# Aviation Investigation Final Report

| | | | |
|---|---|---|---|
| **Location:** | Brooklyn, New York | **Accident Number:** | ERA10TA493 |
| **Date & Time:** | September 22, 2010, 15:52 Local | **Registration:** | N412PD |
| **Aircraft:** | Bell 412 | **Aircraft Damage:** | Substantial |
| **Defining Event:** | Powerplant sys/comp malf/fail | **Injuries:** | 6 Minor |
| **Flight Conducted Under:** | Public aircraft | | |

## Analysis

The helicopter was on final approach to its home heliport following an uneventful local patrol flight. About 300 feet above the ground, the flight crew heard a loud sound from the engine compartment, which was immediately followed by a loss of main rotor rpm. The crew subsequently performed an autorotation to the water below, and upon contact with the water, the installed flotation devices deployed. Examination of the helicopter's reduction gearbox revealed an approximate 3-inch by 9-inch exit hole centered at the top of the reduction gearbox, and its output drive gear had fractured.

Metallurgical examination of the fractured pieces of output drive gear revealed features that were consistent with fatigue. The crack initiation site was identified along the outer rim section of the gear, at the root of one of the gear teeth. Even though the crack initiation site was heavily damaged, features indicative of intergranular cracking transitioning to a transgranular fatigue crack propagation were noted. No anomalies or foreign material were noted at the crack origin.

The location and size of the intergranular cracking area was within the carburization layer specified by the manufacturing print. Examination of the remaining output drive gear teeth revealed a total of six additional secondary cracks that were localized around an approximate 22-degree arc near the initial fracture location and located in the same general tooth root location as the initial fatigue fracture. The secondary cracks were examined in detail, revealing the presence of fatigue, plastic deformation, and oxidation near the origins of the cracks, which are clear indications that the cracks initiated and propagated prior to the complete failure of the output drive gear. The existence of multiple fatigue-type cracks implied that the cracking was likely the result of a systematic part anomaly or defect, rather than a localized defect, since no such defect was detected in the fracture surface of the secondary cracks.

The proper material composition, case hardness and depth, and grain structure along with no evidence of a material process issue indicated that the failed output drive shaft was manufactured as intended. Chemical analyses were conducted on the primary and secondary fracture surfaces to determine if any of these detrimental impurity elements were present and in quantities sufficient to cause a weakening of the material and lead to the initiation of the fatigue crack. Hydrogen content on the primary fracture surface was reported as 1 part per million. Hydrogen concentrations of a few parts per million dissolved in the steel could cause hairline cracking and loss of tensile ductility. Since hydrogen could diffuse out of the part easily under certain conditions, there was no way to definitively determine what the hydrogen level at the fracture surface was at the time of the crack initiation; however, the hydrogen concentration level found on the fractured tooth was in the general neighborhood where hydrogen embrittlement could occur. Thus, embrittlement was considered as a possible contributor to the fatigue failure. Embrittlement is a loss of ductility and/or toughness of a material and in steels could take various forms. Embrittlers such a hydrogen, phosphorus, and nitrogen, could be detrimental to the desired mechanical properties and are typically grain boundary embrittlers that produced low energy, intergranular ductile fractures.

Cracks caused by hydrogen embrittlement often originate near or at the surface, usually do not branch, and the crack path could be either transgranular or intergranular and could sometimes change from one plane to the other as it propagated. The output drive gear fatigue crack found on the primary fracture surface was a single crack located at the surface that initially propagated intergranularly then transitioned transgranularly prior to failing in overload. This was consistent with a hydrogen embrittlement induced fatigue crack. Hydrogen uptake could come from a various sources, including the electrochemical plating processes, which the output drive gears experienced three times. In order to prevent hydrogen embrittlement, hydrogen that was picked up during the plating process was driven out by a process called dehydrogenization. Review of the manufacturing production order showed that after each of the three plating operations, the output drive gears was subjected to a dehydrogenization process.

## Probable Cause and Findings

The National Transportation Safety Board determines the probable cause(s) of this accident to be:
The fatigue fracture of the reduction gearbox output drive gear, which resulted in the loss of

power output from the engines to the helicopter rotor blade system and a subsequent forced landing. The fracture of the output drive gear was caused by a fatigue crack that originated in a helical tooth root most likely as a result of hydrogen embrittlement during the manufacturing process.

