IAGT SYMPOSIUM 17

IAGT Industrial Application of Gas Turbines

www.iagtcommittee.com

October 23rd - 25th, 2017, Banff, Alberta

SOLUTION FOR GAS TURBINE ROTOR END OF LIFE

By

R.Annigeri*†, B.Freeman**

EthosEnergy, Power Plant Services*

12000 Deerfield Parkway, Suite 315, Alpharetta GA 30004

(†ravindra.annigeri@ethosenergygroup.com)

**EthosEnergy, Power Plant Services Americas

Presented at the 2017 Symposium on Industrial Application of Gas Turbines (IAGT)

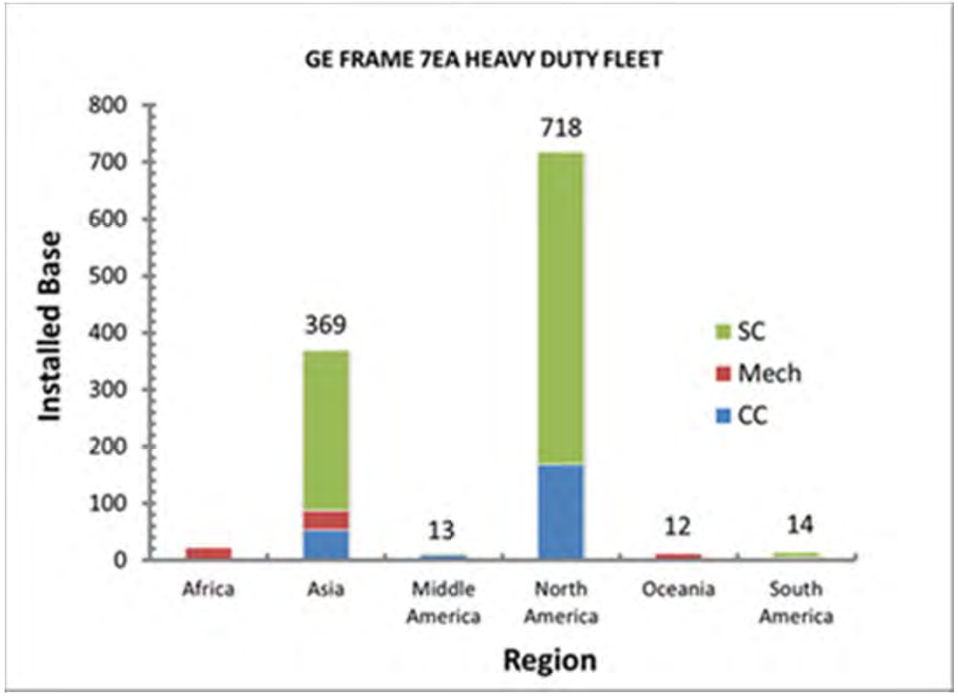
Banff, Alberta, Canada - October 2017

Presentation Agenda

- Frame 7 Introduction
- Rotor End of Life
- Reverse Engineering Process
- Rotor Component Design and Analysis
- Production of Rotor Components
- Rotor Overhaul Example
- oOEM Experience List
- Summary
- Q&A

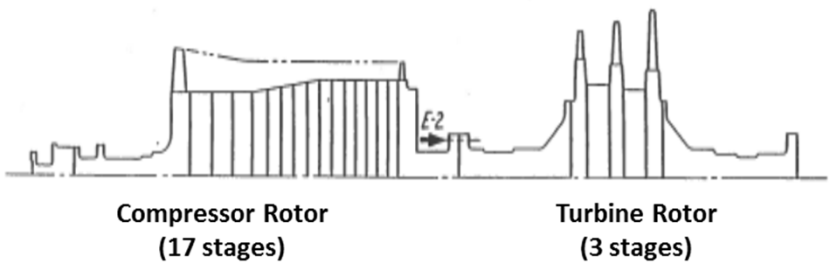
Frame 7EA Introduction

- GE® Frame heavy duty 7EA gas turbines, installed 1970 through to-date.
- Approximately 1100 units in operation.
- Note that recent model designation changed by OEM (7E.03)



Rotor Construction

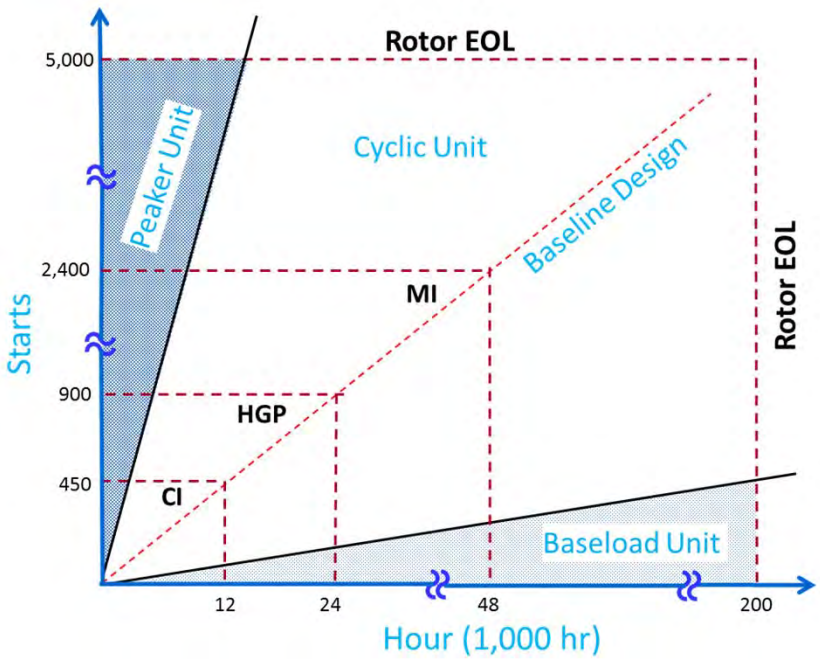
- 7EA gas turbines have 17-stage compressor.
- Compressor rotor is assembled from individual stage bladed-wheel assemblies held by through-bolts.
- Compressor blades are installed on broached slots and held in axial position by staking.



