Australian Government
Australian Transport Safety Bureau

In-flight break-up involving Airbus Zephyr unmanned aerial vehicle

Near Wyndham Airport, Western Australia on 28 September 2019

ATSB Transport Safety Report
Aviation Occurrence Investigation (Short)
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Addendum

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Safety summary

What happened

On 28 September 2019, an Airbus Zephyr 8 (Zephyr) unmanned aerial vehicle (UAV) was launched from Wyndham Airport, Western Australia. The UAV was being operated by Airbus and the purpose of the flight was to conduct beyond visual line of site, high-altitude aerial work.

While climbing through 8,000 ft above mean sea level, the UAV experienced a series of uncommanded turns. The UAV self-recovered from the first two uncommanded turns however, the third upset resulted in the aircraft entering an uncontrolled spiral descent. Despite attempts to return to controlled flight, the UAV sustained an in-flight break-up.

What the ATSB found

The investigation found that the UAV entered an area of unstable atmospheric conditions that were beyond the aircraft's ability to remain in controlled flight. Once the UAV departed controlled flight, it exceeded its structural limitations, resulting in an in-flight break-up.

Airbus operated the UAV within the Civil Aviation Safety Authority's authorisation and their own established procedures. As a result, the operation of the Zephyr aircraft was conducted with minimal risk to the public and environment.

What has been done as a result

Airbus conducted an investigation of this occurrence, which resulted in several safety recommendations being directed to the design and operational departments of the Zephyr program. Implementation of these recommendations will likely contribute to continued safe development of the Zephyr UAV.

Safety message

The number of UAVs and remotely piloted aircraft (RPA) in Australia, and worldwide, is increasing rapidly. Through reporting and investigation of UAV and RPA accidents and incidents, the ATSB is able to monitor trends and identify areas for safety improvement. This information is used to enhance the safety of all aircraft, and the public in general, enabling this sector of the aviation industry to continue to grow and develop.

The investigation

Decisions regarding whether to conduct an investigation, and the scope of an investigation, are based on many factors, including the level of safety benefit likely to be obtained from an investigation. For this occurrence, a limited-scope investigation was conducted in order to produce a short investigation report, and allow for greater industry awareness of findings that affect safety and potential learning opportunities.

The occurrence

On 28 September 2019, at 2143 Western Standard Time[1] an Airbus Zephyr 8 unmanned aerial vehicle (UAV), serial number Z8B-03,[2] was launched from Wyndham Airport, Western Australia. The UAV was being operated by Airbus and the purpose of the flight was to conduct beyond visual line of site, high-altitude aerial work. The launch was described by the crew as 'ideal' and a systems check, conducted at about 1,200 ft above mean sea level, did not identify any issues. The UAV continued to climb, in a south-easterly direction, toward its typical operational altitude of 60,000-74,000 ft.

At about 2240, while climbing through 5,200 ft, the UAV experienced an uncommanded roll of about 15˚ to the right. This was likely induced by isolated thermal turbulence as the aircraft passed over a dry salt lake. The UAV's track changed approximately 180˚, before self-recovering. At this point, the crew elected to continue the climb, to the north, toward anticipated smoother conditions. Power was increased to counter the corresponding headwinds, however, the UAV's ground speed reduced to around 1 kt.

As the climb continued, the UAV entered an area of increasingly unstable atmospheric conditions. At about 2307, while passing through 8,700 ft, the UAV experienced another uncommanded roll of 14˚ to the right, followed by 17˚ to the left. The aircraft again self-recovered, however, the turbulent conditions persisted. The UAV descended about 1,000 ft over the next 7 minutes, while the crew increased power and tried to direct the aircraft to calmer conditions.

The UAV sustained a third uncommanded roll to the right, at about 2315, from which it was slow to recover. During the attempted recovery, the UAV exceeded its maximum airspeed (Vne).[3] The aircraft, with full left rudder applied, did not self-recover and the roll angle subsequently increased beyond limits. The UAV then entered an uncontrolled spiral descent.

