ACCIDENT

Aircraft Type and Registration:	DJI Matrice 210 (UAS, registration N/A)
No & Type of Engines:	4 electric motors
Year of Manufacture:	2018 (Serial no: 0G0DF8F0240057)
Date & Time (UTC):	16 March 2019 at 1310 hrs
Location:	Temple Newsam, Leeds, Yorkshire
Type of Flight:	Commercial Operation
Persons on Board:	Crew - N/A Passengers - N/A
Injuries:	Crew - N/A Passengers - N/A
Nature of Damage:	Damage to rotor arms, propellers, and camera payload
Commander's Licence:	Not applicable
Commander's Age:	42 years
Commander's Flying Experience:	67 hours (of which 67 were on type) Last 90 days - 17 hours Last 28 days - 9 hours
Information Source:	Aircraft Accident Report Form submitted by the pilot and further enquiries by the AAIB

Synopsis

The DJI Matrice 210 small unmanned aircraft was being operated commercially to record video footage of an outdoor athletics event. The pilot started to position the aircraft back towards the landing site due to an increase in the rainfall. The pilot then saw the aircraft "wobble" slightly and as it neared the landing site it flipped over before descending rapidly to the ground from a height of about 3 m (10 ft). No one was injured. During the accident flight the aircraft had been operating at heights of up to about 30 m (100 ft) near to, and above people on the ground. This investigation reviewed other similar accidents and the risk of injury to people on the ground. Two Safety Recommendations are made to the UK CAA.

History of the flight

The DJI Matrice 210 small unmanned aircraft (SUA)[1] was being operated on a commercial[2] flight to record footage of an outdoor athletics event[3] that was taking place in the grounds of

Footnote

[1] A SUA is defined by the Air Navigation Order (ANO) 2016 (Amendment 13 March 2019) as '*any unmanned aircraft, other than a balloon or a kite, having a mass of not more than 20 kg without its fuel, but including any articles or equipment installed in or attached to the aircraft at the commencement of its flight*.' This meaning includes traditional remotely controlled model aeroplanes, helicopters or gliders, as well as multirotor 'drones' and remotely controlled '*toy*' aircraft.

[2] A commercial operation involves a flight or flights '*in return for remuneration or other valuable consideration*.' The full definition is available at http://www.legislation.gov.uk/uksi/2016/765/article/7/made [accessed November 2019].

[3] English schools cross country championship 2019.

Temple Newsam House, Leeds. The event was attended by several hundred competitors and spectators. There had been intermittent rain showers throughout the day and the wind was from the west at about 10 kt, with gusts of approximately 22 kt.

Prior to the event, attendees had been made aware of the planned operation of an unmanned aircraft system (UAS)[4] by providing details of the intended operation in the 'event application form' and by briefings on the day. The pilot[5] of the aircraft stated that he had liaised with the event safety officer and considered that attendees were:

> *'under my control as they were part of the event, briefed about the operation, and able to be informed if an emergency situation occurred via the event staff over the tannoys'* [public address system].

A cordoned takeoff and landing site (TOLS) situated away from the public area was used. The aircraft was flown three times in the morning, during which it had rained lightly for about 20 minutes. The pilot advised that since purchasing the UAS from new in August 2018, the aircraft had been operated in light rain on several occasions without incident.

At 1303 hrs the aircraft took off from the TOLS and was positioned overhead the venue at a height of about 30 m (100 ft) agl, where filming took place (Figure 1). During the initial part of the flight it had been raining "lightly" but after about six minutes the rainfall started to increase. The pilot then decided to position the aircraft back towards the TOLS, which was about 400 m away, whilst also descending the aircraft.

Whilst en route to the TOLS, the aircraft passed overhead people at a height of about 10 m (~30 ft) agl (Figure 2 and Figure 3). At some point during this period the pilot saw the aircraft do "a little wobble" and became concerned that there was a problem and stopped filming. As the aircraft approached the TOLS at a height of about 3 m (10 ft) agl it suddenly "flipped itself upside down and drove itself into the ground". No person was injured, but the aircraft was severely damaged. The recorded flight time was about eight minutes.

Footnote

[4] A UAS comprises a SUA with its controller..
[5] The ANO refer to a person in control of an unmanned aircraft as a remote pilot. In this report, the remote pilot is referred to as 'pilot'.

Figure 1
Footage from aircraft at a height of about 30 m (100 ft) agl

Figure 2
Footage taken whilst en route back to the TOLS

Figure 3
Footage captured one minute before the accident

UAS information

The Matrice 210 is a quadcopter aircraft with a maximum takeoff mass of 6.14 kg (Figure 4). With its flight controller, the aircraft forms a UAS. During the accident flight the mass was 4.97 kg, which included an underslung camera mounted on a gimbal and two TB55 batteries. The Matrice 210 forms part of the manufacturer's model range referred to as the Matrice 200 series.

