民航意外調查機構
AAIA
Air Accident Investigation Authority

Loss of Control – Inflight

Investigation Report

Accident

Robinson R44 Clipper II, B-KTK,

Lam Kam Road

Hong Kong

19 May 2019

01-2024

AAIA Investigations

Pursuant to Annex 13 to the Convention on International Civil Aviation and the Hong Kong Civil Aviation (Investigation of Accidents) Regulations (Cap. 448B), the sole objective of the investigation and the Investigation Report is the prevention of accidents and incidents. It is not the purpose of the investigation to apportion blame or liability.

The Chief Inspector ordered an inspector's investigation into the accident in accordance with the provisions in Cap. 448B.

This accident Investigation Report contains information of an occurrence involving a Robinson R44 Clipper II helicopter, registration B-KTK, operated by Hong Kong Aviation Club, which occurred on 19 May 2019.

The National Transportation Safety Board of the United States of America (NTSB), being the investigation authority representing the State of Design and the State of Manufacture, the Civil Aviation Department (CAD), Hong Kong Aviation Club (HKAC), Robinson Helicopter Company (RHC), and Lycoming Engines provided assistance to the investigation.

Unless otherwise indicated, recommendations in this report are addressed to the regulatory authorities of the State or Administration having responsibility for the matters with which the recommendation is concerned. It is for those authorities to decide what action is taken.

This Investigation Report supersedes all previous Preliminary Report and Interim Statements concerning this accident investigation.

All times in this Investigation Report are in Hong Kong Local Times unless otherwise stated.

Hong Kong Local Time is Coordinated Universal Time (UTC) + 8 hours.

Chief Accident and Safety Investigator

Air Accident Investigation Authority

Transport and Logistics Bureau

Hong Kong

March, 2024

Synopsis

On 19 May 2019, the pilot (hereafter referred to as "the Pilot") of a Robinson R44 Clipper II helicopter, registration B-KTK, was returning to Shek Kong Airfield from a solo flight in the Tai Po area. At approximately 1725 hrs approaching the Kadoorie Gap at about 2,000 ft. above mean sea level (AMSL), the helicopter sustained an inflight breakup overhead Lam Kam Road.

The fuselage of the helicopter impacted the terrain on a private farm and botanic garden to the west of Tai Mo Shan Country Park. The fuselage ignited on impact and was partially destroyed by fire. The other components were scattered in the wreckage trail, which extended 500 metres back from the fuselage impact point.

No distress call was made by the Pilot who was fatally injured.

The investigation team has made one safety recommendation.

Contents

1. FACTUAL INFORMATION

1.1. History of the Flight

(1) On 19 May 2019, the Pilot of a Robinson R44 Clipper II helicopter (hereafter referred to as the R44 helicopter), registration B-KTK, was returning to Shek Kong Airfield from a solo flight in the Tai Po area.

(2) At 1723:48 hrs the Pilot advised Air Traffic Control (ATC) that B-KTK was approaching Shek Kong inbound. Both the Pilot and ATC acknowledged that the flight plan was cancelled at 1724:00 hrs.

(3) At 1724:08 hrs B-KTK was recorded at an altitude of approximately 2,000 ft on a track of 267° heading in the direction of Shek Kong airfield.

(4) The transponder[1] installed in the helicopter was probably selected to 'Standby' by the Pilot at 1724:48 hrs as the identification disappeared from the ATC radar screen at this time.

(5) At approximately 1725 hrs, overhead Lam Kam Road, heading south-west and approaching the Kadoorie Gap at about 2,000 ft. AMSL, the helicopter sustained an inflight breakup.

(6) No distress call was made by the Pilot.

(7) The fuselage of the helicopter initially impacted mature trees and came to rest on the terraced hillside on Kadoorie Farm and Botanic Garden, a private farm to the west of Tai Mo Shan Country Park.

(8) The helicopter fuselage ignited on impact and was partially destroyed by fire.

(9) The debris trail of the helicopter following the inflight breakup was scattered in a south-westerly direction beginning at Lam Kam Road, approximately 500 metres (m) from the fuselage impact point.

(10) The Pilot was fatally injured.

(11) There were no known witnesses to the initial inflight breakup.

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[1] Transponder - An aircraft's transponder (short for "transmitter-responder") is an electronic device on an aircraft that transmits a four-digit code which allows the aircraft to be identified by Air Traffic Control.

(12) A number of witnesses observed components of the post breakup of B-KTK descending and the subsequent impact of the main wreckage.

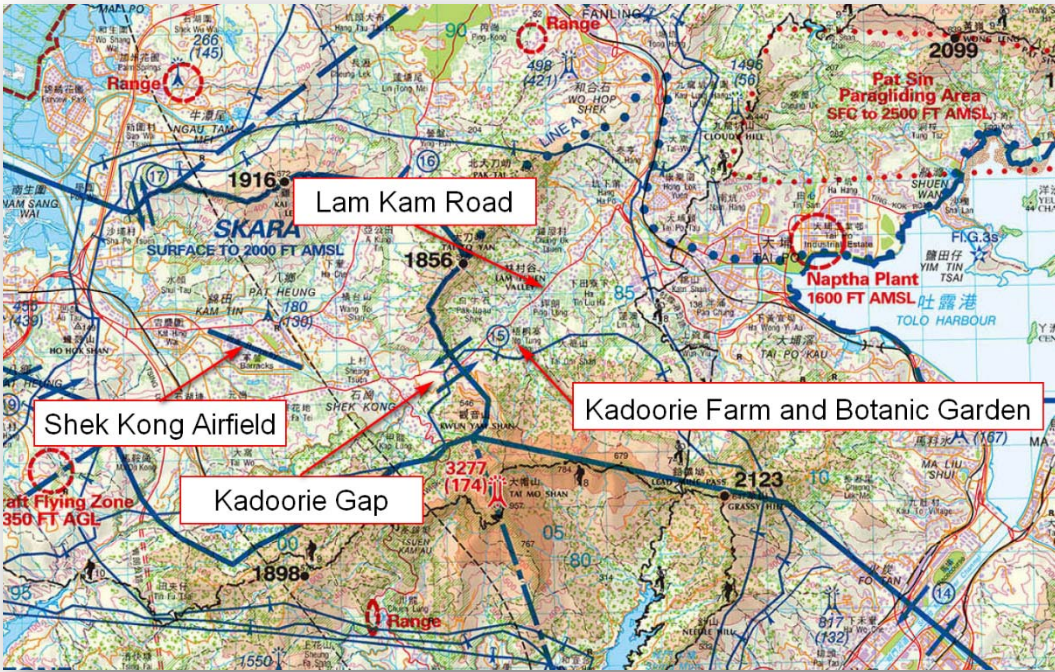

Figure 1: Accident and Wreckage Locations

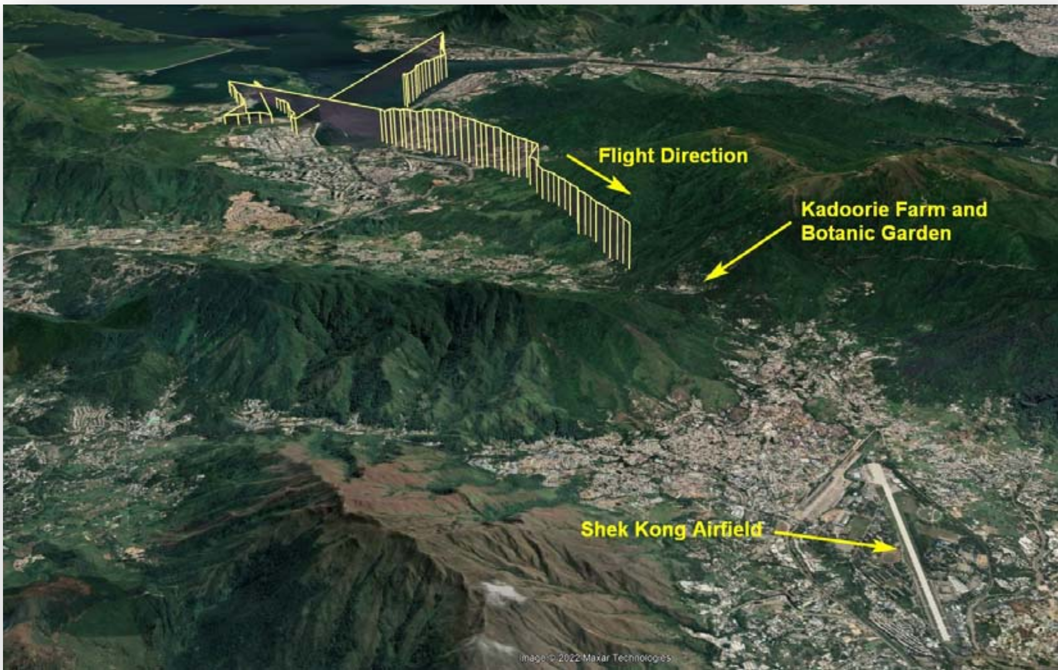

Figure 2: Radar Data Plots

1.2. Injuries to Persons

The Pilot was the only occupant of the aircraft and was fatally injured.

Injuries to Persons						
Persons on board:	Crew	1	Passengers	0	Others	0
Injuries	Crew	1	Passengers	0		

Table 1: Injuries to Persons

1.3. Damage - Aircraft

(1) The helicopter was destroyed during the inflight breakup and subsequent ground impact with a post-crash fire.

(2) The known wreckage debris trail extended approximately 500 m from where the fuselage impacted. Refer to 1.12 for details.

Figure 3: The Main Wreckage

1.4. Other Damage

The remaining section of fuselage impacted at a section of Kadoorie Farm and Botanic Garden damaging some of the facilities.[2]

1.5. Personnel Information

1.5.1. Pilot Information

1.5.1.1. Licence

(1) The Pilot held a valid Private Pilot's Licence (Helicopters) (PPL (H)), issued by the CAD on 16 May 2018.

(2) The Pilot held a valid Private Pilot's Licence (Aeroplanes) (PPL (A)), issued by the CAD on 14 Dec 2016.

(3) The Pilot's information is in Section 6.2.

1.5.1.2. Medical

The Pilot held a valid Class 2 Medical Certificate, with the limitation that '*corrective lenses to be worn and additional spectacles to be available*'.

1.5.2. Pilot's Training on R44

(1) The Pilot commenced a Robinson R22 helicopter flying course at the HKAC in April 2017. After completing the course, a Private Pilot's Licence (Helicopters) (PPL (H)) was issued by the CAD on 16 May 2018.

(2) The Pilot commenced flying the R44 helicopter after the issue of the PPL(H).

1.6. Aircraft Information

1.6.1. General

The R44 helicopter is a single-engined helicopter manufactured in the United States. The maximum gross weight for this helicopter is 2,500 lb. The airframe is primarily constructed of welded steel tubing covered with aluminium skin and is supported by a

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2 Kadoorie Farm and Botanic Garden (KFBG) is a conservation and education centre, which comprises facility buildings and a nature reserve over an area of 149 hectares.

skid type landing gear. The tail cone is a typical monocoque[3] aluminium structure. There are two front and two rear seats in the cabin. The helicopter is equipped with dual controls and certified for single pilot operations on the right front seat. Flight controls for the left front seat should be removed if the person occupying this seat is not a rated helicopter pilot.

