SOUTH AFRICAN CIVIL AVIATION AUTHORITY
(SACAA)

ACCIDENT INVESTIGATION REPORT

ACCIDENT INCIDENT INVESTIGATION DIVISION (AIID)
REF: CA18/2/3/8692

FINAL REPORT

Jetstream Aircraft 4100 ZS-NRM:

Loss of control after engine failure and misidentified engine shutdown after take-off from Durban Airport, South Africa on 24 September 2009

This report is issued in the interests of aviation safety
and with the objective of preventing any similar occurrence.

Publication title
Jetstream aircraft 4100 ZS-NRM: Loss of control after engine failure and misidentified engine shutdown after take-off from Durban Airport, South Africa, on 24 September 2009.

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Purpose of accident/incident investigations
In terms of Regulation 12.03.1 of the Civil Aviation Regulations (1997), this report is compiled in the interests of the promotion of aviation safety and the reduction of the risk of aviation accidents or incidents and not to establish legal liability.

All times given in this report are based on Co-ordinated Universal Time (UTC) and are denoted by (Z). South African Standard Time (B) is UTC plus two hours.

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Executive Summary

On 23 September 2009, the aircraft took off from O R Tambo International Airport on a scheduled flight to Pietermaritzburg Airport. Due to inclement weather at Pietermaritzburg, the captain made two failed approaches and then diverted to Durban Airport, where the aircraft landed safely. The passengers were bussed to Pietermaritzburg, and on the following day, the crew took off from Durban for a repositioning flight to Pietermaritzburg Airport. There were only three on board: the captain (PNF), the co-pilot (PF) and a cabin attendant, who occupied the flight deck jump-seat.

There were no reported technical problems during the pre-flight preparation and the co-pilot requested permission to start the engines from air traffic control at 0530Z. The aircraft, call sign Link 911, commenced its take-off roll from runway 06 at 0556Z, with the co-pilot designated as the pilot flying. The captain was designated as pilot not flying (PNF).

During the take-off roll, the cockpit crew of another airliner observed smoke pouring from the right engine of ZS-NRM. They were shocked, yet reluctant to tell the crew of ZS-NRM to abort the take-off as they felt that they might be blamed had the abort gone wrong. Instead, the witnessing pilots enquired from the tower whether the aircraft was aware of the smoke. By the time the ATC responded, the aircraft was already in the air, but with its landing gear not yet retracted. Another aircraft lining up at the holding point informed ZS-NRM that their undercarriage was still extended, and the captain of ZS-NRM then transmitted (instead of using the intercom) an instruction to his co-pilot to raise the gear. During this transmission, the sound of what was possibly a warning sound could be heard in the background.

The aircraft became airborne and climbed to approximately 500 ft above mean sea level before losing altitude and making a forced landing on a small field in the Merebank residential area, about 1,4 km from the end of the runway.

During the forced landing, a member of the public was struck by the wing of the aircraft and the three crew members were seriously injured in the accident. The captain subsequently died from his injuries.

The accident occurred during daylight conditions at a geographical position determined to be South 29º57.303' East 030º58.235'.

The cabin attendant stated that just after take-off, as they were about to retract the undercarriage, an alarm sounded in the cockpit, which was silenced by the co-pilot. The cabin attendant reported that she could feel the aircraft losing power and saw the captain reach to the console between the seats and pull the left lever (fuel-condition lever), after which they started descending. At this point, the co-pilot placed her hands on her lap. The cabin attendant looked outside the windows, and to her left could see a grass field towards which the captain now directed the aircraft.

Investigators interviewed the co-pilot and cabin attendant. At the time of the interview, the co-pilot, who had been the designated pilot flying, could no longer recall any detail of the take-off and subsequent accident, due to shock. Fortunately, she had shared some of these details with her husband during the first two days after the accident, and he was able to pass these on to the investigators. The investigators consulted the doctors and it was concluded that it was possible for the first officer not to have remembered certain parts of the event.

Playback of the cockpit voice and flight data recorder information confirmed the sequence of events in the cockpit.

Examination of the wreckage confirmed that the right-hand engine (engine 1) had suffered a catastrophic failure of the second-stage turbine seal plate and that subsequently the serviceable engine had been shut down, resulting in a forced landing.

The incorrect identification of the failed engine is attributed to the apparent breakdown of the crew resource management action within the cockpit and total deviation from the operator's prescribed standard operating procedures.

Three safety recommendations have been developed and are addressed to the SACAA and the manufacturer regarding the design and manufacture of the engine involved. These are:

The SACAA conducts a comprehensive audit of compliance with all aspects of its Air Operator Certificate requirements, including its training procedures and assessments of the operator involved. This recommendation was actioned by SACAA and a satisfactory action plan, which was implemented, was submitted by the operator to SACAA.
Because of the inappropriate crew response to the propulsion system malfunction that resulted in the loss of control prior to shutting down the wrong engine, it is recommended that: • The SACAA conducts a comprehensive audit of the compliance with all aspects of engine inoperative training at flight schools, and that more emphasis is placed on simulator training.
The SACAA therefore makes the following safety recommendation to the Federal Aviation Administration (FAA): The FAA should require Honeywell Aerospace to expedite efforts to produce an engineering solution to the problem of second-stage turbine rotating air seal failures on Honeywell TPE331-14G/H engines.

Acceptance and implementation of these safety recommendations should ensure improvement in the level of safety within the South African civil aviation safety system and thereby enhance the management of risk.

Figure 1. The failed seal plate.

ACCIDENT INVESTIGATION REPORT

Jetstream Aircraft 4100 ZS-NRM:

Loss of control after engine failure and misidentified engine shutdown *after takeoff from Durban Airport,* South Africa

All times given in this report are based on Co-ordinated Universal Time (UTC) and are denoted by (Z). South African Standard Time (B) is UTC plus two hours.

1 FACTUAL INFORMATION

Name of owner/operator	:	SA Airlink (Pty) Ltd
Aircraft manufacturer	:	British Aerospace
Model	:	Jetstream 4100
Nationality	:	South African
Registration marks	:	ZS-NRM
Place	:	Merebank (Durban), South Africa
Date	:	24 September 2009
Time	:	0557Z

1.1 History of flight

1.1.1 On the evening of 23 September 2009, the aircraft flew from Johannesburg on a scheduled flight to Pietermaritzburg Airport. Due to poor weather conditions at the destination, the pilots made two failed approaches and then diverted to Durban Airport, where the aircraft landed safely. The passengers were bussed to Pietermaritzburg. The crew rested overnight at a local hotel before reporting for duty at 0445Z the next day to reposition the aircraft to Pietermaritzburg. The crew consisted of the captain, who occupied the left-hand seat, the co-pilot, in the right-hand seat, and a cabin attendant, who sat on the flight deck jump seat. The co-pilot was designated as the pilot flying and the captain as the pilot not flying.

1.1.2 There were no reported technical problems during the pre-flight preparation and at 0530Z the co-pilot requested permission from the ATC to start the engines. As the aircraft had not been scheduled to be at Durban Airport, no ground power unit was immediately available and the crew therefore attempted to start the aircraft using the internal battery. Two unsuccessful attempts were made to start engine no. 1 (the left-hand engine), after which the ground engineer left to obtain a ground power unit. On returning to the aircraft, he noted that the crew had managed to start both engines and subsequently gave him a thumbs-up signal as they taxied off. There was no-one present to witness the start but it was determined from the cockpit voice recorder and flight data recorder that engine no. 2 had been started first.

1.1.3 The co-pilot called for taxi instructions at 05:48:59Z. The aircraft was cleared to taxi to the holding point for runway 06 and at 05:56:16Z the ATC cleared the aircraft for takeoff.

1.1.4 The aircraft, call sign "Link 911", commenced its takeoff roll from runway 06 at 05:56Z, with the co-pilot as the pilot flying. The following transmissions were recorded on Durban Tower frequency:

05:56:48Z (Another aircraft on the ground at the airport):	*Requesting start, you see the aircraft taking off with all the smoke?*
05:56:53Z DBN TWR:	*Er, LNK 911, just to be advised there is a smoke trail behind you*
05:57:01Z (Unknown aircraft):	*Severe smoke*
05:57:24Z DBN TWR:	*LNK 911 Do you read?*
05:57:25Z LNK 911 (Captain speaking):	*Yeah, we've lost an engine*
05:57:30Z (Unknown aircraft):	Your gear is still down
05:57:35Z DBN TWR:	*OK, LNK 911, you can join the right down for runway 06*
05:57:42Z LNK 911 (Captain speaking):	*Pick the gear up.*

1.1.5 The tower controller later stated that the aircraft was still on the runway and in the vicinity of the intersection with taxiway G when he became aware of smoke coming from it. He could not, however, make out exactly from which part of the aircraft the smoke was coming from.

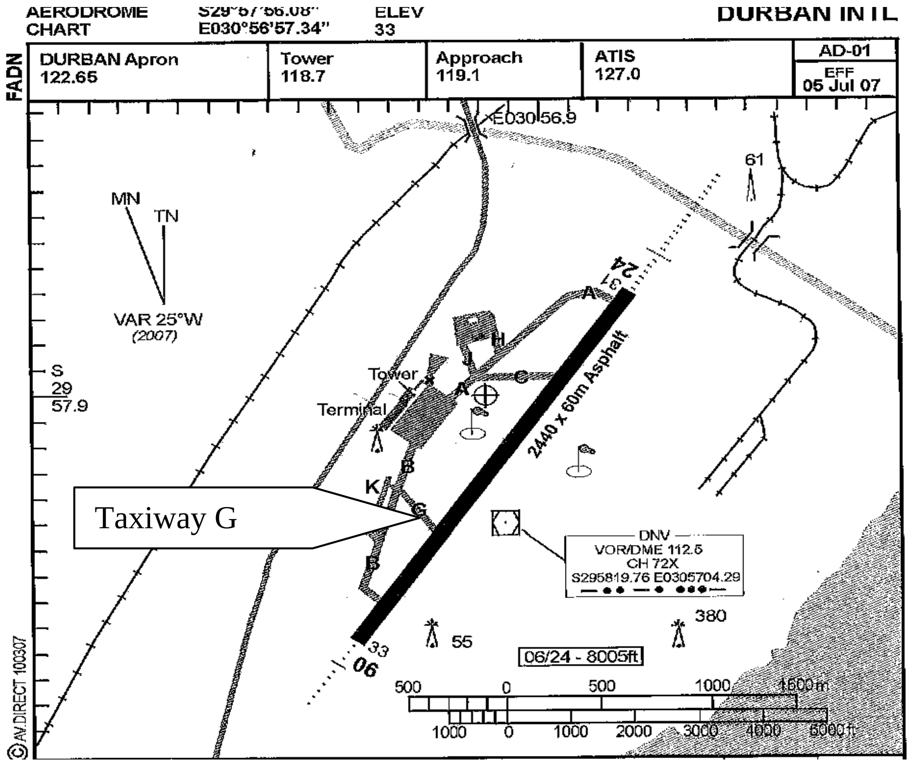

Figure 2. Durban International Airport.