Figure 4

RTK version of the Matrice 210
The accident aircraft was fitted with one camera and
did not have external GPS antennas attached (two white circular components)

Electronic Speed Controller

Each of the four propeller motors was controlled by an associated electronic speed controller (ESC) that was fitted in a chamber located below each motor (Figure 5). The ESC consisted of electronic components soldered to a circuit board that was connected to the motor and main body of the aircraft using a push-fit connector and soldered connections. Fitted to each ESC was a label (Figure 6) that changed colour if it was exposed to moisture or liquids. Moisture can result in erroneous operation or failure of electronic components and/or electrical connections.

To prevent moisture and dust[6] ingress into the ESC chamber the UAS manufacturer advised that most of the chamber was sealed using adhesive and gaskets, but the attachment holes and seam between the antenna case and lower chamber were not sealed. The

Footnote

[6] Particles of up to 1 mm in diameter (refer to later section on environmental protection).

manufacturer advised that they were working on an improvement to seal this area but did not confirm if this had been introduced on new aircraft, or if it would be offered as a retrofit for aircraft already in-service.

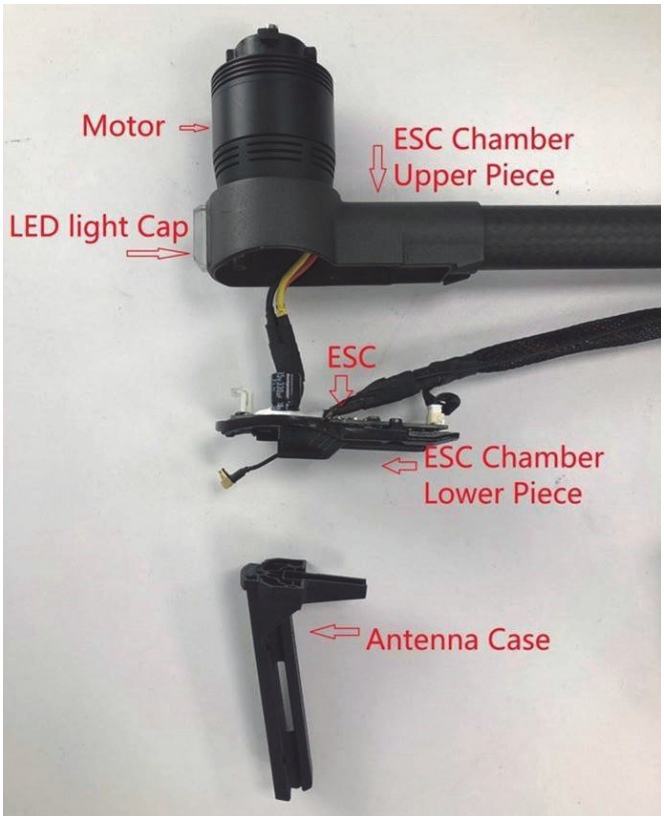

Figure 5
Motor, ESC, chamber and antenna

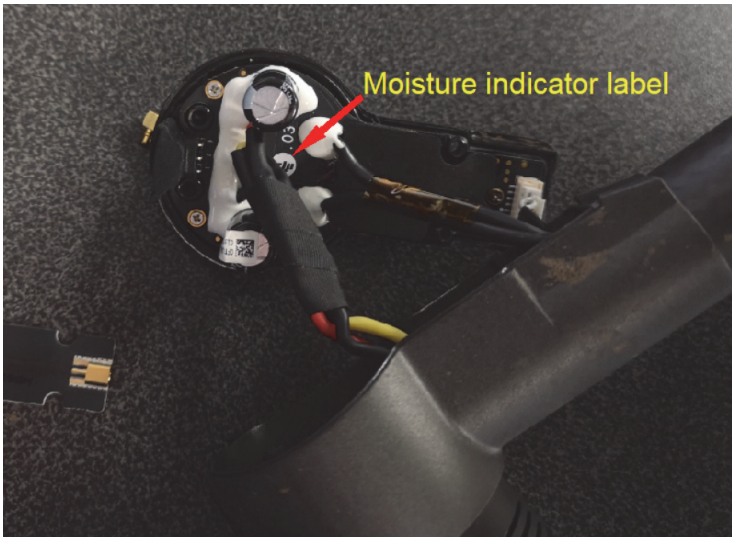

Figure 6
ESC moisture indicator position

Environmental protection

The UAS manufacturer stated that the Matrice 200 series had been tested to meet IP[7]43 standards, which included the following water and solid object ingress requirements:

- vertically dripping water shall have no harmful effect.
- vertically dripping water shall have no harmful effect when the enclosure is tilted at an angle up to 15° from its normal position.
- water falling as a spray[8] at any angle up to 60° from the vertical for a duration of 10 minutes shall have no harmful effect.
- Solid objects with a diameter of 1 mm or more should not be able to enter the unit.

During IP43 accreditation testing, the propeller motors were operated but the propellers were not fitted. The manufacturer advised that the facility that carried out the testing could not accommodate the aircraft when these items were fitted. The manufacturer subsequently carried out its own in-house test with the propellers fitted whilst water was sprayed onto the aircraft. The manufacturer stated that no moisture was subsequently found within the unit.

