ACCIDENT INVESTIGATION COMMISSION

FINAL REPORT

AIC 23-1003

Heli Solutions Limited

P2 - HSM

Bell - 407

Tail Rotor Component Failure - Inflight

3.5 NM Northwest of Wapenamanda Airport

Enga Province

Papua New Guinea

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ABOUT THE AIC

The Accident Investigation Commission (AIC) is an independent statutory agency within Papua New Guinea (PNG). The AIC is governed by a Commission and is entirely separate from the judiciary, transport regulators, policy makers and service providers. The AIC's function is to improve safety and public confidence in the aviation mode of transport through excellence in: independent investigation of aviation accidents and other safety occurrences within the aviation system; safety data recording and analysis; and fostering safety awareness, knowledge and action.

The AIC is responsible for investigating accidents and other transport safety matters involving civil aviation in PNG, as well as participating in overseas investigations involving PNG registered aircraft. A primary concern is the safety of commercial transport, with particular regard to fare-paying passenger operations.

The AIC performs its functions in accordance with the provisions of the *PNG Civil Aviation Act 2000 (As Amended),* and the *Commissions of Inquiry Act 1951*, and in accordance with *Annex 13* to the *Convention on International Civil Aviation.*

The objective of a safety investigation is to identify and reduce safety-related risk. AIC investigations determine and communicate the safety factors related to the transport safety matter being investigated.

It is not a function of the AIC to apportion blame or determine liability. At the same time, an investigation report must include relevant factual material of sufficient weight to support the analysis and findings. At all times the AIC endeavours to balance the use of material that could imply adverse comment with the need to properly explain what happened, and why it happened, in a fair and unbiased manner.

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About this Report

On 18 February 2023 at 11:40 local time (01:40 UTC), the AIC was notified by the operator via a phone call of an accident involving a helicopter, registered P2-HSM, owned and operated by Heli Solution Ltd at Kwimanda, 3.5 nautical miles (NM) Northwest of Wapenamanda Airport, Enga Province. The AIC immediately commenced an investigation and deployed a team of investigators to the accident site on 19 February 2024.

This Accident *Final Report* has been produced by the PNG AIC pursuant to *ICAO Annex 13, Chapter 6, paragraph 6.5* and has been approved for public release.

The report is based on the investigation carried out by the AIC under the Papua New Guinea *Civil Aviation Act 2000 (As Amended),* and *Annex 13* to the *Convention on International Civil Aviation.*

It contains information, analysis of that information, findings and contributing (causal) factors, other factors, safety actions, and safety recommendations.

Although AIC investigations explore the areas surrounding an occurrence, only those facts that are relevant to understanding how and why the accident occurred are included in the report. The report may also contain other non-contributing factors which have been identified as safety deficiencies for the purpose of improving safety.

Readers are advised that in accordance with *Annex 13* to the *Convention on International Civil Aviation*, it is not the purpose of an AIC aircraft accident investigation to apportion blame or liability. The sole objective of the investigation and the final report is the prevention of accidents and incidents (Reference: *ICAO Annex 13, Chapter 3, paragraph 3.1*). Consequently, AIC reports are confined to matters of safety significance and may be misleading if used for any other purpose.

Maryanne J. Wal
Chief Commissioner
22 August 2024

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GLOSSARY OF ABBREVIATION

AFF	: Aircraft flight manual
AGL	: Above ground level
AIC	: Accident investigation commission
AMM	: Aircraft maintenance manual
AMSL	: Above mean sea level
AOC	: Air operator certificate
ASB	: Alert service bulletin
ATS	: Air traffic service
CAR	: Civil aviation rules
CASA PNG	: Civil aviation safety authority of PNG
CPL A	: Commercial pilot license aeroplane
CVR	: Cockpit voice recorder
ECU	: Engine Control Unit
ELT	: Emergency locator transmitter
ERP	: Emergency response plan
ETA	: Estimated time of arrival
FDR	: Flight data recorder
FIS	: Flight Information Service
FM	: Flight manual
Ft	: Foot (feet)
HF	: High frequency (3 000 to 30 000 kHz)
HPa	: Hectopascal
Incerfa	: Uncertainty SAR phase
INI	: Initial notification of incident
Kt	: Knot(s)
M	: Meter(s)
MEL	: Minimum equipment list
MH_z	: Megahertz
MOC	: Maintenance operating certificate
NM	: Nautical miles
OEM	: Original equipment manufacturer
SAR	: Search and Rescue
S/N	: Serial Number
SOP	: Standard operating procedure(s)
TEM	: Threat and error
TRB	: Tail rotor blades
TR	: Tail rotor
TRDSA	: Tail rotor drive shaft assembly
TRGB	: Tail rotor gearbox
UTC	: Coordinated universal time
VFR	: Visual flight rules
VHF	: Very high frequency (30 to 300 MHz)

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INTRODUCTION

SYNOPSIS

On 18 February 2023, at about 11:40 local time (01:40 UTC), a Bell 407 helicopter, registered P2-HSM, owned and operated by Heli Solutions Limited, while conducting a single pilot passenger charter flight from Epopi village to Wapenamanda Airport in Enga Province, sustained a complete loss of its tail rotor. The pilot subsequently conducted an emergency landing on a garden patch, approximately 3.5 nautical miles (NM) Northwest of Wapenamanda Airport.

There were six persons on board: the pilot, a Loadmaster and four passengers. There were no injuries reported.

The pilot had departed Mt. Hagen and completed a number of legs before landing at Epopi Village to deliver medical supplies at 11:08 with his Loadmaster. However, before departing, he was asked to transport two patients with their two guardians from Epopi to Wapenamanda for treatment.

The helicopter departed Epopi at 11:20, climbed above 9,000 ft and began tracking Southeast toward Wapenamanda Airport. There was no significant weather along the route.

At about 9 NM from Wapenamanda, during the descent phase, the pilot heard a loud bang noise from the rear of the helicopter, suspecting it originated from the tail rotor section. He checked the foot pedals, finding them loose, indicating loss of tail rotor thrust. Vibrations and yawing followed, leading to a spin. Soon after, another loud bang occurred, accompanied by vigorous airframe vibration as the helicopter continued spinning. The pilot alerted the Loadmaster who instructed passengers to brace for an emergency landing via intercom.

The pilot subsequently initiated the Emergency/Malfunction Procedures. After verifying control, he reduced power and airspeed to 80 knots, effectively stabilizing the helicopter and ceasing the spin. Recognising the hazards of maneuvering and landing without tail rotor thrust, he decided for an alternative landing spot, a local garden in Kuimanda Village, situated less than a nautical mile from his position at an elevation of 5,896 feet.

Expecting a soft-landing surface due to frequent rainfall, he maneuvered towards the garden, making slight power adjustments and utilising forward airspeed for directional control during the approach. Nonetheless, he noticed unintended yawing as he adjusted power and speed. Just before touchdown, he further decreased power and flared the helicopter to slow the descent and ensure initial skid contact, aiming to prevent a rollover. Despite these efforts, the helicopter entered a spin, with the pilot experiencing two full rotations before touchdown.

The complete loss of the helicopter's tail rotor thrust during the descent phase was attributed to the snapping of the four mounting studs. This was caused by the failure of the mounting stud assembly. The damage sustained on the studs and bores indicates that they sustained cyclic stress and vibrations above normal levels. The investigation concluded that there were several factors that contributed to the accelerated wear and tear of the component, including the helicopter vibrations that were reported numerous times throughout the year. Maintenance records showed that these reported issues were partially resolved. The AIC also noted that certain defects are written into the Technical Log by the pilots or only reported verbally to the maintenance engineers who record the defects on behalf of the pilots.

The Manufacturer, Bell Helicopters, issued an information letter requiring the use of vibration analysis equipment. The Manufacturer's Maintenance Manual itself also specifically requires vibration analysis equipment following pilot defect report or adjusts. The operator's maintenance records for 2 and 3 January 2023 showed that although maintenance was carried out following pilot reported vibration issues, a vibration analyser was not used.

Helicopter vibration analysers are quite accurate and can assist in diagnosis and identification of vibration sources and magnitude. Conducting maintenance activities relating to excessive vibration reports without the use of vibration analysers poses a significant risk of misdiagnosis and continued manifestation of issues leading to such failures experienced during the accident flight. A significant risk, which would not likely be the case if an analyser is used, remained that underlying sources of vibration may not have been completely resolved or that a level of imbalance persists. It cannot be determined for certain that the helicopter vibrations are within the specified parameters without the use of vibration analyser. The sources of any excessive vibration, single or multiple, are also difficult to identify without an analyser.

The AIC recommends that the Heli Solutions Ltd should ensure to standardise systems and protocols are established and implemented for defect reporting, maintenance practice, and compliance with requirements in the Manufacturer's Maintenance Manual relating to unscheduled maintenance.

1. FACTUAL INFORMATION

1.1 History of the flight

On 18 February 2023, at about 11:40 local time 01:40 Coordinated Universal Time (UTC), a Bell 407 helicopter, registered P2-HSM (HSM), owned and operated by Heli Solutions Limited (Ltd), was conducting a single pilot VFR passenger charter flight from Epopi village to Wapenamanda Airport in Enga Province, when it sustained a complete loss of tail rotor thrust, resulting in an emergency landing on a garden patch, approximately 3.5 nautical miles (NM) Northwest of Wapenamanda Airport.

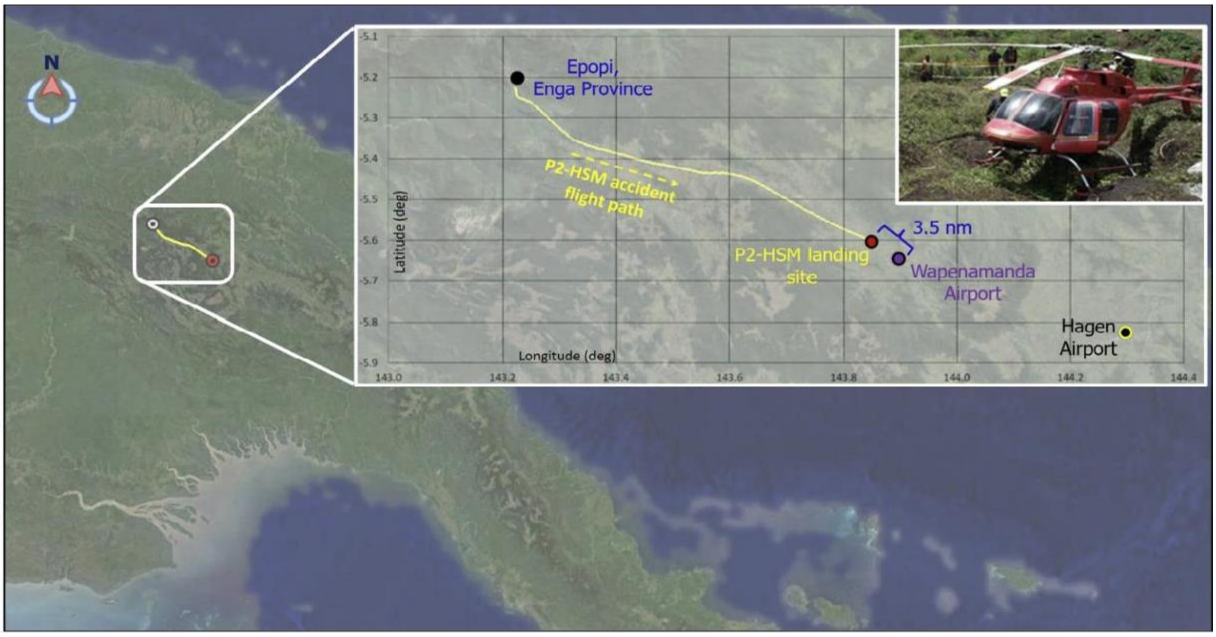

Figure 1: Overview of the HSM accident flight and landing site.

There were six persons on board the helicopter: one pilot, a Loadmaster and four passengers.

The helicopter departed from Mt. Hagen at 09:46 and completed three sectors, totaling about two hours of flight time, before the accident flight. These sectors were Mt. Hagen to Wapenamanda then to Malamaunda, and finally to Epopi.

According to the recorded data[1], at 11:08 while the helicopter was about 17 NM South of Malamaunda, the pilot contacted ATS and advised that he had departed Malamaunda and was tracking not above 9,000 ft Above Mean Sea Level (AMSL) for Mt. Hagen. He added that there were two persons onboard, with an estimated arrival time in Mt. Hagen of 11:45.

At 11:15, the helicopter landed in Epopi Village from Malamaunda. It was confirmed during interviews with the pilot that the stopover at Epopi Village was to deliver medical supplies. The pilot added that after arriving at Epopi Village, he was informed about two patients and their guardians who needed to be transported to Wabag Hospital. The patients and their guardians boarded the helicopter and they departed for Wapenamanda.

At around 11:20, while outbound from Epopi, the pilot contacted ATS to amend his destination to Wapenamanda, with an estimated arrival time of 11:46. The helicopter climbed to above 9,000 ft and tracked Southeast for Wapenamanda Airport. The pilot also stated that there was no significant weather along the route as he tracked for Wapenamanda.

The recorded data showed that at about 13 NM Northwest of Wapenamanda, the helicopter initiated a shallow descent from about 9,300 ft, as the Top of Descent for Wapenamanda.

[1] The recorded data is referring to aircraft Garmin Aero 660 GPS, Spidertracks recorded data and ATC recorded data synchronized. Refer Section 1.11. Referred to hereon as recorded data.

The pilot stated during interview that when they were about 9 NM from Wapenamanda, during the descent phase, he heard a loud bang from the back of the helicopter. He recalled suspecting that noise had emanated from the tail rotor section. He subsequently checked the foot pedals but felt no resistance. The pedals were moving loosely, which he said indicated that the helicopter had lost tail rotor thrust. He recalled feeling vibrations as the helicopter yawed toward the right with its nose pitching dipping which characterized the helicopter entering a spin.

Shortly after, the pilot heard another loud bang from the back of the helicopter, followed by vigorous airframe vibration while the helicopter continued to spin. He immediately alerted the Loadmaster of the situation and announced that an emergency landing was imminent. The Loadmaster subsequently instructed the passengers over the intercom to brace for an emergency landing.

The recorded data indicated that the descent was a steeper descent profile from that point, coupled with a fluctuating rate of descent, peaking at 800 feet per minute.