1.1.6 The technician on the ground in parking bay A4 reported watching the accident aircraft take off. He stated that the takeoff roll appeared uneventful but that just after rotation there was “a large cloud of black smoke that erupted from the right-hand engine”. During the climb, the smoke changed colour to a whitish-brown and diminished in volume. As the aircraft crossed the end of the runway, it appeared to yaw to the right and then started to lose altitude. It then veered suddenly to the left, rapidly losing altitude, before disappearing from view.

1.1.7 Another witness, an airline pilot, stated that his own aircraft was taxiing to the apron as the accident aircraft started rolling. According to this pilot, ZS-NRM became totally engulfed in smoke from the moment when it increased power (“not just smoke but THICK blue smoke”). The pilot added that as the aircraft rolled down the runway, it looked “like an airshow”, with smoke emanating from the right engine. He and his co-pilot were shocked, yet were reluctant to tell the crew of ZS-NRM to stop because they feared being blamed if the abort went wrong. Instead, they enquired of the tower whether the aircraft was aware of the smoke. By the time the ATC responded, ZS-NRM was already in the air, but with its landing gear still down. The pilot of another aircraft, waiting at the holding point, informed ZS-NRM that their undercarriage was still lowered. The captain of ZS-NRM then transmitted (instead of using the intercom) an instruction to his co-pilot to raise the gear. During this transmission, the sound of the fire-warning bell could be identified in the background. At that point, the airline pilot reported that he could no longer see ZS-NRM.

1.1.8 The cabin attendant stated that just after take-off, as they were about to retract the undercarriage, an alarm had gone off in the cockpit. The co-pilot reached to the lights that flashed just below the dashboard and switched off the warning. The cabin attendant reported that she could feel the aircraft losing power. As she was looking outside the windows, she also saw the captain reach to the console between their seats and pull a pale-green lever to the right of the thrust levers (the left fuel-condition lever). The aircraft began to lose height. At this point, the co-pilot placed her hands on her lap. The cabin attendant looked outside the windows, and to her left could see a grass field towards which the captain now began to guide the aircraft.

1.1.9 The cabin attendant also mentioned that after the captain had shut down the engine, he unlatched his safety harness. She also felt vibrations at about this time; however, she thought this was turbulence as there were some clouds about.

1.1.10 The aircraft descended towards a small open area within the residential suburb of Merebank, 1,4 km from the end of runway 06. After the initial impact with the ground in this area, it continued across the open area, slid across a road and struck a concrete palisade fence, coming to rest on the sports field of the Merebank High School. A road worker was seriously injured when he was struck by the wing of the aircraft. The three crew members were all seriously injured and had to be freed from the wreckage by the emergency services.

1.1.11 Investigators interviewed the surviving crew members. The co-pilot, who was the designated pilot flying during the take-off, could no longer recall any details of the take-off and subsequent accident. Fortunately, she had shared some of these details with her husband during the first two days after the accident, and he was able to pass these on to the investigators. Following this, the investigators consulted the doctors and it was concluded that it is possible for the first officer not to remember certain parts of the event. The cabin attendant was able to provide a description of what she had observed during the take-off and the actions in the cockpit.

1.2. Injuries to Persons

Injuries	Pilot	Crew	Pass.	Road worker
Fatal	1	-	-	-
Serious	1	1	-	1
Minor	-	-	-	-
None	-	-	-	-

1.2.1 The other person injured was not on board the aircraft; he was a road worker working on the road when he was hit by the left wing of the aircraft.

1.3. Damage to aircraft

1.3.1 The aircraft was destroyed during the forced landing due to impact forces.

Figure 3. The main wreckage.

1.4. Other damage

1.4.1 Impact damage to the concrete palisade fence. An electrical pole was also knocked over by the right wing.

1.5 Personnel information

1.5.1 Captain (Pilot not flying)

Nationality	South African	Gender	Male	Age	40
Licence number	*****************	Licence Type	Airline Transport		
Licence valid	Yes	Type Endorsed	Yes		
Ratings ATPL	BE10, BE9L, JS41, Z194, Z180				
Ratings instructor	Instructor grade 2; Test pilot class 2; Instrument; Flight test on piston multi- and single-engine				
Last proficiency check	21 August 2009				

Last line check	8 September 2009
Emergency and safety equipment check	23 June 2009
CRM check	23 October 2008
Last Instrument Renewal	28 February 2009
Last instructor renewal	3 April 2009
Medical expiry date	30 September 2009
Restrictions	None
Previous accidents	Yes, see description below.

1.5.2 The pilot, accompanied by five passengers, took off from Manzengwenya Aerodrome on 21 August 2005 for a chartered flight to Virginia Aerodrome (FAVG). He reported that although it was drizzling, visibility was good. He reported his position to the FAVG ATC and requested joining instructions for FAVG. The ATC cleared the pilot to land on runway 05. When he was on short finals, the tower noticed that the aircraft was drifting away from the runway centreline and called the pilot.

1.5.3 The Captain stated that he was experiencing an engine problem and was initiating a go-around. The aircraft turned to the left and away from the runway centreline, and then flew over the nearby M4 highway and towards a residential area.

1.5.4 The aircraft struck the roof of a private home with its left wing and nose, and came to rest in a tail-high, inverted position.

Flying experience:

Total all types	2 956 hours
Total on type	751 hours
Total past 90 days	162 hours
Total past 28 days	65 hours
Last 24 hours	4 hours
Previous rest period	9 hours 45 minutes

The captain joined the operator in 2008 as a first officer. He was promoted to senior first officer on 2 March 2009 and subsequently completed all the required training as specified by the airline to become a captain. He was appointed as a captain on the J41-type aircraft on 10 September 2009, 14 days before the accident.

According to the operator’s training manual, all the aircrew are required to undertake psychometric testing before the command assessment phase begins. An applicant eligible for the command assessment phase must be within 700 hours of the minimum requirement for command on their respective fleets. The captain underwent all the relevant training as outlined in the training manual, as approved by the regulator. He was upgraded 14 days prior to the accident.

The captain was also the holder of an instructor rating and was active in providing instruction within the general aviation environment.

1.5.2 Co-pilot (Pilot flying):

Nationality	South African	Gender	Female	Age	26
Licence number	*****************	Licence type	Airline Transport		
Licence valid	Yes	Type endorsed	Yes		
Ratings	C208, E120, JS41				
Last proficiency check	22 August 2009				
Last line check	4 March 2009				
Emergency and safety equipment check	10 March 2009				
CRM check	12 March 2009				
Last instrument renewal	22 August 2009				
Medical expiry date	30 April 2009				
Restrictions	Suitable corrective lenses				
Previous accidents	None				

Flying experience:

Total all types	2 002 hours
Total on type	1 027 hours
Total past 90 days	127 hours
Total past 28 days	36 hours
Last 24 hours	4 hours
Previous rest period	9 hours 45 minutes

The co-pilot possessed a valid Airline Transport Pilot's Licence (ATPL) (Aeroplane) issued by the regulator. Her PPL (Aeroplane) was first issued in 2002 after she had accumulated 60, 7 hours, mostly on a Cessna 172. In 2005, she obtained her CPL (Aeroplane). In 2006, she obtained her Grade 3 Instructor's rating and started to work as an instructor at the training school in 2007. Her ATPL (Aeroplane) was issued 16 days before the accident. There was no record of any involvement in an accident according to her personal file at the SACAA.

The co-pilot could not remember most of the events leading up to the accident; she reported that she could only remember from the taxi-phase up to the line-up position**.** The co-pilot had been issued with an ATPL 16 days before the accident.

1.5.3. Cabin Attendant:

The cabin attendant held a valid licence and a valid medical certificate at the time of the accident. She had completed all the relevant training as stipulated by the regulator and her cabin crew licence was issued on 13 March 2008, with the aircraft type endorsed on her licence. The required medical certificate, issued on 6 June 2008 with an expiry date of 30 June 2010, was endorsed with the restriction of corrective lenses.

1.5.4. Roster:

In the ten days prior to the accident, the captain had flown on five days and the co-pilot on six days. Over the same period, the captain had also completed three home reserve days and the co-pilot two home reserve days. They had both also had two days off. On the day prior to the accident, the captain and co-pilot had reported for duty at O R Tambo International Airport, their home base, at 11h45 for a planned three-sector day.

On the last sector, the aircraft had diverted from its intended destination, Pietermaritzburg, to Durban, due to poor weather. The crew had gone off duty at 19h00 and driven themselves in a hired car to their hotel 20 km away, a drive of about 20 minutes.

The crew's rest period was within the prescribed flight time limitations as called for in Regulation 121.02.10 of the South African Civil Aviation Regulations. This required a minimum rest period of nine hours under the applicable circumstances.

1.6 Aircraft Information

1.6.1 Airframe

Type	J4100	
Serial number	41069	
Manufacturer	BAE Systems (Operations) Ltd	
Date of manufacture	July 1995	
Total airframe hours (at time of accident)	27 429,20	
Last MPI (date & hours)	18 July 2009	27 104,45
Hours since last inspection	421,25	
C of A (issue date)	26 September 1995 (due to expire 25 September 2010)	
C of R (issue date) (present owner)	10 June 2008	
Operating categories	Standard Part 121	

1.6.2 Engines

Engine 1 (left-hand engine):

Type	Garret TPE331-14 GR
Serial number	P75040
Hours since new	13 406,25
Hours since overhaul	5 370,25
Cycles since new	15 411,25
Cycles since overhaul	6 320,25
Date of overhaul or manufacturer	25 August 1993 (DOM)

Engine 2 (Right-hand engine):

Type	Garret TPE331-14 HR
Serial number	P76059
Hours since new	23 747,25
Hours since overhaul	5 999,25
Cycles since new	23 978,25
Cycles since overhaul	6 127,25
Date of overhaul or manufacturer	30 April 1994 (DOM)

Engine start problems

The cabin attendant reported that after closing the main aircraft door and securing the cabin, the captain had invited her to sit on the jump seat in the cockpit. The left-hand engine (No. 1) was started first, but it sounded different to the usual engine starts, and soon thereafter, the engine was shut down. When asked why, the captain informed the cabin attendant that as the aircraft had been parked at B9 and a GPU was not available, they had had to do a battery start and that the "rotation of the engine went up to 13%, and didn't accelerate any further". According to the co-pilot, the battery voltage went down alarmingly when they started the engine, which contributed to the fact that the rotation had not continued on the percentage scale. The captain then said to the co-pilot that the same thing had happened the previous day when they were starting the engines in Maseru for the MSU/JNB flight.