1.6.2. Airworthiness and Maintenance of Aircraft

(1) The helicopter was a Robinson R44 Clipper II helicopter imported as a new aircraft to Hong Kong in 2008 and registered to a private owner. It was transferred to the HKAC in 2016. Aircraft technical records indicated that the helicopter had been maintained in accordance with Maintenance Schedule MS/R44/01 Issue 1 Revision 1 and there had not been any significant airworthiness problems. The most recent scheduled maintenance check was a 50-hour Inspection carried out on 1 March 2019. At the time of that inspection, the airframe and engine had each accumulated 1,302.8 flight hours since new.

(2) The helicopter had a valid certificate of airworthiness.

(3) During April 2019 engine maintenance was completed in accordance with the manufacturer's specifications by a company in Australia. Various parts were replaced and the engine was refitted in May 2019. A post maintenance flight check was carried out on 18 May 2019 which was satisfactory.

(4) A review of the Aircraft Log Book indicated that the helicopter had no outstanding defects prior to the accident flight.

(5) The aircraft details are in Section 6.3.

1.6.3. Powerplant and Transmission System

(1) The helicopter is powered by a Lycoming IO-540-AE1A5 fuel injected piston engine with a five-minute maximum take-off power rating of 245 brake horse power (BHP). The maximum continuous rating is 205 BHP. A pulley sheave (lower sheave) carried on the horizontal engine output shaft drives four vee-belts which transmit power to an upper sheave when the belts are tensioned by an electric screw jack clutch actuator.

(2) When activated, the actuator raises the upper sheave and automatically sets and maintains the required tension. An over-running clutch within the upper sheave transmits power forward to a main rotor gearbox and aft to

3 A structure in which the metal skin carries the torsional and bending stresses. It may be supported by bulkheads but has no longitudinal stiffeners.

a tail rotor drive shaft and also allows the rotors to continue to turn in the event of an engine stoppage.

(3) The main rotor gearbox contains a spiral-bevel gear set that drives a vertical main rotor shaft.

1.6.4. Main and Tail Rotors

(1) The semi-rigid main rotor system has two all-metal blades with stainless steel skin attached to a main rotor hub. The main rotor hub is mounted to the shaft with a horizontal teeter hinge located above the coning hinges. The main rotor rotation is anti-clockwise when viewed from above. Pitch-change bearings for the blades are enclosed in a housing at the respective blade root.

(2) The tail rotor system has two all-metal blades with aluminium skin. The tail rotor drive shaft, running inside the tail boom, transmits power to a splash-lubricated gearbox which in turn drives a horizontal tail rotor shaft. The two tail rotor blades are attached to a teetering hub with a fixed coning angle, elastomeric teetering and Teflon pitch-change bearings.

1.6.5. Flight Controls

(1) R44 has dual controls actuated through push-pull tubes and bellcranks. The cyclic grip is free to move vertically and hinges at the centre pivot of the cyclic stick. The collective stick is equipped with a twist-grip throttle control. The main rotor blade pitch angle is controlled by the cyclic stick and the collective stick.

(2) The cyclic and the collective control systems are assisted by three hydraulic servos connecting to the three push-pull tubes that support the main rotor swashplate. The hydraulic pump is powered by the main gearbox so that hydraulic pressure is maintained as long as the main rotor is rotating.

(3) Directional control is effected by varying the collective pitch of the tail rotor blades using yaw pedals which are connected to the tail rotor blades by push-pull tubes and bellcranks.

1.6.6. Hydraulic System

(1) The aircraft has hydraulically boosted main rotor controls that eliminate cyclic and collective feedback forces. The system is designed to enhance the pilot's comfort by reducing vibration from the rotor head to the controls and reduces the required input forces the pilot has to make.

(2) The system is controlled by a HYD/OFF switch on the pilot's cyclic control and can be deactivated by placing the switch to OFF. The Pilot's Operating Handbook (POH) [4] requires the hydraulic system to be operational for flight and normal operation is with the switch selected HYD.

(3) The hydraulic system is not required to incorporate an independent cockpit indication, such as a visual and/or aural caution or warning, to assist in the identification of a hydraulic system failure.

(4) In flight identification of a failure is indicated by heavy or stiff control forces. Control will be normal but there will be an increase in control forces. The emergency procedure is to verify that the switch is selected to HYD, then if the problem still exists to place the switch to OFF.[5]

1.6.7. Engine Controls

(1) The engine power is controlled by a twist-grip throttle located on either of the two interconnected collective sticks. When the engine revolutions per minute (RPM) is above 80%, the electronic governor will be activated to maintain a constant engine RPM for various flight control inputs and helicopter manoeuvres. While the governor drives the whole throttle system, including the twist-grip, the pilot may override the governor with the twist-grip through a friction clutch in the linkage between the governor and the whole throttle system.

(2) The governor system consists of two major components, namely the governor controller and the governor assembly. The governor controller is a solid-state analogue-circuit control unit which senses engine RPM via tachometer points in the engine right magneto and provides a corrective signal to the governor assembly. When activated by the governor controller, the governor motor drives a friction clutch connected to the throttle to maintain a constant engine RPM.

(3) The R44 POH specifies that flight with the governor selected 'OFF' is prohibited, except in the case of inflight malfunction of the system or for emergency procedures training.

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4 POH - A handbook issued by the aircraft manufacturer that describes the aircraft's systems in brief, provides checks and procedures, and indicates the actions to be taken in various contingencies. It also provides operating data and limitations.

5 Robinson POH Emergency Procedures on page 3-7 dated 21 Feb 2014

1.6.8. Performance and Centre of Gravity

The investigation team was unable to locate a record of any preflight calculation being completed before the flight.

1.6.9. Fuel

The investigation team has not been able to accurately ascertain the exact amount of fuel on board due to the breakup of the helicopter.

1.7. Meteorological Factors

1.7.1. Meteorological Aerodrome Report (METAR)

(1) There was no METAR[6] for Shek Kong. The nearest METAR available in the Hong Kong area was issued for Hong Kong International Airport (HKIA) at 1700 hrs and 1730 hrs respectively are as follows:

METAR VHHH 190900Z 20013KT 170V230 9999 FEW012 32/25 Q1005 NOSIG=
METAR VHHH 190930Z 20013KT 9999 FEW012 32/25 Q1005 NOSIG=

(2) The weather information can be interpreted as follows.

Wind	True direction = 200 degrees varying between 170 and 230 degrees; Speed = 13 knots
Visibility	10 kilometres or above
Cloud coverage	Few (1 to 2 oktas) at 1200 feet above aerodrome level
Temperature	32 degrees Celsius
Dewpoint	25 degrees Celsius
QNH	1005 hPa
NOSIG	No significant change

Table 2: Weather Information

[6] A METAR is a routine weather report issued at hourly or half-hourly intervals. It is a description of the meteorological elements observed at an airport at a specific time.

(3) There was no Special Weather Report (SPECI[7]) issued for significant deterioration or improvement in airport weather conditions during the period.

(4) Generally, a METAR should be representative over the whole operating area of the issuing aerodrome. In Hong Kong, a METAR is representative of conditions at HKIA, and for certain specified weather phenomena, in its vicinity, i.e. the area that lies within a radius of approximately 8 km and 16 km of the aerodrome reference point (ARP[8]). Shek Kong, the airfield the helicopter departed from and its intended destination is located 20 kilometres to the north east of HKIA. It does not have the facilities to issue METARs and is not required to.

(5) The Hong Kong Observatory (HKO) has anemometer stations, which measure the wind direction and speed, at Shek Kong airfield and at Tai Po Kau which is on the shoreline of Tolo Harbour. Recordings for the time of the accident are tabulated below.

Time (L)	10 minute mean wind direction (degrees)	10 minute mean wind speed (knots)	10 minute gust (knots)	1 minute gust (knots)
17:24	206	5	10	10
17:25	208	5	10	8
17:26	206	5	10	7

Table 3: Shek Kong Anemometer Station

Time (L)	10 minute mean wind direction (degrees)	10 minute mean wind speed (knots)	10 minute gust (knots)	1 minute gust (knots)
17:24	Variable	6	15	7
17:25	Variable	6	15	5
17:26	228	5	13	12

Table 4: Tai Po Kau Anemometer Station

[7] A SPECI is a special weather report issued when there is significant deterioration or improvement in airport weather conditions, such as significant changes of surface winds, visibility, cloud base height and occurrence of severe weather.

[8] HK AIP GEN 3.5 Section 3.5 https://www.ais.gov.hk/HKAIP/aipall.pdf

1.8. Navigation Aids

The flight was conducted in daytime under Visual Flight Rules (VFR) and the helicopter was appropriately equipped with navigation aids for such a flight.

1.9. Communications

(1) The accident took place at Lam Kam Road near Kadoorie Farm and Botanic Garden, which is within one of the seven Uncontrolled Airspace Reporting Areas (UCARAs) in Hong Kong.

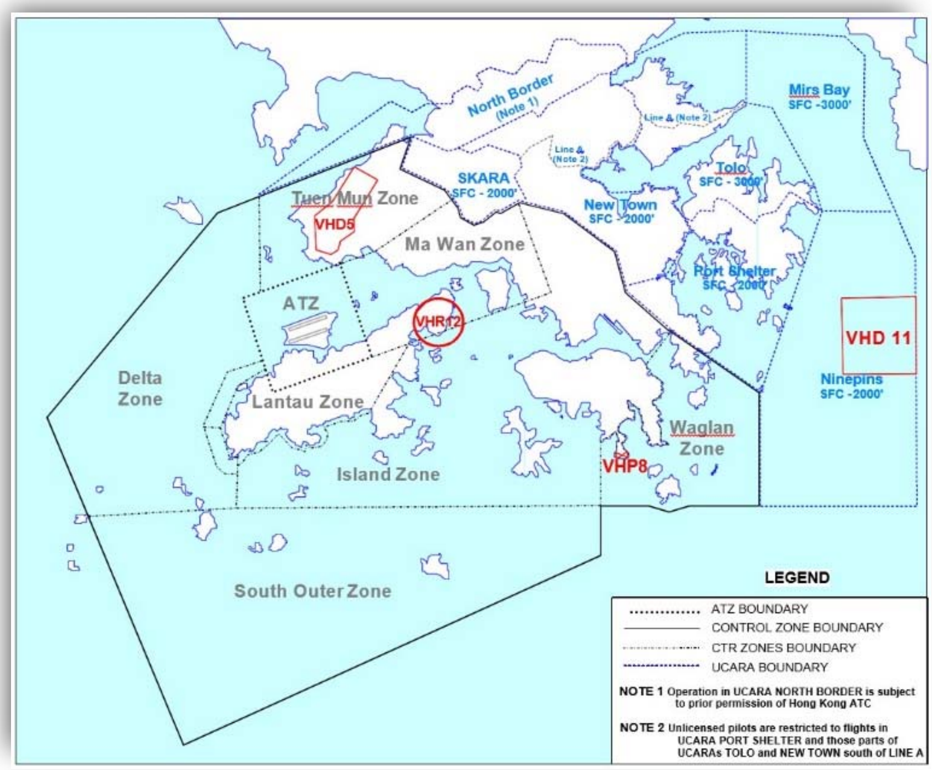

Figure 4: The Control Zone and Uncontrolled Airspace Reporting Areas

(2) In UCARAs, 'Hong Kong Information' is the Hong Kong Air Traffic Service (ATS) unit that provides Flight Information Service (FIS)[9] and alerting service to aircraft. In accordance with the provisions of the Hong Kong Aeronautical Information Publication (HK AIP) issued by the CAD, local flights are permitted to take place under VFR in UCARAs, but with an

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9 FIS refers to a service provided for the purpose of giving advice and information useful for the safe and efficient conduct of flights. Alerting service refers to a service provided to notify appropriate organizations regarding aircraft in need of search and rescue aid, and assist such organizations as required.

additional requirement for two-way radio communication with 'Hong Kong Information' on the designated VHF frequency 122.4 MHz.

