



NATIONAL TRANSPORTATION SAFETY BOARD
Office of Aviation Safety
Washington, D.C. 20594

April 5, 2016

POWERPLANT GROUP CHAIRMAN'S FACTUAL REPORT

NTSB No: WPR13GA374

A. ACCIDENT

Location: Burns, Oregon

Date: August 12, 2013

Time: 1400 Pacific Daylight Time

Aircraft: MD Helicopter Inc. (MDHI) 369E Helicopter, Registration Number N62PJ

B. POWERPLANTS GROUP

Group Chairman: Harald Reichel
National Transportation Safety Board
Washington, DC

Safety Board IIC: Joshua Cawthra
Air Safety Investigator
Seattle, Washington

Member: Jon Michael
Rolls-Royce
Indianapolis, Indiana

Member: John Hobby
MD Helicopters, Inc.
Mesa, Arizona

C. SUMMARY

On August 12, 2013, about 1400 pacific daylight time, a MDHI 369E, serial number 0535E, registration number 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, as a public use flight. The commercial pilot and his passenger were not injured. Visual meteorological conditions prevailed and no flight plan was filed for the local flight. The pilot reported that during cruise flight at an altitude of about 400 feet above ground level over mountainous terrain, he heard a loud bang originate from the engine followed by an immediate loss of engine power. The pilot performed a 180-degree autorotation and landed hard on a forest service logging road. 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.

The Rolls Royce M250-C20B turbo-shaft engine was sent to the Rolls-Royce manufacturing facilities in Indianapolis, Indiana for examination. The 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.

Disassembly and examination of the engine revealed that one blade of the 4th stage turbine wheel was fractured near the inner platform in a process involving a combination of low cycle fatigue which progressed to a high cycle fatigue mode, causing a sudden loss of power and an un-containment. The wheel was identified as part of a post-service bulletin (SB) commercial engine bulletin (CEB)-1365 or 'enhanced' turbine assembly design. According to Rolls Royce, the pattern and appearance of the fracture on this wheel was similar to the eight other failures of post-SB CEB-1365 power turbine assembly design.

D. DETAILS OF THE INVESTIGATION

D.1 Engine Description

The engine was a Rolls-Royce (RR) M250-C20B turbo-shaft engine which features a 6 stage axial and 1 stage centrifugal compressor section which 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 ([Figure 3](#)) before being exhausted. The RR M250-C20B produces 420 shaft horsepower.

D.2 Engine History

The engine serial number (S/N) was CAE-836896. The operators' engine log book revealed the following recent history of the engine:

Date	TSN ¹ (hours)	TSO (hours)	CSN (cycles)	CSO (cycles)	Notes
2010/10/13	9202.8	0	2840	529	Overhaul
2013/08/12	10,449.6	1246.8			Accident

During the overhaul on October 2010, new post-SB CEB 1365 1st, 2nd, 3rd and 4th stage turbine wheels were installed.

D.3 Examination Of The Engine

D.3.1 Engine Identification

The engine was in a metal engine container which was opened in the presence of the NTSB ([Figure 4](#)). The engine is of a modular design and a complete engine consists of three serialized major assemblies: the compressor module, the gearbox module, the turbine module.

Prior to dis-assembly 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.

D.3.2 Gearbox Module

The gearbox module, S/N CAG 34078 and was intact and appeared to be undamaged ([Figure 5](#)). An examination of the two chip detectors revealed one small shiny flake in the lower chip detector while the upper was clean.

The oil filter was examined and found to be clean.

When the N1 tach generator pad was rotated by hand, the output splines of the fuel control unit and the starter/generator rotated in unison, confirming continuity of the gear train. With the turbine module removed, the N2 tach generator pad was rotated by hand and the power turbine output shaft rotated in unison, confirming continuity of the gearbox power gear train. Therefore the gearbox was not disassembled further.

¹ Abbreviations for operations and service intervals: Time Since New (TSN), Time Since Overhaul (TSO), Cycles Since New (CSN), Cycles Since Overhaul (CSO). Dates are in year/month/day format.

D.3.3 Gas Producer Module

D.3.3.1 *Compressor*

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 (Figure 6), complete and undamaged and the compressor rotor could be rotated by hand. The compressor assembly was not disassembled further.

D.3.3.2 *Gas Producer (Compressor) Turbine*

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 (Figure 7). 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 (Figure 8). 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 (Figure 9 & Figure 10).

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 and oil wetted and could be turned by hand.

D.3.3.3 *Inter-turbine Temperature Thermocouple (ITT) Harness*

The thermocouple harness assembly was intact and undamaged. The ends of the four thermocouple insertion sleeves and the probe tips were black and sooty.

D.3.3.4 *Combustor*

The left-hand compressor discharge tube (CDT) was undamaged. The right-hand² compressor discharge tube was pierced in two locations and dented in multiple locations

² All directional references to front and rear, right and left, top and bottom, and clockwise and counterclockwise are made aft looking forward (ALF) as is the convention. All numbering in the circumferential direction starts with the No. 1 position at the 12:00 o'clock position or immediately clockwise from the 12:00 o'clock position and progresses sequentially clockwise ALF.

at the elbow location which is in the plane of the 4th stage turbine rotor (Figure 3, Figure 11 & Figure 12). The larger pierced hole on the CDT elbow was approximately 2-½ inches long with the width varying from ½ inch to 1 inch (Figure 13 & Figure 14). The smaller hole had a rectangular shape approximately ½ inch x ¾ inch. The edge material condition of the inside wall of both piercings of the CDT tube was ‘petaled’ inwards³; 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 (Figure 15 & Figure 16). 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 (Figure 17). 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.