At about 2316, the UAV's airspeed increased further beyond Vne, which shortly thereafter, resulted in an in-flight break-up, with both wings fracturing at about mid-span (Figure 1). Coincident with the break-up, the crew noted that vision from the wingtip camera[4] was lost. Shortly thereafter, both separated wing sections were observed in vision from the forward-looking camera mounted on the aircraft's fuselage.

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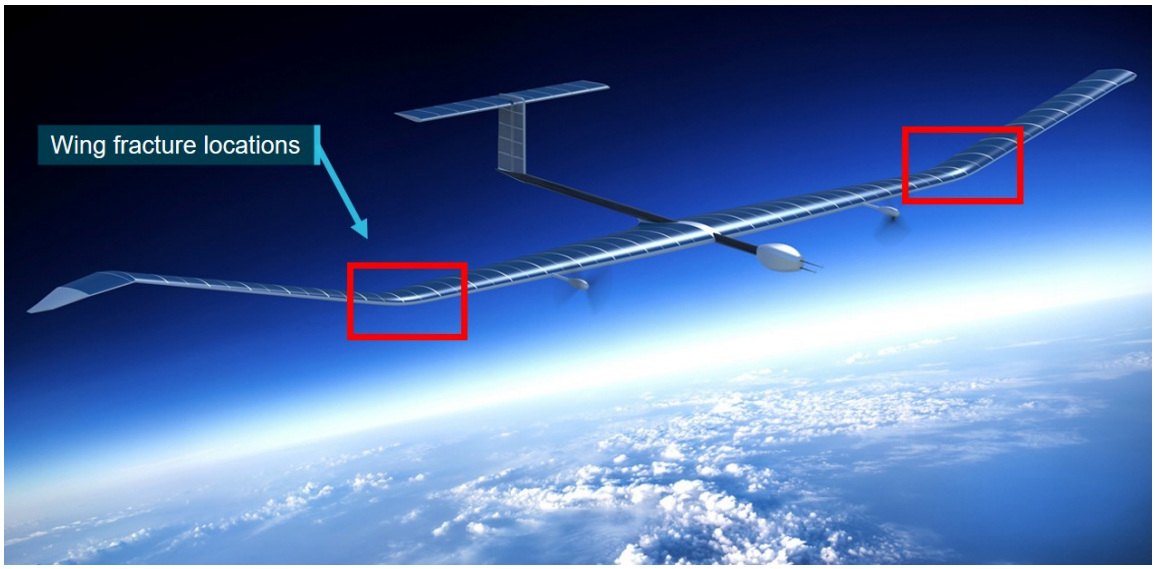
1 Western Standard Time (WST): Coordinated Universal Time (UTC) + 8 hours.

2 The term UAV refers to serial number Z8B-03 for the remainder of the report, except where otherwise noted.

3 Vne – velocity never exceed – indicated airspeed that, if exceeded, may result in structural damage to an aircraft. The Zephyr UAVs Vne was significantly slower than conventional aircraft.