## Findings

| | |
|---|---|
| **Aircraft** | Reduction gear and shaft - Fatigue/wear/corrosion |
| **Organizational issues** | (general) - Manufacturer |
| **Aircraft** | (general) - Failure |

# Factual Information

## History of Flight

| | |
|---|---|
| **Approach-VFR pattern final** | Powerplant sys/comp malf/fail (Defining event) |
| **Emergency descent** | Ditching |

HISTORY OF FLIGHT

On September 22, 2010, at 1552 eastern daylight time a Bell Helicopter 412EP, N412PD, operated by the New York City Police Aviation Unit, was substantially damaged during a forced landing to Jamaica Bay, near Brooklyn, New York. The certificated commercial pilot, the certificated airline transport-rated co-pilot, and 4 additional crewmembers sustained minor injuries. Visual meteorological conditions prevailed and no flight plan was filed for the flight. The public use aerial observation flight originated at New York City Police Department (NYPD) Air Operations Heliport - Floyd Bennett Field (NY22), Brooklyn, New York, at 1510.

In separate written statements, three members of the flight crew recounted the events that transpired prior to and during the accident flight. The flight departed NY22 about 1510 for a local patrol flight. About 30 minutes later, the flight was directed to return to NY22 for refueling. While on final approach to, and about 1/2-mile from the heliport at an altitude of 300 feet agl, the crew heard a loud, mechanical "bang" sound from the engine compartment of the helicopter. None of the crew heard or saw any cautions or warnings, but noted that the helicopter immediately began descending, and the co-pilot noted a loss of rotor rpm. The co-pilot transmitted a distress call to the operator's base, and the crew confirmed that the emergency flotation system was armed. About 8 to 10 seconds after the event began, the helicopter impacted the water, the floats deployed, and the windscreens shattered after a portion of the main rotor blade struck the top of the cockpit cabin. The crew subsequently shut down the engines, secured the helicopter, and were retrieved from the scene via boat.

AIRCRAFT INFORMATION

The accident helicopter was equipped with one Pratt & Whitney Canada PT6T-3D turbo-shaft engine assembly. The engine assembly was comprised of two separate power sections, which were coupled to a single reduction gearbox (RGB). Each PT6T-3D power section featured a three-stage axial and single-stage centrifugal compressor driven by a single stage compressor turbine, a reverse-flow annular combustor, and a free turning power turbine coupled to the RGB. The RGB drove the helicopter's main rotor transmission and various engine sensing and indicating components. The PT6T-3D assembly had a takeoff and continuous power limit of 1,800 shaft horsepower (SHP) and was flat-rated to 22 degrees C.

The purpose of the RGB was to reduce the power turbines' output speed to a speed suitable for helicopter operation. The RGB had a reduction ratio of 5.0 to 1, resulting in a nominal output shaft speed of 6,600 revolutions per minute (rpm), and rotated the output drive gear clockwise. The rotational speed was further reduced, at a ratio of 20.4 to 1, through an airframe transmission to a nominal speed of 324 rpm. The RGB assembly outer structure was comprised of five cast magnesium housings: output housing (most forward), diaphragm, input housing (aft), and 2 covers mounted on the input housing (left and right).

The internal components of the RGB featured a pair of main input drive shafts (left/right) that received power from each of the power sections, idler drive spur gears, clutch drive gear assemblies, and the intermediate drive helical gears (also referred to as the 2nd stage helical gears) that drove a single output drive gear (ODG) from its circumference. The output from the ODG drove the helicopter's transmission.

The accident helicopter was manufactured by Bell Helicopter in January 2009, issued a standard United States Airworthiness Certificate on March 23, 2009, and delivered to the NYPD on December 21, 2009. When the NYPD took procession of the helicopter, both the helicopter and engines had accumulated 30.3 hours total time since new (TSN) and the engines had accumulated 60 cycles since new (CSN).