D.3.3.5 Power Turbine & Exhaust Collector

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 and 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 width varied between ¾ and 1 inch opening. 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 (Figure 18). 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

³ Particles piercing and fracturing sheet metal plates at lower speeds leave the fractured but retained unsupported panels with a large radius of curvature over the unsupported length of the fractured panel or a relatively flat condition, while higher speed particles impart a smaller radius of curvature or ‘curl’ on the unsupported panels nearer the impact location. The small radius curls are described as a ‘petaled’ condition.

degree segment of the blade 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 (Figure 19). 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 (Figure 20 & Figure 21). The missing blade was fractured near the inner rim (Figure 22). 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 shroud segment and were twisted (Figure 23). The leading and lagging adjacent blades were still 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 blade 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 (Figure 24).

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 is adjacent to the damage to the right hand compressor discharge tube.

D.3.3.6 Externals

The fuel control unit (FCU), power turbine governor, fuel pump, oil pump, lube distribution system were intact and externally undamaged and were not further tested.

D.4 Other Testing

D.4.1 Metallurgical Analysis of the 4th Stage Turbine Wheel

The 4th stage turbine wheel and other related parts were submitted to the Rolls-Royce metallurgical laboratory for analysis. A review of the findings of the report are:

- 1) The 4th stage turbine wheel was P/N 23055944-F, S/N X586178.
- 2) One 4th stage turbine wheel airfoil fractured and separated due to fatigue. The fracture initiated as a low cycle fatigue (LCF) crack at the trailing edge of the airfoil at about 0.025 inch outboard of the hub rim (Figure 25) and propagated forward for 0.035 inch (Figure 26), at which point it transitioned

into a high cycle fatigue (HCF) crack, growing approximately 0.494 inches long before the airfoil separated in overload (Figure 27).

- 3) Fluorescent penetrant inspection of the 4th stage turbine wheel did not reveal any other crack indications.
- 4) The microstructure, hardness, and composition of the fourth stage turbine wheel conformed to the requirements of the engineering drawing.

E. Historical Data & Other Factors Considered

E.1 History of SB CEB-1365 3rd & 4th Stage Turbine Failures on the Rolls-Royce 250-C20 Engine

Even though the failure of the 4th stage turbine wheel was the cause of this accident, this report accumulates the data from all 3rd and 4th stage turbine failures of RR M250-C20B engines that have had the SB CEB-1365 'enhanced' turbines installed. While the root cause of the 4th stage wheel failure has been determined, the investigation of the 3rd stage continues.

There have been 4 previous NTSB-investigated failures of 3rd & 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.

E.1.1 RR M250-C20 Engine Failures Investigated by NTSB

E.1.1.1 LAX03LA212 – Kualapuu, Hawaii - MDHI 369D on 6/26/2003

According to the NTSB factual report, this engine sustained a 3rd stage turbine wheel high-cycle fatigue (HCF) failure originating from the trailing edge of the blade near the platform. The SB CEB-1365 kit (enhanced 3rd & 4th stage nozzles and wheels) had been installed at 1,043 hours prior to the failure. This was the 1st known failure of the enhanced kit.

E.1.1.2 CHI08GA028 – Columbus, Ohio – MDHI 369E on 10/29/2007

According to the NTSB factual report, this engine sustained a post-CEB-1365 4th stage turbine wheel HCF failure originating from the trailing edge of the blade near the platform fillet. This wheel had accumulated 2,918.7 hours TSN and 1,718 CSN.

The factual report further stated that RR was in the process of redesigning the enhanced power turbine section to be more robust, and that the estimated time for the Fixed Process Approval was the end of 2011, after which production was scheduled to begin.

E.1.1.3 ERA09LA317 – Greenville, VA – MDHI 369D on 06/02/2009

According to the NTSB factual report, this engine sustained a post-SB CEB-1365 4th stage turbine wheel HCF failure originating from the trailing edge of the blade near the platform fillet. This wheel had undergone the required Fluorescent Particle Inspection (FPI) inspection at 1750 hours, and was approved for continued service. After re-installation into the engine it then accumulated an additional 921 hours until it failed.

According to the director of maintenance (DOM) of Aerial Solutions, Inc., following release of SB CEB-A-1400 ([see Rolls-Royce Alert SB CEB-A-1400](#)) in December 2006, which introduced a steady-state turbine (N2) revolutions per minute (RPM) operation avoidance range limit, the company flight crew members and mechanics were briefed about the details of the bulletin. The pilots were advised that this range could be encountered during a slow acceleration from ground idle to flight rpm, and the mechanics were advised that the range could be encountered when balancing the main rotor hub without the main rotor blades, or during vibration surveys of the engine. The pilot and mechanics were advised to report any steady state operation in the speed avoidance range. To his knowledge, there was no reported steady state operation of the engine in the N2 speed avoidance range. Additionally, the DOM stated that he later created a graphic depiction of the speed avoidance range which he used during training classes and general meetings to, "...underline the importance of the service bulletin." Review of the maintenance records from January 7, 2006, to June 1, 2009, revealed no entry indicating any steady state engine operation in the N2 speed avoidance range.

E.1.1.4 ERA09LA460 – Acworth, Georgia – MDHI 369E on 08/12/2009

According to the NTSB factual report, this engine sustained a post-SB CEB-1365 3rd stage turbine wheel HCF failure originating from the trailing edge of the blade near the platform fillet.

