Aviation Investigation Factual Report

Location:	Burns, Oregon	**Accident Number:**	WPR13GA374
Date & Time:	August 12, 2013, 14:00 Local	**Registration:**	N62PJ
Aircraft:	McDonnell Douglas Helicopter 369E	**Aircraft Damage:**	Substantial
Defining Event:	Loss of engine power (total)	**Injuries:**	2 None
Flight Conducted Under:	Public aircraft		

On August 12, 2013, about 1400 Pacific daylight time, a McDonnell Douglas Helicopter Inc. (MDHI) 369E, N62PJ, sustained substantial damage during a forced landing following a loss of engine power near Burns, Oregon. The helicopter was registered to and operated by PJ Helicopters, Red Bluff, California, under the provisions of Title 14 Code of Federal Regulations Part 91. The commercial pilot and his passenger were not injured. Visual meteorological conditions prevailed, and a company visual flight rules flight plan was filed for the local public aircraft flight. The flight originated from a staging area about 1245.

The pilot reported that during cruise flight at an altitude about 400 feet above ground level over densely wooded mountainous terrain, he heard a "loud bang" originate from the engine followed by a left yaw and a "severe medium frequency vibration." The pilot performed a 180-degree left turn autorotation to a nearby forest service logging road. During the landing, the main rotor blades struck trees adjacent to the road, and the left skid slid into a ditch, which resulted in the helicopter rotating 90-degrees and subsequently the separation of the left skid.

Examination of the helicopter by the pilot revealed that the tailboom was separated, and the left landing skid was separated. The helicopter was recovered to a secure location for further examination.

Pilot Information

Certificate:	Commercial	**Age:**	29,Male
Airplane Rating(s):	None	**Seat Occupied:**	Right
Other Aircraft Rating(s):	None	**Restraint Used:**	4-point
Instrument Rating(s):	Helicopter	**Second Pilot Present:**	No
Instructor Rating(s):	None	**Toxicology Performed:**	No
Medical Certification:	Class 2 With waivers/limitations	**Last FAA Medical Exam:**	January 30, 2013
Occupational Pilot:	Yes	**Last Flight Review or Equivalent:**	April 4, 2013
Flight Time:	5030 hours (Total, all aircraft), 205 hours (Total, this make and model), 4950 hours (Pilot In Command, all aircraft), 238 hours (Last 90 days, all aircraft), 106 hours (Last 30 days, all aircraft), 5 hours (Last 24 hours, all aircraft)		

Aircraft and Owner/Operator Information

Aircraft Make:	McDonnell Douglas Helicopter	**Registration:**	N62PJ
Model/Series:	369E	**Aircraft Category:**	Helicopter
Year of Manufacture:		**Amateur Built:**	
Airworthiness Certificate:	Normal	**Serial Number:**	0535E
Landing Gear Type:	Skid	**Seats:**	4
Date/Type of Last Inspection:	July 26, 2013 100 hour	**Certified Max Gross Wt.:**	3000 lbs
Time Since Last Inspection:	55 Hrs	**Engines:**	1 Turbo shaft
Airframe Total Time:	10450 Hrs at time of accident	**Engine Manufacturer:**	Rolls Royce
ELT:	C91 installed, not activated	**Engine Model/Series:**	250-C20B
Registered Owner:	P J HELICOPTERS	**Rated Power:**	420 Horsepower
Operator:	P J HELICOPTERS	**Operating Certificate(s) Held:**	None

The helicopter was equipped with a Rolls-Royce (RR) M250-C20B turbo-shaft engine, which features a 6 stage axial and 1 stage centrifugal compressor section that directs the diffused air via an external 180 degree compressor discharge tube system to the combustor. The hot gases from the combustor are then directed against a two-stage gas producer turbine and subsequently a two-stage power turbine before being exhausted. The RR M250-C20B produces 420 shaft horsepower.

The engine serial number (S/N) was CAE-836896. The engine logbook revealed that the engine was overhauled on October 13, 2010, at a time since new (TSN) of 9,202.8 hours, cycles since new (CSN) of 2,840, and cycles since overhaul (CSO) of 529. At the time of the overhaul, new post Service Bulletin (SB) Commercial Engine Bulletin (CEB) 1365 1st, 2nd, 3rd, and 4th stage turbine wheels were installed.