4 The wingtip camera was located on the left and oriented to view the aircraft.

Figure 1: Typical zephyr - showing wing fracture locations



Source: Airbus, annotated by ATSB

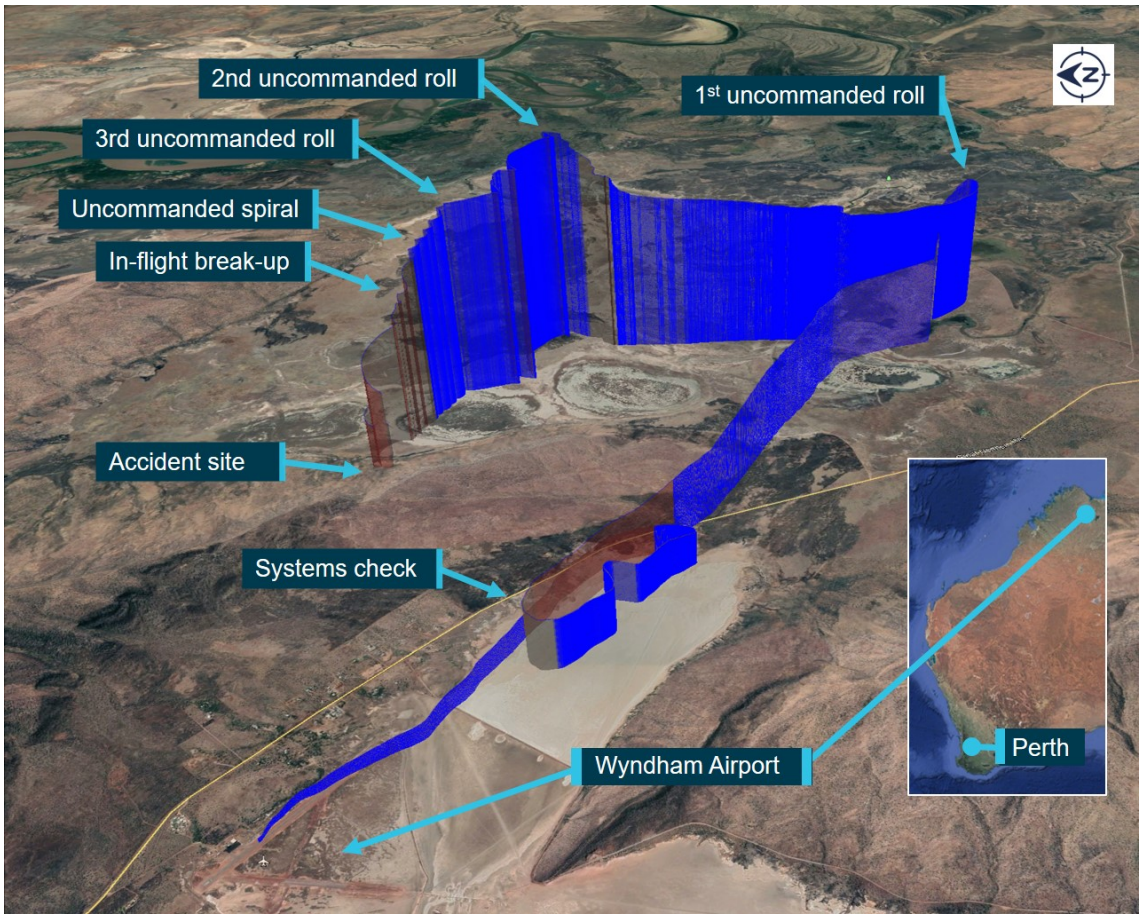
The loss of the outboard section of both wings meant the UAV was no longer able to maintain itself in the flight envelope and it entered into the 'soft termination' phase.[5] The intent of soft termination was to have the UAV descend within the predicted 'cut-down' vector.[6] The soft termination phase also disabled the aircraft's battery charging system to reduce the risk of a post-accident fire.

The crew initiated the post-crash management plan and monitored the telemetry from the UAV until it was lost behind terrain, at 872 ft, about 5 minutes later. The accident site was located about 5.5 km east of Wyndham Airport and within the predicted cut-down zone (Figure 2).

[5] Soft termination can also be commanded by the crew.

[6] The cut-down vector is determined using aircraft telemetry to predict the aircraft's likely point of collision with terrain.

Figure 2: Flight path



Source: Airbus, Google Earth – annotated by ATSB

The distribution of the wreckage was consistent with an in-flight break-up. The rudder was not located despite an extensive search. The recovered components were taken to a hangar at Wyndham Airport for examination. Examination of the wreckage identified that the wings failed about mid-span, due to overstress (Figure 3 and Figure 4). The aircraft batteries were tested and were all found to be within operational voltages.