Compliance with SB CEB-A-1400 and CEB-A-1407 ([see Rolls-Royce Alert SB CEB –A-1407](#)) was not recorded in the NTSB factual report. RR CEB-A-1407, released in November 26, 2010 introduced a one-time FPI inspection of the 3rd and 4th stage post-SB CEB-1365 turbine wheels.

E.1.1.5 CEN12TA550 – Columbus, Ohio – MDHI 369E on 08/16/2012

According to the NTSB factual report, this engine sustained a post-SB CEB-1365 4th stage turbine wheel fracture near the inner platform in a process involving a combination of low cycle fatigue (LCF) which progressed to a high cycle fatigue (HCF) mode, causing a sudden loss of power and an un-containment. The wheel was identified as part of a post-service bulletin (SB) commercial engine bulletin (CEB)-1365 or ‘enhanced’ turbine assembly design. According to Rolls Royce, the pattern and appearance of the fracture on this wheel was similar to the seven other failures of post-SB CEB-1365 power turbine assembly design.

E.1.2 Other Failures Reported by Rolls-Royce⁴

6/2005 – Bell OH-58C – U.S. Army - 4th stage turbine wheel failure
 9/2008 – MDHI 369 – Windward - 4th stage turbine wheel failure
 5/2009 – MDHI 369 – Houston Police Department - 4th stage turbine wheel failure

E.1.3 A Review Rolls-Royce Service Bulletins Relating to the Enhanced Power Turbines

E.1.3.1 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 via Rolls-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.

⁴ These events were not investigated by the NTSB.

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 is 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.

E.1.3.3 Rolls-Royce Alert SB CEB -A-1407

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 a 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 crack 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 and separation. The compliance code of this SB was 6: 'To be complied with at or within next 1750 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 1750 hours.' This Alert CEB is referenced in FAA Airworthiness Directive (AD) 2012-14-06.

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 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 1750 hours.'

Revision 3 of Rolls-Royce CEB-A-1407, issued on May 19, 2014, after a total of 4 - 4th stage failures, increased the compliance code from 6 to 2 'To be complied with at each 1750 hour gas producer turbine wheel replacement, a continuing repetitive rather

than a one-time inspection. Revision 3 had a compliance code 4 'To be complied with anytime the turbine module is at an authorized repair/overhaul facility and is disassembled for any reason. 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 Airworthiness Directive (AD) 2015-02-22.

E.1.4 A Review of Rolls Royce Maintenance Manual Changes Relating to the Enhanced Power Turbines

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.

E.1.5 MDHI Bulletins

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° C and 1 second above 927° 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.

E.1.6 Honeywell/Chadwick Balancing Equipment & Process

After the original Rolls Royce issued SB CEB A-1400, which introduced the N2 speed-avoid limitations between 75-88%, two more 4th stage turbine wheel failures occurred in 2007 and 2008. It was subsequently discovered that the maintenance procedures for the Honeywell rotor balancing equipment required a rotor speed range within 75-88 percent. On March 2009, the Honeywell/Chadwick procedures were changed to reflect this by requiring a 70% Nr (rotor or N2) speed for all balancing procedures.

E.1.7 Airworthiness Directive 2012-14-06

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 uncontainment, 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. It was issued to mandate the incorporation of CEB-A-1407 Rev. 3. 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.

E.1.8 Differences in installation settings between MDHI and Bell

It was noted that all post SB CEB-1365 turbine failures, to date, occurred only in MDHI helicopters (and one US Army OH58C which was not investigated by the NTSB). Additionally, no clear root cause of the failures due specifically to the engine design or manufacturing problems was able to be determined.

A review and comparison of the different airframe installations was done in an effort to determine if the LCF crack initiation could be due to any airframe related causes or combination of causes. The mechanical and operational variables that are common to the MDHI and Bell installations:

- Piloting technique.
- Frequency of auto-rotations with power recovery.
- Fuel control system acceleration schedule/start de-richment - start temperature.
- Turbine wheel material property or casting variances.
- Maintenance practices (engines and controls).

- Environment.

The mechanical and operational variables that are different between the MDHI and Bell installations are (See [Table 1](#)):

- The MDHI rotor system inertia is lower than the Bell.
- Because of the low rotor system inertia on the MDHI, the control system response is therefore faster than on the Bell. Its throttle damping characteristics are therefore also less, so that the engine can react faster to a low rotor RPM condition.
- MDHI has a higher max speed power-off transmission limit.
- MDHI has a higher max speed power-on transmission limit.
- MDHI has a higher beep check speed.
- MDHI has a higher maximum continuous (Mcont) power (350 SHP Mcont power limitation at 34,289 RPM (103%) versus the Bell installation with 270 SHP Mcont power limitation at 33,290 RPM (100%).
- MDHI FCU maximum fuel flow stop is higher than that on the Bell.
- Gauge markings in the cockpit are different (See [Figure 1](#) & [Figure 2](#))
- Low rotor RPM warning is higher on the MDHI.

	MDHI	Bell	Robinson (Ref. only)	OH-58C (Ref. only)
Maximum Nr – Power off	109%	107%	106%	110%
Maximum Nr – Power on	103%	100%	101%	100%
N2 Operating Limits – Power on	102-103%	97-100%	99-101%	98-100%
N2 Speed Avoidance Range	75-88%	75-88%	78-88%	78-88%
Tail Rotor Track and Balance N2 Speed	70 & 100%	100%	99-101%	100%
N1 Ground Idle Speed	64-65%	60-64%	65-67%	62-64%
PTG Beep Check	97-105%	97-100%	97-103%	95-103%
Low Rotor Warning RPM	98%	90%	-	-

[Table 1](#) – Comparison of Airframe Speed and Power Limitations

A review and comparison of the differences of the cockpit gauges was done in an effort to determine if the instrumentation could affect the way in which the engine power is managed by the pilot. A comparison of the HDHI and the Bell 206 gauge marking is seen on [Figure 1](#) and [Figure 2](#). The Bell 206 gauge continuous operating range shows a 97 – 100% power turbine RPM versus 102 and 103% on the MDHI gauge, a higher and slightly narrower band.

