Air Accident Investigation Unit Ireland

SYNOPTIC REPORT

ACCIDENT
Unmanned Aircraft, GEN 3.8
Tankardstown, Balbriggan, Co. Dublin

14 July 2022

An Roinn Iompair
Department of Transport

Foreword

This safety investigation is exclusively of a technical nature and the Final Report reflects the determination of the AAIU regarding the circumstances of this occurrence and its probable causes.

In accordance with the provisions of Annex 13[1] to the Convention on International Civil Aviation, Regulation (EU) No 996/2010[2] and Statutory Instrument No. 460 of 2009[3], safety investigations are in no case concerned with apportioning blame or liability. They are independent of, separate from and without prejudice to any judicial or administrative proceedings to apportion blame or liability. The sole objective of this safety investigation and Final Report is the prevention of accidents and incidents.

Accordingly, it is inappropriate that AAIU Reports should be used to assign fault or blame or determine liability, since neither the safety investigation nor the reporting process has been undertaken for that purpose.

Extracts from this Report may be published providing that the source is acknowledged, the material is accurately reproduced and that it is not used in a derogatory or misleading context.

[1] **Annex 13**: International Civil Aviation Organization (ICAO), Annex 13, Aircraft Accident and Incident Investigation.
[2] **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.
[3] **Statutory Instrument (SI) No. 460 of 2009**: Air Navigation (Notification and Investigation of Accidents, Serious Incidents and Incidents) Regulations 2009.

AAIU Report No: 2024-011

State File No: IRL00922032

Report Format: Synoptic Report

Published: 8 November 2024

In accordance with Annex 13 to the Convention on International Civil Aviation, Regulation (EU) No 996/2010 and the provisions of SI No. 460 of 2009, the Chief Inspector of Air Accidents, on 15 July 2022, appointed Ray Jordan as the Investigator-in-Charge to carry out an Investigation into this Accident and prepare a Report.

Aircraft Type:	GEN 3.8 (Unmanned Aircraft)
No. and Type of Engines:	8 x T-Motor U8 Electric Motors
Year of Manufacture:	2022
Date and Time (UTC)[4]:	14 July 2022 @ 16:51 hrs
Location:	Tankardstown, Balbriggan, Co Dublin, Ireland
Type of Operation:	Urban Delivery
Injuries:	Minor (to an individual on the ground)
Nature of Damage:	Minor
Remote Pilot Qualification	Course Completion Certificate for STS[5] & PDRA[6] Theoretical Knowledge Course &Exam Practical skill assessment in order to conduct Unmanned Air System (UAS) Visual Line Of Site (VLOS) operations
Remote Pilot's Age:	23 years
Remote Pilot's Flying Experience:	105.5 hours
Notification Source:	The Operator
Information Source:	AAIU Report Form submitted by the Remote Pilot AAIU Field Investigation

[4] **UTC**: Co-ordinated Universal Time. All times in this report are quoted in UTC unless otherwise stated; local time was UTC + 1 hour on the date of the occurrence.

[5] **STS**: Standard Scenario means a type of UAS operation in the '*specific*' category, as defined in Appendix 1 of Regulation (EU) 2019/947, for which a precise list of mitigating measures has been identified in such a way that the competent authority can be satisfied with declarations in which operators declare that they will apply the mitigating measures when executing this type of operation.

[6] **PDRA**: Predefined Risk Assessment (PDRA) is an operational scenario for which the European Union Aviation Safety Agency (EASA) has already carried out the risk assessment and has been published as an acceptable means of compliance (AMC) to the Article 11 (risk assessment) of Regulation (EU) 2019/947.

SYNOPSIS

During an urban delivery flight, a propeller blade separated from the Unmanned Aircraft (UA). This caused severe vibrations and the subsequent failure of an electric motor which in turn triggered the onboard Flight Termination System and emergency parachute deployment. The UA impacted the ground, resulting in minor damage to the UA. The propeller blade that had separated struck an individual on the ground causing a minor injury. The Investigation determined that the probable cause of the accident was a fatigue fracture of a bolt securing the propeller blade, which caused the blade to separate from the UA.

NOTIFICATION AND RESPONSE

The AAIU first became aware of the accident through social media on the evening of 14 July 2022. The Operator contacted the Irish Aviation Authority on the day of the accident. Following further enquiries by the AAIU, an Investigation was commenced.

PREAMBLE

At the time of the occurrence, the Operation involved the delivery of small packages to customers in the Balbriggan area who ordered online through an app. A staff member, referred to as the '*Mission Controller',* generated a flight path to a customer's address, avoiding assemblies of people and overflight of sensitive areas such as schools. A Remote Pilot (RP) monitored the flight and could intervene directly to control the aircraft if required. Prior to delivery, a Visual Observer (VO) was dispatched to the customer's address in order to assess the ground and air risk at the location. The VO was in UHF radio communication with the RP at all times and could abort the delivery at any stage. Upon arrival at a delivery address, the UA descended to approximately 15 metres above the ground and the packages were lowered as depicted in **Photo No. 1**. Following delivery, the UA returned to its operating base which was located at a local shopping centre in Balbriggan, Co. Dublin.