At the time of the accident, the engine had 10,449.6 hours TSN and 1,246.8 hours since major overhaul.

Meteorological Information and Flight Plan

Conditions at Accident Site:	Visual (VMC)	**Condition of Light:**	Day
Observation Facility, Elevation:	BNO,4159 ft msl	**Distance from Accident Site:**	20 Nautical Miles
Observation Time:	13:53 Local	**Direction from Accident Site:**	199°
Lowest Cloud Condition:	Clear	**Visibility**	10 miles
Lowest Ceiling:	None	**Visibility (RVR):**	
Wind Speed/Gusts:	7 knots / None	**Turbulence Type Forecast/Actual:**	/
Wind Direction:		**Turbulence Severity Forecast/Actual:**	/
Altimeter Setting:	30.04 inches Hg	**Temperature/Dew Point:**	29°C / 3°C
Precipitation and Obscuration:	No Obscuration; No Precipitation		
Departure Point:	Burns, OR	**Type of Flight Plan Filed:**	Company VFR
Destination:	Burns, OR	**Type of Clearance:**	None
Departure Time:	12:45 Local	**Type of Airspace:**	Class G

Wreckage and Impact Information

Crew Injuries:	1 None	**Aircraft Damage:**	Substantial
Passenger Injuries:	1 None	**Aircraft Fire:**	None
Ground Injuries:	N/A	**Aircraft Explosion:**	None
Total Injuries:	2 None	**Latitude, Longitude:**	43.743888,-118.879447(est)

The Rolls Royce M250-C20B turbo-shaft engine was removed from the airframe, and subsequently sent to the Rolls-Royce manufacturing facilities in Indianapolis, Indiana, for examination. The investigation team met on September 18, 2013, for the engine teardown, and to establish further testing and/or examinations that were necessary to complete the investigation.

Prior to engine disassembly, the N1 (Gas Producer) rotor was free to rotate, and its drive train continuity between the compressor and the starter generator pad was confirmed. The N2 (Power Turbine) rotor and associated drive train could not be rotated.

The gearbox module, S/N CAG 34078, was intact, and appeared to be undamaged. An examination of the two chip detectors revealed one small shiny flake in the lower chip detector while the upper was clean.

The compressor module, S/N CAC 38234F and the diffuser scroll case were intact, and appeared to be undamaged. The 1st stage compressor blades were intact, complete, and undamaged; the compressor rotor could be rotated by hand. The compressor assembly was not disassembled further.

The gas producer turbine module S/N was CAT 36932. The gas producer turbine support was intact and undamaged. The No. 8 bearing support was undamaged, oil wetted, and oil darkened.

The 1st stage turbine nozzle was intact and undamaged. All the airfoils were coated with a flaky black sooty deposit that was easily removed with finger pressure. The 1st stage turbine wheel was intact and undamaged. The curvic coupling was intact and undamaged. The 2nd stage turbine nozzle was intact and undamaged. The 2nd stage turbine wheel and its curvic coupling was intact and undamaged. The turbine-to-compressor coupling was intact and undamaged.

The N1 (Gas Producer) spool bearing set consists of the No. 1, No. 2, No. 2-½ , No. 7 and No. 8 bearings. Bearings No. 7 and 8 were intact, undamaged, oil wetted, and could be turned by hand.

The left-hand compressor discharge tube (CDT) was undamaged. The right-hand compressor discharge tube was pierced in two locations, and dented in multiple locations at the elbow location, which is in the plane of the 4th stage turbine rotor. The larger pierced hole on the CDT elbow was approximately 2-½ inches long with the width varying from 1/2 inch to 1 inch. The smaller hole had a rectangular shape approximately 1/2 inch x 3/8 inch. The edge material condition of the inside wall of both piercings of the CDT tube was 'petaled' inwards; consistent with a high-speed particle entering the tube, and the edge material condition of the outside wall was 'petaled' outwards, consistent with a high-speed particle material exiting the tube.

The outer combustor case was intact and undamaged; however the combustor liner had a 2 inch long radial fracture of the fish-mouth seal at the 8 o'clock location. The combustor liner was also heat distorted at the 8 o'clock location. The heat distortion started as a point at one of the aft most dilution holes, and continued in an increasing pattern until meeting the fish-mouth. The 1st stage nozzle deflector shield heat shield was slightly distorted. The heat shield is a plate that is welded onto the deflector shield, and has a wavy pattern corresponding to the mounting dimples on the deflector shield. The clearance between the edges of the heat shield and the deflector shield is approximately 1/8 inch, however at the 8 o'clock location the edges were in direct contact with the deflector shield material.