The maximum power turbine gauge mark was 107% for Bell 206 vs 113% for the MDHI. These values can be reached during an autorotation maneuver. RR stated that during autorotation, in order to store as much energy in the low inertia rotor system, MDHI pilots maintained a high rotor speed, close to the 113%. In contrast, the Bell high inertia rotor system store sufficient energy at 107%.

Though not evident on the instrumentation gauges, it was noted that the audible low rotor warning RPM on the Bell 206 occurred at 90% compared to 98% on the MDHI installation.

In summary, the power turbine speed variation that an engine is subject to on MDHI application was between 98% to 113% RPM while the Bell application was between 90% to 107%.

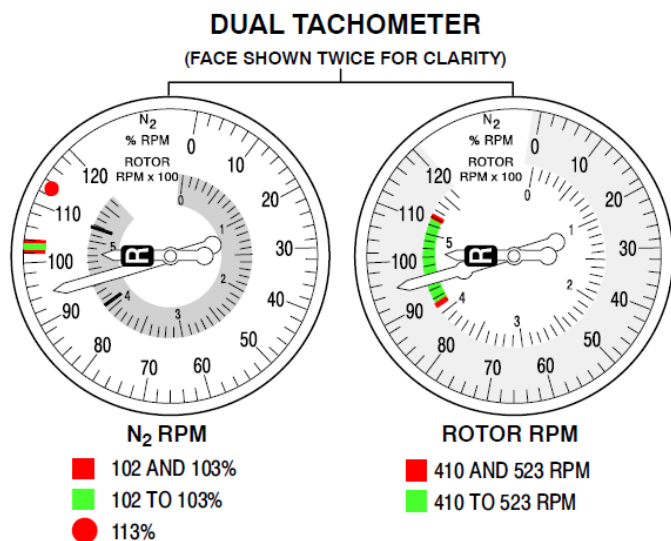


Figure 1 – MDHI Engine- Rotor RPM Gauge

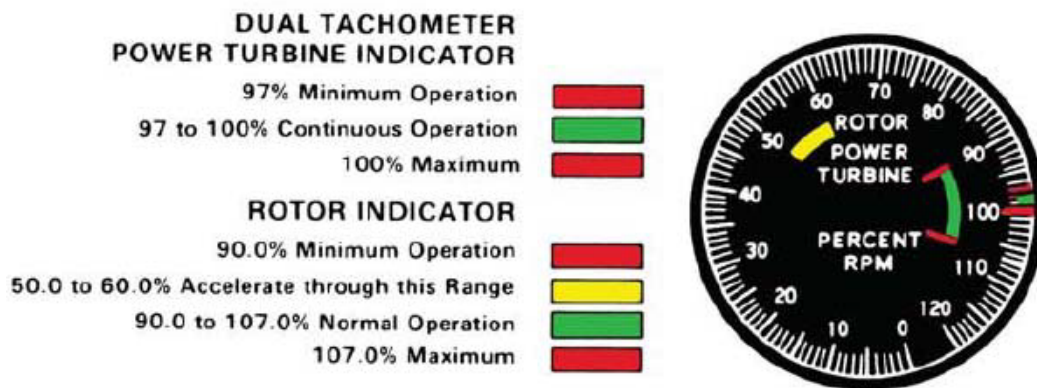


Figure 2 – Bell 206 Engine-Rotor RPM Gauge

According to Rolls-Royce engineering, after extensive analysis, the initiation of the LCF crack is 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 and the second, during transient operation, such as auto-rotation,

which impart a combination of high negative thermal gradient and high speed stress into the blade. During auto-rotation, the rotor RPM on MDHI helicopter can reach 113 percent, This cause is consistent with the observation that the MDHI helicopters are more susceptible to this failure mode than the Bell installation.

E.1.9 Operators Field Studies

In 2014, field data was collected by RR to try to determine the fidelity of the factory installation settings and to isolate the differences between the Bell and MDHI installations since all turbine blade failures occurred only in the MDHI installation.

From the data collected, it was noted that the largest variations was in the N2 ground idle (GI) speeds: A review and comparison of the pilot operating handbook (POH) of the two installations revealed that the MDHI idle was to be set at 64-65% vs the Bell instructions which require GI to be set at 60-64% (see red ovals in Table 1). MDHI and RR personnel performed a field review of many of their operators, which revealed a high variance of the GI setting. The maxima/minima GI values observed in the Bell operators was between 55-69% while the MDHI operators had a higher variance of 55-74%, a potential speed conflict with RR 74.7% stated critical speed avoid ranges.

E.1.10 Continuing RR work on turbine wheel failure containment

E.1.10.1 Near Term Mitigation Plans

- To address LCF Crack Initiation:

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 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 2015.

RR has performed plastic model analysis studies based on videos of typical PJ Helicopter, Inc. mission operations to compare these mission 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.

E.1.10.2 Long Term Mitigation Plans

- Release 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 technical problems with the casting in 2013, the design was terminated. A new design was started and is expected to be released in 2016.

