ACCIDENT

Aircraft Type and Registration:	DJI Phantom 4 RTK (UAS, registration n/a)
No & Type of Engines:	4 electric motors
Year of Manufacture:	2020 (Serial no: 0V2GDC6RA30246)
Date & Time (UTC):	2 December 2020 at 1209 hrs
Location:	Newtongrange, Dalkeith, Midlothian
Type of Flight:	Commercial Operations (UAS)
Persons on Board:	Crew - N/A Passengers - N/A
Injuries:	Crew - N/A Passengers - N/A
Nature of Damage:	Damage to motors, propellers, arms, landing gear and fuselage
Commander's Licence:	Other
Commander's Age:	50 years
Commander's Flying Experience:	98 hours (of which 98 were on type) Last 90 days - 5 hours Last 28 days - 2 hours
Information Source:	AAIB Field Investigation

Synopsis

The UAS, a DJI Phantom 4 RTK, was being operated in an automated flight mode to survey a railway track and surrounding infrastructure when one of the four propellers detached whilst in-flight. The aircraft rapidly descended from a height of 70 m (230 ft) where it struck the ground in the rear garden of a house. No persons were injured.

This investigation has reviewed the new UAS regulations introduced on 31 December 2020 concerning the safe overflight of people and data available to assist in risk assessments. Two Safety Recommendations are made to the UK CAA.

History of the flight

The UAS, a DJI Phantom 4 RTK, was being operated commercially[1] to capture survey data of a railway track and adjacent infrastructure near to Newtongrange railway station. This was part of an extensive survey of approximately 45 km of railway track between the towns of Newcraighall, located to the north of Newtongrange, and Tweedbank to the south. This work was to be completed in separate phases, with the first phase taking

Footnote

[1] A commercial operation involves a flight or flights 'in return for remuneration or other valuable consideration'. The full definition is available at https://www.legislation.gov.uk/uksi/2016/765/article/7/made [accessed 28 February 2021].

place between Newcraighall and Newtongrange. The survey work was being conducted on behalf of Network Rail[2].

On the day of the accident, the aircraft was being flown from two different takeoff and landing sites (TOLS). There was no precipitation and the visibility was 10 km with the wind from a south-westerly direction at about 11 kt. The aircraft was flown using its automated flight mode[3] whilst remaining within visual line of sight (VLOS) of the pilot and at a horizontal range of less than 500 m. The pilot was also accompanied by an observer. Having successfully completed two flights, the UAS was shut down and the aircraft, with its propellers removed, was placed into its transport case. The pilot and observer then drove to the next TOLS, which was located in the carpark of Newtongrange railway station.

The propellers were refitted to the aircraft and a flight lasting about 20 minutes was successfully completed. The battery was then replaced with a fully charged unit before the aircraft took off at 1149 hrs for the next flight (Figure 1). This included overflying the railway track, adjacent industrial buildings, and a housing estate at a height of about 55m (180 ft) agl before landing back at the TOLS at 1200 hrs.

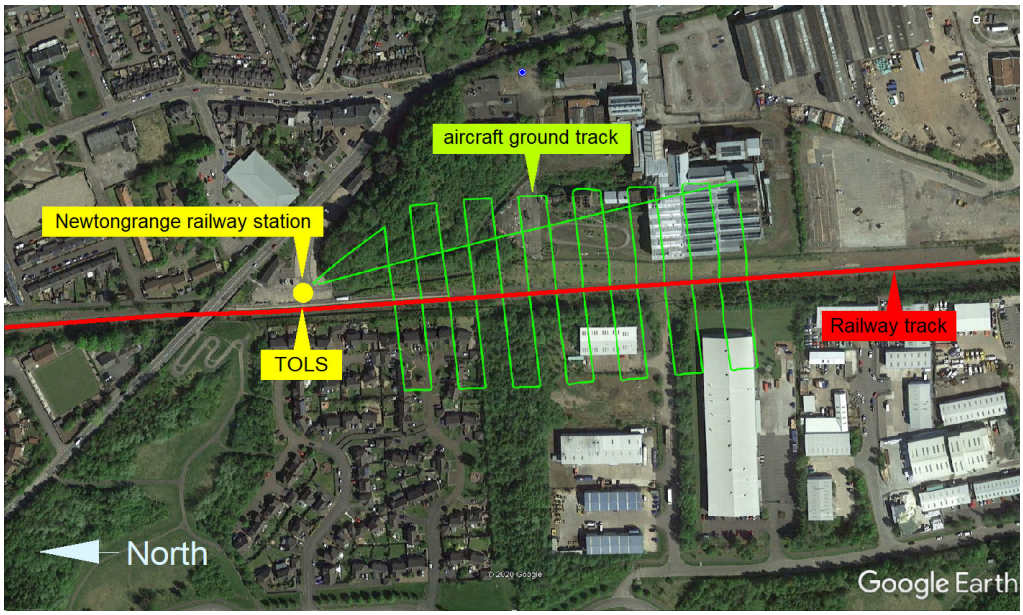


Figure 1

Aircraft ground track prior to the accident flight
© 2020 Google, Image © Maxar Technologies

The pilot, having checked that the aircraft battery had sufficient charge, then programmed the next flight route. This was for the aircraft to fly at a height of about 70 m (230 ft) agl, whilst remaining approximately overhead the railway track. The route would take the aircraft initially to the south of the TOLS, and then to the north before returning to land.

