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AUTORIDADE DE AVIAÇÃO CIVIL
CIVIL AVIATION AUTHORITY

Aviation Occurrence Investigation Final Report

INCID/01/2018

Aircraft Damage Caused by Hard Landing

Beijing Capital Airlines

Airbus A320-214, B6952

Macau International Airport

28 August 2018

3 April 2019

Foreword

The report is based on the joint investigation carried out by the Civil Aviation Authority, Macao, China (AACM) and Civil Aviation Administration of China (CAAC).

The sole objective of the investigation of an aviation occurrence is the prevention of accidents and incidents. It is not the purpose of these activities to apportion blame or liability.

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Abbreviations

AACM	Civil Aviation Authority, Macao, China
AMM	Aircraft Maintenance Manual
ATC	Air Traffic Control
CAAC	Civil Aviation Administration of China
CAPT	Captain
CASTC	China Academy of Civil Aviation Science and Technology
CVR	Cockpit Voice Recorder
DBA	Airport Rescue and Fire Fighting Services, Macao
DD	Deferred Defect
ECAM	Electronic Centralized Aircraft Monitor
ECU	Engine Control Unit
EGT	Exhaust Gas Temperature
F/O	First Officer
FOD	Foreign Object Debris
FCOM	Flight Crew Operating Manual
FDR	Flight Data Recorder
MEL	Minimum Equipment List
MLG	Main Landing Gear
NLG	Nose Landing Gear
PF	Pilot Flying
PM	Pilot Monitoring
QAR	Quick Access Recorder
RA	Radio Altimeter
TOGA	Takeoff / go-around
Vapp	Approach Speed

Synopsis

On 28 August 2018, an Airbus A320-214 aircraft, registered B-6952, departed from Beijing Capital International Airport (ZBAA) to Macau International Airport Macao, China (VMMC), operated by Beijing Capital Airlines as a schedule passenger flight, JD5759 / CBJ5759. The touchdown of the aircraft was being affected by a momentary 27 knot tailwind, it touched down on the main landing gear at runway 34 of Macau International Airport and bounced up in the air and touched down again (all gears compressed within the same second) with peak vertical acceleration 3.41G at about 635 metres after the threshold of runway 34. The nose landing gear was damaged with front tires and wheels detached. Some debris were ingested into both engines, resulting both engines were damaged.

After the second touchdown, the captain conducted miss approach procedures and diverted to Shenzhen. The aircraft finally landed at Shenzhen Bao'an International Airport with substantial damage and there was no outbreak of fire.

All 166 persons onboard were evacuated through evacuation slides. 5 passengers suffered from contusion and were sent to hospital for examination and treatment. No hospitalization were needed.

1 Factual information

All times used in this report are in Coordinated Universal Time (UTC).

1.1 Event history

The flight was normal until final approach. As the aircraft was in final stages of the approach and descending from 50 to 30 feet above ground level, the indicated airspeed decreased from 133 to 128 knot and the rate of descent was about 790 feet/min. The airspeed decrease occurred within 1-2 seconds and by touchdown the aircraft was being affected by a 27 knot tailwind.

At 03:15:34, the aircraft touched down on the main landing gear with peak vertical acceleration 2.36G at about 350 metres after the threshold of runway 34 at Macau International Airport and bounced up in the air.

At 03:15:38, the aircraft touched down again on the nose landing gear with peak vertical acceleration 3.41G at about 635 metres after the threshold of runway 34. The nose landing gear was damage and debris were ingested into both engines, damaged both engines.

After the second touchdown, the captain conducted missed approach procedures with low climb rate.

At 03:16:21 Macau Air Traffic Control (ATC) informed the flight crews that fire was observed coming out from its Engine #1.

At around 03:20:00, a tire was found on the Macau runway and flight crews were informed.

The captain declared mayday and sought suitable airport to land the aircraft, navigation system was inoperative after the hard landing and backup navigation system was activated.

After evaluating the situation, flight crew decided to divert to Shenzhen and requested full emergency landing at Shenzhen Bao’an International Airport.

At 03:57:55, the aircraft landed in Shenzhen Bao’an International Airport. The Aircraft sustained substantial damage and there was no outbreak of fire.

The crews activated emergency evacuation procedures and all persons onboard were evacuated through evacuation slides from door 1 right and door 4 right.

1.2 Injuries to persons

There were a total of 166 persons on board, consisting of the 3 flight crews (1 as observer), 6 cabin crews and 157 passengers.

After the evacuation in Shenzhen Bao'an International Airport, 5 passengers suffered from contusion and were sent to hospital for examination and treatment. No hospitalization were needed.

1.3 Damage to aircraft

Nose landing gear (NLG)

1. NLG was damaged with 2 wheels lost.
2. NLG sliding tube fractured.
3. Bottom of NLG main fitting wear.
4. NLG lower torque link fractured.
5. Taxi light bracket fractured.
6. NLG Flight / Ground Sensing Mechanism fractured.

Forward fuselage

1. Deformation at frame 17 – frame 24, stringer 30 right hand – right hand lower stringer.
2. Deformation at frame 18 – frame 24，lower right hand stringer trace – lower left hand stringer trace.
3. Deformation at frame 15 – frame 24, stringer 30 left hand – left hand lower stringer.
4. Deformation at frame 20 and cabin floor beam.

Figure 1: Aircraft fuselage damage

Engine #1 (left engine)

1. All 36 fan blades damaged.
2. 2 penetration damages in fan case.
3. Severe damage at low-pressure compressor (LPC) and high-pressure compressor (HPC) blades due to foreign object debris.
4. Combustor, high-pressure turbine (HPT) and low-pressure turbine (LPT) are attached with melted metal.
5. Penetration damage at leading edge of inner fan cowl.
6. Severe damage at acoustic panels.
7. Nicks and dents at thrust reversers.
8. 3 Nicks at pylon movable fairing.

Figure 2: Engine #1 (left engine) damage

Engine #2 (right engine)

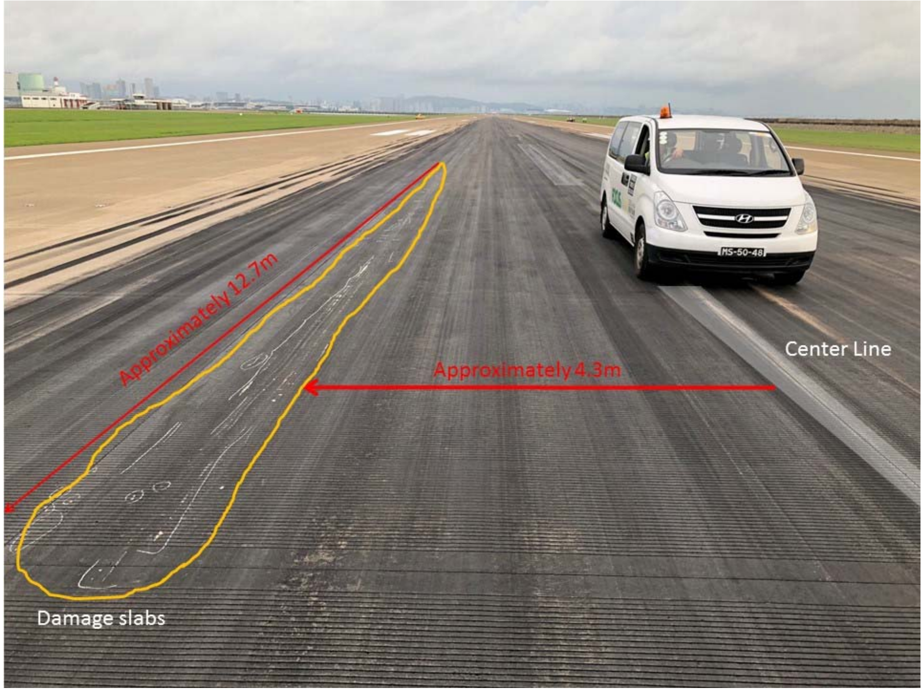
1. 6 fan blades were damaged.
2. 2 acoustic panels were damaged.
3. Damage at LPC and HPC blades within Aircraft Maintenance Manual (AMM) limit.
4. 4 nicks and dents at inner fan cowl.

Damage at left hand main landing gear (MLG) fixed fairing.
Drain mast at AFT fuselage was deformed with abrasion wear.
Abrasion wear at auxiliary power unit (APU) drain mast.

1.4 Other damage

After the hard landing in Macao, some runway slabs were damaged with scratch of approximately 12.7 metres long.

Figure 3: Runway slabs damage at Macau International Airport



After the aircraft landed at Shenzhen, some runway slabs were damaged with scratch of approximately 395 metres long. 3 runway lights were damaged.

Figure 4: Runway slabs damage at Shenzhen Bao'an International Airport

1.5 Personnel information

This flight was operated by a captain (PF) at the left-hand side control of the cockpit, first officer (PM) at the right-hand side control of the cockpit and an observer (at the observer seat).

1.5.1 Captain

The captain held an Airline Transport Pilot License – Aeroplanes (ATPL(A)) issued by the CAAC. The captain's last proficiency check prior to the occurrence was completed on 25 April 2018. He held a valid Class 1 Medical Certificate with no restriction. The captain's flying experience is outlined in Table 1.

Table 1: Captain's flying experience

Total flight hours	9,920
Total flying hours on A320 series	6,797
Total flying hours as Captain	2,808

The captain stated that his physical condition was fit and was not under influence of alcohol and medication before this flight.

1.5.2 First officer

The first officer held a Commercial Pilot License – Aeroplane (CPL(A)) issued by the CAAC. He completed his last proficiency check on 9 May 2018 prior to the occurrence. The first officer held a valid Class 1 Medical Certificate with restriction of wearing corrective lens for right eye hyperopia. The first officer's flying experience is outlined in Table 2.

Table 2: First officer's flying experience

Total flight hours	2,591
Total flying hours on A320 series	1,351

The first officer stated that his physical condition was fit and was not under influence of alcohol and medication before this flight.

1.5.3 Observer

The observer held a Commercial Pilot Licence – Aeroplane (CPL(A)) issued by the CAAC. He completed his last proficiency check on 25 June 2018 prior to the occurrence. The observer held a valid Class 1 Medical Certificate with no restriction. The observer's flying experience is outlined in Table 3.

Table 3: Observer's flying experience

Total flight hours	2,393
Total flying hours on A320 series	1,610

The observer stated that his physical condition was fit and was not under influence of alcohol and medication before this flight.

1.6 Aircraft information

1.6.1 General

The aircraft was a low-wing, commercial air transport category (passengers) aircraft that was manufactured by Airbus in Toulouse France in 2012. The aircraft could carry a maximum of 174 passengers in two classes.

The aircraft was fitted with two CFM International Engines CFM56-5B4/3 high-bypass turbofan engines.

The aircraft and engine information is summarized in Table 4 and 5 respectively.