Figure 3: Right wing outboard section

Source: Airbus

Figure 4: Left wing outboard sections

Source: Airbus

Context

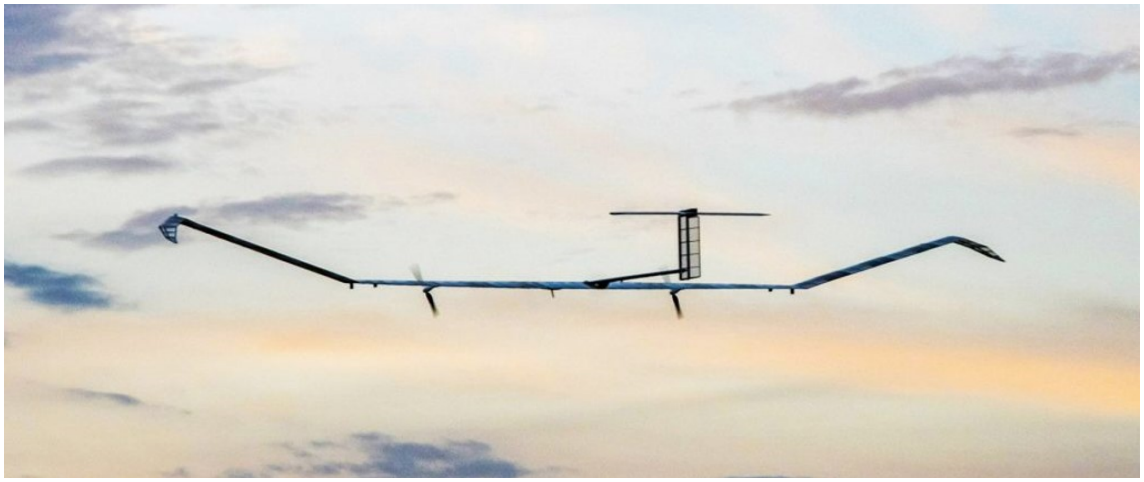
Aircraft information

The Airbus Zephyr unmanned aerial vehicle was an ultra-light weight, high-altitude pseudo-satellite, developed by Airbus Defence and Space.[7] The Zephyr was solar-electric and designed to operate in the stratosphere,[8] above the weather and conventional air traffic (refer to section titled *Meteorological information*). Flight testing begun in 2008, with multiple successful missions launched from Arizona, in the United States, and Dubai, in the United Arab Emirates. These missions provided valuable operational experience and flight data, for the research and development phase. In August 2018, a Zephyr completed a 25-day flight. The ultimate goal for the program was to operate for over 100 days without landing.

The Zephyr (Figure 5) has a polyhedral wingspan of 25 m,[9] weighed about 65 kg and could accommodate various payloads, for communication and surveillance roles. The carbon-fibre wing structure contained an array of solar panels which powered the two motors, aircraft systems and recharged the aircraft's batteries. Control was provided via the rudder, elevators and differential power from the motors.[10] The Zephyr was launched by hand[11], and climbed at a low airspeed with a climb rate of about 5,000 ft/hr. Due to the Zephyr's light weight and low airspeed it was susceptible to turbulent atmospheric conditions.

The Zephyr UAV design was similar to a glider where, ascending during daylight under power, to a maximum altitude of about 74,000 ft, was similar to a glider being towed to altitude. The UAV then slowly descended overnight (to about 60,000 ft) in a glide, reducing reliance on the aircraft batteries until the latter part of the night.

Figure 5: Airbus Zephyr



Source: Airbus

[7] QinetiQ initially designed the Zephyr in 2003, before Airbus Defence and Space gained control of the program in 2013.

[8] The stratosphere is located above the troposphere, about 18-25 km above the earth's surface. In this zone, air temperature increases with altitude, avoiding convection and resulting in stabilised atmospheric conditions

[9] The wings consisted of a mid-span 15˚ dihedral (upward) and wing tip anhedral (downward).

