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| IP Classification | R00 | | | | |

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# ETN SGT-A35 User Group Day 2 Technical Session

Siemens 8th October 2020

# Agenda
# Siemens SGT-A35 Technical Sessions 1&2

| Index No. | Title | Presenter |
|---|---|---|
| 122 | Spare parts lead time excessively long + supply chain changes since business takeover from Rolls Royce | Angelo Gazzillo |
| 66 | Feedback on the FMV design released in March 2019 | Regis Fowler |
| 107 | Different designs developed during manufacturing phase | |
| 110.1, 110.2 | Lack of alternatives for RT Power Turbines overhaul (RT61) | |
| 115 | Power Turbine disk & rotor inspection and life extension criteria | |
| 111 | Water mist on hot engine external casings, turning to steam and burning electrical cables | |
| 71 | Status of Siemens' alarms and trips rationalisation programme initiated in 2017 | Johann Wiseman |
| 101.2 | NoX emissions – status of emissions improvement project | Mark Scudamore |
| 116 | Potential risk associated to abradable Metco coating in the HP compressor coming out in chunks | Steve Broomfield |
| 109 | Mitigate/reduce the effects of hot corrosion | |
| 23.1, 23.2, 23.3, 125 | HP Thrust Bearing material review update | |
| 123 | HPT blade failure event (2018), and risk for the fleet | |
| 103 | IP turbine blade failures, and risk for the fleet | |
| 121 | Hexavalent Chromium | |
| 128 | Procedure to commission a DLE engine after overhaul: FT-110/125 controls & STI187 | |
| 124 | Tripping on Center Bearing LO dp | |
| 127 | HPC Stg1 blade - high cycle fatigue crack | |