7EA Unit Rotor

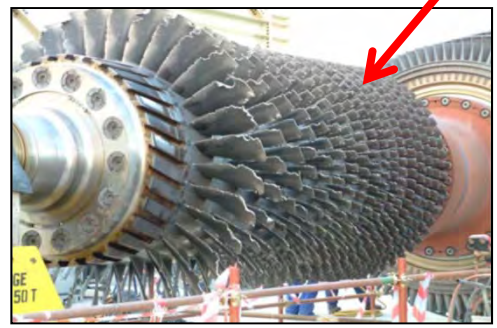
Rotor End of Life

- For 7EA, rotor inspection at 200,000 Factored Fired Hour (FFH) or 5,000 Factored Fired Start (FFS).
- FFH and FFS calculated per OEM GER-3620.
- Rotor end of life defined by GETIL 1576/GER3620
- Failure to perform these inspections leaves the gas turbine at greater risk for failure.



Rotor Failure Mechanism

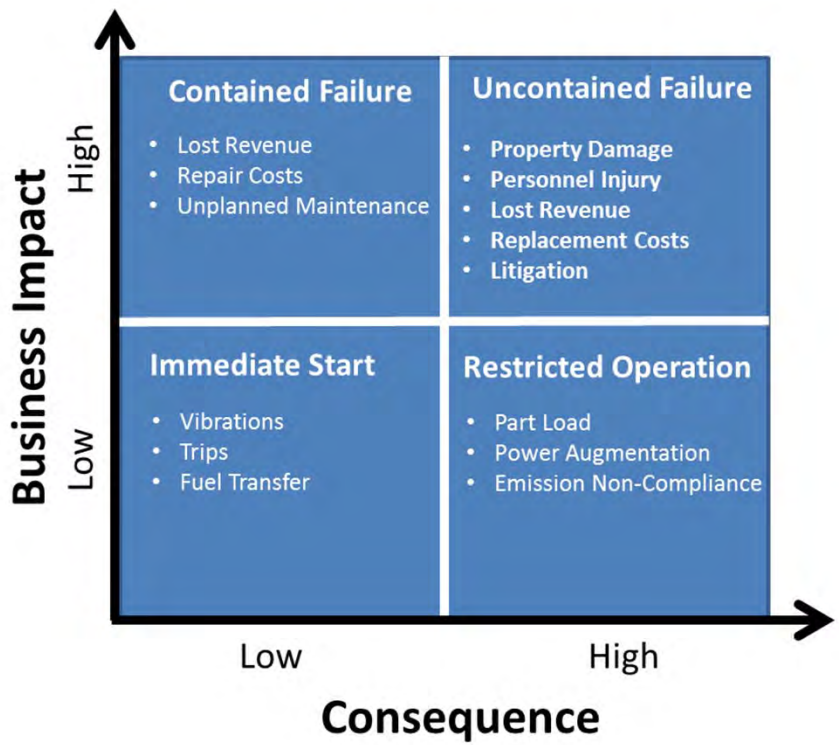
- Rotor carries highest energy. High stress & high temperature
- Environment (like salt corrosion, erosion) may contribute to premature failure of parts.
- Time, start-shutdown cycle, temperature, stresses impact low cycle fatigue (LCF) & creep.
- Rotor parts have finite design life. Planned inspection & life management critical