Table 4: Aircraft information

Aircraft manufacturer	Airbus
Aircraft type	A320-214
Aircraft serial number	5331
Operator	Beijing Capital Airlines
Total hour	17,838:59
Total cycle	9,628
Year of manufacture	2012
Date of issue of certificate of registration	24 October 2012
Date of issue of certificate of airworthiness	24 October 2012
Maximum certificated take-off weight	75,500 kg
Actual take-off weight	72,200 kg
Maximum certificated landing weight	66,000 kg
Actual landing weight	63,340 kg

Table 5: Engine information

	Engine #1	Engine #2
Engine manufacturer	CFM International	CFM International
Engine type	CFM56-5B4/3	CFM56-5B4/3
Engine serial number	645296	645301
Date of Manufacture	03-SEP-2012	03-SEP-2012
Date of Installation	17-SEP-2012	17-SEP-2012
Type of Release Form	EASA Form 1	EASA Form 1
Overhauled	New Engine	New Engine

1.6.2 Airworthiness and maintenance

Aircraft maintenance checks

In the period between February 2018 and August 2018, B - 6952 has performed A Check 3 times, the details was shown in Table 6:

Table 6: Aircraft maintenance checks

Location	Level	Date
Xian	A Check	14th March 2018
Xian	A Check	10th June 2018
Xian	A Check	23rd August 2018

Line maintenance troubleshooting

In the period between 28th March 2018 and 28th August 2018, maintenance troubleshooting performed according to the Aircraft Maintenance Manual (AMM) related to B - 6952 landing gear system were:

- Tire change due to wear limit reached: 13 times (nose landing gear: 5 times & main landing gear: 8 times)
- Breaking disc change due to wear limit reached: 3 times (right inner, left inner and right outer)
- Break accumulator service due to pressure below 810: 1 time

There were 3 times of system failures related to the B - 6952 aircraft engines, details please find below:

- Date 9th April 2018, a crack found on the Engine #2 intake anti-icing exhaust pipe. Right after replacing the pipe, no abnormal was found and aircraft was released.
- Date 12nd April 2018, flight crews observed Exhaust Gas Temperature (EGT) fluctuations. Maintenance team hereafter changed CJ13 and J13 wire, EGT junction box, Engine Control Unit (ECU) and the engine starter, EGT reading became normal and aircraft was released
- Date 10th July 2018, flight crews observed Engine #2 vibration when N2 above 1.6, vibration reduced once decreased N2 and disappeared when N2 below 1.3. Detailed visual inspection has been performed, no Foreign Object Damage found and no abnormality observed regarding fan blade and fan blade mounting.

According to the maintenance record on the date of 28th August 2018, there was 1 Deferred Defect (DD) related to a brush discharge damage on the horizontal stabilizer of B - 6952 left wing tip and there were also 7 items related to the aircraft cabin. All defects were deferred in accordance with approved Minimum Equipment List (MEL). No malfunction circumstance has been deferred related to the aircraft landing gear and engine.

1.7 Meteorological information

According to METAR published at 02:56:59, the weather for the approach into Macau International Airport runway 34 included 4 knot of wind in direction 200, visibility 10 Km, Few (1 - 2 oktas） clouds at a height of 1,200 feet, scattered (3 - 4 oktas） clouds at a height of 3,000 feet. The temperature on the ground was 29 °C.

Raw data collected from wind sensor at runway 34 shown from 03:15:00 to 03:15:57, gust wind sudden changed from 10 knot to 22 knot with wind direction ranging from 170 to 190 which was tail wind.

Airbus did a wind reconstruction using recorded flight data, wind reconstruction shown:

- Tailwind increasing gradient of approximately 13 knot/s between 19 feet RA and the touchdown
- Decrease of the left crosswind at 3.3 knot/s between 88 feet RA and the touchdown
- Light vertical wind shear (maximum 4 knots variations) below 100 feet with downdraft tendency.

1.8 Aids to navigation

After the landings in Macau, Navigation system was inoperative after the hard landing and backup navigation system was activated.

1.9 Communications

At 03:16:07, during the climb phase of the miss approach, the Macau ATC observed fire coming out from the aircraft’s left engine and informed the flight crews. Both flight crews were not clear about which engine had fire coming out and requested confirmation with Macau ATC. Macau ATC repeated left engine. The flight crew repeated left engine unintelligibly. At 03:16:35, the flight crew set the engine #2 lever to idle for about 15 seconds. At this point, the airspeed decrease and AOA increase and triggered the stall warning twice for 2 and 9 seconds respectively.

From 03:27:00 to 03:35:00, the aircraft was orbiting over the sea in between Macao and Shenzhen trying to assess the aircraft status and sought a suitable airport to land. After releasing IR1-2-3 failure and received the message of tire found in Macau, the flight crews declared Mayday at 03:29:00 and intended to squawk transponder code 7700 (general emergency), but accidently squawk 7600 (loss of communications) for a short while.

1.10 Aerodrome information (Macau International Airport)

1.10.1 General

Macau International Airport had one runway oriented north-north-west to south-south-east on magnetic headings of 164°/344°. Those runways were designated 16/34 indicating their relative position when looking along the runway. The aircraft landed on runway 34 with declared distance of 3,360 metres concrete surface.

1.10.2 Emergency services

Macau International Airport was designated as a category 9 aerodrome[1] for the purposes of rescue and firefighting support. The 24-hour airport rescue and firefighting service is provided by Airport Rescue and Fire Fighting Services, Macao (DBA).

1.10.3 Air Traffic Control Services

Macau International Airport Company Limited (CAM) is authorized to operate and maintain the ATC services and respective systems with a team of licensed controllers and dedicated engineers.

After the missed approach by the JD5759 at around 03:16:00, runway 34 was continued in operation. At around 03:20:00, EVA Airlines EVA807 successfully landed on runway 34. EVA did not report any FOD on the runway.

[1] Category 9 was defined in the International Civil Aviation Organization (ICAO) Annex 14 *Aerodromes* as having the capacity to provide firefighting and rescue support for aircraft with overall length of between 61 m and 75 m, with a maximum fuselage width of 7 m. The A321 has an overall length of 44.51 m and a fuselage width of 3.95 m.

Right after EVA807 landed, DBA informed Macau Tower a tire was found on the runway. Macau Tower immediately hold all the landings and departures and request for runway inspection.

1.11 Flight recorders

The aircraft was equipped with a Honeywell solid state flight data recorder (FDR), approximately 27 flight hours of data were recorded.

Meanwhile, the Teledyne Quick Access Recorder (QAR) was a wireless QAR, approximately 138 flight hours of data were recorded.

The cockpit voice recorder (CVR) was Honeywell solid-state which could record the most recent 2 hours of voice data.

The flight data readout was performed by CAAC； Airbus, BEA and CAAC did perform flight data decoding and analysis.

1.12 Organizational and management information

Beijing Capital Airlines is headquartered in Beijing. At the time of the occurrence, the company operated 79 aircraft including 20 Airbus-A319, 34 Airbus-A320, 17 Airbus-A321 and 8 Airbus-A330. It has been a Chinese Air Operator Certificate holder since year 2006.

1.13 Survival aspects

1.13.1 Evacuation

The crews activated emergency evacuation procedures and all persons onboard were evacuated through evacuation slides from door 1 right and door 4 right.

1.14 Test and research

1.14.1 Nose landing gear debris examination

Wreckage collected from Macau International Airport:

1. 2 front tires
2. 1 outboard wheel half
3. Debris from outboard wheel half
4. Debris from wheel bearings and bearing rollers
5. Wheel half tie bolts

Wreckage collected from Shenzhen Bao'an International Airport:

1. 2 inboard wheel halves
2. 3 wheel half hubs
3. 4 inner wheel bearings
4. 1 outer wheel bearing
5. 40 pieces of wheel bearing rollers
6. 4 bearing cages
7. Several bearing seals
8. 2 pieces of wheel axles
9. 2 bearing stuck nuts
10. Small pieces of axle sleeves and broken bolts

Nose landing gear metallic debris collected from Macau International Airport and Shenzhen Bao'an International Airport were sent to China Academy of Civil Aviation Science and Technology (CASTC) for fracture and damage analysis, in order to determine the cause of failure. (See Appendix 02)

Figure 5: Spectral analysis on the 2 dark grey color debris found in Engine #1

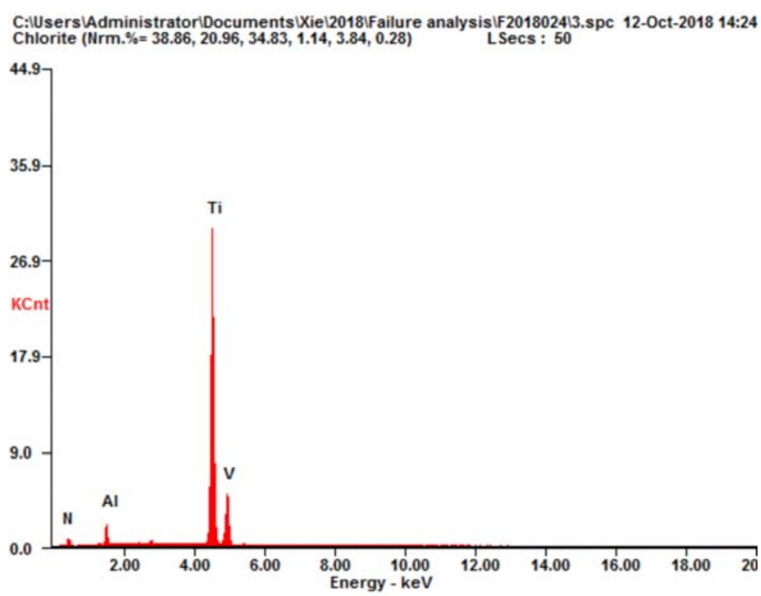
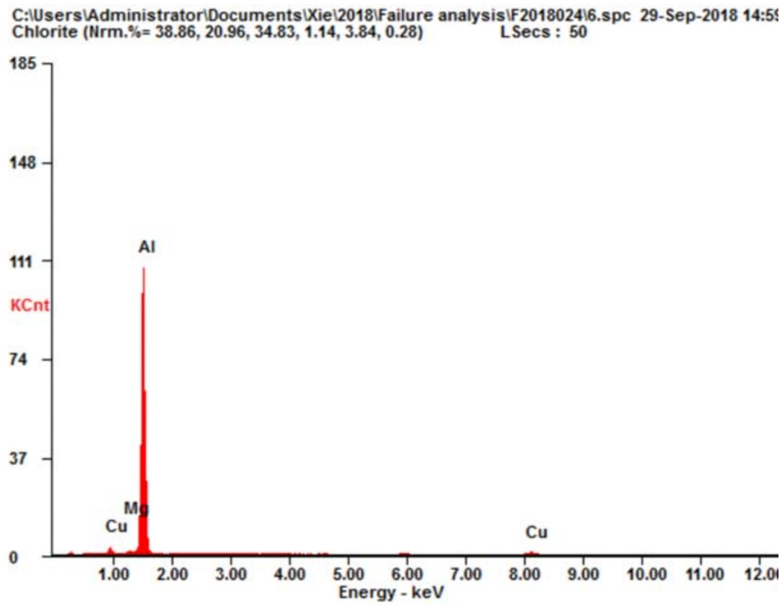


Figure 6: Spectral analysis on the debris sample found in Engine #1



2 Analysis

2.1 General

The flight and cabin crewmembers were properly certificated and qualified under relevant regulations. No evidence indicated any preexisting medical or physical condition that might have adversely affected the crewmembers' performance during the incident flight.