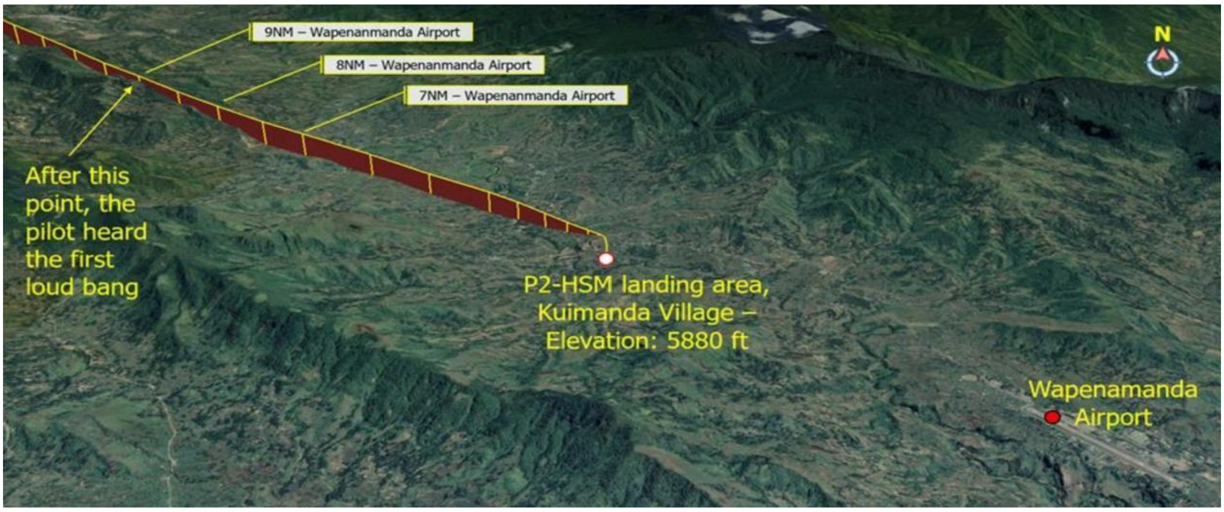

Figure 2: HSM position, 9NM from Wapenamanda Airport (5.5 NM from emergency landing position)

The pilot actioned the *Bell 407 Rotorcraft Flight Manual Emergency/Malfunction Procedures for Complete Loss of Tail Rotor Thrust, refer to Section 5.1 Appendix A Complete Loss of Tail Rotor Thrust*. The pilot stated that he carried out a controllability check in accordance with the emergency procedure and he subsequently reduced the power and the airspeed to 80 kts. He further stated that the reduced power and airspeed helped stabilize the helicopter and arrest the spin.

The pilot reported that following the malfunction, he initially elected to fly the helicopter to Wapenamanda Airport. However, he considered the path he would have to maneuver and the power inputs he would have needed to make would have posed a significant risk of the helicopter re-entering a spin. He stated that he also considered that the effects of conducting an emergency landing on the hard surface at Wapenamanda Airport would potentially result in the helicopter rolling over upon landing without tail rotor thrust.

Therefore, a decision was made to land as soon as possible, and he began his assessment by searching for other open areas to land. He subsequently identified a nearby local garden (elevation: 5,896 ft) at Kuimanda Village, less than a mile from his position. He stated that considering the fact that it had been raining in the area frequently around that time, he believed that the local garden soil would provide a soft surface to land and would cushion the impact of the landing.

The pilot stated that he then tracked to the garden patch for landing using minor power adjustments together with forward airspeed to assist with directional control. He added that during the approach, as he made minor power and speed adjustments, the helicopter inadvertently yawed to the right.

As he got close to the ground, prior to touchdown, he reduced power further and flared the helicopter. He explained that this was in order to arrest the descent as well as to sink the skids first as an attempt to prevent a rollover on impact. He further added that upon doing so, the helicopter began to spin. He recalled experiencing two full spins before the helicopter skids contacted the ground.

The pilot stated that once the tail skid contacted the ground, he pushed the collective forward and made a hard landing on the skids.

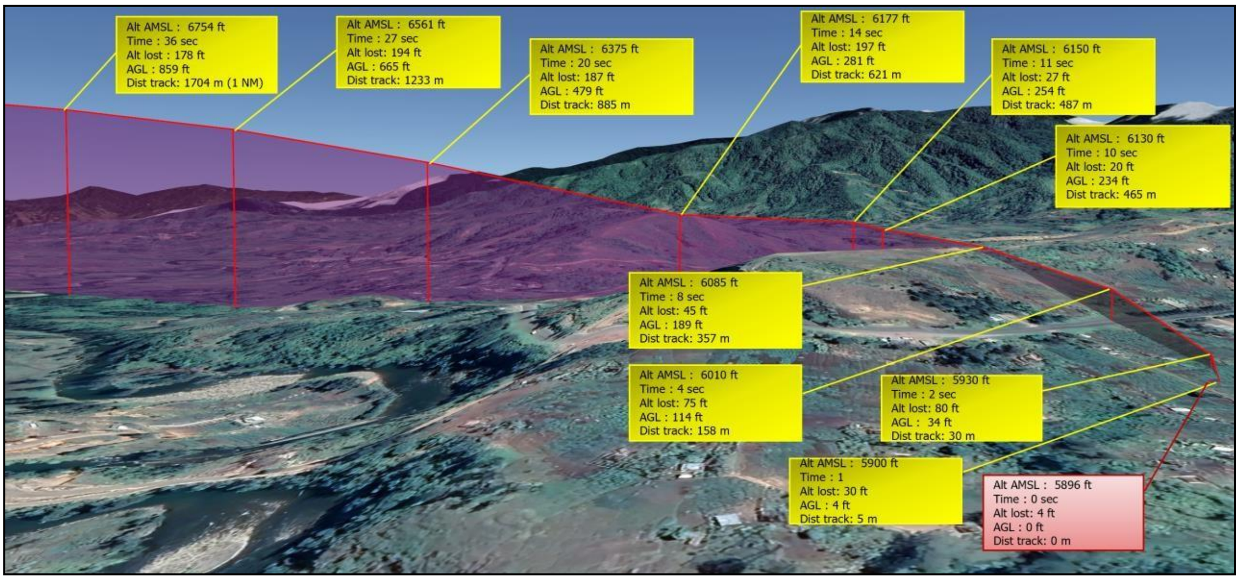

Figure 3: HSM altitude (6750 ft AMSL) and position (about 1NM from emergency landing position).

According to the pilot, the helicopter's skids immediately sank into the soil. Once the pilot observed that the helicopter was firmly stabilized on the ground, he shut down the engine and instructed the Load Master to evacuate the passengers.

The Load Master evacuated the passengers away from the helicopter. The pilot exited the aircraft and completed a walk-around to inspect the helicopter for damage sustained before following the passengers to a safe distance. He subsequently called the Operator's base to notify them about the accident.

1.2 Injuries to persons

Injuries	Flight crew	Passengers[2]	Total in Aircraft	Others
Fatal	-	-	-	-
Serious	-	-	-	-
Minor	-	-	-	Not applicable
Nil Injuries	1	5	6	Not applicable
TOTAL	1	5	6	-

Table 1: Injuries to persons

1.3 Damage to aircraft

The aircraft sustained substantial damage. Refer to *Section 1.12* for a detailed description of damage to relevant components of the aircraft.

1.4 Other damage

There were no other damage as a result of this accident.

[2] Four passengers and the Loadmaster

1.5 Personnel information

1.5.1 Pilot

Age	: 59
Gender	: Male
Nationality	: Papua New Guinean
Position	: Line Pilot
Type of license	: CPL (H)
Type rating	: (SEA)- R44; AS350; BH204/205; BH206; BH407 (MEA)- B105; BK117; BH212; BH412
Total hours flying time	: 17,488.4
Total hours on type	: 4,500
Total hours last 90 days on type	: 80.7
Total hours last 7 days	: 12.2
Total hours last 7 days on type	: 12.2
Total last 24 hours	: 2.2
Total on the type last 24 hours	: 2.2
Total on duty last 48 hours	: 2.2
Total rest period(s) last 48 hours	: 48.0
Last recurrent training	: 12 May 2022
Last proficiency check	: 17 May 2022
Last line check	: 12 May 2022
Route recency	: 17 May 2022
Aerodrome recency	: NA
Medical class	: One (1)
Valid to	: 29 May 2023
Medical limitation	: Spectacles (Prescription lenses required)

1.6 Helicopter Information

1.6.1 Aircraft data

Aircraft Manufacturer	: Bell Helicopter – Textron Inc
Model	: Bell 407
Serial Number	53791
Year of Manufacture	2007
Total Airframe Hours	: 4,805.8
Total Airframe Cycles	: 13,861
Registration	: P2-HSM
Name of the Owner	: Heli Solutions Limited
Name of the Operator	: Heli Solutions Limited
Certificate of Registration number	236
Certificate of Registration issued	: 13 March 2012
Certificate of Registration valid to	: Non-Terminating
Certificate of Airworthiness number	236
Certificate of Airworthiness issued	: 18 December 2018
Certificate of Airworthiness valid to	: Non-Terminating

1.6.2 Engine data

Engine Type	: Turboshaft
Manufacturer	: Rolls-Royce
Model	: 250-C47B
Serial Number	: CAE-848050
Year of Manufacture	: 2006
Total Time Since New	: 3,729.6
Cycles Since New	: 4644
Time Hours Since Overhaul	: 3,729.6

Evidence gathered including the downloaded data from the Engine Control Unit (ECU) and the pilot's statement showed that the engine was operating normally throughout the flight leading up to the accident.

1.6.3 Main Rotor Blades

Manufacturer	: Bell Helicopters
Year of manufacture	: Blade 1 & 2 – Oct 2007 / Blade 3 & 4 – Jan 2008
Part Number	: 407-015-001-137 (All 4 Blades)
Serial Numbers	
Blade 1	: A-3454
Blade 2	: A-3776
Blade 3	: A-4023
Blade 4	: A-4067
Total Time Since New	
Blade 1	: 3,948.5
Blade 2	: 3,790.5
Blade 3	: 2,104.0
Blade 4	: 2,104.0

1.6.4 Tail Rotor Blades

Manufacturer	: Bell Helicopters
Year of manufacture	: 2001
Serial Numbers	
Blade 1	: A-4810
Blade 2	: A-2999
Total Time Since New	
Blade 1	: 2,876.6
Blade 2	: 2,804.2

1.6.5 Tail Rotor Gearbox

Manufacturer	: Bell Helicopters
Year of manufacture	: August 2007
Log of last Overhaul	: August 2007
Last component Retorque	: 01 January 2023
Total Time Since New	: 4, 808

Evidence gathered indicated that Tail Rotor Gearbox mounting studs failed in flight. For further details regarding the tail rotor system, refer to subsequent sections of this report.

1.6.6 Tail Rotor Drive System Description

According to the *Bell 407 Maintenance Manual* (Bell 407 MM), the tail rotor drive system includes the following components:

- Forward short shaft assembly with the splined flywheel adapter
- Oil cooler blower assemble
- Aft short shaft assembly
- Tail rotor driveshaft segment assemblies
- Coupling disc packs
- Tail rotor gearbox

The tail rotor gearbox (TRGB) is mounted on the aft end of the tail boom by a washer and a self-locking nut on each of the four studs and has two dowel pins for alignment. On the output shaft of the TRGB, the tail rotor blades (TRB) are fitted with the pitch control mechanism.

The TRGB is driven by the engine through a segmented tail rotor drive shaft connected aft freewheel section by a segmented tail rotor drive shaft.

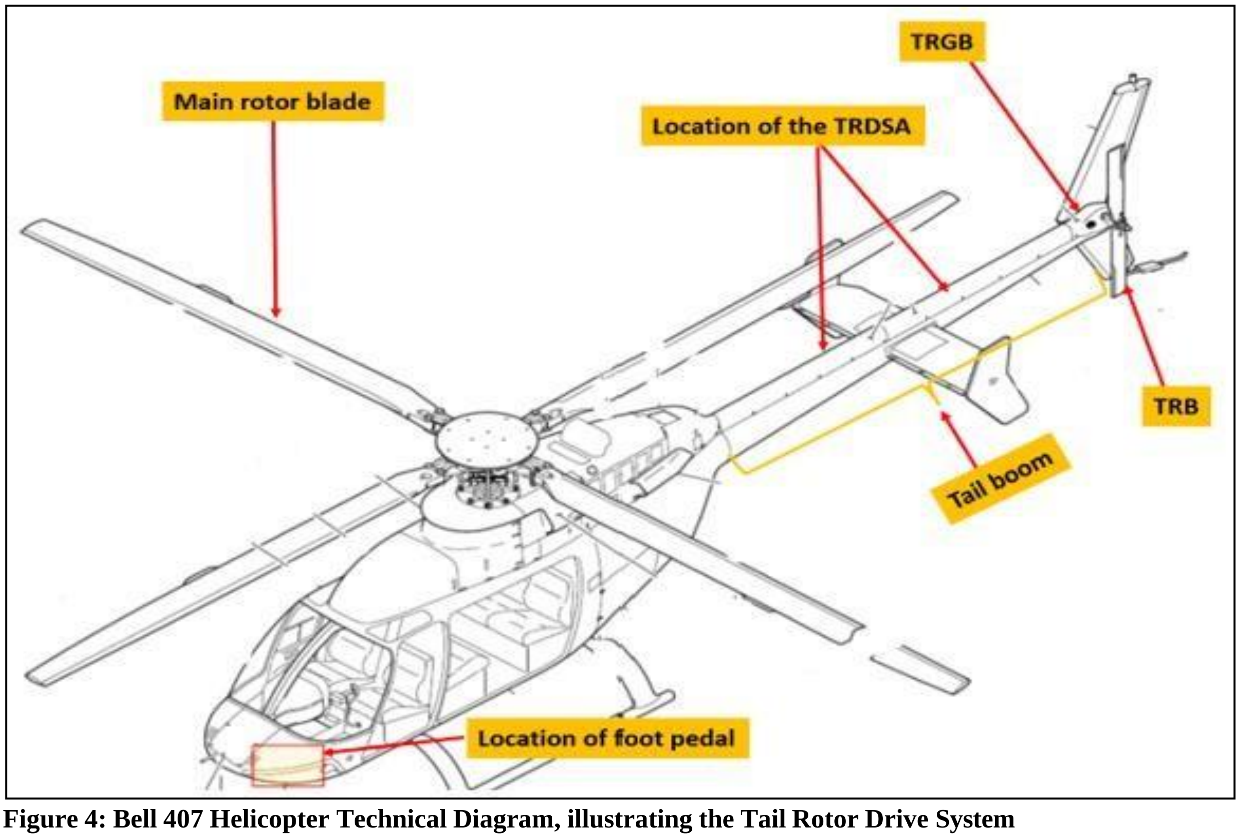

Figure 4: Bell 407 Helicopter Technical Diagram, illustrating the Tail Rotor Drive System

During engine operation, the power from the engine freewheel unit turns the forward short shaft and supplies power to an oil cooler blower assembly. The power then goes through the five tail rotor drive shaft assembly (TRDSA) to the input pinion of the tail rotor gearbox. The tail rotor gearbox then changes direction through the gears inside of the power and reduces the speed. The TR blades rotate at this reduced speed and the pilot controls the aircraft's direction by changing the pitch angle of the tail rotor blades using the foot pedals in the cockpit.

When the pilot steps either the left or right foot pedal, this movement is transmitted to the TRB via its control link and the pitch control mechanism which are connected through the tail rotor gearbox shaft as long as power transmission is maintained through the TRGB shafts.

1.6.7 TRGB Mounting Studs and Inserts-Standard Studs Identification

According to the Bell 407 Standard Practice Manual (SPM), Chapter 8 "Miscellaneous Practices,*8-31 (1) (a) (b) (e)*", Studs are identified with a mark on both ends (AN studs) or on one end only (Bell studs). AN studs have a mark on the top end of the stud to give the stud material. The mark is visible when the stud is installed. AN studs have a mark on the opposite end of the stud. The mark shows if the stud is oversized or undersized. Studs installed during manufacture are usually standard size. If it is not possible to get the required height and torque with a standard stud, an oversized stud can be installed.