Footnote

[2] Network Rail owns, operates, and develops Britain's State railway infrastructure.
[3] In automated flight mode the aircraft can take off, fly between preset positions and then land without the intervention of the pilot.

The aircraft took off at 1206 hrs (Figure 2) and followed the programmed route, whilst the pilot and observer monitored its progress. At 1209 hrs, the aircraft reached its northerly turning point, where it slowed and commenced its turn back towards the TOLS. This coincided with the aircraft's camera capturing a survey photograph of the railway track and houses below (Figure 3). Shortly after this, the pilot reported that the UAS controller emitted a short "beep". Whilst the observer continued to watch the aircraft, the pilot checked the controller, but no error messages were displayed. The aircraft then rapidly descended vertically. As the aircraft neared the ground, the pilot and observer lost sight of it and, shortly after, a series of error messages were displayed on the controller.

The observer stated that, as the aircraft had descended, it appeared as though the "aircraft's motors had stopped and that it was on its back in free fall".

The pilot and observer subsequently found the aircraft in the rear garden of a terrace house (Figure 3) about 20 m from the railway track and below where the loss of control had occurred. The house was part of a large, densely populated housing estate and there were no people in the garden when the accident occurred. However, when the overhead image (Figure 3) was taken, a member of the public was 10 m from where the aircraft subsequently struck the ground.

The aircraft's motors, propellers, arms, landing gear, camera and fuselage were damaged (Figure 4). Inspection of the aircraft's battery shortly after the aircraft was found, showed that it had about 50 % charge remaining. The left rear propeller had detached and was not found.

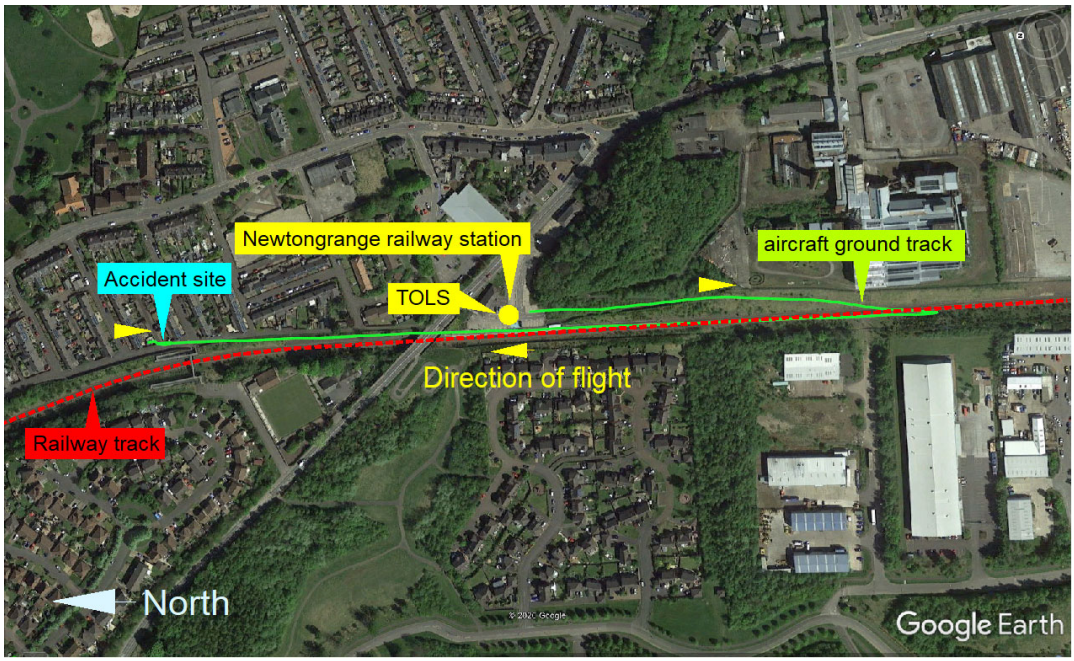


Figure 2

Aircraft ground track during the accident flight
© 2020 Google, Image © Maxar Technologies

Figure 3

Image captured by the aircraft shortly before the loss of control

Figure 4

Aircraft after being recovered from garden

Recorded information

A recorded log of the accident flight was downloaded from the aircraft by the operator and provided to the AAIB and the aircraft manufacturer. This indicated that, just after the aircraft had completed its turn back towards the TOLS, the left rear motor had suddenly increased to its maximum speed. This coincided with the aircraft rapidly spinning and tumbling whilst descending vertically to the ground. The aircraft's four motors continued to operate as it descended.