2.2 Flight performance analysis

Flight data indicated that the flight from Beijing to Macau was uneventful until the final approach stage into Macau International Airport runway 34. Hence, the following analysis will focus on the events occurred between the final approach stage into Macau International Airport and the full stop landing at Shenzhen Bao'an International Airport.

At the initial contact with Macau Tower (2 minutes before the first touchdown) and at the last wind check provided by Macau Tower at about 1,200 feet (1 minute 25 seconds before 1st touchdown), the Macau Tower air traffic controller reported the surface wind to the pilots as 7 knot at 220 degree (4 knot tailwind and 6 knot crosswind).

2.2.1 Between 500 feet radio altitude to first touchdown

2.2.1.1 At 500 feet RA

At 500 feet RA during the final approach into Macau International Airport, flight data showed that the airspeed was stabilized at around 142 knot (Vapp 139 knot) with ground speed of about 156 knot. The wind computed by the aircraft was from 226 degrees at 26 knot (23 knot crosswind from left to right and 10 knot tailwind). The aircraft was on the Runway 34 ILS glideslope and the attitude was normal with landing gear down.

According to Beijing Capital Airlines Flight Crew Operating Manual (FCOM) LIM-AG-OPS P 2/4, the maximum allowable tailwind component for landing is 10 knot. At this point, the aircraft tailwind component was at the upper allowable limit.

2.2.1.2 Between 500 feet RA and 1st touchdown

The autopilot was disconnected at 370 feet RA. According to flight data, the aircraft experienced an increasing tailwind component during this phase of the final approach with tailwind increasing from 9 knot at 200 feet RA (airspeed 139 knot), to 27 knot at 5 feet RA (airspeed 119 knot). The change of tailwind component and indicated airspeed against height is outlined in Table 7:

Table 7: Change of tailwind component and indicated airspeed against height

Height AGL (ft)	Tailwind component (kt)	Indicated airspeed (kt)
200	9	139
150	14	135
100	9	136
50	17	131
20	14	131
5	27	119

The tailwind increased from 9 knot at 100 feet RA to the peak of 27 knot at 5 feet RA within 12 seconds (increased by 18 knot within a vertical displacement of 95 feet within 12 seconds), which is categorized as severe low-level wind shear (over 12 knot of wind speed change within a vertical displacement of 100 feet).

The ground speed of the aircraft was maintained at around 150 knot during the final approach stage, the increase in tailwind speed resulted in the decrease of airspeed.

As retrieved from the flight data, the airspeed decreased to 119 knot momentarily before the first touchdown (about 1 second before main landing gear touchdown), and at the point of touchdown the airspeed was at around 127 knot with ground speed of 150 knot and rate of descent was about 260 feet/min.

According to Beijing Capital Airlines Standard Operating Procedures (PRO-NOR-SOP-18-B P5/6), the pilot monitoring (PM) should monitor a number of flight parameters during the approach phase. In case there is a deviation of 5 knot below or 10 knot above the target speed (in this case the target speed Vapp was 139 knot), the PM should call out such deviation. After which the pilot flying (PF) and pilot monitoring (PM) should evaluate and execute necessary actions.

In view of the decrease in airspeed of more than 5 knot from the Vapp speed (in this case 134 knot, airspeed became 5 knot less than the Vapp speed at 90 feet RA), there was no evidence indicating the abovementioned callout was done. The timing of this decrease of airspeed could have contributed to the lack of such callout, as at the time the aircraft was passing 90 feet RA it was about 7.5 seconds from touchdown, both pilots were likely to have focused primarily on performing the flare and landing maneuvers.

Regarding to the maximum landing tailwind limitation of 10 knot, the pilots were provided with the wind information by the Macau Tower and also the wind information from the aircraft onboard display (calculated wind at actual altitude). The Macau Tower reported surface wind of 7 knot and 220 degree to the pilots at around 1 minutes 25 seconds before the first touchdown (4 knot tailwind and 6 knot crosswind); while the tailwind calculated by the aircraft varied and exceeded the 10 knot limitation below 200 feet RA.

As the wind at any location may vary at different altitude, it is normal for the reported surface wind be different from the onboard calculated wind, and that the tailwind limitation should be applicable and most critical at the surface (runway level), it was likely that the pilots depended on the surface wind reported by Macau Tower at 1 minutes 25 seconds prior to the first touchdown as the reference to assess whether the landing could be performed within the tailwind limitation.

However, the wind at the surface varied rapidly in both direction and strength to 22 knot at 189 degree (20 knot tailwind and 9 knot crosswind) momentarily before the aircraft's first touchdown. The pilots were not notified of such an abrupt change in surface wind by the Macau Tower. The lack of low-level wind shear detection system at the Macau International Airport contributed to the failure of identifying such abrupt wind change. Although the onboard calculated wind display could be made reference to as an additional source of wind direction and strength reference close to the surface level (indicating tailwind in excess of 10 knot at 200 feet RA and below, and increasing), there was no evidence this additional wind reference was used by the pilots to make themselves become aware of the abrupt wind change and possible tailwind exceedance close to and at the surface.

The captain and the first officer reported that 飛機突然直接拍到跑道上 (in English "the aircraft experienced a sudden drop onto the runway") momentarily before the first touchdown. According to aerodynamic principle, the amount of lift generated by aircraft wings is directly proportional to airspeed square. As the airspeed decreased rapidly from around 139 knot to 119 knot momentarily before touchdown due to the increasing strength of tailwind component which peaked at 27 knot at 5 feet RA, the lift generated by the wings decreased considerably and caused the aircraft to "drop". This matches the pilots' sensation of experiencing a "sudden drop".

This "drop", the higher-than-usual vertical speed on the first touchdown, was contributed also by the late initiation of flare by the PF (flare initiated at 15ft RA) which led to the aircraft did not have sufficient time to reduce its negative (downwards, descending) vertical speed before the touchdown.

The above factors contributed to the "drop" and the subsequent first touchdown onto the runway with the main landing gear resulted in a vertical acceleration of 2.36G, which was not considered as a hard landing (According to Airbus definition, a hard landing means a vertical acceleration that is equal to or more than 2.6G and less than 2.86G).

According to the wind data captured by ground-based equipment at the threshold of Runway 34 of Macau International Airport, there was a rapid increase in tailwind component from less than 10 knot to about 22 knot during the first touchdown.

The wind measuring ground equipment and the aircraft onboard system confirmed that there was a rapid increase of tailwind momentarily before the aircraft touchdown.

Moreover, the wind reconstruction conducted by Airbus showed that there was a tailwind increase gradient of approximately 13 knot/s momentarily before the 1^{st} touchdown and there was a vertical wind shear with downdraft tendency.

It is evident that, based on the above wind information, momentarily prior to the first touchdown, the aircraft experienced severe low-level wind shear with rapid tailwind increase and downdraft tendency, which led to the reduction of airspeed and lift, resulting in the higher-than-usual vertical acceleration at the first touchdown.

Also, the aircraft landed with tailwind of 20 knot at the first touchdown which exceeded the 10 knot tailwind limitation specified in the airline's FCOM.

2.2.2 Between the first touchdown and initiation of go-around

After the first touchdown with the main landing gear at a vertical acceleration of 2.36G, the aircraft bounced up at an initial pitch angle of about 7.5 degree nose up and lifted-off again, then reaching a maximum height of 7 feet RA.

According to flight data, at the first touchdown the thrust lever was not retarded to idle but moved to above the CLIMB detent (between MCT and TOGA detent). The Standard Operating Procedures mentioned that the pilot must ensure the thrust levers are at the idle detent to ensure ground spoiler extension at touchdown. The fact that the thrust levers position were above the CLIMB detent at the first touchdown was in contrary to the SOP. This prevented the activation of the Phased Lift Dumping (PLD) function. The PLD function is designed to reduce the severity of a possible bounce at landing by partially extending the ground spoiler under certain conditions, one of which being the thrust levers at or below the CLIMB detent (FCOM DSC-27-10-20).

Immediately after the first touchdown, an automatic callout "PITCH, PITCH" was triggered. This callout is designed to protect the aircraft from tail strike and is triggered when the aircraft has excessive nose up attitude.

According to flight data, after the bounce the PF applied a nose down side stick input. As a result, the pitch angle of the aircraft decreased from 7.5 degree nose up to 1.8 degree nose down in 4 seconds. During the bounce, the aircraft displaced 300 metres of runway.

One of the possibilities that the PF applied nose down input after the bounce was to respond to the "PITCH, PITCH" callout to avoid tail strike.

Moreover, flight data revealed that the thrust levers were moved to idle during the bounce, this resulted in the activation of the ground spoiler by the PLD function even when the aircraft was actually airborne (due to the memorization of the ground condition for 3 seconds).

Combining the extension of the ground spoilers and the aircraft attitude became nose down, the aircraft lost altitude and resulted in all three landing gears touched down within the same second. This second touchdown resulted in a vertical acceleration of 3.41G which was a severe hard landing (according to Airbus definition, any landing with a vertical acceleration equal to or more than 2.86G is a severe hard landing). At the second touchdown, the aircraft had a ground speed of about 156 knot (about 289 km/h) and airspeed of 146 knot. This second touchdown directly caused the fracture of the aircraft nose wheels.

According to the Airbus Flight Operations Briefing Notes – Landing Techniques – Bounce Recovery – Rejected Landing, in case of a bounced landing (regardless of a light bounce or high bounce), the typical recovery technique that should be applied is first to maintain a normal landing pitch attitude. This means the pilot should try to maintain the landing pitch angle. The same Briefing Notes also suggested that to recover from a light bounce, the pilot may choose to continue the landing and keep thrust at idle; or, in case of a high bounce, to initiate a go-around. In both cases and as mentioned before, a normal landing pitch attitude should be maintained.

Also, the SOP documented in the Beijing Capital Airline's Flight Crew Training Manual recommended the maintenance of a pitch up attitude upon a light or high bounced landing (FCTM-PR-NP-SOP-250-00020014.0001001 / 20 MAR 17).

In this case, however, the PF executed nose down input at varying amplitude for about 7 seconds. This input was likely, initially, to response to the "PITCH, PITCH" callout to avoid excessive pitch angle (tail strike) but normal pitch attitude was compromised thereafter due to the continued and prolonged nose down input. This directly caused all three landing gears to touchdown within the same second, which led to the fracture of the aircraft nose wheels.

At about 3 seconds after the second touchdown the PF initiated go-around by advancing the thrust levers to the TOGA position and engaged full nose up input. Due to the full nose up input, the aircraft attitude increased to 15 degree nose up. This led to the second “PITCH, PITCH” callout and tail strike. The APU drain mast on the underside on the tailcone was damaged as a result.

The PF then applied nose down input to reduce the nose up attitude to around 7.7 degrees and the aircraft gradually climbed out of runway 34 of Macau International Airport.