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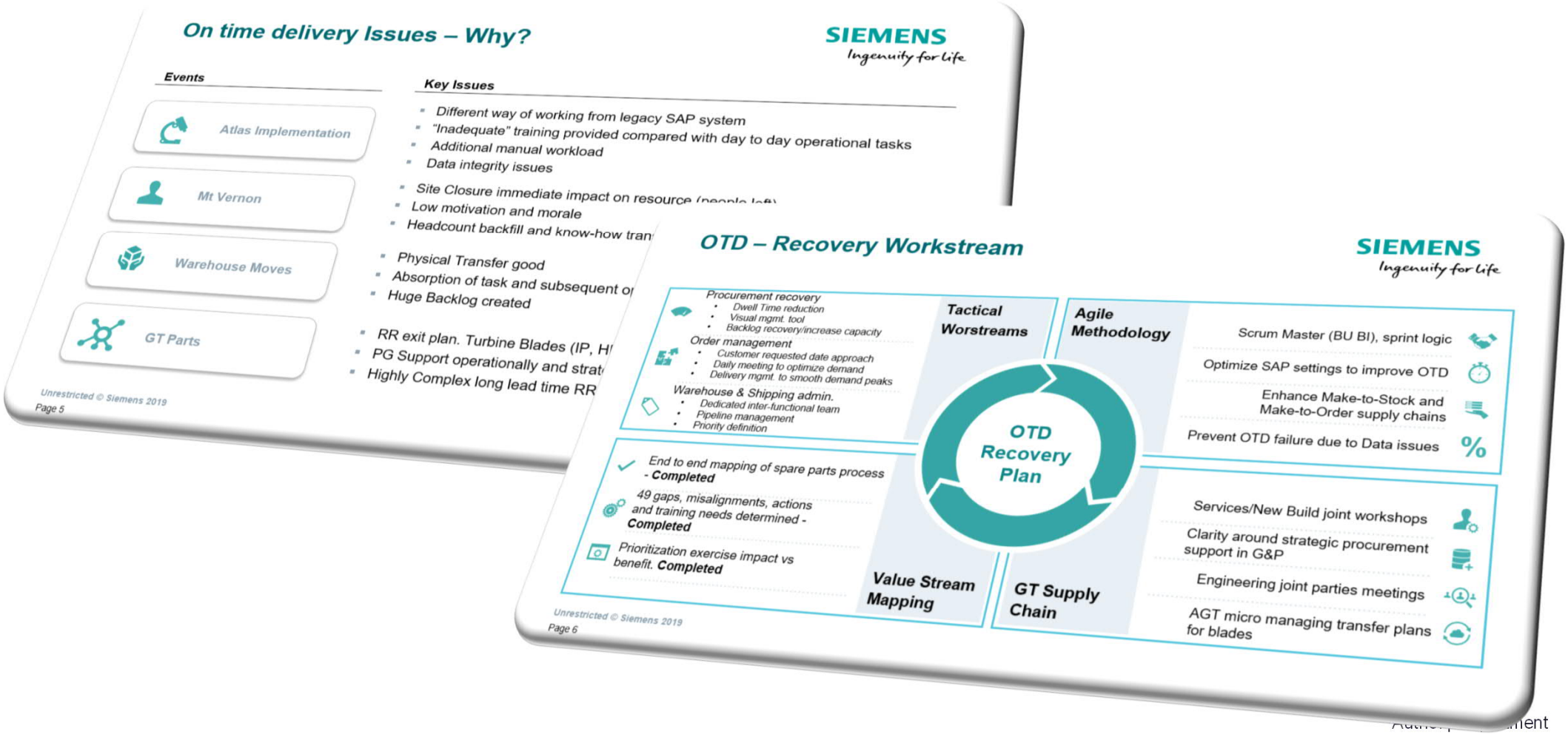