The data indicated that, from a height of about 60 m, the aircraft descent rate increased beyond that associated with free fall. This was because of thrust from the propellers whilst the aircraft was inverted. The final speed of the aircraft at impact was estimated to have been 36 m/s (~70 kt) and its kinetic energy was about 900 Joules[4].

UAS information

The DJI Phantom 4 RTK is a quadcopter aircraft and has a maximum takeoff mass of 1.391 kg (Figure 5). The accident aircraft had been purchased new in October 2020 by the operator and had accumulated four hours of flight time. There are several versions of the DJI Phantom 4, of which the RTK provided enhanced GPS capability.

The design of the aircraft allows for its propellers to be quickly fitted and removed. This is accomplished by a 'push, twist and release' process that engages and disengages the propeller hub with the motor locking mechanism. The aircraft manufacturer recommended that the propellers were removed when transporting the aircraft.

The manufacturer provided online guidance to assist operators in checking their aircraft, which included a visual inspection of it and its propellers for signs of damage. The manufacturer did not provide a maintenance schedule, such as if, or when, parts of the aircraft may require routine servicing or replacement.

Figure 5

Phantom 4 RTK and controller

Footnote

[4] The Joule is a unit of energy equal to the work done by a force of one newton acting through one metre.

UAS examination and fault analysis

The operator notified the AAIB of the accident on 11 December 2020. Prior to notifying the AAIB, the operator had sent the aircraft wreckage to a dealer in the UK, who forwarded it to the aircraft manufacturer's facility in the Netherlands. The aircraft was repaired by the manufacturer shortly after receiving it and returned to the operator.

The manufacturer analysed the flight log and stated that the loss of control had occurred because the left rear propeller had detached in flight.

The AAIB asked the manufacturer if the accident aircraft had been subject to a detailed inspection to identify why the propeller may have detached. The manufacturer did not confirm if they had inspected the aircraft in detail, but referring to the in-flight loss of propellers, they stated that they had '*currently not seen any recurring pattern of similar cases*'.

UAS accidents reported to the AAIB

Between February 2015 and January 2021, the AAIB received 190 notifications of incidents involving UAS. This included 73 accidents where a loss of control occurred, of which 69 aircraft had a maximum takeoff mass (MTOM) of less than 25 kg. These accidents had occurred to a number of different manufacturers and models of UAS.

17 accidents involved DJI Phantom 4s, of which nine were reported in 2020. This included an accident on 1 December 2020 involving a RTK model, for which the pilot attributed the cause to a possible propeller failure or in-flight loss of a propeller. The AAIB also identified information on the internet indicating another in-flight loss of a propeller from a DJI Phantom 4 RTK.

UAS loss of control accidents resulting in injury to people

The Australian Transport Safety Bureau (ATSB) is investigating an accident involving a DJI Inspire 2 UAS that occurred on 15 January 2021 at Darling Harbour, New South Wales, Australia. The initial ATSB report[5] states that while conducting aerial photography, the aircraft was flown to approximately 10 m above ground level when the pilot reportedly lost control of the aircraft. The aircraft flew away and subsequently collided with the window of a building, causing it to break. A person in the building sustained minor injuries. The ATSB has indicated that the final report will be published during Q3 of 2021.

Operational requirements and UAS regulations

UAS regulations prior to 31 December 2020

At the time of the accident, any person or organisation commercially operating a UAS aircraft in the UK with a mass of no more than 20 kg[6] required permission from the CAA. This permission was commonly referred to as Permissions for Commercial Operations (PfCO).

Footnote

[5] https://www.atsb.gov.au/publications/investigation_reports/2021/aair/ao-2021-001/ [accessed 28 February 2021].

[6] The ANO refers to a UAS falling into this category as a Small Unmanned Aircraft (SUA).

The applicant for a PfCO needed to show pilot competence and provide an operations manual, which detailed the scope of the organisation and the procedures to be followed.

The operator of the accident UAS held a PfCO and had several trained pilots that operated under this permission. It also operated another DJI Phantom 4 RTK, a DJI Matrice, DJI Inspire (quadcopters) and a WingtraOne (fixed-wing, vertical takeoff and landing) aircraft.

The operator's PfCO included a requirement to report an accident within 72 hours of occurrence, and its operations manual referred to reporting all accidents and incidents to the AAIB.

The operator had permission to overfly uninvolved persons[7] with their UAS, as long as it was no closer than 50 m to them (except that during takeoff and landing this distance could be reduced to 30 m). However, this does not absolve the operator of its responsibilities under the ANO regarding overflight, which included 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'*[8]. To assist operators in this matter, the CAA published Safety Notice SN-2020/002[9] in January 2020. This provided guidance and best practice information for operators to consider when overflying uninvolved persons.

SN-2020/002 included the following guidance:

- 'Only fly directly over people when absolutely necessary to achieve the aim of the flight, and minimise the time doing so.'
- 'When flying over uninvolved people remote pilots should, whenever reasonably possible, maintain some horizontal separation between their aircraft and those uninvolved people.'
- 'Wherever reasonably possible, consider the use of technologies such as…… use of ballistic recovery system (e.g. parachutes) to reduce the risk of harm to uninvolved people following a loss of control of the small unmanned aircraft.'