Information on the operation of the Matrice 200 series aircraft in rain was available on the manufacturer's website. In the FAQ (frequently asked questions) section it was stated that the '*IP43 protection rating allows the Matrice 200 series to maintain stable flight in light rain weather conditions (less than 10 mm/h rainfall)'*. The guidance also stated that in rain, the frame (motor) arms should not be folded and the aircraft should not be operated at pitch angles of more than 60°. Users were advised to use either a TB55 or TB50-M200 battery and not to use an external GPS module.

The manufacturer's website also provided thirteen[9] 'documents and manuals' relating to the operation of the Matrice 200 series aircraft. The '*User Manual*' and '*disclaimer and safety guidelines*'[10] manuals contained the following information:

- *'Under stable laboratory conditions, the Matrice 200 series achieves IP43 rating by IEC60529 standards when equipped with TB50-M200 or TB55 intelligent Flight Batteries. However, this protection rating is not permanent and may reduce over time after long-term use.*
- *DO NOT fly when the amount of rainfall exceeds 10 mm/h.'*

Footnote

[7] IP (International Protection Marking) IEC standard 60529 defines the degree of protection provided by mechanical casings and electrical enclosures against intrusion, dust, accidental contact, and water. The European equivalent standard is EN 60529.

[8] A spray nozzle is used with a flow rate of 10 litres per minute at a pressure of 50 to 150 kPa. The duration of the test must be one minute per square metre of surface or a minimum of five minutes.

[9] https://www.dji.com/uk/matrice-200-series/info [accessed September 2019]

[10] https://dl.djicdn.com/downloads/M200/20170926/M200_210_210-RTK+Disclaimer+and+Safety+Guidelines+V1.2.pdf [accessed September 2019]

Reference to the longevity of the IP43 protection was not included in the manufacturer's information, and no guidance was provided as to how to ascertain if the IP43 protection had degraded, or what was considered to be '*long-term use*' of the system, or how to determine if the level of rainfall exceeded the recommended operating limit of 10 mm/h.

In addition to the information provided by the manufacturer, one of its approved Enterprise[11] dealer's in the UK provided the following information on its website:

- *'The Matrice 200 is the first DJI platform to feature IP43 Ingress protection. In practice - this means the Matrice 200 will be fully protected when flying in wet conditions, either through precipitation or moisture in the atmosphere.'*

The UK Met Office use various gauges to measure rainfall and provided the following definitions (Table 1):

Rainfall type	Description	Rainfall category
Drizzle	Water droplet size of < 0.5 mm	Not applicable
Rain	Water droplet size of > 0.5 mm	Slight = < 0.5 mm/h Moderate = 0.5 to 4 mm/h Heavy = > 4 mm/h
Rain showers	Water droplet size of > 0.5 mm Precipitation from convective cloud (cumulus or cumulonimbus) and often characterized by short duration and rapid fluctuations of intensity	Slight = 0 to 2 mm/h Moderate = 2 to 10 mm/h Heavy = 10 to 50 mm/h Violent = > 50 mm/h

Table 1

UK Met Office rainfall description

UAS examination

The pilot sent the aircraft to an Enterprise dealer in the UK for examination. It was found that the No 3 motor ESC moisture indicator had been activated and evidence of liquid residue was found on the ESC circuit board (Figure 7).

The No 3 motor arm had remained intact following the accident and the pilot stated that the arms had never been folded since the aircraft had been purchased from new in August 2018. The remaining ESC's were inspected, but no evidence of moisture ingress was found.

The onboard recorded data contained fault messages that coincided with the loss of control of the aircraft. These messages referred to a No 3 motor ESC '*link down*' and a fault with the No 4 motor ESC. The manufacturer reviewed this data and advised its Enterprise dealer that the accident had been caused by a fault with the No 4 ESC. The aircraft was subsequently

Footnote

[11] A manufacturer approved dealer that has access to commercial UAS platforms and equipment.

sent to the manufacturer for further evaluation. At the time of report publication, no further information had been provided by the manufacturer on the cause of the No 4 ESC failure or if the moisture found on the No 3 ESC had caused this ESC to also fail.