The exhaust collector was pierced in three locations. One of the exhaust collector center support casting arms was fractured in two locations and found loose. The three pierced holes were at the 9:30, 11:00, and 2:30 o'clock locations on the plane of the 4th stage turbine wheel. The hole at 9:30 o'clock was approximately 3.5 inches long in the circumferential direction, and maximum width of the hole was 1 inch in the axial direction. The material around the tear was petaled outwards, and there was no loss of material. The hole at 11 o'clock was approximately 1 inch long in the circumferential direction with a maximum width of 1 inch in the axial direction; the edges of the hole were fractured, and the entire patch of material was missing. The fracture at 2:30 o'clock was 4 inches long in the circumferential direction, and the opening width varied between ¾ and 1 inch. The missing piece of the housing material was approximately 2 square inches in total area.

The power turbine support was intact and undamaged. The 3rd stage turbine nozzle was intact and undamaged. The 3rd stage turbine wheel was intact. Five of the curvic coupling teeth were damaged on their contact faces, however they were still intact. The outer shroud was intact; however a 90 degree segment of the outer shroud labyrinth seal was heavily scored, consistent with contact against the blade track.

The 4th stage turbine nozzle was generally intact; however a 190 degree segment of the 4th stage turbine blade track was fractured in the plane of the 4th stage turbine wheel, consistent in location with the fracture of the exhaust collector housing. The 4th stage blade track was heavily rotationally scored. All the nozzle vanes were present and undamaged. The 3rd stage turbine blade track was rotationally scored, consistent with contact against the 3rd stage turbine wheel labyrinth seals.

The 4th stage turbine wheel was missing one blade. The missing blade was fractured near the inner rim. A 4-blade span of the shroud was also missing; it was located outboard of the liberated and three adjacent lagging blades. The three lagging adjacent blades were fractured near the tips, were missing the entire rim segment, and were twisted. The leading and lagging adjacent blades were fully attached to the inner platform rim. All the other blades were present and intact, however all were dented at the trailing edges approximately ½ inch inwards from the shroud. Nine of the curvic coupling teeth, which mate to the 3rd stage turbine wheel, were smeared on their contact faces; however, all were still intact.

The N2 (power turbine) bearing set consists of the No. 3, No. 4, No. 5 and No. 6 bearings. The No. 5 bearing snap ring was found dislodged from its groove. The forward right hand portion of the lower fire shield was deformed and torn in an area of approximately 4 inches by 2 inches. This damage was adjacent to the damage to the right hand compressor discharge tube

Tests and Research

The 4th stage turbine wheel and other related parts were submitted to the Rolls-Royce metallurgical laboratory and the NTSB Materials Laboratory for further examination.

A Senior Materials Engineer examined the 4th stage turbine wheel along with the additional related parts. The engineer reported that the 4th stage turbine wheel was originally cast as a single article that contained 32 airfoils; however one of the airfoils was fractured just outboard of the rim of the wheel. The fractured airfoil was designated as airfoil #1, and the rest of the airfoils were incrementally numbered proceeding in a clockwise direction when viewing the wheel from the leading edge side. The airfoils smoothly transitioned into a continuous outer shroud that ran around the circumference of the wheel. The outer shroud was fractured adjacent to airfoils #29 and #2, and was missing across the intermediate airfoils #30–#32. The outer shroud fractures had rough appearances that were consistent with overstress fractures.

Airfoil #1 was sectioned from the wheel, and first examined using an optical microscope. The fracture, as described below, initiated along the airfoil trailing edge and progressed by fatigue toward the leading edge. The length of the fatigue crack, measured from the trailing edge, was approximately 0.54 inch. Beyond the progression of the fracture, the fracture surface exhibited a comparatively rough appearance that was consistent with the remaining ligament failing in overstress. The fracture initiated approximately 0.025 inch above the rim where a fillet radius blended into the airfoil trailing edge. As the crack initially progressed toward the airfoil leading edge, it also progressed inward toward the rim. At a distance of 0.028 inch from the trailing edge, the crack began to progress outward away from the rim as it continued its progression toward the leading edge.