Risk assessment

The operator of the accident UAS had produced a risk assessment and method statement for the survey flights it intended on making between Newcraighall and Newtongrange. This included the use of its DJI Phantom 4 RTKs, DJI Matrice and WingtraOne UAS. The risk assessment used a 5x5 matrix and incorporated an assessment of the failure of the aircraft (Figure 6).

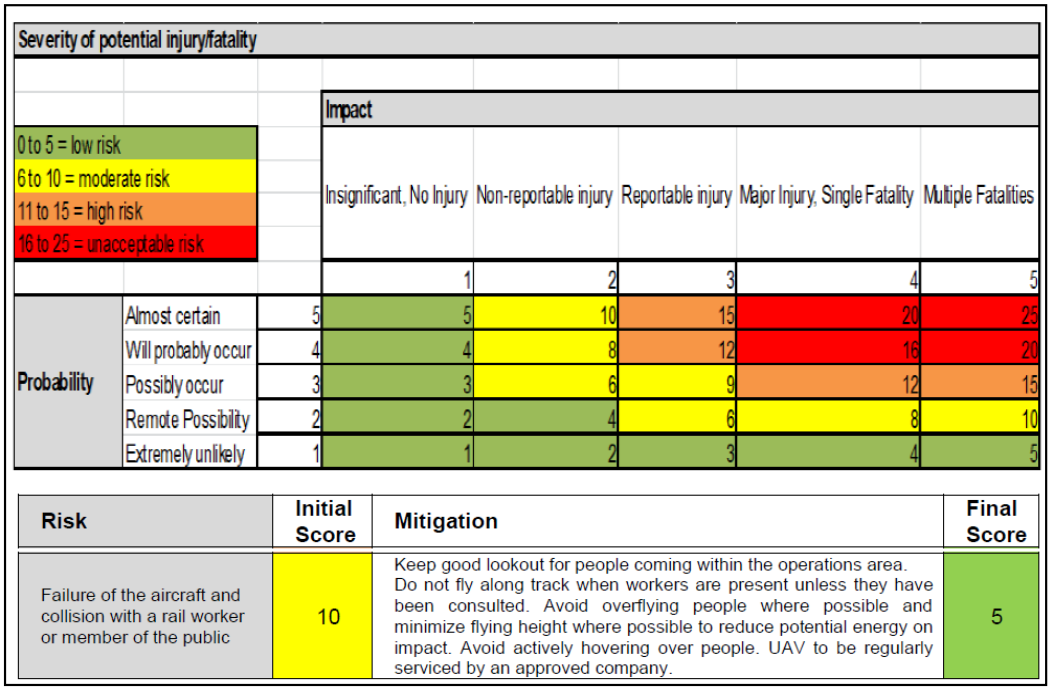
The operator's initial risk score of ten (moderate) concerning the potential failure of the aircraft was not based on published failure rates for the types of UAS it operated, as the operator

Footnote

[7] People that are not a part of the flying operation (ie third parties). This includes people in the open and occupants of any vehicle, vessel or structure.
[8] A small unmanned aircraft was an aircraft of a mass of 20 kg or less.
[9] https://publicapps.caa.co.uk/docs/33/SafetyNotice2020002.pdf [accessed 28 February 2021].

did not have access to such information. Instead, the operator had used an assumed value based on an awareness of previous UAS incidents, which included a UAS flyaway incident[10] that occurred to a different operator whilst surveying Network Rail infrastructure.

To reduce the risk of colliding with people and causing injuries that could be fatal, the operator cited several mitigations. These included minimising overflight of uninvolved persons. However, discussions with the operator indicated that it was not always practicable to achieve this, as the flights could often take place in densely populated (congested) areas. Discussions with other commercial operators also indicated similar difficulties. The operator considered that its stated mitigations would result in a final risk score of five (low risk).



Severity of potential injury/fatality

0 to 5 = low risk 6 to 10 = moderate risk 11 to 15 = high risk 16 to 25 = unacceptable risk			Impact				
			Insignificant, No Injury	Non-reportable injury	Reportable injury	Major Injury, Single Fatality	Multiple Fatalities
			1	2	3	4	5
Probability	Almost certain	5	5	10	15	20	25
	Will probably occur	4	4	8	12	16	20
	Possibly occur	3	3	6	9	12	15
	Remote Possibility	2	2	4	6	8	10
	Extremely unlikely	1	1	2	3	4	5

Risk	Initial Score	Mitigation	Final Score
Failure of the aircraft and collision with a rail worker or member of the public	10	Keep good lookout for people coming within the operations area. Do not fly along track when workers are present unless they have been consulted. Avoid overflying people where possible and minimize flying height where possible to reduce potential energy on impact. Avoid actively hovering over people. UAV to be regularly serviced by an approved company.	5

Figure 6

Operator's risk assessment of aircraft failure and mitigating actions

UAS regulations in the UK from 31 December 2020

New UAS regulations in the UK were introduced on 31 December 2020. These were adopted from Commission Implementing Regulation (IR) (EU) 2019/947 and Commission Delegated Regulation (DR) (EU) 2019/945 to harmonize UAS regulations within Europe. This included the following three categories under which a UAS is to be operated:

- 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 predefined characteristics and are not subject to any further authorisation requirements. The Open category is divided into operational

Footnote

[10] https://assets.publishing.service.gov.uk/media/5f3beeabd3bf7f1b17facec6/Aerialtronics_Altura_Zenith_ATX8_na_011019_05-20.pdf [accessed 28 February 2021].

subcategories A1 (fly over people), A2 (fly near to people) and A3 (fly far from people). Within each subcategory are five classes of UAS which are C0, C1, C2, C3 and C4.