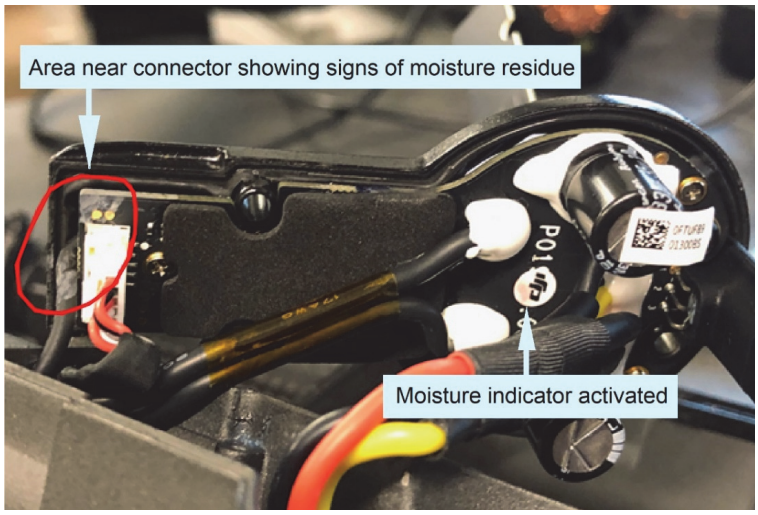

Figure 7

No 3 ESC from accident aircraft

UAS accidents

Matrice 200 series

The manufacturer provided information (Table 2) on the 'probable cause'[12] of 44 accidents involving the Matrice 200 series that had occurred internationally between October 2018 and March 2019. The manufacturer was asked to provide information on the number of Matrice 200 series aircraft sold in the UK and internationally, but this was not provided.

UAS component	Type of failure	Number of units	Percentage of units % (value is rounded)
ESC	Water damage	4	9
	Loss of PPM (pulse position modulation) signal	2	5
	Hardware damage	4	9
Non-ESC	Propeller motor	12	27
	Loss of propeller during flight	2	5
	Incorrectly installed propellers	1	2
	Propeller damage	1	2
	Excessive load/payload	1	2
	Unable to determine cause	17	39

Table 2

Manufacturer findings on Matrice 200 series failures

Footnote

[12] The manufacturer stated that the probable cause was identified by analysing the UAS and/or its recorded data. Where neither data nor the aircraft was available for evaluation, or where the results were inconclusive, 'educated guesses' were made as to the possible cause of the failure.

The manufacturer stated the following concerning ESC failures due to water ingress:

> *'Physical component analysis showed that water ingress points are close to the center part of the ESC board, which is close to the antenna, and damaged parts of the ESC are mostly located on the back side of the PCB board (the side of the antenna). Therefore, there is the possibility that water seeped in from the closing part of the antenna case. Water ingress will cause the ESC and other components to short circuit, causing complete damage and signal lost* [sic]*, or to send out abnormal signals causing abnormal motor behaviour* [sic]*, which may lead to an incident.'*

Non-ESC failures included malfunction of the propeller motors. The cause of these failures was considered by the manufacturer to have been caused by the motor either becoming 'clogged' by sand, dust or other small particles, or having been damaged prior to the accident, such as during a previous collision with a hard surface. The IP43 rating provided protection against entry of solid objects with a diameter of >1 mm but not smaller particles, such as dust or sand.

UAS accidents reported to the AAIB

Table 3 provides information on 59 UAS accidents[13] reported to the AAIB between February 2015 and 31 July 2019. This information included 18 accidents involving the Matrice 200 series aircraft.

UAS mass	Type of failure	Number of occurrences (all types)	Number of DJI Matrice 200 series occurrences
<20 kg	Technical fault resulting in loss of control of the aircraft	34	16
	Loss of aircraft control due to pilot action.	6	0
	CFIT[14]	5	1
	Mid-air collision	3	0
	Other[15]	4	1
>20 kg	Technical fault - resulting in loss of control of the aircraft.	3	
	Loss of control due to pilot action.	2	
	Other	2	

Table 3

UAS incidents and accident reported to AAIB between February 2015 and March 2019

Footnote

[13] The UAS was damaged during collision with the ground or water.

[14] CFIT - Controlled Flight Into Terrain – includes unplanned deviation from flight path due to excessive wind speed or gusts.

[15] Accidents caused by incorrectly fitted propellers and other causes.

Table 4 provides a detailed breakdown of the 16 Matrice 200 series accidents that involved technical failures.