The captain asked the engineer what needed to be done about the situation, and he replied that he could swop the batteries with that of the Jetstream in the parking bay next to B6 – ZS-OMZ – but this would require paperwork. Alternatively, the captain could start the right-hand engine and see if the problem persisted. The engineer then left and after some indecision, the captain decided to start the right-hand engine (No. 2). This was done successfully, and thereafter engine No. 1 was started.

During the interviews conducted by the investigation team, the co-pilot and cabin attendant said that the starting difficulties had originated from the ignition switches having been left in the “on” position the previous evening.

1.6.3 Propellers

Propeller 1 (left hand - rotating clockwise):

Type	McCauley
Serial number	040291
Hours since new	1 714,61
Hours since overhaul	Not applicable
Date of overhaul/midlife inspection	Not applicable
Date newly installed	3 October 2008

Propeller 2 (Right hand - rotating counter-clockwise):

Type	McCauley
Serial Number	050598
Hours since New	6 360,43
Hours since Overhaul	3 019,55
Date of overhaul/midlife inspection	12 December 2007
Date newly installed	25 November 2005

1.7 Meteorological information

1.7.1 The following information on the conditions at the time and date of the accident was provided by Durban ATC:

Wind direction	060º	Wind speed	11 kt	Visibility	9999
Temperature	20ºC	Cloud cover	FEW	Cloud base	1 200 m
Dew point	18°C				

1.8 Aids to navigation

1.8.1 The aircraft was equipped to navigate by VOR (VHF Omni-directional Range) and GNSS (Global Navigation Satellite System). No defects were reported prior to, or at the time of the accident.

1.9 Communications

1.9.1 Communications at the time of the accident between the aircraft and ATC (Durban Tower) were by VHF radio on frequency 118.7. The ATC transcript may be found below as Attachment A to this report.

1.10 Aerodrome information

Aerodrome location	Durban International Aerodrome
Aerodrome co-ordinates	S29˚57´56.0˝ E030˚56´57.3˝
Aerodrome elevation	33 ft AMSL
Runway designations	06/24
Runway dimensions	2 440 m x 60 m
Runway used	06
Runway surface	Tar
Approach facilities	ILS Runway 06/24; PAPI 3˚

1.10.1 All aircraft operations at the time of the accident were from runway 06 with no restrictions in effect.

1.11 Flight recorders

1.11.1 The aircraft was equipped with a cockpit voice recorder (CVR) and flight data recorder (FDR) as required by the relevant South African Civil Aviation Regulations, 1997. On 29 September 2009, the AAIB audio laboratory received the following CVR: recorder manufacturer/model: Fairchild F1000 model; recorder serial no.: 01005.

1.11.2 Both the CVR and FDR were recovered from the wreckage and successfully read out at the UK Air Accidents Investigation Branch (AAIB) laboratories. The CVR was of 30 minutes' duration, and the FDR provided just over 60 hours of data. The CVR record commenced just before first engine start and ended as the aircraft struck the ground. The CVR operates when either the aircraft battery or external electrical power is applied to the aircraft, whereas the FDR operates from electrical power provided by the engine-driven generators. The FDR record ended approximately two seconds before the CVR, due to the fact that electrical power from the generators ceases when engine RPM reduces through 60%. The final FDR record indicated an engine rpm of about 65%.

1.11.3 Engine parameters included engine RPM and torque. The throttle and condition lever positions were not recorded by the FDR. CAR Part 91.04.13(4b) does not give adequate information or guidance in terms of the number and identification of parameters to be recorded by an FDR.

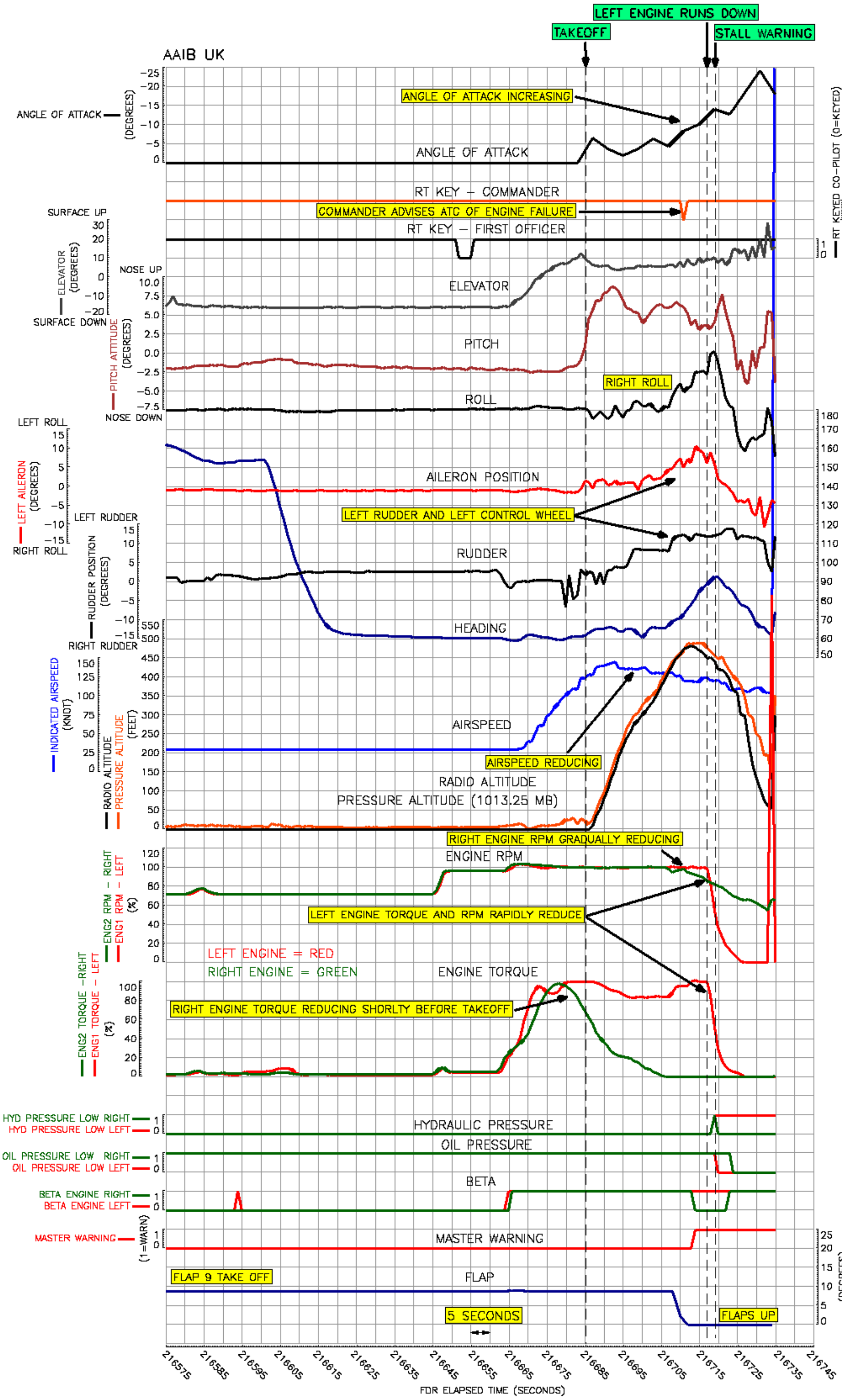

Figure 4. The FDR parameters.

1.11.4 The recorders provided confirmation that the aircraft was configured for a flap-9 takeoff and that initially the co-pilot was the pilot flying. The initial takeoff roll appeared normal, but as the aircraft accelerated through about 90 kt, 5 kt below V1, the right-hand engine torque started to reduce. As it dropped, the associated engine RPM remained at about 100% and there were no recorded warnings generated at that time. Evidence from the CVR indicates that it was at about this point that a transmission from another aircraft was made on the tower frequency, advising that smoke was emanating from ZS-NRM. The ATC relayed this information to ZS-NRM, but the commander simultaneously called "V1, rotate" as the aircraft accelerated through about 95 kt.

The aircraft became airborne at about 125 kt. Seconds later, as it was climbing through a height of about 100 ft above mean sea level (AMSL), there followed the first of a series of flight deck aural attention chimes. The first of these was confirmed by the co-pilot as being due to "right oil contamination". The aircraft continued to climb and about five seconds after the co-pilot's comment, the captain stated: "We have lost an engine, we are losing an engine". The co-pilot responded: "I have it, I have it, keeping runway track 6 000 ft. Flap is zero. We have lost an engine."

The aircraft continued to climb, but as the right engine torque reduced below 20%, the airspeed started to decay; the maximum airspeed recorded being about 145 kt at 185 ft AMSL. As the aircraft approached about 400 ft AMSL, the right engine torque had reduced to 0% and the airspeed was reducing through 132 kt. This was followed by a gradual reduction in right-engine RPM. At 440 ft AMSL, the flaps were retracted, by which time the aircraft had begun to roll progressively and turn to the right despite both left rudder and left aileron being applied.

At 490 ft AMSL, the aircraft momentarily levelled out, with the airspeed now reducing through about 120 knots. At about this point, the co-pilot stated: "We're not maintaining", which was acknowledged by the captain. This was followed by the sound of the master warning activating. At the same time, the right engine Beta discrete value indicated zero. An unidentified radio transmission also advised: "Your gear is still down." The captain was then again heard to say: "OK", just before the left engine torque and RPM indications rapidly reduced to 0%, accompanied by left-engine low oil pressure and hydraulic low pressure warnings – consistent with the left engine having been manually shut down.

The co-pilot could be heard calling for the gear to be raised, which the captain acknowledged. Further alerts could also be heard sounding. The aircraft had started to descend and as the angle of attack, which had been gradually increasing, reached approximately 14°, the stick shaker activated.

At this point, the co-pilot referred to the captain by name, saying: "Pitch forward." There was no recorded handover of control, although it appears that from this point the captain was the handling pilot. There was also no recorded acknowledgement following the taking over of control by the captain.

The aircraft continued to descend and on passing 400 ft AMSL, the right-engine low oil pressure warning activated. Various ground proximity warnings could be heard on the CVR, together with occasional stick shaker activations, until the aircraft struck the ground. The FDR stopped recording approximately two seconds before impact due to its power supply being lost as the engines ran down.