(3) The helicopter was fitted with a VHF radio communication equipment and the radio was serviceable on the day of the accident. The helicopter had been maintaining satisfactory communication with 'Hong Kong Information' during the flight. The last communication with 'Hong Kong Information' made by the helicopter was at 1723:48 hrs when the Pilot advised that B-KTK was approaching Shek Kong inbound. This transmission was acknowledged by 'Hong Kong Information'. The helicopter disappeared from the radar screen 40 seconds later.

1.10. Aerodrome Information

(1) The helicopter took off from Shek Kong Airfield and was returning to land. The accident site is a conservation and education centre open for the general public.

(2) The airfield information is listed in Section 6.4.

1.11. Flight Recorders

The helicopter was not fitted with any flight recorder and there was no requirement for this class of helicopter to be so fitted.

1.12. Wreckage and Impact

(1) The trail and the cluster patterns of the recovered debris aided in understanding the relative sequencing of the helicopter breakup. The trail covered a rectangular area of approximately 500 m x 100 m from the start in a south-westerly direction to the most south-westerly end at Kadoorie Farm where the main wreckage impacted.

(2) The location of debris on the ground was determined by when the debris separated from the helicopter and how far the object travelled down the trail. Given factors like shape, size, and wind effect constant, heavier pieces travelled farther than lighter ones to the southwest.

(3) The heaviest section of the helicopter wreckage consisting of the engine was found at end of the trail.

1.12.1. Main Wreckage

(1) The main wreckage consisting of the middle fuselage and the main rotor system landed on a terrace slope in Kadoorie Farm. It ignited on impact and was mostly consumed by fire.

(2) The majority of the cabin was consumed by fire. A portion of the centre tunnel and forward floor remained tethered by wires and cyclic controls. The high pressure cylinder for the pop out floats remained with this section of cabin structure and sustained thermal damage.

(3) Seat belt components were recovered with the main wreckage and sustained extensive thermal damage.

(4) The tail rotor pedals were with the main wreckage and sustained thermal damage with the exception of the pilot side right pedal, which was recovered separately (see Figure 5). The surface of the fracture was angular and jagged. The adjustable portion of the pedal remained in the pedal socket although the retaining pip pin was no longer present. The pip pin was sheared and the head was located inside the pilot's cyclic grip. The left pedal pip pin remained in the left pedal. Impact marks suggest that the rotor blade impacted the pedal.

Figure 5: Pilot Side Right Tail Rotor Pedal

(5) The cyclic cross tube was disconnected from the pivot point and the cyclic grip was disconnected from the cross tube. The lower cyclic stick remained with the main wreckage and sustained thermal damage. The cross tube and grip pieces were recovered in the debris field with no thermal damage. The collective control remained with the main wreckage and sustained thermal damage. The collective friction slider hardware sustained extensive thermal damage rendering collective position undetermined.

(6) The fuel shut off control knob was separated and sustained minor thermal damage.

1.12.2. Damage to the Cockpit

(1) The upper and lower instrument panels, the console visors and portions of the supporting keel panels were recovered separately. Several instruments were separated from the upper panel and the wires and hose connections were all aggressively disconnected from the lights and instruments leaving the terminals and connectors damaged. Several warning lights sustained impact damage.

(2) The lower panel sustained direct impact damage separating the panel into several sections and leaving a dent in the right side of the instrument cluster which appeared to match the size and shape of the leading edge of the main rotor blade. The wires remaining attached to the lower panel were also aggressively disconnected or damaged along with associated switches, lights, and instruments. The avionics were recovered with the main wreckage and sustained only thermal damage.

(3) Components located near the nose of the cabin such as the fire extinguisher, the compass, the POH, and the optional Global Positioning System (GPS) console were recovered in the debris field, all with impact damage.

(4) The forward right seat bottom and the forward right floor carpets were recovered separately from the main wreckage with no thermal damage.

(5) The lower instrument panel sustained direct impact damage separating the panel into several sections and leaving a dent in the right side of the instrument cluster which appeared to match the size and shape of the leading edge of the counter clockwise rotating main rotor blade (see Figures 6 and 7).

Figure 6: Lower Instrument Cluster

Figure 7: Dent in Right Side of Instrument Cluster

(6) The witness marks on the windshield frame, the impact dent on the right of the lower instrument panel, and the yellow paint transfer from the rotor blade revealed that the advancing main rotor blade (i.e. the forward

moving blade at the starboard side of the rotor plane viewed from above) had flapped down to this extreme angle (see Figures 8 and 9).

Figure 8: Yellow Paint Transfer on Cockpit Canopy Bow

Figure 9: Yellow Paint Transfer on the Cockpit Structure

(7) It is highly likely that the front of the cockpit had been hit by the diverged advancing blade at the initial breakup of the helicopter.

1.12.3. Damage to Main Rotor

(1) Main rotor blade serial number 4684 had a disconnect 2 feet from the hub with a downward bend in the spar. At 6 feet from the tip, it had a disconnect in the spar with upward bending and there was approximately 15 inches of afterbody separated from the blade with many dents and scuff marks running chordwise throughout the area. The fractured surfaces at the disconnects were angular and jagged.

(2) In the area of disconnection, yellow paint transfer was evident (see Figure 10).

Figure 10: Main Rotor Blade Section

(3) Main rotor blade serial number 4686 was bent upward approximately 80° at 3 feet from the hub with a partial fracture of the spar and another upward bend approximately 70° at 7 feet from the hub. The spar was completely fractured along with a portion of the afterbody, which was bent downward approximately 45° at 3 inches from the tip. The surface of the fractures were angular and jagged. There were multiple creases running chordwise along the length of the blade. The trailing edge sustained impact damage.

(4) The damage to the cabin and main rotor blades indicated that one of the blades had entered the cabin under rotation. The outboard section of this blade had broken off when the leading edge made contact.

(5) Both elastomeric teeter stops were damaged and had split in the middle in this accident (see Figure 11).

Figure 11: Teeter Stops of B-KTK

1.13. Medical/Pathological Information

1.13.1. Medical Certificate

The Pilot held a valid Class 2 Medical Certificate issued by the CAD in accordance with Annex 1 to the Convention on International Civil Aviation, with a limitation – '*Corrective lenses to be worn and additional spectacles to be available*'.

1.13.2. Pathology

An autopsy conducted by a forensic pathologist of the Department of Health indicated that the direct cause of death of the Pilot appeared to be multiple injuries.

1.14. Smoke, Fire, and Fumes

The remaining section of the fuselage was destroyed by the impact and the intense fire which followed.

1.15. Survival Aspects

1.15.1. Seat Restraints / Harnesses

The Pilot was found restrained by a four-point harness[10] which was found intact. The attachment points of the harness were attached to the aircraft structure with no damage. Due to the injuries received prior to impact, the accident was not survivable.

10 This provides two shoulder straps, which are attached to the lap section of the seatbelt at the respective buckle and latch.

1.15.2. Search and Rescue

No search and rescue was required as a result of this occurrence. The police and firemen arrived at the scene shortly after the accident occurred.

1.16. Tests and Research

1.16.1. Metallurgical Investigation of Pitch Change Link

1.16.1.1. Initial Metallurgical Examination

The upper rod ends of both pitch change link[11] assemblies were found broken. Non-destructive examinations were conducted on the fracture surfaces using a scanning electron microscopy (SEM) and an energy dispersive x-ray (EDS) Microanalyser in a Hong Kong laboratory. The results were communicated verbally to the AAIA in early January and the report was received on 15 January 2021. It observed metallurgical features and opined that fatigue cracking was initiated with a very small propagation rate.

Figure 12: Broken Pitch Change Links

1.16.1.2. AAIA Communication with the CAD

(1) The AAIA communicated with the CAD on 11 January 2021 advising that the draft metallurgical examination undertaken by a Hong Kong laboratory concluded that the fracture of the upper rod end links involved crack propagation.

[11] Pitch change link is the term used in the report. It can also be referred to as 'pitch link assembly' and 'pitch link rod'.

(2) The CAD proactively issued a CAD Safety Information Bulletin – Airworthiness (SIB) No. 2021-01 on 29 January 2021 for the upper rod ends of both pitch link assemblies to operators/owners of R44/R44 II & R66 helicopters in Hong Kong.

(3) The SIB recommended two proactive safety measures on the pitch link assemblies. Regardless the part-numbers of the pitch link assemblies installed on R44/R44 II (SL-58) and R66 (SL-20) helicopters, operator/owner should consider either of the following safety measures and proactive maintenance actions:

(a) Carry out Magnetic Particle Inspection (MPI) in accordance with RHC Maintenance Manual on the upper rod end threaded portion of the pitch link assemblies; or

(b) Replace the pitch link assemblies[12] with P/N C258-5 in pair per the above-mentioned RHC Service Letters with new assemblies.

1.16.1.3. AAIA Communication with the FAA

On 18 January 2021, the investigation team issued a Safety Recommendation Report (01-2021) to the Federal Aviation Administration (FAA) advising them to ask RHC to review the service life and the continuing airworthiness requirements, including but not limited to maintenance inspection requirements, of the main rotor pitch change link assemblies on Robinson R44 helicopters.

1.16.1.4. NTSB Metallurgical Examination

(1) In order to further augment the analysis, the link assemblies were later sent to the NTSB[13] materials laboratory for non-destructive examination with a field emission scanning electron microscope (FESEM).[14]

(2) After further analysis, the NTSB determined that the collective metallurgical features observed macroscopically and microscopically on the fracture surfaces were consistent with overstress fracture. End remnants A-D fractured from bending overstress (see Figure 13). End

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12 The Robinson Service Letters referred that pitch link assembly part had been superseded by a new part number.