Date	Location	UA Type	Description of accident	AAIB Bulletin Number	AAIB File Reference
20/12/2017	La Route de la Trinite, Jersey	Matrice 210	At a height of 84 m all four motors stopped and the UA fell to the ground due to a battery firmware issue.	10/2018	EW/G2017/12/07
18/07/2018	Keith, Aberdeenshire	Matrice 210 RTK	At a height of 25 m all four motors stopped and the UA fell to the ground due to a battery firmware issue.	11/2019	EW/G2018/07/43
04/09/2018	Tilbury Docks, London	Matrice 210	At a height of 20 m all four motors stopped and the UA fell to the ground due to a battery firmware issue.	11/2019	EW/G2018/09/04
15/10/2018	Brierley Hill, West Midlands	Matrice 210	At a height of about 50 m over a building the UA suddenly dropped vertically and struck the roof of the building. The No 4 ESC had failed. Light drizzle was reported.	01/2020	EW/G2018/10/23
20/10/2018	Manchester	Matrice 210 RTK	At a height of 80 m all four motors stopped and the UA fell to the ground due to a battery firmware issue.	11/2019	EW/G2018/10/09
26/10/2018	Ledbury, Herefordshire	Matrice 210	At a height of 4 m all four motors stopped and the UA fell to the ground due to a battery firmware issue.	11/2019	EW/G2018/10/17
14/01/2019	Colwyn Bay, Conway	Matrice 210 RTK	From a height of 70 m the UA entered a rapid uncontrolled descent until it struck the ground. The UA was overweight with a non-standard payload but cause unknown.	7/2019	EW/G2019/01/05
19/01/2019	Clevedon, Somerset	Matrice 210	From a height of 120 m the UA fell vertically to the ground while flying in light drizzle. The No 2 ESC had failed.	01/2020	EW/G2019/01/14
29/01/2019	Little Hulton, Manchester	Matrice 210	From a height of 69 m the UA entered a tight spiral descent to the ground. One motor had a propulsion error.	4/2019	EW/2019/01/02
18/02/2019	Feltham, London	Matrice 210	Following a loud mechanical noise the UA descended rapidly to the ground in light rain. The ESC had failed, possibly due to an earlier accident.	5/2019	EW/G2019/02/23
03/03/2019	Leicester	Matrice 210	From a height of 90 m the UA started spinning and rapidly fell to the ground. It was raining and the No 3 motor had failed.	01/2020	EW/G2019/03/03
16/03/2019	Temple Newsham, Leeds	Matrice 210	This report. Rapid descent from a height of 3 m in rain.	01/2020	EW/C2019/03/02
18/03/2019	Manchester	Matrice 210	At a height of 2 m the UA wobbled, slewed sideways and then struck the ground inverted. The manufacturer determined that a motor had failed.	01/2020	EW/G2019/03/08
20/04/2019	Dearne Old Moor, S. Yorkshire	Matrice 210	At a height of 5 m the UA became unstable and one of the motor arms broke causing the UA to drop to the ground. Data showed that the No 2 and No 3 motors had stalled. It could not be determined if this occurred before or after the arm failed.	01/2020	EW/G2019/04/14
11/06/2019	Hammon Court, Norfolk	Matrice 210	From a height of 80 m the UA started spinning and descended rapidly to the ground. Cause unknown.	01/2020	EW/G2019/06/08
28/07/2019	Chedburgh, Suffolk	Matrice 210	The aircraft dropped vertically from 71 m and hit a building, damaging its roof. There was light rain. The manufacturer reported an issue with the No 2 motor.	01/2020	EW/G2019/07/40

Table 4

Matrice 200 series UAS accidents reported to AAIB between December 2017 and July 2019 which involved technical failures (16 in total)

The majority of UAS accidents reported to the AAIB have involved quadcopters. In the event of a motor failure, the configuration of a quadcopter means it is unlikely to remain controllable. The evidence available to the AAIB shows that, in these cases, the UAS tumbles and falls rapidly to the ground. Where electrical power has been lost to all motors, the UAS will free fall to the ground.

UAS regulations

At the time of the accident the UK CAA defined three categories of UAS:

- *'20 kg or less - Small Unmanned Aircraft (SUA) - this class covered all types including traditional remotely controlled model aeroplanes, helicopters or gliders, as well as multirotor 'drones' and remotely controlled 'toy' aircraft. They were subject to some parts of UK aviation law, which is discussed in the following sections of this report.*
- *>20 kg to 150 kg - Light Unmanned Aircraft (LUA) - this class covered larger and potentially more complex types of unmanned aircraft (UA) and large model aircraft. They were subject to all aspects of UK aviation law, but exemptions could be granted to some requirements.*
- *Over 150 kg – aircraft operating within this class would normally be subject to the same level of regulatory approval requirement as would be used for traditional manned aircraft.'*

The CAA stated that they had not carried out a risk assessment concerning the overflight of people by an SUA. The Air Navigation Order (ANO) required a pilot operating a SUA (commercially or for private use) that was equipped to undertake any form of surveillance[16] or data acquisition to comply with the following requirements, unless in accordance with a permission[17] issued by the CAA:

- *'Must not operate an aircraft over or within 150 metres of any congested[18] area;*
- *Must not operate an aircraft over or within 150 metres of an organised open-air assembly of more than 1,000 persons;*
- *Must not operate an aircraft within 50 metres of any vessel, vehicle, structure or person which is not under the control of the pilot of the aircraft;*
- *Must not operate an aircraft within 30 metres of any person (except the pilot) during takeoff or landing unless a person is under the control of the pilot.'*

Footnote

[16] An aircraft fitted with a camera or other sensor that can collect information.

[17] The CAA advised that if a pilot wanted to operate a SUA closer to people (not under the control of the operator) than the limits set out in the ANO article 95, an operating safety case with appropriate mitigating actions would need to be submitted and agreed with the CAA.

[18] The ANO defines a congested area '*in relation to a city, town or settlement, means any area which is substantially used for residential, industrial, commercial or recreational purposes*'.

The ANO also included several articles relevant to the safe operation of a UAS, which included:

- Article 241 '*a person must not* recklessly *or negligently cause or permit an aircraft to endanger any person or property*'
- Article 94 '*(2) The remote pilot of a small unmanned aircraft may only fly the aircraft if reasonably satisfied that the flight can safely be made'*

On 11 June 2019 regulations relating to the harmonized use of UAS within Europe were published. This contained the following regulations (the CAA has also issued CAP1789[19] that summarises these):

- Commission Implementing Regulation (IR) (EU) 2019/947 on the procedures and rules for the operation of a UA.
- Commission Delegated Regulation (DR) (EU) 2019/945 on a UA and on third country operators.