Contained failure

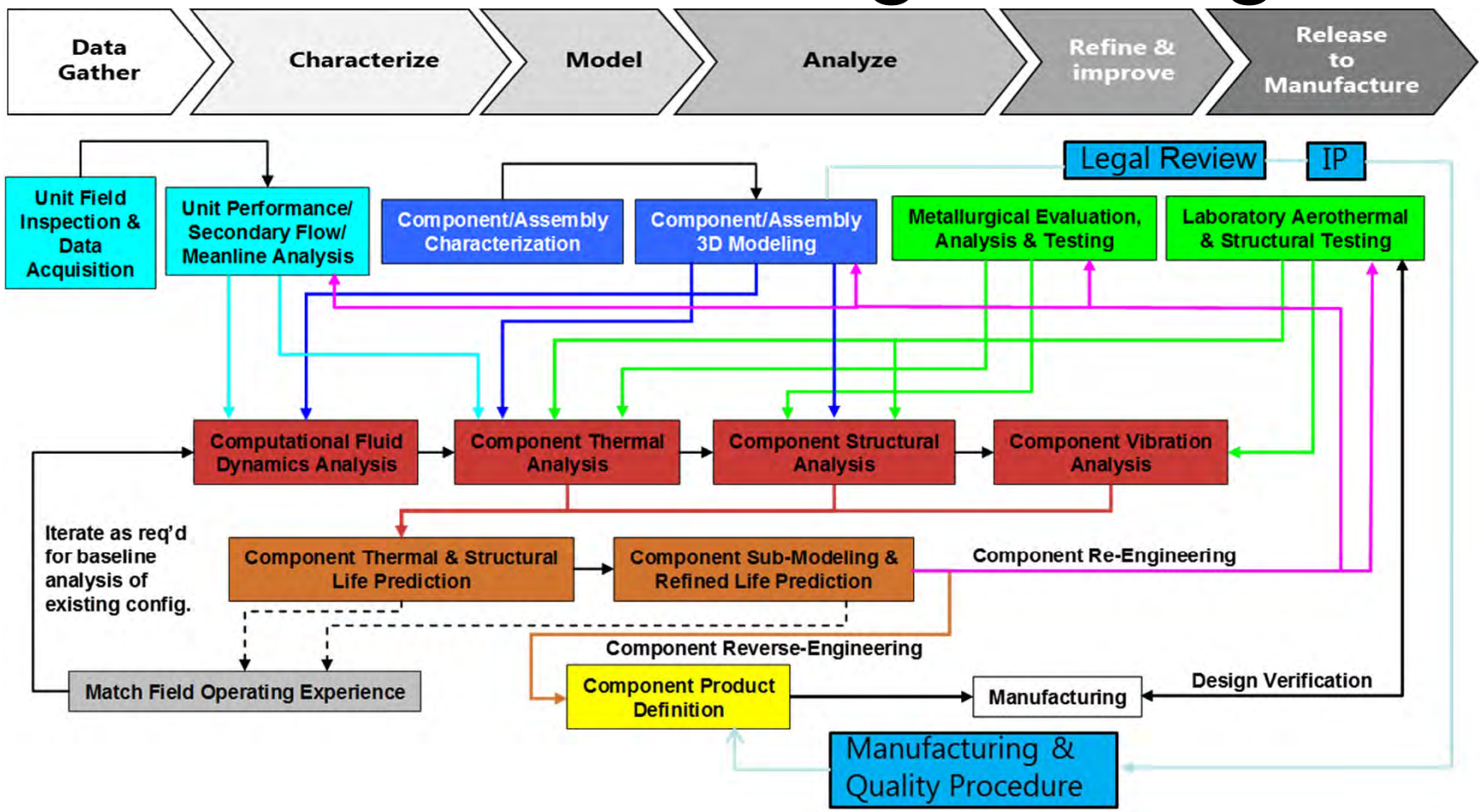
Rotor Failure Consequence

- Operational restrictions (e.g. power augmentation)
- Forced outage (e.g. trips, vibration)…Unit restarted immediately after remedy
- Contained failure (e.g. R0 blade or bucket liberation)..Unit restored after major repair
- Uncontained failure (e.g. wheel burst)..Serious damage to personnel/property



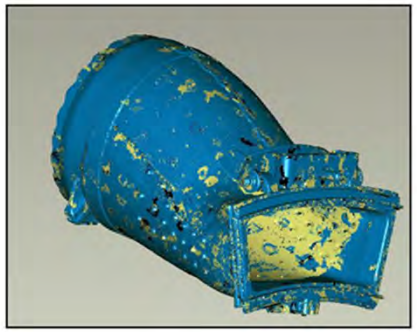
+ Frame 7EA – Nameplate 87 MW
+ **Rotor Energy ~75 tons of TNT**

Reverse/Re Engineering



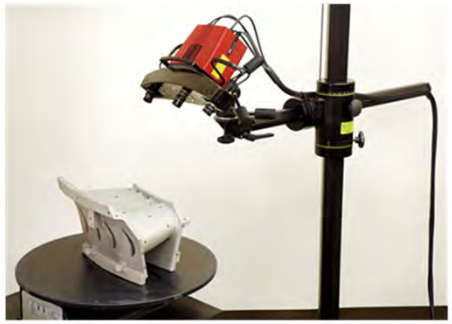
Reverse Engineering - Tools

- ATOS II triple scan blue light 3-D analyzer showing scanning of nozzle
- FARO Laser Scan of bucket

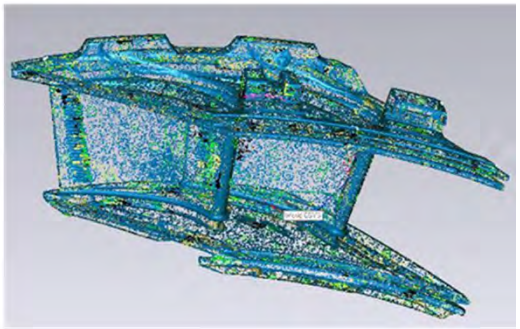


FARO Laser

FARO arm



ATOS II



Reverse Engineering - Outage

- Typical Reverse Engineering data includes sub assemblies measurement, operational data, outage data, unit configuration, part numbers.
- Data collected before and after rotor is removed from unit. Casings and other sub-assemblies scanned

Prior to rotor removal

After rotor removal

Casings Data

Reverse Engineering - Overhaul

- Typically at onsite, EthosEnergy location.
- Individual parts and sub-assembly characterization
- Rotor is typically disassembled for scanning of parts.

