DUTCH
SAFETY BOARD

Fly-away after compass malfunction

DJI Inspire 2 Unmanned Aircraft System

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DJI Inspire 2 Unmanned Aircraft System

Den Haag, February 2023

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Photograph cover: The photo concerns a representation of the DJI Cadence remote controller and the DJI Inspire 2 unmanned aircraft without payload. (Source photos: djicdn.com)

The Dutch Safety Board

When accidents or disasters happen, the Dutch Safety Board investigates how it was possible for these to occur, with the aim of learning lessons for the future and, ultimately, improving safety in the Netherlands. The Safety Board is independent and is free to decide which incidents to investigate. In particular, it focuses on situations in which people's personal safety is dependent on third parties, such as the government or companies. In certain cases the Board is under an obligation to carry out an investigation. Its investigations do not address issues of blame or liability.

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N.B: This report is published in the English language, with a separate summary in the Dutch language. If there is a difference in interpretation between the Dutch and English version, the English text will prevail.

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SUMMARY

The occurrence

On 11 April 2020 the crew of PH-5MV, consisting of the pilot, the payload operator and two observers intended to perform a crowd observation and crowd control mission in the Zuiderpark, The Hague. The flight was performed with a DJI Inspire 2 Unmanned Aircraft System (UAS)[1] with a camera payload. Shortly after take-off, during post take-off checks, the pilot lost control over the aircraft. Roughly 30 minutes later the crew was notified that witnesses had found the Unmanned Aircraft (UA) crashed on the sidewalk of a street in The Hague and reported it to the police. Following the crash, the operator initiated a safety investigation. Additionally, the Dutch Safety Board decided to conduct an investigation due to the potential for damage and injury to third parties.

Loss of control: compass malfunction as result of different payload

As part of the investigation, the Safety Board analysed the flight data obtained from the Inspire 2. This analysis revealed that shortly after take-off, the UA did not consistently respond to the pilot's Remote Controller (RC) input. This inconsistency mainly occurred in roll and pitch. The investigation showed that, at the same time, the Inspire 2 registered multiple compass faults. This, along with a deviation of the compass angle from the angle of the GPS-track, indicated that a compass malfunction contributed to the unexpected UA response.

Further investigation showed that on the flight prior to the incident flight, a loudspeaker payload was used. This payload, with its own (electromagnetic) characteristics and manufactured by a third-party, differed from the camera payload on the incident flight. During preparation of the incident flight, the DJI GO 4 app[2] did not show a compass calibration warning on the main screen and therefore the pilots did not recalibrate the compass. As a result, the flight was conducted with an incorrectly calibrated compass, ultimately rendering the UA uncontrollable.

Cause of the crash

After the loss of control, a fly-away occurred. While the pilot tried to regain control, the UA flew over a line of trees, blocking the line-of-sight between the RC and the UA, after which the connection with it was lost. Thereafter, the UA flew uncontrolled over the city of The Hague. After about 18 minutes of flight, the UA initiated an automated landing sequence due to low battery voltage, but was unable to complete it. The aircraft hovered until insufficient power was left and subsequently crashed in an urban area on a sidewalk.

1 UAS typically consist of a ground station or remote controller and an unmanned aircraft. Also see Section 2.3 of this report.

2 DJI GO 4 is an application on a mobile device to control the unmanned aircraft.

The crash remained without consequences to third parties, but given the mass and size of the UA, a collision with a person could have led to serious consequences.

Lessons learned: compass calibration, flight mode selection and the safe use of payload

The operator did not have procedures for compass calibration in relation to payload changes and relied on indications from the DJI GO 4 app. By doing so, the operator complied with the UAS manufacturer's recommendation, which stresses to only calibrate the compass when indicated by the software. This investigation shows that the DJI GO 4 app is not able to detect an incorrectly calibrated compass in all cases. Therefore, it is advisable to manually start a compass calibration after a payload change, to prevent an unwanted compass offset that may lead to a loss of control.

After the loss of control, the pilot switched to the Return-To-Home (RTH) flight mode. This was in line with the operator's procedures and the UAS manufacturer's guidelines. However, the RTH flight mode also depends on the compass. Therefore, in some cases switching to the A(ttitude)-mode should be given priority because it eliminates the dependence on the compass. Switching to A-mode is advisable if the crew is unsure whether there is a compass malfunction because RTH still works when flying in A-mode.

Legally, under national regulations, it is not allowed to fly with payload other than the payload that was assessed to obtain the special certificate of airworthiness (S-BvL). The operator and payload developer were unaware of this requirement. As a result, no S-BvL-assessment was done for the loudspeaker payload. The manufacturer of the loudspeaker payload indicated that the product was tested for a limited number of conditions before it was made available to the customer. It is important that risks associated with using payload are considered by the user in advance. As this is not always possible, it remains important for users to be particularly observant when using different payloads.

During the course of this investigation, the operator has made a number of changes to its own operation, incorporating the lessons learned from the incident.

The manufacturer of the loudspeaker payload did test for interference during development, but not extensively. There was no coordination between the UAS and payload manufacturers, which is an important prerequisite for the development of payloads that can be used safely.

Support to safety investigations by the manufacturer

Despite multiple requests, the manufacturer of the UAS did not provide the Dutch Safety Board with all the information needed for the investigation. Therefore some aspects (e.g. why the failure condition in the compass could exist) could not be investigated and the investigation is partly inconclusive. Part of the information about the technical cause is known only because the operator has invested a great deal in finding the possible cause of the fly-away. Not all operators have the resources to contract third-party expertise for such investigations.

In order to learn from accidents and incidents involving UAS, it would be recommendable for all parties involved, among which manufacturers, to share the information needed for the investigation as much as possible. Also participating in safety investigations would improve the way all involved parties can learn from accidents and incidents, and subsequent investigations such as the one laid out in this report. All in all, in order to improve flight safety, the engagement of all parties involved is essential to learn from accidents and incidents.

RECOMMENDATIONS

To conduct Unmanned Aircraft System (UAS) flights, it is important that the operator and pilots have access to up-to-date information about the UAS, the (functioning of) onboard systems, payload and recommended procedures and safety guidelines. In that respect, operators and private users largely rely on the manufacturer's best practices when using UAS.

The manufacturer has published manuals and safety guidelines for the UAS. Although the average life span of a UAS is shorter than that of a regular aircraft, UAS can be in use for many years, even after production has ceased. It therefore remains important to update the guidelines using the latest safety insights, in such that users always have access to up-to-date information about the safe use of their UAS and the risks of flying with it.

To improve the safety of the use of UAS, the Dutch Safety Board issues the following recommendation:

To Da-Jiang Innovations Science and Technology Co., Ltd. (DJI):

1. Review the UAS user manual and safety guidelines using the safety lessons learned from this incident, and clarify the following aspects:
   a. actions in the event of controllability issues and when to use the RTH and A(ttitude)-mode;
   b. in which cases the compass must be calibrated;
   c. the risks associated with flying with (different) payload types.

To learn from accidents and incidents and to prevent them from happening again, it is vital that all parties involved, such as state safety investigation authorities and UAS operators, have access to the relevant information. In this regard, manufacturer support is essential.

Manufacturers have a responsibility with regard to the quality and safety of a product. In the area of cooperation with regard to safety investigations, the Board sees room for improvement on the part of the manufacturer, both towards the safety investigation authorities and operators.

Therefore, the Dutch Safety Board issues the following recommendation:

To Da-Jiang Innovations Science and Technology Co., Ltd. (DJI):

2. Ensure that safety investigation authorities and operators are timely provided with technical support and relevant information for the purpose of safety investigation regarding UAS manufactured by DJI.

Deliberations with safety investigation authorities from other states have revealed that the abovementioned issue is not unique to the Netherlands. Therefore, in addition to the recommendation, the Dutch Safety Board will continue to stimulate discussion on this topic with other safety investigation authorities, emphasising the importance of manufacturer participation in safety investigations in the appropriate international bodies, in particular the International Civil Aviation Organization (ICAO).

S. Zouridis
Vice Chairperson Dutch Safety Board

C.A.J.F. Verheij
Secretary Director

ABBREVIATIONS

CAVOK	Ceiling And Visibility OK
EHAM	Amsterdam Airport Schiphol
ESC	Engine Speed Controller
FCF	Functional Check Flight
FOM	Flight Operations Manager
GPS	Global Positioning System
ICAO	International Civil Aviation Organization
ILT	Human Environment and Transport Inspectorate
IMU	Inertial Measurement Unit
METAR	METeorological Aerodrome Report
NOSIG	NO SIGnificant change
PIC	Pilot In Command
RC	Remote Controller
ROABL	Regulation on remotely piloted aircraft
RPA-L	Remotely Piloted Aircraft License
RPM	Revolutions Per Minute
RTH	Return-To-Home
SARPs	Standards and Recommended Practices
S-BvL	Special certificate of airworthiness
UAS	Unmanned Aircraft System
UA	Unmanned Aircraft (also referred to as drone)
UTC	Universal Time Coordinated

GENERAL OVERVIEW

Identification number:	2020020
Classification:	Serious Incident
Date, time of occurrence:	11 April 2020, 13.30 hours[3]
Location of occurrence:	Soestdijksekade, The Hague
Operator:	National Police
Registration:	PH-5MV
Aircraft type:	Da-Jiang Innovations Science and Technology Co., Ltd. (DJI) Inspire 2 – T650A
Aircraft category:	Unmanned Aircraft System
Type of flight:	Surveillance
Phase of operation:	Take-off
Damage to aircraft:	Damage to the propellers, landing gear and payload
Flight crew:	Two (pilot and payload operator) and two observers
Passengers:	Not applicable
Injuries:	None
Other damage:	None
Light conditions:	Daylight

3 All times in this report are local times unless indicated otherwise.

1 INTRODUCTION

The occurrence
On 11 April 2020, a flight crew of the unmanned aviation team of the National Police conducted an Unmanned Aircraft System (UAS)[4] flight over the Zuiderpark in The Hague in the scope of a crowd observation and crowd control operation. The Unmanned Aircraft (UA) used, was of the make and type DJI Inspire 2, registration PH-5MV. The UA was equipped with a DJI-camera as payload.

Shortly after take-off and while performing the flight control checks, the pilot lost control of the UA. The UA flew away at a high speed in a climbing flight. According to the pilot, the UA did not respond in any way to the stick input, and activating the Return-To-Home (RTH) function did not have the desired effect either. Having lost connection between the remote controller (RC) and the UA, the crew initiated a search and informed other police units. After approximately half an hour, the UA was found with a flat battery on the sidewalk of the Soestdijksekade, in The Hague. It had damage to the propellers, landing gear and payload. There were no injuries or third party damage as a result of the crash.

Because the definitions used in this report may differ slightly from the definitions used in manned aviation, an explanation is given in the blue box below.

Definitions
Loss of control refers to the inability of the pilot to effectively control the Unmanned Aircraft (UA) through the remote controller (RC). There may still be a connection between the RC and the UA, but the UA does not respond to what the pilot commands through the RC, or responds in unexpected ways (behaviour inconsistent with input).

Loss of connection refers to a loss of the connection between the RC and the UA. After a loss of connection, it is no longer possible to transmit commands from the RC to the UA. Loss of connection always implies a loss of control.[5]

Fly-away is a condition in which the UA has an undesired velocity, e.g. under the influence of wind and/or as a result of system failure(s), while the pilot (through the RC) has no control over the UA's movement (loss of control).

4 UAS typically consist of a ground station or remote controller and an unmanned aircraft. Also see Section 2.3 of this report.
5 A loss of connection is not always problematic. If the UA is flying a pre-programmed flight (e.g. for mapping) it can still finish the flight and land safely. For safety however, it is desirable that the pilot is always able to intervene.

Occurrence notification and investigation obligation
Users, operators and manufacturers of UAS are currently often unfamiliar with aircraft accident and incident investigation. National and international laws and regulations have established frameworks that prescribe when an investigation must be carried out and how it should be conducted. At the global level, ICAO Annex 13 lays down standards and recommended practices (SARPs) for aircraft accident and incident investigation.[6] These SARPs of Annex 13 are implemented in national regulations of Member States. For European Union (EU) Member States, this is largely done in EU Regulation 996/2010.[7] This regulation prescribes more precisely the reporting and investigation obligations and clarifies the participation within international investigations. At the national level, for the Netherlands, the Kingdom Act Dutch Safety Board contains additional arrangements.[8]

For some occurrences, those involved have an obligation to notify the safety investigation authority (also see blue box below). According to EU 996/2010, any person involved who has knowledge of the occurrence of an accident or serious incident shall notify the safety investigation authority. However, as the concerned flight was conducted with a state aircraft, EU 996/2010 does not apply. In Dutch national legislation, on the other hand, it is regulated that in the event of an aviation accident or serious incident, the captain and operator of the aircraft are obliged to report this to the Safety Board.[9] No distinction is made between manned or unmanned aviation and state or non-state operated. Hence, for this serious incident, there was an obligation to notify, based on national legislation.

Obligation to notify
In the case of an accident or serious incident[10] involving an unmanned aircraft (system), there is an obligation for those involved to notify the safety investigation authority. For commercial or recreational flights, European rules apply: any person involved who has knowledge of the occurrence of an accident or serious incident shall notify the safety investigation authority, which in the Netherlands is the Dutch Safety Board. For state aircraft operations, only national regulations apply. In that case, the captain and operator of the unmanned aircraft are obliged to report any accident or serious incident to the Dutch Safety Board. Notifications should be made as soon as possible via the 24-h reporting line +31 70 6353 688 or website www.safetyboard.nl.