The DR became applicable on 1 July 2019 and the IR becomes applicable on 1 July 2020.

Operations of UAS will then be placed into one of three categories:

- *'Open category (less than 25 kg) – operations that present a low (or no) risk to third parties. Operations are to be conducted in accordance with basic and pre-defined characteristics and are not subject to any further authorisation requirements. The open category is divided into operational 'subcategories' A1, A2 and A3. Within each subcategory are classes of UAS that include C0, C1, C2, C3 and C4 (Table 4).*
- *Specific category – operations that present a greater risk than that of the open category, or where one or more elements of the operation fall outside the boundaries of the open category. Operations will require an operational authorisation from the national aviation authority (i.e. the CAA in the UK) based on a safety risk assessment.*
- *Certified category – operations that present an equivalent risk to that of manned aviation and will be subject to the same regulatory regime (i.e. certification of the aircraft, certification of the operator, licensing of the pilot).'*

Footnote

[19] Available from https://www.caa.co.uk/Our-work/Publications/Publications/ [accessed September 2019]

Operation		UAS			UAS Operator	Remote pilot	
Subcategory	Operating Area	Class	Mass/KE/Speed	Operating Date limitations	Registration	Min Age (solo flight)	Competency
All	- Max height 120m/400ft (see UAS.OPEN.010 [3] & [4] for specific obstacle and sailplane limits) - No dropping of articles - No carriage of dangerous goods					If directly supervising another remote pilot - 16	
A1	Fly over uninvolved people, but not over crowds	Privately built	<250g and <19m/s	Nil	Only if 'camera' equipped (but not toys)	Nil	Read user manual
		Legacy (placed on market before 1 Jul 22)	<250g			UK – 12 EU – 16 (unless reduced in State)	
		C0 (toy)	<250g and ≤19m/s			Nil	
		C0 (not a toy)				UK – 12 EU – 16 (unless reduced in State)	User manual - Online training - Online (foundation) test
	No intentional flight over uninvolved persons	C1	<900g or <80 J	Nil	Yes	UK – 12 EU – 16 (unless reduced in State)	- User manual - Online training - Online (foundation) test
		A1 Transitional (Article 22)	<500g	Not after 30 Jun 22			To be defined by the State
A2	No closer than 30m horizontally from uninvolved persons (5m in 'low speed' mode)	C2 (can also be used in A3)	<4kg	Nil	Yes	UK – 12 EU – 16 (unless reduced in State)	- User manual - Online training - Online (foundation) test - Self-practical training - A2 CofC Theoretical test
	No closer than 50m horizontally from uninvolved persons	A2 Transitional (Article 22)	<2kg	Not after 30 Jun 22			
A3	- No uninvolved people present within the area of flight - No flight within 150m horizontally of residential, commercial, industrial or recreational areas	C3	<25kg	Nil	Yes	UK – 12 EU – 16 unless reduced in State)	- User manual - Online training - Online (foundation) test
		C4					
		Privately built					
		Legacy (placed on market before 1 Jul 22)					
		A3 transitional (Article 22)	>2kg to <25kg	Not after 30 Jun 22			

Table 5

CAP 1789 Annex C, open category and subcategories A1, A2 and A3

The open category is expected to apply to hobbyist users and some commercial operators. In this category, only a UA with a mass of less than 250 grams and, for UA's introduced after 1 July 2022, a maximum velocity of 19 m/s, is permitted to fly over '*uninvolved people'* but it must never be flown over an assembly of people (crowd). A UA of 250 grams or more must not be flown over '*uninvolved people*'.

The Europen Union (EU) implementing regulations define uninvolved people as '*persons who are not participating in the UA operation or who are not aware of the instructions and safety precautions given by the UA operator*'. In order to be an involved person, they need to have been given explicit consent to be part of the UA operation and have received some form of safety precautions/instructions.

The definition provided in the EU Implementing regulations for an assembly of people (crowd) is '*gatherings where persons are unable to move away due to the density of the people present'*.

The CAA also provided the following clarifications to the AAIB:

- Informing an assembly of people, such as at a concert, that a UA will be flying overhead is not sufficient and these people would be considered to be 'uninvolved'.
- In the A1 subcategory, a UA must never overfly an assembly of people (either involved or uninvolved).

The specific category will typically apply to commercial operations in the UK. This category introduces the concept of 'standard scenarios' of use, for which a risk assessment has already been made and mitigating safety actions provided relative to the task involved.

If a scenario matches the intended task, the operator will make a statement of declaration to the CAA that includes the need to comply with any mitigating safety actions. If the intended task is not covered by the scenarios, the operator is required to carry out a risk assessment and apply to the CAA for operational authorisation. The scenarios are expected to be published by the European Commission (EC) in early 2021. Discussions with the CAA indicate that one of several mitigating actions could include the fitment of an aircraft parachute recovery system.