- 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 CAA 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 (ie certification of the aircraft, certification of the operator, licensing of the pilot).

The Open category will apply to hobbyist users and some commercial operators. In this category, only an aircraft with a mass of less than 250 grams and, for aircraft introduced after 1 July 2022, a maximum velocity of 19 m/s, is permitted to fly over uninvolved persons but it must never be flown over an assembly of people (crowd). An aircraft of 250 grams or more, or one able to impart more than 80 Joules of kinetic energy, must not be flown over uninvolved persons.

The Specific category will typically apply to many commercial operations in the UK. To operate in this category an operator must have obtained an operational authorisation from the CAA. Holders of a currently valid PfCO may continue to operate under the same privileges until the PfCO expiry date, or 1 January 2022, whichever is earlier. After this, the operator will need to apply for an operational authorisation. During annual renewal of an operational authorisation, pilots are required to provide evidence of logged flight hours to the CAA. Operators are also required to record, and retain for two years, a log for each aircraft operated, which is to include the aircraft model, number of flights, flight hours, defects, repairs and any incidents or accidents.

Operators applying for an operational authorisation may apply under a Predefined Risk Assessment (PDRA). CAP 722[11] Edition 8, section 2.3.2 states:

> *'A PDRA is a shortened set of prescriptive conditions that must be complied with by a UAS operator in order to conduct a pre-determined type of operation. In these cases, the CAA conducts the risk assessment, rather than each individual operator, and then publishes a short series of requirements (covering topics such as remote pilot competency, ops manual contents etc) that the UAS operator must provide to the CAA as part of a 'shortened' application for an operational authorisation. This is a prescriptive set of instructions that must be followed, leading to a 'known' operation with a known and understood risk, that must be authorised on the basis of following the set of instructions. Much like following a cake recipe exactly, the intention is to produce an identical cake*

Footnote

[11] Civil Aviation Authority Unmanned Aircraft System Operations in UK Airspace – Guidance CAP 722 Edition 8. https://publicapps.caa.co.uk/docs/33/CAP722%20Edition8(p).pdf [accessed 28 February 2021].

every time; and an identical safety risk is presented by the operation. This type of approach would apply to operations that would most likely be conducted by a large number of operators (i.e. it is a pre-defined scenario), but the safety mitigations are relatively simple.'

CAP 722 Edition 8 provides two PDRAs, of which UKPDRA01 is applicable to aircraft with a MTOM of less than 25 kg, and UKPDRA02 for aircraft with a MTOM of between 25 kg and 150 kg.

UKPDRA01 provides the same operating privileges to those previously available under a PfCO, in that an operator may still overfly uninvolved persons as long as they are no closer than 50 m to them (or less if agreed with the CAA) ie a 50 m 'bubble' around people. The PDRA states that operators must produce an operations manual, which details how flights will be conducted, and pilots must have a General VLOS Certificate (GVC). The GVC is a qualification that satisfies the pilot competency requirements for VLOS operations within the Specific category.

The CAA confirmed that UKPDRA01 is applicable to operators carrying out the same type of operation as that of the accident flight, and that mitigation against injuring uninvolved persons is provided by operators having an operations manual and trained pilots. The CAA considered that these mitigations were appropriate as they had been in place previously as part of the PfCO and also that no uninvolved persons had been injured to date.

Following discussions with the CAA in 2019, the AAIB's understanding was that the new UAS regulations applicable to the Specific category would incorporate the concept of standard scenarios. These were understood to provide mitigating safety actions relative to the tasks involved, such as when operating in congested areas and overflying uninvolved people. CAP 722 Edition 8 includes a section for standard scenarios but only states:

'Reserved for future use.

Note: The concept of 'standard scenarios' is omitted in the retained version of the UAS IR and therefore will not be used in the UK for the foreseeable future.'

During the AAIB investigation into this accident, the CAA stated that standard scenarios were omitted from CAP 722 because they were not applicable when the EU regulations were adopted and that the CAA considered that UKPDRA01 provided a 'simpler and more comprehensive' solution than standard scenarios.

Risk of injury due to falling objects

The AAIB has previously[12] highlighted the potential for injury from a falling unmanned aircraft based on the dropped object prevention scheme (DROPS)[13]. This provides an indication

Footnote

[12] https://www.gov.uk/aaib-reports/aaib-investigation-to-dji-matrice-210-uas-registration-n-a-16-march-2019, https://www.gov.uk/aaib-reports/aaib-investigation-to-dji-m600-pro-uas-registration-n-a-131219 [accessed 28 February 2021].