The fracture surface of airfoil 1 was examined using a scanning electron microscope (SEM), and exhibited curved fatigue crack propagation features near the trailing edge. The curvature and orientation of the features were used to trace the crack path back to an initiation site along the airfoil trailing edge. The crack initiated along a straight segment of the airfoil trailing edge approximately 0.0045 inch from a curved segment on the pressure side of the airfoil. The initiation site exhibited features consistent with oxidation and mechanical rubbing/smearing.

Examination of the fracture surface in the SEM revealed a boundary at which the fatigue fracture morphology changed as the crack progressed toward the airfoil leading edge. From the initiation site up to the boundary, the fracture surface exhibited the curved fatigue crack progression features described above. Beyond the boundary the curved crack progression, features diminished in appearance, and the fracture surface began to exhibit feathery features. The transition occurred as far as 0.038 inch from the trailing edge of the airfoil. The feathery features persisted as the fatigue crack progressed toward the leading edge until it reached the overstress region described above.

The Rockwell hardness of the wheel was measured in accordance with ASTM E18 on the curvic teeth on the trailing edge side of the wheel, and measured 35.5 HRC, 34.0 HRC, 33.6 HRC, 34.6 HRC, and 36.4 HRC. The hardness values were in accordance with the material requirement.

After the conclusion of the group exam, the wheel was sent to Rolls-Royce to inspect the other airfoil trailing edges for the presence of cracks. The wheel was cleaned with grit blast, and the remaining airfoil trailing edges were inspected using a fluorescent penetrant. No additional cracks were detected.

The microstructure of the fractured airfoil was also examined by preparing a metallurgical specimen. The fractured airfoil was cross sectioned, ground, and polished in accordance with ASTM E3. The sample was then etched using a mixture of 33% acetic acid, 33% nitric acid, 33% water, and 1% hydrofluoric acid. The microstructure had an appearance of a typical cast microstructure, and there were no apparent microstructural anomalies at or near the trailing edge.

For further details, see the Materials Laboratory Factual Report in the public docket for this accident.

Representatives from Rolls-Royce engineering reported that after extensive analysis, the initiation of the low cycle fatigue (LCF) crack was most likely caused by a combination of two factors: The first being a high positive thermal gradient in the airfoil trailing edge material near the hub during the engine starting process. The second factor was during transient operation, such as auto-rotation, which produces a combination of high negative thermal gradient and high speed stress into the blade.

Additional Information

There have been four previous NTSB-investigated failures of 4th stage turbine wheels in RR M250-

C20B engines installed in MDHI 369 helicopters, which have had the post-SB CEB-1365 power turbine assembly incorporated. There has been one 4th stage turbine failure in a Bell OH-58 operated by the US Army; however it was reported that this helicopter was used extensively for auto-rotation training, and no further details were available.

Service Bulletins

Rolls-Royce SB CEB-1365

The 'enhanced' power turbine section was developed by Rolls-Royce as a product improvement, designed to increase both power and fuel efficiency. SB CEB-1365 hardware was a major re-design of the 3rd and 4th stage turbine assembly, with the main differences between the pre- and post-SB CEB-1365 being different airfoil size, shape, tilt, lean, flow, and quantity of airfoils per stage for both turbine nozzles and wheels.

The enhanced power turbine design was released for new production engines built after August 1999. It was then released as a customer option to fielded engines viaRolls-Royce SB CEB-1365 in November 1999. The modification applied to all M250-C20 series engines, with the exception of turbo-prop variants, and was to be complied with as a customer option. Release of enhanced power turbine to M250–B17F/2 turbo-prop variants occurred in August, 2008, while release of all other turbo-prop applications was in November, 2009. The previous "non-enhanced" power turbine part numbers were discontinued from production in August 2009, and discontinued from Service/Spares orders in March 2013. Thus, the SB CEB-1365 enhanced power turbine is the only current production and service released hardware.