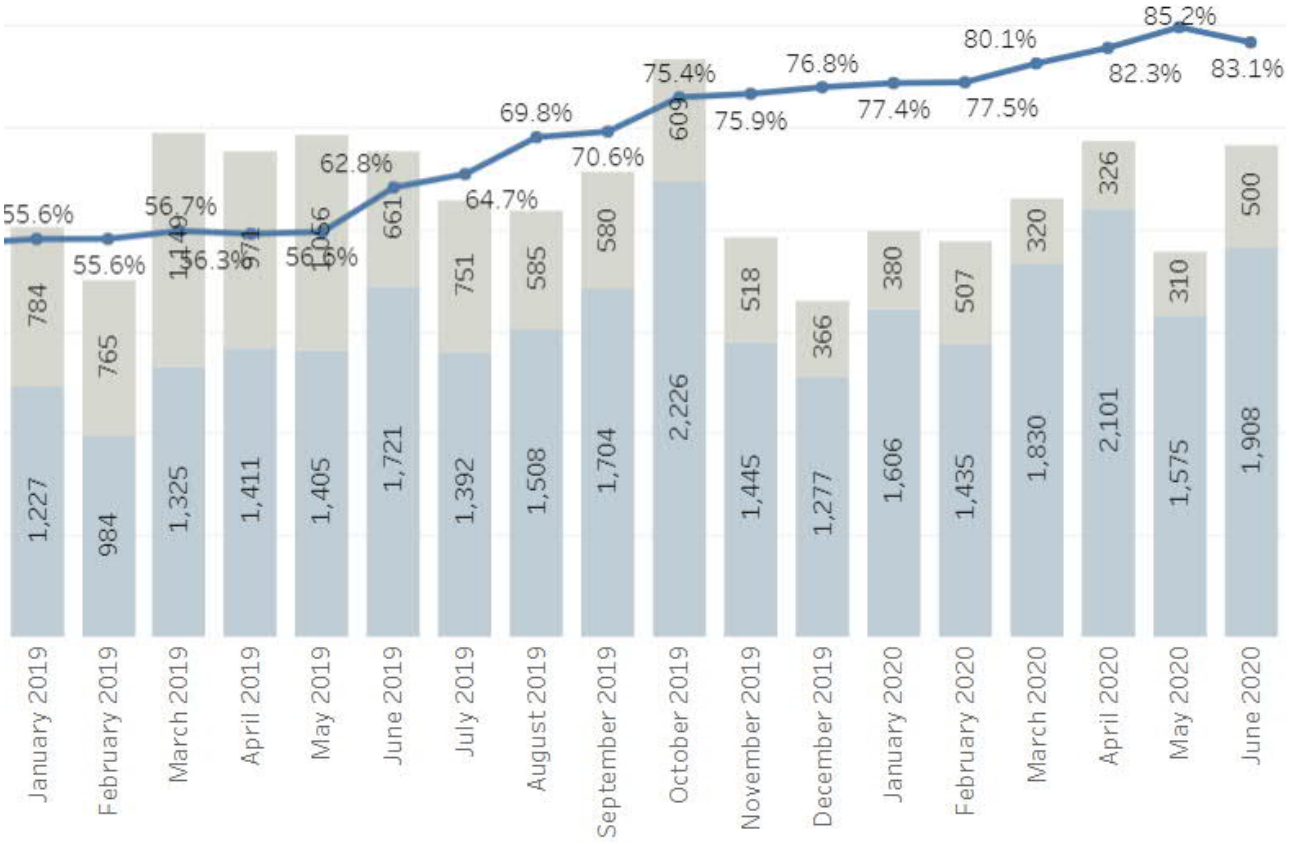
# AGT – On Time Delivery Customer Requested date