[13] https://www.dropsonline.org [accessed 28 February 2021].

as to the possible outcome[14] of a blunt object in free fall striking a person wearing personal protective equipment (ie hard hat, eye protection). The scheme is based on an object with an energy of 40 Joules or more upon impact with a person.

Analysis using the DROPS calculator indicated that a blunt object with the same mass as a DJI Phantom 4 RTK (1.391 kg) and falling from a height of 8 m (~25 ft) agl or more, could result in a fatal injury to someone wearing a hard hat.

In 2013, a research paper[15] for the Australian Civil Aviation Safety Authority (CASA) reviewed the severity of an injury following a collision with remote piloted aircraft (RPA) that have a mass of between 0.5 kg and 20 kg. The CASA paper stated that the highest risk of injury was during an impact to the head, with energies[16] of between 40 and 120 Joules being '*dangerous*' and more than 120 Joules as '*causing severe damage to humans*'.

The CASA research paper considered that the three parameters determining injury severity were aircraft mass, velocity at impact, and local radius (diameter) of the aircraft part contacting a person. The conclusions of the research included:

- *'A 2kg RPA at 10m/s is predicted to cause skull fracture, even when impacting with its flat side (equivalent to a 2kg aluminium plate dropped from a height of 5m).'*

- *For a 2kg RPA, the highest tolerable velocity for the head impact is below 7.5m/s (15kts). A minimum RPA part diameter of 10cm is required for this case. The impact energy is equivalent to a solid 11cm aluminium sphere dropped from a height of 3m.*

- *The velocities in the loss-of-control scenario, in which the RPA descends from altitudes >60m reaching its terminal velocity, lie far above the determined acceptable values (typically above 30m/s). At such high impact velocities practically any RPA mass is likely to cause unacceptably severe injuries.'*

Previous AAIB Safety Recommendations

On 9 January 2020 the AAIB published its report on an accident involving a DJI Matrice 210[17] that occurred at Temple Newsam, Leeds, where the aircraft fell to the ground during an outdoor event attended by several hundred people.

Footnote

[14] 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.

[15] https://www.casa.gov.au/files/human-injury-model-small-unmanned-aircraft-impacts.pdf [accessed 28 February 2021].

[16] The kinetic energy is a function of the mass of an object and its velocity at impact. For the same mass in free fall, the higher the object is above the ground, the higher the kinetic energy is at impact.

[17] https://www.gov.uk/aaib-reports/aaib-investigation-to-dji-matrice-210-uas-registration-n-a-16-march-2019 [accessed 28 February 2021].

This report contained the following Safety Recommendation to the CAA:

> **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.

In response to Safety Recommendation 2020-002, the CAA published SN-2020/002 and provided the following response:

> *'The CAA believes that this recommendation is met through the introduction of the European Commission's new regulations pertaining to UAS that will be implemented in the UK on 31 Dec 20. With the extant regulations, there are no specific requirements that must be met for UAS to be flown over people; the existing rule set specifies that uninvolved third parties must be avoided by a 50m 'bubble,' which allows for overflight. Advice on the requirements to achieve this safely were covered through the release of Safety Notices and assessment of individual Operational Authorisations, but it was not within our remit to change the legislation directly to disallow overflight or enforce these requirements.*
>
> *The new regulations specify that the 50m 'bubble' will be replaced by a 'cylinder,' meaning that UAS cannot fly within a 50m horizontal distance of uninvolved 3rd parties when operating in the A2 and A3 categories. The A2 category also demands extra requirements in terms of pilot competence and product standards. Overflight in the A1 category is permitted and mitigated by the mass limit of 250g and additional product standards.'*

Based on an understanding that the new regulations introduced on 31 December 2020 would address Safety Recommendation 2020-002, the response from the CAA was assessed by the AAIB as 'Adequate'.

Network Rail UAS operations

Surveying of Network Rail's infrastructure was overseen by its Air Operations department, which used a combination of helicopters and UAS. This department held a PfCO and operated about 80 UAS flown by 43 pilots. About 95% of the fleet was made up of Mavic, Phantom, Inspire and M200/210 quadcopter aircraft manufactured by DJI, with the remaining 5% made up of Disco fixed-wing and Anafi quadcopter aircraft manufactured by Parrott, and a Robot Aviation FX10 fixed-wing aircraft. The UAS surveying activity was also supplemented by four operators under contract; these are referred to as Framework companies.

Network Rail advised that its use of UAS was a balance between the risk of an aircraft injuring a person and that posed to people having to work in close proximity to hazards if a UAS was not used. Its pilots were advised to minimise overflight of uninvolved persons. For Framework companies, they were expected to adhere to their PfCO or operational authorisation and the requirements of the ANO.

