimetre(s)
mph	miles per hour
MTWA	Maximum Total Weight Authorised
NDB	non-directional radio beacon
nm	nautical mile(s)
NOTAM	Notice to Airman
OCH	Obstacle Clearance Height
PAPI	Precision Approach Path Indicator
PAR	precision approach radar
PFA	Popular Flying Association
PIC	pilot in command
psi	pounds per square inch
QFE	pressure setting to indicate height above aerodrome
QNH	pressure setting to indicate elevation above mean sea level
RPM	revolutions per minute
RTF	radiotelephony
RVR	runway visual range
SAR	Search and rescue
SSR	secondary surveillance radar
TAF	Terminal Aerodrome Forecast
TAS	true airspeed
TGT	turbine gas temperature
UTC	Co-ordinated Universal Time
V_1	Decision speed
V_2	Take-off safety speed
VASI	Visual Approach Slope Indicator
VFR	Visual Flight Rules
VHF	very high frequency
VMC	Visual Meteorological Conditions
V_{ne}	never exceed airspeed
V_R	Rotation speed
VOR	VHF omni-range