Photo No. 1: A GEN 3.8 during a typical urban delivery flight

On the day of the accident, the Operator was using a GEN. 3.8 UA for urban delivery flights, which incorporated eight electrically driven propellers, with two propellers at each corner mounted in a coaxial[7] configuration (**Photo No. 2**).

Photo No. 2: A GEN 3.8 UA (viewed from the rear)

1. FACTUAL INFORMATION

1.1 History of Flight

This History of Flight is based primarily on a technical report provided by the Operator, interviews with the RP, and witness accounts. The UA was tasked with conducting an urban delivery to an address in the Tankardstown area of Balbriggan, Co. Dublin. At 16:49 hrs, the UA departed from its base of operations, located on top of a multistorey carpark at the Millfield Shopping Centre in Balbriggan. The UA ascended to a height of 71 metres (m) and proceeded on its pre-programmed route towards its drop point. Whilst on a north-easterly track and 52 seconds into its flight, a vibration consistent with a propulsion unit imbalance was registered by the onboard software, and a propeller blade driven by the upper rear-right electric motor separated from the UA.

The route flown by the UA and the approximate position at which propeller blade separation occurred is depicted in **Figure No. 1**.

Figure No. 1: Approximate track of the UA (*Google Earth*)

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[7] **Coaxial:** In this case, a design feature whereby two sets of propellers share the same central axis but rotate in opposite directions.

Following separation of the propeller blade, the UA pitched up and rolled to the right. To compensate for this uncommanded pitch and roll, and in an attempt to maintain stable flight, the UA automatically reduced thrust on the electric motors located on the front left arm and commanded an increase in thrust from the motors on the right rear arm. The UA recovered attitude control and maintained altitude for the next 20 seconds.

Due to vibration, the UA's master Flight Control Unit (FCU) was unable to accurately compute the UA's attitude and altitude, and automatic switching to a backup FCU occurred. This was followed by a drop in altitude of approximately 2.5 m. To compensate for this height loss, increased thrust was commanded from the remaining propellers followed by a short climb segment. Approximately five seconds after the FCU switching, the lower rear right electric motor failed completely due to the effects of vibration, with the remaining (upper) motor on the rear-right arm driving a single propeller blade.

The UA's automatic Smart Return To Land (SRTL) feature activated in an attempt to automatically return the UA to its operating base. Due to the yaw demands commanded by the SRTL, the UA descended with a speed of 3 m per second (m/s) and the onboard monitoring system detected increasing errors in both pitch and roll axes. The UA continued to descend with the rate of descent increasing to a maximum of 8.5 m/s and all remaining motors were automatically stopped. The Flight Termination System (FTS) activated and the onboard parachute was ejected from its tube. As the UA descended through approximately 20 m, the rate of descent decreased to 4.9 m/s before the UA impacted with grassy terrain and came to rest, inverted, near a public footpath (**Photo No. 3**). The Operator initiated their Emergency Response Plan (ERP) and its personnel travelled to the accident site. The UA was video recorded in situ and subsequently recovered to the Operator's base.

Photo No. 3: Final position of the UA

1.2 Injuries to Persons

One individual informed the Investigation that he was mowing the lawn in his back garden when he was struck by what he believed to be part of a propeller from a '*drone*'. He stated that he did not notice anything unusual prior to being struck due to the noise emitted from his lawn mower. He said that he sustained a small cut to his head but did not require either stitches or hospitalisation. This individual provided the Investigation with an image of what he states struck him in the head (**Photo No. 4**).

Photo No. 4: Image of propeller blade

1.3 Interview with the Remote Pilot

The RP said that prior to the accident flight, a pre-flight inspection of the UA was completed and that the UA departed normally but approximately *'two thirds'* into the mission a series of notifications (warning messages) began to be received on the control tablet.

The first notification was an indication that the master FCU *'went into crit'* and had failed. This failure initiated the automatic SRTL feature of the UA. The RP reported that approximately three seconds later, a notification of a *'Potential Motor Failure'* was received, which was followed two seconds later by a *'Parachute Deployed'* notification. The RP stated that following this last notification, it was clear that the *'the drone had gone down'.* The '*Mission Controller'* was immediately contacted, as was the ground team who were in the vicinity of the accident site. The Operator's ERP was initiated and a team including the RP deployed to the site. The RP reported that a member of the ground team was already at the location and had disconnected the battery to silence the onboard warning siren that had activated during the occurrence.

The RP stated that a crowd of approximately 30 people had gathered at the accident site. The Investigation was informed that there was some interaction between members of the public and a senior manager from the Operator, and that a second individual reported having been struck by a propeller blade fragment.

Due to the nature of the damage sustained by the UA, the RP was of the opinion that it did not impact the ground with excessive force. The Investigation was subsequently informed that the UA was recovered to the Operator's base and all flight operations temporarily ceased until a root cause for the accident could be established by the Operator.