[10] There is no aileron flight control system on the Zephyr.

[11] Zephyr is typically hand-launched by four to five ground crew, fast-walking/jogging into an ideal 2-3 kt headwind.

Design standard

At the time of publication of this report, there were no design standards for unmanned aircraft systems (UAS). In the absence of a defined certification process, Airbus developed their own design standard, which was approved through the Ministry of Defence, United Kingdom.

The Joint Authorities for Rulemaking on Unmanned Systems (JARUS) consisted of a group of experts from various national aviation authorities and international safety organisations. Their objective was to provide guidance material to facilitate each national authority to develop their own specific technical, safety and operational requirements for the certification and safe integration of UAS requirements, while avoiding duplicated effort.

The Civil Aviation Safety Authority (CASA), utilised the JARUS specific operations risk assessment (SORA) to identify and set minimum operational organisational and technical requirements to achieve an acceptable level of safety for operations in Australia.

Operational information

The Zephyr program commenced operations from Wyndham Airport, 2,200 km north-east of Perth, Western Australia, in late 2018. Wyndham was chosen due to its remoteness, providing good separation from standard flight routes and areas of high population.

CASA issued Airbus with an authorisation to operate beyond visual line of sight (BVLOS), and at night, from the surface to 90,000 ft, over the defined movement area and not within 3 NM of any other aerodrome. Some of the authorisation's requirements were:

- a current 'notice to airmen' (NOTAM)[12] was required for all operations over 400 ft above ground level and BVLOS
- Airbus was to coordinate air traffic from the ground to 18,000 ft (FL180)[13]
- Airservices Australia was to coordinate traffic between FL180 and FL550.

The operational base at Wyndham Airport consisted of two ground control stations (GCS).[14] The GCS contained the necessary equipment to support flight operations. In addition, the Zephyr could be monitored and controlled from the main base in Farnborough, United Kingdom, or any other GCS however, only the Wyndham GCS was authorised by CASA for Australian operations.

Crew information

The core crew, for the launch and initial climb, consisted of a remote pilot, remote pilot in command, mission planner and flight test engineer. In addition, there were several subject matter experts, observing and providing guidance as required. All crewmembers were appropriately qualified for this mission. Further, all self-reported to being healthy and not suffering from a level of fatigue that may affect their ability to carry out their roles.

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12 A notice to airmen (NOTAM) advises personnel concerned with flight operations of information concerning the establishment, condition or change in any aeronautical facility, service, procedure, or hazard, the timely knowledge of which is essential to safe flight.

13 Flight level (FL): An aircraft's height above mean sea level when the pressure at sea level is 1013.2 hPa, called pressure altitude. FL 220 equates to 22,000 ft pressure altitude.

14 Typically, when two Zephyrs were in operation; each GCS would control an individual aircraft. On this flight, the second GCS acted as a back-up facility.

Meteorological information

Wyndham's climate includes a wet season, from late November to March, and a dry season typically from April to early November. [15] The wet season is associated with convective atmospheric conditions that are not compatible with Zephyr operations.

Weather forecast

Knowledge of the effects that atmospherics conditions had on the UAV were developed over several years of operation in the northern hemisphere. Wyndham weather information was obtained via various global weather forecasting organisations, the Bureau of Meteorology (Australia) and locally launched radiosondes.[16] The crew reported that, due to the remote, and mostly rural, location of Wyndham, the weather forecasting data was lower in resolution than was required for their operations. Therefore, the locally launched radiosondes, combined with their knowledge base from the northern hemisphere-operations, were utilised for forecast modelling during mission planning.

Forecast weather for the occurrence flight identified:

- a broad scale upper trough to the west, slowly progressing east
- no cloud expected above inversion layer, located at approximately 11,000 ft
- a mixing layer (rising and descending air) just below the inversion layer
- no storm activity
- likely areas of turbulence, both terrain-induced and atmospheric.