6 Annex 13 to the Convention on International Civil Aviation, Aircraft Accident and Incident Investigation (12th ed. July 2020). The Convention on International Civil Aviation (1944) is also known as the Chicago Convention.
7 Regulation (EU) No. 996/2010 of the European Parliament and of the Council of 20 October 2010 on the Investigation and Prevention of Accidents and Incidents in Civil Aviation and Repealing Directive 94/56/EC, OJ L 295, 12 November 2010, p. 35-50, consolidated version available at https://eur-lex.europa.eu/eli/reg/2010/996/2018-09-11, accessed on 23 June 2022.
8 Rijkswet Onderzoeksraad voor veiligheid, available at https://wetten.overheid.nl/BWBR0017613, accessed on 23 June 2022.
9 Besluit Onderzoeksraad voor veiligheid, available at https://wetten.overheid.nl/BWBR0017681/2022-01-01, accessed on 23 June 2022.
10 Examples of serious incidents can be found in the annex of Regulation (EU) No. 996/2010, see https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:02010R0996-20180911&from=EN#tocId28. E.g. a near collision, aircraft structural failure and malfunctions of aircraft systems affecting the operation of the aircraft.

In manned and unmanned aviation, investigation obligations apply to accidents and serious incidents. This can be found both in Regulation (EU) 996/2010 and in national regulations, stemming from international standards for accident and incident investigation, laid down in Annex 13 to the Convention on International Civil Aviation.[11] In this case, however, an exception applies as the European Regulation does not apply to safety investigations into accidents and serious incidents involving an aircraft carrying out military, customs, police or similar activities, unless the Member State concerned and national legislation provide otherwise. However, Dutch legislation does not yet have an obligation to investigate accidents and serious incidents involving unmanned aircraft. The investigation and aforementioned reporting obligation are independent of each other; even in the event that there may be no investigation obligation for the safety investigation authority, the reporting obligation is still in effect for those involved.

Despite the fact that in this case there is no obligation to investigate, the Dutch Safety Board has the authority to initiate an investigation into occurrences on, above or below the territory of the Netherlands including waters under Dutch jurisdiction.[12]

Investigation rationale and questions

In this particular case the Dutch Safety Board decided to conduct an investigation due to the nature of the incident and the potential for damage and injury to third parties resulting from the fly-away. This is the first unilateral occurrence with an unmanned aircraft that the Safety Board has investigated.[13]

The aim of the investigation is to determine the direct and underlying causes of the crash, in order to reduce the likelihood of recurrence. The following questions were central to the investigation:

1. What was the direct cause of the crash of the UA?
2. What was most likely the cause of the loss of control of the UA and the subsequent fly-away?
3. How were the risks associated with using different types of payload on the same UAS managed by the involved parties and what improvements are possible?

This report is limited to the national legislation governing flying with unmanned aircraft [14] because the flight in question was operated under this legislation. Since 31 December 2020, European legislation[15] is in force for flights other than state aircraft. The regulation of risks associated with payload under this European legislation is not discussed in this report.

11 Annex 13 to the Convention on International Civil Aviation, Aircraft Accident and Incident Investigation (12th ed. July 2020).

12 Article 4 paragraph 1a, of the Kingdom Act Dutch Safety Board.

13 At the time of publication of this report, the Dutch Safety Board had already published a report of another UAS accident that occurred later.

14 Regeling op afstand bestuurbare luchtvaartuigen, as applicable on 11 April 2020, available at https://wetten.overheid.nl/BWBR0036568/2020-12-31, accessed on 23 June 2022.

15 Commission implementing Regulation (EU) 2019/947 of 24 May 2019 on the rules and procedures for the operation of unmanned aircraft, available at http://data.europa.eu/eli/reg_impl/2019/947/2022-04-04, accessed on 23 June 2022.

Aspects related to cybersecurity were a focus of attention at the start of this investigation. However, there were no strong indications that the connection between crew and UA was disrupted or taken over by a third party. These aspects were therefore not further considered in this investigation.

In Chapter 2 of this report, the factual information, gathered and considered relevant, is provided, according to the ICAO Annex 13 standard. In Chapter 3, the occurrence is analysed and in Chapter 4 the conclusions and safety lessons are presented. Chapter 5 lists the recommendations.

2 FACTUAL INFORMATION

In this chapter, the relevant factual information, collected as part of this investigation, and needed for further interpretation in the analysis, is presented. First, the narrative is presented, after which several sections are dedicated to provide information about the Unmanned Aircraft System (UAS) and its subsystems, to allow for further interpretation of the flight data. Finally, this chapter provides information on the operational procedures of the operator and highlights some relevant legislation.

2.1 History of the flight

Flight preparation

On Saturday 11 April 2020, the crew of PH-5MV, consisting of the pilot, the payload operator and two observers[16], intended to perform a crowd observation and crowd control mission as part of the Staff large-scale and special operations Corona[17] in the Zuiderpark, The Hague. The plan was to take off from the terrain of the The Hague Police Sports Club in the park using an Unmanned Aircraft (UA) equipped with a camera. In the week prior, the same UA, with different types of payload, was used for seven flights from the same location. All those flights were uneventful.

As this was the first flight of the day, the pilot prepared the UAS for flight and the payload operator performed the pre-flight check using the appropriate checklist. The DJI Inspire 2 UA was positioned on the tarmac of the access road with its nose outward at a distance of about 6-7 metres from the pilot. Two to three minutes after powering on the UA, the motors of the UA started at approximately 13.27 hours. Soon after the start of the motors, the payload operator noticed the 'Home point updated, please check it on the map' notification from the controller. When he checked the map, the home point was in line with his expectation. The batteries of the UA were fully charged.

Take-off

Shortly after the motor start, the pilot made the UA take off and climb to a height of about 2 metres. As the UA was responding as expected, the pilot then started his control check, which he verbally announced. After having let the UA roll right and subsequently left, the pilot stated that the UA levelled out. Then, before giving any input, he observed the UA pitching nose down and moving forward as if maximum forward input had been given. In response, the pilot immediately gave maximum throttle input to make the UA

16 Observers are responsible for the safety of the environment, both in the air and on the ground. For example, they warn bystanders if an emergency situation occurs.

17 A Staff large-scale and special operations (SGBO, from the Dutch *Staf Grootschalig en Bijzonder Optreden*) is a command and control structure within the police for major incidents. SGBO Corona was specifically aimed at enforcing COVID-19 rules.

gain altitude, but to no initial effect. According to both the pilot and payload operator the UA then kept flying forward (i.e. away from the crew) while gaining altitude. The pilot announced 'lost controls' and the payload operator, who had the controller of the pilot in sight, confirmed the lack of response of the UA.

Fly-away
As the UA was heading for a line of trees, the pilot announced 'emergency procedure' and activated the Return-To-Home (RTH) button on his remote control. The command was confirmed by the controller of the pilot, but both the pilot and payload operator noticed no change of heading or velocity of the UA. Shortly after, they noticed loss of connection between their remote controllers and the UA.

The crew was informed by a witness that the UA had flown towards the city and coast with a substantial velocity. The crew then informed other police units in the city of the fly-away. Roughly 30 minutes later the crew was notified that witnesses had found the UA on the sidewalk of a street in The Hague (Soestdijksekade) and reported it to the police.

Damage to the aircraft
The aircraft was found powered off and with lowered landing gear. First inspection learned that there were green traces on the propeller blades. Additionally, the rear landing gear legs and mounted camera were damaged. When the two batteries were removed, both had one of the four indicator lights flashing, indicating that the battery charge level was between 0 and 13%.

Notification
The Dutch Safety Board was not notified of this serious incident, but learned of it through a news article[18] and then contacted the operator.

2.2 Take-off and crash site information

The take-off location and intended area of operation were in the Zuiderpark, The Hague. The Zuiderpark is a park located in the southern part of the city. The take-off location was chosen by the flight crew because of its proximity to the area of operation, while offering an enclosed area with sufficient space for taking off and landing. The take-off point is marked in Figure 1 (right). A large part of the park contains trees.

18 *Politie verliest controle over drone, politiedrone vliegt kilometer over Den Haag*, available at https://regio15.nl/nieuws/corona/31568/politie-verliest-controle-over-drone-politiedrone-vliegt-kilometer-over-den-haag/, accessed on 23 June 2022.

Figure 1: The area of operation (left) and take-off location inside the area of operation (right). (Source map: Google Earth)

Roughly 700 metres north of the take-off location and intended area of operation, the Rustenburg Oostbroek neighborhood is situated, an urban residential area consisting of mostly three-story walk-up flats. At the end of its flight, the Inspire 2 crashed in this area on a sidewalk between a building and the Soestdijksekade, a busy combined cycle and roadway. See Figure 2. The tree adjacent to the location where the UA was found showed signs of contact with the UA.

Figure 2: The crash location on the Soestdijksekade (left) and photo of the crash site (right). (Source map: Google Earth, source photo: National police)

2.3 Aircraft information

UAS typically consist of a ground station or remote controller (RC) and a UA. The ground station is a combination of hardware and software that allows the operator to control the UA. The UA itself consists of several subsystems, including payload that can be mounted on the vehicle exterior. Examples of payload are cameras and loudspeakers. Figure 3 outlines the general UAS layout.

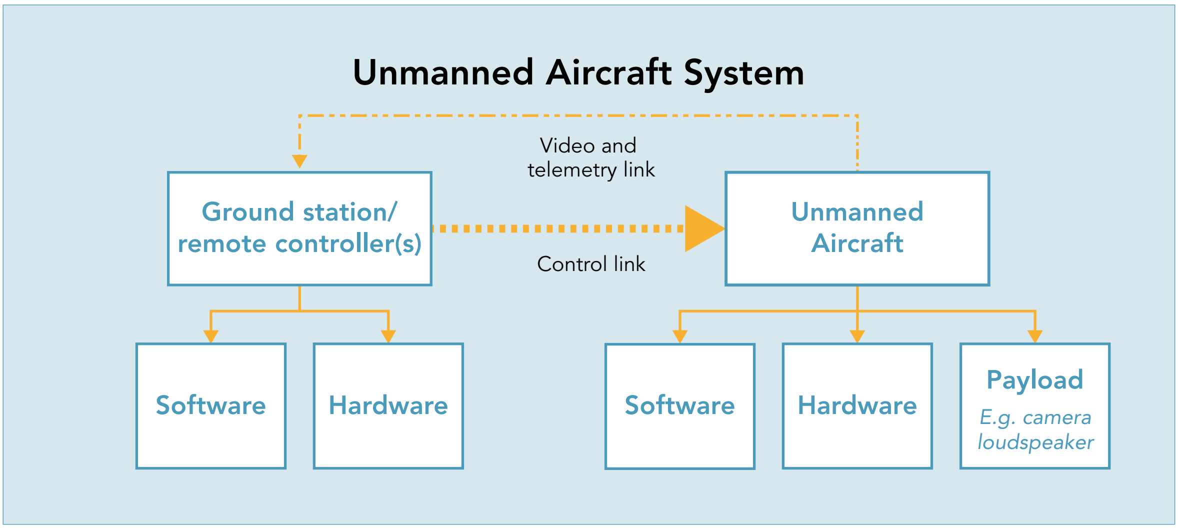

Figure 3: A general overview of an Unmanned Aircraft System, its components and subsystems. (Source: Dutch Safety Board)

The following sections describe the different components and subsystems of the UAS involved in the accident.

2.3.1 The remote controller

In general, control of a UA from the ground is possible using a remote controller and direct eye contact, without the feedback provided by a monitor.[19] Most UAS are delivered with standard remote control units that support the use of additional devices as monitor.[20] When flying in a professional context, a second remote control with monitor is often used to operate the payload, as was the case here.

The two remote controllers used during the flight were DJI Cendence remote controllers[21] with dedicated DJI CrystalSky[22] monitors. The CrystalSky monitor is preloaded with the DJI GO 4 application[23], see Figure 4.

19 Feedback can be in the form of the camera view and/or sensor data (e.g. altitude, speed).
20 A device can generally only act as monitor if it can be connected to the remote control, using a data cable and if the necessary application is installed.
21 *DJI Cendence website*, available at https://www.dji.com/nl/cendence, accessed on 23 June 2022.
22 *DJI Cendence website*, available at https://www.dji.com/nl/cendence, accessed on 22 April 2022.
23 *DJI, DJI GO 4 Manual: The Pilot's Handbook*, 2017, available at https://store.dji.com/guides/dji-go-4-manual/, accessed on 23 June 2022.

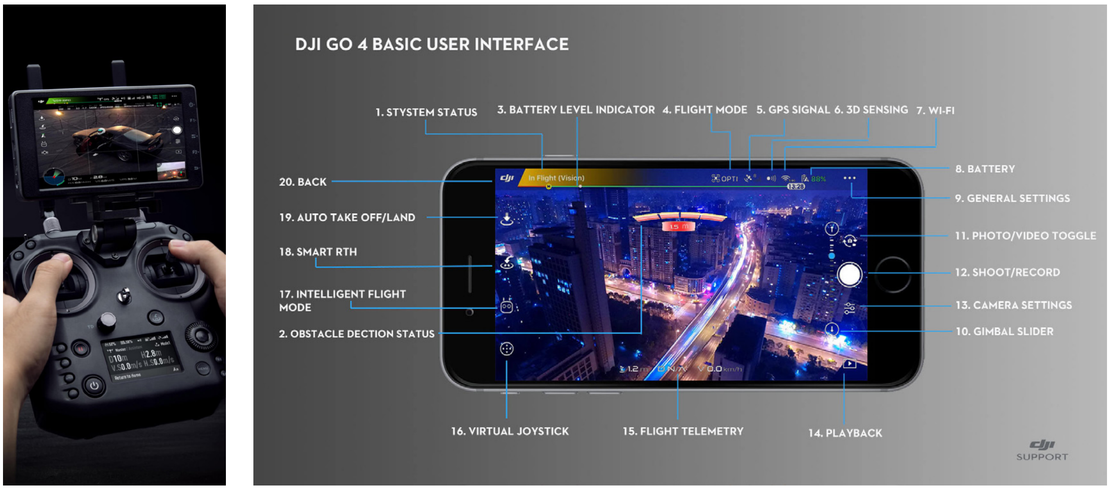

Figure 4: DJI Cendence remote controller with CrystalSky monitor (left) and DJI GO 4 application user interface (right). Note the system status (1.) in this example from DJI. (Source: DJI.com)

Through the two sticks of the remote controller, the pilot can control the altitude, heading and velocity of the UA. In addition, the remote controller also allows the pilot to set different modes of flight and raise or lower the landing gear. Other settings (e.g. camera settings, home point, maximum altitude, etc.) can be changed before and during flight through the application on the monitor. In the configuration used in the incident flight, a secondary controller was used to operate the payload (camera, also see Section 2.3.4).