13 The NTSB (National Transportation Safety Board) is an independent USA government investigative agency responsible for civil transportation accident investigation.

14 Field emission scanning electron microscopy (FESEM) provides topographical and elemental information at magnifications of 10x to 300,000x, with virtually unlimited depth of field. Compared with convention scanning electron microscopy (SEM), field emission SEM (FESEM) produces clearer, less electrostatically distorted images with spatial resolution down to 1 1/2 nanometers – three to six times better.

remnants B-C fractured from torsional overstress (see Figure 14). The NTSB did not observe any features consistent with indications of pre-existing cracking.

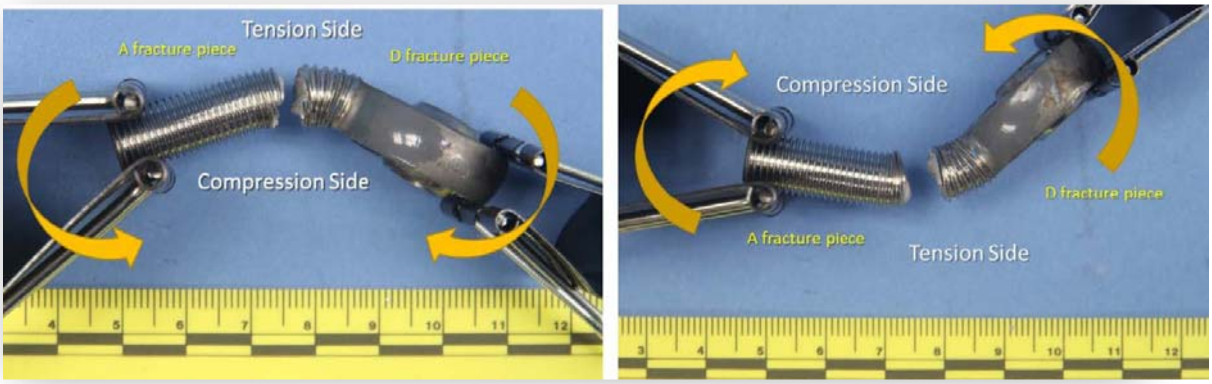

Figure 13: End Remnants A-D

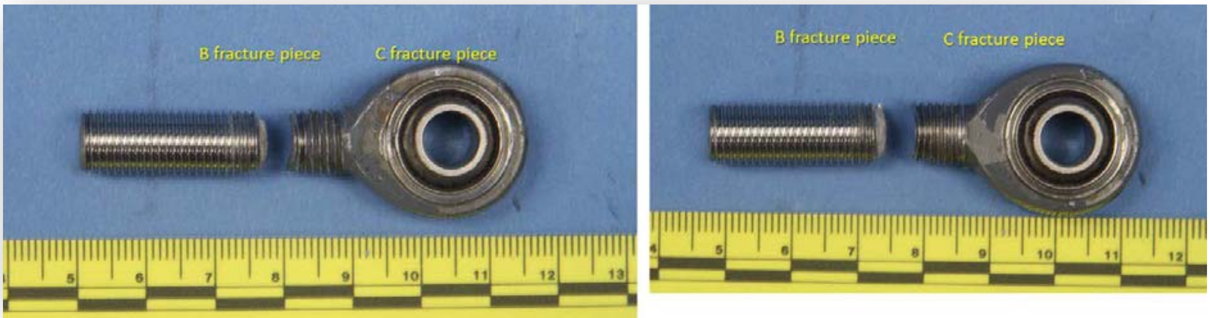

Figure 14: End Remnants B-C

(Source: NTSB Materials Laboratory Report. 21 April 2022)

1.16.2. Engine Maintenance before the Accident

(1) The engine was uninstalled and sent to an engine maintenance facility in Australia in April 2019.

(2) This action was taken after an analysis of the oil filter and suction screen was carried out. There was a high concentration of copper particles found and the HKAC took the decision to diagnose the problem.

(3) Lycoming in their IO-540 Series maintenance manual advises what measures to take if certain materials are found. The Bushings, Camshaft and Crankshaft are possible problem sources if copper is found.

(4) There was a large amount of copper detected so the HKAC decided to get a 'bulk strip' done. A 'bulk strip' is a precautionary or diagnostic inspection in which parts will be replaced if they are worn or broken.

(5) In the process various major parts were replaced including the crankshaft front bearing.

(6) The engine was returned to Hong Kong and reinstalled in B-KTK on 18 May 2019.

(7) A test flight was performed on 18 May 2019 which was noted as satisfactory.

(8) According to the aircraft maintenance log books the magnetos were replaced when the aircraft had flown 1,202 hours on 17 Nov 2018.

1.16.3. Post-Accident Engine Inspection by the Manufacturer

(1) The engine was sent to the manufacturer, Lycoming Engines, at their facility in the USA, where the engine was disassembled and inspected. This was completed with oversight from the FAA.

(2) During the inspection it was found that the left hand magneto was not sparking at the leads. A carbon brush inside the left magneto[15] was not making contact and two of the wire connections were not connected. Lycoming advised that the carbon brush wedging in the gear may have been a result of the impact sequence.

(3) As aero engines have redundancy by having dual magnetos, in the event of one malfunctioning the engine will continue to operate via the remaining magneto.

(4) The right magneto was tested at the AAIA facilities and all indications were that it would have operated normally.

(5) No defect was found that would have prevented the engine from delivering power prior to the breakup and impact sequence.

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[15] A magneto is a self-contained electrical generator that uses magnets to produce a high voltage current that fires the engine spark plugs. Aircraft piston engines are designed with two independent ignition systems - two spark plugs per cylinder. Likewise, there are two magnetos, left and right. The left aircraft magneto fires one plug per cylinder, while the right aircraft magneto fires the other. This redundant system ensures that the ignition will keep sparking even if one magneto fails.

1.17. Organisation, Management, System Safety

1.17.1. Hong Kong Aviation Club

(1) The HKAC is a private members club operating from Shek Kong Airfield. As a private members club, under the current legislation, the HKAC is not required to hold a flying training organisation approval issued by the CAD for its operations.

(2) It is an HKAC requirement that prior to each flight all pilots certify that their aircrew licences are valid and that they have read and understood all relevant flying notices, orders, and NOTAM[16] by signing the aircraft Flight Authorisation Log (FAL). Local aviation weather forecast and reports (METAR/SPECI) issued by HKO are reviewed by pilots during flight preparation.

1.18. Additional Information

1.18.1. Mast Bumping

(1) Mast bumping occurs when a portion of the rotor system (two blades connected by the hub) exceeds the teetering limit and strikes the mast of the helicopter, usually with sufficient force to cause mast deformation or mast failure.[17]

(2) Masts used on semi-rigid rotors are susceptible to mast bumping which is the action of the semi-rigid rotor head striking the mast and the result of excessive rotor flapping. Each rotor system design has a maximum flapping angle. If flapping exceeds the design value, the teeter stop, a component of the main rotor providing limited movement of strap fittings and a contoured surface between the mast and hub, will contact the mast. The violent contact between the teeter stop and the mast during flight causes mast damage or separation. This contact must be avoided at all times[18].

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[16] A NOTAM (Notice to Airmen) is a notice containing information, not known far enough in advance to be publicised by other means, concerning the establishment, condition or change in any aeronautical facility, service, procedure or hazard, the timely knowledge of which is essential to personnel concerned with flight operations.

[17] NTSB/SIR-96/03 Special Investigation Report Robinson Helicopter Company R22 Loss of Main Rotor Control Accidents.

[18] FAA Helicopter Flying Handbook FAA-8083-21B 4-3

(3) The R44 rotor head design has a maximum teetering angle controlled by a teeter stop, an elastomeric pad mounted between the hub (spindle) and mast, preventing the hub (spindle) from contacting the mast. If the teetering of the hub becomes excessive, it will damage the teeter stop, allowing mast bumping to occur. With each revolution of the rotor, the teetering becomes more excessive and more violent. The violent mast bumping quickly causes damage to, or separation of, the mast.

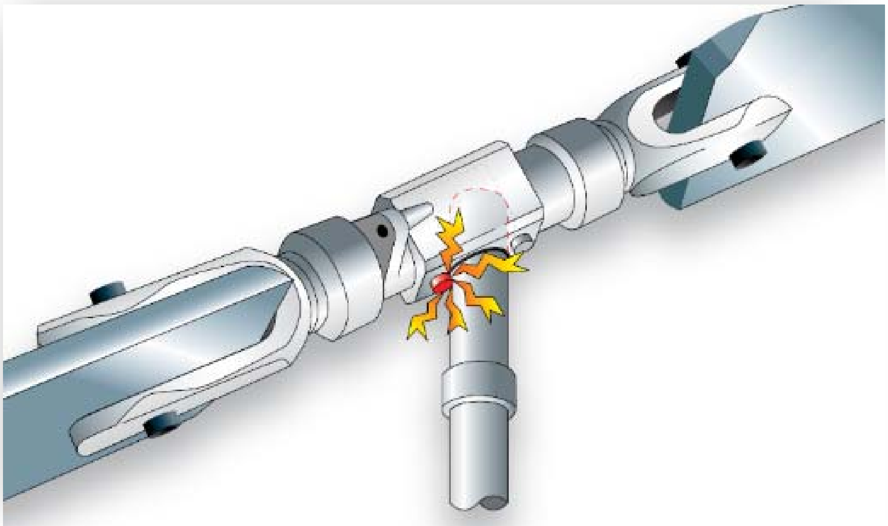

Figure 15: Mast Bumping

Figure 16: R44 Main Rotor Head

(*Source: https://commons.wikimedia.org/wiki/File:R44_rotorhub.jpg*)

(4) Mast bumping is directly related to how much the blade system flaps. In straight and level flight, blade flapping is minimal, perhaps 2° under usual flight conditions. At low rotor RPM, high-density altitudes, or high gross weights, and when encountering turbulence, flapping angles increase

slightly with high forward speeds. Manoeuvring the aircraft in a sideslip or during low-speed flight at extreme Centre of Gravity (CG)[19] positions can induce larger flapping angles.

1.18.2. Inflight Breakup

(1) The conditions that can lead to inflight breakups are known to manufacturers and safety and accident investigation bodies. Factors that can each lead to an inflight breakup in a Robinson are:

- *main rotor RPM below the normal operating range (low main rotor RPM)*
- *abrupt or inappropriate cyclic control movements*
- *Low-G conditions resulting in mast-bumping[20].*

(2) In accidents attributed to main rotor RPM below the normal operating range (low main rotor RPM), leading to a rotor stall, there is evidence of the rearward travelling rotor blade impacting the tail and separating the tail boom which did not occur in this case.

(3) The damage to the helicopters main rotor blades, teeter stops and blade spindles are indicative that extreme teetering occurred prior to the inflight breakup.

(4) Mast bumping is the contact between an inner part of a main rotor blade or a rotor hub and the main rotor drive shaft (or ‘mast’). This can occur when the main rotor teeters (or see-saws) beyond the normal operating limits and repeatedly contacting the main rotor driveshaft (or ‘mast’).