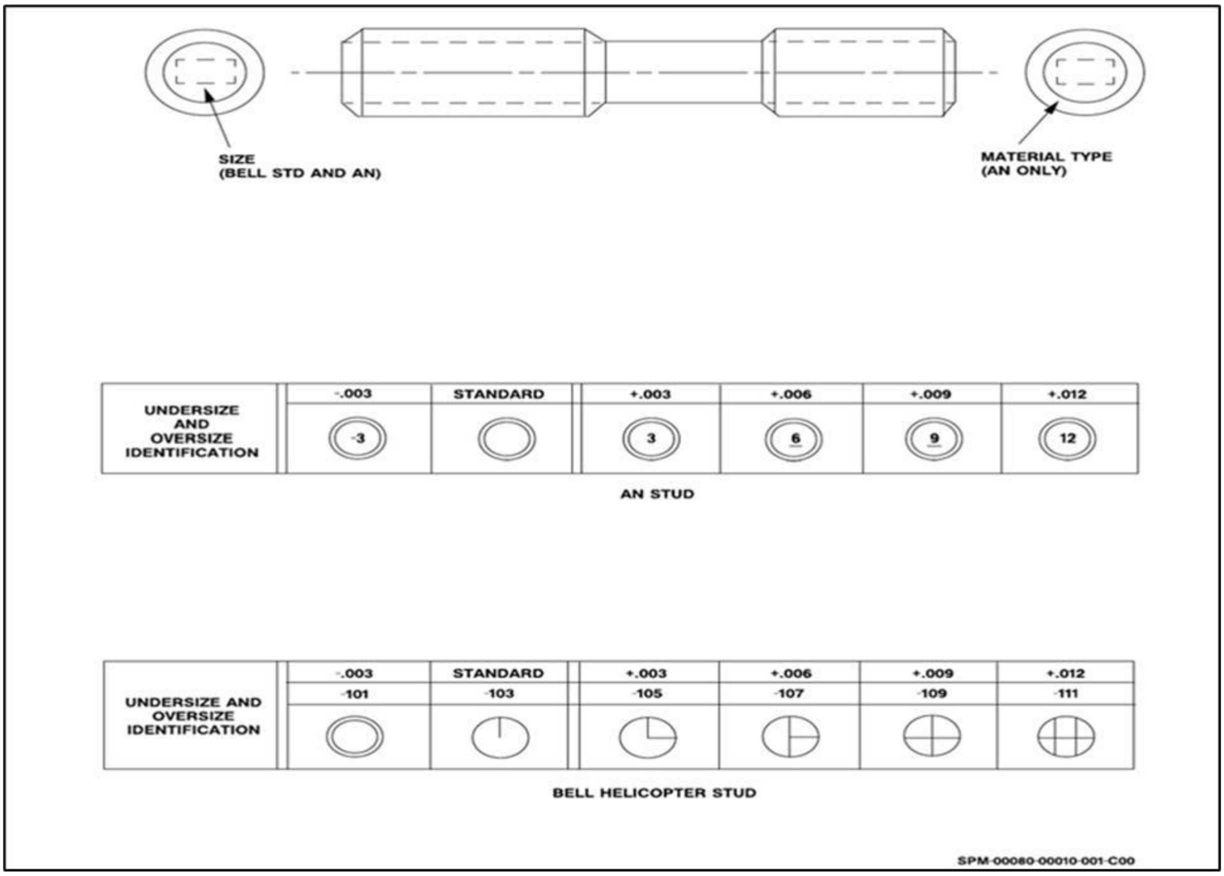

Figure 5: Studs and Inserts-Standard Stud Identification

During the on-site investigation, it was found that the four studs inserted into the TRGB had snapped off from its attachment point, refer to Figure 5. During the onsite investigation, the AIC retrieved three of the four snapped studs with nuts securely attached. The investigation did not locate the other missing stud and nut at the accident site. The nuts were found to be MS21042L4 which were superseded by NAS9962-4L or could remain in service and be replaced by attrition if they are serviceable and meet the minimum torque requirement or until depletion. The four Studs part number was AN126 324 ,0.003, standard size.

According to the manufacturer, the Studs were installed during the original manufacturing process of the TRGB and can be replaced when it is due for repair or an overhaul. (Refer to *1.6.8 TRGB Overhaul and Inspection*). The studs installed on the accident aircraft were determined to be standard size studs as they were installed during manufacturing.

1.6.8 TRGB Mating Surfaces

The TRGB mating surface was inspected and the following were observed.

- TRGB is found to be made of magnesium alloy.
- Dent sustained on the RH mating surfaces.
- Fretting (both new and old) on the mating surface.
- Dowel pin holes were expanded in the direction of applied force.
- The studs on the RH forward and aft were snapped from the inside.
- Studs on the LH forward and aft were snapped from the mating surface.
- There was no dowel pin on the TRGB.

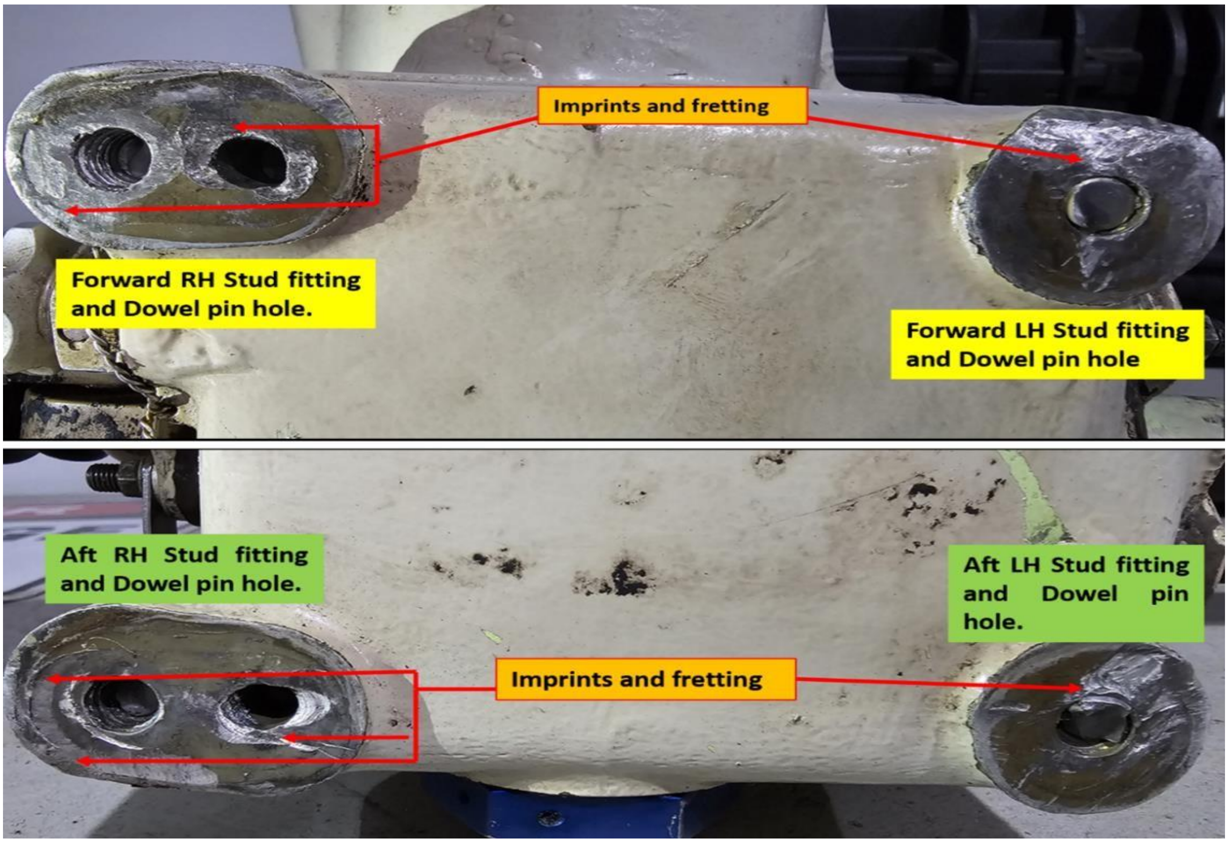

Figure 6: TRGB mating surface

1.6.9 Studs

According to the maintenance documents provided, the studs, as part of the TRGB assembly had been in operation on P2-HSM for 4,982 hours since manufacture. The AIC further examined the studs and the following were observed:

- The nuts were attached to the studs.
- LH forward stud snapped from the mating surface.
- RH aft and forward stud snapped off from the inner side.
- The stud thread was damaged from the TRGB bore and discoloured.
- Both studs' thread were damaged and believed to be just above the mating surface.

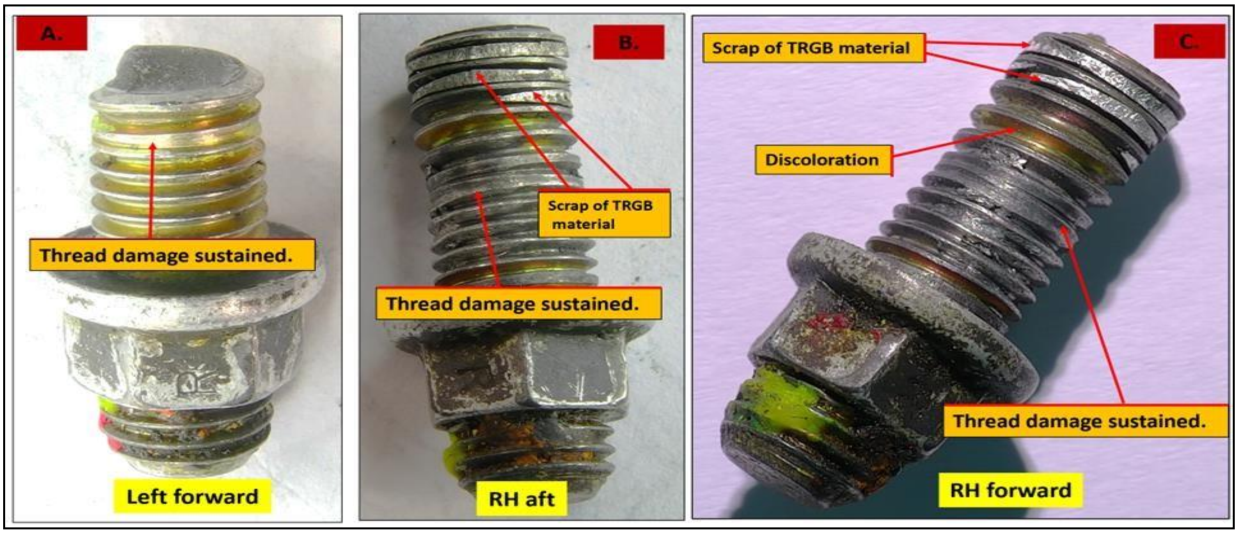

Figure 7: Studs retrieved from the accident site

1.6.10 Helicopter Vibration

According to the Bell 407 MM, all rotating components generate vibration due to imbalances in mass and/or aerodynamics. A certain level of vibration from each source is normal and unavoidable. The magnitude of each vibration is controlled by either the amount of force generated or the sympathy of individual components to the generated force. The normal level of vibration is dependent upon location, loading, and flight condition. Consistency in measuring vibration levels needs to take these into account along with how the vibration sensor is mounted. Helicopter vibration is often referred to as low, medium, and high frequency vibration. Helicopter vibration is also sometimes referred to as lateral, vertical, and fore-aft vibration. Terms such as intermittent and continuous vibration are also used.

The manufacturer recommends the *RADS-AT* [3] device to measure and analyse vibrations. However, they also recommend other vibration analysers as long as they are placed at the location of interest on the helicopter to detect vibration.

The MM has a table, *Helicopter Vibration Troubleshooting* that contains *COMPLAINT*, *SYMPTOM*, *POSSIBLE CAUSE* and *ACTION*. Refer to *Section 5.2 Appendix B of this report for the Troubleshooting - Conditions for Rotor Smoothing and Mechanical Troubleshooting.*

The table addresses the most common types of vibrations encountered on the Bell 407 helicopters. Even though a static component may cause vibration, more frequently the vibration will be caused by a dynamic component. Most of the time when a static component is the source of a vibration, it is because the component is not secured properly or it gets more energy by the vibration of a dynamic component. Troubleshooting of this type of vibration is more complex and often necessitates a spectrum analysis to be performed.

1.6.11 Helicopter Airworthiness and Maintenance

At the time of the accident, P2-HSM had a valid Certificate of Airworthiness (CoA) and Certificate of Annual Airworthiness Review (AAR).

The AIC reviewed HSM's maintenance records and observed that the helicopter's most recent scheduled maintenance was a "Compressor Wash" carried out by the operator on 17 February 2023, a day before the accident. There was no outstanding scheduled maintenance. The AIC also identified from the records that there were no outstanding defects at the time of the accident.

Therefore, it was identified that the helicopter was serviceable and airworthy at the time of the accident.

[3] Equipment required to do vibrations test and analysis.

1.6.12 12-Month Pre-Accident Maintenance Record Review

1.6.12.1 *Scheduled Maintenance*

The AIC reviewed the maintenance records provided by the operator for HSM within the 12 months preceding the accident.

It was found that there was a 100 hour/ 90-day Corrosion Inspection carried out on 13 January 2023. It was noted that the scheduled inspection was carried out in accordance with *Bell 407 MM* inspection sheet, *section 14*, 30-5 which listed a Tail Rotor thorough corrosion inspection. The entry indicated that the scheduled inspection was carried out and signed by licensed maintenance personnel as satisfactory.

The AIC also found that on 29 January 2023, a 300-hour/12-month Airframe and Engine Maintenance Inspection was carried out. Within this maintenance inspection, Progressive Inspection Events 1, 2, 3, and 4, which involved inspection of the Tail Rotor Assembly were also carried out. The operator's scheduled maintenance worksheet also showed evidence that Progressive Inspection Events 1, 2, 3, and 4 were carried out for the Tail Rotor Assembly.

It was noted during the review that the *Progressive Inspection Event 4*, item one, involved an inspection of the TRGB for condition and serviceability. Additionally, there was also a requirement to conduct a torque check on the four (4) TRGB attachment nuts to confirm that they fell within the range of 140-to-160-inch pounds (16 to 18 nm). The maintenance personnel performed the torque checks, recording the check as completed with no specific torque values recorded, nor was it required by the Maintenance Manual (MM). Refer to *Section 5.3 Appendix C TRGB Inspection and Torque Check* for further details.

The scheduled maintenance was carried out, signed, and released for return to service on 2 February 2023 by the Operator's licensed maintenance personnel.

The AIC also reviewed other scheduled maintenance conducted in 2021 and 2022 in relation to torque checks conducted. It was noted that no torque values were documented on the schedule worksheet following torque check. The MM does not require the recording of torque values following torque checks.

1.6.12.2 Unscheduled Maintenance – Vibration Recurring Event

According to the technical log for the 12-month period prior to the accident, the AIC observed five separate instances in which helicopter vibrations were reported and recorded (see Table 2). The technical log indicated that some entries were made by the pilot while other entries were made by the maintenance personnel. The Operator confirmed that the entries by the maintenance personnel were made following verbal reports by the pilot who had last flown the helicopter.

The technical log showed a defect entry on 2 January 2023 made by maintenance personnel following a flight that morning which stated:

> *TAIL ROTOR DRIVE SYSTEM COMPONENT SERVICEABILITY CHECK TO BE C/OUT DUE TO VIBRATION.*

The corrective action of the defect was recorded as:

> *SERVICEABILITY CHECK CARRIED OUT I.A.W DMC 407-A-65-10- 00-00A-320A-A. TROUBLE SHOOTING CHART.*

The release to service certification *(CAR 43.105)* was signed, indicating that all maintenance was completed. Following the certification, the aircraft was not flown, nor was the engine run.