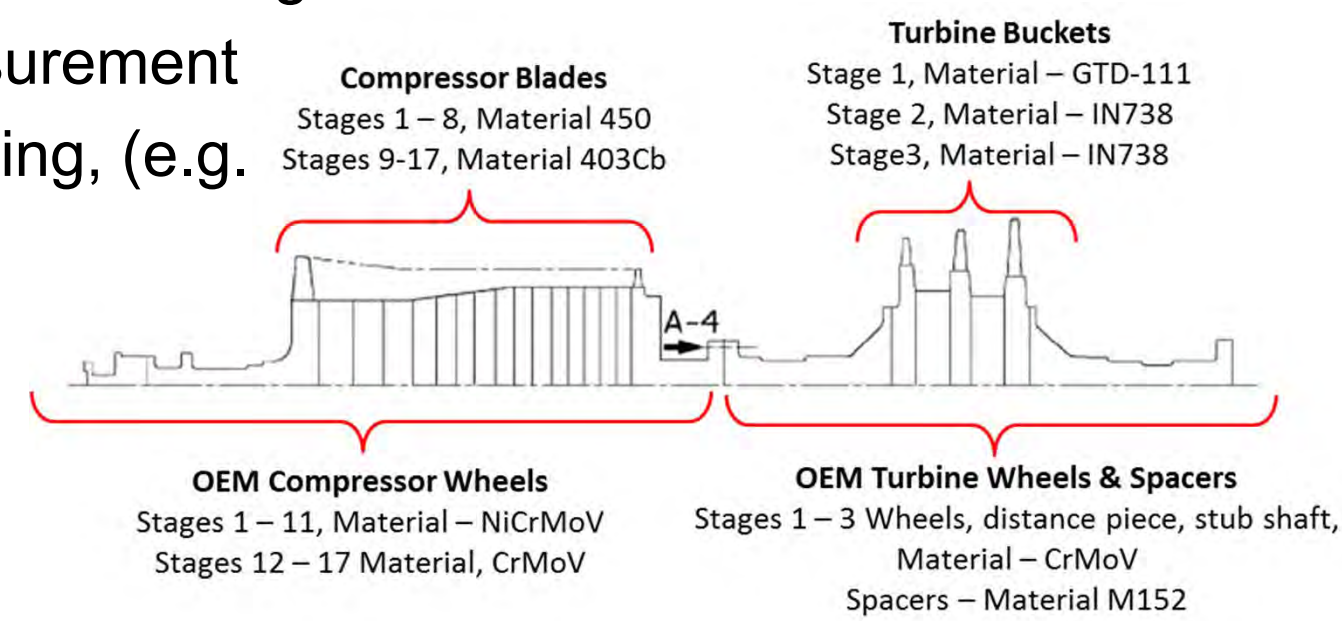
Bladed Wheel

Prior to blade removal

Rotor Assembly

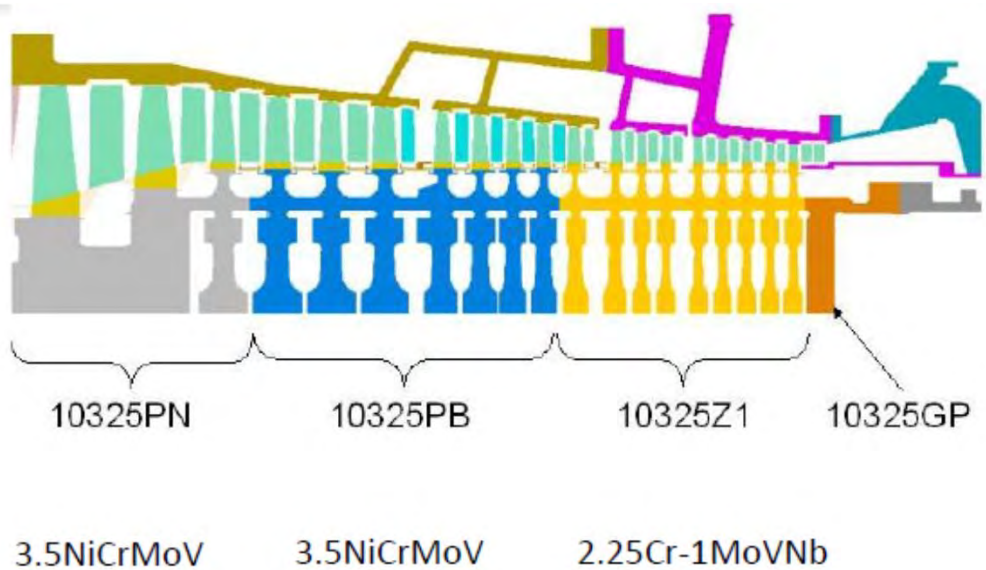
Rotor Materials - oOEM

- Chemistry determination using X-ray diffraction technique
- Macro/ micro grain etching
- Hardness measurement
- Mechanical testing, (e.g. LCF, tensile).



Rotor Materials – OEM

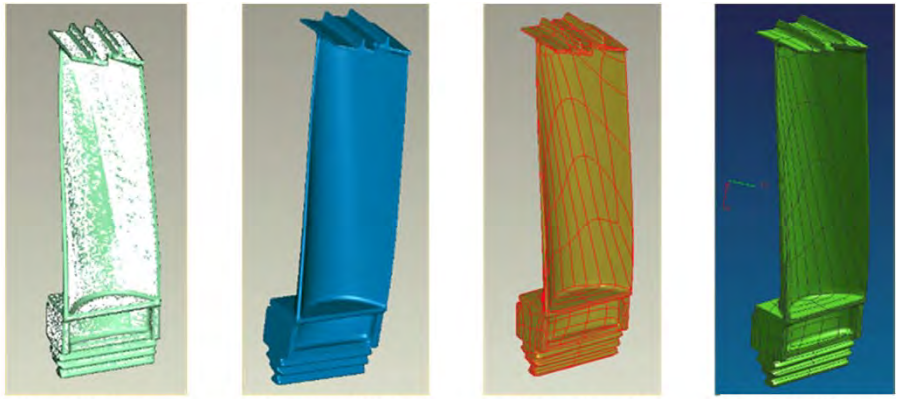
- OEM Material data base used for rotors (such as NiCrMoV materials) and other parts.
- Design Basis & Standards
- OEM design practices and modeling tools
- EthosEnergy Standards & Processes
- OEM inspection and NDE standards



Typical W501D rotor

Engineering Analysis

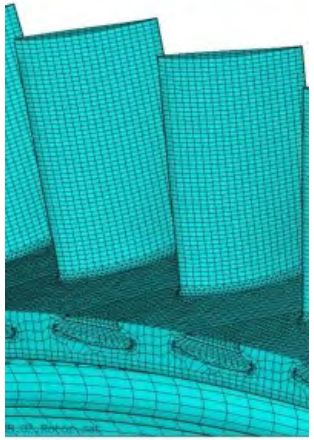
- Access to tools & design methods
- Intellectual property
- Finite element modeling
- Transient analysis (cold start, start, warm start) Simulation
- Thermal analysis
- Structural analysis
- Lifing analysis
- Correlate observed failure modes
- Design improvements



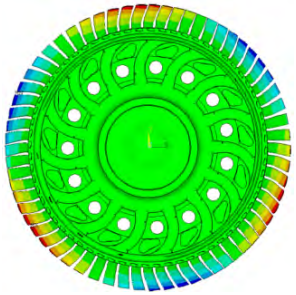
Raw Point Cloud Data → Wrapped Point Cloud Data → Point Cloud Model → Point Cloud Solid

Summary Results

- Stresses & temperature profile
- Critical locations
- LCF life calculations
- Blade frequency analysis
- Tolerance & stacking
- Assembly methods
- Parts & assembly drawings
- First article & process qualifications
- Process capability studies