- On Wing 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 induce 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.

Harald Reichel
Aerospace Engineer – Powerplants

Figure 3 – Rolls-Royce 250-C20 - Turbine Section

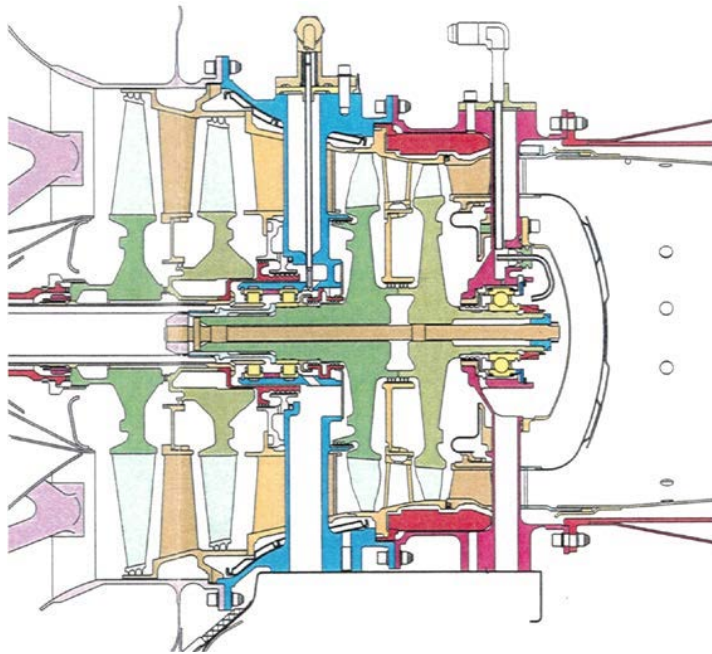


Figure 4 – Engine S/N CAE-836896 – As Received



Compressor
Discharge
Tube - Pierced