On the following day, another defect entry was made on the technical log. It was recorded as:

> *RESTRAINT SPRING ASSEMBLY FOUND REAR ATTCH BEARING U/S ON LEFT SIDE.*

The corrective action of the defect was recorded as:

> *NEW SPRING ASSEMBLY FITTED + SECURED I.A.W. DMC407-A-63-31-00A-720A-A*

Records show that on 5 January 2023, a Charter flight was operated.

The AIC also noted that on the technical log provided for 2022, there were defect entries for vibration related issues.

	Place Defer\BY And Date	Details of DEFECT	TRADE	CORRECTIVE ACTION	CERTIFICATION DATE
1	Engineering O2/01/23	TAIL ROTOR DRIVE SYSTEM COMPONENT SERVICEABILITY CHECK TO BE C/OUT DUE TO VIBRATION	ENGINEERING	SERVICEABILITY CHECK C/OUT I.A.W DMC-A-65-10-00-00A-320A-A. TROUBLE SHOOTING CHART	02/01/23
2	Pilot 13/12/22	VIBRATION VERY EVIDENT INFLIGHT AND GROUND	PILOT	INVESTIGATION C/OUT FOUND M/R BLADES ERODES CAUSING IMBALANCE SERVICEABILE SET OF BLADES FITTED	16/12/22
	Engineering 13/12/22	M/T TRACK AND BALANCE REQ	ENGINEERING	TRACK & BALANCE C/OUT SATISFACTORY. REFER JOB/NO. HSM-41/22	16/12/22
3	Engineering 25/07/22	TAIL ROTOR TRACKING CHECK TO BE C/OUT AS REQUIRED	ENGINEERING	T/R TRACKING AND BALANCE C/OUT AND MAKE FEW ADJUSTMENTS. FINAL READING IS 0.048 ips @7.29 IAW BHT 407 MM DMC-407-A-18-10-00	25/07/22
4	Engineering 05/05/22	M/R & T/R BALANCE CHECK REQUIRED TO BE C/OUT DUE EXCESS VIBRATION	ENGINEERING	MAIN ROTOR TRACK & BALANCE C/OUT FOUND READING WITHIN LIMITS BELOW 0.40 ips@F/A-V/FUND AND V/AFF.T/R ADJUSTED TO 0.09 ip@154 IAW BHT 407 MM CH:18. FOUND SATIS	05/05/22
5	Pilot 23/01/22	TAIL ROTOR SUSPECT FISH TAILING	PILOT	C/O T/R TRACK & BAL ADJUSTED TO 0.28 @ 6.26 Found Satisfied	26/01/22

Table 2: Technical Log Entries

The AIC identified from the records that there was no evidence in the records indicating that the operator recorded vibration data before and after conducting the Helicopter Vibration Troubleshooting as outlined in Chapter 18 of the Bell Helicopter Maintenance Manual. Additionally, it was found during the investigation that on certain occasions, pilots verbally reported levels of vibration to the maintenance team but did not make entries in the Technical Log for maintenance action.

1.6.13 TRGB Overhaul and Inspection

According to the *Bell 407 MM*, the TRGB must go for an overhaul when the operating time of the TRGB reaches 5,000 hours.

According to the maintenance document provided by the Operator, the TRGB was installed on 25 August 2007 and had accumulated 4,808 hours at the time of the accident. It had 182 hours remaining before the next overhaul at the time of the accident.

According to the *Bell 407 MM*, the TRGB requires 60 months interim inspection on the TRGB.

The note on the procedure states:

> *Do this inspection if an overhaul inspection has not been accomplished within the past 60 months.*
>
> *Remove the tail rotor gearbox (DMC-407-A-65-20-00-00A-520A-A) and examine the studs and dowel pins that attach the tail rotor gearbox to the tail boom for condition and security (DMC-407-A-65-20-00-00A-280A-A).*
> *Examine the housing where it comes together with the tail boom for condition (DMC-407-A-65-20-00-00A-280A-A)*

The maintenance records supplied by the Operator showed that the TRGB 60-month interim inspection was conducted on June 25, 2017. The subsequent 60-month interim check was conducted on December 13, 2021, roughly 5 months before reaching the 60-month mark. No abnormalities were observed during this inspection.

According to the Operator's Maintenance Control manual, the maximum period that an inspection may be extended up to is 10% periodic inspection unless prohibited by another Rule. There was no requirement for scheduling the inspection before the required periodic inspection.

1.6.14 Technical Bulletins

1.6.14.1 Alert Service Bulletin 407-09-89

On 29 April 2009, the Helicopter Manufacturer issued an *Alert Service Bulletin* (ASB) 407-09-89, to the owners and operators of BELL 407 helicopters with serial number (S/N) 53000 through 53888, 53890 through 53899, 53912 through 53926, and 53928. The ASB 407-09-89 required one-time inspections to be carried out on *TAIL ROTOR GEARBOX P/N 406-040-400-ALL AND TAIL ROTOR GEARBOX CASE ASSEMBLY P/N 406-040-406-ALL*. One of the requirements was to inspect for proper stud and dowel pin installation.

The accident helicopter, HSM, bore serial number 53791, falling within the specified range, and its TRGB case assembly featured part number 406-040-400-121. Thus, it was subject to ASB 407-09-89.

According to the records provided by the operator, ASB 407-09-89 was carried out on 13 May 2009.

1.6.15 Fuel information.

The AIC determined that fuel was not a contributing factor to this accident.

1.6.16 Weight and Balance

The evidence revealed that the helicopter's weight was within the prescribed limit and was not a factor in this accident.

1.6.17 Collision Avoidance Systems

The helicopter was equipped with a Mode C transponder and its serviceability was not a factor in this accident.

1.7 Meteorological information

1.7.1 PNG National Weather Service Forecast Data

The Terminal Aerodrome Forecast (TAF) Wapenamanda was issued at 16:00 UTC on 18 February and was valid from 19:00 to 09:00

- Wind: Variable at 3kts Visibility 5000m in fog
- From 0001: Wind Variable at 3kts visibility greater than 10km in light showers and rain
- Cloud: Scattered at 1600ft Broken at 3000ft
- Inter: Valid from 03:00 to 09:00 Visibility 4000m in heavy showers and rain
- Cloud: Broken at 800ft
- QNH: 1018 1020 1019 1017

1.8 Aids to Navigation

Not applicable

1.9 Aerodrome

Not applicable

1.10 Communication

The helicopter was equipped with a High Frequency (HF) and Very High Frequency (VHF) two-way communication radio. Both communication systems were found to be serviceable at the time of the accident.

The pilot stated during interview that a Distress call was transmitted blind during the abnormal phase of flight. The pilot stated that he had made a distress call but did not receive any response. The ATC radio communication records did not show any record of a distress call from HSM. The geographical area that the pilot recalls making the distress call had poor radio signal coverage due to terrain.

1.11Flight recorders

The helicopter was not equipped with a Flight data recorder or a Cockpit voice recorder, neither were they required by PNG Civil Aviation Rules.

1.11.1 Other Recording Source – Garmin Aera 660 GPS

The helicopter was equipped with a Garmin Aera 660 GPS, known for its reliability, and tailored for aviation use. Featuring a vibrant touchscreen, it offers access to various aviation-specific functions. Notably, the Garmin Aera 660 excels in recording flight data, including GPS position, altitude, speed, and heading, aiding in post-flight analysis, performance assessment, and regulatory compliance.

The data captured by the Garmin Aera 660 GPS was utilized in creating the graph below to complement the investigation. The graph displays recorded and computed data, detailing altitude loss, distance travelled, elapsed time, and above ground level (AGL) in feet. It correlates with the elevation of the emergency landing site, approximately 5,800 feet AGL.

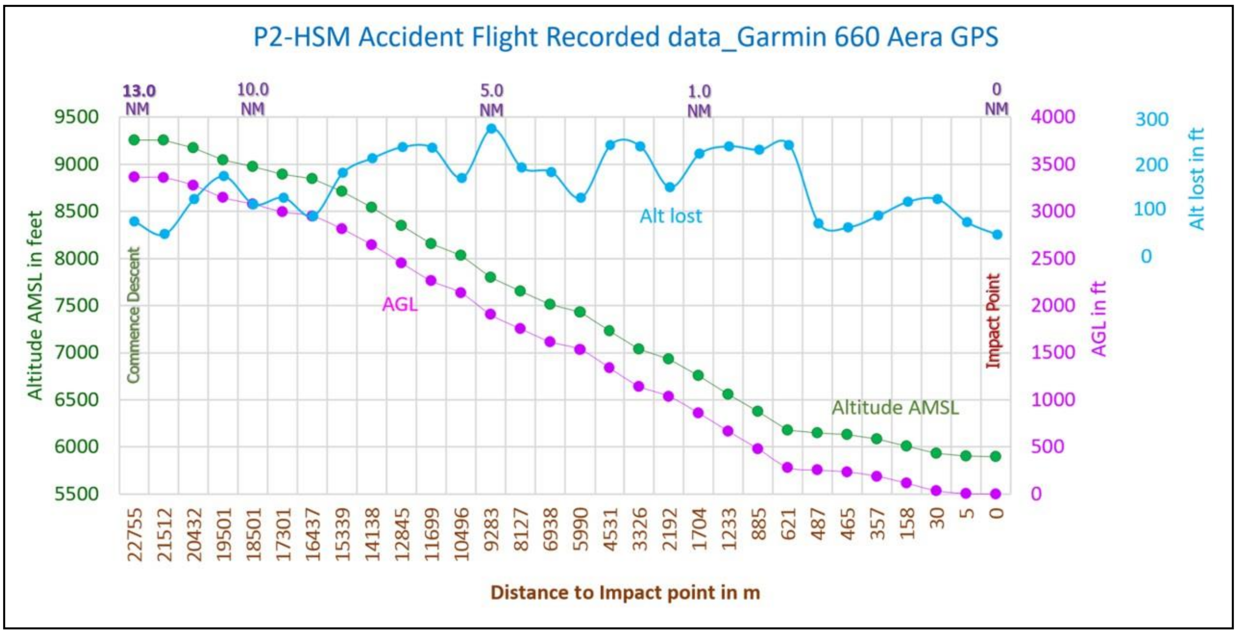

Figure 8: Garmin Aera 660 GPS recorded data and computed data plot.

1.12 Wreckage and impact information

1.12.1 Overview of the wreckage distribution

A total loss of tail rotor thrust occurred about 9 NM Northwest of Wapenamanda Airport, prompting the helicopter to perform an emergency landing approximately 3.5 NM Northwest of the airport.

The fifth segment of the tail rotor drive shaft was detached in-flight and was later recovered about 700 metres Northwest of HSM's resting position (Refer to Figure 7).

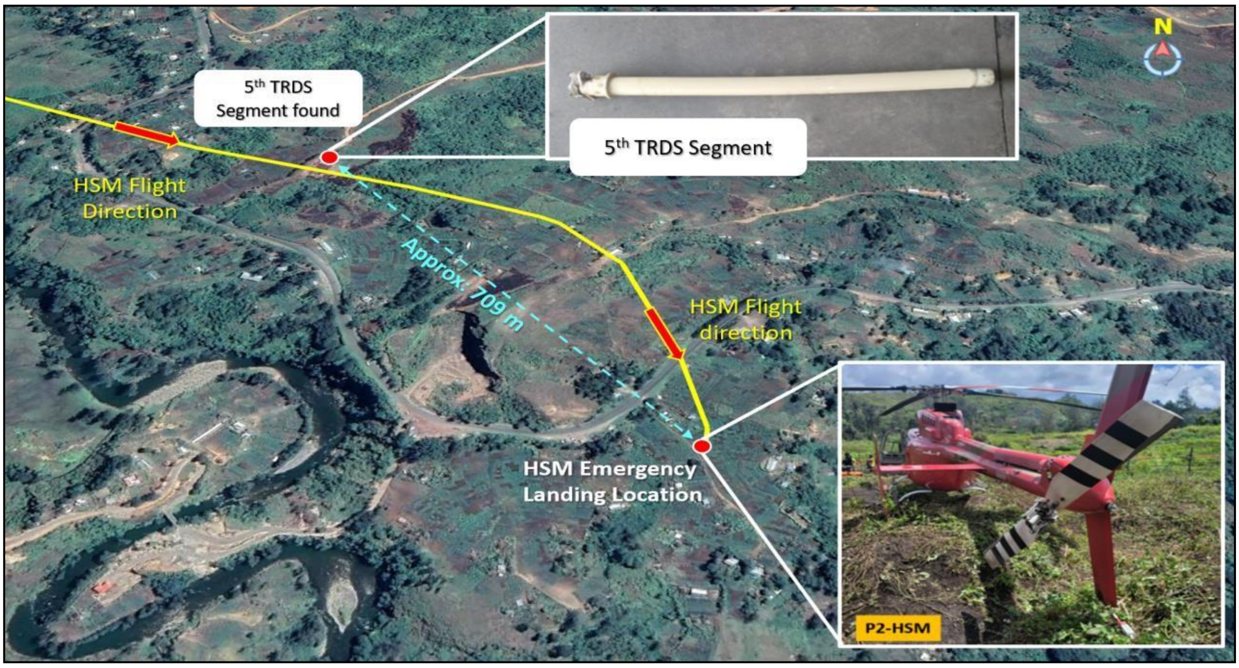

Figure 9: Overview of the Accident Site

1.12.2 Damages Sustained

The helicopter suffered notable structural damage to several components, including the tail boom, tail rotor gearbox, tail rotor hub and blades, and tail rotor driveshaft (Refer to Figure 8). Additionally, minor damage was observed on the skid rear cross tube, and there was a crack in the chin bubble on the left side.

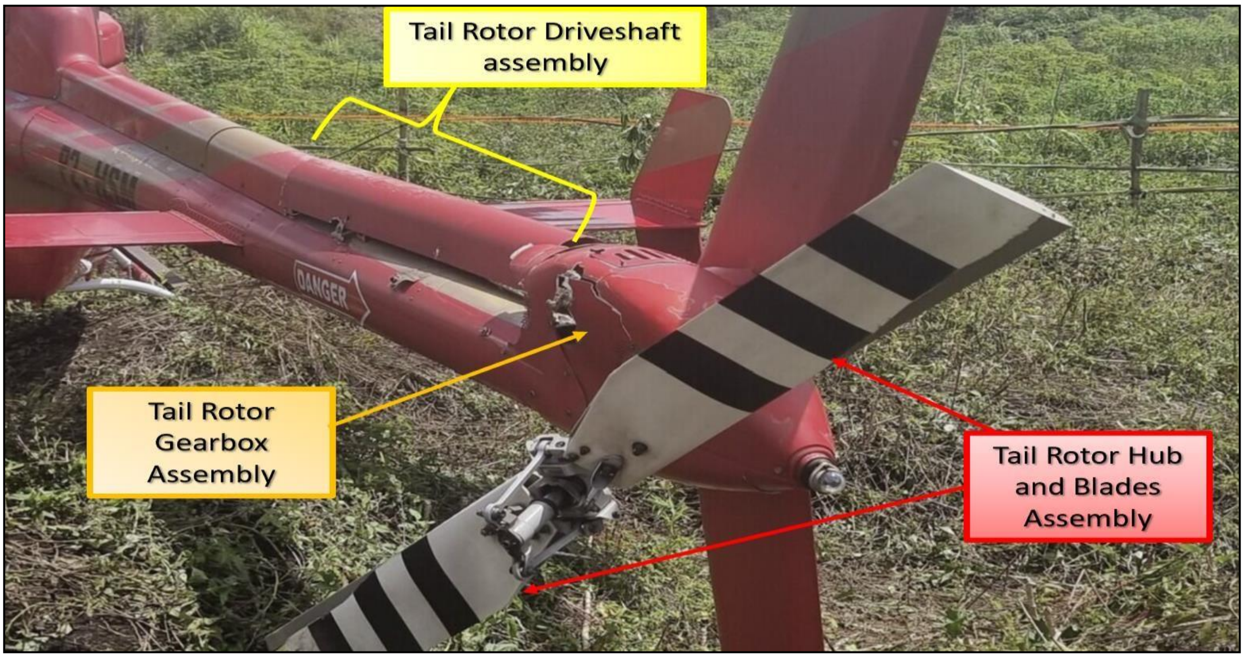

Figure 10: Damage Sustained

The TRGB became detached from its mount, with only the tail rotor blade control link preventing complete separation. Upon site inspection, damage was visible on both the TRGB and the top fairing of the tail rotor shaft. Furthermore, the aft tail rotor driveshaft assembly had completely fractured, causing the gearbox to shift from its original position and move leftward from its designated mount. This displacement resulted in the tail rotor blades hanging over. Subsequent examination revealed that the four fastening hardware securing the gearbox had failed. As a result, the TRGB was left suspended on the tail boom solely by the control mechanism.