1.4 Witness

The Investigation interviewed the second individual. He was walking his dogs close to the accident site. He stated that, whilst in flight, *'the drone had gone back and forth a couple of times'* and *'it wobbled for a second and then bits and pieces started showering down'.* The witness informed the Investigation that a propeller blade fragment had struck him on the shoulder but that he did not sustain any injury as there was very little weight to it. He said that the *'props shattered in mid-air'* and that the *'drone'* started *'to come down sideways'* before the parachute deployed at an estimated height of 40-45 feet. The witness further stated that when the parachute deployed *'the drone then flipped on its back'* and that *'it landed upside down'.* He said he heard a *'beeping alarm from the drone'* which was disabled by an individual employed by the Operator who had arrived at the site.

1.5 Damage to Unmanned Aircraft

The UA sustained damage to its landing gear legs and to the arms upon which the electric motors were mounted. There was damage to the plastic outer shell and three propeller blades were missing from the rear-right arm (**Photo No. 5**).

Photo No. 5: Damage to plastic outer shell and missing propeller blades (UA inverted)

Fragments from two of the three missing propeller blades were recovered by the Operator at the scene. The Investigation noted that the missing propeller blades from the lower electric motor on the rear-right arm had fractured at their roots; however, the propeller hub and associated propeller retaining bolts, which were manufactured from alloy steel, were intact. The bolt used to secure a propeller blade to the hub on the upper rear-right electric motor was fractured and the associated blade was missing. The location of the fractured bolt is shown in **Figure No. 2** where it is described as an '*M6 Inner-hexagon Screw*'.

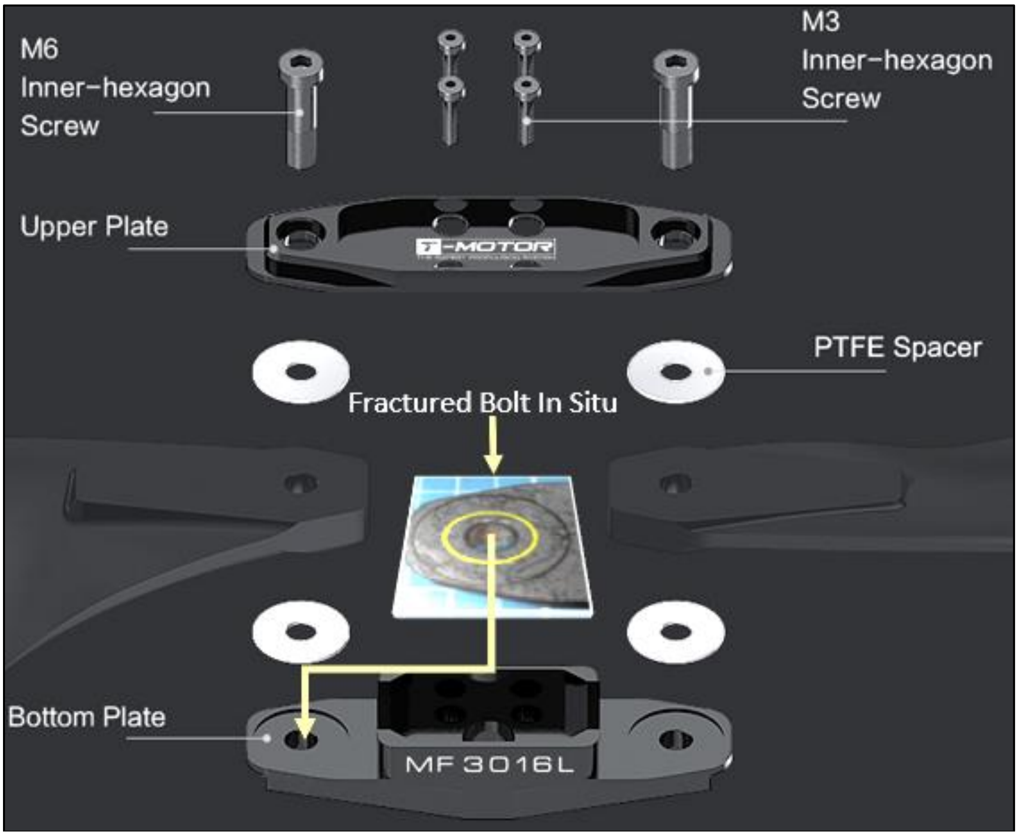

Figure No. 2: Location of fractured bolt (*figure adapted from manufacturer's website)*

1.6 Personnel Information

The RP received training from a Declared UAS Training Organisation (DUTO), which was recognised by the Irish Aviation Authority (IAA). A Course Completion Certificate was issued on 3 June 2022 and was awarded to the RP for successfully completing the *'STS & PDRA Theoretical Knowledge Course &Exam'*.

The RP completed a practical skill assessment with the same DUTO on 27 May 2022 in order to conduct Unmanned Air System (UAS) Visual Line Of Site (VLOS) operations. The RP was issued with a '*Practical Assessment Completion Certificate'* by the DUTO; however, the certificate was dated 1 June 2023. The RP stated that there had been a '*miscommunication'* with the DUTO which delayed the issuance of this certificate until after the accident. Although it was not a factor in this accident, the Operator advised the Investigation that subsequent to the accident, a safety action was initiated whereby a RP cannot be rostered to fly if the appropriate certificates are not in date.