Figure 5 – Gearbox – External View



Figure 6 – 1st Stage Compressor

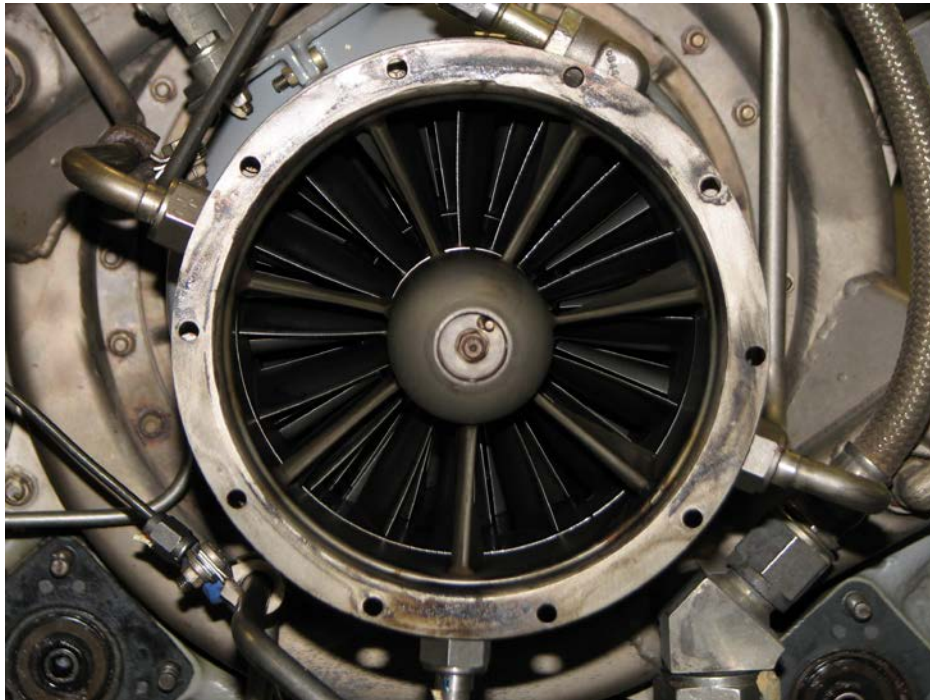


Figure 7 – 1st Stage Turbine Nozzle

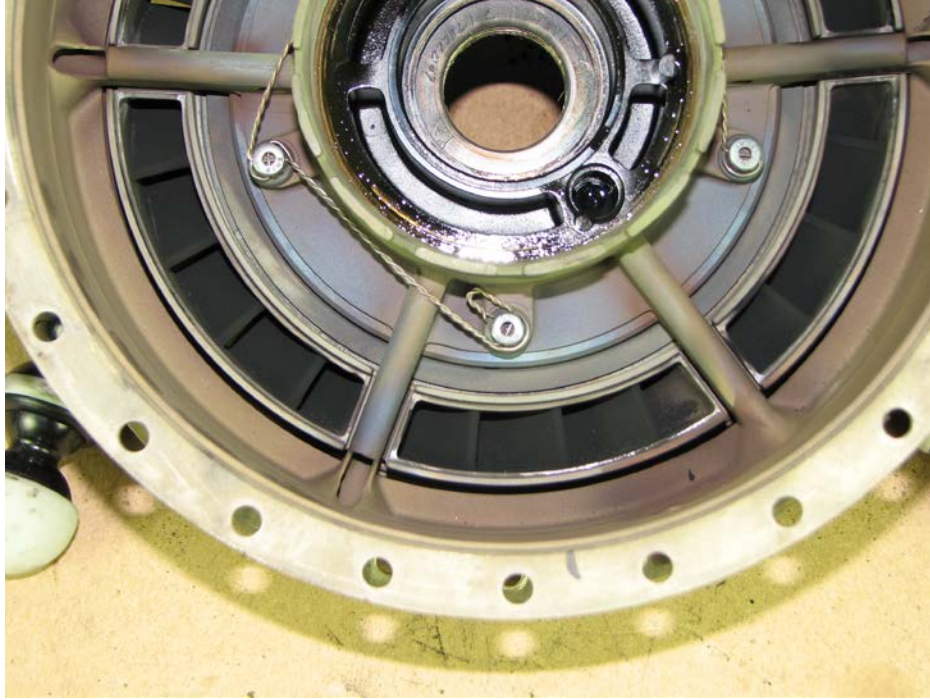


Figure 8 – 1st Stage Turbine Wheel



Figure 9 – 2nd Stage Turbine Wheel



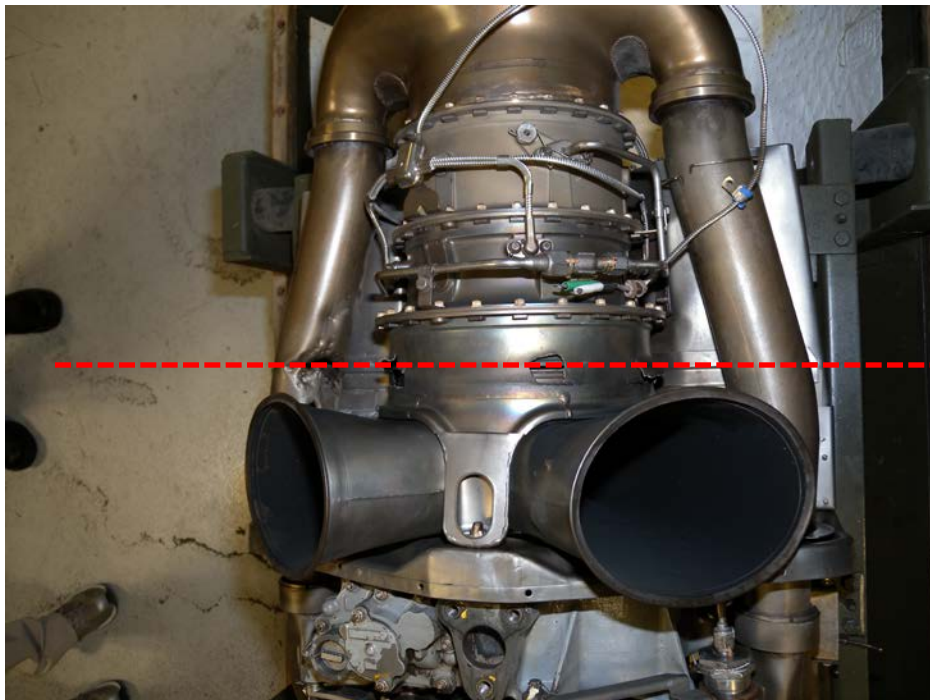
Figure 10 – 2nd Stage Turbine Wheel Curvic Coupling