2.2.3 After initiation of go-around

The flight data showed that during the go-around climb out of Macau International Airport with TOGA thrust command, Engine #2 was operating at about 90% N1 (fan speed) and Engine #1 at a fluctuating level of 50-60% N1. (N1 is the rotation speed of the engine fan which is proportional to the amount of thrust produced).

Besides, the flap setting was changed from “full” to “3” which was in compliance with the company’s standard operating procedures for go-around (PRO-NOR-SOP-20 P 1/2).

It was evident that the low N1 of Engine #1 was caused by the damage induced by the debris of the nose landing gear assembly and such damages reduced the performance of the engine. Although Engine #2 was also damaged, the performance of this engine was not degraded as much as Engine #1. This is consistent with the post-flight damage report which confirmed that the damage in Engine #1 was much more extensive than Engine #2.

The flight data showed that the landing gears remained “down”. The cockpit voice record also revealed that the pilots mentioned “收不了, 收不了, 起落架損壞了”（meaning in English “the gears cannot be retracted”) soon after the go-around was initiated.

Around 30 seconds after go-around was initiated, Macau Tower’s air traffic controller notified the pilots “I observed fire coming out from your left engine”. After receiving this notification, a voice stating “Fire, Fire, 右發, 右發有…右發有火”（ meaning in English “fire, the right engine has fire”)” was heard in the cockpit voice record. The flight data then showed that, immediately afterward, the Engine #2 thrust lever was moved from the TOGA position to idle position. CVR record revealed that there was no communication between the pilots before the thrust lever of Engine #2 was idled.

Despite the observation of fire by the air traffic controller, there was no engine fire warning triggered by the aircraft. Post-flight inspection confirmed that there was no evidence of fire in the engines, it is likely that the fire observed was actually spark produced by the high speed abrasion between debris of the fractured nose gear and the rotating parts of Engine #1.

Before Engine #2 was being idled, the ECAM showed that the N1 rating for Engine #1 and Engine #2 were about 55% and 94% respectively (implying the problem was more likely to be with Engine #1 as its N1 did not match up with the TOGA thrust command).

The idling of Engine #2 resulted in Engine #1 being commanded at TOGA thrust while producing only about 50% N1, and resulted in Engine #2 commanded at idle and producing around 27% N1.

With this thrust output and the fact that the landing gear was down as well as the flap configuration of “3”, the actual thrust output was insufficient to maintain the aircraft in a positive rate of climb. During the time of this thrust setting, the aircraft lost altitude of 425 feet from 1047 feet RA (reaching a lowest altitude of 622 feet RA) with a maximum rate of -1,500 feet/min and maximum pitch angle of 14.41 degree nose up.

During the altitude loss, the aircraft “don’t sink” automatic call out was triggered and stall warning was activated twice. The first stall warning was triggered at 950 feet RA and lasted for 2 seconds (airspeed 123 knot with true angle of attach at around 15.0 degree); while the second stall warning was triggered at 765 feet RA and lasted for 9 seconds (airspeed 126 knot with true angle of attack at 15.1 degree). The pilots responded to the second stall warning by advancing the Engine #2 thrust lever back to the TOGA position. The aircraft then regained airspeed and positive climb.

According to the cockpit voice record, as soon as the Engine #2 thrust lever was moved to the idle position, one of the pilots immediately questioned “是 Left 還是 Right? (meaning in English “is it left or right?”). Then a voice (cannot confirm which pilot) requested the air traffic control to reconfirm whether it was the left or right engine on fire. The ATC did not respond to the question about the engines and requested the pilots to follow standard missed-approach procedure. The voice immediately asked again, but no responses from the ATC was heard immediately afterwards.

The thrust lever of the Engine #2 was unnecessarily moved to the idle position for about 15 seconds which led to the stall warning triggered twice.

Around 35 seconds after the first request to the ATC to confirm which engine was on fire, a voice was heard on the cockpit voice record saying in English "Captain 5759, confirm which engine on fire", the ATC immediately responded "left engine". The left engine (Engine 1) thrust lever was then immediately moved to the idle position as shown by the flight data.

The CVR record revealed that there was another aircraft on final approach into Macau International Airport. This may have distracted the ATC and contributed to the need for the pilots to ask 3 times and took 35 seconds in total to re-confirm which engine was on fire. As a result, the damaged Engine #1 was left unnecessarily operating at TOGA command which could have led to other failures.

The initiative taken by the pilots to question and challenge each other's actions immediately after the thrust lever of Engine #2 was moved to the idle position contributed positively to the earlier recognition of the error in thrust setting and prevented further altitude loss.

2.2.4 Diversion to Shenzhen Bao'an International Airport

The pilots decided to divert to Shenzhen Bao'an International Airport to perform a low-pass for the local air traffic controller to visually inspect the status of the engines and landing gear. The low-pass was conducted at 1,100 feet and the air traffic controller confirmed to the pilots that the landing gear was down and no fire was observed, but could not confirm the status of the nose landing gear tire. However, the air traffic controller confirmed the pilots that a tire was found on the runway of Macau International Airport.

After the low-pass, the crew confirmed the diversion to Shenzhen Bao'an International Airport due to more favourable weather condition (Visual Meteorological Condition). According to the cockpit voice record, the pilots discussed the evacuation plan with a flight attendant, specifying the evacuation to be conducted through the right side as left engine may be on fire (Engine #1), and also requested air traffic controllers to order emergency services to be ready for the landing.

The pilots recognized the possible damage to the nose landing gear and decided to hold the aircraft nose upwards for as long as possible on landing.

The aircraft successfully landed in Shenzhen Bao'an International Airport. Evacuation was initiated immediately after which was orderly completed.

2.3 Aircraft

2.3.1 Airworthiness of the aircraft

The Certificate of Airworthiness was in force prior to the occurrence flight.

The MEL is valid with revision ref. R6T3 25-JUN-2018 and approved by CAAC. The Certificate of Registration (CoR), Certificate of Airworthiness (CoA) and Aircraft Station License (ASL) were issued by CAAC and valid at the time of the incident.

The certifying staff holds a valid The People's Republic of China Civil Aircraft Maintenance Personnel License with appropriate aircraft type rating endorsed (A318/319/320/321 (CFM56) AV II) carried out inspection of the aircraft and released for the flight.

The aircraft was equipped, dispatched, and maintained in accordance with relevant regulations.

2.3.2 Nose landing gear fracture and damage

All inner wheel bearings and outer wheel bearings were found with mechanical scratches only, no high temperature discoloration and metal fusion welding characteristic. Out of the 40 pieces of wheel bearing rollers collected, part of the roller surface were seriously worn, But except for the melting and high temperature characteristics observed at the end of one bearing roller, all the rest bearing rollers with no obvious high temperature characteristics. That shown the fracture of the two nose wheel were not caused by failure of wheel bearings.

The fracture surface of the 2 inboard wheel halves and 3 wheel center hubs collected were found with rough flat fracture and flat diagonal fracture, without any flat smooth fracture zone. The characteristic of the fracture surface shown the separation of the wheel halves were caused by overload fracture.

One of the front tire were found with multiple bursts at the sidewall, and one of the wheel half were broken into many small pieces. That proven one of the front wheel withstand high impact and led to tire burst and wheel fracture.

Spectral analysis were conducted to the debris found in the left engine, 2 pieces of debris in dark grey color are confirmed with Ti-6AI-4V Titanium Alloy composition which matched the material of the engine fan blades. Samples of the rest of the debris were confirmed with 2017 and 2024 Aluminum Alloy composition which matched the material of the nose wheel.

2.4 ATC procedures

Macau International Airport Company Limited (CAM) Operational Procedure Document number: OP-ATC-07 Coordination Routine, this procedure establishes the methods for ATC co-ordination actions in order to develop the rules for a safe, orderly and expeditious flow of air traffic. It applies to all the coordination action between Macao Tower and other units and applies to all ATC staff.

Mandatory runway inspection procedure are located in operator's operational procedure OP-ATC-07. The procedure stated "Mandatory" runway inspection to be conducted before allowing runway operation when there was confirmed evidence of FOD presence on the runway and aircraft technical problems occurred with high possibility of FOD's remain. 3 examples of aircraft technical problems were listed in the procedure that could had been linked to this incident:

Example 1: Rejected take-off or landing with hard braking causing tire burst;

Example 2: Landing with gear or brake problems (smoke observed);

Example 3: Landing with fire in the aircraft;

Examples 1 & 2 listed were specific technical problem, Macau ATC had no information of tire burst, gear or brake problem before being informed a tire was found on the runway. The signs of aircraft technical problems to Macau ATC were the abnormal landing with bounces causing JD5759 missed approach, then fire was observed coming out from the left engine after the second landing during initial climb phase of miss approach. That did not trigger Macau ATC to hold runway operations for inspection. Macau ATC then issued a landing clearance for the consecutive landing traffic EVA807 as the runway was in operations, though abnormal situations of the missed approached of JD5759 were observed. 5 minutes after the missed approach, Macau ATC was being informed there was a tire found on the runway and they immediately hold runway operation and requested for runway inspection due to confirmed evidence of FOD presence on the runway.

2.5 Survivability

2.5.1 Evacuation

Before evacuation, the flight crews did go through the emergency evacuation procedures, after checking the engine status and confirmed with no engine fire, order cabin only use evacuation slide from right side due to left engine failure. After the cabin crew supervisor declared all passengers had been evacuated, captain walk around the cabin confirm no passenger on board, then all 3 flight crews left the aircraft.

3 Conclusion

The occurrence was classified as a serious incident.

3.1 Findings

The flight was uneventful up to the final approach stage into Macau International Airport.

Momentarily prior to the first touchdown, the aircraft experienced severe low-level wind shear with rapid tailwind increase and downdraft tendency, which led to the reduction of airspeed and lift, resulting in the higher-than-usual vertical acceleration at the first touchdown.

Macau International Airport had no equipment to detect low-level wind shear, hence there was no low-level wind shear information about runway 34 was provided to the JD5759 pilots at landing.

According to recorded flight data, no wind shear alarm was triggered.

The aircraft main landing gear touched down (first touchdown) with a rate of descent of 640 feet/min resulting in a vertical acceleration of 2.36G.

At the first touchdown the thrust lever was not retarded to idle but moved to above the CLIMB detent (between MCT and TOGA detent) which was in contrary to the SOP. This prevented the activation of the Phased Lift Dumping (PLD) function.

The aircraft bounced and lifted-off again after the first touchdown for 4 seconds, reaching a maximum height of 7 feet.

During the bounce lift-off, the forward side-stick input was applied for about 7 seconds commanding a nose down pitch at varying amplitude.

The aircraft was not maintained at a normal landing attitude during the bounce.

The thrust levers were moved to idle during the bounce, this resulted in the activation of the ground spoiler by the PLD function even when the aircraft was actually airborne (due to the memorization of the ground condition for 3 seconds).

At the second touchdown, all three landing gears touched down within the same second with an attitude of -1.8 degree (nose down) and resulted in a vertical acceleration of 3.41G.

The nose landing gear wheels were fractured as a result.