2.3.2 The unmanned aircraft

The aircraft that was used during the flight was a Da-Jiang Innovations Science and Technology, Co., Ltd. (DJI) type Inspire 2 – T650A. The Inspire 2 (see Figure 5) is a UA of the type quadrocopter and is propelled by four independent electric motors. The involved Inspire 2, with registration PH-5MV, was used by the operator for several types of operations, including surveillance flights over built-up areas. The UA consisted of only standard, unmodified parts. The Inspire 2 weighs 3.29 kg (including batteries, without gimbal and camera) and measures approximately 60 cm in diagonal.

Figure 5: DJI Inspire 2 without payload. (Source: DJI.com)

Airworthiness and certification
The UAS was certified as airworthy with a special certificate of airworthiness (S-BvL), issued by the Dutch Human Environment and Transport Inspectorate (ILT) on 5 June 2019, valid up to and including 4 June 2020. During the assessment required for obtaining the S-BvL, the UAS was tested in combination with the camera payload.[24] The loudspeaker payload was not part of such an assessment.

In addition, the operator held a valid certificate of registration and no noise requirement statement for the UA. Both were issued on 5 June 2019.

2.3.3 Flight control

Different from conventional aircraft, the pilot does not directly control the control surfaces (e.g. elevator, aileron, rudder; a quadrocopter does not have any) or the rotational speed (RPM) of the propellers. Instead, the commands from the pilot are input for the flight computer. This input is processed in the flight mode-dependent control laws of the flight computer and translated into signals for the four electronic speed controllers (ESCs), which each regulate the speed of one motor.

The flight computer is at the heart of the UA's control system and is also referred to as autopilot system. Its control algorithm uses both the vehicle's state (attitude, altitude, velocity, etc.) and the input given by the pilot to send the signals to the motors. In order to be able to do so, the flight computer is fed with information coming from different sources, of which the most important are the Inertial Measurement Unit (IMU), GPS[25,26] antenna, magnetic compass and air pressure sensors.[27]

An IMU makes an estimation of the vehicle state. It does so by using gyroscopes, accelerometers and software together with output from some of the other UA sensors. The estimation of the vehicle state is necessary because not all state variables can be measured directly. For example, the pitch angle is derived from the accelerometers and gyroscopes output. The IMU also enables high-frequency control calculations by providing estimates of variables that have a sampling rate lower than the calculation frequency. The Inspire 2 is equipped with two IMUs for redundancy.[28]

For the control calculations, the control algorithm ultimately determines a final state estimation by weighing the state estimated by the IMU and the measurements coming from the other sensors. Figure 6 depicts the control flow and the components involved.

24 This assessment results in a document referred to as the Certificate of Recommendation.
25 In this report, GPS can also mean position data from other Global Navigation Satellite Systems (GNSSs).
26 The flight computer does not use the GPS position information in all flight modes.
27 The Inspire 2 also features (less common) forward and downward optical orientation systems.
28 *DJI Inspire 2 website*, available at https://www.dji.com/nl/inspire-2, accessed on 22 April 2022. It is unclear how the IMUs are wired, e.g. primary secondary, cross-talk, etc.

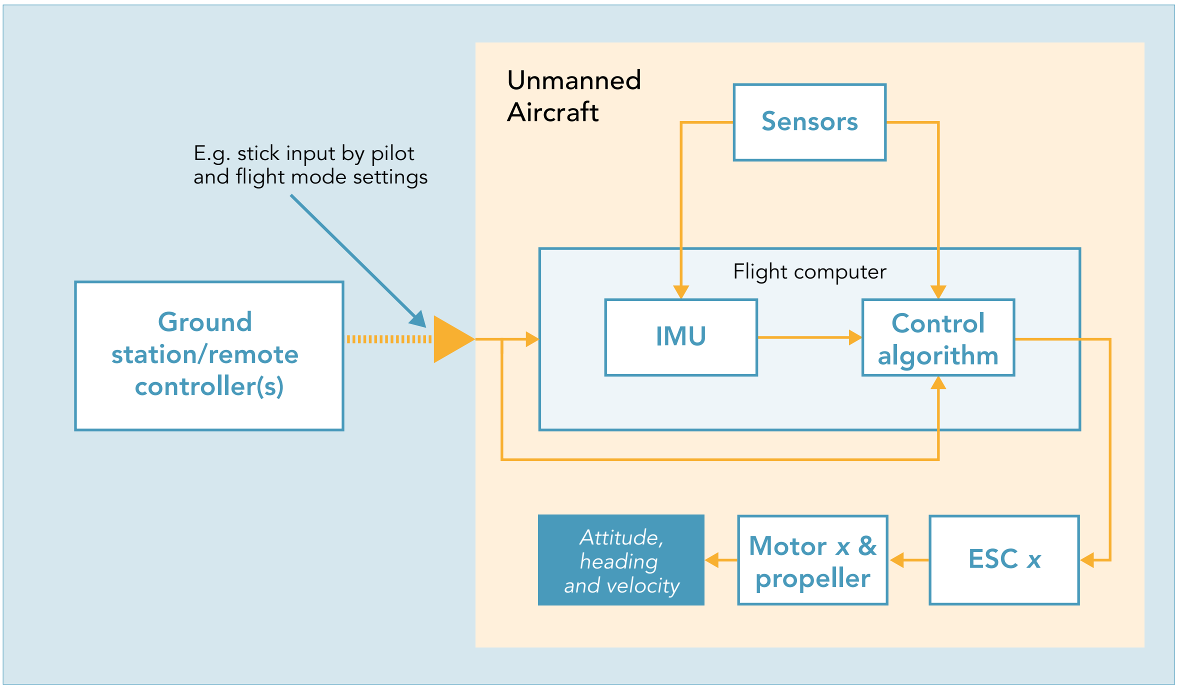

Figure 6: From control input to vehicle state: the UAS control flow and components involved. (Source: Dutch Safety Board)

Flight modes

In general, UA can be operated in different flight modes. These can be classified into three main modes: the positioning mode, the attitude mode and the fail-safe mode. By using the switch on the left shoulder of the Inspire 2 remote controller,[29] the flight mode can be changed. The selected flight mode affects the way in which the aircraft is controlled by the flight computer. The characteristics of the main flight modes are illustrated in the blue box.

29 This is the same on the DJI Cendence controller.

The three main flight modes of the Inspire 2 are:[30]

P(ositioning)-mode[31]

When flying in P-mode, the flight computer uses the ground position to actively correct the aircraft response for external influences such as wind. For instance, if the pilot releases controls, it will automatically reduce the UA speed and then have it maintain its position and altitude. This is the most used flying mode.

In P-mode, the pilot's input is interpreted by the system as the desired rates of change of ground position, heading and altitude. In order to respond correctly, it requires accurate and precise information on its position and orientation. For that reason, the P-mode relies on GPS-positioning and the magnetic compass. When activated, under some conditions the Inspire 2 will also utilize its Forward and Downward Vision systems to control the aircraft's position and altitude.[32] The air pressure sensor is always used to maintain altitude.

In some cases when the UA cannot maintain its position, the system will automatically switch from P-mode to attitude stabilization (A-mode). The Inspire 2 will enter A-mode automatically when the GPS signal is weak or when there is compass interference and the Vision system is not available.

A(ttitude)-mode

While flying in A-mode, the flight computer does not (or cannot) use GPS or its compass to hold its position and the aircraft therefore responds relative to the air it is in, just like conventional aircraft. When the pilot releases controls in A-mode, the UA will level out and maintain its altitude, but it can drift, i.e. maintain its horizontal velocity, due to for instance its inertia or wind.

In A-mode, the pilot input is interpreted by the system as the desired pitch and roll angles and the desired rates of change of heading and altitude.

Fail-safe mode

The Inspire 2 features a Return-To-Home (RTH) mode. When activated, the UA will navigate autonomously back to its home point and land. The home point is normally automatically set to the take-off location, but it can be set manually. In order to navigate in the RTH mode, the system relies on GPS and compass information.

The RTH-mode can be activated in different ways. Using a button on the RC or automatically when either the connection between the RC and the Inspire 2 is lost or when the battery level is below a certain threshold.

30 DJI, *Inspire 2 Series User Manual v2.4*, July 2019, available at https://dl.djicdn.com/downloads/inspire_2/20201120/INSPIRE_2_SERIES_User_Manual_EN_20201120.pdf, accessed on 23 June 2022.

31 The S(port)-mode of the Inspire 2 is similar to the P-mode in terms of its control laws; it also depends on GPS-positioning and the compass to determine the reference for its movement. In this mode, however, the visions systems are not used, the flight envelope is larger and the response to input is more aggressive.

32 The downward optical orientation system only works up to an altitude of 10 metres.

2.3.4 Payload

The Inspire 2 comes with a factory fitted front mount, located under the nose of the aircraft body. DJI refers to this mounting point as the DJI Gimbal Connector V2.0 (DGC2.0). An additional mount can be attached at the center of the main body underside. The Inspire 2 was equipped with a single payload, see Table 1, using the front mount.

Table 1: The payload and its specifications.

Characteristic	Value
Mount location	Front of the body underside
Payload type	DJI Zenmuse X7 camera + lens
Payload weight	449 g, excluding lens

The gimbal connector allows for mounting different types of payload under the Inspire 2. A payload change can be performed when the aircraft is on the ground, with the motors switched off, by pressing the gimbal release button and replacing the payload. No change in settings or execution of calibration is required, according to the Inspire 2 user manual.[33]

During previous flights, in the week prior to the incident, the Inspire 2 was operated with two different payloads. A flight with a Zenmuse X7 camera as payload was sometimes followed by a flight with a loudspeaker. This loudspeaker, produced by a Dutch supplier, contained an electromagnet.

2.4 Flight preparation and procedures

The operator had an operations manual[34] in use that described various (UA type specific) procedures. This manual was reviewed by the ILT as part of the issuing process for the exemptions of the operator for UAS operations. The following sections highlight some relevant procedures described by the operations manual.

2.4.1 Type of operation

The UAS' crew intended to perform a crowd observation mission in the Zuiderpark, The Hague, which is an urban environment. In the operations manual, the operator distinguished between operational and non-operational use[35] of the UAS. For both types several scenarios were included. The flight that led to the incident was operational and according to the scenario '*in beeld brengen*' (imaging).[36]

33 DJI, *Inspire 2 Series User Manual v2.4*, July 2019, p. 7, available at https://dl.djicdn.com/downloads/inspire_2/20201120/INSPIRE_2_SERIES_User_Manual_EN_20201120.pdf, accessed on 23 June 2022.
34 Nationale Politie, Team Onbemande Luchtvaartuigen, *Operationeel handboek deel A t/m E versie 1.0 (Operations Manual part A to E version 1.0)*, September 2018.
35 By operational use, the operator refers to flights that are urgent in nature, as a result of which they cannot be planned and/or prepared in advance, or only to a limited extent. Non-operational flights can be planned and prepared in advance.
36 Page 129 of operations manual Part A.

According to the general procedure for operational use[37], a flight plan was made prior to the flight and a checklist was used as part of the flight preparation, execution and wrap-up.[38]

2.4.2 Flight crew

The operator procedures dictated requirements for crew composition and qualification.[39] At the time, a UAS operation required a crew with at least one pilot, one payload operator and one observer. Each of these roles had a corresponding set of qualifications that the crew member had to meet. On top of that, there were general crew qualifications (e.g. fit to fly, work hours).

The Pilot In Command (PIC) and payload operator were both qualified to act as UAS pilot for the operator. Both had a valid remote pilot license (RPA-L) and medical certificate (LAPL). The PIC had a total flying experience of over 70 hours. The qualification and experience of the two observers is unknown to the Dutch Safety Board, but is not considered relevant for this investigation.

2.4.3 UAS configuration

The operations manual only allowed flight operations with the configuration as certified by the S-BvL (including software).[40] According to the operations manual, deviation from this configuration was only allowed after consultation with the Flight Operations Manager (FOM). The use of the loudspeaker payload was discussed with the FOM and it had been used in several flights since.

The operations manual also mentioned that a Functional Check Flight (FCF) was to be performed when a UA was equipped with a new payload. During an FCF, which is carried out under normal weather conditions, the UAS is tested in its full operational configuration and all systems and emergency procedures are tested.[41]

The flight mode of the UAS had to be chosen to fit the type of operation.[42] In general, the positioning mode is the preferred mode.

2.4.4 Abnormal procedures

The abnormal procedures are defined for each UAS type separately. Those for the Inspire 2 are written down under 'abnormal procedures' in part B of the operations manual.[43]

Six of the procedures concern the technical aspects of the UAS controllability. Several of those procedures can be considered applicable during different parts of the incident flight. These are listed below.

37 Page 72 of operations manual part A.
38 Pages 71 and 72 of operations manual part A.
39 Chapters 5 to 9 of operations manual part A.
40 Page 73 of operations manual part A.
41 Page 126 of operations manual part A.
42 Page 106 of operations manual part A.
43 Pages 59 to 63 of operations manual part B.

- *'No response to control input' dictates the pilot to (amongst other things) turn off the RC to try to activate the RTH-functionality.*
- *'Limited control' requires the pilot in command to immediately land the UA. If that is not possible, then the RC should be turned off.*
- *'Autopilot malfunction' requires the pilot to change flight mode.*[44]
- *'Fly away' requires (amongst other things) the pilot in command and payload operator to turn off their RC's.*

2.5 Meteorological information

In order to determine the meteorological conditions at the time of the incident, the Dutch Safety Board obtained meteorological information from the Royal Netherlands Meteorological Institute (KNMI).[45] The KNMI weather station closest to the incident location was Voorschoten.