1.7 Unmanned Aircraft Information

1.7.1 General

The GEN 3.8 UA is a coaxial octorotor. It has a bodyshell constructed of High Impact PolyStyrene (HIPS) and is equipped with a fixed landing gear consisting of four carbon fibre tubes. The UA's maximum take-off weight was 23.6 kgs.

Components are a mixture of off-the-shelf parts sourced from third party providers, and bespoke elements designed to the Operator's own specifications. Final assembly of the UA takes place near the Operator's flight testing facility in Co. Offaly, Ireland.

The GEN 3.8 measures 1.702 metres (m) in length, 0.667 m in height and 2.032 m in width. A maximum payload of 2.25 kgs can be loaded into a cargo compartment located in the main body. During an urban delivery and when in the hover at a pre-set height, small packages are lowered from the cargo compartment on biodegradable thread through two small cargo doors.

Eight brushless electric motors drive eight polymer, two-bladed propellers. The electric motors and polymer propellers are manufactured in China. The propeller blades when extended have a diameter of 775.8 millimetres. The main electrical power source is a Lithium Ion 25 Amp-hour (Ah) battery with backup power supplied by a Lithium Polymer 2 Ah battery. The UA is approved for both day and nighttime flying and is equipped with a siren which is triggered by the FTS. The siren is to warn individuals on the ground that the UA is descending under canopy.

Extant at the time of the accident, flight in rain or icing conditions was prohibited and was limited to operating in average wind speeds of 6 m/s, and gusts of up to 11 m/s. The UA did not have a Certificate of Airworthiness or a Design Verification Report[8] nor was it required to.

1.7.2 Parachute Recovery System

The UA was equipped with a ballistic parachute located at the rear which was designed to activate automatically on loss of control of the UA. According to the manufacturer, it is designed for an Unmanned Air Vehicle (UAV) operating in the 15-35 kg weight range. The parachute, when inflated, has a nominal diameter of 3 m and is supported by 14 lines. Activation is automatically tiggered by the FTS or can be deployed manually by the RP. The parachute is contained within a tube; a '*STAY CLEAR'* warning is printed on the top cover (**Photo No. 6**).

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[8] **Design Verification Report:** This is a report issued by the EASA which documents that a UAS design complies with the applicable Operational Safety Objectives, which includes any possible limitations or assumptions the actual drone model needs to operate.

Photo No. 6: Parachute tube and warning label

In a report provided to the Investigation following the occurrence, the Operator stated that when the parachute is deployed, the UA adopts a nose down attitude to reduce the possibility of injury to people on the ground. The Investigation viewed flight test footage provided by the Operator of two parachute deployments. One deployment was at cruise speed and the second was in the hover. In both instances, the test UA adopted a nose down attitude once the parachute was fully inflated (**Photo No.7**).

Photo No. 7: Still image of parachute deployment

1.7.3 Unmanned Aircraft System (UAS)

According to Commission Implementing Regulation (EU) 2019/947, dated 24 May 2019, a UAS is defined as *'an unmanned aircraft and the equipment to control it remotely'.*

The primary means of controlling the UA was through the RP's dashboard. This was displayed on a tablet device which was mounted on a set of conventional radio controls that could have been used if the RP needed to assume manual control (**Photo No. 8**).

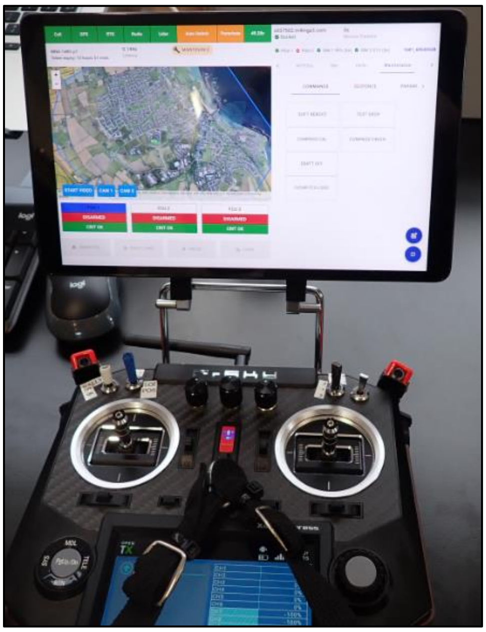

Photo No. 8: RP controls and dashboard

When the UA was ready to fly a mission, the RP selected a tab on the dashboard and the UA would take off automatically and fly a pre-programmed route to the customer's address. When a package was delivered, the UA automatically returned to the Operator's base of operations. There were five levels of RP notification ranging from informational to critical. There was also an associated aural warning for important notifications. The UA was fitted with two cameras which provided a live stream to the RP; however, this video was neither recorded nor saved. The primary means of navigation was through the use of onboard GNSS[9] receivers with some level of redundancy. The UA was also equipped with LiDAR[10] technology for range finding at low altitude when in the vicinity of obstacles such as buildings.

1.8 Bolt Failure

1.8.1 Operator's Technical Report

The Operator stated that some weeks before the accident, a new propeller-retaining bolt tightening procedure had been introduced into its Balbriggan operation. To facilitate this, a *'Prop Tightening Checklist'* was introduced which set a minimum torque[11] value but not a maximum.