1.12 Wreckage and impact information

1.12.1 The ventral fin on the tail cone struck the ground first, followed by the propeller blades of both engines. The propeller ground marks indicated that the propellers hit the surface approximately 7 m before the right engine collided with the ground. The left engine then struck the ground. The aircraft skidded for approximately 25 m before hitting a power pole and skidding across a tarmac road. The bottom nose section of the aircraft then collided with a palisade fence and the fuselage broke apart above the wings. The distance from the first impact point to the main wreckage was 62 m and the main wreckage came to rest on a heading of 60ºM.

Figure 5. The first impact mark of the tail cone.

1.12.2 Both pilots' seats were bent forward by the impact deceleration. Both power levers were found in the full power position. Evidence suggests that the captain was not wearing his shoulder harness at the time of impact.

1.12.3 The No. 1(left-hand) engine fuel condition lever was found in the cut-off position and the No. 2 (righthand) engine fuel condition lever was found in the flight position. The elevator trim pointer was within the green arc.

Figure 6. The main wreckage.

1.13 Medical and pathological information

1.13.1 The captain, who was seriously injured, died a fortnight after the crash. A post-mortem report concluded that the cause of death was multiple organ trauma associated with blunt chest and lower limb injuries.

1.13.2 The blood toxicology report was not available at the time of release of this report. Should any of the results have a bearing on the circumstances leading to this accident, it will be treated as new evidence necessitating the re-opening of this investigation.

1.14 Fire

1.14.1 There was no pre- or post-impact fire.

1.15 Survival aspects

1.15.1 The cabin attendant reported that, after closing the main aircraft door and securing the cabin, the captain had invited her to sit on the jump seat in the cockpit for the flight. The jump seat is situated immediately in front of the cockpit door.

The Durban Airport Rescue and Fire-Fighting Services (RFFS) responded to the accident and arrived at the site outside of the airport perimeter within approximately seven minutes. They had difficulty in gaining access to the cockpit to extract the crew members, as the cabin attendant was unable to get out of her seat.

1.16 Tests and research

1.16.1 Engines

1.16.1.1 During the investigation at the accident site, the left and right engines were found to have damage to the nose cone, propellers, engine cowls, intake cowls and exhausts. The right engine rear bearing cover was found missing. Although a search was conducted at the accident site, the airport and surrounding areas, it was not recovered.

Figure 7; The right-hand engine with rear bearing cover and tail cone missing.
The insert picture shows similar parts from another engine.

1.16.1.2 Both engines were removed from the wreckage and transported to a hangar in Johannesburg for further investigation. The propellers were removed and sent to an approved facility for a teardown investigation, assisted by a representative from the propeller manufacturer. After the removal of the engine cowls, the engines were packaged and sent to the manufacturer for a further teardown investigation.

1.16.1.3 Engine No. 1 (left hand)

Prior to shipment of the engine to the manufacturer, the following was noted at the hangar facility in Johannesburg:

- The rotation of the third-stage turbine produced a corresponding rotation of the output shaft and starter/generator cooling fan;

- As viewed through the inlet, the first-stage impeller appeared to be intact;
- No visual damage to the third-stage turbine (at exhaust) was noted;
- The nose cone housing was cracked.

The engine was disassembled into modules during the teardown investigation conducted at the manufacturer's facilities, and no failures were evident.

1.16.1.4 Engine No. 2 (right hand)

Prior to shipment, the following was noted at the facility in Johannesburg:

- The rotation of the propeller produced a corresponding rotation of the turbine section;
- A review of the rear turbine bearing area disclosed that the tailcone, thermal blanket, bearing cover, rear turbine bearing inner race, roller elements, bearing cage, bearing retaining nut, and lock cup to be missing;
- The bearing cover attachment portion of the turbine bearing oil supply line and oil scavenge line had separated and was missing.

During the teardown investigation conducted at the manufacturer's facilities, the following was found:

- Metal particles were found on the magnetic chip detector;
- Metal particles were found in the oil filter;
- The second-stage turbine seal plate had failed (this was considered to be the primary cause of the engine failure);
- Damage was caused to the impeller, turbine rotor blades and turbine stator.

1.16.1.5 Second-stage turbine seal plate failures

The second-stage turbine rotating seal plate is effectively a machined plate, which is an interference fit on a boss on the turbine disc. The purpose of the rim is to serve as a mounting for the air seal between the rotor and the second-stage nozzle guide vanes. It also has the function of retaining the second-stage turbine blades and preventing these from migrating forward in their fir-tree slots. According to the engine manufacturer, there should be a small clearance between the rim and the blade roots.

In 1999, when the first case of second-stage turbine rotating seal plate rim failure was recognised, metallurgical examination revealed that a fatigue mechanism had been responsible and that the fatigue had originated at an area of sharp fretting or wear caused by contact between the rim and the blade roots. Blade movement was discounted as the cause of the contact and instead it was thought that the seal plate itself had been flexing, probably under some form of resonant condition.

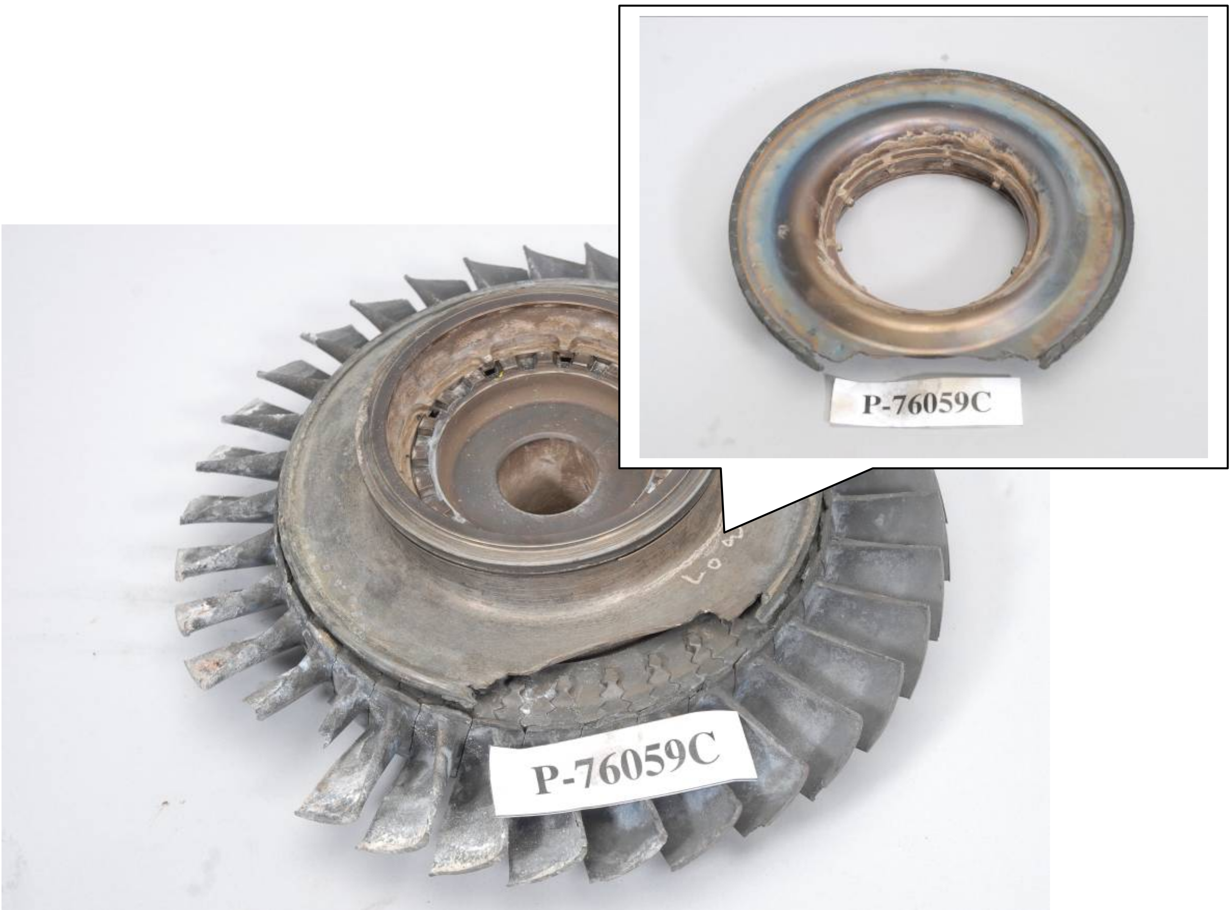

Figure 8. The right-hand engine's second-stage turbine seal plate.

The most damaging effect of the seal plate rim failure appears to be a severe imbalance of the second-stage turbine rotor. Typically, this vibration led to fatigue failures of the rear bearing oil feed and scavenge pipes with consequent oil starvation and deterioration of the bearing. It is understood that detachment of the bearing cover, tail cone and retention nut had not been seen before, except for one case that occurred in 2009.

Two previous cases of second-stage turbine seal plate rim failure, similar to the accident failure, led to the issue of Service Bulletin (SB) 72-7204 in 2001, which required examination of the seal rim for wear at each hot section inspection (HSI) of the engine, currently every 4 500 engine hours.

However, at least seven cases of second-stage turbine seal plate rim failure have occurred since the issuance of SB 72-7204 on parts which have not accumulated 4 500 hours since new (TSN), with some having failed after only some 1 500 cycles since new (CSN). These occurrences do not include the ZS-NRM failure, nor a recent case in which a Jetstream 4100 aircraft reportedly suffered two seal plate rim failure events within a 12-day period in 2009.

On the right engine of ZS-NRM, the seal plate had failed after 1 314 CSN, while the left engine was found with the seal plate rim worn beyond limits after only 570 CSN.

1.16.2 Manufacturer's conclusion on review of both engines

The report, prepared by the engine manufacturer, presents the findings of a teardown and examination conducted on a Garrett Model TPE331-14GR-901H turbo-propeller engine and a TPE331-14HR-805H turbo-propeller engine, serial numbers P-75040C and P-76059C respectively. The inspection took place at the Honeywell Investigation Laboratory in Phoenix, Arizona, on October 12-16, 2009. The inspection was conducted at the request of, and under the cognisance of, the South African Civil Aviation Authority, with accredited representation of the Air Accidents Investigation Branch and National Transportation Safety Board (examination delegated to the FAA).

The teardown examination and FDR review revealed that the left-hand engine, serial number P-75040C, was not operating or rotating at the time of impact with the ground. No pre-existing condition was found on the left engine that would have interfered with normal operation.