The EU regulations also make provision for an optional light UAS operator certificate (LUC) scheme, which allows the CAA as a national aviation authority to issue privileges to UAS operators, including the possibility of authorising their own operations.

CAA guidance on UAS overflight of people, built-up areas and crowds

In October 2019, the CAA published The Drone and Model Aircraft Code[20]. This provided the following guidance on operating a UAS of 20 kg or less near to people:

- *'Never fly closer to people than 50m. Even when your drone is more than 50m away from people, it's safer to avoid flying or hovering directly over them. You're responsible for flying safely whenever you fly.'*

The code also included the following examples of built-up and busy areas, and where crowds of more than 1,000 people shall not be flown near to or over by a UAS of 20 kg or less.

- *'cities and towns, villages, beaches and recreational parks that are part of a city, town or village, housing estates, schools and offices, retail, warehouse, industrial and business parks, theme parks, sports events, music festivals or concerts, marches or rallies or carnivals.'*

UAS design, production and maintenance

A SUA (a mass of 20 kg or less) operating in the UK does not require airworthiness approval or require CAA oversight of its design, production or maintenance. However, manufacturers can declare that their UAS meets European Standards (EN). Relevant EN's include 60950-1 and 62311:2008 that include risk of fire, electric shock or injury to the operator and exposure to electromagnetic fields. The manufacturer of the Matrice 200 series had declared that it was compliant with six EN's, however EN's do not assure product reliability or that a fault will not cause loss of control of the aircraft.

The rules introduced in DR 2019/945 and IR 2019/947 require that a UAS operating in the open category will be subject to a set of product standards similar to the 'Conformité Européene (CE)'[21] marking scheme. It will require that all UAS operating in this category must be marked with the appropriate UAS class number (C0, C1, C2, C3 or C4) by 01 July 2022. A UAS sold for use in the specific category will come under a different set of requirements that are still to be developed, but have been outlined as being:

- set out in the operational authorisation issued to the operator;
- set out in the standard scenario that the operator has declared will be used;
- set out in the LUC.

The regulations also introduce transitional arrangements that enable a UAS that does not comply with the new requirements to continue to be operated, but under a more restrictive set of requirements concerning flight near to people.

Footnote

[20] https://register-drones.caa.co.uk/drone-code [accessed November 2019]

[21] Conformité Européene means European Conformity and by affixing the CE marking to a product, a manufacturer declares that the product meets all the legal requirements for CE marking and that it can be sold throughout the European Economic Area (EEA). CE marking applies to products made in Europe and other countries that are sold in the EEA

Overflight of people and property by manned aircraft

Prior to 2010, Permit to Fly manned aircraft, under the conditions of their permit, were not allowed to fly over congested areas. This was understood to have been put in place as the airworthiness of aircraft in this category were not considered to have been to an equivalent standard as aircraft with a Certificate of Airworthiness. In 2007, The Popular Flying Association made a recommendation to the CAA asking for the restriction to be removed. The recommendation was supported by a safety case that showed Permit to Fly aircraft were not a higher risk than Certificate of Airworthiness aircraft.

In July 2010, CAA exemption (E3175) was issued to allow certain permit aircraft (microlight aeroplanes, amateur-built aeroplanes up to 1,500 kg, and factory-built aeroplanes up to 1,500 kg that were previously on a Certificate of Airworthiness) to overfly congested areas, subject to the normal rules of the air. These rules included retaining the capability of a single engine aircraft to glide clear and maintain minimum clearances with obstacles. The exemption did not apply when test flying or check-flying the aircraft. In February 2012, the exemption was superseded by Information Notice IN-2012/003 which made the arrangement permanent.

Risk of injury due to falling objects

The AAIB is not aware of any research relating to the potential for injury from a falling UAS. However, in the 1990's a dropped object prevention scheme (DROPS)[22] was introduced as part of a safety initiative by the UK Oil and Gas industry. The program has since expanded to include about 200 organisations, with the development of a DROPS analysis tool. This tool provides an indication as to the possible[23] outcome of a blunt object in free fall striking a person wearing personal protective equipment (i.e hard hat, eye protection).

Analysis using the DROPS calculator[24] indicated that a blunt object with a mass of 4.97 kg (the mass of the accident aircraft) falling from a height of more than about 3 m (~10 ft) agl could result in a fatal injury to someone wearing a hard hat. It also indicated that a 1 kg blunt object could cause a fatal injury from a height of 11 m.

The rules introduced by DR 2019/945 and IR 2019/947 for the open category state that aircraft able to impart 80 joules of kinetic energy shall not be operated intentionally over '*uninvolved people*'. The kinetic energy of the accident aircraft in free fall from about 3 m (10 ft) would be about 140 joules.

A Matrice 200 series aircraft in free fall from a height of 50 m (164 ft) would take about three seconds before it reached the ground. At its maximum takeoff mass, which was 6.14 kg,

Footnote

[22] https://www.dropsonline.org/ [accessed September 2019]

[23] It is not possible to be definitive due to varying factors such as where an object strikes a person or if it penetrates the body.