Angelo Gazzillo

# Journey So Far



# On Time Delivery – Customer Requested Date

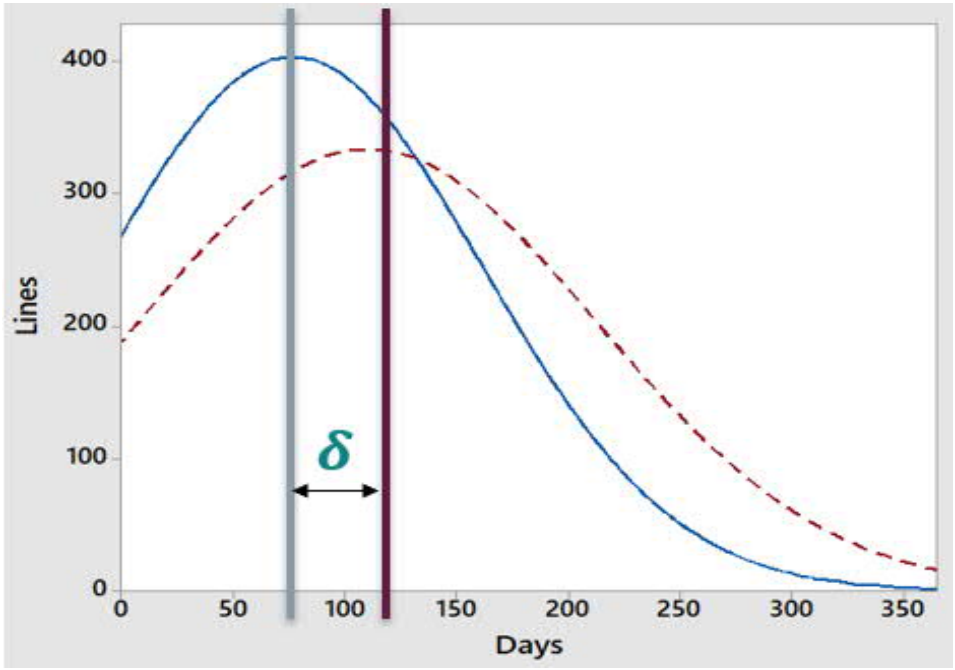



## How do we measure On Time Delivery?

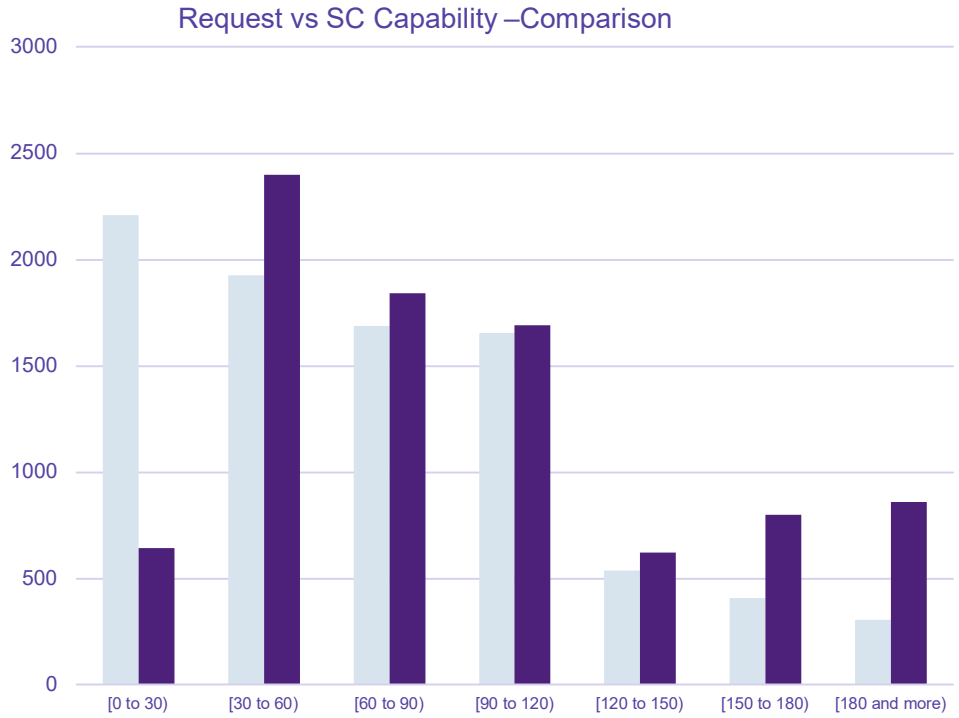
It is defined as AGT Supply Chain capability to deliver parts within the customer requested date.

$$\text{OTD} = \frac{nr.\ of\ line\ items\ delivered\ on\ time}{total\ nr.\ of\ line\ items\ delivered}$$

# Mismatch between Customer Request and SC Capability




**Identified trend from customers to order with expected short lead times**

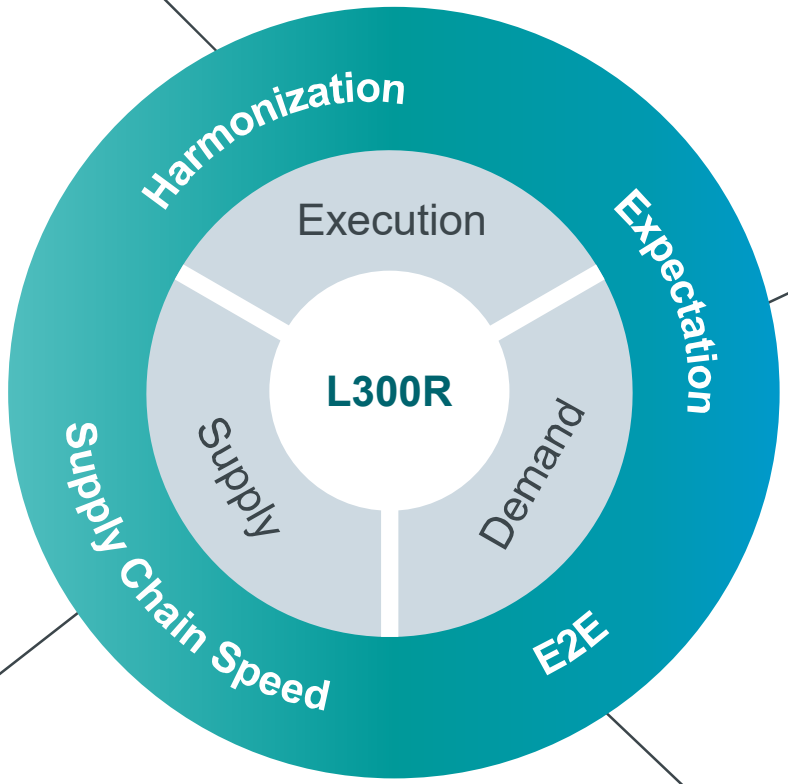



**Strong mismatch between delivery capability and customer request in 0 to 30 day delivery time**

# Improvement Workstreams

## Global Sites

- Focus Site: Warwick
- Focus Site: Houston
- Focus Site: Kongsberg
- Focus Site: Indianapolis