(5) In a typical case of mast-bumping the teeter stops are crushed, the mast itself is contacted, control is lost and an inflight breakup occurs which is fatal for those on board.

(6) A significant proportion of mast bumping accidents have been found to have occurred in ‘Low-G’ flight conditions[21]. Because they are normally fatal the available evidence has not allowed the circumstances and causes of all of these ‘mast bumping’ accidents to be fully determined.

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19 FAA Helicopter Flying Handbook FAA-8083-21B 4-3

20 Low-G is a weightless flight condition. Robinson Helicopter Company Safety Notice SN-11 revision Nov 2000

21 TAIC NZ Watchlist - Robinson helicopters: Mast bumping accidents in NZ Updated 2021 https://www.taic.org.nz/watchlist/robinson-helicopters-mast-bumping-accidents-nz

(7) Helicopters with semi-rigid two-bladed main rotor systems, as used on Robinson helicopters, are particularly susceptible to an uncommanded right roll in “Low-G” conditions, which if the pilot does not recover from can lead to mast bumping.

(8) Low-G can be caused by;

- *Large or abrupt flight control inputs*
- *Turbulence.*

(9) The risk of Low-G conditions in turbulence increases with high power settings and operating at high speed and lightweight.

(10) Low-G conditions can arise in turbulence. Areas of Hong Kong have significant high terrain and coupled with wind conditions can produce turbulence especially on the lee[22] side of rising terrain.

1.18.3. Low-G Conditions

(1) Helicopters rely on positive G to provide much or all of their response to pilot control inputs. The pilot uses the cyclic to tilt the rotor disk, and, at one G, the rotor is producing thrust equal to aircraft weight. The tilting of the thrust vector provides a moment about the centre of gravity to pitch or roll the fuselage. In a Low-G (weightless) condition, the thrust and consequently the control authority, as perceived by the pilot, are greatly reduced. Helicopters with two-bladed teetering rotors rely entirely on the tilt of the thrust vector for control. Therefore, Low-G conditions can be catastrophic for two-bladed helicopters if proper recovery techniques are not applied.

(2) An abrupt forward cyclic input or pushover in a two-bladed helicopter can be dangerous and must be avoided, particularly at higher speeds. During a pushover from moderate or high airspeed, as the helicopter noses over, it enters a Low-G condition. Thrust is reduced, and the pilot has lost control of fuselage attitude but may not immediately realise it. Tail rotor thrust or other aerodynamic factors will often induce a roll. The pilot still has control of the rotor disk, and may instinctively try to correct the roll, but the fuselage does not respond due to the lack of thrust. If the fuselage is rolling right, and the pilot puts in left cyclic to correct, the combination of fuselage angle to the right and rotor disk angle to the left becomes quite large (extreme teetering) and may exceed the clearances built into the rotor hub. This results in mast bumping.

[22] World Meteorological Organisation WMO https://cloudatlas.wmo.int/en/orographic-influence-on-the-leeward-side.html

(3) Turbulence, especially severe downdrafts, can also cause a Low-G condition and, when combined with high airspeed, may lead to a very rapid right roll, and with an inappropriate control reaction from the pilot, mast bumping will possibly be induced. During flight in turbulence, momentary excursions in airspeed, altitude, and attitude are to be expected. Pilots should respond with smooth, gentle control inputs and avoid over controlling. Most importantly, pilots should slow down, as mast bumping is less likely at lower airspeeds.

(4) Low-G mast bumping has been identified in numerous fatal accidents. The accident sequence may be extremely rapid, and the energy and inertia in the rotor system can sever the mast or allow rotor blades to strike the canopy and the tail.

(5) Pilots can avoid mast bumping accidents in semi-rigid two-bladed helicopters as follows[23]:

(a) Avoid abrupt forward cyclic inputs. Fixed wing pilots may find this a difficult habit to break because pushing the nose down is an accepted collision avoidance manoeuvre in an aircraft. Helicopter pilots would accomplish the same rapid descent by lowering the collective, and pilots should train to make this instinctual.

(b) Recognize the weightless feeling associated with the onset of Low-G and quickly take corrective action before the situation becomes critical.

(c) Recognize that an uncommanded right roll for helicopters with main rotors which rotate counter-clockwise when viewed from above indicates that loss of control is imminent, and immediate corrective action must be taken.

(d) Recover from a Low-G situation by first gently applying aft cyclic to load the rotor before attempting to correct any roll.

(e) If turbulence is expected or encountered, reduce power and use a slower than normal cruise speed. Turbulence (where high rotor flapping angles are already present), and higher airspeeds (where the controls are more sensitive) both increase susceptibility to Low-G conditions and a more rapid right roll.

[23] FAA Helicopter Flying Handbook FAA-8083-21B 11-15

1.18.4. Safety Tips and Notices in Pilot's Operating Handbook

(1) For Low-G and mast bumping, the POH recommends pilots to review the following safety tips:

- *Avoidance*
  - *Reduce airspeed in turbulence*
  - *Monitor airspeed when lightly loaded*
  - *Ensure passenger controls are removed*
- *Recognition and recovery*

(2) In addition, the following Safety Notices are included in the POH:

- *SN-11 Low-G Pushovers - Extremely Dangerous*
- *SN-29 Airplane Pilots High Risk When Flying Helicopters*
- *SN-32 High Winds or Turbulence*

1.19. Useful or Effective Investigation Techniques

Not applicable in this investigation.

2. Safety Analysis

The Safety Analysis provides a detailed discussion of the safety factors identified during the investigation, providing the evidence required to establish the findings, causes, contributing factors and the safety recommendations.

2.1. Introduction

(1) The flight originated as a proficiency check flight for the Pilot. This was carried out by an HKAC Instructor.

(2) During the check flight, a series of manoeuvres were flown. There were three repeats on two of the exercises, including an autorotation but were eventually completed to a satisfactory standard and the Pilot was released for the solo flight[24].

(3) The instructor conducted the Pilot's check and after thirty minutes they landed back at the club area where the instructor exited the helicopter with the engine running and the Pilot then departed on the accident flight.

(4) There are no indications that the local flight was anything but normal until enroute, returning to Shek Kong and approaching the Kadoorie Gap, a catastrophic inflight breakup occurred.

2.2. Engineering

2.2.1. Powerplant

(1) The powerplant was sent to the manufacturer, Lycoming for examination.

(2) According to the aircraft maintenance log books the magnetos were replaced when the aircraft had flown 1202 hours on 17 Nov 2018.

(3) The report did not reveal any faults to indicate that the engine malfunctioned or was operating outside normal parameters.

(4) The governor switch was in the ON position. There was no evidence to suggest the main rotor RPM was below the normal operating range (low

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24 Instructor's interview

main rotor RPM) and the helicopter suffered a rotor stall at the time of the accident.

2.2.2. Fuel

The investigation team has not been able to accurately ascertain the amount of fuel on board the accident flight.

2.2.3. Hydraulic System Failure

(1) If the system did fail in flight this could have led to a temporary distraction whilst the Pilot went through the procedure.

(2) The control switch was found in the OFF position. The backshell of the switch assembly had impact damage and could be rotated freely shifting the switch position between HYD and OFF.

(3) The investigation team was unable to determine if the Hydraulic OFF switch position was due to Pilot input or impact damage.

2.2.4. Cyclic and Collective Control Friction Device

(1) The cyclic and collective controls are equipped with adjustable friction devices. The cyclic friction knob is located left of the cyclic stick. Cyclic friction is normally applied only on the ground[25].

(2) These devices allow the pilot to adjust the amount of force, which is required to move the controls. Evidently, it is the practice with some pilots to tighten them to reduce the possibility of making an abrupt control input especially in turbulence. The tighter the friction device, any input is more restrictive and conversely if it is loose little input is required for a large control movement.

(3) It is not possible to ascertain the setting or if the Pilot adjusted it before departure.

2.2.5. Possible Magneto Failure

(1) A magneto is a self-contained electrical generator that uses magnets to produce a high voltage current that fires the engine spark plugs. Aircraft piston engines are designed with two independent ignition systems.

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[25] Robinson POH Systems Description 7-6 13 May 2009

(2) The two independent ignition systems provide redundancy. If a magneto fails in flight it may not be noticeable initially; there will be a slight decrease in engine power but the engine will keep running on the remaining magneto.

(3) A magneto can also malfunction in its failure to ignite the spark plugs, or the internal timing may malfunction. In this instance, the pilot will notice the engine beginning to run roughly.

(4) Lycoming advised from their inspection that the left hand magneto was not sparking at the leads. The magneto was disassembled and it was found the carbon brush inside was not making contact and two of the wire connections were not connected. Lycoming opined that the carbon brush wedging in the gear may have been a result of the impact sequence but that the possibility of a magneto failure cannot be eliminated.

(5) The right magneto was tested at the AAIA facilities and all indications were that it would have operated normally.

(6) From the evidence available it is not possible to determine if the left magneto failed in flight.

2.2.6. Teeter Stop Damage

The main rotor and mast were inspected for evidence of inflight damage. Both elastomeric teeter stops had been crushed by the blade spindle compressing against the main rotor shaft. The damaged teeter stops were still held in position by the teeter stop brackets. The crushing of the teeter stops found on the mast head was a clear indication that the blades had teetered excessively beyond limits, and mast bumping had occurred.

2.3. Flight Operations

2.3.1. Pilot Qualifications

2.3.1.1. Pilot's Recent Flying Experience

(1) The Pilot had flown 5 hours in the R22 type helicopter in the last 90 days.

(2) Apart from the 30 minutes flight with a HKAC Instructor immediately prior to the accident flight the Pilot had not flown the R44 for 8 months.

(3) This was his second solo flight in the R44, the first being in September 2018.

(4) During the flight with the instructor, several exercises were repeated to achieve the required standard expected by the instructor. This is not uncommon taking into account the Pilot's recent amount of flying.

2.3.1.2. Medical Limitations

(1) A limitation on the Pilot's medical certificate required that corrective lenses to be worn and additional spectacles to be available.

(2) It is not known if the Pilot was wearing corrective lenses at the time of the accident.

2.3.2. Operational Procedures

2.3.2.1. Centre of Gravity Limits[26]

(1) The right hand pilot's door had been removed. The investigation was unable to ascertain if this was taken into account regarding the calculated Centre of Gravity (CG) of the accident flight.

(2) The CG Limits state with all doors installed a solo pilot weight of 150 lb or greater will ensure CG within limits[27].

(3) A forward CG may occur when a heavy pilot and passenger take off without baggage or proper ballast located aft of the rotor mast[28].

(4) The weight of the Pilot at 170 lb would indicate that the forward CG was within limits. Fuel consumed during the flight would cause the CG to move forward during the flight but there is no evidence the forward CG limit was exceeded.

(5) Due to insufficient evidence, an accurate centre of gravity could not be determined for the flight.

2.3.3. Weather

The weather was suitable for the flight which was conducted under VFR conditions.