Table 2: Meteorological information weather station Voorschoten, 11 April 2020.

Time	Wind direction (°)	Mean wind speed (m/s)	Maximum wind gust (m/s)	Temperature (°C)	Horizontal visibility (km)	Relative atmospheric humidity (%)
12.00	110	3.0	5.0	17.9	35-40	32
13.00	110	2.0	4.0	18.7	30-35	30
14.00	150	2.0	4.0	19.8	30-35	30

The closest airport, Amsterdam Airport Schiphol, published the following Meteorological Aerodrome Report (METAR):

Table 3: Amsterdam Airport Schiphol METAR, 11 April 2020.

Time	METAR
13.25	METAR EHAM 111125Z 12004KT 050V200 CAVOK 18/00 Q1024 NOSIG=
13.55	METAR EHAM 111155Z 09003KT 020V160 CAVOK 19/01 Q1024 NOSIG=

Both the meteorological data from weather station Voorschoten (Table 2) and Amsterdam Airport Schiphol METAR (Table 3) show calm meteorological conditions, with wind speeds varying around 2 metres/second (approximately 4 knots) coming from direction 020 – 160 degrees.

44 The mentioned flight mode change (from F to P) is not consistent with the modes of the DJI Inspire 2. If the procedure was based on the DJI Inspire 1 (which has those modes), then it means a change from one GPS-mode to another GPS-mode.

45 Daily weather forecasts can be obtained from the KNMI website: see https://www.daggegevens.knmi.nl/klimatologie/uurgegevens.

The global Kp-index[46] reported by the GFZ German Research Centre for Geosciences[47] was low, varying between 1 and 2 (see Table 4).

Table 4: Global Kp-index.

Timeslot	Kp index three-hourly average
11.00 – 14.00	1-
14.00 – 17.00	2o

2.6 Flight data

Flight data are stored in different locations in the UAS and have different characteristics. This is further explained in the sections below.

2.6.1 SD card data

Within the Control and Preprocessing Center of the main body of the Inspire 2, an SD card slot is located. The main use for the SD card is to store in-flight photos and videos recordings. In addition, flight data is also stored on this SD card. This storage is not crash protected, however in most cases it is possible to recover data from the SD card.

After the occurrence, a readout of the SD card was performed by the operator. This resulted in ten flight data files and some additional system log files. The flight data files included five previous flights, the incident flight and four post-crash system boots.[48] A copy of the contents of the SD card was shared with the Dutch Safety Board.

The Safety Board analyzed the flight data using the data file of the flight of the serious incident. Because the flight data has a proprietary format and hence cannot be read directly, specialized software was required. In addition to the Safety Board's analysis, the manufacturer of the UAS was requested to decode and analyse the flight data, which was not acted upon.[49]

2.6.2 Remote controller data

The DJI GO 4 software application that was used in combination with the Cendence remote controller and CrystalSky monitor also stores flight data. The operator downloaded this data for investigation. The data stored by the GO 4 application is a subset of the flight data on the SD card of the UA, i.e. it contains fewer parameters at a

46 The Kp-index is a measure to indicate irregular disturbances of the geomagnetic field, caused by solar particle radiation within 3-hour intervals. The Kp-index is expressed in a scale of thirds (28 values): 0o, 0+, 1-, 1o, 1+, … , 8+, 9-, 9o.

47 Matzka, J., et al., *Geomagnetic Kp index. V. 1.0. GFZ Data Services*, 2021. Datasets are available at https://www.gfz-potsdam.de/en/kp-index/, accessed on 23 June 2022.

48 One data file is generated per power cycle: the system starts recording data to the SD-card whenever it boots/is provided with power and stops recording when turned off. Hence, recordings are also made when the system is started but no flight is performed.

49 A short discussion on the use of DJI and third party software, its characteristics, limitations and implications for the investigation process can be found in Appendix C.1.

lower sampling rate. Since the data from the RC was consistent with that from the SD card, the RC data was not used for further analysis.

2.7 Regulatory framework

Flying with unmanned aircraft is subject to specific rules. Chapter 1 already highlighted some legislation with respect to reporting and investigation obligations. At the European Union level, Regulation (EU) 2018/1139 and the related Commission Implementing Regulation (EU) 2019/947 apply to most types of civil operations with unmanned aircraft. The latter contains the rules and procedures for operation.[50] At the time of the incident, this regulation was not yet in force. Because the flight was part of a state operation, it was carried out under national legislation.

At the national level, the regulation on remotely piloted aircraft[51] (ROABL) sets out rules for operating unmanned aircraft, including State flights, and covers licensing, airworthiness, maintenance and flight operations, among other things. The regulation requires, for instance, that UAS pilots must hold a valid remote pilot license (RPA-L) and requires the operator to have an operations manual.

The following elements of the ROABL are relevant to the investigation:

- Paragraph 3 Airworthiness, Article 7: issuance of the special certificate of airworthiness and noise certificate. This article states that a special certificate of airworthiness may be issued if an acceptance inspection, issued by a company recognized for this purpose, is submitted with the application, demonstrating that the aircraft complies with the airworthiness requirements set out in Annex 3 to this Regulation.
- Accompanying Article 7, Annex 3 is an enumeration of elements to be assessed in order to meet the airworthiness requirements for obtaining a special certificate of airworthiness. This enumeration lists, among other things, that a declaration is required from a company recognized for this purpose, stating that the unmanned aircraft is technically sufficiently safe to conduct operations in accordance with the operator's operations manual. The annex also lists the minimum criteria to be examined during this inspection. These include electronic systems (e.g. the flight control system, navigation system) and payload. According to the annex, payload is to be inspected on its influence on systems required for safe flight operations. This includes aspects such as electromagnetic interference, mechanical interference and weight distribution.

50 Commission implementing Regulation (EU) 2019/947 of 24 May 2019 on the rules and procedures for the operation of unmanned aircraft, available at http://data.europa.eu/eli/reg_impl/2019/947/2022-04-04, accessed on 23 June 2022. Effective as of 31 December 2020.

51 Regeling op afstand bestuurbare vliegtuigen, as applicable on 11 April 2020, available at https://wetten.overheid.nl/BWBR0036568/2019-11-07, accessed on 23 June 2022.

3 INVESTIGATION AND ANALYSIS

In this chapter, the analysis of the occurrence is described. A distinction is made between the first phase of the flight, up to the loss of connection with the Unmanned Aircraft (UA), described in Section 3.1, and the remainder of the flight which resulted in a crash, described in Section 3.2. Subsequent sections discuss the systemic factors that contributed to the occurrence of the serious incident.

At several places in this chapter, reference is made to investigations which were conducted on behalf of, or at the request of the operator. The key findings of these investigations by the manufacturer and the Netherlands Aerospace Centre are listed in Appendix B to this report and are mentioned in the relevant sections of this chapter.

3.1 Cause of the loss of control and connection

Initial data analysis by the Dutch Safety Board and an analysis by the manufacturer have indicated that the connection between the UA and Remote Controller (RC) was lost at about 27 seconds into the flight. Activation of the Return-To-Home (RTH) occurred before the loss of connection. Figure 7 depicts the ground track of the UA during the first 30 seconds of the flight. To determine to what extent the pilot of the unmanned aircraft was in control, and to establish the (probable) cause of the loss of control, an analysis of the inputs for the first 30 seconds of the flight is presented below.

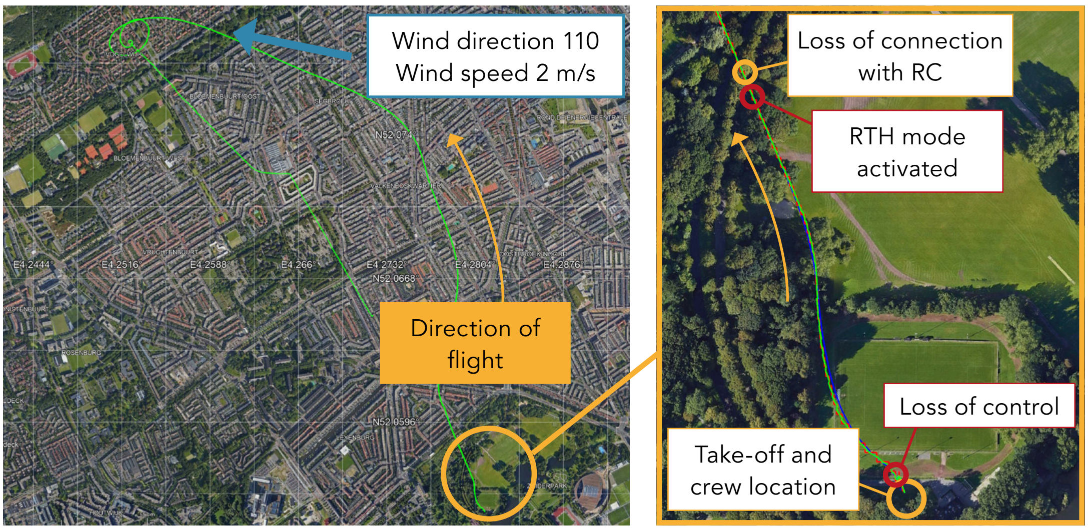

Figure 7: The ground track of the UA obtained from the recorded data together with the wind direction. The orange inset shows the ground track for the first 30 seconds of the flight. The colors of the traces in the right figure represent the different data sources from which the track was obtained. (Source map: Google Earth)

3.1.1 Input response

In Figures 8 and 9, the input from the four different RC stick axes are shown together with the corresponding UA response. Also indicated are the moments when the UA was in-flight and when the RTH functionality was activated. During this period, the status of the connection between the RC and the UA was normal according to the logged RC signal strength, which remained around 95-100%. The RC inputs on the left side of the graphs were those given to start the UA motors. The relation between the input and the response of the UA is not for all directions of movement equally consistent.

Left stick response

The response for throttle and yaw, depicted in Figure 8, is generally as expected. The sign (i.e. positive or negative value) of the throttle input is, apart from a delay, consistent with the change in recorded altitude. Hence, the changes in altitude can be attributed to the given throttle input. The changes in yaw as measured by the gyroscope are consistent with the yaw-input of the RC. This indicates that the changes of the UA heading can generally be attributed to the provided yaw input.

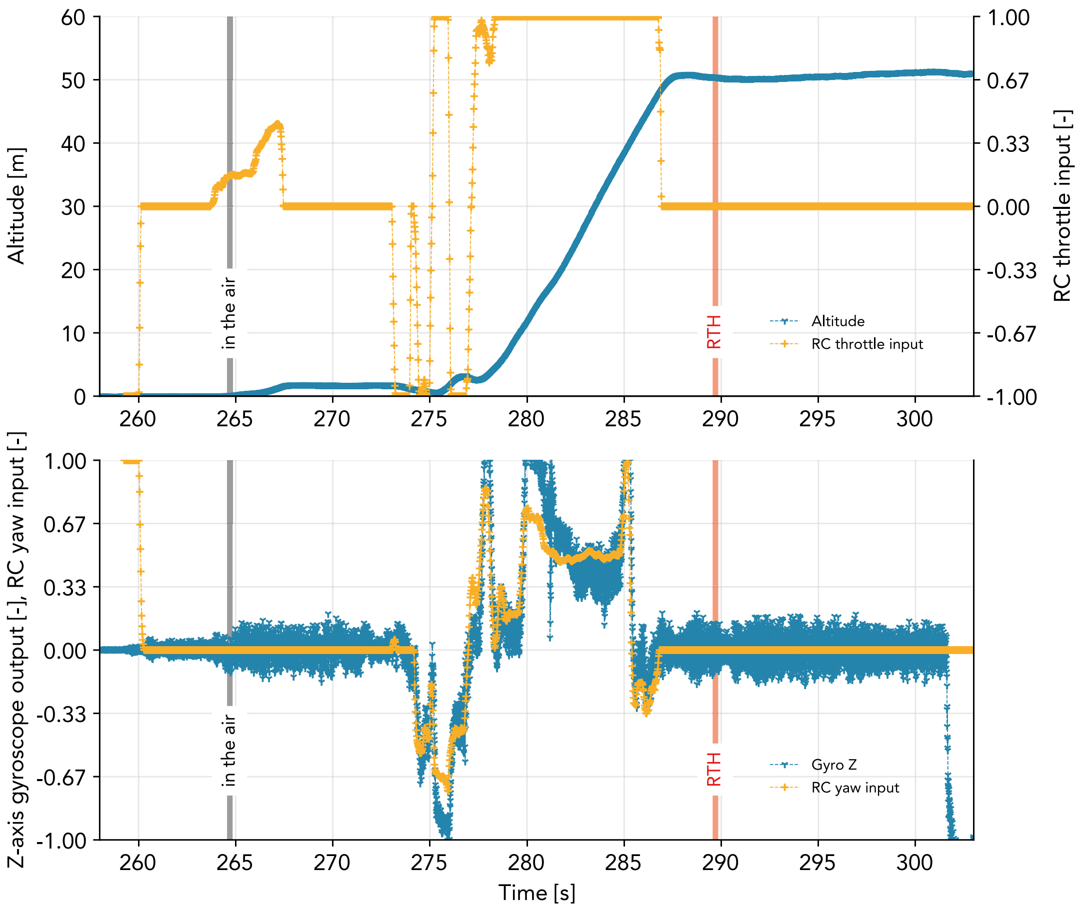

Figure 8: The altitude and remote controller throttle input versus time (top) and z-axis gyroscope output and remote controller yaw input versus time (bottom). The input from the left RC stick (in orange) is compared with the corresponding UA response (in blue). Also indicated are the moments when the UA was in-flight and when the RTH functionality was activated.