E.1.3.2 Rolls-Royce Alert SB CEB -A-1400

CEB-A-1400, entitled 'Steady State Operation Avoidance Range Limit' was originally released in December 2006, and specified turbine (N2) revolutions per minute (rpm) of the speed ranges that should be avoided. The current revision, CEB-A-1400-revision 3, dated January 19, 2009, advises to avoid steady state engine operation in the N2 speed avoidance range of 75 - 88 percent for operation above 85 shaft horsepower (SHP). Steady-state operation below 85 SHP or transient operation thru the speed avoidance range is allowable. The revised SB requires an entry in the maintenance records documenting steady-state operation in the speed avoidance range when operating above 85 SHP.

On November 29, 2010, Rolls-Royce issued CEB-A-1407, which was only applicable to M250-C20B engines installed on MDHI 369 models equipped with post-CEB-1365 hardware. It required a one-time inspection of the 3rd and 4th stage turbine wheels for possible airfoil cracks to be completed within 1,750 hours, and required the removal of the applicable turbine wheels for fluorescent-penetrant and visual inspections. The SB mandated the replacement of any wheel that contained any cracks of an airfoil trailing edge where the platform fillet engages. Additionally, it warned operators to avoid prolonged engine operation in the 75-88 percent N2 speed range, failure of which could result in possible turbine wheel airfoil fracture. The compliance code of this SB was 6: 'To be complied with at or within next 1,750 hours gas producer turbine overhaul'.

Revision 1 of Rolls-Royce CEB-A-1407 on February 7, 2011, pertained to M250-C20B engines installed with an enhanced power turbine 4th stage power turbine wheel P/N 23055944 (applicable to the accident engine and helicopter), revealed that the analysis of recent failures of enhanced power turbine wheels determined the most possible cause to be operation of the engine in the N2 speed avoidance range of 75 to 88 percent. The SB called for a one-time inspection of the 3rd and 4th stage turbine wheels for cracks in the airfoils. The compliance code of this SB was 6: 'To be complied with at the next 1,750 hours.'

Revision 2 of Rolls-Royce CEB-A-1407, issued on August 2012 stated that 3rd or 4th stage turbine wheels that were installed after September 2011 were not subject to the one-time inspection due to the issuance of an MDHI Helicopter bald rotor blade tracking procedure revision and prior speed avoidance actions regarding tail rotor balancing. The compliance code of this SB was 6: 'To be complied with at the next 1,750 hours.' In addition, this alert was referenced in FAA Airworthiness Directive (AD) 202-14-06.

Revision 3 of Rolls-Royce CEB-A-1407, issued on May 19, 2014, after a total of four - 4th stage failures, increased the compliance code from 6 to 2 'To be complied with at each 1,750 hour gas producer turbine wheel replacement, a continuing repetitive rather than a one-time inspection. It also retracted Revision 2 by requiring all turbine wheels, even those installed after September, 2011, to be subject to the inspection. This Alert CEB is referenced in FAA AD 2015-02-22.

In November 2013, Rolls Royce issued a change in their maintenance manual (MM) requiring the removal and scrap of all post SB CEB 1365 3rd and 4th stage turbine wheels if any temperature limits were exceeded.

MDHI Operation Manual Changes

On March 21, 2007, MDHI issued Revision 16 of the MDHI 369E flight manual, which incorporated the Rolls-Royce CEB-A-1400 operational limitations to the power turbine by introducing a rotational speed avoid range and a turbine transient temperature limit to operators of the MDHI 369 helicopter. The turbine speed avoid range of 75 – 88 percent was introduced, and the transition time while passing through the range was now limited to 1 minute. Transient temperature limits during start and shutdown were now limited to 10 seconds above 810 degrees C and a maximum of 927 degrees C.

On September 30, 2010, MDHI issued Revision 17 of the 369E flight manual, which incorporated two additional limitations. Firstly, steady state operations between 75 and 88 percent were now required to be recorded. Secondly, a caution was added, warning operators to maintain the main rotor speed above 420 rpm during auto-rotation practice maneuvers, to avoid entering the speed avoid range.

Airworthiness Directives

AD 2012-14-06, released on July 10, 2012, required a one-time visual inspection and fluorescent penetrant inspection (FPI) on post-SB CEB 1365 3rd and 4th stage turbine wheels for cracks in the trailing edges of the turbine blades. It was issued to mandate the incorporation of CEB-A-1407 in an attempt to prevent further failures of 3rd or 4th stage turbine wheel blades, which could cause an engine failure, immediate power loss and un-containment, resulting in damage to the airplane.