## Supply Chain Speed

- Dwell Time & Backlog
- Inventory Optimization
- Package Strategy & Price Agreement
- Digitalization
- Vendor LT Programme.
- Obsolescence Programme
- Quality

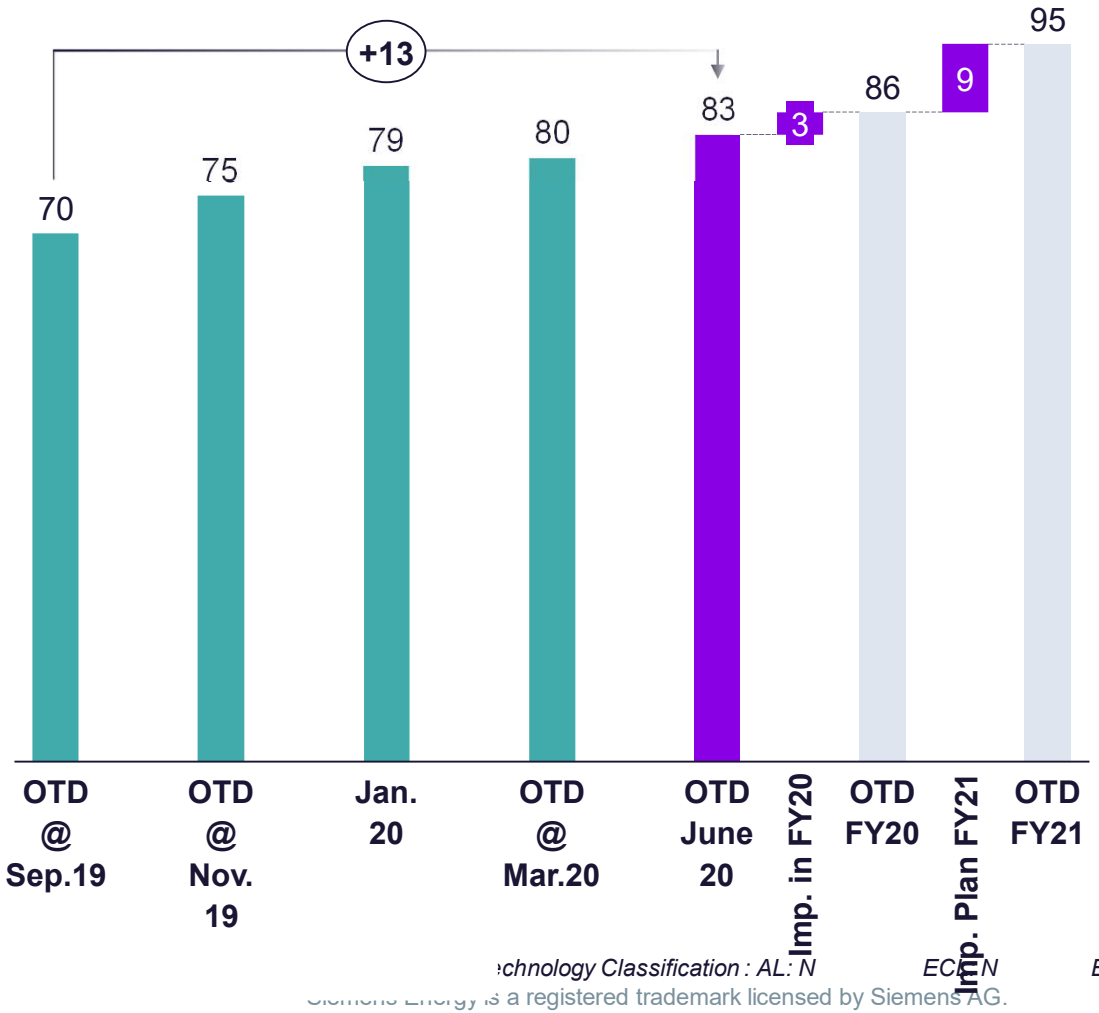
## Customer Demand mgmt.