Right stick response

For roll and pitch, the relation between the recorded angle and the input was not always consistent. This is shown in Figure 9. Some deviation of the roll and pitch angle from the input is generally expected in the P-mode[52], as the flight computer autonomously tilts the UA to generate lateral forces that can compensate for wind drag. As there was little wind on the day of the flight (mean wind speeds up to 3.0 m/s, see Section 2.5), the roll and pitch angles associated with autonomous control are expected to be relatively small. During the first five seconds of the flight that was generally the case, yet from 270 seconds onward, the pitch and roll angles increased up to ten degrees without corresponding input. During the second half of the shown timespan, the correlation between the pitch and roll angles and the provided input was low in magnitude and sign.

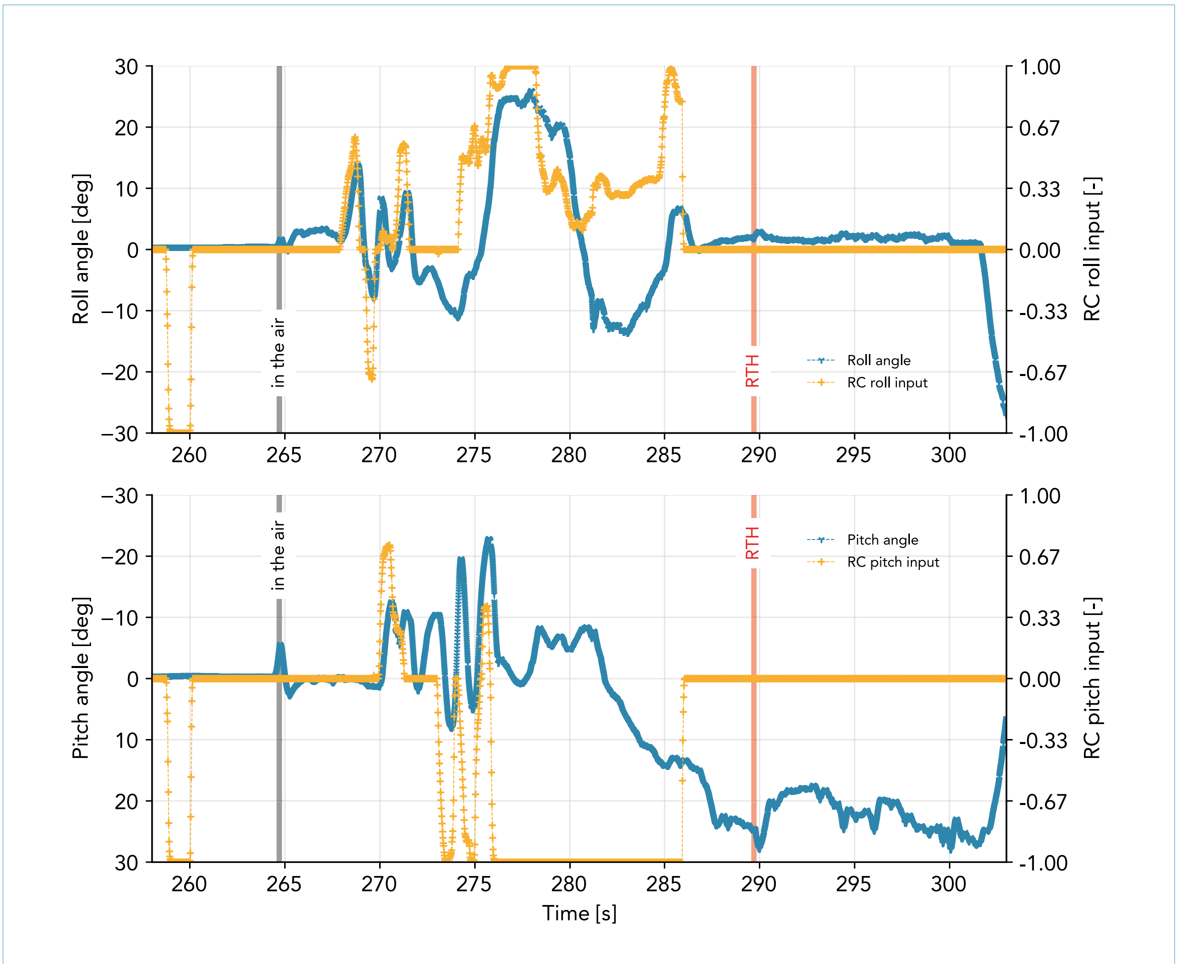

Figure 9: The roll angle of the UA and the remote controller roll input versus time (top) and pitch angle of the UA and the remote controller pitch input versus time (bottom). The input from the right RC stick (in orange) is compared with the corresponding UA response (in blue). Also indicated are the moments when the UA was in-flight and when the RTH functionality was activated. A positive roll input corresponds to a positive, rightward roll angle. A positive pitch input corresponds to a negative, forward pitch angle.

52 Further explanation of the flight modes can be found in the blue box in Section 2.3.2.

3.1.2 Sequence of events

The motors were turned on roughly five seconds before take-off.[53,54] Roughly one second after the input for take-off the UA was in the air and climbed in two seconds to an altitude of about 2 metres. The Pilot In Command (PIC) then started the UA control check by rolling right and left. The subsequent check of the forward-backward response was aborted halfway through. The positive (forward) pitch input (and minor roll input) was not immediately followed by negative pitch input, because the UA did not respond in accordance with the pilot's expectation. Just after the forward pitch input a compass fault[55] was registered and then resolved (fault off) within 0.2 seconds.

During the next nine seconds this fault was registered and closed four more times, followed by three new log entries in the fifteenth second of the flight.[56] It is unclear whether these log registrations were indicated to the pilot and payload operator through the DJI Go 4 app. The algorithm behind it is not known to the Dutch Safety Board and no information regarding this was provided by the manufacturer. Neither the pilot nor the payload operator noticed indications on the display of their remote controller.

The exact UA response after the first compass fault is unclear. The pitch and roll data indicate that after a few seconds, the UA movement was dominated by the P-mode control, as there was little correlation with the right-stick pilot input. The registered pitch and roll angles of sometimes more than 20 degrees, were not in line with the pilot's expectations and affected the pilot's sense of control. Regarding the input from the left RC stick, the UA response seems to have been normal. For about fifteen seconds after the aborted control check, the pilot tried to gain control through input of both sticks. According to the pilot, the result of this was a UA that kept flying away from the crew and accelerated.

Not having been able to regain control, the pilot activated the Return-To-Home (RTH) button on the remote control. This was registered roughly 26 seconds into the flight. About one second later the connection with the RC was registered as lost. This was also indicated on the display of the pilot and payload operator. The ground track of the UA shows that this moment corresponded to when the UA flew over a line of trees, blocking the line of sight between the RC and the UA. The analysis by the manufacturer of the UA indicated that this was most likely the cause of the loss of connection.

After the loss of control and connection with the UA, the aircraft continued its flight over The Hague while being in RTH mode. The remainder of the flight and events leading to the crash are further analysed in Section 3.2.

53 For electrical motors this means they are powered to the level that the propellers reach the idle speed.
54 Visible in Figures 8 and 9 by the RC input around t=260 seconds.
55 [L-FDI]NS(0) COMPASS(0): fault on, over_large.
56 Those entries were: [L-FDI]NS(0) COMPASS(0): fault on, interfere, [L-FDI]NS(0) COMPASS(0): fault on, noise and [L-FMU/MOTOR]mag_need_action: restart drone.

3.1.3 IMU and compass discrepancy

The data of the first 30 seconds of the flight contains a discrepancy related to the heading, in particular between yaw and compass angle[57], see Figure 10 (top). Both angles start at roughly 180 degrees, but several seconds into the flight, the angle of the compass vector starts to deviate from the yaw angle. The discrepancy increases after a flight time of about 10 seconds, reaching a more or less constant difference of roughly 180 degrees. The flight data of the previous flight of the same UA reveals no such discrepancy, see Figure 10 (bottom).

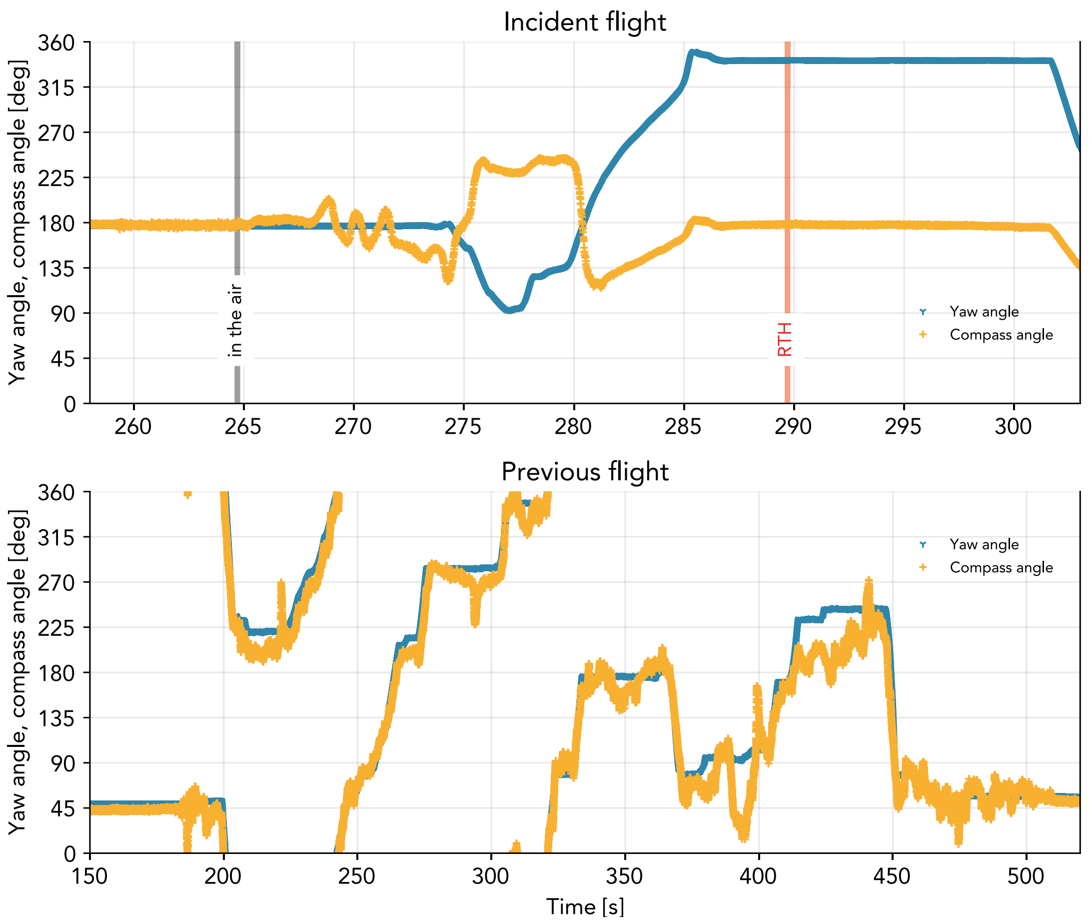

Figure 10: Yaw angle and the magnetic heading indicated by the compass versus time for the incident flight (top) and for a previous flight (bottom). The yaw angle (in blue) is normally consistent with the compass angle (in orange).

57 The Dutch Safety Board computed the compass angle as the angle of the compass vector in the x-y-plane, the z-axis component was ignored.

Comparison with the heading derived from the GPS track for the first 30 seconds of the flight indicates a general match with the yaw angle. The compass angle thus deviated from the actual UA heading.

3.1.4 Compass faults

The compass faults and the compass angle deviation indicate that the compass most likely influenced the UA response. Because no details regarding the working of the compass, the processing of its output or the registration of its values in the flight data are available, it was not possible to analyze this in more detail. Given the absence of power supply infrastructure close to the take-off location, it is considered unlikely that the interference caused by it led to a compass deviation. In any case, it can be said that the deviation was not the result of disturbances to the earth's geomagnetic field by solar particle radiation, given the low Kp factor (see Section 2.5).

The Inspire 2 manual indicates that the UA switches autonomously from P-mode to A-mode under the conditions mentioned in the blue box in Section 2.3.3. One of the criteria for switching involves compass interference. However, for the analyzed flight there are no indications that the UA switched to A-mode. As the relevant data were not provided by the manufacturer it was not possible to determine whether this was a factor in the fly-away.

During the whole flight, the GPS status was logged as 'very strong'; it can therefore be ruled out that the loss of control was caused by poor GPS reception.[58,59]

3.1.5 Payload influence on the compass

During the incident flight, the UA was equipped with a camera, see Section 2.3.4. On the previous day, the same UA was used with a loudspeaker as payload. Hence, a payload change was performed before the fly-away took place. Theoretically, a different type of payload could affect the magnetic field around the aircraft and may therefore require a compass calibration. This is especially likely when the payload contains an electromagnet, such as a loudspeaker.

Further investigation by the operator confirmed this theory. A fly-away was observed in a simulation flight by conducting a flight after changing the payload (loudspeaker to camera) without calibration of the compass (see Appendix B.2). In effect, after the payload change, the aircraft was flown with an incorrectly calibrated compass or compass mismatch. The fly-away with the camera payload only occurred after the previous simulation was performed with a specific tilt (angle) of the loudspeaker payload, which could explain why it did not occur during other flights.

Before the simulated fly-away occurred, the main view of the GO 4 application provided the pilot with system status green 'ready to fly'. The compass interference indication in

58 DatCon data indicates that during the whole flight the UA had access to signals from over 12 GNSS satellites.
59 General consensus is that at least 12 satellites are required for safe flight in GPS stabilized mode, see for instance https://forum.dji.com/forum.php?mod=viewthread&tid=209533 (accessed on 23 June 2022) and https://forum.dji.com/thread-205194-1-1.html (accessed on 23 June 2022).

the sensor state menu had however decreased from excellent (green) to good (yellow). Some level of interference was thus detected, but not to an extent that take-off was prevented or discouraged through a warning on the GO 4 main view. How this could occur was not further investigated because the necessary information was not provided by the manufacturer of the UAS.