According to the Operator, this resulted in the propeller retention bolts on Balbriggan based UAs to be torqued (tightened) to higher values than those on their counterparts at the Operator's test facility. The Operator informed the Investigation that bolt tightening at the test facility was performed solely by technicians and in their opinion, staff at Balbriggan tended to overtighten the retention bolts. The Operator examined the fracture surface of

[9] **GNSS:** Global Navigation Satellite System refers to a constellation of satellites providing signals from space that transmit positioning and timing data to GNSS receivers.
[10] **LiDAR:** Light Detection and Ranging using a pulsed laser to measure distance.
[11] **Torque:** A force that produces rotation or torsion about an axis. In this case, torque applied to the bolt had the effect of tightening it into position.

the fractured propeller retaining bolt and opined that overtightening in conjunction with a pre-existing fatigue crack likely caused the bolt to eventually fail and for the propeller to separate from the UA. The Operator informed the Investigation that the bolt tightening procedure has since been revised and that all bolts in operation at the time of the accident were removed from service and destroyed.

Subsequent to the accident, the Operator redesigned the propeller hub with what was described as being a *'failsafe'* mechanism which would prevent the separation of a propeller blade from the hub in the event of a retaining bolt failure. The Investigation notes that this redesign involved the replacement of the manufacturer's original mounting plates (as supplied with the propellers) with mounting plates of the Operator's own design.

1.8.2 Independent Metallurgical Report

The Investigation sent the fractured propeller retaining bolt to a metallurgist for an independent detailed examination. The information contained in this section is based on this metallurgical examination. The report stated that the bolt had fractured through its threaded diameter, approximately flush with the surface of the mounting plate; surface irregularities are due to chemical treatment applied to the mounting plate prior to shipment for examination (**Figure No. 3**).

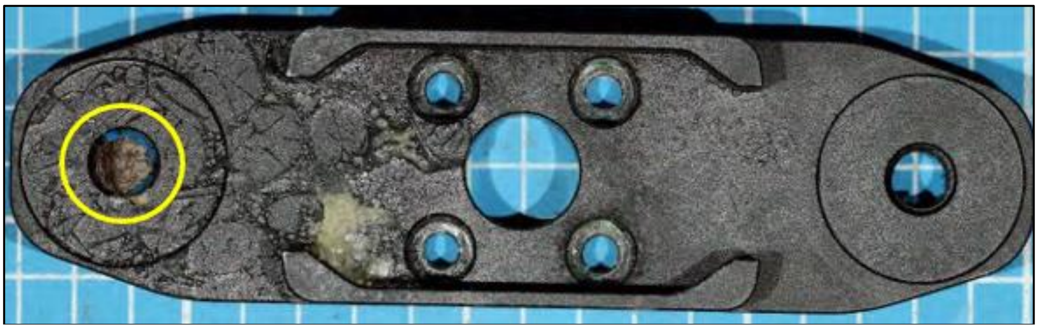

Figure No. 3: Fractured retaining bolt (ringed in yellow, all scale markers are 5mm squares)

Crack progression marks[12] on the fracture surface indicated that the bolt had failed in fatigue[13] (**Figure No. 4**). Ratchet marks[14] around the edge of the fracture surface indicated that multiple fatigue cracks had initiated within a thread root, on opposite sides of the bolt diameter. There was no evidence of pre-existing material defects at the sites of crack initiation. The incipient fatigue cracks coalesced as they propagated inwards, forming two major fatigue crack fronts.

[12] **Crack progression marks:** Macroscopic concentric marks on a fracture surface, denoting the position of the crack front at different stages of stable fatigue crack growth.

[13] **Fatigue Failure:** The progressive, localised, and permanent structural change that occurs in a material subjected to repeated or fluctuating strains at nominal stresses that have maximum values less than the static yield strength of the material. Fatigue may culminate in cracks and cause fracture after a sufficient number of fluctuations.

[14] **Ratchet marks:** Macroscopic steps in the edge of a fracture surface, formed when two adjacent crack planes join together.