According to the helicopter's discrepancy log, low oil quantity within the RGB was reported on January 9, 2010 and on June 30, 2010. The helicopter and engines had both accumulated 39.2 hours TSN and 226.7 hours TSN, respectively, on those dates. The helicopter's most recent routine maintenance inspection was completed on August 16, 2010, at 303 hours TSN, and consisted of the 25, 100, and 300-hour inspection requirements. The only engine maintenance actions during the inspection were standard oil replenishment and filter replacement. The helicopter had accumulated approximately 359 hours TSN at the time of the accident.

WRECKAGE AND IMPACT INFORMATION

The helicopter was examined by a Federal Aviation Administration inspector after it was recovered from Jamaica Bay. The helicopter had sustained impact-related damage to all four main rotor blades, underside of the fuselage, tail boom, and tail rotor blades. Additionally, a 3- by 9-inch hole centered at the top of the RGB was observed. The engine assembly, including RGB, was subsequently removed from the helicopter and forwarded to the manufacturer's facility for further examination.

Engine Assembly and RGB External Examination

Visual examination of the engine assembly revealed that neither power section exhibited any signs of fire, breaches, or impact damage. The accessory gearboxes of both power sections were attached and their respective accessories were in place and undamaged. The inlet screens were removed from each power section and reaching through the inlet case, the compressor on each power section rotated freely by hand in both directions. Tactile examination of the leading edges of the first stage compressor blades revealed no nicks, tears or damage consistent with foreign object ingestion.

The RGB exhibited an approximate 3-inch axial (longitudinal) by 9-inch lateral exit hole in the output housing in-line with the axial position of the ODG. Pieces of the output housing in the areas of hole were either missing or were fractured and pushed outwards. Looking into the RGB, the ODG was fractured with about half the helical gear outer rim portion no longer attached to the remainder of the gear assembly.

RGB Disassembly

The power sections were removed from the RGB exposing the input cavities of the output housing. Pieces of output housing debris fell from the No. 1 power section input cavity and were collected. The output housing exhibited an approximate 2-inch axial by 6.5-inch circumferential internal hole in the wall that divided the output housing center section (output cavity) with the No. 1 power section input cavity. A section representing about 1/2 of the circumference of the ODG outer rim was found sticking through the hole in the wall that divided the output housing center section with the No. 1 power section input cavity. All of the gear teeth were present and there were three distinct areas where the helical teeth were pushed and smeared in the direction of rotation. This section of the ODG had three stubs of the web arm still attached; each exhibited varying degrees of impact damage.

The No. 1 power section main input drive shaft support structure exhibited four distinctive rub marks, located radially outward from the center cavity exit hole and in the vicinity of the No. 7 flanged roller bearing, consistent with contact with the fractured piece of the ODG. The oil transfer hole on the No 1. power section input cavity was occluded with metallic debris. The No 1. power section main input drive shaft appeared undamaged and the spiral retaining ring was still engaged. The No. 2 power section input cavity was clean and undamaged, and the oil transfer tube was unobstructed. The No. 2 power section main input drive shaft appeared undamaged and the spiral retaining ring was slightly dislodged.

The output housing was examined with the remaining portion of the ODG and both intermediate drive helical gears still installed. A large amount of metallic debris was found within the center section of the output housing, including an intact bolt that was undamaged, a stud securing lobe from the housing itself, and a piece of gear tooth. The locking feature of the portion of the ODG that remained installed was intact and secure. Approximately half of the ODG (input side of the gear) was fractured through the web and missing. On the remaining portion of the ODG, all the helical gear teeth were broken and worn away near or flush to the base of the teeth. The output splines were all present, intact and appeared to be undamaged.

The installed and other recovered portions of the ODG were sent to the engine manufacturer's Material Investigation Laboratory for further analysis.

ODG Examination

The portion of the ODG that remained installed in the RGB, consisting of the majority of the helical teeth, the shaft portion, and the output splines was arbitrarily numbered 1, and the section of the ODG outer ring recovered from the RGB output housing center section was numbered 2. The helical gear portion of piece 1 was fractured at two tooth locations with the No. 1 tooth location arbitrarily chosen at one of the two fracture locations. Piece 1 consisted of teeth number from No. 1 to No. 57 in the direction rotation of the gear while piece 2 consisted of teeth number from No. 57 to No. 115 also in the direction of rotation.