The flight data indicates that the UA responded as expected during the first five seconds of the flight. The event log shows a compass fault after six seconds and this corresponds to the moment the UA started to show pitch and roll behaviour that was increasingly inconsistent with the input of the PIC. The behaviour led to a loss of control, followed by a loss of connection and a fly-away.

The inconsistency is most likely related to the autonomous position control associated with flying in the P(ositioning)-mode. A deviation of the compass angle from the angle of the GPS-track, together with several logged compass faults, indicates that the compass contributed to the unexpected UA-response.

The loss of control and subsequent fly-away was most likely caused by an incorrectly calibrated compass, a condition that could exist because of a payload change without compass calibration before the incident flight.

3.2 Fly-away and cause of the crash

After the connection with the RCs was lost, the UA flew over the city of The Hague for about 18 minutes. During this part of the flight, additional compass faults were registered. The GPS-based ground track of the aircraft, annotated with the locations of the compass faults and RTH activation, is shown in Figure 11. The orientation data for this part of the flight is considered to be insufficiently accurate because of multiple compass faults and was therefore not used for further analysis.

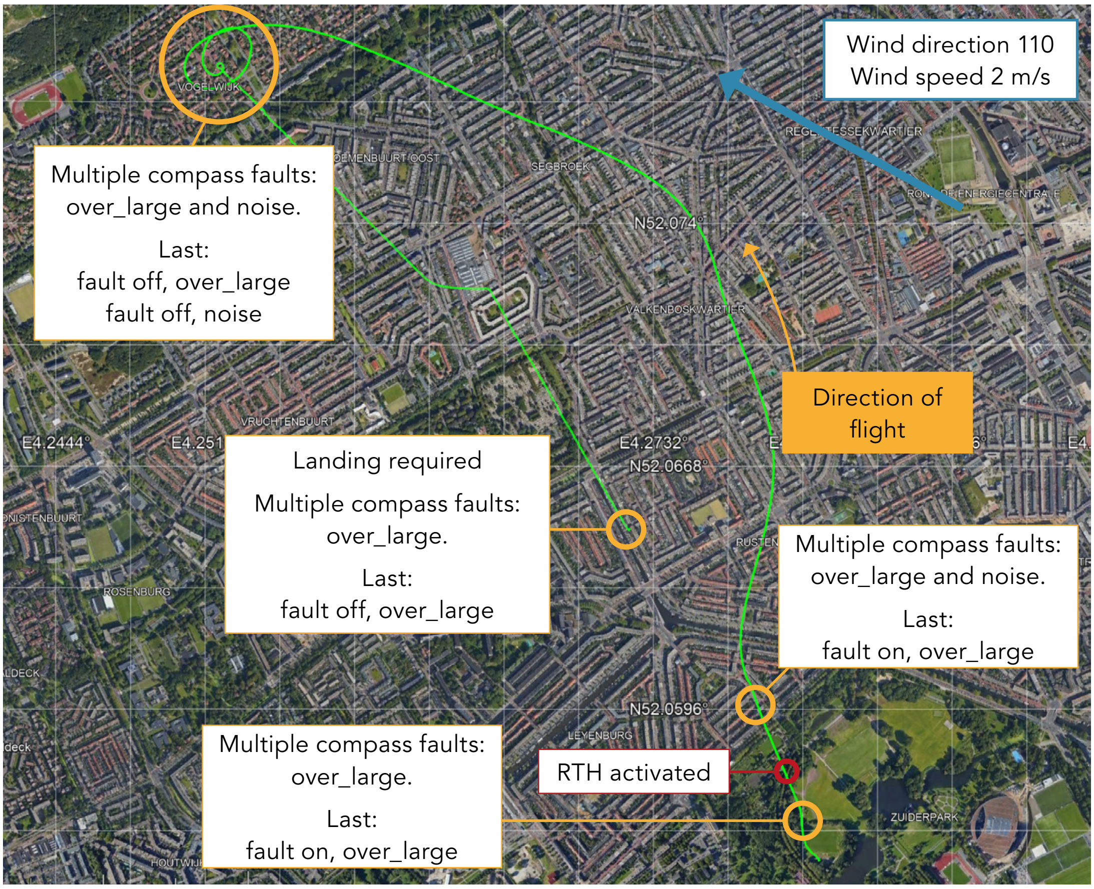

Figure 11: Ground track of the Inspire 2, annotated with the locations of compass errors. (Source map: Google Earth)

The ground track is characterized by multiple straight segments combined with a curved trajectory. Most notably, the UA also performed two orbits. According to the data, these orbits coincide with a portion of the flight during which multiple compass faults were registered. The simultaneity of the orbits and multiple compass errors is another indication of serious compass malfunctioning.

In addition, a difference between the geographical location as registered by the GPS antenna[60] and IMUs (Inertial Measurement Units) is indicative for problems with position estimation within the UA flight computer. Such a difference was found during this part of the flight, but also shortly after take-off. As the IMUs use the compass for an accurate estimation of the orientation and location of the aircraft (see Section 2.3.2 and Figure 6), the significant difference in GPS location and IMU position estimation could also be the result of a compass malfunction.

After the second, smaller orbit, compass faults disappeared and the UA continued on a semi-straight trajectory, roughly in the direction of the home point. The absence of

60 As no further processing took place, the GPS coordinates as registered by the GPS antenna are considered to be the ground truth, in disregards of the always present error margin.

compass faults in that portion of the flight and the fact that the RTH mode was still activated, may explain that the direction of flight was roughly in the direction of the home point.

During the last portion of the flight, multiple events were logged, of which the most pertinent are shown in Table 5.

Table 5: Relevant event logs in the final segment of the flight as recorded in the error log on the aircraft, obtained from DatCon.

Timestamp (seconds after start recording)	Event message	Notes
1,228.383	`[L-BATTERY]smart bat 2 req landing`	Battery systems reports low battery voltage, landing required
1,228.409	`[L-GEAR]send gear state:0x2f`	Landing gear automatically lowered
1,228.749	`[L-FDI]NS(0) COMPASS(0): fault on . over_large`	Compass faults registered again
1,229.198	`[L-RC]Start landing. rc vib!`	
1,294.320	`[L-FDI]NS(0) COMPASS(0): fault off, over_large`	Last recorded compass fault before crash
1,352.633	`[L-BATTERY]battery_dangerous req force landing`	Forced landing initiated
1,358.094	`[L-FMU/MOTOR]safe_near_grd:true`	
1,360.492	`[L-RC]Near GND reminder. rc vib!`	

The event log shows that at timestamp 1,228.383 seconds, the smart battery system reports a low battery voltage and sends out the message 'landing required'. From the subsequent event messages it can be inferred that the flight control system of the UA initiated automated landing.

The time trace of the altitude (see Appendix C.2) shows that after initiating an automated landing, the UA lowered to approximately 20 metres above the ground and subsequently remained at this altitude for a duration of more than two minutes. This is expected behaviour; according to the user manual the aircraft will descend to 20 metres without input. Consistent with the event message "*battery dangerous req force landing*", the UA started descending again at timestamp 1,352 seconds. The last altitude that was registered was around 7 metres above the ground. Most likely, power was lost at this altitude.

The acceleration in the direction of the z-axis of the UA during the last seconds shows an increasing gradient. Due to a loss of power, the propellers were unable to generate lift and the UA entered a free fall.

From the data it cannot be determined with confidence why the UA did not successfully complete its automated landing in the time between the initiation of the automated landing sequence (1,229 seconds) and the forced landing (1,294 seconds). According to the manufacturer, the aircraft detected that the ground was not safe for landing and hovered until no power was left. Data from the ultrasonic sensor shows that, at the time of the hover, an ultrasonic height of 4-5 metres was detected. Given the pressure altitude of 20 metres, this could indicate for an object of around 15 metres tall positioned below the UA.

The pattern of damage to the UA and its payload is consistent with the findings from the data. The damage appears to be the result of the crash or contact with another object. Since no mechanical defects were found, a mechanical failure does not appear to be at the root of the incident.

After connection with the UA was lost, it flew uncontrolled over the city of The Hague. The pattern of the ground track, multiple straight segments combined with a curved trajectory, multiple registered compass faults and discrepancy between the GPS track and IMU track are again indicative for problems with the compass.

After over 18 minutes of flight, the UA initiated an automated landing sequence due to a low battery voltage, but was unable to complete it. The aircraft hovered until no power was left and subsequently crashed.

3.3 Flight mode influence on controllability

Shortly before the fly-away occurred, the flight crew took off in positioning mode (P-mode). According to the operations manual of the operator, P-mode is the preferred mode of flight. The Inspire 2 disclaimer and safety guidelines also mention the P-mode to be the preferred mode for most flight scenarios.[61] The same document states that users can switch to A-mode when GPS stabilized modes are not available. According to the pilot the GO 4 app indicated the P-mode was available.

The operations manual of the operator describes several *abnormal procedures*. In case of a loss of control or fly-away, the pilot may revert to any of the procedures listed in Section 2.4.4. These procedures focus mainly on having the UA switch to the RTH mode[62] and do not mention changing to the A-mode. This is in line with the manufacturer's guidelines. These guidelines advise to land immediately in case of severe drifting and also mention the use of the RTH mode in case of emergency (fail safe mode), but do not go into more detail.58 Analysis has indicated compass failure, and given that the RTH-functionality relies on the compass (see Section 2.3.2), RTH mode would not work in such

61 DJI, *Inspire 2 Disclaimer and safety guidelines V1.2*, 2017, p.13, available at https://dl.djicdn.com/downloads/Spark/20171012/Spark_Disclaimer_and_Safety_Guidelines_V1.2_EN.pdf, accessed on 23 June 2022.
62 Automatically, e.g. by turning off the remote controller.

cases. The serious incident has shown that, especially in the initial phase of the fly-away, the RTH mode did not return the aircraft to its home point.

Analysis also indicates that there were about 20 seconds between the start of the loss of control and the activation of the RTH mode and loss of connection. Timely switching to the A-mode could potentially have helped the crew to regain control over the aircraft in a timely manner because it eliminates the dependence on the UA's autonomous positioning, including the GPS and compass. One of the outcomes of the operator's internal investigation is the recommendation to switch to A-mode in case the crew suspects a compass error. Switching to A-mode is in most cases a measure without adverse effects since the RTH function can still be used.[63]

> Before the fly-away, the UA was operated in positioning mode. In line with the procedures and manufacturer's guidelines, the operator switched to the RTH-mode after the loss of control. The RTH-mode however, relies on the compass. As in this case, there was a compass malfunction, switching to A-mode could potentially have helped the crew to regain control over the aircraft. Neither the operations manual of the operator, nor the manufacturers' guidelines mention switching to A-mode in their *abnormal procedures.*

3.4 Payload and associated risks

3.4.1 Calibration procedures

Interviews with the operator and a review of its operational manual revealed that no formal or informal procedures existed to provide guidance on when the compass should be recalibrated. The flight crew mainly relied on indications from the software on when to perform this procedure. In effect, the flight crew did not recalibrate the compass after the payload change and hence the conditions that ultimately led to a fly-away came into existence.

The operator's and flight crew's consideration to rely on the software for indications on when to calibrate is understandable. The manufacturer of the UAS stresses in the official user manual of the aircraft[64] and the disclaimer and safety guidelines[65] to *only calibrate the compass when the DJI GO 4 app or the status indicator prompt to do so*. The operator followed the manufacturer's official advice.

Further investigation into how the conditions inside the GO 4 app could exist that allowed for flight with a wrongly calibrated compass was inconclusive because the

63 In cases where GPS is available and other on-board systems function correctly.
64 DJI, *Inspire 2 Series User Manual v2.4*, July 2019, p. 62, available at https://dl.djicdn.com/downloads/inspire_2/20201120/INSPIRE_2_SERIES_User_Manual_EN_20201120.pdf, accessed on 23 June 2022.
65 DJI, *Inspire 2 Disclaimer and safety guidelines V1.2*, 2017, pp. 2, 8, available at https://dl.djicdn.com/downloads/Spark/20171012/Spark_Disclaimer_and_Safety_Guidelines_V1.2_EN.pdf, accessed on 23 June 2022.

manufacturer was unresponsive to questions from the Dutch Safety Board about the software calibration logic. The findings in this report demonstrate that there are safety gains to be made in further improving detection of compass offset conditions or more effectively presenting compass related information to the flight crew.

3.4.2 Acceptance of new payload

The question that arises, is whether the risks of (changing) payload and its associated effect on the magnetic field could have been known to the operator. An operator could become aware of substantial influence of a particular payload on the compass through assessment/testing. For the UAS involved in the incident flight, it is a legal requirement that UAS are assessed as part of obtaining a special certificate of airworthiness (S-BvL). In particular, on matters related to interference of payload on systems required for safe flight operation (see Section 2.7). In addition, operator-specific procedures require execution and reporting of a so-called Functional Check Flight (FCF) when flying with new payload types.

According to the operator, the UAS-loudspeaker configuration was tested on several occasions, but a formal FCF was not performed. Investigation also shows that the operator had an assessment performed as part of the application for an S-BvL. This assessment was done with a 'standard' DJI-manufactured payload (camera) and was not repeated when the loudspeaker payload was put into service, despite the legal requirement. Both the operator and developer of the payload have indicated that they were not aware of this legal requirement.

Neither the S-BvL nor the underlying assessment report[66] specifies the allowed/tested payload, making it relatively difficult for the user to keep track of what payload may and may not be used. The ILT indicates that during inspections it is not checked for which the assessment report was issued. Although formally not allowed, in practice it is possible, and common, to fly with different types of payload without them being part of the assessment for obtaining the S-BvL.

3.4.3 Payload development by third parties

Another factor that could have contributed, was that the payload was custom made. It is possible for other parties to develop payload for DJI UAS. As part of its Software Development Kit (SDK)[67], DJI describes criteria for the payload to ensure safety. These criteria include hardware interface standards and interference compatibility requirements to be used by third parties in payload development.[68] However, according to the website, the SDK is not applicable to the Inspire 2. DJI does not maintain a list of payload developed by third parties. In addition, DJI does not provide guidelines regarding the use of third-party payload and states to use custom payload at the user's own risk.