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[26] The centre of gravity is the single point in the helicopter through which the weight (and force of gravity) acts.

[27] Robinson POH Limitations 2-3 21 Feb 2014

[28] FAA Helicopter Flying Handbook FAA-8083-21B 6-3

2.3.4. Communications

The Pilot's last communication with 'Hong Kong Information' was made at 1723:48 hrs advising that B-KTK was approaching Shek Kong inbound. This transmission was acknowledged by 'Hong Kong Information'. The Pilot's voice was normal and calm and did not mention any anomaly or request for assistance. The helicopter disappeared from the radar screen 40 seconds later.

2.3.5. Low-G and Its Effects

(1) Low-G flight is a condition when the occupants feel a sensation of reduced weight.

(2) A Low-G condition occurs when an object is subjected to a net vertical force less than the force of gravity. When the vertical force is zero the sensation is described as being 'weightless'[29].

(3) As Low-G leads to mast bumping and inflight breakup the possibility of it occurring was investigated. The factors that cause it are turbulence or large or abrupt flight control inputs.

(4) These factors are discussed below.

2.3.5.1. Possibility of Turbulence

(1) Turbulence is caused by rapid irregular motion of air. It brings about rapid bumps or jolts but does not normally influence the intended flight path of an aircraft significantly. Turbulence events can be very small scale, sporadic and transient in nature and may affect successive aircraft differently.

(2) Rising terrain disrupts the flow of air across it and hence this may induce turbulence with up draughts on the upwind side and down draughts with 'rotors' on the downwind side (lee)[30]. Vegetation can also produce turbulence in the form of updrafts and downdrafts.

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[29] TAIC NZ AO-2014-006 Robinson R44 II, ZK-HBQ, Mast-Bump and In-Flight Break-Up, Kahurangi National Park, 7 October 2014

[30] Windshear and Turbulence in Hong Kong https://www.hko.gov.hk/en/aviat/articles/files/WS-turb-booklet-eng-3rd.pdf

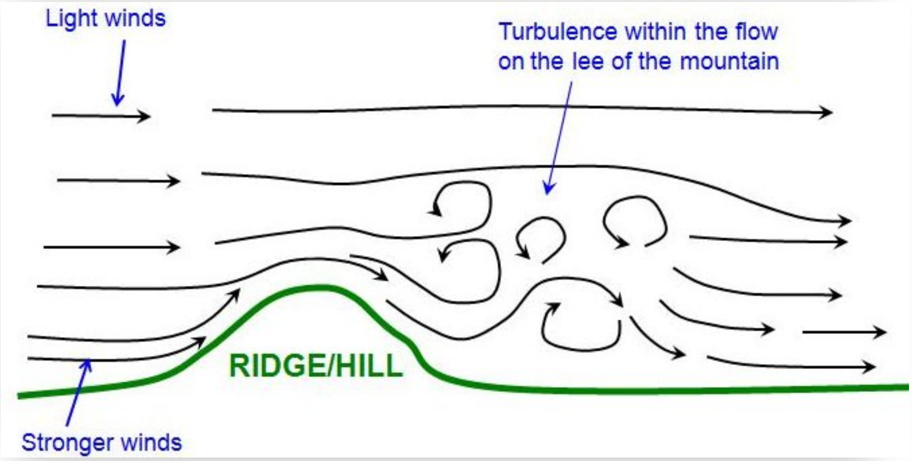

Figure 17: Wind Flow over a Ridge or Hill[31]

(3) The helicopter was returning to Shek Kong Airfield via an entry point called Kadoorie Gap. This is a pass between steeply rising ground to the left and right. The terrain to the right of track rises to a spot height of 1,856 ft in one mile and to the left to 3,140 ft in one and a half miles.

(4) Usually aircraft and helicopters approaching the gap fly from the east on the left hand side at 2,000 ft.

(5) Generally, Hong Kong's terrain is hilly and mountainous with a pattern of ridges and valleys with steep slopes. Tai Mo Shan, Hong Kong's highest peak, is at 3,140 ft. Six other peaks are more than 2,500 ft high. The local topography in the accident area has ridges on both sides of Kadoorie Gap, which are orientated along a line approximately in a northwest to southeast direction. The forecast winds were blowing at almost right angles to the terrain and would be channelling through the gap itself. These conditions are known to create turbulence.

(6) The HKO local aviation weather forecast valid from 1300 hrs to 2300 hrs for a 100 km radius around Hong Kong indicated the 2,000 ft wind to be from 230 degrees at 15-20 kt and the wind at 5,000 ft to be from 250 degrees at 20 kt[32].

(7) A building in the farm area has a CCTV camera. This is a fixed camera and during the period before and after the accident it was observed that the branches and leaves on a nearby tree are constantly moving signifying

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31 World Meteorological Organization (WMO) https://community.wmo.int/activity-areas/aviation/hazards/turbulence

32 A knot is a speed of one nautical mile per hour which equates to 1.85 kilometres per hour

that there was wind present. Other cameras recording also indicated the presence of significant wind.

(8) As surface winds can be affected by the local topography it was possible that the prevailing wind velocity at the time of the accident was greater than the wind reported in the surrounding area by the HKO due to ‘valley effect’ as the winds were funnelled towards the narrow valley.

(9) Considering that the helicopter was approaching from the lee side of the terrain where any turbulence would have been present and an increased wind speed at the gap itself the possibility of a turbulence encounter exists.

(10) Robinson produced a safety video in 2017 to accompany Safety Notice SN-32, which pertains to high wind and turbulence. The investigation team were informed by the HKAC that the Pilot had viewed this.

(11) Due to the wind speed and terrain the possibility exists that turbulence was encountered leading to an inadvertent cyclic control input.

2.3.5.2. Large or Abrupt Flight Control Inputs

(1) The Pilot’s helicopter flying experience had been mostly in the R22 model whereas the R44 differs in that it is fitted with hydraulically assisted main rotor controls. This system eliminates cyclic and collective feedback forces and only small smooth pilot inputs are required.

(2) The R44 is very responsive to pilot control inputs especially as the hydraulically boosted controls provide little feedback. The cyclic control stick in particular requires only light forces to achieve the full range of movement.

(3) The Robinson POH specifically states in the Limitations section: ‘*Low –G cyclic pushovers prohibited*’[33].

(4) A positive push forward on the cyclic would induce Low-G conditions. The HKAC informed the investigation team that the Pilot had been provided with safety awareness training on Low-G as part of a safety seminar on 21 July 2017. In addition, pilots are required to be conversant with the Robinson POH prior to each flight[34].

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[33] Robinson POH Limitations 2-5 7 May 2018

[34] Robinson POH General 1-1 10 Jul 2012

2.3.5.3. Effects of Low-G

In a Low-G occurrence, due to the position of the Robinson tail rotor (located above the C of G) it will cause the fuselage to roll right.

2.3.5.3.1. Pilot Recovery Actions

(1) Mast bumping occurs when the pilot, attempting to correct for the right roll, applies left cyclic. Due to the Low-G, the main rotor is unloaded and will bump against the stops.

(2) The correct method is to smoothly apply aft cyclic to 'reload' the main rotor and re-establish level flight.

(3) It cannot be excluded as a possible factor but the investigation team was unable to establish whether the Pilot made an inadvertent control input that contributed to the inflight breakup.

(4) The use of aft cyclic is not an intuitive reaction to an unexpected and sudden right roll (which in some cases can occur immediately after Low-G is first felt).

(5) However, the manufacturer's Low-G recovery technique has been proven during cyclic pushovers, and remains the only approved recovery technique.[35]

(6) The key to applying the manufacturer's recovery technique successfully, is the early recognition or anticipation of Low-G, and the immediate gentle application of aft cyclic before the right roll develops.

(7) Techniques that a fixed wing aircraft pilot use are not necessarily the required reaction to unexpected events during helicopter operations.

(8) Research by TAIC NZ[36] indicates that a common factor identified in some early mast-bumping and inflight breakup accidents was that the pilots were relatively inexperienced on helicopters and had more experience flying fixed wing aircraft.[37] Robinson issued a safety notice in March 1993

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[35] Robinson POH Limitations 2-5 7 May 2018

[36] The Transport Accident Investigation Commission (TAIC) is the transport safety body of New Zealand. The agency investigates aviation, marine, and rail accidents and incidents occurring in New Zealand.

[37] TAIC NZ Final Report Robinson R44 II AO-2014-006 4.4.3

which was revised in June 1994 warning of inexperienced helicopter pilots using ingrained fixed wing flying reactions.[38]

(9) The Pilot initially learnt to fly fixed wing aircraft in Malaysia starting in October 2014 and converting the Malaysian PPL to a HK PPL (A) (14 Dec 2016). The Pilot continued to alternate fixed wing flying in Hong Kong and Malaysia up until July 2018. The Pilot's total fixed wing time was 131:10 hours[39].

(10) The Pilot commenced a helicopter flying course at the HKAC in April 2017. After completing the course, a PPL (H) was issued by the CAD on 16 May 2018.

(11) At the time of the accident the Pilot had 81.1 hours helicopter flying experience[40] which included 71.8 hours on the R22 and 9.3 hours on the R44.

(12) There had been a period of flying on the R44 in May and June 2018 converting on to the R44 with one solo flight in September 2018.

(13) The investigation team could not establish evidence that inexperience was a factor.

2.3.6. Flight with the Right Door Removed

(1) The Robinson POH states that '*All four doors may be removed and installed by maintenance personnel or pilots*'[41].

(2) The right hand door had been removed for several days in an effort to increase the environmental comfort for pilots. The aircraft was equipped with an air-conditioning unit but this was unserviceable. With the door removed the Pilot would have a source of cooling in the high ambient temperatures.

(3) Robinson also states in the R44 POH that '*Doors off operation up to 100 KIAS approved with any or all doors removed*'.[42]

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38 Robinson Helicopter Company Safety Notice SN-29 Revised June 1994

39 Pilot Personal Flying Logbook

40 Pilot Personal Flying Logbook

41 Robinson POH Handling and Maintenance 8-6 5 Mar 2015

42 Robinson POH Limitations 2-5 7 May 2018

(4) The Robinson POH also adds a caution to ensure that all seat belts must be fastened as rear seat cushions and items in baggage compartments could be blown out if not restrained[43].

(5) The instructor stated that he had reminded and briefed the Pilot on the limitation[44].

(6) The last speed recorded on radar was 72 kts ground speed and there is no evidence that the Pilot exceeded the 100 KIAS speed limitation or that the removal of the door contributed to the accident.

2.3.7. Loose Objects in the Cockpit

(1) The Robinson POH states that with solo flight from the right seat the forward left seat belt must be buckled.[45]

(2) This is to prevent the possibility of any interference by flaying belts with the controls if disturbed by turbulence.

(3) Dual flight controls were installed.[46] The possibility of a loose object obstructing or causing inadvertent control inputs was considered but there is no evidence that this occurred.

(4) The instructor, who had been sitting in the left seat stated that when he left the helicopter he buckled the left seat belt.[47]

(5) It is not possible to ascertain if the left seat belt was buckled at the time of the accident from examination of the wreckage due to fire damage.