Moreover, the rivets connecting the forward and aft TRDSAs at the bearing hanger were absent, and noticeable abrasion was observed on the tail boom structure where the aft TRDSA connects to the input pinion of the TRGB. A notable dent on the leading edge of the TRB's tip was attributed to impact with a soft foreign object.

Figure 11: Damage sustained to the TRGB and Tail Boom

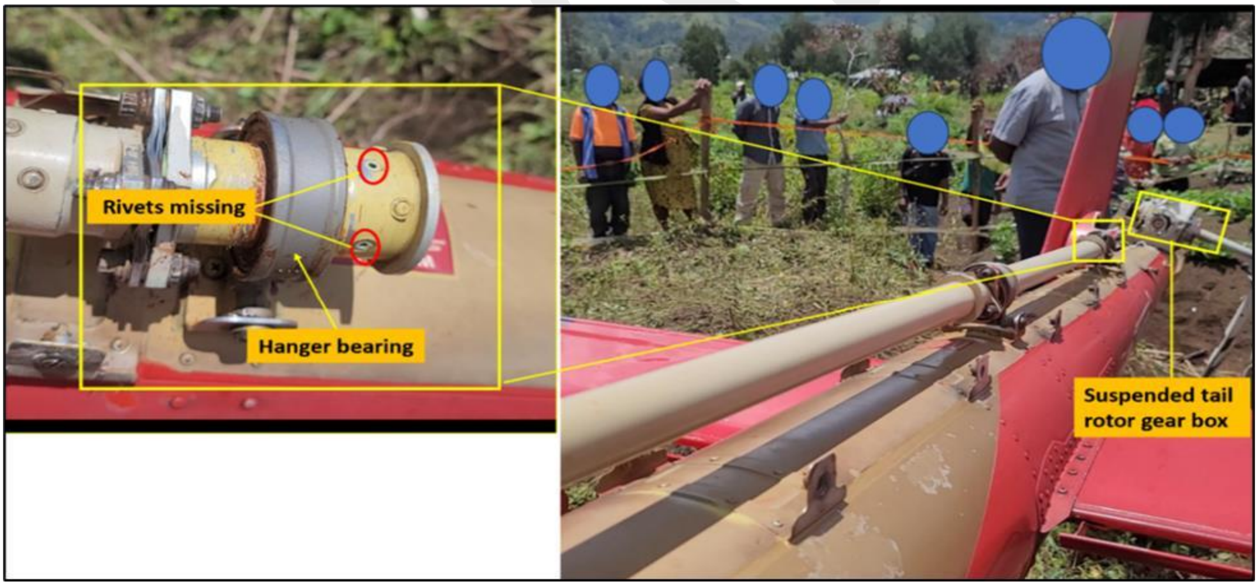

Figure 12: Drive shaft and TRGB

The TRGB mounting studs fractured, causing the gearbox to detach from the tail boom support. Of the four studs that failed, two were positioned within the stud bores of the gearbox, while one was situated on the surface of the TRGB mounting, as illustrated in *Figure 11.* The location of the remaining stud was undetermined. Refer to *Section Figure 7* for details regarding the attachment positions of the studs with secured nuts and to view a microscopic picture.

During inspection of the tail boom support (TRGB mounting surface), cracks were observed extending from the forward right stud hole to the dowel pin hole position (Refer to *Figure 11)*

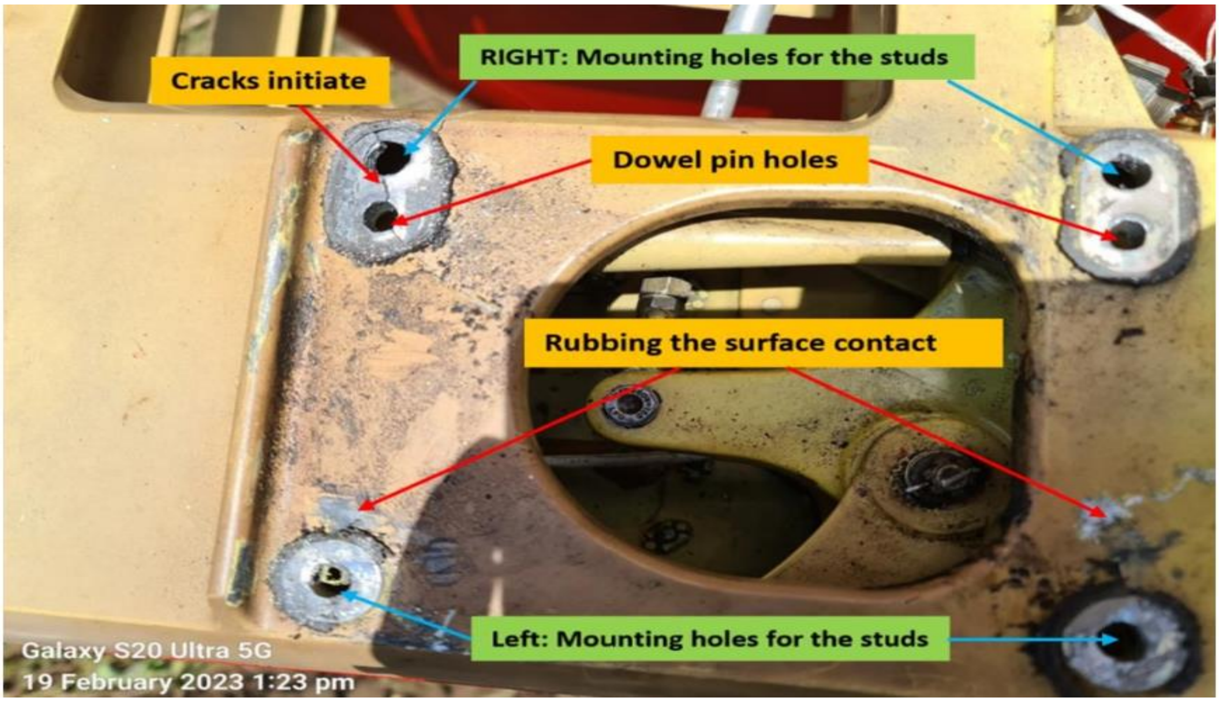

Figure 13: Tail Boom mating surface.

1.13 Medical and pathological information

No medical or pathological investigations were conducted as a result of this occurrence.

1.14 Fire

There was no evidence of pre- or post-impact fire.

1.15 Survival aspects

1.15.1 Search and Rescue

During the interview, the pilot mentioned transmitting a distress call on the area FIS frequency but received no response from ATS or other traffic. The pilot continued to concentrate on managing the emergency.

The helicopter was equipped with Spidertracks, a third-party tracking system featuring an Emergency or SOS Pilot activation button that sends a distress alert back to the operating Base. However, due to the high workload during the emergency, the pilot did not activate the SOS function on the tracker and only remembered to do so after shutting down the engine following the impact.

ATS audio recordings revealed that Moresby FIS initiated radio communication checks on HF 6538 KHz at 11:44, lasting until 11:55, with no response from HSM. ATS records indicated the declaration of an INCERFA at 12:01.

Following the shutdown and evacuation, the pilot notified the Operator of the situation via a phone call. The Operator's Emergency Response Plan (ERP) was then activated, and a team was dispatched from the Operator’s base, Mt Hagen, Westen Highlands Province to the accident site via road.

According to NiuSky Pacific Limited Initial Notification of Incident (INI), the Operator contacted ATS at 12:06 to inform them about the accident, and by 13:00, the INCERFA was cancelled.

1.16 Tests and Research

No tests or research were required to be conducted as a result of this occurrence.

1.17 Organisational and Management Information

1.17.1 Heli Solutions Ltd Limited (HSL)

Heli Solutions Ltd is an aircraft Operator which conducts charter and regular Fares & Freight (F&F) operations under the VFR category, within PNG. Most of its operations are in remote areas, servicing rural communities.

Heli Solutions Ltd holds an Air Operator's Certificate, or AOC number 119/061 issued pursuant to section 47 (3) and 49 of the Civil Aviation Act 2000 (as amended) and Part 119.9, which authorizes the operator to perform commercial air operations in accordance with its exposition and CAR Part 136.

The Operator also holds a Maintenance Organization Certificate, or MOC number: 145/061, current issue on 1 September 2021 and expires on 31 August 2025.This certificate certifies that the operator is authorized to engage in activities in compliance with CARs and Civil Aviation Act 2000 (as amended) and the maintenance organizations exposition (Part 145 Exposition). The Heli Solutions Ltd Maintenance Organization is based at Mt. Hagen (Kagamuga) Airport, Western Highlands Province.

1.17.2 Bell Textron Inc

Bell Textron Inc is an American aerospace manufacturer headquartered in Fort Worth, Texas. It is a subsidiary of Textron, Bell manufactures military rotorcraft at facilities in Fort Worth, and Amarillo, Texas, USA as well as commercial helicopters in Mirabel, Quebec, Canada.

The Bell 407 Type Certificate was issued by Canada as the State of Design. The helicopter's design was originally initiated in the US according to Title 14 Code of Federal Regulations (14 CFR). However, during the development process, the design jurisdiction was transferred to Canada. Despite this transfer, 14 CFR remained the basis of the design as indicated on the Type Certificate Data Sheet.

1.17.2.1 Bell Response on the Stud Photos Provided

During the investigation, the AIC provided the photos of the studs that were retrieved from the accident to Bell Helicopters for their assessment. In an email response on 5 April 2024, they provided an Alert Service Bulletin (ASB) that was issued in 1997 to prevent loosening of the mounting hardware like studs and nuts. This was incorporated into the accident aircraft during manufacture. They stated that any fretting[4] movement that is left unattended, overtime may develop cracks in support and / or could lead to stud fractures.

Based on their assessment of the photos provided, they stated that there was evidence of fretting on the TRGB mounting surface.

1.17.2.2 Vibration Analyser/Track and Balance Equipment

According to the Bell 407 MM, it states:

> *All vibration data gathering and automated analysis procedures in this chapter use the Rotor Analysis Diagnostics System - Advanced Technology (RADS-AT). It is acceptable to use a different system provided the measurements are taken at the locations specified in this chapter.*

[4] Rubbing together of solid surfaces, especially slight movement but high contact pressure.

However, the level of technical support provided for vibration issues where a RADS-AT system is used is better due to experience and software availability. The Zing Test Elite (ZTE) is a Bell Textron (BT) accepted alternative to the RADS-AT

During the investigation, the AIC noted that the vibration analyser, *COBRA II*, used by the Operator to conduct vibration analysis was different than what was recommended in the Bell 407 MM. The AIC sought clarification from the manufacturer regarding the approval of the vibration analyser used by the Operator to conduct its maintenance activities. The manufacturer referred to the provisions in the manual. Refer to *Appendix 5.4, Appendix D Vibration Analyser/Track and Balance Equipment*

1.18 Additional information

1.18.1 Complete Loss of Tail Rotor Thrust Inflight Procedure in the Bell 407 Flight Manual

According to the *Bell 407 Flight Manual, 3-5 'Tail Rotor*',

There is no single emergency procedure for all types of antitorque malfunctions. A key factor to a pilot successfully handling a tail rotor emergency lies in the ability to quickly recognize the type of malfunction that has occurred**.**

B*ell 407 Flight Manual, 3-5-A 'Complete Loss of Tail Rotor Thrust*' states,

This is a situation involving a break in drive system (e.g., severed driveshaft), wherein the tail rotor stops turning and delivers no thrust.

INDICATIONS:

1. Uncontrollable yawing[5] to right (left side slip).
2. Nose down tucking.
3. Possible roll of fuselage

NOTE

Severity of initial reaction of helicopter will be affected by AIRSPEED, CG, power being used, and HD.

Due to the complete loss of tail rotor thrust, there was no anti-torque produced by the tail rotor located on the end of the tail boom extension at the rear of the fuselage. The tail rotor produces thrust opposite to torque reaction developed by the main rotor. Anti torque pedals enable the pilot to compensate for torque variance. The tail rotor compensates for additional torque generated by the main rotor and keeps the heading of the helicopter fixed. Without the tail rotor, the helicopter's body would spin in the opposite direction as the main rotor.

The tail rotor system receives power from the engine through the tail drive shaft system, which is made up of five individual shafts that are linked. The most aft shaft had detached in flight

When the pilot realised that he had complete loss of tail rotor thrust, he then decided to conduct an emergency landing. The pilot then executed the procedure in the *Bell 407 Flight Manual, Section 3 Emergency/Malfunction Procedures,3-5-Complete Loss of Tail Rotor Thrust*', specifically 3-5-A-2, 'Inflight' which states**;**

[5] The official definition is a twisting, or rotation of up to 360 degrees, of a aircraft around a vertical axis. Aircraft move in three dimensions, which adds to the complexity of stability and control. Therefore, a change in any one of a plane's three dimensions of motion affects the other two. Yaw is one of these dimensions. The other two are roll and pitch.

Reduce throttle to idle, immediately enter autorotation[6]*, and maintain a minimum AIRSPEED of 55 KIAS during descent.*

NOTE

When a suitable landing site is not available, vertical fin [7] *may permit controlled flight at low power levels and sufficient AIRSPEED. During final stages of approach, a mild flare should be executed, making sure all power to rotor is off. Maintain helicopter in a slight flare and smoothly use collective*[8] *to execute a soft, slightly nose-high landing. Landing on aft portion of skids will tend to correct side drift. This technique will, in most cases, result in a run-on type landing.*

Caution*: In a run-on type of landing after touching down, do not use cyclic to reduce foward speed.*

The pilot stated that he did not reduce throttle to idle and enter autorotation because he could not see a suitable landing site, therefore he executed the procedure in the NOTE.

1.18.2 Threat and Error Management (TEM)

ICAO Doc. 9683, Human Factors Training Manual, provides a perspective to Threat and Error Management (TEM), as follows:

Threats and errors are pervasive in the operational environment within which flight crews operate. Threats are factors that originate outside the influence of the flight crew but must be managed by them. Threats are external to the flight deck. They increase the complexity of the operational environment and thus have the potential to foster flight crew errors. Bad weather, time pressures to meet departure/arrival slots, delays and, more recently, security events, are but a few of the real-life factors that impinge upon commercial flight operations. Flight crews must manage an ever-present "rain" of threats and errors, intrinsic to flight operations, to achieve the safety and efficiency goals of commercial air transportation. Sometimes these goals pose an apparent conflict.