Features consistent with fatigue were found on ODG piece 1 at the No. 1 helical tooth location. It was determined that the crack initiated from the root, immediately next to the chamfer of tooth No. 1, approximately 0.020-inches from the rear end face. The No. 1 tooth fracture surface also exhibited regions with a reddish-brown color in the tooth area as well as a dark-bluish color at the web. The fractures through the No. 57 tooth and the three web arms all exhibited features consistent with tensile overload. The web arms also exhibited a noticeable reduction in cross section that was consistent with tensile overload. According to the engine manufacturer, the dark-bluish color observed at the web arm locations was consistent with heat distress generated from heavy rubbing following the fracture of the gear, and the reddish-brown color observed on the No. 1 tooth location was consistent with oil coke deposits generated by elevated oil and ODG temperatures as the helical gear teeth rubbed and wore following the fracture sequence of the gear. A detailed examination of what remained of the helical teeth revealed two secondary cracks on the rear end face of the No. 2 and No. 4 teeth emanating from fillet radius in the root of tooth.

Examination of the mating fracture surfaces on piece “2” revealed the corresponding fatigue on one surface and the tensile overload on the other surface. Due to the amount of collateral damage to the fatigue fracture surface, the fatigue origin was destroyed. A detailed examination of the helical teeth revealed four secondary cracks on the rear end face of the Nos. 111, 112, 113, and 115 teeth emanating from fillet radius in the root of tooth. A total of six secondary cracks were identified and all the cracks were localized around about a 22° arc near the fatigue fracture location (No. 1 tooth).

A scanning electron microscope was used to exam the fatigue fracture surface on ODG piece 1. River lines were observed on the fracture surface of piece 1 pointing towards a point of convergence in the root of the No. 1 tooth near the rear end face chamfer. The point of convergence was identified as the fatigue crack origin. The crack origin area was heavily damaged; however, clear evidence of grain facets indicative of intergranular cracking were observed starting adjacent to the origin, then transitioning to transgranular fatigue crack propagation. No anomalies or foreign material were noted at the crack origin. The location and size of the intergranular cracking area measured approximately 0.025-inches in length by 0.008-inches in depth, which was within the carburization layer specified by the manufacturing print.

ODG Case Hardness and Material Composition

Tooth No. 62 was arbitrarily chosen to conduct a micro-hardness traverse to determine the case and core hardness as well as the depth of the case layer. The micro-hardness traverses revealed no material anomalies, the surface and core harnesses' were within the range specified on the manufacturing print, and the both the effective and total case depths were within the minimum and maximum respectively.

Samples from the fractured ODG were chemically analyzed to determine material composition. The ODG was made out of an Aerospace Material Specification (AMS) 6265 wrought alloy steel. The ODG met the AMS 6265 specification requirements. The samples were also examined for the presence of detrimental elements including hydrogen and nitrogen. The hydrogen content was reported as 1 part per million and the maximum nitrogen level was 0.0052% by weight.

A Time-of-Flight Secondary Ion Mass Spectrometry (TOF-SIMS) chemical analysis of the secondary crack fracture surfaces on tooth No. 113 was performed to determine whether potentially detrimental elements such as phosphorus, hydrogen, nitrogen, chlorine, or oxygen were present in sufficient quantities along the grain boundaries to have contributed to or caused the initiation of the fatigue crack observed. The analysis found no significant difference between the intergranular and transgranular regions. Nitrogen and Phosphorus were found, but not in the amounts significant for material embrittlement.

ODG Manufacturing Process

The raw material used to manufacture the ODG, was produced in January 2008 as part of a 15 bar lot of material. The material was subsequently forged into ODGs in May 2008 under heat code number EPHTL. The eight semi-finished forged pieces under heat code number EPHTL were carburized, finish machined, heat treated, and plated beginning in June 2008. Of the eight ODGs from this batch, one, was scrapped during the manufacturing process due to a problem in a grinding operation and was never installed in an RGB or used as a spare; thus only seven of the eight ODGs from this manufacturing batch entered operational service. The production of the seven acceptable pieces was completed in August 2008.

The manufacturing of the ODGs involved several chemical and electrochemical operations, such as carburization, plating, etching, and stripping, along with machining and heat treating operations. Examination of the accident ODG showed that the case and core harnesses were within specification, and the effective and total case depths were within the minimum and maximum respectively.