The teardown examination and FDR review revealed that the right engine, serial number P-76059C, experienced a pre-impact separation of the second-stage turbine seal plate. The seal plate separation created an imbalance of the power section rotating group, resulting in a fatigue fracture of the turbine-bearing oil supply tube and subsequent damage to the turbine bearing. The turbine bearing damage resulted in the loss of the power section centreline positioning; thus the loss of turbine efficiency proportional to the ability of the engine to produce positive torque to the propeller.

1.16.3 Propellers

Note: The propellers were dismantled at an independent, approved facility in South Africa from 12-16 October 2009. A specialist from the propeller manufacturer assisted the investigation team.

1.16.3.1 Observations of the damage to the No. 1 propeller (left – rotating clockwise):

i. As found, all the blades were on the latches with a low blade angle;
ii. The propeller blades were bent aft and found at a low blade angle at the accident site. Examination of the pitch change mechanism found it to be fractured, allowing the propeller blades to move within the hub;
iii. The blades did not show any significant signs of power during the impact sequence;
iv. No visual assembly anomalies or maintenance errors were noted during the propeller teardown and examination.

1.16.3.2 Observations of the damage to the No. 2 propeller (right – rotating counter-clockwise):

i. All the link pins were broken and it could not be established whether the propeller blades were on the latches at the time of impact;

ii. The propeller blades were curled in the direction opposite to rotation, consistent with the propeller blades rotating at impact. The amount of propeller blade curling is consistent with the propeller rotating at reduced speed. The propeller blades were found at the accident site in the reverse pitch position;

iii. This is confirmed by the damage sustained to the trailing edges of all the blades as well as the twisting of the blades. According to the FDR, it would also appear that the propeller RPM at the time of impact was approximately 56%;

iv. No visual assembly anomalies or maintenance errors were noted during the propeller teardown and examination.

Figure 9. Damage to No. 1 propeller.

Figure 10. Damage to No. 2 propeller.

1.16.4 Propeller manufacturer's conclusion

1.16.4.1 The status of each propeller at impact was established from a combination of the physical examination and FDR data. It was concluded that the left propeller had been feathered on impact and was not rotating: the "as found" low blade angle was explained by fracture of the pitch change mechanism, which had forced the blades out of the feathered position on impact.

The right propeller, despite being found in the reverse pitch condition, had been rotating at a low speed and with a low blade angle on impact. Information from the FDR indicates that the RPM was about 65%. The blades had moved after initial impact due to fracture of all five pitch link pins in the hub.

All fractures and disconnections were considered to be as a result of impact forces and both propellers appeared to be serviceable prior to impact.

1.17 Organisational and management information

1.17.1 The operator's records of flight operations with regard to training and assessment procedures were reviewed by investigators of the AIID (Accident and Incident Investigation Department). Following the review the recommendation was issued by AIID to conduct a comprehensive audit in respect of the compliance by the operator. During the audit, findings were identified which led to the suspension of both the certificate of operation and the certificate of airworthiness. The operator then appointed two experts with the mandate to review the procedures, policies, culture, recruitment, and training within the flight operations department. The reason was to highlight the shortcomings and to make recommendations to the operator to improve and assist with the implementations.

1.17.2 The last SACAA audit of the operator was performed on 26 March 2009. No major findings were recorded.

1.17.3 The operator was in possession of a valid Part 121 operating certificate (AOC; FO 4329), which had been issued on 19 April 2009 and was due to expire on 30 April 2010. The aircraft in question was duly authorised to operate under the AOC.

1.17.4 The Aircraft Maintenance Organisation (AMO) was in possession of a valid AMO approval issued on 1 May 2009 and due to expire on 30 April 2010. The last audit of the AMO was performed on 7 April 2009. The last maintenance inspection performed on the aircraft prior to the accident was certified by the AMO on 18 July 2009.

1.17.5 The operator had developed and implemented standard operating procedures which pilots were to follow during emergencies. Competency of crew was verified during an actual flight test or in a simulator.

1.17.6 According to the operator's flight operations manual, it is a requirement that pilots should be trained and competent to take off, fly, and land these aircraft with one engine inoperative. Pilots are required to maintain competency and are regularly assessed to ensure that such competency is maintained.

1.17.7 Design and certification requirements of the Jetstream 4100 type aircraft call for the aircraft to be capable of take-off, climb, *en route* flight and landing should one engine become inoperative. This is demonstrated to the relevant certificating authority during the aircraft's certification process by the designer and manufacturer.

1.17.8 The Jetstream 4100 aircraft has been certificated to require an operating crew of two pilots and is able of taking off and climbing should one engine fail, even at its maximum certificated mass.

1.17.9 According to the operator's flight operations training manual (Vol D-39-2.2.8), the crew resource management training is provided to flight crew members together with initial training. Recurrent crew resource management (CRM) training is also conducted at the discretion of the chief training captain.

Training includes personality profiles, developing leadership skills, effective communication, decision-making, poor judgement chains, self-management skills, attitudes, self-image, handling stress, responsibility, conflict resolution, prioritising situational awareness and interface between man and machine.

1.17.10 The crew flying ZS-NRM had received CRM training, but it seems that in this accident the CRM process failed the crew, because interpersonal communication, leadership, and decision-making in the cockpit was not evident.

1.17.11 The following subparts – under "flight crew composition" – of the operator's flight operations manual were reviewed at the time of compiling this report:

- **Flight deck crew:** Aircraft certified above 5 700kg – minimum crew complement of two (2) pilots, or as directed by the manufacturer's aircraft flight operations manual;
- **Crew complement:** The crew complement shall consist of two (2) flight deck crew and cabin crew. The flight deck crew shall consist of 1 (one) Captain and 1 (one) First Officer, as designated by OCC (operation control centre);
- **Cabin Crew:** According to Civil Aviation Technical Standards (CATS) 121.02.5, the minimum required number of flight attendants shall be not less than one (1) flight attendant per fifty (50) passengers, or part thereof installed on the same deck;
- **Qualifications:** All flight crew members shall be properly licensed and current on the type of aircraft, and for the specific operation type to be undertaken (e.g. Instrument Flight (IF) – rating and medical);
- **Designation of pilot in command:** The operator's aircraft is operated based on the two-crew concept, comprising the captain and the first officer. The flying is normally (at the discretion of the captain), done leg-for-leg and the pilot operating the controls is referred to as the Pilot Flying (PF) and the non-flying pilot is referred to as the Pilot Not Flying (PNF). Please also take note that the flight attendants are also part of the multi-crew operation and are vital in the general safety and running of an operator. They are also responsible to the captain.
- **Responsibility of all crew:** All crew must be fully conversant, and comply with all operator's orders and notices, pertaining to their duties and responsibilities, statutory regulations and state-published documents;

- **Responsibility of the pilot in command:** The captain is the person responsible for the operation and safety of the aircraft, from the moment the aircraft is ready to move for the purpose of taking off, until the moment it finally comes to rest at the end of the flight and the engines are shut down, regardless of whether or not he is manipulating the controls. He/she will be the holder of a valid P1 rating on the aircraft type. The captain assigned for the flight shall be responsible for the safety of all crew, passengers and cargo on board when the doors are closed;
- **Inexperienced Flight Crew Operations:** It is the policy of the operator that no newly appointed first officer on any type shall be rostered with inexperienced captains, with less than 4 months' operational flying time, on the specific type as captain. No newly appointed captain shall be rostered to fly with inexperienced first officers, with less than 4 months' operational flying time, on the specific type as First Officer;
- These limits may be reduced if the person has previous company experience in terms of time on type and destinations. This waiver will have to be approved by the chief pilot and the specific fleet captain.

1.17.12 The investigation team reviewed the training file of the captain. During the captain's PICUS (Pilot In Command Under Supervision) training, it was found that the gradings were between 1 and 5 and on average the captain scored a 3, (1 means below standard, 3 means satisfactory and 5 means a high standard). It is not clear why the operator had documented a 3 as satisfactory whilst there was a 4. One would expect that on average an ATP would score at least a 4 on his competency assessments.

1.17.13 The final assessment on the J41 simulator recurrent training by the training captain stated that the captain flew well and showed good CRM qualities. The captain was able to identify and rectify problems quickly and with confidence. In conclusion, the assessment said that the captain had no problem adapting to the left-hand seat quickly.

1.17.14 The training was completed over a period of three days, with a total of 12 hours logged, and covered the syllabus as laid down in the operations manual.

1.18 Additional information

(From Jetstream Series 4100; Flight Manual J41.01; Aircraft-ZS-NRM)

1.18.1 Engine failure on take-off procedures:

Before decision speed (V1):

- Power levers ……… ground range
- Apply maximum braking
- Apply reverse thrust

- Maintain directional control

When aircraft has stopped, for failed engine:

- Condition lever ……… Feather/Shut off
- Fuel and hydraulic LP valve captions …. Confirm SHUT

If fuel and hydraulic valve caption do not indicate SHUT:

- Fuel and hydraulic valve switches …….. Select SHUT
- Flow selector ……… Off
- Propeller ice protector ……. Off
- Engine/ELEV ice

At or after decision speed (V1):

- Continue the take-off
- Maintain directional control, rotate at Vr
- Landing gear selector…....UP
- Accelerate to (if required), and maintain, take-off safety speed V2

When at 500 ft AMSL, identify failed engine and for the affected engine:

- Power lever ………….. Flight idle
- Condition lever ……… Feather/Shut off – confirm LP valve captions indicate SHUT

If LP valve captions do not indicate SHUT:

- Fuel and hydraulic LP valve switches ………. SHUT.

1.18.2 QRH (quick-reference handbook) procedures – engine failure before V1

At or after decision speed (V1) with automatic power reserve (APR) armed:
Caution: The exhaust gas temperature (EGT) of the operating engine will reduce after 10 minutes of APR operations.

- Continue the take-off
- Maintain directional control, rotate at Vr
- Landing gear……….Up
- Accelerate to and maintain V2

If the "PWR" switch is armed for take-off and APR caption is not on, or there is not a torque increase of the operating engine.

- [APR O/RIDE] SWITCH…………..Press and check for torque increase

At 500 ft (150 m) AAL, identify failed engine and for the affected engine:

- Power lever……….Flight idle
- Condition lever…….Feather/shutoff

- Fuel and hydraulic LP valve captions……. Confirm shut

If fuel and LP valve captions do not indicate, shut:

- Fuel and hydraulic LP valve captions….Confirm shut
- If fuel and LP valve captions do not indicate shut:
- Fuel and hydraulic LP valve switches…. Select SHUT

For affected engine:

- Flow selector……….Off
- Propeller ice protection switch…….Off
- ENG/ELEV ice protection switch……Off
- GEN switch……..Off

NOTE: If the APR O/RIDE switch has been used, it must be pressed again to deselect APR.