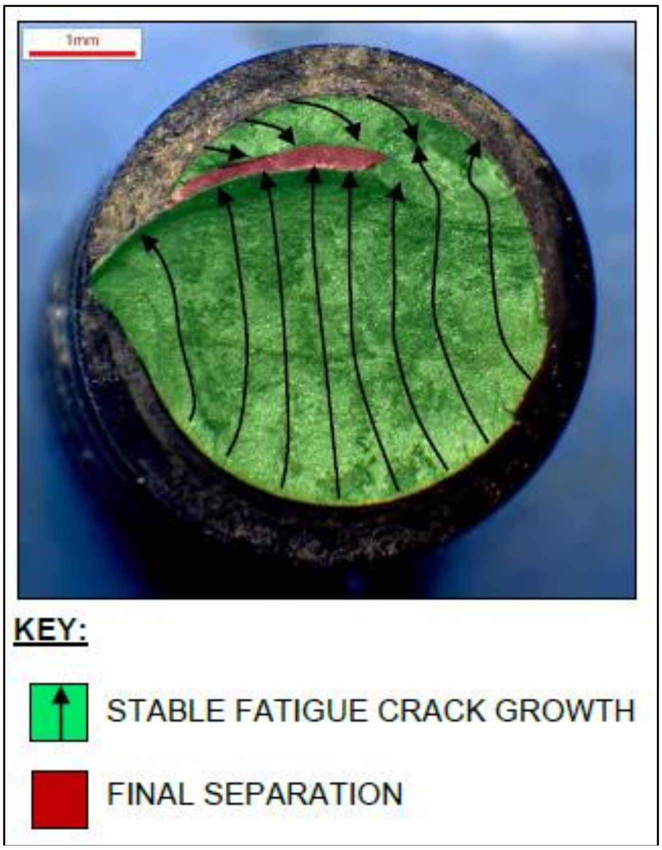

Figure No. 4: Crack progression markings

A ridge in the fracture surface identified the boundary between these two crack fronts and the region of final separation. The total surface area occupied by stable fatigue crack growth was large, in comparison with that occupied by final separation. This indicated that the fracture had occurred under the influence of cyclic stresses of relatively low amplitude, with a high number of cycles to failure (high-cycle fatigue). The metallurgist was of the opinion that this was consistent with vibrational loading.

The report listed the following conclusions:

- The bolt had suffered a fatigue fracture, which had initiated from no apparent pre-existing material defects.

- The fatigue fracture had occurred under a cyclic load spectrum of relatively low amplitude, with a high number of cycles to failure. This was consistent with vibration.

- A common cause of fatigue fractures of threaded fasteners, which are subject to vibrational loading, is insufficient assembly torque. However, it was not possible to determine the assembly torque which had been applied to the subject bolt.

1.8.3 Fatigue in Threaded Fasteners

Regarding threaded fasteners, the following is an extract from the American Society for Metals (ASM) Handbook (Volume 11, Failure Analysis and Prevention, Failures of Manufactured Components & Assemblies, - Failures of Mechanical Fasteners):

'Fatigue is one of the most common failure mechanisms of threaded fasteners. Insufficient tightening of fasteners can result in flexing, with subsequent fatigue fracture. Higher clamping forces make more rigid joints and thus increase fastener fatigue life. The fatigue origin is usually at some point of stress concentration, such as an abrupt change of section, a deep scratch, a notch, a nick, a fold, a large inclusion, or a marked change in grain size; however, fatigue failures are most frequently located at the washer face of the nut, at the threaded runover, or at the head-to-shank fillet.'

1.9 Propeller Manufacturer

As stated in **Section 1.7.1**, the electric motors and polymer propellers as fitted on the GEN 3.8 were manufactured in China. The Investigation noted the following caution on the manufacturer's website: '*Polymer props for coaxial configuration are under testing. Please DO NOT run polymer props on coaxial frames'.*

The AAIU requested, and received, assistance from the Civil Aviation Administration of China (CAAC) in order to facilitate communication with the manufacturer. The AAIU sought clarification on what was stated on the manufacturer's website in relation to the subject propellers. Their response was that the propellers are:

'not designed to be used on coaxial setup. Although the strength of the hub is sufficient, the root structure of the blade is not suitable for the coaxial due to the complicated load condition of the coaxial configuration with the current materials used for the propeller.'

1.10 Operator's Reliability Report

1.10.1 General

As a result of the findings outlined above, the Operator provided the Investigation with a flight testing and reliability report concerning the use of the subject propellers in a coaxial configuration. The report stated that between April 2020 and 23 August 2023, the Operator conducted approximately 115,000 flights which comprised 5,972 hours of flight time. The Operator stated that the majority of these flights were conducted using the GEN 3.8 platform and the subject propellers.

The measured flight time commenced upon initial propeller spin up and concluded when the propeller stopped at the end of the flight. The Operator stated that in the period between April 2021 and August 2023 there had been some incidents involving their unmanned aircraft and *'Any failure recorded for the rotors were determined to be human error and not a system failure…'*

The Operator stated that it had conducted ground testing of the propeller blade type, which simulated the loads experienced in flight at maximum thrust. The report showed an upward deflection of the propeller blade when put under load. The report concluded that at maximum deflection there was still sufficient clearance between the lower propeller and the arm on which it was mounted.

1.10.2 Future Design

The Operator informed the Investigation of their intention to redesign the GEN 3.8 and to replace the coaxial configuration with, *inter alia,* a single, larger propeller mounted on each arm. This redesign involves significant flight and ground testing with a target date to be fully operational by the fourth quarter of 2025.

1.11 EU Drone Regulations

1.11.1 General

According to COMMISSION IMPLEMENTING REGULATION (EU) 2019/947 of 24 May 2019 on the rules and procedures for the operation of unmanned aircraft, there are three categories of UAS operations. These are *'open'*, '*specific*' and *'certified'*. The Irish Aviation Authority (IAA) is the civil aviation authority for Ireland and has responsibilities for aviation safety, security, consumer interests and market surveillance. The IAA published on its website a guide titled '*EU DRONE REGULATIONS-OUTLINE'* which states, amongst other things, the following;

> ➢ '*'Open' category – operations that present a low (or no) risk to third parties. Operations are conducted in accordance with basic and predefined characteristics and are not subject to any further authorisation requirements.*
>
> ➢ *'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* [national Civil Aviation Authority]*, based on a safety risk assessment.*
>
> ➢ *'Certified' category – operations that present an equivalent risk to that of manned aviation and so will be subjected to the same regulatory regime.'*