After the helical teeth were carburized, the ODG was subjected to hardening, a cold treatment (sub-zero treatment), tempering, grinding of the helical teeth to their finished machined dimensions as specified in the manufacturing print, and MPI'd, before plating. The subject ODGs were hardened, cold treated, and tempered all in the same day with the MPI conducted 5 days later. None of the eight original pieces were rejected due to cracks or anomalies.

After finish machining, but before the plating processes, the roots of the helical gear teeth shot peened, which relieved any residual tensile stresses that were built up during the grinding process introduced a layer of compressive residual stress that increased resistance to fatigue cracking. The helical teeth of the accident ODG had been shot peened. The ODG was then plated in different areas and with differing chemicals for various reasons, but no plating was done to the helical or spline gear teeth. No plating was found in the accident ODG gear teeth.

Nascent hydrogen uptake, or hydrogen embrittlement, into the ODG could occur from various sources such as pickling to remove scale and rust, during quenching when water or vapor water reacted with the part at high temperatures, but especially during electroplating. Delayed cracking could occur if the hydrogen was not relieved from the gear by baking at an elevated temperature shortly after electroplating. In order to prevent this from occurring, the part was dehydrogenized to drive hydrogen out. Review of the manufacturing production order showed that after each of the three plating operations, the ODG was subjected to a dehydrogenization process.

ADDITIONAL INFORMATION

On October 7, 2010, the engine manufacturer issued Alert Service Bulletin (ASB), PT6T-72-A5517 entitled “TURBOSHAFT ENGINE REDUCTION GEARBOX – REMOVAL” to inform PT6T-3 turboshaft operators that certain ODGs may have a manufacturing anomaly that could cause a fracture during operation resulting in loss of power. The suspect population of ODGs was identified as all coming from the same manufacturing batch as the accident ODG. Since the suspect population of seven units was relatively low, all operators were contacted directly by engine manufacturer prior to the release of the ASB so that proper and expedient arrangements could be made to have the reduction gearboxes removed.

The six suspect ODGs from the same manufacturing batch as the accident gear were all removed before the end of December 2010 and sent to the engine manufacturer for examination. All the ODGs were subjected to a Fluorescent Penetrant Inspection and an MPI to in order to detect any potential cracks. No cracks were found in any of the ODGs using either technique. The engine manufacturer also sectioned one of six suspect ODGs and performed a metallographic examination. The result of the metallographic examination indicated that the case hardness and core microstructure requirements were satisfactory and within specifications.

## Pilot Information

| | | | |
|---|---|---|---|
| **Certificate:** | Commercial; Flight instructor | **Age:** | 34,Female |
| **Airplane Rating(s):** | Single-engine land; Single-engine sea; Multi-engine land | **Seat Occupied:** | Right |
| **Other Aircraft Rating(s):** | Helicopter | **Restraint Used:** | |
| **Instrument Rating(s):** | Airplane; Helicopter | **Second Pilot Present:** | Yes |
| **Instructor Rating(s):** | Airplane multi-engine; Airplane single-engine; Instrument airplane; Instrument helicopter | **Toxicology Performed:** | No |
| **Medical Certification:** | Class 2 Without waivers/limitations | **Last FAA Medical Exam:** | September 23, 2009 |
| **Occupational Pilot:** | Yes | **Last Flight Review or Equivalent:** | August 24, 2009 |
| **Flight Time:** | 3680 hours (Total, all aircraft), 465 hours (Total, this make and model), 3480 hours (Pilot In Command, all aircraft), 80 hours (Last 90 days, all aircraft), 60 hours (Last 30 days, all aircraft) | | |

## Co-pilot Information

| | | | |
|---|---|---|---|
| **Certificate:** | Airline transport; Flight instructor | **Age:** | 38,Male |
| **Airplane Rating(s):** | Single-engine land; Single-engine sea; Multi-engine land | **Seat Occupied:** | Left |
| **Other Aircraft Rating(s):** | Helicopter | **Restraint Used:** | |
| **Instrument Rating(s):** | Airplane; Helicopter | **Second Pilot Present:** | Yes |
| **Instructor Rating(s):** | Airplane multi-engine; Airplane single-engine; Helicopter; Instrument airplane; Instrument helicopter | **Toxicology Performed:** | No |
| **Medical Certification:** | Class 1 Without waivers/limitations | **Last FAA Medical Exam:** | April 9, 2010 |
| **Occupational Pilot:** | Yes | **Last Flight Review or Equivalent:** | May 7, 2009 |
| **Flight Time:** | 5349 hours (Total, all aircraft), 95 hours (Total, this make and model) | | |