[24] https://www.dropsonline.org/resources-and-guidance/drops-calculator/e-drops-calculator/ This calculator calculates the potential energy of an object (Mass(m) x Height(h) x Gravitational Acceleration). The DROPS Calculator is a guide only and is intended to give a general idea of the potential severity of a dropped object. [accessed September 2019]

the aircraft would have a kinetic energy of approximately 3,000 joules when it reached the ground. Reducing this height to 30 m (~100 ft), it would take about 2.5 seconds for the aircraft to reach the ground and impart about 1,800 joules.

Analysis

Failure of DJI Matrice 210 SUA at Temple Newsam

The manufacturer stated that the accident had been caused by the failure of the No 4 ESC, but no information was made available as to why this component had failed. When the No 4 ESC had failed, a No 3 ESC '*link down*' message was also recorded. The manufacturer did not confirm what this message meant, or if this ESC had also failed.

Subsequent inspection of the aircraft found that moisture had entered the No 3 ESC chamber and residue was present on the ESC circuit board. No evidence of moisture was found on the other ESC's. Since owning the aircraft from new, the pilot had followed the manufacturer's guidelines to prevent moisture entering the aircraft and during the accident the No 3 motor arm had remained intact. It is therefore more likely that the moisture entered the No 3 ESC chamber during the last three minutes of the accident flight when the rainfall increased rather than during previous operation or following the accident.

The lower section of the ESC chambers adjacent to the antennas were not sealed and this could have provided an entry path for rainwater. The IP 43 accreditation testing was also not performed with the propellers installed and so it is possible that these tests did not fully reflect in-service operation in rain. It is also possible that rainwater entered the unit due to rainfall exceeding the manufacturer's limitation of 10 mm/h or that the IP 43 protection had degraded over time.

Although it was not confirmed if moisture ingress caused this accident, information shows that other Matrice 200 series accidents have been caused by moisture entering the aircraft. The manufacturer's analysis also showed that 27% of accidents were attributed to a loss of propeller motor propulsion that were for reasons other than a fault with the ESC. The manufacturer did not provide guidance on ascertaining if the rainfall exceeded limitations, or the duration that the IP 43 protection may remain in place. It is therefore possible that pilots of the Matrice 200 series could operate the aircraft in rain without knowing that it could result in the loss of control of the aircraft due to moisture ingress. The following Safety Recommendation is therefore made:

Safety Recommendation 2020-001

It is recommended that the Civil Aviation Authority notify users of the DJI Matrice 200 series of the possibility of moisture entering the aircraft when operating in rain and that this could result in a sudden loss of control of the aircraft.

Operation of UAS over persons

The ANO allows a UA with a mass of up to 20 kg to be flown over assemblies of up to 1,000 people as long as the aircraft maintains a height of at least 50 m. UA's such as the DJI Matrice 200 series rely upon their propulsion system for lift. If propulsion is lost, aircraft of this type typically fall vertically to the ground. From a height of 50 m, the descent would take about three seconds, which would provide limited time for a pilot to warn people and for them to take avoiding action if possible. The risk of injury to a person on the ground if struck by a falling UA is high, with the DROPS analysis indicating that a UA with a mass of only a few kg falling from a height of just several metres could result in a serious or even fatal injury.

In accordance with the ANO, a person must not 'permit an aircraft to endanger any person' and may only fly the aircraft 'if reasonably satisfied that the flight can safely be made'. It is therefore up to the operator or remote pilot to decide if flying a UA over people will endanger them. However, there is no guidance available from the CAA on how to make that assessment. This could include consideration of standards of safety, reliability, UA mass and type, the operational environment and whether any secondary safety systems are fitted.

IR (EU) 2019/947 is due to come into force in July 2020 and will require that a UA operating in the open category with a mass of more than 250 grams must not be flown over 'uninvolved persons'. If operating a UA in the specific category, the operator will need to comply with mitigating safety actions to prevent injury to people. However, these actions are not due to be published by the EC until 2021 which leaves an unresolved hazard prior to publication. The following Safety Recommendation is therefore made:

Safety Recommendation 2020-002

It is recommended that the Civil Aviation Authority specify the conditions that must be met for an unmanned aircraft to be flown safely over people.

Conclusion

The DJI Matrice 210 crashed whilst operating in rain. The manufacturer stated that the accident had been caused by a fault with the No 4 motor ESC. Moisture was also found on the No 3 motor ESC, but it was not established if this contributed to the accident. However, information showed that other Matrice 200 series accidents involving aircraft operating in rain had been caused by ESC failures due to moisture ingress. Other types of DJI Matrice 200 series failures included contamination of the motors by fine particles that the IP43 rating did not provide protection against.

Failures of the Matrice 200 series aircraft resulted in a loss of power and control, with the aircraft typically falling vertically to the ground. This poses a risk of injury to people on the ground which is not mitigated by the current UK regulations or the published guidance material. To address this, two Safety Recommendations have been made to the CAA.