Network Rail oversee about 1,000 flights per year, of which approximately:

- 35% are flown by its own pilots, of which 35% are training flights to stay current and 65% are for operational requirements.
- 35% are Framework company flights.
- 30% are flights made by external operators that have a requirement to fly a UA within 50 m of the railway track.

Network Rail had Work Instructions (WI) that set out, among other aspects, the operating arrangements for its own pilots, Framework company pilots, or any external organisation's pilots wanting to operate a UA near or overhead the Network Rail infrastructure. The WI specified that unless permission was provided by Network Rail, all other pilots should not fly a UA closer than 50 m to its infrastructure. Depending upon PfCO or operational authorisation limitations, Network Rail pilots and Framework company pilots could operate a UA vertically to a minimum of 20 m and 5 m laterally during daytime from the railway track and, at night, these limits were increased to 50 m and 25 m respectively.

The WI also included minimum equipment requirements for its, and Framework companies' UAS. These included a return-to-home[18] function and that system technology compliant with the operators' CAA permission and approved operations manual, was fitted.

Network Rail had previously considered the use of parachute technology to limit the energy of a falling UAS. However, concerns were raised about inadvertent operation and possible entanglement in the overhead line electrification system, which would create alternate risks.

In November 2020 Network Rail introduced a UAS Flight Management System (FMS) that was used to collate and share information on flight planning to ensure that aircraft were not operated in the same area at the same time. The FMS also collates operational information such as the aircraft make, model and weight of aircraft for in-house, Framework and any external operators' flights near Network Rail infrastructure. It also keeps a record of the flight hours for in-house flights and the associated pilot. Network Rail also collate information on incidents and accident involving its in-house, Framework and external operations near its infrastructure.

In January 2021, Network Rail precluded the use of DJI Phantom 4s in support of its survey activities. Furthermore, they advised that they intend to carry out trials using a UAS with a MTOM of less than 250 grams for when there is a need for UAS operations over uninvolved people. The FMS is also being updated to provide a 'risk map' to include information on areas having known hazards, such as transmission masts that could affect UAS operations.

Footnote

[18] In normal operation the RTH function would automatically land the aircraft at its takeoff position.

Analysis

Failure of the DJI Phantom 4 RTK's propeller

Analysis of the recorded flight log indicated that the left rear propeller had detached from the aircraft in flight. This resulted in a loss of control, with the aircraft descending rapidly and vertically to the ground.

After the propellers were fitted and before the accident flight, the aircraft had successfully completed two flights and flown for more than 30 minutes. This indicates that the propeller had probably been fitted correctly prior to flight and therefore either the propeller or its locking mechanism to the motor may have failed. The manufacturer did not confirm if it had carried out a detailed inspection of the aircraft and therefore it was not possible to determine the cause of the in-flight separation. However, the manufacturer stated that it had '*currently not seen any recurring pattern of similar cases'.*

In 2020, the AAIB was notified of nine accidents involving DJI Phantom 4s of which one was an accident on 1 December 2020 where the pilot of a RTK model attributed the accident to a possible propeller failure or in-flight loss of a propeller.

Notification of accidents to the AAIB

The AAIB was notified nine days after the accident occurred, by which time the operator had already sent the damaged aircraft to the manufacturer. It is important that the AAIB is notified of accidents and serious incidents in a timely manner, and within the time frames required by a PfCO or operational authorisation issued by the CAA which, for this operator, was 72 hours. This is so that the appropriate evidence can be secured and that aspects such as the subsequent inspection of a UAS can be coordinated by the AAIB. CAP 722 provides information on reporting UAS accident to the AAIB and CAA. Further information can also be found on the AAIB website[19].

UAS failure rates

Neither the operator in its risk assessment, nor the CAA in UKPDRA01, based mitigating actions on data published for UAS failure rates per flying hour. Whilst it is recognised that UAS manufacturers would be understandably reluctant to publish such information, large operators such as Network Rail are collating aircraft usage data, and UK operators are also now required to record usage data for each aircraft in addition to individual pilot flight hours to support annual applications to the CAA for the renewal of an operational authorisation. Collation and dissemination of such data would enable, in particular for operations involving overflight of people, the actual risk to uninvolved persons on the ground to be assessed with greater accuracy.

Footnote

[19] https://www.gov.uk/government/publications/investigating-accidents-to-unmanned-aircraft-systems/investigating-accidents-to-unmanned-aircraft-systems [accessed 28 February 2021].

Therefore, the following Safety Recommendation is made:

Safety Recommendation 2021-023

It is recommended that the Civil Aviation Authority collate up to date information regarding the failure rates per flying hour for unmanned aircraft systems operating in the Specific category, or previously under a CAA Permission for Commercial Operations, to facilitate effective risk assessments.

Operation of UAS over uninvolved persons

Aircraft such as the DJI Phantom 4 RTK series rely upon their propulsion system for lift. If propulsion is lost, aircraft of this type typically fall vertically to the ground.