CASA Australia, *Safety behaviours: human factors for pilot's 2nd edition Resource booklet 8 Threat and error management states;*

Threats are generally external (such as bad weather) or internal (such as physiological and psychological state). Pilots need good situational awareness to anticipate, recognise and manage threats as they occur. The TEM model includes three threat categories: *anticipated*, *unanticipated* and *latent*. All three can reduce safety margins. Latent threats may not be clear and may need to be uncovered by formal safety analysis and specifically addressed in your organisation's training and procedures.

Threats can be anticipated or unanticipated, unexpectedly, suddenly and without warning. Pilots must apply the skills and knowledge they have acquired through training and operational experience to deal with issues. Some threats may be latent and not be directly obvious to, or observable by, pilots and may need to be discovered through formal safety analysis.

The investigation identified the following unanticipated threats:

In-flight Aircraft Malfunction

Two distinct loud bangs emanated from the tail rotor section seconds apart, with erratic changes in the helicopter's stability.

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[6] In a helicopter, an autorotative descent is a power-off maneuver in which the engine is disengaged from the main rotor disk and the rotor blades are driven solely by the upward flow of air through the rotor. In other words, the engine is no longer supplying power to the main rotor. The most common reason for an autorotation is failure of the engine or drive line, but autorotation may also be performed in the event of a complete tail rotor failure, since there is virtually no torque produced in an autorotation. This upward flow of air through the rotor disk provides sufficient thrust to maintain rotor rpm throughout the descent. Since the tail rotor is driven by the main rotor transmission during autorotation, heading control is maintained with the antitorque pedals as in normal flight.

[7] The vertical fin of the 407 is designed as such that in cruise flight over 40 knots, the tail rotor should be almost completely off-loaded and require close to no input from the pilot as long as excessive cross wind conditions do not exist.

[8] As the helicopter approaches the ground, pull back on the cyclic to stop the descent and pull collective to ensure the rotor doesn't overspeed.

The pilot assessed the helicopter's performance and determined that the issue was a loss of tail rotor thrust. To gain directional control, the pilot applied pressure to the foot pedals but noticed free pedal movement. The pilot then assessed the helicopter's behavior and indications following the loud bangs, and concluded that the issue was a structural failure, resulting in the total loss of tail rotor thrust and controllability.

Environmental Operational Pressure

Once the pilot determined that the helicopter was experiencing a loss of tail rotor thrust inflight, he executed the *Complete Loss of Tail Rotor Thrust Emergency procedure* outlined in *section 3-5-A-2* of the manufacturer's manual. During the execution of the emergency procedure, the pilot adhered to the 'NOTE' outlined in the procedure, by maintaining a suitable speed at a low power setting, as he continued to manoeuvre the helicopter towards Wapenamanda.

Runway 14 at Wapenamanda Airport was unsuitable for landing due to the necessity of conducting a steep right turn against the direction of the main rotor blades' rotation. Such a manoeuvre would risk the helicopter to roll upon impact, potentially causing a collision with nearby houses. In response, the pilot identified a local garden as a suitable landing surface, noting the recent rainfall would have softened the soil, and safely landed the aircraft.

The investigation concluded that the pilot demonstrated situational awareness by identifying and mitigating threats to prevent a catastrophic outcome.

1.19 Useful or effective investigation techniques

The investigation was conducted in accordance with the *Papua New Guinea Civil Aviation Act 2000* (*As Amended*), and the Accident Investigation Commission's approved policies and procedures, and in accordance with the Standards and Recommended Practices of *Annex 13* to the *Chicago Convention on International Civil Aviation.*

2 ANALYSIS

2.1 General

The analysis of this report will discuss the relevant issues and circumstances resulting in P2-HSM helicopter experiencing a complete loss of tail rotor thrust inflight, resulting in an emergency landing at Kuimanda, 3.5 nautical miles (NM) Northwest of Wapenamanda Airport, Enga Province.

2.1.1 Flight Operation

In most instances of complete tail rotor thrust loss worldwide, accidents have resulted in catastrophic outcomes. However, in this accident, the AIC believes that the pilot's actions demonstrate adherence to established emergency procedures and prompt decision-making in a critical situation. The pilot exhibited a methodical approach to resolving the issue. Additionally, the pilot's decision to decide for an alternate landing site was a decisive choice. From the AIC's perspective, the pilot's competence, resourcefulness, and effective decision-making in managing this challenging emergency prevented the helicopter from experiencing a catastrophic outcome and resulted in no reported injuries.

2.1.2 TRGB Studs and vibration

Upon review, several factors were identified as contributing to the premature rupturing of the TRGB studs. Significant wear was observed in the TRGB inner bores, suggesting excessive exposure to vibrations above normal. The inner studs exhibited fatigue cracks along the thread grooves, indicates repeated stress cycles and vibration, leading to material fatigue and cumulative weakening over time.

Despite maintenance efforts, the helicopter may have continued to sustain vibrations to a certain degree above optimum levels and are believed to have persisted, indicating that the issues were not fully resolved or that underlying problems were not fully diagnosed or addressed. This is evidenced by records showing that proper maintenance action is unlikely to have been taken.

The flattened stud threads along the length of the mounting points suggest predominant lateral vibrations prior to the studs rupturing. The elongation observed on the inner stud bores and the dowel pin bores also supports this observation. Sustained vibrations weakened the studs, and additional fatigue cracks were observed along the length of the inner studs. The continued weakening of the studs through these vibrations reduced their structural integrity below that of the nuts. Evidence of fretting in the stud bores further indicates that as fretting continued to create clearance between the stud and bore making the stud movement more pronounced, promoting further weakening and cracking.

The bore material continued sustaining fretting until the remaining thinned and weakened threads stripped when the studs snapped. This compromised the TRGB mounting surface security, which further exacerbated the effects of vibration on the stud assembly.

Due to the significantly weakened state, during flight on the day of the accident, the studs ruptured, causing the separation of the TRGB from the tail rotor drive system.

The AIC could not determine the magnitude and source of the vibration due to the damage sustained and the lack of analysis information. However, it was considered that any vibration above the normal vibration levels would naturally cause permanent weakening materials and reduce their lifespan leading to premature failure.

Considering that it is part of the pylon assembly and that its purpose is to maintain the alignment of the Transmission to the engine and attenuation of the vibrations, damage to one of the restraint spring assembly would contribute to the amplification of vibrations. However, one of the possible causes of premature damage to a restraint spring assembly bearing is vibrations above helicopter specified limits.

The recorded maintenance actions carried out on the 2 and 3 January 2023 suggest that the maintenance personnel may not have been certain if the vibration was forward or aft of the engine. After physical inspection of the aft section, drive shafts and oil cooler blower, no defects were found. A check forward of the engine led to the identification of defective left restraint spring assembly bearing. The helicopter was released following replacement of this spring assembly. It was considered that the spring assembly, may itself, as part of the pylon assembly, have been subject to vibration from another vibration source. The amplified vibration failure may, itself, exacerbated wear and tear on other components.

As such, its premature failure, with no other observable cause, was likely due to vibrations from other sources, would not necessarily mean that a replacement of the component rectifies the issue. On the contrary, it should prompt further analysis.

Helicopter vibration analysers are quite accurate and can assist in diagnosis and identification of vibration sources and magnitude. Conducting maintenance activities relating to excessive vibration reports without the use of vibration analysers pose a significant risk of misdiagnosis and continued manifestation of issues leading to such failures.

The AIC found that the Manufacturers Maintenance Manual specifically requires the use of procedures for troubleshooting or analysing helicopter vibration under certain circumstances. One of the specific circumstances is when reported by the crew/pilots. For excessive vibration related maintenance on 22 December 2022 and between 2 to 3 January 2023, there were no records of engine starts. There were also no helicopter hour advances between the last charter flights before and after the vibration related maintenance. Furthermore, Bell MM reference provided on the work carried out on these dates does not involve the use of the vibration analyzer. The AIC therefore deduced for maintenance activities on those days, (22/12/22, and 2, 3/01/2023), a vibration analyser was not used.

A significant risk, which would not likely be the case if an analyser is used, remained that underlying sources of vibration may not have been completely resolved or that a level of imbalance. It cannot be determined for certain that the helicopter vibrations are within the specified parameters without the use of vibration analyser. The sources of any excessive vibration, single or multiple, are also difficult to identify without an analyser.

3 CONCLUSIONS

3.1 Findings

3.1.1 Aircraft

a) The helicopter was certified, equipped, and maintained in accordance with existing regulations and approved procedures.

b) The helicopter had a valid Certificate of Airworthiness and had been maintained in compliance with the regulations.

c) There was no outstanding scheduled or unscheduled maintenance.

d) The helicopter was airworthy and serviceable during the accident time.

e) Last 60 months inspection was conducted 5 months early.

f) There was evidence of a defect or malfunction in the aircraft that could have contributed to the accident.

g) The aircraft was not structurally intact prior to impact.

h) All control surfaces were accounted for and all damage to the aircraft was attributable to the in-flight tail rotor failure.

i) There was engine power available following the in-flight tail rotor failure.

j) The aircraft lost its control with forward momentum available.

k) The 4 TRGB attachment studs were snapped off in-flight causing the 5th drive shaft to snap off inflight.

l) The 3 of the 4 TRGB attachment suds were found at the accident site.

m) There was evidence of fretting on the TRGB mating surface.

n) The operator was using a vibration analyser that was not recommended by the Manufacturer.

o) Proper maintenance procedures were not carried out following vibration reports.

p) Vibration analyser was not used as required following excessive vibration reports on 2 January 2024.

q) Troubleshooting during the vibration related maintenance was conducted by visual inspections on 2 January 2024.

3.1.2 Pilot

a) The pilot was licensed and qualified for the flight in accordance with existing regulations.

b) The pilot was properly licensed, medically fit and adequately rested to operate the flight.

c) The pilot’s flight and duty time was in compliance with the regulations.

d) The pilot’s actions and statements indicated that his knowledge and understanding of the aircraft systems were adequate.

3.1.3 Flight operations

a) There was no unusual weather condition reported along the routes prior to the loss of tail rotor thrust.

b) The flight crew carried out normal radio communications with the relevant ATS units.

c) During cruise, the aircraft began to vibrate and spin with nose tucking and subsequently complete loss of tail rotor thrust.

d) The pilot executed the Bell Helicopter AFM Complete Loss of Tail Rotor Thrust Emergency, but the pilot did not conduct auto ration.

e) The wind conditions in which the pilot landed the aircraft were outside the limits detailed in the Flight Manual and the Operations Manual.

3.1.4 Operator

a) The Standard Operating Procedure for the non-handling pilot to monitor the progress of the approach.

b) The operator's Quality Assurance system had not identified frequent deviations from the requirements of the Aircraft Maintenance Manual over a considerable period of time.

c) The operator was using a different vibration analyser, COBRA II, which although not recommended, was accepted under specific conditions in the Bell 407 MM.

d) The defect entry on the tech log was done by engineers instead of the pilot.

e) Defects are written into the Technical Log by the pilots or reported verbally only to the maintenance engineers who write them in on behalf of the pilots.

3.1.5 Flight Recorders

a) The aircraft was not equipped with a FDR or a CVR; neither was required by the regulation.

3.1.6 Medical

a) There was no evidence that incapacitation or physiological factors affected the flight crew.

b) There was no evidence that the pilot suffered any sudden illness or incapacity.

3.1.7 Survivability

a) The accident was survivable.

b) There were no injuries sustained by the occupants of the accident flight.

3.2 Causes [Contributing factors]

The complete loss of tail rotor thrust during the descent phase was attributed to the snapping of the four mounting studs. This was caused by the failure of the mounting stud assembly. The damage sustained on the studs and bores indicate that they sustained cyclic stress and vibrations above normal levels. The AIC concluded that there were several factors that contributed to the accelerated wear and tear of the component, including the helicopter vibrations that were reported on numerous occasions throughout the year. Maintenance records showed that these reported issues were partially resolved. It is likely that some underlying issues may not have been detected and resolved because the vibration analyser was not used during maintenance action as required by the Manufacturer's Maintenance Manual. As such, the vibrations continued, and specified limits may have persevered causing accelerated wear leading to failure in the tail rotor gearbox mounting.

Furthermore, because the excessive wear was found to have initiated and grown in a part of the stud assembly that is not visible during inspection, any damage, or signs of wear and/or fatigue would have been impossible to detect, allowing the undesired issue to manifest and eventually cause a failure of the stud assembly without detection.

3.3 Other factors

The investigation found non-contributing safety deficiencies. These are addressed in the factual and safety recommendations.

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4 RECOMMENDATIONS

4.1 Recommendations

As a result of the investigation into the accident involving P2-HSM, the Papua New Guinea Accident Investigation Commission issued the following recommendations to address the safety concerns identified during the investigation.

4.1.1 Recommendation number AIC 24-R02/23-1003 to Heli Solutions Ltd

The AIC recommends that Heli Solutions Ltd should ensure that standardized systems and protocols are established and implemented for defect reporting, maintenance practice, and compliance with requirements in the Manufacturer's Maintenance Manual relating to unscheduled maintenance.

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5 APPENDIX

5.1 Appendix A: Complete Loss of Tail Rotor Thrust

5/10/24, 10:05 AM BHT - Technical Publications

BHT-407-FM-1, null, PRINTED 10-May-2024

BHT-407-FM-1 TC APPROVED

• PROCEDURE:

1. In-flight — Start descent.
2. AIR COND BLO switch (if installed) — OFF.
3. HEATER switch (if installed) — OFF.
4. All vents — Open.
5. Side windows — Open.

If time and altitude permits:

6. Source — Attempt to identify and secure.
7. If source is identified and smoke and/or fumes still persist — Land as soon as possible.
8. If source is identified and smoke and/or fumes are cleared — Land as soon as practical.

3-4-D. ELECTRICAL FIRE

• INDICATIONS:

1. Smoke fumes or fire.
2. Possible indication of abnormal amps.

• PROCEDURE:

1. Vents/side windows — Open, as required; ventilate cabin.
2. Begin descent.
3. GEN switch — OFF.
4. Airspeed — 60 KIAS or less.
5. BATT switch — OFF.
6. FUEL BOOST/XFR LEFT circuit breaker switch — LEFT (on).
7. Land as soon as possible.

WARNING

PRIOR TO BATTERY DEPLETION, ALTITUDE MUST BE REDUCED BELOW 8000 FEET H_P (JET A) OR 4000 FEET H_P (JET B). UNUSABLE FUEL MAY BE AS HIGH AS 151.0 POUNDS AFTER THE BATTERY IS DEPLETED DUE TO INABILITY TO TRANSFER FUEL FROM FORWARD CELLS.

NOTE

With battery and generator OFF, an 80% charged battery will operate left fuel boost pump and left fuel transfer pump for approximately 1.7 hours (2.8 hours with optional 28 amp-hour battery).

NOTE

Pedal stop disengages with loss of electrical power.

When throttle is repositioned to the IDLE stop (during engine shutdown), the PMA will go offline and the engine may flame out.

3-5. TAIL ROTOR

There is no single emergency procedure for all types of antitorque malfunctions. One key to a pilot successfully handling a tail rotor emergency lies in the ability to quickly recognize the type of malfunction that has occurred.

3-5-A. COMPLETE LOSS OF TAIL ROTOR THRUST

This is a situation involving a break in drive system (e.g., severed driveshaft), wherein tail rotor stops turning and delivers no thrust.