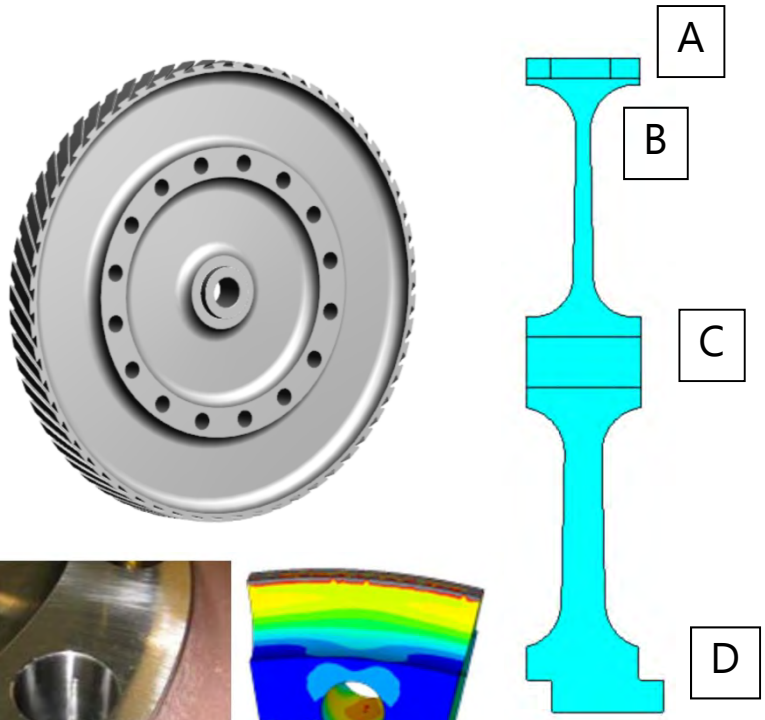
FEM Model Mesh

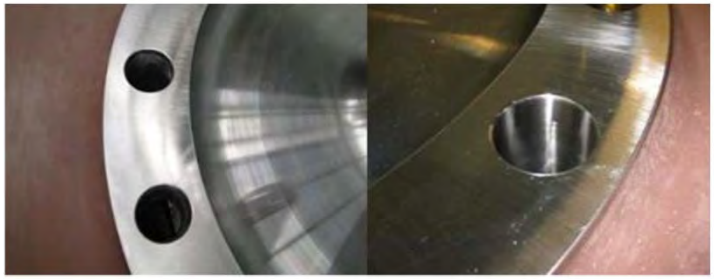


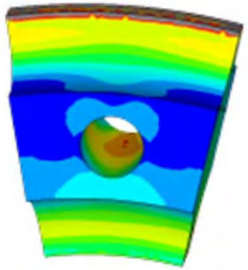
Contour Plot

Stress Prediction

- A - Blade Attachment (stress and temperature)
- B - Wheel Neck (stress and temperature)
- C - Bore/bolt holes (contact stresses)
- D - Female bore (operating stresses)



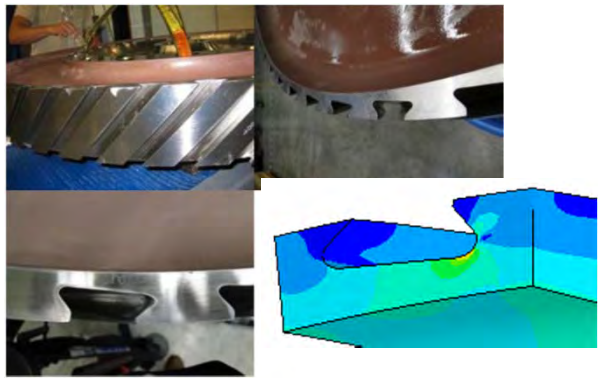




Critical Locations

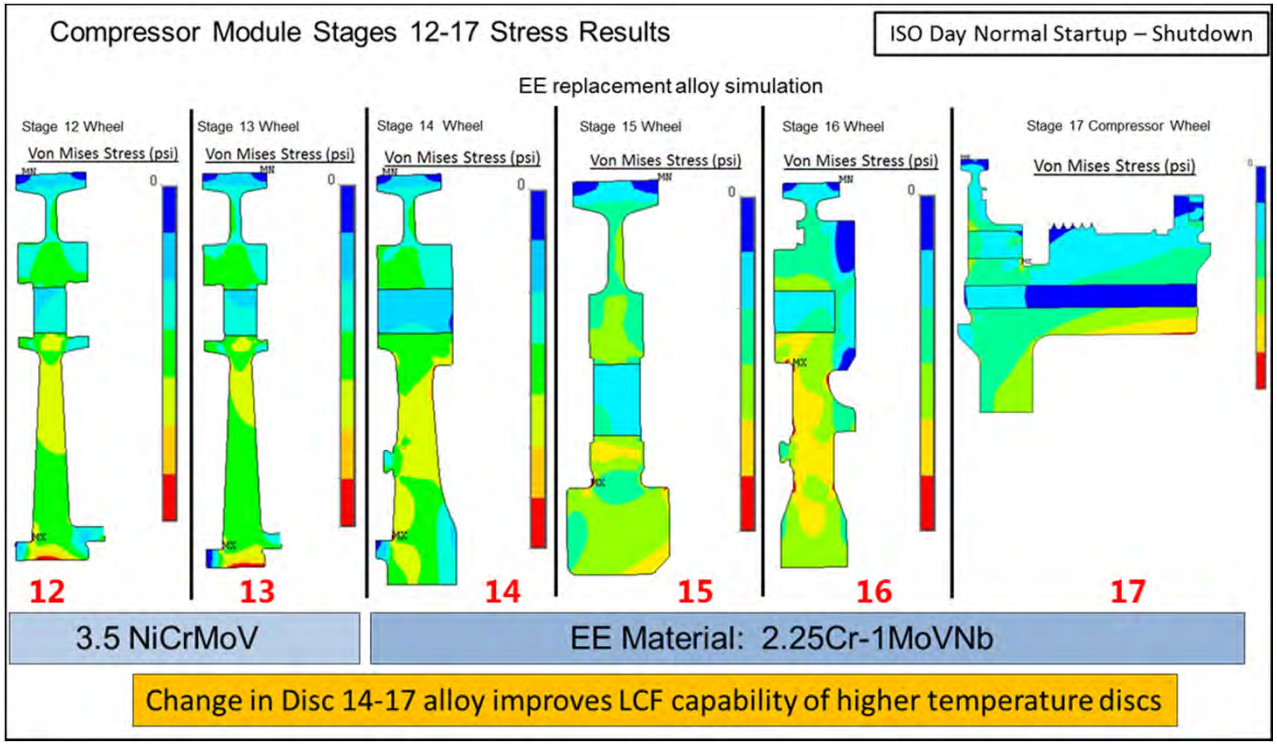
- Internal and outer edge surfaces of all bolt holes inspected for flaws.
- High contact stresses due to bolt loading.
- Small edge radius on holes.
- Contact marks from bolt contact.
- Surfaces are uncoated.