NOTE: If the engine failure is accompanied by other engine emergencies, such as fire, severe vibrations or NTS (negative torque system) failure, the engine may be feathered below 500 ft (150 m).

Use net take-off flight-path option in accordance with pre-flight briefing

1.18.3 Automatic power reserve (APR)

The APR system is used to increase engine power in the event of a single-engine failure on take-off or landing. This is accomplished by adding more fuel through the enrichment torque motor. With the APR switch in the “ARMED” position, RPM ever at high, and power lever above 65% power, if the integrated electronic control (IEC) detects a decrease in torque on the opposite engine, it will open the enrichment valve to obtain a torque value 10% higher than target torque, but limited to a maximum torque of 100%. The IEC will also increase the variable red line (VRL)[1] by a minimum of 38°C to prevent the torque and temperature limiter from bypassing the extra fuel.

The VRL indicates the engine EGT limit during engine operation.

1.18.4 **Aircraft performance**

The takeoff and landing data (TOLD) card for the accident flight was recovered from the aircraft and a copy of the load-sheet obtained. The recorded information for a normal (no water/methanol), flap-9 takeoff was:

- Takeoff weight of 8 240 kg
- OAT 15°C
- V1/VR 95 kt
- V2 (Flap-9) 103 kt

- V2 (Flap zero) 116 kt
- VYSC (single-engine *en route* speed) 120 kt
- 60 kg water/methanol on board.

These figures have been confirmed to be correct for the given conditions and take-off weight. The maximum takeoff weight for the aircraft under the prevailing conditions was 10 886 kg.

1.18.5 Fuel

The captain's voyage report recorded a start-up fuel figure of 1 410 kg for the accident flight. The aircraft had been refuelled at Durban at 1842Z on the evening prior to the accident, uploading 712 litres of Jet A1 fuel.

Fuel sample tests were carried out by BP Southern Africa (SA) within hours of the accident. Test results indicated that the specification requirements of the AFQROS joint fuel system for Jet-1were met.

1.18.6 Abnormal and emergency procedures

The following information is taken from the operator's flight operations manual (Section 2; page 2 - 4):

Abnormal and emergency procedures:

These procedures would be strictly in accordance with the individual aircraft flight manual (AFM) of the aircraft to be utilised. Also, refer to the specific standard operating procedures as contained in the controlled document Airlink Flight Operations Manual Volume B part 1.

Pilots are to use the DODAR (diagnosis, options, decision, assign and review) decision-making process to manage abnormal occurrences. This process is initiated by the captain, and is normally carried out after any appropriate checklist has been completed. This is valid for non-technical occurrences as well as technical ones. If the captain is PF, he may choose to delegate the PF role to the FO unless otherwise stated for that applicable emergency.

DODAR stands for:

Diagnosis	Determine the nature of the problem
Options	Consider the alternative courses of action available
Decision	Decide which course of action to take
Assign tasks	Allocate PF, management, RT, cabin crew tasks etc as appropriate
Review and Risk Assessment	Review the first four steps, especially in the light of any change in the situation or new information,

so that the decision followed is the most suitable and tasks are assigned or re-assigned to suit any change of decision. Assess the risk level of the current situation.

During each step of the DODAR process, the captain is to obtain feedback and input from the first officer.

1.18.7 Detailed review of FDR and CVR information

The last one minute and six seconds of the CVR were analysed and combined with the information obtained from the FDR. A related FDR graph is included as an attachment in 1.11 “Flight recorders” (Figure 4).

The first officer was the co-pilot flying (PF) and the captain was pilot not flying (PNF).

From the FDR data, it is evident that the right engine failed after 90 kt but prior to V1, as indicated by the right engine torque, which started reducing. This occurred as the tower advised the co-pilot of a smoke trail behind the aircraft. All hydraulic and oil pressures were still normal at this stage. During rotation at 05:57:01Z, an unknown aircraft transmitted the words: “Severe smoke.”

A warning sound (a ping) is then heard and the co-pilot states: “Right oil contamination”. The FDR data indicates that the aircraft was at a pressure altitude of approximately 100 ft AMSL and at an indicated airspeed of 140 kt.

At 05:57:10Z, the captain states: “We have lost an engine” and then “We are losing an engine”. At 05:57:14Z, the co-pilot responds: “I have it, I have it … keeping runway track six thousand feet … flap is zero” and confirmed: “We have lost an engine.” The FDR now indicates a pressure altitude of approximately 350 ft with an indicated airspeed of 140 kt, and the RPM of both engines at 100%. The left engine torque decreases from 104% to approximately 85% while torque of the right engine reduces to about 83%. The hydraulic and oil pressures are normal.

At 05:57:25Z, the captain notifies the tower: “Okay we’ve lost an engine”. The associated pressure altitude is approximately 480 ft with an indicated airspeed of 120 kt. The right-hand and left-hand engine rpm is at 100% with the left-hand engine torque increasing to 104% and hydraulic and oil pressure normal. The co-pilot comments: “We’re not maintaining.”

At 05:57:28Z, three audible warning sounds (pings) are heard and the master warning switch is activated. The right engine beta goes to zero. The left engine torque is at 100%. The pressure altitude is at approximately 490 ft and indicated airspeed is 120 kt. An unidentified transmission advises: “Your gear is still down.”

At 05:57:30Z, the co-pilot states: “Gear up”, followed by the captain saying: “OK gear up.” However, the left engine now spools down from 100% to zero within seven seconds. The pressure altitude is approximately 480 ft with an indicated airspeed of 125 kt.

At 05:57:33, three audible warning sounds (pings) are heard together with stick shaker activation. The indicated airspeed reduces to approximately 117 kt with the angle of attack at 14 degrees. The FDR indicates low hydraulic pressure and low oil pressure in the right-hand engine.

A clicking sound like a switch or handle moving is then heard with an associated sound of an engine running down. The co-pilot states: “Wait, wait, pitch forward, captain.” The pressure altitude is approximately 450 ft, indicated airspeed is 115 kt and pitch attitude is 7,5° nose up. A ground proximity warning system (GPWS) alert of “Don’t sink” is followed immediately by three audible pings.

At 05:57:39Z, the stick shaker is heard again followed by three audible warning pings. The associated pressure altitude is approximately 350 ft with an indicated airspeed of 110 kt. The pitch attitude is -2,5° nose down, the angle of attack is 14° and flap setting is zero. The co-pilot comments: “Fly it out of here,” and this is followed by the GPWS stating: “Too low.” Another three warning pings are heard, together with a stick shaker sound in the background and the co-pilot states: “Gear is up flaps is***” and the captain confirms: “Gear is up flaps***”. The FDR now indicates a pressure altitude of approximately 150 ft and an indicated airspeed of 70 kt. The pitch attitude is 2,5° nose up with a flap setting of zero and a further three warning pings are heard.

At 05:57:52, the CVR recording stops.

1.18.8 FDR loss of power

FDR power was lost about two seconds before impact due to both generators dropping offline, as the No. 1 engine was shut down and the No. 2 engine failed and was spooling down. Recorded data of the last two seconds of the flight is therefore not available. It should be noted that the settings of the throttle levers and condition levers are not parameters recorded on the FDR.

1.19 Useful or effective investigation techniques

Not applicable.

2. ANALYSIS

2.1 The aircraft was on a repositioning flight from Durban International Airport to Pietermaritzburg Airport with only the three crew members on board. During the take-off roll, smoke was seen coming from the aircraft’s right-hand engine. The aircraft became airborne and climbed to approximately 500 ft AMSL before losing altitude and making a forced landing on a small field in a residential area about 1,4 km from the end of the departure runway.

2.2 The failure of the right-hand engine occurred shortly before the aircraft reached V1. The warning passed to the crew over the radio was received just as the captain called for rotation and there is no evidence that either pilot heard, or understood the significance of the messages being passed at that point. The most obvious indication of a problem would have been a drop in the right engine torque. As there were no apparent associated cockpit alerts, had neither of the pilots been monitoring the engine instruments at that point, this cue would have been missed. As the engine torque dropped, the captain might well have experienced the aircraft swinging to the right, but the cause might not have been recognised in the short amount of time between the failure and the call to rotate. However, considering the experience that both pilots had, this oversight seems surprising.

2.3 After rotation, the failure of an engine was identified. However, key points in the appropriate SOPs were not followed. The co-pilot correctly identified the oil contamination warning referring to the right-hand engine, and it should have been apparent that the aircraft was rolling to the right as well. This, together with the different torque indications, should have indicated which engine had failed, yet there appears to have been no positive attempt between the pilots to identify the problem. There was a gradual loss of control with the captain seemingly attempting to feather the propeller on the failed engine quickly in order to regain control. In doing so, he inadvertently selected the wrong engine. Having done so, a forced landing became inevitable.

2.4 The actions of the pilots were possibly affected by the reports of smoke and the gradual loss of control, both of which would have created a heightened degree of urgency. The operator’s training procedures were apparently adequate and neither pilot had any major problems identified in their training records. Both pilots should have been capable of successfully handling the failure.

2.5 The captain had been involved in a very similar accident on 21 August 2005. The ATC had cleared the captain to land on runway 05 at Virginia Aerodrome in KwaZulu-Natal Province. When the captain was on short finals, the tower noticed that the aircraft was drifting away from the runway centreline and called the pilot. He stated that he was experiencing an engine problem and was initiating a go-around. The aircraft turned out to the left and away from the runway centreline, and the pilot allowed the aircraft to continue flying over the nearby M4 motorway and then towards a residential area. The aircraft struck the roof of a private home and came to rest in a tail-high, inverted position.

It thus appears that on both occasions the pilot had difficulty in controlling the aircraft after an engine failure.

2.6 The No. 2 or right-hand engine failed on rotation and a power reduction occurred on the No. 1 engine as the aircraft climbed to about 480 ft AMSL. The aircraft was seen to climb and thereafter descended and struck the ground. The total time from start of the take-off roll until impact was about 110 seconds.

2.7 Analysis of the FDR data (Figure 4) revealed that during take-off, at about the moment of rotation, five seconds before actually lifting off the runway, the right-hand engine failed and the thrust gradually reduced to zero in about 25 seconds. The take-off was continued. As shown by the FDR data, the dynamic effects caused by the failing engine were minimal, although the aircraft entered two small rudder pulses to the right immediately after the engine failure. The aircraft started climbing and the captain initially maintained approximate runway heading with a small, but increasing rudder input to the left. The bank angle (roll) varied slightly around wings-level; roll control power by the ailerons was adequately available. Despite the reduction of thrust from the right-hand engine, the airspeed continued to increase for about 12 seconds to approximately 135 kt, which was still much higher than the required V_2 (103 kt) for this flight phase. The captain increased the rudder deflection for maintaining the heading, but allowed a small bank angle to the right, into the inoperative engine, rather than away from it. Consequently, the drag must have increased and as a result, the airspeed started to decrease. The bank angle could still be controlled using the ailerons, but was not five degrees (or less, as is preferred by the manufacturer) away from the inoperative engine, as is required for minimum drag and lowest possible minimum control speed while the thrust is asymmetrical.