UAS.SPEC.010 General provisions of COMMISSION IMPLEMENTING REGULATION (EU) 2019/947 states the following regarding UAS operations in the '*specific'* category;

> *'The UAS operator shall provide the competent authority with an operational risk assessment for the intended operation in accordance with Article 11, or submit a declaration when point UAS.SPEC.020 is applicable, unless the operator holds a light UAS operator certificate (LUC) with the appropriate privileges, in accordance with Part C of this Annex. The UAS operator shall regularly evaluate the adequacy of the mitigation measures taken and update them where necessary.'*

The Operator was conducting urban delivery flights in accordance with the Specific Category on the day of the accident.

1.11.2 Operator's LUC Certificate

The Operator was issued with a LUC by the IAA on 20 May 2021. The LUC stated, *inter alia,* that the UAS must be fitted with an '*Operational Flight Termination System (FTS Parachute)*' and a maximum operational height of 120 m, unless otherwise approved by the IAA.

Operations were further restricted to within 2 kilometres (km) of the Operator's base and in accordance with VLOS operations with a requirement to have *'Visual Observers(s)'.*

1.12 Meteorological Information

Met Éireann, the Irish meteorological service, was asked to provide an aftercast of the estimated weather conditions prevailing in the Balbriggan area on the day of the accident. Details from the report received are reproduced in **Table No. 1**.

Meteorological Situation:	High pressure centred on the south-west of Ireland maintains a light to moderate west to north-west airflow over the country.
Surface Wind: **Wind at 2,000 feet (ft):**	Westerly, 5-10 knots (kt) North-westerly, 10 kt
Visibility:	40 km
Weather:	Sunny spells and cloudy patches
Cloud:	Scattered (1-2/8ths oktas[15]) clouds with bases between 3,000 and 4,000 feet (ft) and broken (5-7/8 ths oktas) cloud with bases between 6,000 and 7,000 ft
Surface Temperature/Dew Point:	20/09 degrees Celsius
Mean Sea Level (MSL) Pressure:	1025 hectoPascals (hPa)
Freezing Level:	10,000 ft

Table No. 1: Meteorological aftercast for the Balbriggan area at the time of the accident

The meteorological information as provided to the Investigation was derived from a number of sources to give the best estimate of conditions for the Balbriggan area with a bias towards the most representative stations at Dublin Airport and Dunsany. When converted, a surface windspeed of 10 Knots is equivalent to 5m/s.

1.13 Notification of Accidents

SI No. 460 of 2009 defines an accident as:

> *' … an event associated with the operation of an aircraft with the intention of flight which, in the case of manned aircraft, takes place from the time any person boards the aircraft with the intention of flight until such time as all persons have disembarked, or in the case of unmanned aircraft, takes place between the time the aircraft is ready to move for the purpose of flight until such time it comes to rest at the end of the flight and the primary propulsion system is shut down, in which—*
>
> […]

[15] **Okta:** Unit of cloud amount, expressed as number of eighths of the sky dome that is covered by clouds.

(b) the aircraft sustains damage or structural failure which —

(i) adversely affects the structural strength, performance or flight characteristics of the aircraft and

(ii) would normally require major repair or replacement of the affected component,'.

SI No. 460 of 2009 states the following regarding the reporting of occurrences:

'9. (1) When an accident or serious incident to which these Regulations apply occurs, the pilot in command, or if he or she is incapacitated, the operator of the aircraft, shall, as soon as practicable, send notice of the accident or serious incident to the Chief Inspector at the AAIU by the most rapid practicable means available and, in the case of an accident, shall also immediately notify An Garda Síochána or, if it occurs outside the State, the appropriate local authorities.'

SI No. 24 of 2023 which was published subsequent to the accident, states the following regarding the reporting of accidents and incidents involving Unmanned Aircraft Systems:

'12. In the case of an accident or serious incident, the operator of the UAS shall immediately notify the UAS Division of the Authority, an Garda Síochána, and in accordance with the Air Navigation (Notification and Investigation of Accidents, Serious Incidents and Incidents) Regulations 2009, the Air Accident Investigation Unit.'

The Operator contacted the IAA on the day of the accident, however, due to a misunderstanding of the requirements to contact the AAIU by the most rapid practical means available, there was a delay before an Investigation could be initiated. The AAIU operates a 24 hour emergency telephone service, details of which are available on its website.

2. ANALYSIS

2.1 The Accident Flight

The Operator was issued with a LUC by the IAA on 20 May 2021 and commenced commercial operations delivering small packages to addresses in the Balbriggan area. On the day of the accident, the UA was conducting a local delivery flight in good visibility and within the specified wind limitations. The UA ascended normally to its cruising height and proceeded on a north-easterly track when, approximately 52 seconds into its flight, a propeller blade separated from the rear-right upper electric motor and struck an individual on the ground causing a minor injury, while a blade fragment reportedly landed on a second individual who was uninjured. The propeller blade separation caused severe vibrations in the UA due to an imbalanced condition, which led to a failure of the rear-right lower electric motor. The RP received a series of warnings on their tablet device as the UA attempted a SRTL manoeuvre to return the UA to its base of operations.