Mission planning

Due to the UAV's susceptibility to turbulence, the climb and descent phases were considered critical as they took up to 10 hours to transit the troposphere.[17] As a result, the climb and descent phases were carefully planned to avoid areas of convective activity. A launch would not go ahead when a mixing layer greater than 1,500 ft was identified. Experience had shown mixing layers typically reduced or dissipated in the evening. In addition, the possibility of aircraft drift had to be considered, to ensure the UAV remained within the defined operational area.

Weather forecasting data was analysed at each 'launch decision point' throughout the day, analysis continued for the duration of the climb and in preparation for descent. General considerations included:

- evaluation of upper air wind strength
- notable cloud activity and level
- the risk of icing
- topography assessment of mountain or gravity wave severity
- evaluation of humidity and likely thermal activity
- forecast rain or thunderstorms
- launch requirements of surface temperature less than 40˚C and winds of 2-5 kt.

This flight was originally planned to launch on 27 September 2019. The crew conducted the mission planning as per their procedures, however, the surface winds were not suitable for launch.

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[15] The wet season is usually preceded by a 'build-up', generally from October to late November, where temperature and humidity 'build', before monsoonal rain sets in, resulting in a period of unstable weather conditions.

[16] A radiosonde is a small telemetry instrument, which measures various atmospheric parameters as it is carried into the atmosphere by a weather balloon, transmitting the data to a ground receiver.

[17] The troposphere, the atmospheric layer between the earth's surface and the stratosphere, is where almost all weather phenomena takes place.

The flight was subsequently put on hold, pending assessment of weather conditions the following morning.

On the morning of 28 September 2019, some of the crew met at 1100 for a briefing and review of the latest weather information. Over the course of the day, the crew noted that the conditions improved as the day progressed into evening, as was anticipated. In addition, the crew reported that while likely areas of turbulence had been identified, 'it was not expected to be unmanageable'. When the surface conditions were identified as 29˚C with winds of 2-4 kt, from the south-east, the decision was made to launch.

Other occurrence

In March 2019, another Zephyr 8 was involved in an accident, after launching from Wyndham Airport, WA. The resulting collision with terrain was also within the safe, predicted cut-down vector and there were no injuries to people or damage to local infrastructure. Following this occurrence, Airbus developed several safety recommendations. These included:

- enhanced pre-mission forecasting based on a better understanding of the effects of weather on the Zephyr
- expanded mission planning to determine optimum flight route, designed to avoid weather conditions known to affect the Zephyr
- crew to include additional subject matter experts, in operational and observer roles, to provide knowledge and guidance, as required
- refining procedures to ensure that no one person was making critical decisions, while also ensuring every member of the crew had the opportunity to provide input
- refining post-crash management procedures.

The ATSB spoke with eight members of the crew following the September 2019 occurrence, which was the first flight after the March accident. The crew referred, with positive comments, to the enhanced procedures being utilised during the mission planning, flight operations and post-crash management.

Analysis

Designed for high-altitude flight, the Zephyr unmanned aerial vehicle (UAV) was extremely sensitive to atmospheric instability during the climb and descent phases. At the time of the occurrence, the Zephyr program was in its early operation phase. As such, information regarding the UAV's structural limitations and methods to forecast turbulence were still evolving.

About one hour after launch, the UAV encountered atmospheric conditions that resulted in a departure from the planned flight. The UAV self-recovered from several turbulence-induced upsets, and the crew increased power and tried to command the aircraft into calmer conditions. Due to the UAV's low air speed, local winds reduced the groundspeed to around 1 kt, reducing its ability to move out of the unstable conditions in a timely manner. The UAV was unable to self-recover from the final uncommanded turn and entered into an uncontrolled spiral descent. During this descent, a combination of high bank angles and airspeed exceeded its structural limitations and resulted in an in-flight break-up.