At the go-around, the aircraft experienced a tail strike.

The thrust lever of the Engine #2 was moved to the idle position despite the air traffic controller notified the pilots of observing fire coming out from Engine #1.

The aircraft could not maintain positive rate of climb during the go-around climb, triggering the stall warning twice which lasted for 2 and 9 seconds respectively. This led to a loss of 419 feet of altitude, reaching a lowest altitude of 627 feet RA before positive rate of climb was re-established.

3.2 Contributing factors

First touchdown at 2.36G and bounce

1. Encountered severe low-level wind shear with rapid tailwind increase and downdraft tendency momentarily before touchdown
2. Macau International Airport had no equipment to detect low-level wind shear.
3. The aircraft landed with excessive tailwind.

Second touchdown at 3.41G with nose landing gear

1. A normal landing pitch attitude was not maintained after the bounced landing.
2. The thrust levers were moved to idle from above the CLIMB detent during the bounce, this resulted in the activation of the ground spoiler by the PLD function even when the aircraft was actually airborne (due to the memorization of the ground condition for 3 seconds).

4 Safety actions and safety recommendations

4.1 Safety actions taken by the operator

1. Implemented new plans to identify pilot skills and classified into 3 categories being used as reference for crew pairings, task assignments and targeted trainings.

2. Provided theoretical training to all A320 and A330 flight crews through the E-learning system related to the following modules: handling of landing with wind shear, hard landing and bounce up after hard landing.

3. Provided flight simulation recurrent training on low-altitude wind shear handling, low-altitude go-around and landing deviation control.

4. The flight department reminded all flight crews to pay sufficient attention to wind direction, wind speed, tailwind speed and airspeed at low altitude during final approach.

4.2 Safety recommendations

4.2.1 Safety recommendations to Macau International Airport

1. Evaluate historic runway weather data to determine the necessity to implement low-level wind shear detection system or terminal Doppler weather radar for the detection of hazardous weather conditions. [Recommendation AR-2018-001]

2. Review Operational Procedure Document number: OP-ATC-07 regarding "Mandatory" runway inspection to be conducted before allowing runway operation when there was confirmed evidence of FOD presence on the runway and aircraft technical problems occurred with high possibility of FOD's remain. Clearly specify how to determine aircraft technical problems occurred with high possibility of FOD's remain. [Recommendation AR-2018-002]

3. Consider to implement automatic FOD detection system for timely detection of any FOD presence on runway. [Recommendation AR-2018-003]

4.2.2 Safety recommendations to Beijing Capital Airlines

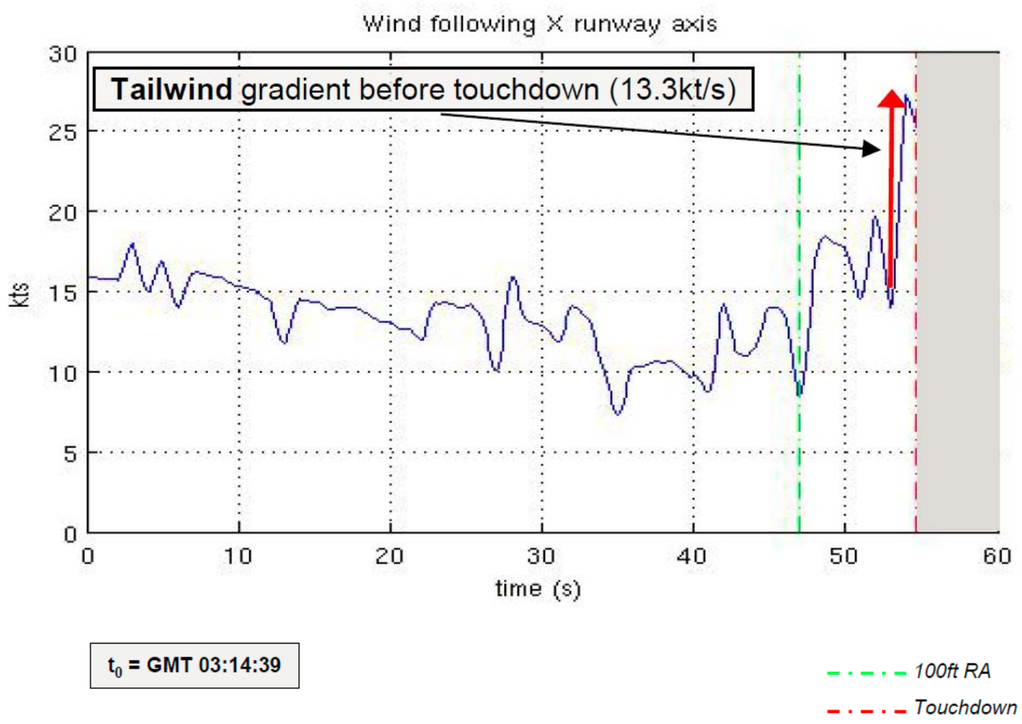
1. Incorporate, during initial and recurrent training, ground and simulator sessions on bounced landing identification and bounce recovery.

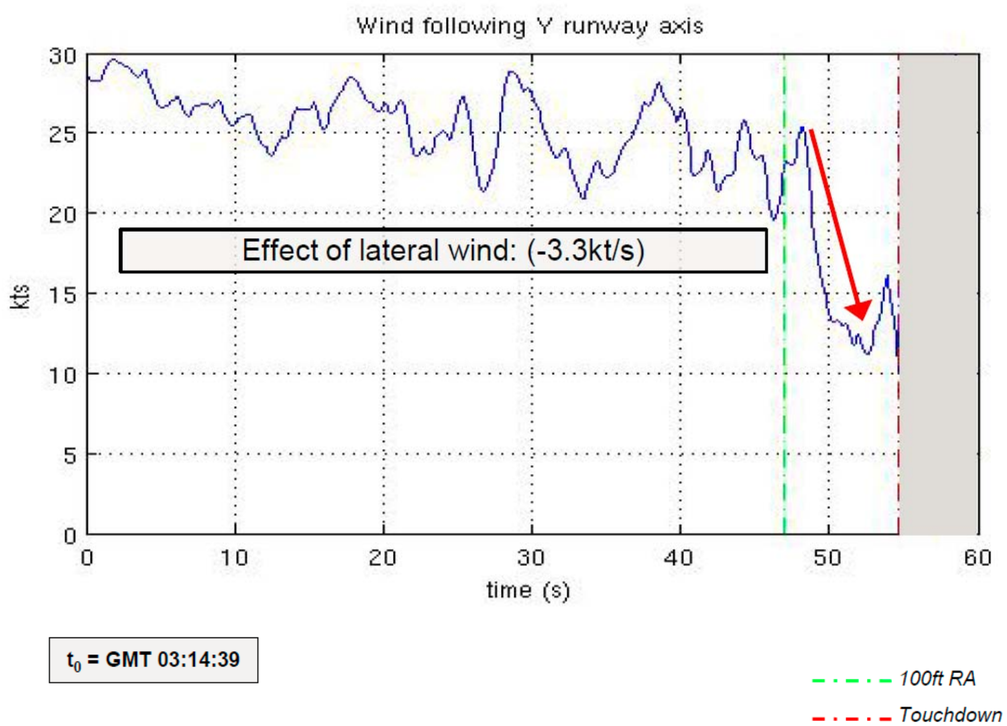
[Recommendation AR-2018-004]

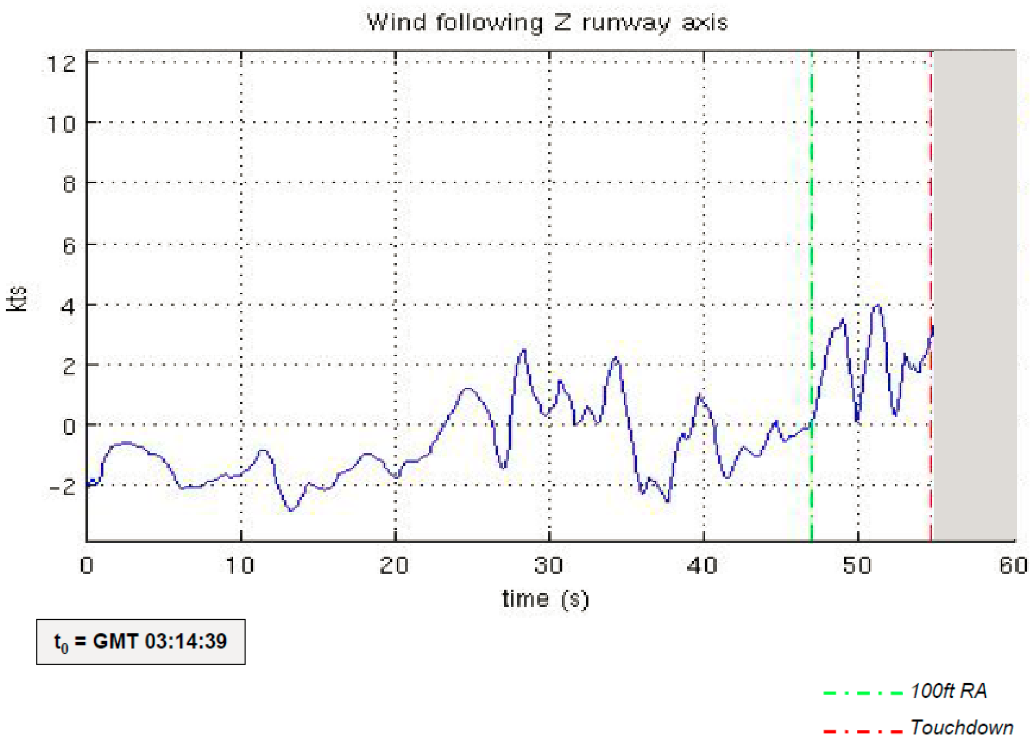
2. Enhance pilot training to ensure that, in case of a need to perform key changes to critical flight controls/systems based on information provided by external parties, necessary cross-checks are performed with the information available from the aircraft systems and between pilots before such changes are made. [Recommendation AR-2018-005]