Figure 11 – Uncontained Particle Damage



Figure 12 – Engine Top View



Plane of 4th Stage
Turbine Rotor

Figure 13 – Detail of Compressor Discharge Tube Damage - Inside



Figure 14 – Detail of Compressor Discharge Tube Damage - Outside



Crack at
Fishmouth
Seal

Figure 15 – Combustor Liner

Heat Distorted
Area

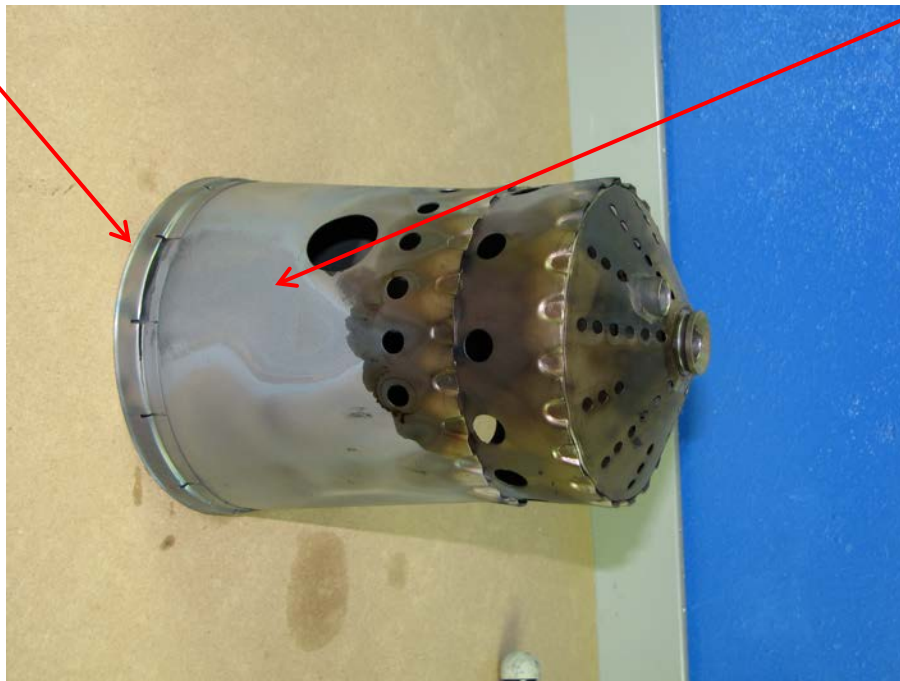


Figure 16 – Combustor Liner – Detail of Crack at Fishmouth Seal



Figure 17 – 1st Stage Nozzle Deflector Shield

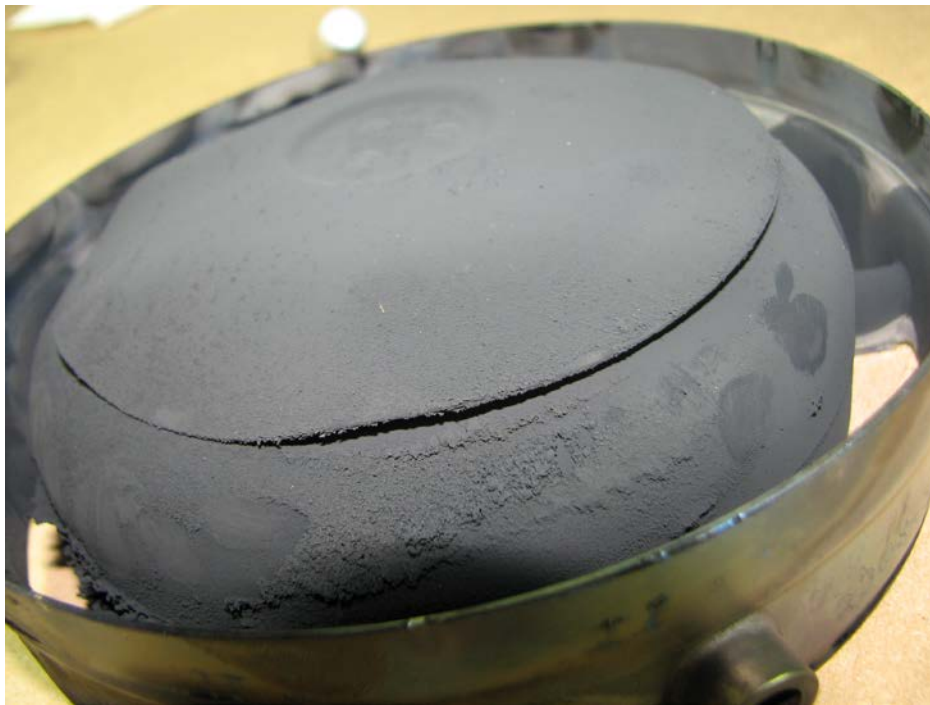
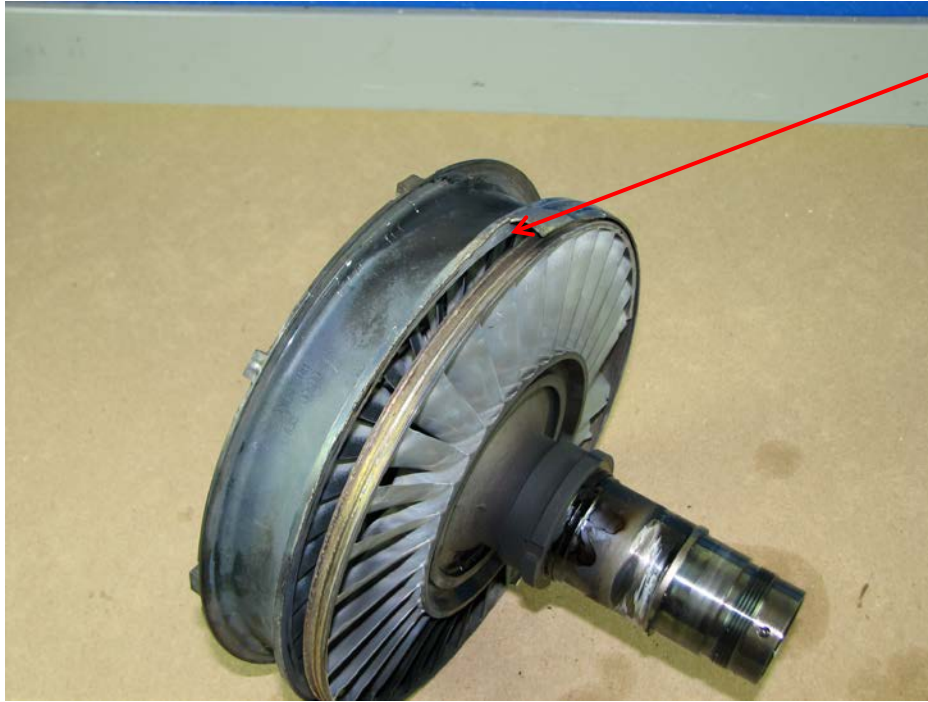