2.3.8. Temporary Redirection of Attention

(1) There is the possibility that when a pilot changes radio frequencies or the transponder setting by looking down at the console to do this an inadvertent input can be made to the cyclic inducing a Low G situation.[48]

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[43] Robinson POH Normal procedures 4-9 21 October 2016

[44] Instructor's Interview.

[45] Robinson POH Limitations 2-5 07 May 2018

[46] A second set of flight controls is fitted to permit instruction from the left seat.

[47] Instructor's Interview.

[48] Anomaly of Rotor Dynamics in Ultra-Light Helicopter – Robinson R22(/44/66) Agnieszka Sobieszek Institute of Aviation Poland https://sciendo.com/article/10.2478/kones-2019-0113

(2) Robinson issued a Safety Notice[49] in 2013 which includes advice about not programing avionics in flight as distractions in the cabin have caused pilots to lose control of the helicopter.[50]

(3) The cyclic has a frequency swap button so the pilot can change radio frequencies without looking down.

(4) Although the Pilot's mobile phone was on it was ascertained that the Pilot neither made nor received a call or electronic message during the flight.[51]

(5) There is no evidence that there was a temporary redirection of attention that may have led to an inadvertent cyclic control input.

2.3.9. Carbon Monoxide Poisoning[52]

The possibility of carbon monoxide (CO) poisoning was considered. The autopsy report[53] remarks that carboxyhemoglobin[54] substances were not detected.

2.4. Flight Environment

2.4.1. Bird Activity in Area

(1) The possibility exists that a bird may have been sighted in close vicinity or converging with the helicopter, which startled the Pilot into making an abrupt or large control movement or a combination of both to avoid it. This is recognised as a potential hazard.[55]

(2) The investigation team was informed by staff at Kadoorie Farm that at the time of the accident black kites, a bird of prey with a wing span of up to

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49 The Safety Notices are contained in Section 10 of the POH. They are not part of the FAA approved section and are promulgated by Robinson to enhance safety.

50 Robinson Helicopter Company Safety Notice SN-41 Issued May 2013.

51 Phone records.

52 Carbon monoxide (CO) is a colourless, odourless, tasteless gas by-product of internal combustion engines found in exhaust gases. Sufficiently high levels of CO in the bloodstream will lead to oxygen starvation and the onset of symptoms (such as headaches, drowsiness, nausea, or shortness of breath). NTSB Safety Alerts SA-070.

53 Autopsy Report.

54 Carboxyhemoglobin is formed in carbon monoxide poisoning and leads to oxygen deficiency in the body.

55 Bird Behaviour https://skybrary.aero/articles/bird-behaviour

five feet could be transiting to their roosting area on Hong Kong Island about eight miles to the south.

(3) Sightings have been made in the area of other large birds, with a wingspan up to five feet, sometimes flying in pairs.

(4) Examination of the recovered sections of the wreckage produced no evidence an actual bird strike occurred.[56]

2.4.2. Drones

(1) With drones readily available to the general public there is a possibility that a drone(s) may have been active in the area.

(2) The investigation team could not establish evidence of drone intervention on the operation of the accident helicopter.

2.5. Sequence of Breakup

As there was no recording device on board it is difficult to determine the exact sequence of events that led to the inflight breakup. Examination of the wreckage provided the following:

(1) In accidents attributed to main rotor RPM below the normal operating range (low main rotor RPM), leading to a rotor stall, there is evidence of the rearward travelling rotor blade impacting the tail and separating the tail boom which did not occur in this case.

(2) The investigation team considers the inflight breakup was unlikely to be caused by low main rotor RPM.

(3) The damage to the main rotor blades indicated that one of the blades had entered the cabin under rotation. The outboard section of this blade had broken off when the leading edge made contact.

(4) The windshield bow, portions of the upper and lower windshield frame along with small sections of right side doorframes and cabin structure were recovered with yellow paint transfer in areas of crushed/flattened metal.

(5) The lower instrument panel sustained direct impact damage separating the panel into several sections and leaving a dent in the right side of the

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[56] A bird strike is strictly defined as a collision between a bird and an aircraft which is in flight or on a takeoff or landing roll. https://www.skybrary.aero/index.php/Bird_Strike

instrument cluster, which appeared to match the size and shape of the leading edge of the counter-clockwise rotating main rotor blade.

(6) The witness marks on the windshield frame, the impact dent on the right of the lower instrument panel, and the yellow paint transfer from the rotor blade revealed that the advancing main rotor blade (i.e. the forward moving blade at the starboard side of the rotor plane viewed from above) had flapped down to this extreme angle.

(7) It is highly probable that the front of the cockpit had been hit by the diverged advancing blade at the initial breakup of the helicopter.

(8) The damage is consistent with historical mast bumping events.

2.6. Human Factors

2.6.1. Post Mortem

(1) The cause of death was multiple injuries.

(2) The autopsy[57] showed no evidence of potentially fatal natural disease process.

2.6.2. Fatigue or Physiological Factors

There was no evidence to suggest that the performance of the Pilot had been affected by fatigue or physiological reasons.

2.6.3. Incapacitation

(1) Pilot incapacitation is the term used to describe the inability of a pilot to carry out their normal duties because of the onset, during flight, of the effects of physiological factors.[58]

(2) The Pilot's last Class 2 medical examination was on 7 September 2018 and the Pilot was assessed fit.

(3) The post mortem remarked that the early atherosclerotic changes were unlikely to contribute to sudden collapse or sudden death.

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57 Autopsy Report.

58 Pilot Incapacitation https://skybrary.aero/articles/pilot-incapacitation

2.7. Lack of Evidence

(1) The investigation has not been able to establish conclusively what initiated or contributed to the inflight breakup. The uncertainty around the circumstances of this accident is not unique. Inflight breakups are destructive, making it difficult to determine with certainty whether a mechanical failure of some kind or pilot input could have initiated the mast bumping.

(2) The investigation finds that the true causes of this and other mast bumping and inflight breakups are often not able to be determined because the accidents are usually fatal and hindered by the lack of mandatory cockpit and flight data recorders.

2.8. Flight Data Recording

(1) The International Civil Aviation Organization (ICAO) standards, which include the installation of flight data recorders, apply only to international commercial air transport operations or international general aviation operations.[59]

(2) However, individual states can act at their own behest. The CAD has published an Airworthiness Notice (AN) adopting the ICAO recommended practices that all helicopters of a Maximum Total Weight Authorised (MTWA) of 3,175 kg or less for which the individual certificate of airworthiness is first issued on or after January 2018 should be equipped with (a) a Flight Data Recorder (FDR) or (b) a Class C Airborne Image Recording System (AIRS) which at least should record the flight path and speed parameters displayed to the pilot.[60]

(3) In 2020, the Robinson Helicopter Company began installing digital engine monitoring unit (EMUs) on all new production R44 and R22 helicopters (the EMU records and alerts mechanics and pilots to predominantly engine-related exceedances and provides flight data during accident investigation).[61]

(4) They also fit lightweight flight data recorders at the factory on new production R44 helicopters and they are optional on R22 models. In addition, the cockpit camera installation kits are available for retrofit on

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59 ICAO Annex 6 - Operation of Aircraft - Part III - International Operations - Helicopter - Section I Chapter 2

60 CAD AN-101D P.15, 30 July 2021

61 Transport Accident Investigation Commission, NZ – Watch List (Oct 2021)

R44 helicopters. In 2023, the recorders will be standard on all models and retrofit kits are available.

(5) These technologies would have assisted the investigation of helicopter accidents and potentially provided substantial evidence of the cause or causes, particularly in cases of in-flight breakup accidents involving helicopters with semi-rigid rotor heads. According to RHC, the video captured from the cockpit camera can also be used as a training tool.[62] It would be advantageous for helicopter operators to further explore the use of these technologies to enhance safety and realize these additional benefits.

2.9. HKAC Operational Supervision

(1) The HKAC provides training in both fixed wing and rotary aircraft for its members who wish to fly recreationally. General and flying procedures guidance for members is provided in the form of General Flying Orders (GFOs) enhanced by other safety notices regarding operations at Shek Kong. It is incumbent on the members to read and understand the procedures before each flight.

(2) Recreational pilots may not always be aware of, or have access to continuing technical and safety developments after the initial training is completed. It is important to recognise the difference between training, which develops flying skill and continuing education, which develops airmanship.

(3) Safety is a process shared by the HKAC and the member pilots. In order for the pilot training to be successful, the education, awareness, and input of both is important.

(4) The Pilot had viewed the video provided for HKAC members containing safety procedures relating to the effects of Low-G.

(5) Due to the significance of 'mast bumping', the exact causes of which are difficult to determine, the HKAC should continue to review guidance and scenario-based theoretical training provided for pilots regarding the avoidance of low-G and ensure the accepted method of regaining control is as per the instructions in the Robinson POH.

(6) The manufacturer provides comprehensive and readily available media guidance including the POH and Safety Tips which members should be encouraged to access to increase safety awareness.

62 Robinson Helicopter Company 2023 https://robinsonheli.com/cockpit-camera-4k/

3. Conclusions

From the evidence available, the following findings are made with respect to the occurrence. These findings should not be read as apportion blame or liability to any particular organization or individual.

3.1. Findings

(1) The Pilot was licensed and qualified for the flight in accordance with existing regulations. (1.5.1.1.)

(2) The maintenance records indicated that the aircraft was equipped and maintained in accordance with existing regulations and approved procedures. [1.6.2. (1)]

(3) The aircraft had a valid certificate of airworthiness. [1.6.2. (2)]

(4) It has not been able to accurately ascertain if a preflight performance and centre of gravity calculation was completed before the flight. (1.6.8)

(5) It has not been able to accurately ascertain the exact amount of fuel on board due to the breakup of the helicopter. (1.6.9.)

(6) Analysis conducted by the NTSB determined that the collective metallurgical features observed macroscopically and microscopically on the fracture surfaces were consistent with overstress fracture. The NTSB did not observe any features consistent with indications of pre-existing cracking. (1.16.1.4.)

(7) The governor switch was in the ON position. There was no evidence to suggest the main rotor RPM was below the normal operating range (low main rotor RPM) and the helicopter suffered a rotor stall at the time of the accident [2.2.1. (4)].