Appendix A: Wind reconstruction

Wind Reconstruction

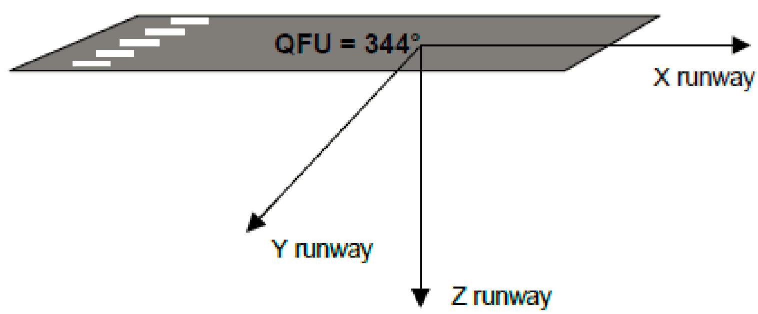




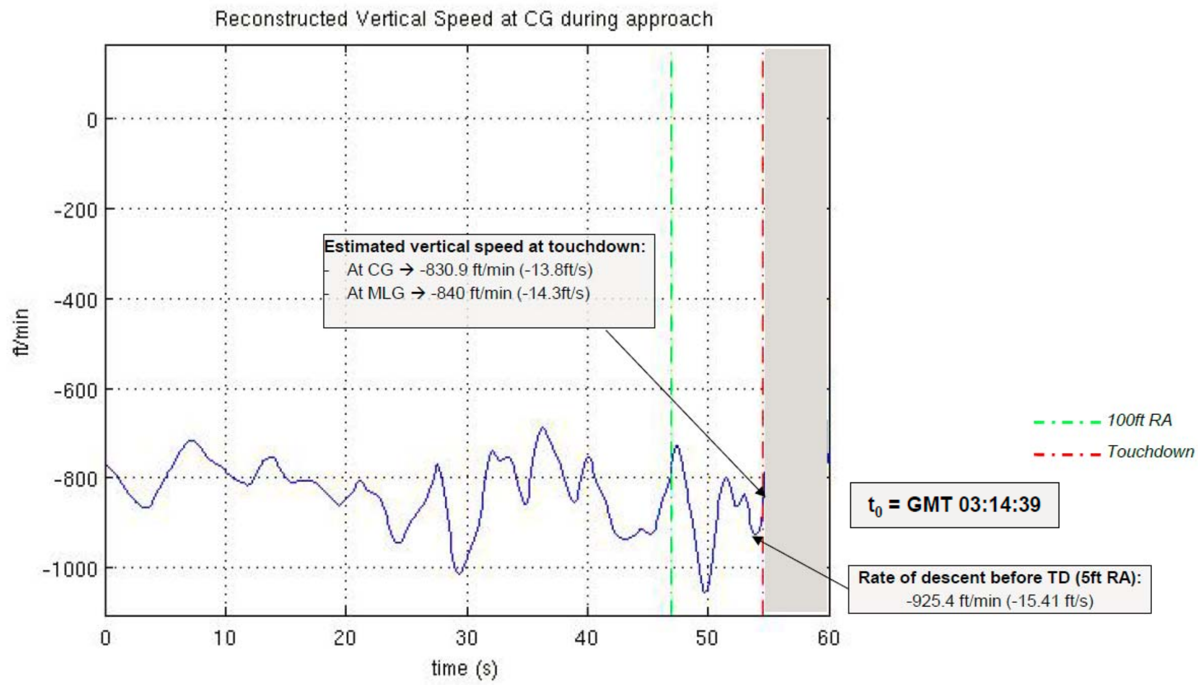


Wind reconstruction shows:

- **Tailwind increasing gradient of approximately 13kt/s between 19ft RA and the touchdown.**
- **Lateral gradient (3.3kt/s) between 88ft RA and the touchdown.**
- **Vertical windshear below 100ft with downdraft tendency.**



Reconstructed Vertical Speed at CG


Reconstructed Vertical Speed at CG during approach
ft/min
0
-200
-400
-600
-800
-1000
0
10
20
30
40
50
60
time (s)
Estimated vertical speed at touchdown:
At CG → -830.9 ft/min (-13.8ft/s)
At MLG → -840 ft/min (-14.3ft/s)
100ft RA
Touchdown
t0 = GMT 03:14:39
Rate of descent before TD (5ft RA):
-925.4 ft/min (-15.41 ft/s)

Appendix B: Nose landing gear fracture and damage analysis report

声　　明

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首都航 B-6952 飞机前起落架机轮组件断裂损伤分析

1 概述

2018 年 8 月 28 日，北京首都航空公司空中巴士 B-6952/A320-214 飞机，由北京首都国际机场 (ZBAA)飞往澳门国际机场 (VMMC)，执行 JD5759 / CBJ5759 的定期客运航班任务。航班在进入最后进场程序前一切正常。直到在进场的最后阶段，下降到地面高度 50 至 30 尺之间，速度由 134 节跌落至 123 节，下降率约为 688 尺每分钟。失速发生在 1 至 2 秒内，在着地瞬间航空器正受风速達 28 节顺风影响。在 34 号跑道入口之后 500 米处，航空器主起落架重着陆并随即发生反弹离开地面。4 秒钟后，航空器再次发生前起落架重着陆，并随即再次反弹离开地面。前方起落架因而受损，并且有碎片被吸入左右两个发动机。

在经过第二次反弹后，机组人员执行复飞程序，并且由于左发动机受碎片击伤，机组人员以低爬升率进行复飞。

随后，机长宣布 Mayday 并评估合适的机场降落航空器，导航系

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统此时因硬着陆而无法正常运行，此时备用导航系统启动。机组人员评估状况后决定转飞往深圳并要求深圳宝安国际机场全面戒备及进行紧急降落。

最终飞机成功在深圳宝安国际机场着陆。飞机遭受了严重破坏，着陆过程中并没有发生火警。

应澳门民航局要求，澳门机场和深圳机场收集到的飞机损伤部件被送到中国民航科学技术研究院进行失效分析，以确定部件失效原因和失效过程。

2 试验过程

2.1 部件损伤形貌

图 1 为澳门机场跑道上收集到的飞机损伤部件形貌，包括 2 个前轮轮胎，1 个较完整的半轮毂，该半轮毂中心毂分离，中心毂周围的辐板缺失，轮毂圆筒外形结构基本完好。另有一段约四分之一周长的半轮毂圆筒断裂件。剩余的断裂部件尺寸较小，其中很多是表面涂有灰漆的轮毂断裂碎块。还有多个断裂的轮毂螺栓，以及一些机轮轴承部件如滚棒，卡圈等。2 个前轮轮胎中一个轮胎胎侧多处破裂，如图 2 所示，另一个轮胎较为完好。

图 3 和图 4 为深圳机场跑道上收集到的飞机损伤部件形貌，包括：1）2 个半轮毂，这 2 个半轮毂的中心毂分离，几乎全部辐板缺失，一个轮毂圆筒因磨损导致圆周局部磨穿，另一个轮毂圆筒因严重磨损导致轮毂圆筒八分之一圆周缺失。2）3 个脱落的较完整轮毂中心毂，

其中 2 个中心毂中带有轴承外圈，这 3 个脱落的轮毂中心毂因发生了严重的局部磨损约 30%圆周缺失。3）4 个机轮轴承内圈，因严重局部磨损约 30%圆周缺失。4）1 个机轮轴承外圈，因发生严重的局部磨损约 30%圆周缺失。5）40 余粒机轮轴承滚棒。6）4 个机轮轴承保持架残件，均发生断裂和变形。7）多个机轮轴承封严和 1 个机轮轴承卡圈。8）一大段和一小段前机轮轮轴。9）2 个磨损到一半周长的机轮轴承卡死螺母。10）一些前轮轴套筒损伤件和螺栓断裂件

图 5 为发动机中收集到的断裂件，包括一段长 250mm 的弧形带螺栓孔的宽厚断裂结构件，另有 2 块带弧形的薄壁碎块和 2 块团块状的碎块，这些断裂件断面呈银灰色，表面涂有灰色或浅绿色油漆，密度较低。这些断裂件的结构形状、颜色和表面涂漆特征与轮毂相符，应为轮毂的断裂碎块。另外 2 个碎块均为黑灰暗薄片状，与轮毂材料特性不符。

前轮轮轴损伤形貌如图 6 所示，2 段轮轴分别为左、右前轮轮轴，一段长 384mm，该段轮轴端头剩余尺寸最大，约剩余三分之一圆周；另一段长 108mm，该段轮轴也是端头剩余尺寸最大，约剩余六分之一圆周。

澳门机场跑道收集到的基本完整半轮毂和半轮毂筒身断裂件形貌如图 7 所示，发动机中收集到的带螺栓孔的轮毂断裂碎块放大形貌如图 8 所示，这些半轮毂或半轮毂断裂件的 O 形密封圈处有凸边的结构，由此可判定澳门机场跑道收集到的基本完整半轮毂和半轮毂断裂件（包括发动机中找到的半轮毂断裂件）为外半轮毂。深圳机场跑

3

道上收集到的两个半轮毂放大形貌如图 9 所示，可见其 O 形密封圈处无凸边的结构，由此判定它们均为内半轮毂。

2 个前轮轮毂，一个序列号为 A7205，另一个序列号为 A0040。根据轮毂和辐板碎块断口开状及断裂件上的手写文字的匹配性可确定一些轮毂辐板碎块属于某个特定的半轮毂。序列号为 A7205 的内、外半轮毂及确定属于这 2 个轮毂的辐板碎块形貌如图 10 所示。序列号为 A0040 的内、外半轮毂及确定属于这 2 个轮毂的辐板碎块形貌如图 11 所示。不能确定属于 A7205 或 A0040 轮毂的轮毂辐板碎块形貌如图 12 所示。序列号为 A0040 的外半轮毂有一片辐板碎块带有部分中心毂圆筒，如图 13 所示，该碎块中心毂圆筒部分长度为中心毂圆筒长度的六分之一，中心毂圆筒不仅沿周向断裂，而且沿周向也发生了断裂。

收集到的 12 根轮毂螺栓断口形貌如图 14 所示，除一根螺栓几乎全部为斜断口外，其余 9 根螺栓均有平断口区和斜断口区，但平断口区较为粗糙，如图 15 所示。

4 个机轮轴承内圈滚道表面形貌如图 16 所示，滚道表面除机械划伤外，无高温变色和金属熔焊特征。3 个分离的轮毂中心毂及安装于其中的机轮轴承外圈形貌如图 17 所示，外圈滚道表面除机械划伤外，同样无高温变色和金属熔焊特征。滚棒形貌如图 18 所示，部分滚棒表面磨损严重，但除一个滚棒端面有熔化和高温特征外，其余滚棒无明显高温变色特征。

3 个内半轮毂辐板断口和 3 个分离的轮毂中心毂辐板断口如图

4

19-22 所示，均为粗糙平断口或较平坦的斜断口，未见平坦光滑的平断口区。全部轮毂辐板碎块的断口也均为粗糙平断口或较平坦的斜断口。发动机中收集到的长 250mm 带螺栓孔的轮毂断裂碎块各个断面形貌如图 23-25 所示，均为粗糙平断口或较平坦斜断口，未见平坦光滑的平断口区。其余轮毂断裂碎块各个断面也均为粗糙平断口或较平坦斜断口，未见平坦光滑的平断口区。

2.2 能谱成分分析

将图 5 所示发动机中收集到的断裂件中 2 个灰暗薄片状碎块进行能谱成分测试，另取 2 个澳门机场跑道收集的灰暗薄片状碎块进行能谱成分测试。此外，在图 5 中箭头所示碎块上取小块材料进行能谱成分测试。4 个灰暗薄片状碎块元素组成相同，其能谱图见图 26，半定量计算结果为（wt%）：6.72%Al，3.2%V，余量为 Ti，与美国 Ti-6Al-4V 钛合金成分相近。切取的小块材料能谱图见图 27，半定量计算结果为（wt%）：0.86Mg%，4.52%Cu，余量为 Al，与美国 2017 或 2024 铝合金成分相近。