Automatic control of the UA was subsequently lost, the FTS and warning siren activated, and the parachute deployed. A witness observed the UA in an unusual attitude as it descended under canopy. Data provided by the Operator indicated that prior to parachute inflation, the UA's rate of descent was 8.5 m/s. This reduced to 4.9 m/s which indicates that the Parachute Recovery System operated as designed. The UA impacted the ground near a public footpath and sustained minor damage. The Operator's ERP was initiated, and the UA was recovered to the Operator's base of operations prior to the AAIU becoming aware of the accident.

2.2 Metallurgical Analysis

The Operator's own analysis as to the root cause of the accident was a '*fatigue failure*' of a propeller retaining bolt. The Operator stated that some weeks before the accident, a new bolt tightening procedure was introduced at their Balbriggan base, which in their opinion resulted in an over-torquing of the retaining bolts.

Independent metallurgical analysis stated that the cause of the failure was that the bolt had suffered a fatigue fracture with '*no apparent pre-existing material defects*', with the fatigue fracture occurring under a cyclic load spectrum of relatively low amplitude, with a high number of cycles to failure (high-cycle fatigue) as described in **Section 1.8.2**. This was consistent with vibration. The independent analysis cited a common cause of fatigue fractures of threaded fasteners which are subject to vibrational loading, as insufficient assembly torque. When a propeller retention bolt is correctly torqued (tightened) it would not normally encounter significant fluctuating loads from the propeller. However, the bolt would be subjected to fluctuating loads while operating at a reduced torque, which would be conducive to high-cycle fatigue.

The Investigation acknowledges that subsequent to the accident, the Operator revised their bolt tightening procedure and that all bolts in operation at the time of the accident were removed from service and destroyed. Furthermore, the Operator redesigned the propeller hub with what they described as a *'failsafe'* mechanism which would prevent the separation of a propeller blade from the hub in the event of a retaining bolt failure. The Investigation notes that this redesign involved the replacement of the manufacturer's original mounting plates (as supplied with the propellers) with mounting plates of the Operator's own design.

2.3 Propeller Manufacturer's Caution

The AAIU sought clarification from the propeller manufacturer on what was stated on their website in relation to the subject propellers. Its response was very specific, insofar as they are not suitable for coaxial UAs due to the '[…] *complicated load condition of the coaxial configuration with the current materials used for the propeller'.*

The Operator informed the Investigation that it had conducted an analysis of a significant number of events and found that… *'Any failure recorded for the rotors were determined to be human error and not a system failure…'.* The GEN 3.8 is not a certified UA, nor was it required to be. However, given that this type of operation is used for commercial reasons, in an urban environment, the Investigation considers that operators should ensure that critical components of UAs should be used in accordance with the manufacturer's instructions.

Although the coaxial configuration was not contributory to the accident, the Investigation notes the Operator's commitment to redesigning the UA, which will involve oversight from the IAA. Therefore, the Investigation does not sustain a safety recommendation at this time.

3. CONCLUSIONS

3.1 Findings

1. The Operator was issued with a LUC by the IAA on 20 May 2021.
2. The UA did not have any airworthiness certification, nor was it required to.
3. The RP was not issued with a '*Practical Assessment Completion Certificate*' until after the accident.
4. During an urban delivery flight, a propeller blade separated from the UA striking an individual on the ground which resulted in a minor injury.
5. The UA's FTS activated, and the parachute deployed.
6. The UA impacted the ground in a public park and sustained some damage.
7. The AAIU was not notified of the accident as required by S.I. 460 of 2009.
8. Independent metallurgical analysis stated that a propeller retaining bolt had suffered a fatigue fracture, which had not initiated from a pre-existing material defect.
9. A common cause of fatigue fractures in threaded fasteners, which are subject to vibrational loading, is insufficient assembly torque.
10. The propeller manufacturer stated that the polymer propeller as used on the subject UA should not be used in a coaxial configuration.
11. The Operator subsequently redesigned the propeller hub.
12. The Operator has committed to changing from the current coaxial configuration to a new design consisting of a single propeller mounted on each arm.

3.2 Probable Cause

Fatigue failure of a bolt securing a propeller blade to the rear-right upper motor resulting in propeller blade separation from the hub.

3.3 Contributory Cause(s)

1. Insufficient torque (tightness) of the propeller blade retaining bolt.
2. Vibration induced failure of the rear-right lower motor which in turn triggered the onboard Flight Termination System and emergency parachute deployment.

- END -

In accordance with Annex 13 to the Convention on International Civil Aviation, Regulation (EU) No. 996/2010, and Statutory Instrument No. 460 of 2009, Air Navigation (Notification and Investigation of Accidents, Serious Incidents and Incidents) Regulation, 2009, the sole purpose of this investigation is to prevent aviation accidents and serious incidents. It is not the purpose of any such investigation and the associated investigation report to apportion blame or liability.

A safety recommendation shall in no case create a presumption of blame or liability for an occurrence.

Produced by the Air Accident Investigation Unit

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