Multiple successful missions, over several years, in the dry desert-like locations in the northern hemisphere, had provided valuable data to assist in identifying the optimum weather conditions for the sensitive climb and descent phases. This was only the second launch from Wyndham and, as such, the unique local terrain and weather conditions were not fully understood. The first, failed launch from Wyndham resulted in the implementation of enhanced planning procedures, which were utilised for this mission, with positive reports from the crew. While this mission also resulted in a loss of the UAV, both launches resulted in a greater understanding of local meteorological conditions.

The two launches from Wyndham, while unsuccessful, have shown that the cut-down vector, soft-termination and post-crash management procedures were effective. These steps reduced the likelihood that the Zephyr UAV would present a fire risk following the collision with terrain, and that it came to rest at the predicted location, minimising risk to the public and environment.

Findings

ATSB investigation report findings focus on safety factors (that is, events and conditions that increase risk). Safety factors include 'contributing factors' and 'other factors that increased risk' (that is, factors that did not meet the definition of a contributing factor for this occurrence but were still considered important to include in the report for the purpose of increasing awareness and enhancing safety). In addition 'other findings' may be included to provide important information about topics other than safety factors.

These findings should not be read as apportioning blame or liability to any particular organisation or individual.

From the evidence available, the following findings are made with respect to the in-flight break-up involving an Airbus Zephyr 8 unmanned aerial vehicle, near Wyndham Airport, Western Australia on 28 September 2019.

Contributing factors

- The Airbus Zephyr 8 entered an area of unstable atmospheric conditions that exceeded the aircraft's ability to remain in the flight envelope, resulting in an in-flight break up.

Other findings

- Operational and post-crash management procedures were effective in minimising risk to the public and environment.

Safety issues and actions

Whether or not the ATSB identifies safety issues in the course of an investigation, relevant organisations may proactively initiate safety action in order to reduce their safety risk. All of the directly involved parties are invited to provide submissions to this draft report. As part of that process, each organisation is asked to communicate what safety actions, if any, they have carried out to reduce the risk associated with this type of occurrences in the future. The ATSB has so far been advised of the following proactive safety action in response to this occurrence.

Safety action by Airbus

As a result of this occurrence, Airbus conducted an investigation which resulted in several safety recommendations. These included the development of tools capable of forecasting local weather phenomena to the higher accuracy and resolution required for the Zephyr Program. These tools are intended to assist the flight crew with mission planning and in-flight decision-making. In addition, enhanced procedures were developed to assist the flight crew in efficiently managing abnormal situations.

Sources and submissions

Sources of information

The sources of information during the investigation included:

- Airbus
- flight crew

Submissions

Under section 26 of the *Transport Safety Investigation Act 2003*, the ATSB may provide a draft report, on a confidential basis, to any person whom the ATSB considers appropriate. That section allows a person receiving a draft report to make submissions to the ATSB about the draft report.

A draft of this report was provided to the following directly involved parties:

- Airbus
- flight crew
- Civil Aviation Safety Authority

Submissions were received from:

- Airbus
- Civil Aviation Safety Authority

The submissions were reviewed and, where considered appropriate, the text of the report was amended accordingly.

General details

Occurrence details

Date and time:	28 September 2019 – 2321 WST	
Occurrence category:	Accident	
Primary occurrence type:	In-flight break-up	
Location:	Near Wyndham Airport, Western Australia	
	Latitude: 15º 30.32' S	Longitude: 128º 12.27' E

Aircraft details

Manufacturer and model:	Airbus Zephyr 8 UAV	
Call sign:	Unmanned Zephyr	
Operator:	Airbus	
Serial number:	Z8B-03	
Type of operation:	Aerial work	
Departure:	Wyndham Airport	
Destination:	Wyndham Airport	
Injuries:	Crew – Nil	Public – Nil
Aircraft damage:	Destroyed	