The DROPS analysis indicated that a DJI Phantom 4 RTK (1.391 kg) falling from a height of 8 m (~25 ft) or more could result in a fatal injury to someone wearing a hard hat. The accident aircraft descended from a height far in excess of this, at 70 m, and at a descent rate greater than free fall because of thrust from its three operating propellers whilst it was inverted. The CASA research paper stated that energies of between 40 and 120 Joules were '*dangerous*' and more than 120 Joules as '*causing severe damage to humans*' when struck on the head. The energy at impact of the accident aircraft was calculated to be 900 Joules. It is therefore highly likely that a fatal injury would have occurred had a person been struck from above.

The new UAS regulations introduced in the UK on 31 December 2020 preclude the overflight of uninvolved people when operating in the Open category with an aircraft with a MTOM of more than 250 grams, or one that is able to impart more than 80 Joules of kinetic energy. However, commercial operators holding a PfCO or operational authorisation issued by the CAA may overfly uninvolved people with a UAS of more than 250 grams and that is able to impart more than 80 Joules of kinetic energy.

Discussions with the CAA in 2019 indicated that the new regulations would introduce standard scenarios, through which predefined safety mitigations for a particular task would be specified, such as operating in a congested area over uninvolved persons. However, standard scenarios have not been adopted into UK regulations and the CAA has published UKPDRA01 and UKPDRA02 as alternatives.

The CAA stated that when operating a UAS of less than 25 kg in the Specific category, UKPDRA01 provides mitigation against injury to uninvolved persons by requiring operators to have an operations manual detailing how flights will be conducted, and pilots to have a GVC. However, this accident, and others, have shown that pilot training does not provide mitigation against failures that result in a loss of control and where aircraft fall vertically to the ground. For these types of failure, an operations manual may also not provide suitable mitigation, unless overflight is precluded, or where the energy of an aircraft falling to the ground is required to be minimised.

SN-2020/002 recommended limiting the amount of overflight and to maintain a lateral distance from people to reduce the risk when overflying uninvolved persons. However, discussions with the operator of the accident aircraft, and other operators, indicated that this was not always possible to achieve when operating in congested areas.

The operator's risk assessment for a failure of the UAS included mitigations to reduce the energy at impact by limiting the maximum height permitted when overflying people. However, the operator, under the requirements of the PfCO, also had to maintain a minimum height of 50 m when flying over uninvolved persons. An aircraft falling from 50 m would be highly likely to cause a fatal injury to a person being struck by it, and the operator's mitigating action would not have been effective in reducing the severity of such injuries.

SN-2020/002 does refer to the use of technology, such as fitting a parachute system that would reduce the energy when descending to the ground following a failure. However, this is only recommended, not required, when operating over uninvolved persons. Furthermore, the use of a parachute can introduce additional risks such as that identified by Network Rail who raised concerns that inadvertent operation could result in entanglement in the overhead line electrification system.

The operator's mitigating actions also referred to performing routine maintenance of the UAS. However, the manufacturer of the DJI Phantom 4 RTK did not provide guidance or requirements for this activity. Therefore, it was unclear as to how this was to be effectively implemented by the operator, and also, specific to this event, if such maintenance could have reduced the risk of a propeller detaching.

The operator's initial risk score for the failure of its UAS was based on an assumed score rather than published information, as this is not available. The CAA also stated that the mitigating actions in UKPDRA01 were not based on data but that the same mitigations had been in place for several years as part of the PfCO and that no person had been injured to date. Since 2015, 73 accidents involving UAS aircraft have been reported to the AAIB where a loss of control occurred, of which 69 had a MTOM of less than 25 kg. It is unclear if the current mitigations intended to prevent injury to uninvolved persons are adequate or that it has been due to chance that a person has not been injured.

This investigation indicates that UAS operations in the Specific category pose a risk to uninvolved people on the ground being struck by an aircraft relying solely upon its propulsion system for lift, following a failure of that propulsion system. Therefore, the following Safety Recommendation is made:

Safety Recommendation 2021-024

It is recommended that, until an analysis of failure rates per flying hour has demonstrated an acceptable level of safety, the Civil Aviation Authority should consider prohibiting the overflight of uninvolved persons for those unmanned aircraft operating in the Specific category which rely solely upon their propulsion system for lift that would, following a failure of the propulsion system, impact the ground with a kinetic energy exceeding 80 Joules.

Conclusion

The DJI Phantom 4 RTK struck the ground in the rear garden of a house whilst conducting an aerial survey. The manufacturer stated that the accident had been caused by the left rear propeller detaching from its motor. Failure of UAS aircraft that then fall to the ground pose a risk of injury to people on the ground which is not mitigated by the current UK regulations or the published guidance and policy material. Information on the failure rate of UAS are also not available on which to determine the risk of overflying uninvolved persons. Two Safety Recommendations are made to the CAA to address these issues.

Safety action

In January 2021, Network Rail precluded the use of DJI Phantom 4s in support of its survey activities. Furthermore, they advised that they intend to carry out trials using a UAS with a MTOM of less than 250 grams for when there is a need for UAS operations over uninvolved persons. The FMS is also being updated to provide a 'risk map' to include information on areas having known hazards, such as transmission masts that could affect UAS communications.

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