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66 Also referred to as the Certificate of Recommendation.

67 The latest version of the payload SDK can be found on DJI's website: https://developer.dji.com/document/6fcaaad3-bbae-4e33-a200-549a7a50ba74, accessed on 23 June 2022.

68 E.g. the payload SDK specifies that the payload should not transmit electromagnetic waves in specific frequency bands and states that payload should minimize magnetic interference.

The manufacturer of the loudspeaker payload, indicated that the product was tested before it was made available to the customer. These tests, including an assessment of compass interference, were limited primarily to tests with the loudspeaker at the design tilt angle. The use of other tilt angles was not tested extensively. During the development, the manufacturer of the payload did not coordinate with DJI about guidelines, tests or other details.

The operator did not have procedures for a payload change and relied on indications from the software on when to calibrate. In doing so, the operator complied with the UAS manufacturer's recommendation, which stresses to only calibrate the compass when it is indicated by the software.

The influence of the particular payload on the compass could have been identified during the Functional Check Flight or assessment as part of obtaining the S-BvL. In this case, no such formal assessment was done before putting the loudspeaker payload into use. In part, because the applicable regulations and certification requirements were unclear to users and manufacturers. Hence, they did not know when a new S-BvL must be applied for and therefore a new assessment should be carried out. This requirement is also not actively enforced by the ILT. Although formally not allowed, in practice it is possible, and common, to fly with different types of payload without them being part of the assessment for obtaining the S-BvL. This contributed to the user underestimating the influence of the loudspeaker payload on the magnetic compass.

The manufacturer of the payload tested the product on compass interference, among other things, but not as extensively with all possible loudspeaker tilt angle combinations. At the same time, there are few guidelines from the UAS manufacturer regarding the use and development of payload. There was no coordination between the two parties.

3.5 Changes made by the operator since the serious incident

After the serious incident occurred and the internal investigation was finished, the operator made a number of changes with respect to its own operation. The most significant changes are listed below.

- Immediately following the incident, the loudspeaker was removed from the operation and is no longer in use by the operator.[69] The operator no longer uses any payload other than the payload with which the UAS underwent an assessment required to obtain the S-BvL.

69 The manufacturer of the custom-made loudspeaker stated that the device is not in use by another operator/customer for the same purpose.

- The flight crews of the operator were briefed on the serious incident, the results of the internal investigation and lessons learned. They were further made aware of the possibility of switching to A-mode in case of a loss of control.
- The operator has third-party payload tested on, among other things, electronic and magnetic interference (with on-board systems) and influence on the center of gravity and aerodynamics of the aircraft by an external party.
- The operator has formalised procedures for changing payload. After a payload change, the interference should be checked in the menu of the GO 4 software application.[70] In addition, a (manual) compass calibration must be performed after a payload change.[71]

The operator has made a number of changes to its own operation, incorporating the lessons learned from the serious incident.

3.6 Participation by the manufacturer

At the international as well as the national level there are various standard and legislative frameworks regarding the conduct of accident investigations, as briefly outlined in Chapter 1. Investigating accidents and incidents is an important part of improving aviation safety. Investigative bodies, such as the Dutch Safety Board, depend on the manufacturer for the provision of detailed information, e.g. about the functioning and (design) limitations of (on-board) systems.

For the above reason, the Dutch Safety Board requested the assistance of the manufacturer of the UAS early in the investigation process. Details regarding the serious incident, including flight data, were shared with the manufacturer and information was requested. In addition, the operator and importer of the UAS independently contacted the manufacturer in the days before the Board learned of the serious incident.

Not all initial information requests were answered by the manufacturer. The data analysis by the manufacturer indicated that the fly-away was most likely caused by a compass error.[72] The manufacturer suggested performing a compass calibration before take-off. The manufacturer did not provide further information requested by the Board, e.g. about systems behavior and software/algorithm design, necessary for identifying contributing factors.

The Dutch Safety Board requested validated flight data from the manufacturer, as the data cannot be read directly from the UA (see Section 2.6). The manufacturer did not

70 In the DJI GO 4 software application menu: Main Controller Settings > Advanced Settings > Sensors > IMU/Compass.
71 In the DJI GO 4 software application: tap the aircraft status bar (top) and select *Calibrate* in the compass section.
72 See Appendix B.1.

respond to those requests. The manufacturer does provide software to convert and analyze flight data. However, the data that can be extracted with this tool is limited.[73]

Not having access to the complete set of (validated) flight data poses a barrier to doing safety investigations. On more recent DJI UAS models, the flight data is encrypted and thus no information is directly available to operators and safety investigators. This further limits the ability to conduct a proper investigation and learn from incidents and accidents.[74]

During the course of the investigation, the Safety Board met with DJI on several occasions. During these meetings, the Board made additional information requests, and arrangements were made concerning the exchange of information for the purpose of the safety investigation. Up to now, some of those requests were answered, but these agreements have not led to a different attitude on the part of the manufacturer. For that reason, this investigation is partially inconclusive.

In line with ICAO Annex 13 Standards and Recommended Practices (SARPs), the Chinese safety investigation authority, the Office of Aviation Safety of the Civil Aviation Administration of China, was notified of the serious incident, but no response was received.

The operator and importer are also parties that have an interest in assistance from the manufacturer in their own investigation process. The operator indicated that they did not get the desired technical support from the manufacturer during their investigation process. In this case, the operator has invested a great deal in investigating the causes of the incident. However, not all operators have access to these resources, and therefore are more dependent on the manufacturer of the UAS in this regard.

At the request of the Dutch Safety Board, DJI indicated that they consider their current processes adequate given the life cycle phase of this aircraft type.

Multiple requests to share detailed information and decode or validate flight data have generally not been met by the manufacturer of the UAS.

The operator has invested a great deal in finding the possible cause of the fly-away. Not all operators have access to resources to contract third-party expertise for their investigation. It therefore remains important that the manufacturer of the UAS shares information with the parties involved so that possible causes can be identified.

73 See Appendix C.1 for a discussion.
74 Sar104, *Mavic Flight Log Retrieval and Analysis Guide*, 2019, available at https://mavicpilots.com/threads/mavic-flight-log-retrieval-and-analysis-guide.78627/, accessed on 22 April 2022.

3.7 Related investigations

In recent years, the Dutch Safety Board has investigated several incidents involving unmanned aircraft. All of these incidents involved airproxes between manned and unmanned aircraft.[75] This investigation is the first in a series of investigations launched into unilateral occurrences involving UAS. During the course of this investigation, two additional (limited) investigations into unilateral accidents with unmanned aircraft were initiated, both with the involvement of a DJI UAS.[76]

The investigation into the crash of a DJI M210 V1 in the Port of Rotterdam was published in the Quarterly Aviation Report over January – March of 2021.[77] Despite the different type of UAS involved, some of its findings also relate to this investigation. In its report, the Board stressed that detailed and validated data is necessary to determine the cause of a crash. Despite several requests, the manufacturer has not produced a detailed analysis of the data from the RC, nor has it validated the available data or converted it into a readable format.

In two of its investigations the Air Accidents Investigation Branch (AAIB) attributed poor GPS signal and/or compass malfunctioning as the cause of the uncontrollable aircraft or fly-away and subsequent crash.[78] As part of an investigation involving a DJI Matrice 200 V1, the AAIB recognized that UAS manufacturers may not be structured or resourced to provide detailed technical support. Despite several requests, the manufacturer did not provide detailed information requested by the safety investigation authority. The AAIB therefore recommended DJI to introduce a system for providing timely technical support to State safety investigations.[79] In its annual safety review over 2021, the AAIB assessed DJI's follow-up to the recommendation as adequate.[80]

75 For example see *Near collision with drone, Boeing 737, near RIVER waypoint (near Brielle), 26 June 2017* in Dutch Safety Board, *Quarterly Aviation Report July - September 2017*, 2018, available at https://www.onderzoeksraad.nl/en/page/4915/bijna-botsing-met-drone-boeing-737-26-juni-2017, accessed on 22 April 2022, and Airprox, Cessna 172, PH-KAC, Remotely Piloted Aircraft Systems (RPAS), near Wijhe, 14 October 2017 in Dutch Safety Board, *Quarterly Aviation Report October – December 2017*, 2018, available at https://www.onderzoeksraad.nl/en/page/4962/airprox-cessna-172m-remotely-piloted-aircraft-systems-rpas-14-october, accessed on 22 April 2022.

76 *Crashed, unmanned aircraft system DJI M210 V1, PH-4PE, Waalhaven, Port of Rotterdam*, 4 July 2020 available at https://www.onderzoeksraad.nl/en/page/17557/crashed-unmanned-aircraft-system-dji-m210-v1-ph-4pe-waalhaven-port-of, accessed on 22 April 2022; and *Fly-away shortly after take-off, DJI M210 v2, The Hague, 12 November 2021*, available at https://www.onderzoeksraad.nl/en/page/19890/fly-away-shortly-after-take-off-dji-m210-v2-the-hague, accessed on 22 April 2022.

77 Dutch Safety Board, *Quarterly Aviation Report January – March 2021*, 2021, available at https://www.onderzoeksraad.nl/nl/media/inline/2021/7/28/quarterly_aviation_report_q1_2021.pdf, accessed on 22 April 2022.

78 *AAIB investigation to DJI M600 Pro, (UAS, registration n/a) 131219* in Air Accidents Investigation Branch, *AAIB Bulletin: 7/2020*, 2020, available at https://www.gov.uk/aaib-reports/aaib-investigation-to-dji-m600-pro-uas-registration-n-a-131219, accessed on 22 April 2022, and *AAIB investigation to DJI Inspire 2, (UAS registration n/a) 080220* in Air Accidents Investigation Branch, *AAIB Bulletin: 6/2020*, 2020, available at https://www.gov.uk/aaib-reports/aaib-investigation-to-dji-inspire-2-uas-registration-n-a-080220, accessed on 22 April 2022.

79 *AAIB investigation to DJI Matrice 200 V1, (UAS, registration n/a) 210919* in Air Accidents Investigation Branch in *AAIB Bulletin 3/2021*, 2021, pp. 88-102, available at https://www.gov.uk/government/publications/air-accident-monthly-bulletin-march-2021, accessed on 22 April 2022.

80 Air Accidents Investigation Branch, *Annual Safety Review 2021*, 2022, pp. 54-56, available at https://www.gov.uk/aaib-reports/annual-safety-review-2021, accessed on 23 June 2022.

Previous investigations also show the consequences of poor GPS signal or compass malfunction, but these investigations did not establish whether the malfunction was the result of incorrect or absent pre-flight calibration.

With regard to the investigation process, other investigations concluded that the approach of DJI towards supporting safety investigation authorities with their investigations may impose a restriction on the progress of the investigation and compromise the ability to learn from occurrences. The engagement of the manufacturer is essential to learn from accidents and incidents and to improve flight safety.

4 CONCLUSIONS

Cause of the loss of control, fly-away and crash

Analysis of the flight data by the Dutch Safety Board shows that the Unmanned Aircraft (UA) responded as expected to pilot input during the first five seconds of the flight. After six seconds into the flight, the UA started to show pitch and roll behaviour that was increasingly inconsistent with the input of the pilot. This behaviour led to a loss of control. At some point, the line of sight between the controller and UA was blocked which led to a loss of connection. A deviation of the compass angle from the angle of the GPS-track, together with several logged compass faults, indicates that the compass contributed to the unexpected UA-response.

The loss of control was most likely caused by an incorrectly calibrated compass, a condition that could exist because of a payload change without compass calibration before the incident flight. The previous payload, a loudspeaker, had different (electromagnetic) characteristics than the payload of the incident flight, which was a camera. After the incident, loss of control was encountered (and recovered in A(ttitude)-mode) in a test flight conducted on behalf of the operator. This flight was performed after the same payload change as before the incident flight, without recalibrating the compass. During the preparation of both the incident and test flight, the application did not inform the pilot of the compass interference through the flight status in the main view, as it remained 'ready to fly'.

After connection with the UA was lost, the aircraft flew uncontrolled over the city of The Hague. The pattern of the ground track, multiple straight segments combined with a curved trajectory, multiple registered compass faults and a discrepancy between the GPS track and the registered heading are again indicative for problems with the compass. After a flight of more than eighteen minutes, the UA initiated an automated landing sequence due to a low battery voltage, but was unable to complete it. The aircraft hovered until no power was left and subsequently crashed in an urban area on a sidewalk.

Several lessons can be learned from this serious incident.

Flight mode influence on controllability

At the time of the fly-away, the aircraft was operated in positioning mode. The operations manual of the operator contained several procedures for abnormal situations, none of which included the action to switch to A-mode. This was in line with guidelines of the manufacturer. One of the lessons learned from the incident is that switching to A-mode should be given priority over engaging the Return-To-Home (RTH) mode in case of compass errors because it eliminates dependence on the compass. Switching to A-mode is also advisable if the crew is unsure whether there is a compass malfunction because RTH still works when flying in A-mode. The operator has already incorporated this lesson learned into its procedures.

Payload influence on compass

The investigation revealed a number of shortcomings at different systemic levels. Firstly, the operator did not have procedures for a payload change and relied on indications from the software on when to calibrate. In doing so, the operator complied with the UAS manufacturer's recommendation, which stresses to only calibrate the compass when it is indicated by the software.

Secondly, at the oversight level, the influence of the particular payload on the compass could have been identified during the assessment as part of obtaining a Special certificate of airworthiness (S-BvL), as the requirements include payload. Despite the legal requirement, no new assessment was performed by the operator before putting the loudspeaker payload into use. In part, because the applicable regulations and certification requirements were unclear to users and manufacturers. Hence, they did not know when a new S-BvL must be applied for and therefore a new assessment should be carried out. This requirement is also not actively enforced by the ILT. Although formally not allowed, in practice it is possible, and common, to fly with different types of payload without them being part of the assessment for obtaining the S-BvL. The above contributed to the user underestimating the potential influence of the payload on the magnetic compass.