2.8 When the decreasing airspeed reached approximately 127 kt (at 05:57:22), the aircraft started rolling to the right. Instead of deflecting the ailerons to the left in the first place as required to prevent the roll, the pilot had allowed the roll to begin. Left aileron input was then increased to 10° out of a maximum 14°, but this was insufficient, at the decreasing actual airspeed, for the ailerons to generate a high enough rolling moment to counter the propulsive thrust rolling moment generated by the blown wing section behind propeller No. 1. Lateral (roll) control was lost at this point (05:57:22). The indicated airspeed had decreased below the actual lateral minimum control speed for the given (less than maximum) aileron deflection and thrust setting.

2.9 The torque of the No. 1 (left) engine, which was slightly reduced to approximately 85% for unknown reasons, was then slowly increased to over 100% in 10 seconds. The increased engine torque increased the thrust yawing moment (and the rolling moment due to thrust) even more. An increase of opposite rudder deflection can be observed, but was not high enough (it was not more than 12° of the available 24°) to prevent the yawing from increasing to the right and maintain the heading at and below airspeed of about 125 kt. Directional control was lost as well at this point (05:57:23). The actual (directional) minimum control speed with only 14° of the available 24 degrees of rudder deflection, the actual engine thrust and the actual bank angle was 125 kt.

2.10 Just after the torque increase started (at 05:57:23), the flaps were selected up. The flaps may have an influence on V_{MCA} (minimum control speed) because the effect of the airflow striking the vertical tail. The flap handle might also be mechanised to switch on or increase the rudder boosting; this will have an effect on the value of V_{MCA} and thereby the controllability of the aircraft.

2.11 From 05:57:23, the aircraft kept rolling and yawing to the right, despite opposite control inputs. The forces generated by these limited (less than maximum) control deflections and the actual airspeed were obviously not high enough to counter the propulsive thrust rolling and yawing moments. Since both lateral and directional control were lost at an indicated airspeed of about 125 kt, this airspeed was obviously the actual V_{MCA} of the aircraft at that instant, with the actual values of power setting, control deflections, bank angle, centre of gravity, weight, etc. This V_{MCA} was higher than that listed in the aircraft flight manual because the actual bank angle and control deflections were not the same as those used to determine the V_{MCA} and take-off speeds (V_R and V_2) in the manual. In addition, V_{MCA} could have been increased by flap retraction (at 05:57:23) or by gear retraction (at approximately 05:57:30), thereby lessening the controllability of the aircraft.

2.12 At 05:57:31, the torque of the other engine also suddenly decreased to zero within ten seconds. Following this total power loss, there was no asymmetrical thrust anymore, and hence no adverse thrust yawing and rolling moments. The graphs in Figure 4 show that lateral and directional control was restored as soon as the torque of the left engine decreased below approximately 80% (at 05:57:35). The deflections of rudder and aileron at that moment were sufficient to counter the reducing engine yawing moment from thereon. The altitude was about 450 ft AMSL. Because the ailerons and rudder were still deflected to the left, the aircraft started rolling and yawing to the left. The rolling was allowed to continue past wings-level to the left, while the rudder deflection was maintained, without reason, because the thrust yawing moment was already zero. The resulting sideslip must have increased the rate of descent. The thrust reduction instantly decreased actual V_{MCA} to a much lower level, in any case below the actual indicated airspeed, because the aircraft responded to the ailerons and rudder that were still deflected to the left by rolling and yawing to the left. An emergency gear-up landing followed ten seconds later.

2.13 The pilot did not apply lateral and directional controls as would be required for maintaining control after engine failure. This might have been due to inappropriate engine-out training and incomplete engine emergency procedures that were not in agreement with the way that aircraft are flight-tested or in accordance with the minimum control speeds as determined by test pilots and flight test engineers.

2.14 The captain and co-pilot were correctly licensed with valid medical certificates. There was no record of any anomaly that could have affected them or could have contributed to the cause of the accident.

2.15 The power reduction of the left engine appears to have been the result of misidentification and shutdown of the engine. This has been verified from analysis of the FDR and CVR information. No clear reason for this misidentification could be established, other than a complete deviation from the operator's SOPs.

2.16 The aircraft was serviceable when certified for the flight and no record of any malfunction or defect was recorded that could have contributed to the accident, or caused the accident.

2.17 FDR data indicated a commanded shutdown of the No.1 engine, P-75040C. This is further supported by the noted position of the condition lever during the wreckage review conducted shortly after the accident. It should be noted that engine P-75040C was neither operating nor rotating, according to the FDR data. The aircraft was equipped with an APR system, which is used to increase engine power in the event of a single-engine failure on take-off or landing. This is accomplished by adding more fuel through the enrichment torque motor. With the captain shutting down the No. 1 engine, it was not possible for the APR to boost the No. 2 engine automatically and thereby allow a single engine take-off.

2.18 A review of the FCU test and design requirements indicated that the fuel shut-off valves of both engines were in the closed position following the accident flight.

2.19 The prevailing weather conditions at the time of the accident were considered not to be a factor in this accident. The wind direction was reported to be from the north-east at a speed of between 11 and 18 kt. The temperature was 20°C.

2.20 The teardown examination and FDR review disclosed that the left engine, serial number P-75040C, was not operating or rotating at the time of impact with the ground. No pre-existing condition was found on the engine that could have interfered with normal operations.

2.21 The teardown examinations and FDR review disclosed that the right engine, serial number P-76059C, had experienced a pre-impact separation of the second-stage turbine seal plate. The second-stage turbine seal plate separation created an imbalance of the power section-rotating group, resulting in a fatigue fracture of the turbine bearing oil-supply tube and subsequent damage to the turbine bearing. The turbine bearing damage resulted in the loss of the power section centreline positioning; thus the loss of turbine efficiency proportional to the ability of the engine to produce positive torque to the propeller.

2.22 The event began with the separation of the second-stage turbine seal plate rim, most likely during the accident flight. The oil supply line separated in fatigue shortly after the second-stage turbine seal plate rim separation. The turbine bearing appeared to have begun to degrade because of oil starvation approximately 17 seconds after acceleration to 96% speed.

2.23 As the bearing deterioration progressed, the bearing initially lost radial clearance because of the loss of cooling resulting from the separated oil supply line. The loss of clearance was severe enough to lock the inner and outer races, which caused the outer race to spin in the bearing retainer. The resultant drag transmitted into the inner race caused the bearing nut locking retainer to become ineffective, and the bearing retaining nut backed off the shaft, allowing the inner race and rollers to separate.

2.24 It is clear from SB72-7204 that the consequences of seal plate failure were seen as an in-flight shutdown (IFSD) due to loss of oil contents caused by cracking of the rear bearing oil-feed pipes. Figures presented by the manufacturer showed that the problem, whilst clearly undesirable, did not exceed the acceptable IFSD rate. Some analysis was carried out which concluded that the seal plate was resonating and therefore contacting the disc and turbine blade roots, leading to fretting and the initiation of fatigue of the plate. This would inevitably require re-design of the seal plate, which in turn would require extensive testing to ensure that the resonant condition had been eliminated. Although the issue remained "under discussion", as far as the manufacturer's airworthiness department was concerned, the funding required to do this work had not been released, since it was believed that the SB was containing the problem within acceptable limits.

2.25 As noted in paragraph 1.16.15, two cases of second-stage turbine seal plate failure were discovered in 2009, prior to the accident to ZS-NRM. It is not known why they both occurred within such a short period, but the additional information that they had failed at relatively low hours and substantially before the time between HSI inspections had elapsed, raised concerns which led to the SACAA issuing the Safety Recommendation described in paragraph 4.3.

2.26 No defects other than the second-stage turbine seal plate failure were found in the right engine and all the physical evidence and recorded data point to this as being the cause of failure of the engine. There were no defects found on the left engine other than the seal plate which was worn beyond limits. The physical and recorded evidence shows that the left engine was shut down and its propeller feathered.

2.27 Following complete deterioration of the turbine bearing, the turbine blades began to make contact with the surrounding static structure, leading to loss of engine-produced positive torque. Approximately 74 seconds from the initial acceleration to 96% speed, the engine lost oil pressure. At some point during the event, probably after the aircraft had cleared the end of the runway, the turbine sump cover departed from the engine.

2.28 The type and extent of blade and propeller damage is indicative of low power. Additionally, FDR data clearly showed a reduction in power and RPM for both engines prior to impact.

2.29 All indications are that the left propeller was feathered on impact. No rotational damage was noted to indicate that the propeller had not been feathered during the crash sequence. Had the propeller not been feathered, the expectation is that some RPM would have been recorded, as well as some torque from the air loads back-driving the propeller. Furthermore, the damage to the blades (which were all bent aft) is more consistent with the propeller having stopped rather than having been rotating on impact.

2.30 All indications are that the right propeller was not feathered on impact. The FDR shows 65% engine RPM seconds before the impact. Had the propeller been feathered, no such RPM would have been recorded. These results also accord with a degraded engine; there is a loss of HPT efficiency (zero torque at the time of impact), and the propeller rotation recorded on the FDR is consistent with air loads slightly back-driving the propeller. It appears that the propeller was wind milling at the time of the accident, but was forced to the reverse-blade angle position due to crash impact forces.

2.31 According to the operator's flight operations manual, pilots are to use the DODAR decision-making process to manage abnormal or emergency occurrences. This is initiated by the captain, and is normally carried out after any appropriate checklist has been completed. It is valid for non-technical as well as technical occurrences. The investigation revealed no indication that the procedure had been followed.

2.32 The elevator data in Figure 4 shows that during the take-off roll, the pilot slowly increased the elevator deflection while the airspeed increased. At airspeed V_R, the elevator was eight degrees up, but the aircraft stayed on the ground. Then the elevator was lowered a little while the pitch increased. The aircraft was not positively rotated from the runway using the elevator – a rather unusual take-off technique. Despite the increased elevator deflection, the aircraft took off only when the airspeed was 125 kt, 22 kt higher than the presented take-off safety speed V_2 of 103 kt (paragraph 1.18.4).