3 分析与讨论

收集到的全部 4 个前机轮轴承内圈和 3 个前机轮轴承外圈滚道表面除机械划伤外，均无高温变色和金属熔焊特征，收集到的 40 余粒滚棒中部分滚棒表面磨损严重，但除一个滚棒端部有熔化和高温特征外，其余滚棒无明显高温变色特征，这表明 2 个前机轮轮毂的断裂失

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效不是由于机轮轴承的失效引起的。

深圳机场跑道和澳门机场跑道共发现 3 个较完整的前轮半轮毂和较多的轮毂碎块，其中 2 个轮毂碎块尺寸较大，由此可判断另一个前轮半轮毂断裂成多个碎块。深圳机场跑道收集到的 2 个前轮半轮毂均为内半轮毂，应分属于左、右前轮，因而澳门机场收集的 1 个前轮半轮毂和一些轮毂断裂件分别为左、右前轮的外半轮毂。

收集到的 3 个半轮毂圆筒、一个半轮毂断裂件、3 个半轮毂中心毂辐板以及全部的辐板碎片、12 根轮毂螺栓的断裂面均为粗糙平断口或较平坦的斜断口，未见平坦光滑的平断口区，这些断口特征显示轮毂的断裂为过载断裂。

两个前轮中，一个前轮轮胎胎侧多处爆裂，另一个前轮轮胎较为完好；一个前轮轮毂的外半轮毂断裂成多个碎块，其中心毂沿轴向和周向都发生了断裂，而另一个前轮轮毂的外半轮毂较为完整。这表明其中一个机轮承受了很大的撞击力，导致轮胎爆裂，外半轮毂包括中心毂断裂成多个碎块，部分轴承滚棒脱落；该机轮内半轮毂中心毂周围的辐板断裂，中心毂从轮毂分离。该机轮外半轮毂断裂为碎块而内半轮毂较为完整，表明飞机前轮接地时飞机向一侧有较大的倾斜，使得巨大的撞击力主要作用在该机轮的外半轮毂上。该机轮轮胎爆裂时轮胎高压气流使得部分轮毂碎块进射入发动机进气道中。另一个前轮也承受了很大的撞击力，但其撞击力明显小于之前发生爆裂的前轮，导致内、外半轮毂中心毂周围的辐板断裂，内、外半轮毂中心毂均从轮毂分离。2 个机轮轮毂的 3 个半轮毂与其中心毂发生分离后（另一

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个外半轮毂断裂成多个碎块而脱落），3 个半轮毂圆筒因失去了固定点发生移位，其中一个外半轮毂由于位于前起落架轮轴的外端很快就从轮轴脱落，2 个内半轮毂位于前起落架轮轴靠里面的位置未发生（从轮轴）脱落。飞机从澳门机场复飞到达深圳机场着陆时，断裂成多个碎块的外半轮毂其中心毂因严重损伤可能已脱落（在澳门机场或复飞后空中），另 3 个与半轮毂发生分离的中心毂连带机轮轴承和 2 个内半轮毂尚在前轮轮轴上。飞机在深圳机场降落滑跑时，首先是 3 个与半轮毂发生分离的中心毂连带机轮轴承和 2 个内半轮毂触地发生滑动磨损。由于 2 个内半轮毂在前轮轴上失去固定，在道面滑行时其在前轮轴上可以轴向滑移，其中一个内半轮毂在轮毂筒壁仅局部磨穿时就发生脱落，另一个内半轮毂和 3 个与半轮毂发生分离的中心毂圆筒（装有机轮轴承外圈）磨穿到足够大的尺寸时相继发生（从轮轴）脱落。中心毂脱落后机轮轴承滚棒和保持架受到磨损，保持架很快发生变形，与滚棒先后发生脱落。接着机轮轴承内圈触地发生磨损，内圈筒壁磨穿后轮轴触地发生磨损。当机轮轴承内圈筒壁磨穿到足够尺寸时相继发生（从轮轴）脱落。此时前轮轴继续触地磨损，直到局部位置磨断而脱落，最后起落架立柱触地磨损，直到飞机停止。

左、右前轮轮轴剩余长度差别巨大，表明飞机在深圳机场降落滑跑时向一侧有较大倾斜。

能谱成分测试表明发动机中收集到的 2 片黑灰色薄片材料成分与美国 Ti-6Al-4V 钛合金成分相近，应为发动机压气机叶片。发动机中收集到的其它碎块材料与美国 2017 或 2024 铝合金成分相近，为轮

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毂断裂件。

4 结论

1）收集到的全部 4 个前机轮轴承内圈和 3 个前机轮轴承外圈滚道表面除机械划伤外，均无高温变色和金属熔焊特征，收集到的 40 余粒滚棒中部分滚棒表面磨损严重，但除一个滚棒端部有熔化和高温特征外，其余滚棒无明显高温变色特征，这表明 2 个前机轮轮毂的断裂失效不是由于机轮轴承的失效引起的。

2）收集到的 3 个半轮毂圆筒、一个半轮毂断裂件、3 个半轮毂中心毂辐板以及全部的辐板碎片、12 根轮毂螺栓的断裂面均为粗糙平断口或较平坦的斜断口，未见平坦光滑的平断口区，这些断口特征显示轮毂的断裂为过载断裂。

3）一个前轮轮胎胎侧多处爆裂，一个前轮轮毂的外半轮毂断裂成多个碎块，这表明 2 个前轮其中的一个承受了很大的撞击力，而且前轮接地时飞机向一侧有较大的倾斜，使得巨大的撞击力主要作用在该机轮的外半轮毂上，导致该机轮轮胎爆裂，外半轮毂断裂成多个碎块，内半轮毂中心毂周围的辐板断裂，中心毂从轮毂分离。轮胎爆裂时高压气流使得部分轮毂碎块迸射入发动机进气道中。

4）另一个前轮轮胎较为完好，另一个前轮轮毂的内、外半轮毂均较为完整，内、外半轮毂中心毂周围的辐板断裂，内、外半轮毂中心毂均从轮毂分离，表明另一个前轮也承受了很大的撞击力，但其撞击力明显小于之前发生爆裂的前轮。

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5） 2 个机轮轮毂的 3 个半轮毂与其中心毂发生分离后（另一个外半轮毂断裂成多个碎块而脱落），3 个半轮毂圆筒因失去了固定点发生移位，其中一个外半轮毂由于位于前起落架轮轴的外端很快就从轮轴脱落，2 个内半轮毂位于前起落架轮轴靠里面的位置未发生（从轮轴）脱落。

6）飞机从澳门机场复飞到达深圳机场着陆时， 3 个与半轮毂发生分离的中心毂连带机轮轴承和 2 个内半轮毂尚在前轮轴上。飞机在深圳机场降落滑跑时，上述部件相继磨损脱落，最后起落架立柱触地磨损，直到飞机停止。

7）左、右前轮轮轴剩余长度差别巨大，表明飞机在深圳机场降落滑跑时向一侧有较大倾斜

8） 能谱成分测试表明发动机中收集到的 2 片黑灰色薄片材料成分与美国 Ti-6Al-4V 钛合金成分相近，应为发动机压气机叶片。发动机中收集到的其它碎块材料与美国 2017 或 2024 铝合金成分相近，为轮毂断裂件。

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图 1、澳门机场跑道上收集到的飞机损伤部件形貌

图 2、一个前轮轮胎胎侧破裂形貌

1

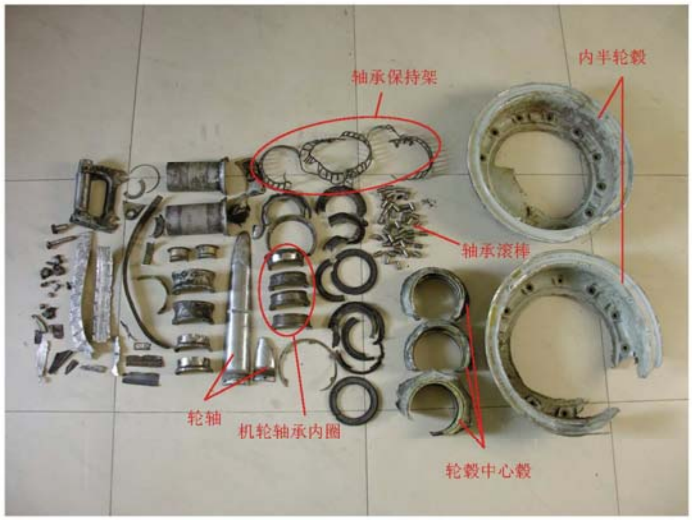

图 3、深圳机场跑道上收集到的飞机损伤部件形貌

图 4、深圳机场跑道上收集到的飞机损伤部件形貌（部分零件角度不同）

2

图 5、发动机中收集到的断裂部件形貌

图 6、前轮轮轴损伤形貌

图 7、澳门机场跑道收集到的基本完整半轮毂和全部的半轮毂筒身断裂件形貌

图 8、发动机中收集到的轮毂断裂碎块放大形貌

4

图 9、深圳机场跑道上收集到的两个半内轮毂放大形貌

图 10、序列号为 A7205 的内、外半轮毂及确定属于这 2 个轮毂的辐板碎块形貌

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图 11、序列号为 A0040 的内、外半轮毂及确定属于这 2 个轮毂的辐板碎块形貌