Figure 18 – 3rd Stage Turbine Wheel



Figure 19 – 4th Stage Turbine Nozzle & Turbine Wheel



190 degree segment
of the 4th stage
turbine shroud was
fractured

Figure 20 – 4th Stage Turbine Wheel



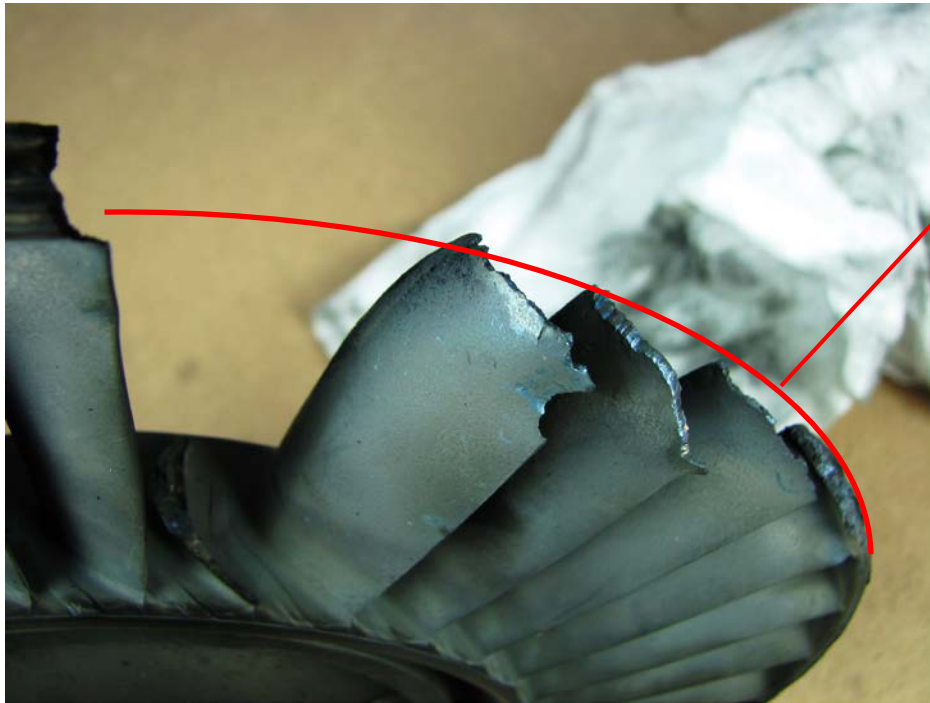
Figure 21 – 4th Stage Turbine Wheel



Figure 22 – 4th Stage Turbine Wheel - Fractured Near the Inner Platform



Figure 23 – 4th Stage Turbine Wheel - Three Lagging Adjacent Blades Were Fractured and Twisted Near the Tips

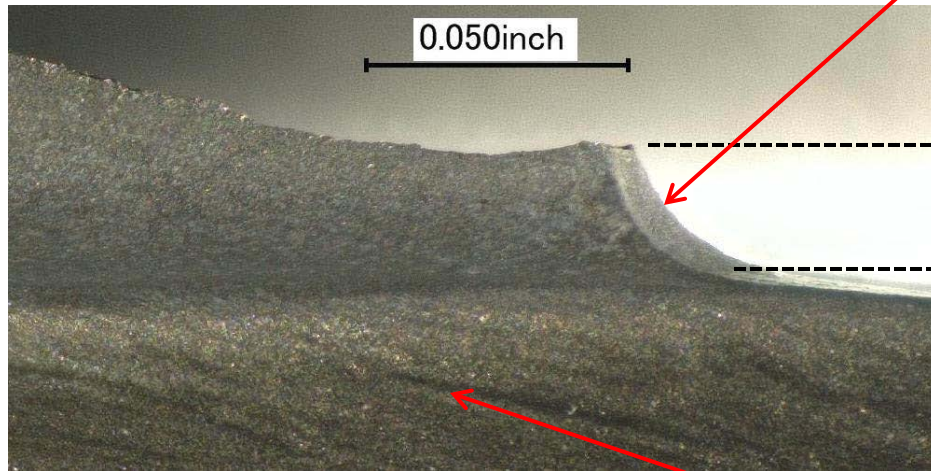


the entire rim
segment of 4 blades
was missing

Figure 24 – 4th Stage Turbine Wheel – Curvic Teeth



Figure 25 – Details of Fractured Airfoil

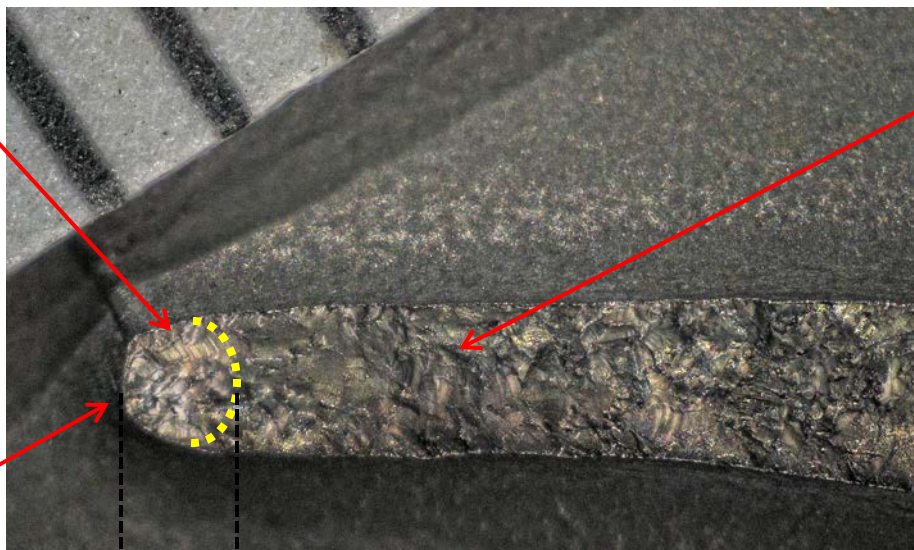


Trailing Edge
Radius

~0.025 inch

Inner Platform
Surface

Figure 26 – Fracture Surface on Failed 4th Stage Turbine Wheel Blade



Low Cycle
Fatigue
(LCF)
Section

High Cycle
Fatigue (HCF)
Section

Trailing
Edge of
Blade

~0.035 inch

Figure 27 – Detail of Trailing Edge of Blade from