3. CONCLUSION

3.1 Findings

3.1.1 Aircraft design and certification requirements call for the capability of a multiple-engine aircraft to continue with take-off, climb, *en route* flight and landing, should one engine become inoperative. This is demonstrated to the relevant certificating authority by the designer and manufacturer during the aircraft's certification process.

3.1.2 The Jetstream 4100 aircraft is certificated to require an operating crew of two pilots and is able to take off and climb should one engine fail, even at its maximum certificated mass.

3.1.3 It is a requirement that pilots should be trained and competent to take off, fly, and land such aircraft with one engine inoperative. Pilots are required to maintain competency and are regularly assessed to ensure that such competency is maintained.

3.1.4 The operator has defined SOPs which its pilots are to follow during emergencies. Such competency is again verified in an actual flight test or in a simulator.

3.1.5 A smoke trail was observed during the take-off roll and the ATC advised the crew accordingly. However, this could only be transmitted to the pilot during and on rotation, thus excluding the possibility of an aborted take-off.

3.1.6 The right-hand engine failed on rotation and a power reduction occurred on the left-hand engine as the aircraft climbed to about 480 ft AMSL.

3.1.7 The aircraft was seen to climb and thereafter descend and strike the ground. The total time from start of the take-off roll until impact was about 110 seconds.

3.1.8 The torque of the operating left engine was allowed to decrease to 80% following the failure of the right engine. When the torque of the left engine was again increased to 104%, both lateral and directional control was lost because aileron and rudder deflections were too small. Control was regained following the inadvertent shutdown of the left engine.

3.1.10 It has been verified that the aircraft's mass was such that it should have been able to have continued to climb and return to land on one engine.

3.1.11 Rescue and fire-fighting services responded appropriately, after the accident was reported to them by the ATC.

3.1.12 The three crew members were seriously injured and a member of the public was injured in the vicinity of the accident site. The captain died from his injuries before investigators could interview him.

3.1.13 As the member of the public was struck by the aircraft without warning; he was unable to add any useful information on the aircraft's movements before the crash.

3.1.14 Investigators interviewed the two surviving crew members. The first officer, who had been the designated PF, could no longer recall any details of the take-off and subsequent accident. Fortunately, she had shared some of these details with her husband during the first two days after the accident, and he was able to pass these on to the investigators. The investigators consulted the doctors and it was concluded that it was possible for the first officer not to have remembered certain parts of the event.

3.1.15 It was verified by means of a teardown examination that the No. 1 engine had in fact been serviceable throughout the flight.

3.1.16 Teardown of the No. 2 engine established that it had suffered a catastrophic failure due to a fatigue failure of the second-stage rotating air seal.

3.1.17 This kind of failure appears to be the 13th known similar failure as stated in paragraph 1.16.1.5 above. One of these failures occurred on the operator's aircraft where the crew was able to abort the take-off. What is of concern is that the number of cycles at which these failures occur indicates a decreasing trend.

3.1.18 The crew flying ZS-NRM had been provided with CRM training, but it seems that in this accident the CRM process failed the crew, because interpersonal communication, leadership, and decision-making in the cockpit was not evident.

3.1.19 The power reduction of the serviceable No. 1 engine appears to have been the result of a misidentification and shutdown of the engine. This has been concluded from analysis of the DFDR and CVR information.

3.1.20 No clear reason for this misidentification could be established, other than a complete deviation from the operator's SOPs and failure to apply the CRM.

3.1.21 Review of the training and assessment procedures of the operator did not identify any deviation or known training issues.

3.1.22 The captain had been upgraded 14 days prior to the accident and the first officer had been issued with an ATPL 16 days before the accident.

3.2 Probable Cause/s

3.2.1 Engine failure after takeoff followed by inappropriate crew response, resulting in the loss of both lateral and directional control, the misidentification of the failed engine, and subsequent shutdown of the remaining serviceable engine.

3.2.2 Contributing factors:

- Separation of the second-stage turbine seal plate rim;
- Failure of the captain and first officer to implement any crew resource management procedures as prescribed in the operator's training manual;
- The crew's failure to follow the correct after take-off engine failure procedures as prescribed in the aircraft's flight manual.

4. SAFETY RECOMMENDATIONS

4.1 As a result of the deviation from the prescribed SOPs, it is recommended that:

The SACAA conducts a comprehensive audit of compliance with all aspects of its Air Operator Certificate requirements, including its training procedures and assessments of the operator involved. This recommendation was actioned by SACAA and a satisfactory action plan, which was implemented, was submitted by the operator to SACAA.

4.2 Because of the inappropriate crew response to propulsion system malfunction that resulted in the loss of control prior to shutting down the wrong engine, it is recommended that:

- The SACAA conducts a comprehensive audit of the compliance with all aspects of engine inoperative training at flight schools and that more emphasis is placed on simulator training.

4.3 The SACAA therefore makes the following safety recommendation to the Federal Aviation Administration (FAA):

The FAA should require Honeywell Aerospace to expedite efforts to produce an engineering solution to the problem of second-stage turbine rotating air seal failures on Honeywell TPE331-14G/H engines.

5. ATTACHMENTS

5.1 Attachment A: ATC transcript.

Report reviewed and amended by the Advisory Safety Panel

-END-

Attachment A: ATC transcript

Time	Station transmitting	
05:10:59 Z	LNK 911	Tower, Link 911, good morning
05:11:04 Z	DBN Tower	LNK 911, Durban tower, good day, go ahead
05:11:08 Z	LNK 911	Thanks 911 Jetstream 41 ZS-NRM requesting 8 000 ft to Pietermaritzburg, parking bay B3 ZS-N….(Double transmission)
05:11:23 Z	DBN Tower	LNK 911 standby for that. Runway 06 in use, QNH 1016, outbound check 0511
05:12:00 Z	LNK 911	Tower for LNK 911, we are not requesting start just the after-departure clearance
05:12:05 Z	DBN Tower	OK, copied
05:12:15 Z	DBN Tower	LNK 911, your after-departure clearance
05:12:17 Z	LNK 911	Go ahead, sir, LNK 911
05:12:20 Z	DBN Tower	LNK 911 is cleared Durban to Pietermaritzburg. After departure runway 06 straight ahead, climb to FL 60 passing 1 000 ft contact approach 119.1, squawk 6721, FL 80 on the request
05:12:39 Z	LNK 911	Thank you. After departure runway 06 straight ahead to FL60 through 1 000 ft, 119.1 and squawk 6721, LNK911
05:12:48 Z	DBN Tower	LKN 911, just for your information Maritzburg is unmanned at this stage
05:12:56 Z	LNK 911	Thank you, sir, we know, we just, er, we will probably of course start at half-past
05:13:04 Z	DBN Tower	LNK 911
05:30:21 Z	LNK911	Tower, LNK 911, requesting start.
05:30:24 Z	DBN Tower	LNK911, start is approved runway 06. Time check 0530
05:30:33 Z	LNK 911	Start approved, runway 06, LNK 911
05:32:46 Z	LNK 911	Durban, LNK 911
05:32:50 Z	DBN Tower	Say your call sign again
05:32:53 Z	LNK 911	It's LNK 911, sir
05:32:55 Z	DBN Tower	LNK 911, go ahead
05:32:57 Z	LNK 911	Sir, we are having a problem with the one engine starting. Will call you back for, er, the, when ready for start next
05:33:04 Z	DBN Tower	LNK 911
05:38:37 Z	LNK 911	Tower, LNK911
05:38:39 Z	DBN Tower	LNK 911, go ahead
05:38:41 Z	LNK 911	We would like to attempt another start now if you can accommodate
05:38:45 Z	DBN Tower	LNK 911 start is approved. Departure runway 06, time check 0539
05:38:53 Z	LNK 911	Start approved, LNK911
05:40:30 Z	LNK911	Durban from LNK911, we would like to cancel

		that start again please
05:40:37 Z	DBN Tower	LNK 911, copied. Call when ready for start
05:40:41 Z	LNK 911	When ready for start next, LNK911
05:41:12 Z	LNK 911	1
05:41:13 Z	DBN Tower	LNK 911
05:41:16 Z	LNK 911	Our apologies for messing you around. We would like to start now if we may, please
05:41:23 Z	DBN Tower	LNK 911, start is approved now. Runway 06, 0542 time check.
05:41:30 Z	LNK 911	Thank you, sir, start is approved, LNK911
05:48:59 Z	LNK 911	911 request clear taxi
05:49:06 Z	DBN Tower	LNK 911 on taxiway Bravo holding point runway 06
05:49:12 Z	LNK 911	On taxiway Bravo holding point runway 06, LNK 911
05:52:20 Z	LNK 911	LNK 911, ready for departure on reaching
05:52:23 Z	LNK 911	LNK 911 hold at holding point
05:52:26 Z	LNK 911	Holding at holding point, runway 06, LNK911
05:54:12 Z	DBN Tower	LNK 911 behind the Boeing 737-800 on final approach, runway 06, line up and wait behind
05:54:21 Z	LNK 911	Behind the Boeing 737-800 on final approach, line up and wait behind, LNK911
05:56:16 Z	DBN Tower	LNK 911, runway 06 cleared takeoff, surface wind 060 at 10 knots, VFR traffic routing northbound, seawards off the coastline, 500 feet just passed abeam
05:56:28 Z	LNK 911	Thank you, sir, will keep a good lookout, cleared for takeoff, runway 06 LNK 911
05:56:48 Z	Tuca 344	Requesting start, you see the aircraft taking off with all the smoke.
05:56:53 Z	DBN Tower	Er, LNK 911 just to be advised there is a smoke trail behind you
05:57:01 Z	Unknown	Severe smoke.
05:57:24 Z	DBN Tower	LNK 911, do you read?
05:57:25 Z	LNK 911	Yeah, we have lost an engine.
05:57:30 Z	Unknown	Your gear is still down.
05:57:42 Z	Unknown	Pick the gear up…
05:57:35 Z	DBN Tower	LNK 911 you can join the right down for runway 06.
05:57:54 Z	Unknown	Jesus, the plane just went down.
05:57:57 Z	DBN Tower	Fire chief
05:58:02 Z	Fire chief	Bakgat
05:58:04 Z	DBN Tower	Fire chief, LNK 911 just got airborne, he went down just to the northern side of the factories at Merewent.
05:58:14 Z	Fire chief	OK
05:58:17 Z	Fire chief	Tower, fire chief
05:58:19 Z	DBN Tower	Fire chief
05:58:24 Z	Fire chief	The problem with the aircraft
05:58:25 Z	DBN Tower	The aircraft just went down, it was just airborne, after airborne it went down at side of Merewent. It is outside the airport
05:58:34 Z	Fire chief	Copied that, sir
05:58:39 Z	DBN Tower	OK and good luck