图 12、不能确定属于上述哪个轮毂的轮毂辐板碎块形貌

6

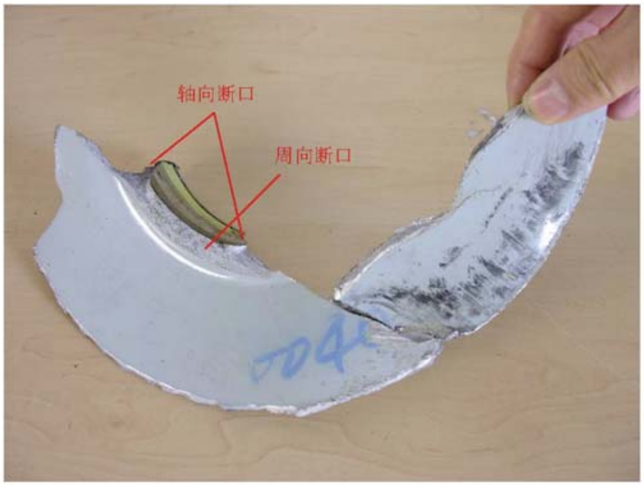

图 13、序列号为 A0040 的外半轮毂的一片带有部分中心毂圆筒的辐板碎块形貌

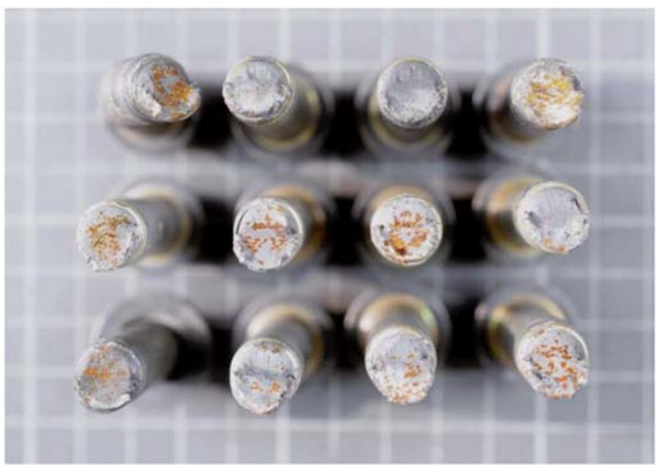

图 14、收集到的 12 根轮毂螺栓断口形貌

7

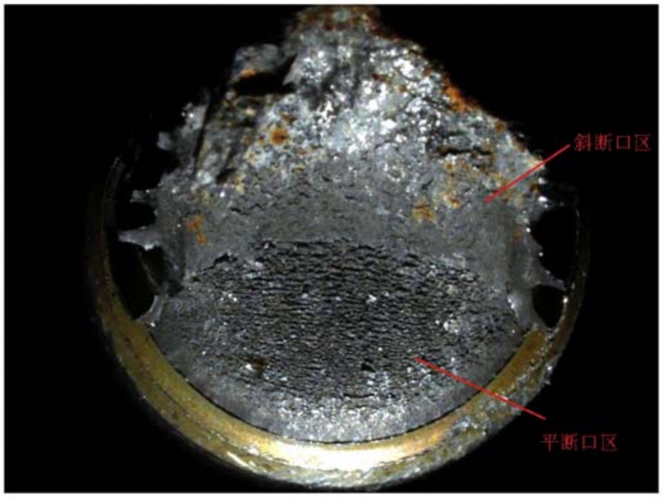

图 15、其中一根螺栓平断口体视显微镜观察形貌

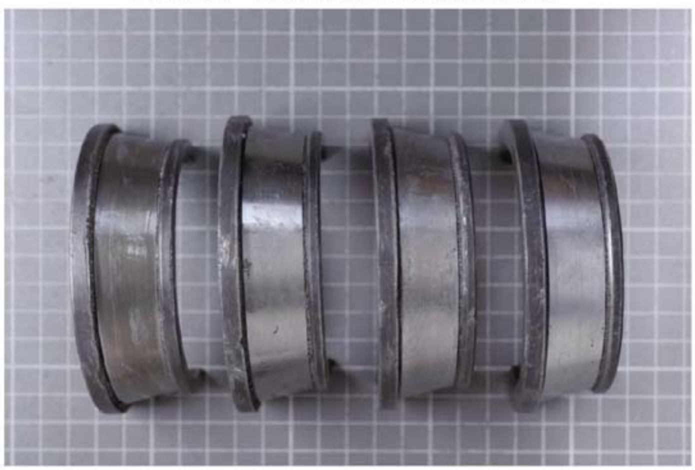

图 16、4 个机轮轴承内圈滚道表面形貌

8

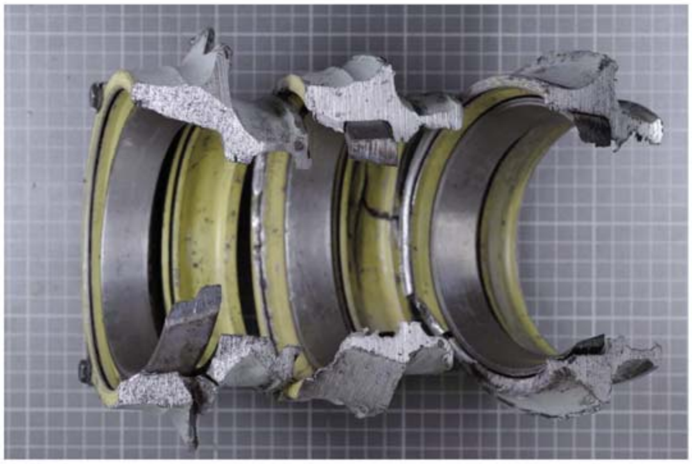

图 17、3 个分离的轮毂中心毂及安装于其中的机轮轴承外圈形貌

图 18、机轮轴承滚棒形貌

9

图 19、序号为 A7205 的内半轮毂辐板断口形貌

图 20、序号为 A0040 的内半轮毂辐板断口形貌

10

图 21、序号 A7205 外半轮毂毂辐板断口形貌

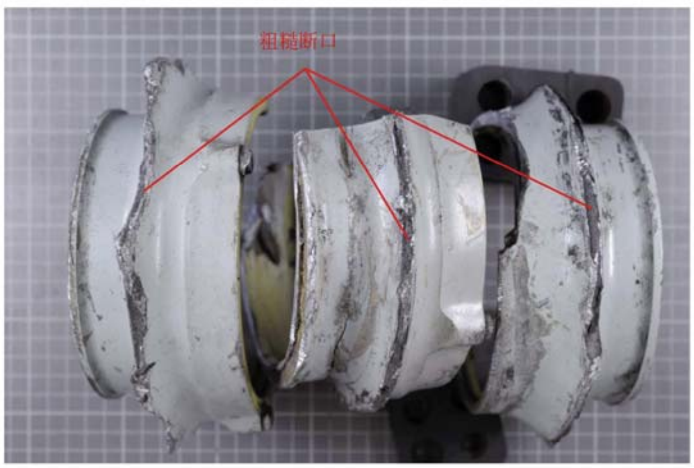

图 22、3 个分离的轮毂中心毂辐板断口形貌

11

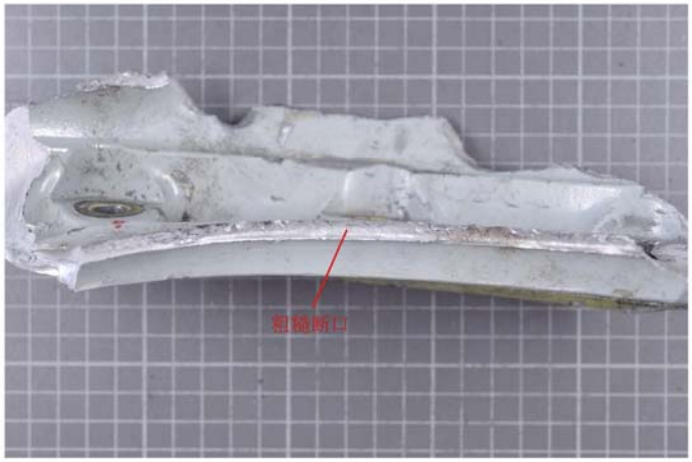

图 23、发动机中收集到的带螺栓孔的轮毂断裂碎块断面形貌

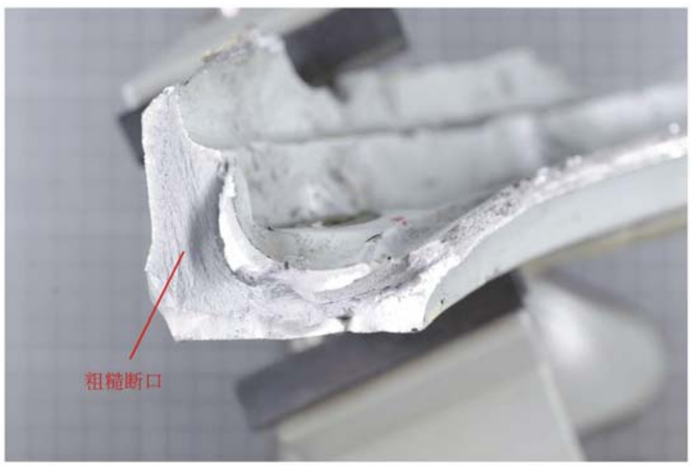

图 24、发动机中收集到的带螺栓孔的轮毂断裂碎块断面形貌

12

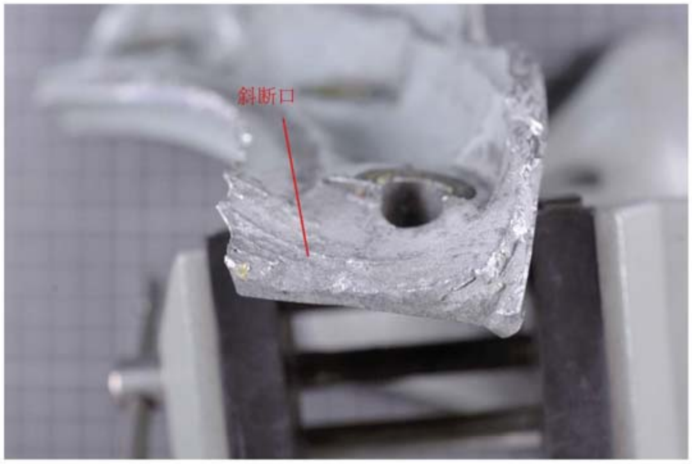

图 25、发动机中收集到的带螺栓孔的轮毂断裂碎块断面形貌

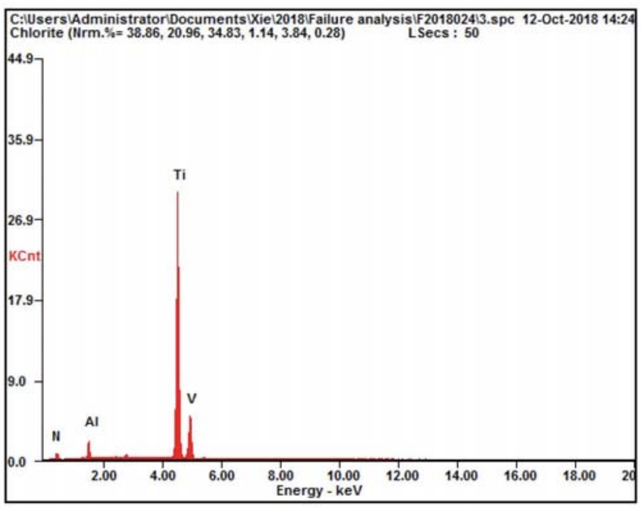

图 26、发动机中收集的 2 个灰暗薄片状碎块能谱图

13

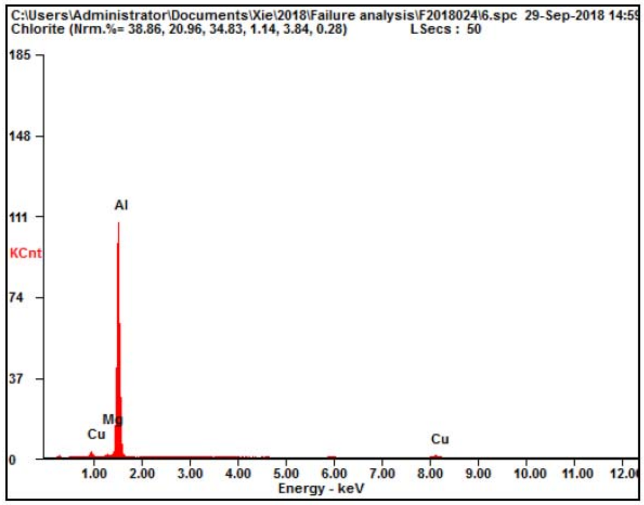

图 27、发动机中收集的块状碎块上切取的小块材料能谱图