3-10 Rev. 20 11 MAR 2022 Export Classification C, ECCN EAR99

• INDICATIONS:

1. Uncontrollable yawing to right (left side slip).
2. Nose down tucking.
3. Possible roll of fuselage.

NOTE

Severity of initial reaction of helicopter will be affected by AIRSPEED, CG, power being used, and H_D.

• PROCEDURE:

3-5-A-1. HOVERING

Close throttle and perform a hovering autorotation landing. A slight rotation can be expected on touchdown.

3-5-A-2. IN FLIGHT

Reduce throttle to idle, immediately enter autorotation, and maintain a minimum AIRSPEED of 55 KIAS during descent.

NOTE

When a suitable landing site is not available, vertical fin may permit controlled flight at low power levels and sufficient AIRSPEED. During final stages of approach, a mild flare should be executed, making sure all power to rotor is off. Maintain helicopter in a slight flare and smoothly use collective to execute a soft, slightly nose-high landing. Landing on aft portion of skids will tend to correct side drift. This technique will, in most cases, result in a run-on type landing.

CAUTION

IN A RUN-ON TYPE LANDING AFTER TOUCHING DOWN, DO NOT USE CYCLIC TO REDUCE FORWARD SPEED.

3-5-B. FIXED PITCH FAILURES

This is a situation involving inability to change tail rotor thrust (blade angle) with anti-torque pedals.

• INDICATIONS:

1. Lack of directional response.
2. Locked pedals.

NOTE

If pedals cannot be moved with a moderate amount of force, do not attempt to apply a maximum effort, since a more serious malfunction could result. If helicopter is in a trimmed condition when malfunction occurs, TRQ and AIRSPEED should be noted and helicopter flown to a suitable landing area. Certain combinations of TRQ, NR, and AIRSPEED will correct a yaw attitude, and these combinations should be used to land helicopter.

• PROCEDURE:

NOTE

Pull pedal stop emergency release to ensure pedal stop is retracted.

3-5-B-1. HOVERING

Do not close throttle unless a severe right yaw occurs. If pedals lock in any position at a hover, landing from a hover can be accomplished with greater safety under power-controlled flight rather than by closing throttle and entering autorotation.

3-5-B-2. IN FLIGHT — LEFT PEDAL APPLIED

In a high power condition, helicopter will yaw to left when power is reduced. Power and

5.2 Appendix B: Rotor Vibration Analysis – General

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Rotor Vibration Analysis - General

NOTE

All vibration data gathering and automated analysis procedures in this chapter use the Rotor Analysis Diagnostics System - Advanced Technology (RADS-AT) . It is acceptable to use a different system provided the measurements are taken at the locations specified in this chapter. However, the level of technical support provided for vibration issues where a RADS-AT system is used is better due to experience and software availability. The Zing Test Elite (ZTE) is a Bell Textron (BT) accepted alternative to the RADS-AT.

The Model 407 has been designed to include provisions to reduce vibrations to acceptable levels at all locations for normal flight conditions. The normal level of vibration will vary with helicopter loading and flight condition. This chapter outlines the routine maintenance and other diagnostic procedures to be used to achieve the desired vibration goals.

The procedures for the main rotor 1/rev track and balance start in 407-A-18-10-02-00A-040B-A / 00115*, 4/rev procedures start in* 407-A-18-10-02-04A-271A-A / 00128*, tail rotor balance procedures start in* 407-A-18-10-03-00A-028A-A / 00132*, while the procedures for tail rotor drivetrain balance start in* 407-A-18-10-03-00A-271A-A / 00135*. The procedures to collect general (spectrum) diagnostic vibration data start in* 407-A-18-10-05-00A-028A-A / 00143*. All vibration data gathering and automated analysis procedures in this chapter are defined relative to the use of the RADS-AT.* Table 1 *summarizes when maintenance actions should be conducted to reduce vibration.*

Table 1. Maintenance Actions to Reduce Vibration

MAINTENANCE TASK	WHEN TASK SHOULD BE DONE	PARAGRAPH
Track and balance the main rotor	After any component change in the hub/blade assembly or after any pitch link is changed or replaced. or At 300-flight hour increments (recommended). or When the flight crew complain of a rough main rotor 1/rev ride. or After any major overhaul is done on the baseline helicopter. (1)	407-A-18-10-02-00A-040B-A / 00115, 407-A-18-10-02-00A-330A-A / 00118, 407-A-18-10-02-00A-720A-A / 00119, 407-A-18-10-02-01A-028A-A / 00120, 407-A-18-10-02-00A-372A-A / 00121, 407-A-18-10-02-01A-372A-A / 00122, 407-A-18-10-02-00A-271A-A / 00123, 407-A-18-10-02-01A-271A-A / 00124, 407-A-18-10-02-02A-271A-A / 00125, 407-A-18-10-02-00A-040A-A / 00126, 407-A-18-10-02-03A-271A-A / 00127, 407-A-18-10-02-04A-271A-A / 00128, 407-A-18-10-02-05A-271A-A / 00129, 407-A-18-10-02-06A-271A-A / 00130 and 407-A-18-10-02-00A-913A-A / 00131
Check main rotor 4/rev vibration	After replacement or repair of the Frahm assembly or one of its components. or When the flight crew complain of a main rotor 4/rev vibration in the cabin. or After a major kit configuration change that changes the center of gravity.	407-A-18-10-02-04A-271A-A / 00128, 407-A-18-10-02-05A-271A-A / 00129 and 407-A-18-10-02-06A-271A-A / 00130

Table 1. Maintenance Actions to Reduce Vibration (continued)

MAINTENANCE TASK	WHEN TASK SHOULD BE DONE	PARAGRAPH
Balance the tail rotor	After any change to the tail rotor assembly. or After 300-flight hour increments (recommended). or When the flight crew complain of tail rotor vibration. or After any major overhaul is done on the tailboom. (1)	407-A-18-10-03-00A-028A-A / 00132, 407-A-18-10-03-00A-720A-A / 00133, 407-A-18-10-03-00A-169A-A / 00134, 407-A-18-10-03-00A-271A-A / 00135 and 407-A-18-10-03-00A-913A-A / 00136
Balance the flywheel	After any change to the assembly. or At 300-flight hour increments (recommended). or When the flight or ground crew complain of flywheel vibration (high frequency vibration).	407-A-18-10-04-00A-720A-A / 00137, 407-A-18-10-04-01A-720A-A / 00138, 407-A-18-10-04-00A-169A-A / 00139 and 407-A-18-10-04-00A-913A-A / 00140
Balance the oil cooler blower driveshaft	After any change to the assembly. or At 300-flight hour increments (recommended). or When the flight or ground crew complain of high frequency vibration.	407-A-18-10-04-00A-169B-A / 00141 and 407-A-18-10-04-01A-913A-A / 00142
General vibration troubleshooting	When the flight or ground crew detect a change in the normal level of vibration of the helicopter.	407-A-18-10-06-00A-090A-A / 00146 and 407-A-18-10-06-00A-420A-A / 00147

NOTE:

1 It is recommended to get the vibration data before any major modification/overhaul. This procedure identifies if a subsequent track and balance issue comes from the modification/overhaul or not.

5.2.1 Appendix B2: Conditions for Rotor Smoothing and Mechanical Troubleshooting

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Troubleshooting - Conditions for Rotor Smoothing and Mechanical Troubleshooting

Vibrations on a helicopter may have multiple sources and sometimes these sources might be difficult to isolate. To help identify the source of a given vibration, refer to Table 1.

It is important to note that the vibration limits given by your vibration analyzer are targets. If the vibration level produced by the helicopter meet the Bell Helicopter Textron targets, the owner and the user determine if the ride meets their requirements or if additional tuning is required.

No dangerous effects have been measured for main rotor 1/rev levels of 1.0 Inch Per Second (IPS) or less. The level of main rotor 1/rev vibration is used to find the ride quality only. Main rotor 1/rev is not a wear or a fatigue problem. However, do not ignore sudden changes in the level of the main rotor 1/rev vibrations. If the level of the main rotor 1/rev vibrations changes suddenly, do an immediate and thorough inspection of the main rotor blades, hub, and control system to find the cause (407-A-62-10-00-01A-280A-A / 00962, 407-A-62-00-00-07A-280A-A / 01021 and 407-A-67-00-00-00A-028A-A / 01408).

Table 1 addresses the most common types of vibrations encountered on the Model 407. Even though a static component may cause vibration, more frequently the vibration will be caused by a dynamic component. Most of the time, when a static component is the source of a vibration, it is because the component is not secured properly or it gets excited by the vibration of a dynamic component. Troubleshooting of this type of vibration is more complex and often necessitates a spectrum analysis to be performed.

Figure 1 is provided as a guide to help troubleshooting vibration problems and to permit you to perform track and balance adjustments without using the corrections provided by the vibration analyzer. When using this chart, only the vibration data for vertical forward is used. By lowering the vertical forward, the vertical aft will follow.

Table 1. Helicopter Vibration Troubleshooting

COMPLAINT	SYMPTOM	POSSIBLE CAUSE	ACTION
Main rotor 1/rev.	Ground bounce.	Autorotation RPM too high.	Adjust as required (407-A-18-10-02-05A-271A-A / 00129).
		Collective minimum friction too low.	Adjust as required (407-A-67-11-05-00A-271A-A / 01459).
		Corner mounts/fore and aft restraints delaminated.	Replace (407-A-63-31-00-00A-685A-A / 01068).
	Intermittent vibration increase or frequent ride change.	Main rotor hub shift (S/N 53631 and prior, or Pre TB 407-05-66).	Perform TB 407-03-48 (cone set shimming) or TB 407-05-66.
	Vibration mainly at low speed.	Corner mounts/fore and aft restraints delaminated.	Replace (407-A-63-31-00-00A-685A-A / 01068).
	Vibration generally too high.	Excessive play in swashplate drive system (1)	Replace worn bushings (407-A-67-13-03-00A-280A-A / 01583).
		Excessive play in flight controls (1) .	Replace worn bearings.
		Swashplate friction too low (1) .	Adjust as required (407-A-67-13-01-00A-271A-A / 01576).
		Excessive fore and aft play of swashplate sleeve on support (0.020 inch (0.51 mm)) and above (1) .	Replace sleeve bearings (407-A-67-13-01-00A-280A-A / 01574).
		Rough or loose pitch link bearings.	Replace.
		Paint/filler missing on blades or eroded leading edge.	Repair. Refer to 407-A-62-10-00-01A-685A-A / 00978 or send to a Bell approved repair facility.
		Sheared or delaminated hub elastomers.	Replace (407-A-62-00-00-07A-280A-A / 01021).
		Cyclic or collective minimum friction too low.	Adjust as required (407-A-18-10-02-00A-010B-A / 00115 or 407-A-67-11-05-00A-271A-A / 01459).

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Table 1. Helicopter Vibration Troubleshooting (continued)

COMPLAINT	SYMPTOM	POSSIBLE CAUSE	ACTION
		Blades out of track (2) .	Perform track and balance (407-A-18-10-02-00A-040B-A / 00115).
Main rotor 4/rev vibrations.	Generally high vibration (normally worse at high speed).	Loose equipment or kit. Loose battery.	Secure properly.Secure properly.
		Frahm damper spring broken.	Replace springs (407-A-62-00-00-05A-530A-A / 01008 and 407-A-62-00-00-05A-710A-A / 01011).
		Frahm detuned.	Tune Frahm.
Driveshaft 1/rev vibrations.	Vibration generally high. Felt on floor, door post, etc.	Fanshaft out of balance.	Balance fanshaft.
		Worn fanshaft drive splines.	Replace fanshaft and drive adapters.
		Dry fanshaft splines.	Lubricate splines.
		~~Dirty oil cooler blower impeller.~~	~~Clean impeller.~~
Tail rotor 1/rev vibrations.	High vibration felt in pedals and on floor.	Loose yoke feathering bearings.	Replace bearings (407-A-64-22-03-00A-520A-A / 01297 and 407-A-64-22-03-00A-720A-A / 01298).
		Delaminated or sheared flapping bearing.	*Replace bearing (BHT-407-CRO, Chapter 64, Component Repair and Overhaul Manual).*
		Bent gearbox output shaft.	*Replace shaft (BHT-407-CRO, Chapter 65, Component Repair and Overhaul Manual).*
		Loose tail rotor gearbox.	Investigate cause. Contact Product Support Engineering.
		Water in one tail rotor blade.	Perform leak check on blade (407-A-64-12-00-00A-364A-A / 01265). Contact Product Support Engineering.
Tail rotor 2/rev vibrations.	High vibration. Generally worse at high speed.	Sheared or delaminated flapping bearing.	Replace bearing.

NOTES:

1 Excessive play at those indicated areas will generally show more at approximately 100 knots. Generally, when excessive play or looseness is at fault, the 100 knots vibration amplitude will be opposite to the other vibration data if plotted on a chart. This is because the M407 has a "zero control load" at approximately 100 knots. This characteristic of the M407 will cause this excessive play to show as a 1/rev at this speed. Until the mechanical discrepancy is fixed, the rotor will always be marginal or rough.

2 The blades being out of track is not necessarily a cause for high vibration. Even though the blade tips are not in track the blades may still produce equal lift, which is the condition we try to achieve when performing track and balance. Depending on the stiffness, twist, weight, etc., a given blade may have to fly with the tip lower than the others and still produce the same lift. The track data is mainly used in flight to identify a potential problem or to identify the best blade match. For example, two blades that have a tendency to climb and fly high would be best suited to fly as a pair (opposite to each other).

5.3 Appendix C: TRGB Inspection and Torque Check

DATA REFERENCE	INSPECTION TASK DESCRIPTION	INITIAL MECH	INITIAL OTHER
	1. Examine the tail rotor driveshaft for condition and security. Examine the components as follows:		
DMC-407-A-65-10-00-00A-320A-A	1.1. All bearings and hangers.		
DMC-407-A-65-10-00-04A-280A-A	1.2. Disc pack couplings.		
	1.3. Do a torque check of the disc pack coupling attachment hardware (150 to 180 inch-pounds (17 to 20Nm)).		
	1.4. Driveshaft tube assemblies.		
DMC-407-A-65-10-00-03A-280A-A	2. Examine the driveshaft segment assemblies for any noticeable rotational or axial (fore and aft) play between the adapter and the tail rotor driveshaft, at all four locations.		
	2.1. If rotational or axial play is found, remove the adapter from the applicable driveshaft assembly and examine the associated parts for allowable damage limits.		
DMC-407-A-65-20-00-00A-280A-A	**TAIL ROTOR GEARBOX**		
	1. Do a torque check of the tail rotor gearbox attachment nuts (140 to 160 inch-pounds (16 to 18 Nm)).		
	2. Examine the tail rotor gearbox for condition, leaks, and security.		
	3. Examine the chip detector of the tail rotor gearbox for metal particles.		
407-A-96-11-24-00A-340B-A	4. Examine the electrical circuit of the chip detector for continuity		
407-A-67-21-10-00A-280A-A	**PITCH CHANGE CONTROL**		
	1. Examine the tail rotor pitch control mechanism for condition and security. Examine the components as follows:		
	1.1. Boot.		
	1.2. Pitch links.		
	1.3. Crosshead sliding seal.		
	ELECTRICAL		
407-A-96-00-00-00A-00SA-A	1. Examine all visible electrical components, wires, cables, and connectors in the area of the tailboom for chafing, and general condition and security.		
407-A-96-00-00-00A-00SA-A	2. Verify navigation lights and anti-collision light for operation, condition, and security.		
407-A-97-00-00-00A-00SA-A	3. Examine antennas for condition and security.		
	GROUND RUN		
BHT-407-FM-X	1. Complete a ground run at 100% N_R to check for leaks and confirm system operation.		