A



Design Improvements

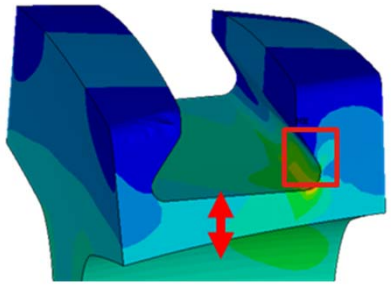
- LCF analysis of wheels
- Stress prediction in compressor wheels
- Proven OEM rotor disc materials.

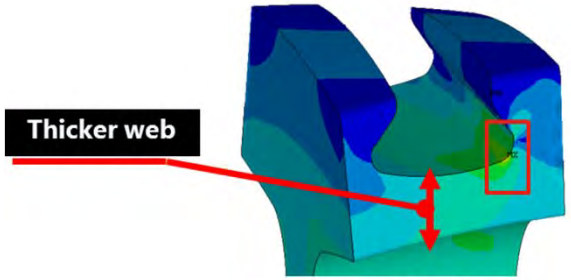


Optimized Root Profile

- Round bottom compressor blade root profile geometry for stages 12-17 compressor wheels.
- EthosEnergy optimized round bottom blade root profile.
- Thicker web design for EthosEnergy wheels.

OEM Flat





EthosEnergy Round Bottom

Wheel - Forging

- Forging pancake and machining drawings
- First article qualification
- Tooling development
- Final, finished machining.
- Final wheel Assembly & balance

Typical Production Sequence

EthosEnergy Production Control Document

TYPE	CRITICAL APPLICABLE DOCUMENTS						NOTES
	CD-12	CD-13	CD-14	CD-15	CD-16	CD-17	
FAI	MSS-1455-71320-1201	MSS-1455-71420-1201	MSS-1455-71520-1201	MSS-1455-71620-1201	MSS-1455-71720-1201	MSS-1455-71820-1201	Part Specific Qualification Documents
Material	CP-1101-33202		CP-1101-33201				Superclean Steel Type By Stage
HT	FS-CP-1101-33202		FS-CP-1101-33201				Furnace Sheets / HT Instructions
FORG	SP-FORG-5010						Controlling Forging Documentation
UT	SP-IC-1000, SP-IC-1001, SP-IC-1009, SP-IC-2100, SP-IC-5000, SP-IC-5300, SP-IC-5311, SNT-TC-1A, ISO 9712						Controlling Ultrasonic Testing Doc's.
MT	SP-IC-1000, SP-IC-1001, SP-IC-1011, SP-IC-2100, SP-IC-5000, SP-IC-5500, SNT-TC-1A, ISO 9712						Controlling Mag. Particle Testing Doc's.
MACH	SP-MACH-2120, SP-MACH-2150						Controlling Machining Doc's.
TQA	ASTM A751, ASTM A788, ASTM A370, ASTM E112						Supporting Testing Doc's.
MARK	SP-MARK-1000, SP-MARK-1101, SP-MARK-1201						Controlling Marking Doc's.

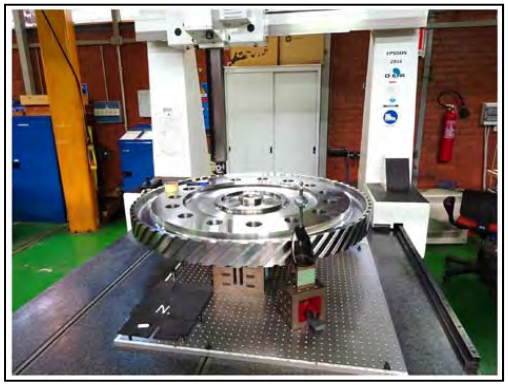
Wheel - Production

- Finish machining operation on individual wheels at EthosEnergy facility
- Manufacturing processes quality control & Service Excellence
- Final acceptance & sign-off of wheels
- Individual stage wheels shipped to Houston TX facility