Thirdly, information exchange between manufacturer and third parties regarding payload development can be improved. The manufacturer of the payload tested the product on compass interference, but not with all possible loudspeaker tilt angle combinations. This was done with few guidelines from the UAS manufacturer regarding the use and development of payload. There was no coordination between the two parties, which is an important prerequisite for the development of payloads that can be used safely.

The Dutch Safety Board recognizes that it is challenging to identify all possible payload failure conditions in advance. The above shows that using payload, without knowing what its influence is on the aircraft's on-board systems, involves risks. These risks have manifested themselves in this incident. In practice, the user is often the only and last barrier in the safe use of payload. It therefore remains important for users to be particularly observant when using different payloads, especially in cases involving payloads with significant electromagnetic characteristics. Also, it is advisable to manually initiate a compass calibration in those situations.

Participation to the safety investigation by the UAS manufacturer

Despite multiple requests, the manufacturer of the UAS did not provide the Dutch Safety Board with all the information needed for the investigation. Therefore some aspects (e.g. why the failure condition in the compass could exist) could not be investigated, resulting in a partly inconclusive investigation.

In order to learn from accidents and incidents involving UAS, it would be recommendable for all parties involved, among which manufacturers, to share the information needed for the investigation as much as possible. Also participating in safety investigations would improve the way all involved parties can learn from accidents and incidents, and subsequent investigations such as the one laid out in this report. All in all, in order to improve flight safety, the engagement of all parties involved is essential to learn from accidents and incidents.

5 RECOMMENDATIONS

To conduct Unmanned Aircraft System (UAS) flights, it is important that the operator and pilots have access to up-to-date information about the UAS, the (functioning of) onboard systems, payload and recommended procedures and safety guidelines. In that respect, operators and private users largely rely on the manufacturer's best practices when using UAS.

The manufacturer has published manuals and safety guidelines for the UAS. Although the average life span of a UAS is shorter than that of a regular aircraft, UAS can be in use for many years, even after production has ceased. It therefore remains important to update the guidelines using the latest safety insights, in such that users always have access to up-to-date information about the safe use of their UAS and the risks of flying with it.

To improve the safety of the use of UAS, the Dutch Safety Board issues the following recommendation:

To Da-Jiang Innovations Science and Technology Co., Ltd. (DJI):

1. Review the UAS user manual and safety guidelines using the safety lessons learned from this incident, and clarify the following aspects:
   a. actions in the event of controllability issues and when to use the RTH and A(ttitude)-mode;
   b. in which cases the compass must be calibrated;
   c. the risks associated with flying with (different) payload types.

To learn from accidents and incidents and to prevent them from happening again, it is vital that all parties involved, such as state safety investigation authorities and UAS operators, have access to the relevant information. In this regard, manufacturer support is essential.

Manufacturers have a responsibility with regard to the quality and safety of a product. In the area of cooperation with regard to safety investigations, the Board sees room for improvement on the part of the manufacturer, both towards the safety investigation authorities and operators.

Therefore, the Dutch Safety Board issues the following recommendation:

To Da-Jiang Innovations Science and Technology Co., Ltd. (DJI):

2. Ensure that safety investigation authorities and operators are timely provided with technical support and relevant information for the purpose of safety investigation regarding UAS manufactured by DJI.

Deliberations with safety investigation authorities from other states have revealed that the abovementioned issue is not unique to the Netherlands. Therefore, in addition to the recommendation, the Dutch Safety Board will continue to stimulate discussion on this topic with other safety investigation authorities, emphasising the importance of manufacturer participation in safety investigations in the appropriate international bodies, in particular the International Civil Aviation Organization (ICAO).

APPENDIX A

RESPONSES TO THE DRAFT REPORT

In accordance with the Dutch Safety Board Act, a draft version of this report was submitted to the parties involved for review. The following parties have been requested to check the report for any factual inaccuracies and ambiguities:

- Office of Aviation Safety of the Civil Aviation Administration of China
- Da-Jiang Innovations Science and Technology, Co., Ltd.
- Dutch Drone Group B.V.
- European Union Aviation Safety Agency
- Ministry of Infrastructure and Water Management, copy Human Environment and Transport Inspectorate
- National Police, Central Unit, copy Aviation Department, Team Unmanned Aviation

The responses received were processed in the following way:

- If the Safety Board decided to adopt responses, they were amended into the final version of the report.
- If the Safety Board did not adopt responses, an explanation is given of why it decided to do so.

The responses received, as well as the way in which they were processed, are set out in a table that can be found on the Dutch Safety Board's website (www.safetyboard.nl).

No response was received from the Office of Aviation Safety of the Civil Aviation Administration of China.

APPENDIX B

OTHER INVESTIGATIONS

B.1 Investigation by the importer and manufacturer

At the request of the operator, the importer of the UAS was asked to investigate whether there were any further technical defects that contributed to the occurrence of the serious incident. To this end, the importer engaged the manufacturer of the UAS to analyze the flight data.

In its analysis, the manufacturer reconstructed the following timeline based on the flight data:

1. The aircraft was set in GPS mode before take-off.
2. 264 seconds after power on, the pilot triggered the take-off through the RC. Immediately, the UA began to drift and could not respond well to the pilot's input because of a compass error.
3. 290 seconds after power on, at a relative height of 50.2 metres and distance to the home point of 300 metres, the failsafe RTH was triggered due to loss of the remote signal. The UA could not return to its home point because of the compass error.
4. 1184 seconds after power on, at a relative height of 53.5 metres and distance to the home point of 1251 metres, landing was triggered due to a critically low battery at 11%. The aircraft started to descend.
5. At 1323 seconds after power on, the flight log ended due to empty batteries.

Based on the above findings and after further investigation by the importer, no technical defects to the aircraft were found.

Furthermore, in response to additional questions from the operator, the manufacturer established that:

- The connection to the UA was lost at a relatively short distance (tens of metres) and as a result the pilot was unable to change the flight mode to A-mode. The cause of the connection loss was an obstacle blocking the signal.
- After take-off and before loss of connection, the UA gained height due to the positive throttle input of the pilot.
- When auto landing was activated due to the critically low battery, the UA detected the ground was not safe for landing. As a result, the UA hovered until the battery reached a level of 0% and then crashed.

In the analysis report, the manufacturer of the UAS also suggests to calibrate the compass before take-off, far away from any source of interference. Despite several requests by the operator, the manufacturer did not release any additional information.

B.2 Third-party investigation

Because there were still many unknown factors with regard to the origin of the compass error and flight path pattern, the operator had additional investigations performed by the Netherlands Aerospace Centre (NLR).

In its first report, dated 20 November 2020, NLR confirmed findings by the manufacturer (see Appendix B.1). In addition, NLR stated that:

- Pilot error during pre-flight/calibration phase and the first part of the flight can be ruled out.
- The aircraft responded to the pilot's input while there was connection between the UA and RC.
- Compass interference due to local disturbances and takeover of control by another controller can be ruled out.

Furthermore, the report concluded that the technical cause of the compass or IMU error could not be established. NLR advised to not use the UA until a technical explanation was found and a repair had been performed by a DJI service centre. It also recommended to perform a compass calibration whenever the UAS asks to do so.

At the request of the operator, NLR conducted a second investigation to further look into the technical cause of the compass or IMU error. In the scope of this investigation, a series of flight tests were performed. NLR concluded in its report, dated February 2022, the following:

- By mounting a different payload, i.e. the loudspeaker, under the UA, calibrating the compass and removing the loudspeaker, flight could be initiated with a poor compass calibration. In doing so, the fly-away was re-created. This scenario is thought to be realistic since a loudspeaker was used in the flights prior to the incident flight, and no recalibration of the compass took place.
- Despite poor compass calibration, it is possible to fly in Positioning mode. The controller only shows a warning beyond a certain calibration threshold. Hence, flight is possible with a poor compass calibration that is still within the threshold.

NLR recommended to thoroughly check for any signs of interference before the start of the flight. This can be done by consulting the sensor state in the DJI GO 4 application. In addition, NLR called attention to training the pilots regarding situations in which the UAS is not functioning properly. In these cases, the use of the Return-To-Home button should be avoided, despite being a logical reaction of the pilot. A better option would be to use the A-mode, in which the UA does not use the compass for positioning and stabilization.

For its analyses NLR used DatCon for data conversion[81], a third-party application. These data were not validated by DJI.

81 Also see Appendix Appendix C for a discussion on the use of DJI and third-party software.

APPENDIX C

ADDITIONAL INFORMATION

C.1 Software

As part of their DJI Assistant 2 software suite[82], the manufacturer of the UAS provides a program called DataViewer. In official documentation, the manufacturer refers to this program for analyzing the cause of accidents.[83] This programs allows for conversion of the raw flight data to 53 parameters, including the geographical location, attitude and altitude. Use of the software indicated that parts of the parameters extracted by DataViewer appear to be truncated (e.g. the geographical location) and are therefore too crude to be useful for further analysis.

There are also some third-party applications that are capable of converting the raw flight data into engineering units. A commonly used program is DatCon.[84] DatCon defines three output categories: DatDefined signals, which uses record definitions, and Engineered and Computed signals, which are modified and derived, respectively. Unlike DataViewer, DatCon can also provide a log file with timestamped status and error messages, as recorded by the UAS flight computer. With DatCon, a total of 1,205 parameters were extracted.

The problem with the use of third-party software is that the software routines and converted data are not validated by DJI. However, on the other hand, this software does allow for the extraction of a much larger amount of information from the same data file. Information that is required in determining underlying system performance and/or failure.

For further analysis, the Dutch Safety Board used both programs to extract parameters from the flight data file. Parameters extracted by both programs were checked for consistency. Regarding DatCon, the use of Engineered and Computed parameters was avoided as much as possible.

82 See https://www.dji.com/nl/downloads/softwares/assistant-dji-2, accessed on 22 April 2022. At the time of writing this report DJI Assistant 2 is discontinued and no longer receives updates.

83 DJI, *Flight Records Analysis Tutorial*, 2018, available at https://dl.djicdn.com/downloads/DJI+Support/Flight+Controller+Data+Analysis+Series+Tutorials+V1.0.pdf, accessed on 22 April 2022.

84 *CsvView/DatCon*, 2020, available at https://datfile.net/, accessed on 22 April 2022. For the flight data analysis in this report, both versions 3 and 4.2.3 of DatCon were used. Where possible, parameters extracted by both versions were compared before further analysis.

C.2 Data time traces

Altitude (pressure sensor), ultrasonic height and vision height

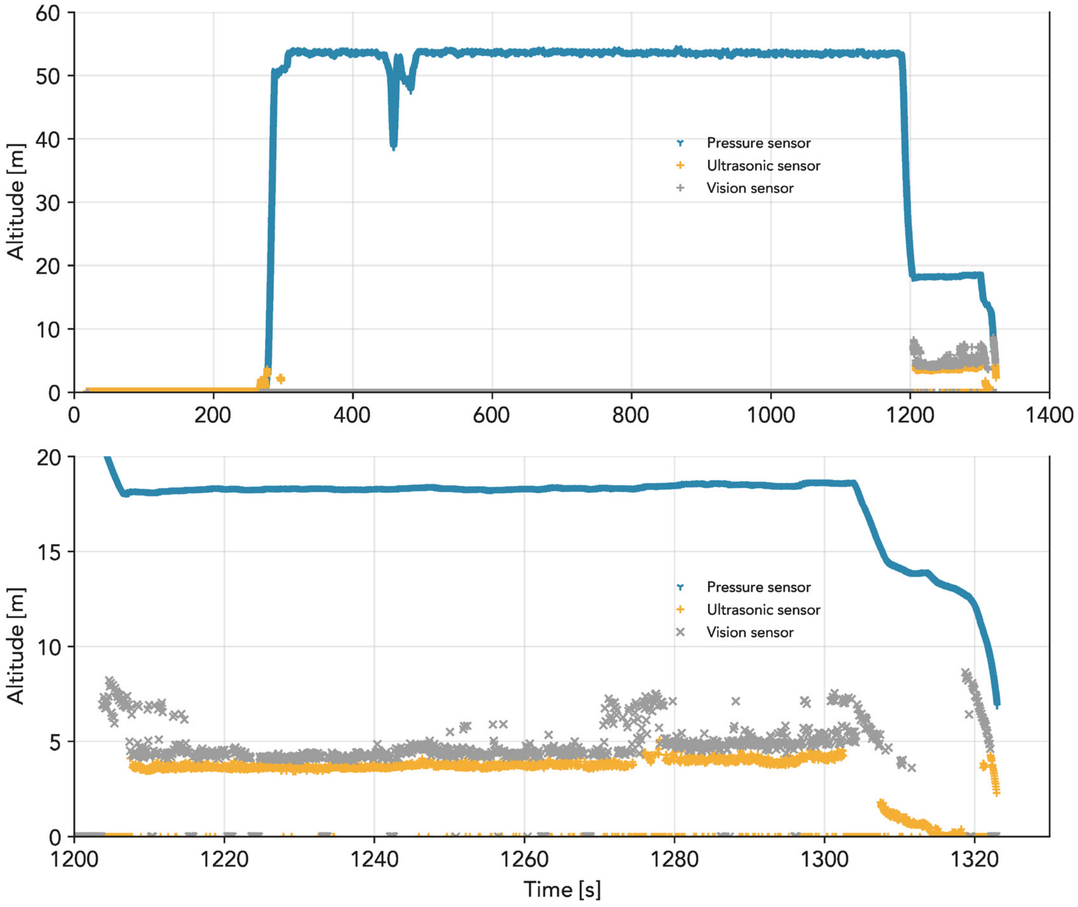

Figure 12: Time trace of the altitude (pressure sensor, ultrasonic sensor and vision based) for the complete flight (top) and final flight phase up to the crash (bottom).

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