## Aircraft and Owner/Operator Information

| | | | |
|---|---|---|---|
| **Aircraft Make:** | Bell | **Registration:** | N412PD |
| **Model/Series:** | 412 EP | **Aircraft Category:** | Helicopter |
| **Year of Manufacture:** | | **Amateur Built:** | |
| **Airworthiness Certificate:** | Transport | **Serial Number:** | 36515 |
| **Landing Gear Type:** | Skid | **Seats:** | 12 |
| **Date/Type of Last Inspection:** | September 13, 2010 Continuous airworthiness | **Certified Max Gross Wt.:** | 11900 lbs |
| **Time Since Last Inspection:** | 56 Hrs | **Engines:** | 2 Turbo shaft |
| **Airframe Total Time:** | 359 Hrs at time of accident | **Engine Manufacturer:** | Pratt and Whitney Canada |
| **ELT:** | Installed, not activated | **Engine Model/Series:** | PT6T-3D |
| **Registered Owner:** | New York City Police Aviation Unit | **Rated Power:** | 1800 Horsepower |
| **Operator:** | New York City Police Aviation Unit | **Operating Certificate(s) Held:** | None |

## Meteorological Information and Flight Plan

| | | | |
|---|---|---|---|
| **Conditions at Accident Site:** | Visual (VMC) | **Condition of Light:** | Day |
| **Observation Facility, Elevation:** | JFK,17 ft msl | **Distance from Accident Site:** | 5 Nautical Miles |
| **Observation Time:** | 15:51 Local | **Direction from Accident Site:** | 230° |
| **Lowest Cloud Condition:** | Few / 2500 ft AGL | **Visibility** | 10 miles |
| **Lowest Ceiling:** | None | **Visibility (RVR):** | |
| **Wind Speed/Gusts:** | 8 knots / None | **Turbulence Type Forecast/Actual:** | / |
| **Wind Direction:** | 170° | **Turbulence Severity Forecast/Actual:** | / |
| **Altimeter Setting:** | 29.97 inches Hg | **Temperature/Dew Point:** | 27°C / 18°C |
| **Precipitation and Obscuration:** | No Obscuration; No Precipitation | | |
| **Departure Point:** | Brooklyn, NY (NY22) | **Type of Flight Plan Filed:** | None |
| **Destination:** | Brooklyn, NY (NY22) | **Type of Clearance:** | None |
| **Departure Time:** | | **Type of Airspace:** | |

## Airport Information

| | | | |
|---|---|---|---|
| **Airport:** | Floyd Bennett Field NY22 | **Runway Surface Type:** | |
| **Airport Elevation:** | 16 ft msl | **Runway Surface Condition:** | |
| **Runway Used:** | | **IFR Approach:** | None |
| **Runway Length/Width:** | | **VFR Approach/Landing:** | Full stop;Straight-in |

## Wreckage and Impact Information

| | | | |
|---|---|---|---|
| **Crew Injuries:** | 6 Minor | **Aircraft Damage:** | Substantial |
| **Passenger Injuries:** | | **Aircraft Fire:** | None |
| **Ground Injuries:** | N/A | **Aircraft Explosion:** | None |
| **Total Injuries:** | 6 Minor | **Latitude, Longitude:** | 40.599998,-73.899444(est) |

## Administrative Information

| | |
|---|---|
| **Investigator In Charge (IIC):** | Wilson, Ralph |
| **Additional Participating Persons:** | Louis Misiano; FAA/FSDO; Farmingdale, NY<br>David Dosker; Bell Helicopter Inc; Ft. Worth, TX<br>Denis Rivard; Transportation Safety Board of Canada; Gatineau, Canada |
| **Original Publish Date:** | April 10, 2013 |
| **Last Revision Date:** | |
| **Investigation Class:** | Class |
| **Note:** | |
| **Investigation Docket:** | https://data.ntsb.gov/Docket?ProjectID=77366 |