Stage 17 wheel - Drilling

Stage 15 wheel - acceptance

Stage 13 wheel - broaching



Stage 14 wheel – final inspection

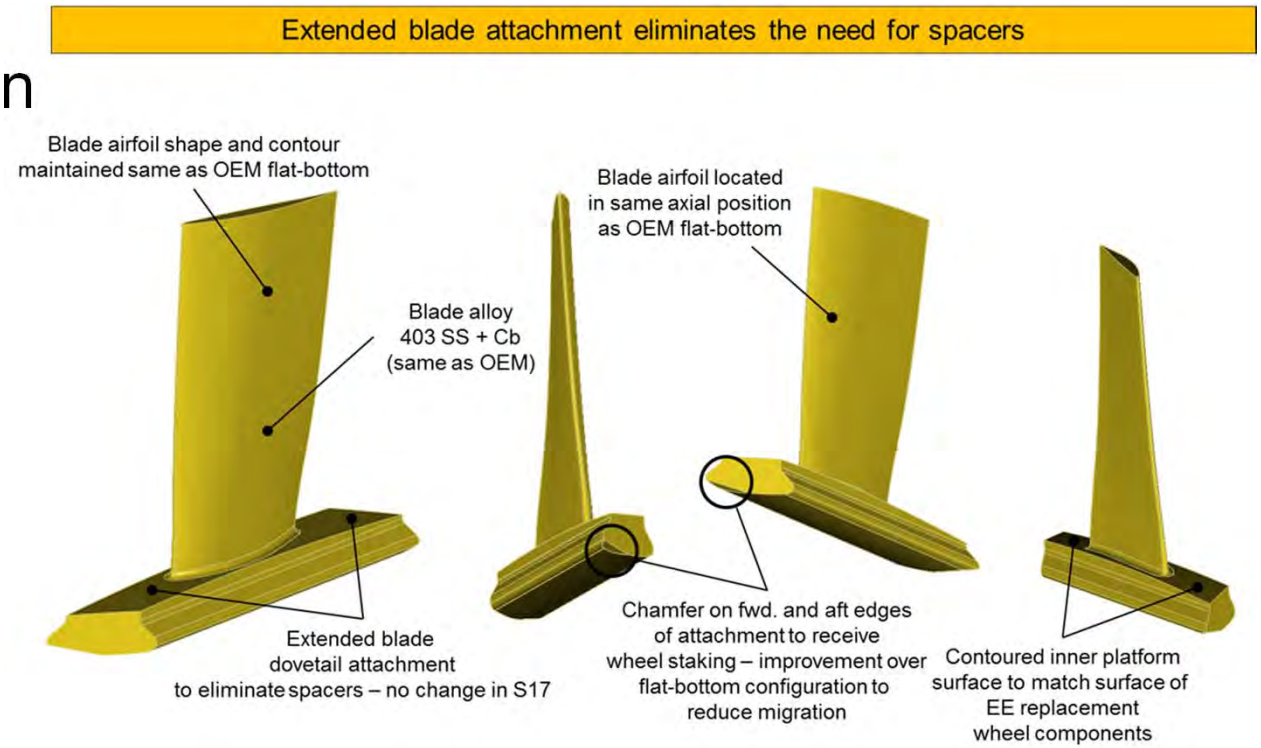
Blade - Production

- Use the same material as OEM (ss403Cb, GTD450, etc.) for blades
- Can produce round slot bottom blades.
- Can produce in-kind blades to replace damaged blades
- Blades manufactured – Chicopee, MA facility
- EthosEnergy has blade inventory

Round Bottom Blade Production – Chicopee, MA

Blades – New Design

- Patent pending round bottom design blade dovetail. Blade airfoil shape interchangeable with OEM-design
- Extended blade dovetail attachments eliminates need for spacers. [No spacer migration issue]