Requirements after job completion

Required Conditions

Action/Condition	Data module/Technical Publication	Applicability
None.		

End of data module

INSPECTIONS

REGISTRATION NUMBER: P2-HSM

30-5. 100-HOUR OR 90-DAY CORROSION INSPECTION GUIDE (CONT)

INITIAL ITEMS FOR AIRWORTHINESS	INITIAL
MAIN INPUT DRIVESHAFT	
1. Inspect for evidence of cad-plate removal (rust) on shaft and couplings.	
TAIL ROTOR DRIVESHAFTS (CAD-PLATED)	
1. Inspect for evidence of cad-plate removal (rust).	
2. Inspect splined joints for corrosion products.	
3. Inspect fasteners.	
TAIL ROTOR DRIVESHAFTS (ALUMINUM)	
1. Inspect for nicks, chips, scratches, and other damage to organic finish (clear lacquer).	
2. Inspect for pitting on shaft.	
3. Inspect flex couplings and fasteners.	
TAIL ROTOR DRIVESHAFT BEARING HANGERS	
1. Inspect for nicks, chips, or blisters in paint. (The hangers just forward and aft of the oil cooler fan are magnesium.)	
2. Inspect other hangers for evidence of corrosion products. Touch up as needed.	
TAIL ROTOR GEARBOX	
1. Inspect for corrosion products around fasteners and attached parts.	
2. Inspect paint for chips, nicks, and blisters.	
CYCLIC AND COLLECTIVE — CABIN ROOF AREA	
1. Actuator support assembly.	
a. Inspect casting for damaged paint, pitting, or cracks.	
b. Inspect roof around support for evidence of corrosion.	

5.4 Appendix D: Vibration Analyser/Track and Balance Equipment

5.4.1 Appendix D1: RADS-AT

GE Aviation
14200 Roosevelt Boulevard
Clearwater
FL 33762
USA
T: +1 727 539 1631
GE Aviation Systems LLC

www.ge.com/aviation

Specifications (continued)

Control and Display Unit (CADU)

- M68000 processor, 1 each
- 2 MB nonvolatile internal RAM
- Backlit LCD display, 256 pixels x 128 pixels, 125 mm x 65 mm
- Credit card memory interface
- Serial and parallel printer ports
- RS-232C port for PC compatibility
- Dimensions – 8.5" H x 11" W x 2.125" D (216 mm H x 279 mm W x 54 mm D)
- Weight – 5.5 lbs (2.5 kg)
- Power Requirements – 12 Vdc external (power converter or DAU), 11 W internal 8-hour battery (NICAD)

Enhanced Universal Tracking Device (E-UTD™)

- Day/night operation
- Absolute track accuracy ±0.04 in. (1 mm)
- Lead/lag ±0.005 minutes of arch
- Dimensions – 6" H x 3.5" W x 5.75" D (152.4 mm H x 88.9 mm W x 146.1 mm D)
- Weight – 1.7 lbs

RADS-AT Basic Kit

- 2 MB Control and Display Unit, 1 each
- Data Acquisition Unit, and cables, 1 each
- Universal Tracking Device, 1 each
- Optical RPM Sensor, with 50 ft cable, 1 each
- Optical RPM Sensor bracket, 1 each
- Magnetic RPM Sensor, with 20 ft of cable, 1 each
- 54 mV/g Accelerometers, brackets, 25 ft and 50 ft cables, 2 each
- RS-232 cable, 6 ft, 1 each
- Shipping and storage case, 1 each
- 12 V battery charger for CADU, 1 each
- 256 KB credit card memory, 1 each
- DAU/CADU canvas carry case, 1 each
- RADS-AT Operator's Manual, 1 each
- Digital gram/ounce scale, 1 each
- 150 ft reflective tape (3M-7610), 1 roll

Accessory kits are available for specific aircraft types. They contain all necessary brackets, special hardware, software and documentation. Please specify aircraft type(s) when ordering.

5.4.2 Appendix D2: RADS-AT Kit

GE Aviation

The RADS-AT™ Aircraft Adapter Kits are made to the highest quality standards and include all of the aircraft specific mounting brackets, cables and other hardware necessary to properly install the RADS-AT system as specified by the aircraft OEM. The kits also include the latest diagnostic software, application notes and installation instructions for the aircraft, ensuring your rotor track and balance operations go smoothly.

The RADS-AT Adapter Kits listed on the back represent our most popular models. We regularly develop new adapter kits in conjunction with aircraft operators and OEMs, so please call the factory at 1800-826-2124 if you don't see a kit listed for your aircraft. Designed to be affordable, the capable RADS-AT Adapter Kits are just one more reason why the RADS-AT is recommended by more aircraft manufacturers than any other system.

RADS-AT™ Aircraft Adapter Kits

Features

- Easy to install. Most installations can be performed in minutes
- Most kits are designed and developed in cooperation with engineers at aircraft OEMs
- Each of the kit components are made to the highest quality standards to ensure a long service life
- All kits come with a rugged transportation and storage case
- On-line support via the worldwide web at http://www.rads-at.com

Platforms

Agusta
- A 109 MkII
- A 109 A/C/E

Beechcraft
- King Air

Bell Helicopter
- 205
- 206/B/L
- 212/412
- 214ST
- 222/230/430
- 407
- 427
- 429
- AH-1/S/W/Z
- OH-58A/C/D
- UH1-H/Y

Boeing Helicopter
- CH-46
- CH-47C/D
- MH-47E
- AH64A/D

Cessna
- 210

Erickson Air Crane
- S-64 E
- S-64 F

RADS-AT™
Aircraft Adapter Kits

5.4.3 Appendix D3: Zing Test Elite (ZTE)

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Zing® Test Elite
Portable Diagnostic and
Rotor Smoothing System

The most capable and cost-effective diagnostic system for helicopters.

Zing® Test Elite

The Test Elite is part of an extensive and growing Zing® Total Condition-Based Maintenance solutions portfolio that includes Zing HUMS onboard Health and Usage Monitoring Systems (HUMS) hardware, Zing Test portable rotor track and balance (RT&B) and Vibration Analysis (VA) hardware, Zing Ware software and Zing Services remote diagnostics and service level agreements.

The Zing Test Elite is an easy-to-operate tool for performing helicopter rotor smoothing, engine performance checks, component balancing, vibration surveys, and complex vibration component analysis. The Test Elite can reduce measuring and verification flights, thereby increasing aircraft operational availability and readiness and enhancing safety.

- **Most advanced and accurate measurement algorithms**
- **More accurate measurements with fewer flights**
- **Increases aircraft availability**
- **Easy to use and intuitive Windows®-based software**

The Test Elite's very accurate airspeed and accelerometer algorithms set it apart from other smoothing solutions. Operators can now achieve maintenance manual specifications in as few as three flights – one or two measurement flights and one to verify.

The Test Elite's easy-to-understand maintenance actions can be displayed on any PC, including the optional Panasonic Toughbook®, using the Zing® Ware Personal Computer – Ground-Based System (PC-GBS) software. The Test Elite can configure the Zing Test to each specific helicopter type, making it especially flexible and cost-effective for multi-platform and mixed helicopter and fixed-wing propeller operators.

Available in Two Configurations

The Test Elite is offered in two configurations – the Basic Kit or Full Kit which includes all components from the Basic Kit plus the Panasonic Toughbook® computer and Intelligent Blade Tracker. An adapter kit is required to configure the Test Elite to a specific helicopter type.

Aircraft-specific adapter kits include sensor mounting brackets, cables and additional sensors as required.

All cables, brackets and sensors from the RADS-AT™/Aviation Vibration Analyzer (AVA) are fully compatible with the new Test Elite. The Zing Test utilizes the latest technology including FPGAs which allow reprogramming and reconfiguration, thereby reducing obsolesces issues.

Benefits for Operators

- Smoothes aircraft in accordance with existing maintenance manuals in as few flights as possible
- All data is collected at once and is processed as one unit resulting in a more accurate solution with fewer flights
- Saves time and money on measurement flights
- Enhances safety
- The Test Elite can be used on both helicopters and propeller-driven aircraft

Features

- Most advanced rotor smoothing technology on the market
- State-of-the-art signal processing and diagnostic algorithms
- Flexible design – configurable for use on most helicopters and propeller-driven aircraft
- Designed for the flight line – solid cast aluminum enclosure is moisture and shock resistant
- MIL-STD EMI shielded connectors compatible with RADS™/AVA
- Electronic Technical Manuals and Help Files
- Rugged transport case with rollers
- Light weight makes it easy to carry when traveling
- Fully qualified to both FAA and military requirements

Technical Specifications	
Dimensions	4.24" x 8.12" x 6.33" (10.8 cm x 20.6 cm x 16.1 cm)
Weight	DAU - 3.25 lbs (1.47 Kg)
Temperature Range	-40C to +71C
Input Power	10-40Vdc a/c power, MIL-STD-704D 50 ms Power Loss Hold-Up
Power Consumption	<18 W
Interconnection	Standard military-type connectors
Environmental Qualification	MIL-STD-810F & DO-160D
Built-in Self-Test	Integrated into PC-GBS software application
EMI/RFI Qualification	MIL-STD-810F, MIL-STD-461E, MIL-STD-704A/D, DO-160D
Wireless (802.11)	Optional
Internal Storage	256MB/8GB (stores over 500+ flights)
Compatibility	PC-compatible, RADS-AT/AVA
Digital Communication	2-RS232/422/485, 1-USB, 2-Ethernet
Software	DO-178B
Data Acquisition	2 or 3 wire accelerometers with programmable sensitivity Universal Tracking Device

Zing® Ware PC-Based Host Software Application

The PC-GBS Windows®-compatible software program receives measured data, stores the data in a database, and then analyzes the data and provides easy-to-understand corrective actions for the maintainers. The PC-GBS software can also act as a simple mechanism to collect and transfer data from the field to a centralized web server. This provides users with remote monitoring, trending, data analysis and automatic software upgrades.

5.4.4 Appendix D4: COBRA II

COBRA II

2-Channel Analyzer for Vibration Analysis & Balancing

The COBRA II is a versatile yet compact instrument that combines all of the diverse technologies required for high-end engine vibration analysis, rotor track and balance, and propeller balance into one tool.

1 Large Full-Color Screen

The COBRA II has a large high resolution, transmissive, full-color display with a super-bright LED backlight that can be easily viewed in direct sunlight.

2 PDF Reporting

Generate PDF reports directly from the analyzer and store on a USB flash drive to be printed or saved in a separate location to retain accurate maintenance records.

*Industry-Unique, No-Cost, 5-Year Warranty

- **Portable Convenience**

  Data storage, transfer, display and analysis is independent of any proprietary software and a PC interface. Application Notes and eSetups are now available to download directly to the analyzer via the web.

- **Solutions Generated**

  The compact COBRA II provides accurate solutions in the minimum number of runs, saving costly run time and fuel. Solutions are an extremely valuable tool that are not offered in similar vibration analysis and balancing instruments as a standard feature for this market.

- **Features**

  All of these maintenance functions can be easily performed on virtually any airframe and/or engine type using the COBRA II.

  - Propeller Balance
  - Main Rotor Track and Balance
  - Tail Rotor Balance
  - Overall Vibration Survey
  - Vibration Spectrum Survey

ACES® SYSTEMS

Cobra II Specifications

Track and Balance

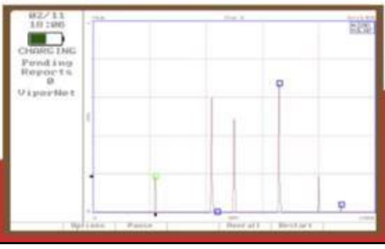
Quick, Automated Track and Balance Solutions

- Stores hundreds of setups for quick use on virtually any engine and airframe type.
- Solutions refined on each run- taking into account the unique properties of each airframe and automatically shortening the process saving costly run time and fuel.
- The COBRA II's setup function allows airframes to be added using industry standard polar charts.

Vibration Analysis

Test Cell Accuracy from a Handheld Device

- True two-channel simultaneous data acquisition
- Full spectral display on large color screen
- Normal and harmonic cursors easily identify vibration peaks



- **Vibration Input:**
  9.5 V Pk-Pk, to 240 IPS Peak with 20mV per IPS sensor
- **Sensor Types:**
  Accepts any vibration signal input (acceleration, velocity, displacement) and any voltage generating sensor. External charge amplifier required for charge mode.
- **Vibration Amplitude Accuracy:**
  +/- 1% across frequency range
- **Frequency Range:**
  Selectable up to 30kHz (1,800,000 RPM)
- **Tachometer Inputs:**
  Better than 1 degree phase accuracy 60 to 10,000 RPM
- **Display:**
  7" Day/night readable color LCD display with super-bright LED backlight
- **Power:**
  Rechargeable lithium ion battery
- **Weight:**
  Approximately 6.0 pounds (2.8 kilograms)
- **Dimensions:**
  10.5" wide, 9.75" long, 5" deep
- **Operating Temperature Range:**
  -20° to +49° Celsius

ACES Systems
Knoxville, TN | USA
Ph: 865-671-2003
www.AcesSystems.com

5.5 Appendix E: Bell Helicopters Information Letter – Recent Suppression of some of the MS21042 and NAS1291 Series Nuts

A Textron Company

INFORMATION LETTER **GEN-18-138**

1 August 2018
Revision A, 9 August 2018

TO: **All owners and operators of Bell helicopters**

SUBJECT: MS21042 AND NAS1291 SERIES NUTS, SUPERSESSION OF

Revision A is a complete reissue of this General Information Letter.

This General Information Letter is to advise owners and operators of the recent supersession of some of the MS21042 and NAS1291 series nuts by the NAS9926 series nuts. Affected nuts are shown in Table 1 of this Information Letter. This change was reflected in all applicable commercial Bell illustrated parts manuals.

MS21042 and NAS1291 series nuts are widely used in the aviation industry. Original Equipment Manufacturers (OEM) and Civil Aviation Authorities have received reports of cracked MS21042 nuts due to hydrogen embrittlement. To mitigate occurrences of cracked nuts, Bell has discontinued the use of the MS21042 (sizes 3 through 6) and NAS1291 (sizes 7 through 10) steel alloy nuts on new production helicopters as well as within our spares inventory and replaced them with the NAS9926 series corrosion resistant steel nuts in some installations. When replacing nuts, there is no requirement to have all the same nut part number in an installation; however, due to weight differences an imbalance condition may result. The same part number nuts should be installed at all locations in dynamic applications such as drive shafts.

The 6-flat MS21042 and the NAS1291 series nuts are made of cadmium plated steel alloy with dry film lubricant. Both the MS21042 and NAS1291 series steel alloy nuts are susceptible to hydrogen embrittlement during the cadmium plating process.

The 12-point NAS9926 series nuts are cadmium plated corrosion resistant steel nuts with dry film lubricant. These nuts are not affected by hydrogen embrittlement, have a thicker wall and, are less susceptible to cracking.

Unless otherwise instructed by a Service Directive, the MS21042 and NAS1291 series nuts currently installed on helicopters can remain in service and be replaced by attrition if they are serviceable and meet the minimum tare torque requirement. Operators having MS21042 and NAS1291 series nuts in spares stock can use them until depletion.

IL GEN-18-138A
Page 1 of 3
Approved for public release.