The compliance stated:

(1) Remove the 3rd stage turbine wheel, P/N 23065818, and the 4th stage turbine wheel, P/N 23055944, within 1,750-hours since last inspection (HSLI).

(2) Perform a one-time visual inspection and a fluorescent penetrant inspection on the 3rd and 4th stage turbine wheels for cracks at the trailing edge of the turbine blades near the fillet at the rim.

(3) If any cracks in the trailing edge near the rim are detected, do not return the wheel to service.

AD 2015-02-22 was issued on March 9, 2015, to supersede AD 2012-14-06, and mandated a repetitive visual inspection and FPI on post-SB CEB 1365 3rd and 4th stage turbine wheels for cracks in the trailing edges of the turbine blades.

The compliance stated:

(1) Within 1,750 HSLI, remove the affected turbine wheels and perform a visual inspection and an FPI on the removed turbine wheels for cracks at the trailing edge of the turbine blades near the fillet at the rim.

(2) Any time the power turbine is disassembled, perform a visual inspection and an FPI on the affected turbine wheels for cracks at the trailing edge of the turbine blades, near the fillet at the rim.

(3) Thereafter, re-inspect every 1,750 HSLI.

(4) Do not return to service any turbine wheels that have cracks detected.

Postaccident Changes

To address LCF crack initiation and in an attempt to limit exposure of the turbine wheels to high tensile stresses that are exacerbating by thermal transients and higher N2 speed, RR is working with MDHI to inform MDHI operators to abort training auto-rotation if N1 and N2 needles do not split.

To address high cycle fatigue (HCF) crack propagation, RR is working with MDHI to reduce the ground idle speed of the MDHI field operations (currently 64-65% N1). The GI field variances were shown to be very close to the 74.7% N2 rpm. Flight tests were approved by the Los Angeles Federal Aviation Administration (FAA) Aircraft Certification Office (ACO) the responsible FAA office for all MDHI airworthiness certification, and were performed in fall 2014.

RR has performed plastic model analysis studies based on videos of typical PJ Helicopter operations to compare the missions between airframes on the pre- and post-SB CEB1365 blades as well as the new design blades. This was undertaken to determine if this analysis will highlight differences that could explain the LCF crack phenomenon. This analysis is on-going.

RR identified and collected turbine wheels from engines that were flown exclusively in Bell helicopters to identify whether this is an MDHI LCF or fleet wide LCF issue. Up to the time of this report, 20 non-

MD wheels have been collected from overhaul facilities. The analysis is continuing and at the time of this report release, no results are available.

Long Term Mitigation Plans

Rolls Royce is in the process of releasing a new 4th Stage Turbine Wheel with Increased Fillet. An attempt to design and fabricate a new turbine design was initiated in October, 2010; however, due to failures from casting problems in 2013, the design was terminated. A new design was started, and is expected to be released in 2016.

On Airframe Inspection Program

Even if the new turbine blade design is produced during 2016, it will take several years until all the post SB CEB-1365 wheels will be removed from service. Until then, an on-wing inspection program has been proposed, and is currently being developed by RR. An eddy current inspection (ECI) method has been selected instead of an ultrasonic or a local FPI method. An ECI probe design and a reliable procedure are currently being developed. RR has cut fine slots in a sample turbine wheel with electrical discharge machining (EDM) to simulate a crack and sent the wheel to a specialized EDM facility, which will design a fixture and develop a robust test procedure to detect the induced flaws. The next phase will be to validate the tool in an installed engine. No date has been established for the completion of the probe development or the validation of the tool.

For further details, see the Powerplant Group Chairman's Factual Report in the public docket for this accident.

Administrative Information

Investigator In Charge (IIC):	Cawthra, Joshua
Additional Participating Persons:	Russell L Carlson; Federal Aviation Administration; Boise, ID Mark Gunsales; PJ Helicopters; Red Bluff, CA David MCCammon; PJ Helicopters; Red Bluff, CA Jon Michael; Rolls Royce; Indianapolis, IN Adrian Booth; Boeing Helicopters; Mesa, AZ John Hobby; MD Helicopters; Mesa, AZ
Report Date:	May 3, 2016
Last Revision Date:	
Investigation Class:	Class
Note:	The NTSB did not travel to the scene of this accident.
Investigation Docket:	https://data.ntsb.gov/Docket?ProjectID=87789