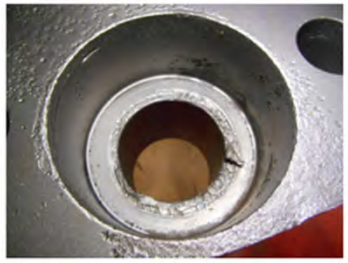


Rotor – Overhaul

Customer's rotor arrives at rotor facility, Houston, Texas

Customer rotor transferred to rotor bay

Inspection – Bolt holes

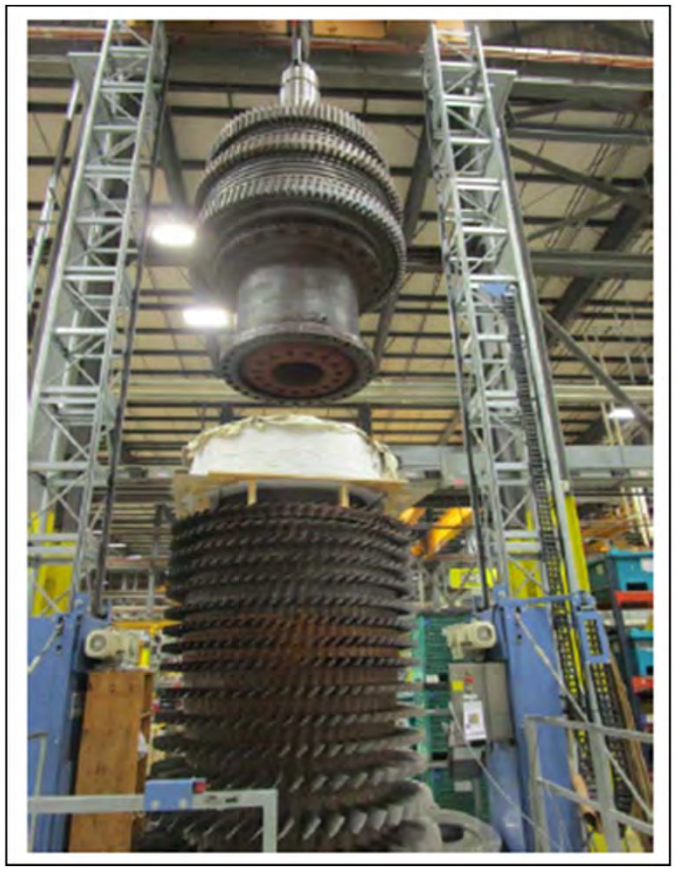


Inspection – Journal

Inspection – Bolt

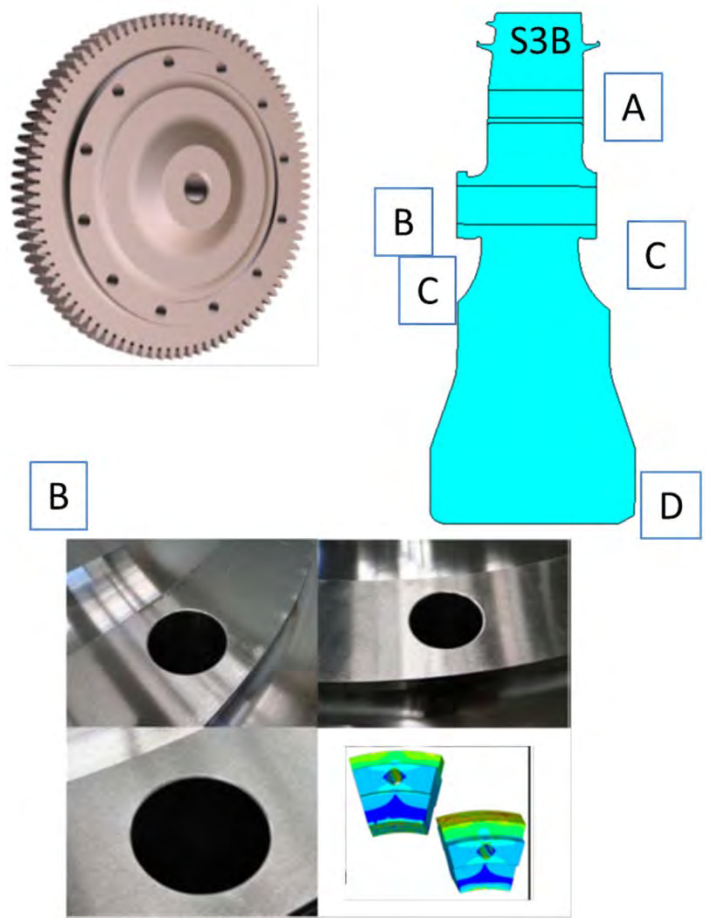
Inspection – S17 blade slot

Rotor – Disassembly



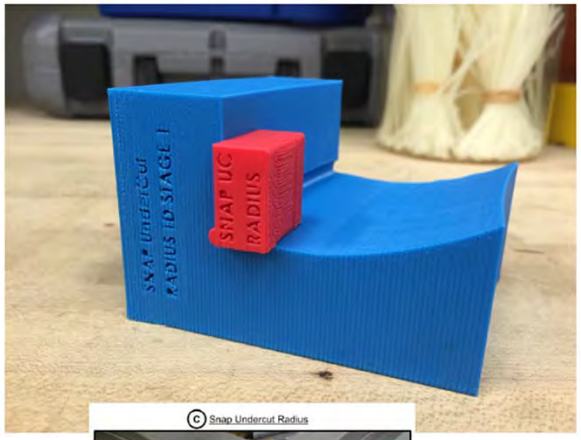
Advanced – NDE

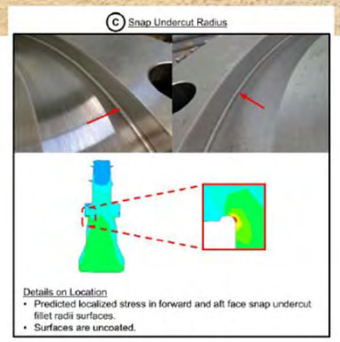
- Mag particle and UT Inspection
- Advanced NDE (UT, Phase Array, etc.)
- Based on OEM and oOEM experience
- Engineering analysis of inspection findings
- Customized probes designed for location and flaw types



NDE – Probe Development

- Phase Array UT probes specific to geometry
- Sized for critical locations
- Blade attachment slots
- Undercut radius
- Wheel Neck
- OEM NDE Collaboration





Inspection – Undercut Radius

Rotor – Stacking

Stage 17 wheel



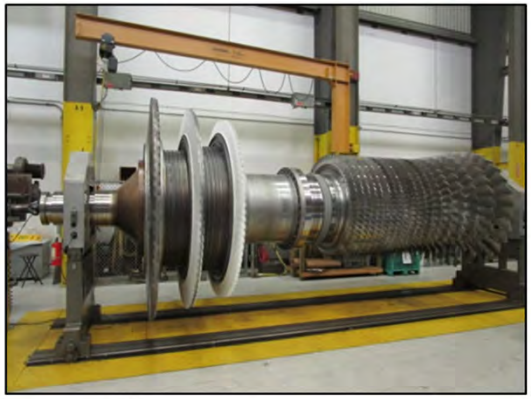
Compressor bolting



Rotor – Final Balance

Mary rotors

Install buckets



Final Balance

Rotor – Pack/Ship

Completed rotor leaves EthosEnergy Facility

Rotor Solution(s)

- Solution A – NDE inspections during typical outage duration. Unit-specific rotor life assessment can be performed either at site or at EthosEnergy facility. No parts replaced.
- Solution B – Replace individual wheels. Rotor re-built during extended MI. Parts to be ordered in advance.
- Solution C – Replace life limiting rotor parts & Rotor Life Management. Rotor re-built during extended MI outage. Parts will be ordered in advance. Reverse engineering data on unit rotor for customized solution.
- Solution D – Exchange rotor option (low operation, overhauled rotor, ready to drop in the unit)

Summary

- **Fully integrated supplier** - EthosEnergy operates a fully equipped rotor service facility in Houston to service gas turbine rotors.
- **Enhanced operating capability** - Upgraded compressor disc material based on Siemens alloys.
- **Detailed Engineering Analysis** - A detailed characterization and design analysis of the entire rotor performed on the entire rotor system.
- Providing compressor rotor solutions to other customers and is in discussions with EPRI on an evaluation of it's technology.

Experience

- EthosEnergy implements its Frame 7 rotor solution for a major US utility customer – unit successfully operating since 2015 and has accumulated over 150 starts.
- Frame 7 rotor solution sold to a major utility customer. EthosEnergy rotor solution to be implemented in 2017-18.
- EthosEnergy rotor solution independent verification – EPRI.

Rotor – Experience List

Frame 3	Frame 5	Frame 6	Frame 7	Frame 9
Gulf South Pipeline®	Savannah Power®	NAES® Bayonne	Progress Energy®	Rusail Oman
PTC	Hydro-Agri	Inland®	Tri-State® Generation and Transmission Association	
Georgia Gulf®	British Petroleum®	E.On®	Texas Gen Co	
	PCS Nitrogen	GLOW	Oceana State	
	Talisman Energy®	Vattenfal	Cinergy®	
	Valero®	Ineos®	Sunoco®	
	ZTEC	Sime Darby	Watson Cogen	
	Fertail Algeria	Berakas Power Management Company	Georgia Gulf®	
	Constellation®	PSE - Encogen	Formosa Plastics®	
	Astoria		British Petroleum®	
	NRG El Cajon		Golden Valley Electric Association	
			PREPA	
			GenOn®	
			Exelon®	
			DOW® Chemical	
			Air Products	
			Eagle Point	

Q&A