(8) The investigation team was unable to determine if the Hydraulic OFF switch position was due to pilot input or impact damage. [2.2.3. (3)]

(9) From the evidence available it is not possible to determine if the left magneto failed in flight. [2.2.5. (6)]

(10) The Pilot had flown the R22 for 5 hours in the previous 90 days. [2.3.1.1. (1)]

(11) This was the Pilot’s first flight in a R44 for 8 months apart from the 30 minutes check flight immediately preceding the accident flight. [2.3.1.1. (2)]

(12) The flight was the Pilot’s second solo flight in the R44. [2.3.1.1. (3)]

(13) Due to the wind speed and terrain the possibility exists that turbulence was encountered leading to an inadvertent cyclic control input. [2.3.5.1. (11)]

(14) The investigation team was unable to establish whether the Pilot made an inadvertent control input that contributed to the inflight breakup. [2.3.5.3.1. (3)]

(15) The aircraft was operated with the right door removed which entailed a speed restriction. There is no evidence the speed restriction was exceeded. [2.3.6. (6)]

(16) The possibility of a loose object obstructing or causing inadvertent control inputs was considered but there is no evidence that this occurred. [2.3.7. (3)]

(17) There is no evidence that there was a temporary redirection of attention, which may have led to an inadvertent cyclic control input. [2.3.8. (5)]

(18) There is no evidence that carbon monoxide poisoning was a factor in the accident. (2.3.9.)

(19) Examination of the recovered sections of the wreckage produced no evidence an actual bird strike occurred. [2.4.1. (4)]

(20) There was no evidence of drone intervention on the operation of the accident helicopter. [2.4.2. (2)]

(21) The investigation team considers the inflight break up was unlikely to be caused by low main rotor RPM. [2.5. (2)]

(22) Impact damage from the blade on the front right cabin is indicative of a low-G mast bumping. [2.5. (4), 2.5. (7)]

(23) For reasons that cannot be determined the aircraft suffered a ‘mast bumping’ which instigated the inflight breakup. (2.5.)

(24) There was no evidence to suggest that the performance of the Pilot had been affected by fatigue or physiological reasons. (2.6.2.)

(25) A FDR and/or AIRS recorder would have assisted this investigation and possibly provided substantial evidence of the cause or causes of the accident. The CAD has published an Airworthiness Notice (AN) adopting the ICAO recommended practices that all helicopters of a Maximum Total Weight Authorised (MTWA) of 3175 kg or less for which the individual certificate of airworthiness is first issued on or after January 2018 should be equipped with (a) a Flight Data Recorder (FDR) or (b) a Class C Airborne Image Recording System (AIRS) which at least should record the flight path and speed parameters displayed to the pilot. [2.8. (2), 2.8. (5)]

3.2. Causes

The aircraft suffered a catastrophic inflight breakup due to a phenomenon known as mast bump which caused the main rotor blades to come in contact with the fuselage and cockpit area. (2.5)

4. Safety Actions Already Implemented

4.1. CAD Safety Actions

The CAD advised the AAIA that:

(1) Upon receipt of the notification from AAIA that the fracture of the upper rod ends of both pitch link assemblies involved fatigue crack propagation, CAD has taken proactive safety measures by issuing a SIB Airworthiness No. 2021-01 for the pitch link assemblies on 29 January 2021.

(2) The SIB alerted local R44 and R66 operators/owners for proactive maintenance to enhance safety. The SIB recommended the operators/owners to either carry out Magnetic Particle Inspection on the upper rod end threaded portion of the pitch link assemblies or replace the pitch link assemblies with new assemblies in pair.

(3) AAIA was informed of the above proactive action taken by CAD vide a letter of the same date.

(4) Subsequent to the issue of the SIB, CAD followed up with the concerned aircraft owners to ensure that the safety measures recommended in the SIB would be properly considered or implemented.

(5) AAIA was updated by CAD on the implementation progress that either the safety measures had been completed or would be conducted at scheduled maintenance inputs.

4.2. HKAC Safety Actions

The HKAC advised the AAIA that:

(1) Following the accident, a safety seminar on Special Federation Aviation Regulation (SFAR) 73 issued by FAA was held at HKAC on 28 May 2019 in order to reinforce the previous training which had been provided to HKAC members on SFAR 73.

(2) On 12 June 2019, as an immediate precaution following the accident, HKAC revised Helicopter Flying Order GEN-09 (Wind and Other Limitations) in order to impose an airspeed limit of 60-70 kts, maintaining straight and level attitude, for pilots flying in and out of Kadoorie Gap. This reiterated the airspeed limitations which were set out in R-02 (Wind Limitations) of the HKAC Helicopter Flying Orders prior to the subject accident.

(3) HKAC held a 4-day Robinson Safety Course for its members in Hong Kong between 28 August and 2 September 2019. This training was delivered by the Robinson Helicopter Company's Chief Instructor.

(4) In 2020, HKAC consolidated its Helicopter Flying Orders, along with all other relevant information, into an Operations Manual. This Operations Manual includes the requirements to be met as part of HKAC pilots' Annual Flying Review (AFR). These requirements include an assessment in relation to emergency operations, which includes a discussion of low-G conditions and mast bumping. These topics were specifically included in the AFR in order to increase the frequency of training on SFAR 73, and also to enhance awareness of those requirements. Pilots are prohibited by the HKAC from flying unless they have completed this AFR, and HKAC's aircraft booking software ensures that aircraft can only be booked by a pilot who is current.

(5) The HKAC Helicopter Training Syllabus and associated training exercises stress the importance of SFAR 73 training, including in relation to mast bumping and low-G hazards, how to avoid those hazards, and how to regain control in a low-G situation. It is also a HKAC requirement that before any student pilot undertakes their first solo flight, that person must have received Robinson safety awareness training in accordance with SFAR 73 within the preceding 90 days.

(6) HKAC requires all of its R-22 and R-44 pilots who have not previously attended a Robinson Safety Course to attend the Course before the expiry of their Certificate of Experience[63]. The curriculum for this training course includes a review of past R22/R44/R66 accidents, major causes of fatal accidents and how they could be avoided, helicopter theory, critical flight conditions, and Awareness Training required by SFAR 73. In addition, it covers the Pilot Operating Handbook, including limitations, emergency procedures and performance, as well as pertinent FAA regulations.

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[63] According to CAD54 (Rev15 – June 2019), the Certificate of Experience (C of E) certifies that the holder of the licence produced, to a person authorized to sign the certificate, his flying log book to show that in a specified period preceding the date on which the certificate was signed he had completed the minimum flying experience required to maintain a valid C of E in relation to the rating. CAD54 also prescribes the functions to which an aircraft rating relates must not be performed unless it bears a valid Certificate of Test (C of T) or Certificate of Experience (C of E).

5. Safety Recommendations

5.1. Safety Recommendation 04-2023

It is recommended that the Aviation Club of Hong Kong, China, continue to promote the safety awareness of club members on 'mast bumping' by reviewing the guidance and theoretical training provided for pilots regarding the avoidance of low-G and the accepted method of regaining control as per the instructions in the Robinson Pilot's Operating Handbook. (2.9)

Safety Recommendation Owner: Aviation Club of Hong Kong, China[64]

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[64] Prior to the completion of this report, the Hong Kong Aviation Club changed their name to Aviation Club of Hong Kong, China.

6. General Details

6.1. Occurrence Details

Date and time:	19 May 2019, 1725 hours (local time)	
Occurrence category:	Accident	
Primary occurrence type:	Loss of Control Inflight (LOC-I)	
Location:	Lam Kam Road and Kadoorie Farm	
	Latitude: 22°18'41.14"N	Longitude: 113°53'58.32"E

6.2. Pilot Information

6.2.1. Pilot-in-Command

Age:	49
Licence:	HK PPL (H)
Aircraft ratings:	Robinson R22/44
Date of first issue of aircraft rating on type:	16 May 2018
Medical certificate:	Class 2 Valid to 30 September 2020
Date of last proficiency check on type:	19 May 2019
ICAO Language Proficiency:	Not Required (ICAO Annex 1 1.2.9.4)
Limitation:	Corrective lenses are required
Flying Experience:	
Total all types:	212:20 hours
Fixed Wing	131:10 hours
Helicopter	81:10 hours

Total on type R44 :	9:15 hours
Total in last 90 days:	6:00 hours
Total in last 30 days :	3:30 hours
Total in last 7 days:	1:00 hours
Total in last 24 hours:	1:00 hours
Day up to the incident flight (Hours:Mins) :	1:00 hours
Day prior to incident (Hours:Mins) :	Nil

6.3. Aircraft Details

Manufacturer and model:	Robinson R44 II
Registration:	Hong Kong B-KTK
Aircraft Serial number:	12472
Year of Manufacture	2008
Engine	Lycoming IO-540-AE1A5
Engine Serial Number	L-33092-48E
Operator:	HKAC
Type of Operation:	Private
Certificate of Airworthiness	Valid to 27 September 2019
Departure:	Shek Kong Airfield
Destination:	Shek Kong Airfield
Maximum Take-off Weight	2500 lbs
Total Airframe Hours	1308:00 hours
Aircraft damage:	Destroyed

6.4. Aerodrome Information

6.4.1. Aerodrome of Departure and Landing

Aerodrome Code	VHSK
Airport Name	Shek Kong
Airport Address	New Territories, Hong Kong SAR
Airport Authority	PLAAF Joint Civil / Military
Air Navigation Services	N/A
Type of Traffic Permitted	VFR
Coordinates	22° 26' 02" N, 114° 04' 08" E
Elevation	50 ft
Runway Length	1882 m
Runway Width	36 m
Stopway	Nil
Runway End Safety Area	Nil
Azimuth	11/29
Category for Rescue and Fire Fighting Services	N/A

7. Abbreviations

ADRS	Aircraft Data Recording System
AIRS	Airborne Image Recording System
AMSL	Above Mean Sea Level
ARP	Aerodrome Reference Point
ATC	Air Traffic Control
BHP	Brake Horse Power
CAD	Hong Kong Civil Aviation Department
CARS	Cockpit Audio Recording System
CG	Centre of Gravity
CO	Carbon Monoxide
DLRS	Data Link Recording System
EASA	European Union Aviation Safety Agency
FAA	Federal Aviation Administration
FAL	Flight Authorisation Log
FDR	Flight Data Recorder
FIS	Flight Information Service
GPS	Global Positioning System
HKAC	Hong Kong Aviation Club - now known as the Aviation Club of Hong Kong, China
HK AIP	Hong Kong Aeronautical Information Publication
HKIA	Hong Kong International Airport
HKO	Hong Kong Observatory
hPa	Hectopascal
ICAO	International Civil Aviation Organisation
KFBG	Kadoorie Farm and Botanic Garden

METAR	Meteorological Aerodrome Report
MHz	Megahertz
MSG	Message
NOTAM	Notice To Airmen
NTSB	National Transport Safety Board
PLAAF	People's Liberation Army Air Force
POH	Pilot’s Operating Handbook
PPL	Private Pilot’s Licence
RHC	Robinson Helicopter Company
RPM	Revolutions Per Minute
SFAR	Special Federation Aviation Regulation
SIB	Safety Information Bulletin
SPECI	Special Weather Report
STC	Supplementary Type Certificate
TAIC NZ	New Zealand Transport Accident Investigation Commission
TC	Type Certificate
UCARAs	Uncontrolled Airspace Reporting Areas
USA	United States of America
UTC	Coordinated Universal Time
VFR	Visual Flight Rules
VHF	Very High Frequency
VHHH	ICAO code of Hong Kong International Airport
VHSK	ICAO code of Shek Kong Airfield

8. Table of Figures and Tables