- Understand R date profile per region/customer
- Reduce number of urgent orders
- Improve collaboration with Region
- Benchmarking & Alignment with other PLs

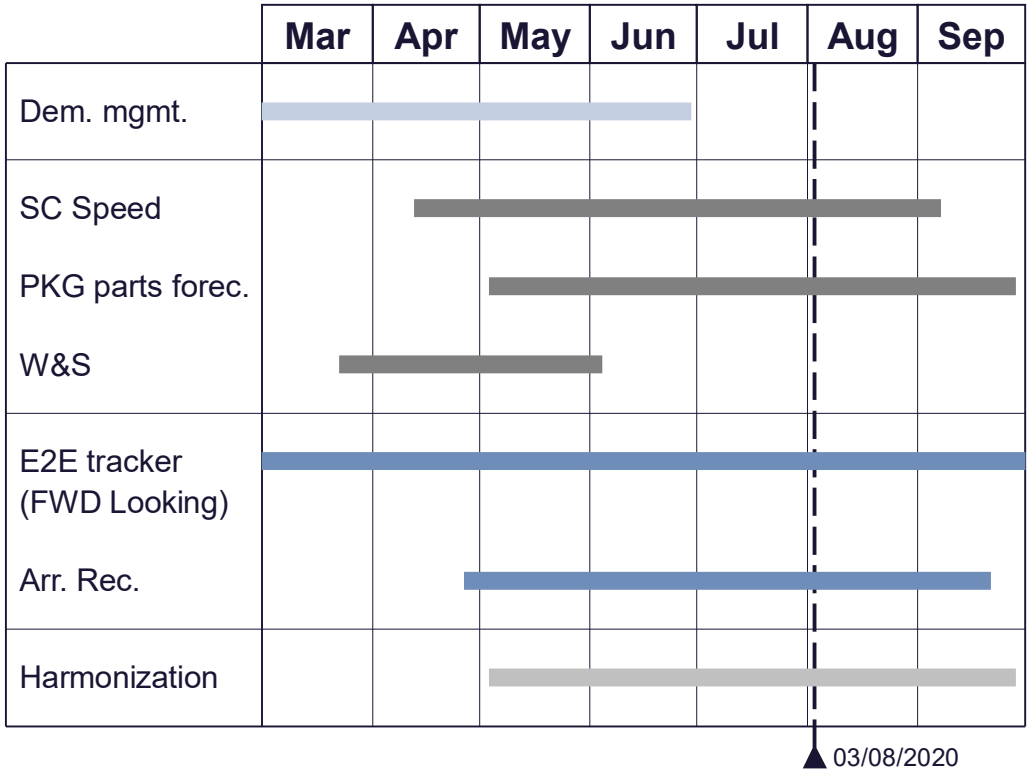
## Proactive Order Management

- Implement digital E2E trackers
- Arrears reduction
- Warehouse & Shipping

# Improvement Plan and OTD Impact FY20




## Workstream Impact Timeline



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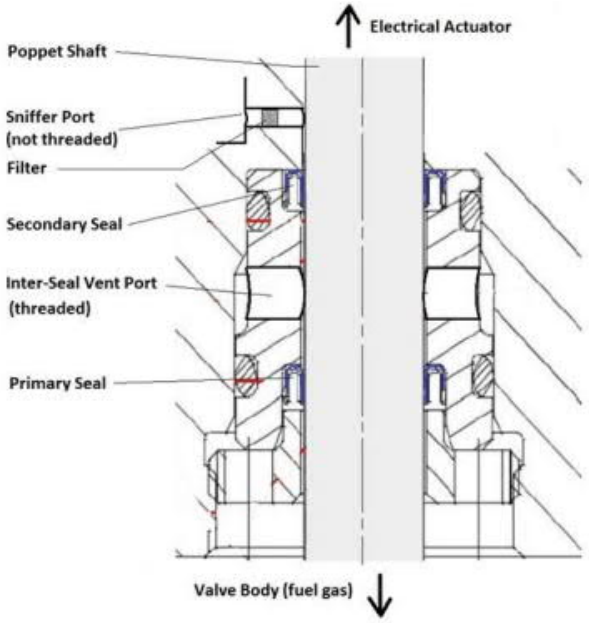
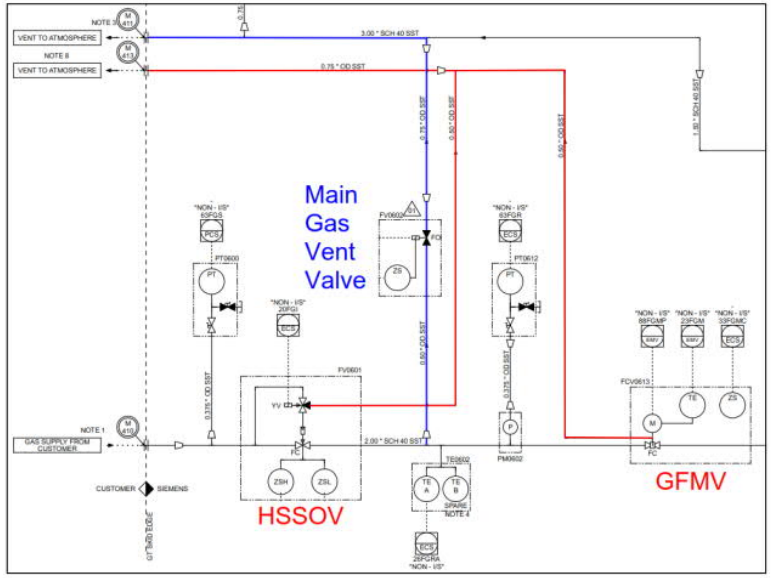
# Power Turbines

Regis Fowler ETN Conference

# Feedback on the FMV design released in March 2019

- See Siemens Product Advisory Bulletin, PAB01-0001-02, original release, Nov 2016 with updates in 2018 & 2019
- Meggitt FMV experiencing stem seal failures.
  - Prior to mid-2007: Inter-seal vent port plugged
  - 2007 to 2014: Inter-seal vented to main gas vent line
  - 2016 to present: Inter-seal vented to separate vent connection as per PAB, as per below.



# Different designs developed during manufacturing phase

- Problem originated during the first of kind feature development for the RT61 power turbine for FPSO applications for further enhancing the pitch and roll capability.
- Two different design concepts were developed during the pre-award phase of the project with multiple EPC customers between 2010 and 2013
  - Option 1: Initial design was developed to manage the various EPC pitch and roll combinations.
  - Option 2: Later developed as a simplification once the final EPC was awarded.

- During the factory test in Oct 2014, oil had flooded into the turbine exhaust.

- Root Cause and CAPA Launched
  - Features of both Option #1 & 2 design concepts were installed onto the unit and represented a non-functional result.
  - Technical issue was corrected and tested on the shop floor prior to shipment to site.
  - Process escape determined as a non-adherence to control of design documentation from R&D environment into the production environment. Process issue corrected with the introduction of the Siemsns Product Development Process (PDP) process.



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# Use of Water Mist Fire Suppression

- Comment received from user group is the concern for water mist on hot engine external casings, turning to steam and burning electrical cables.
- Water mist has been studied and used extensively on gas turbine machinery enclosures.
- Primary function of any suppression system is
  - Control and prevent machinery fires from escaping enclosure
  - Cool and extinguish enclosure fires
  - Protect personnel and equipment in the installed surroundings
- Machinery protection is a secondary benefit over life safety
- In the event of a fire and subsequent suppression, the potential replacement of components is a likely scenario depending on the intensity, location and duration of the fire.
- Our experience has shown no deterioration of cables due to the use of water mist fire suppression systems.

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# Power Turbines

ETN Conference Regis Fowler

110.1 & 110.2

# PT Localization Strategy

**Siemens has listened and heard from its customer base**

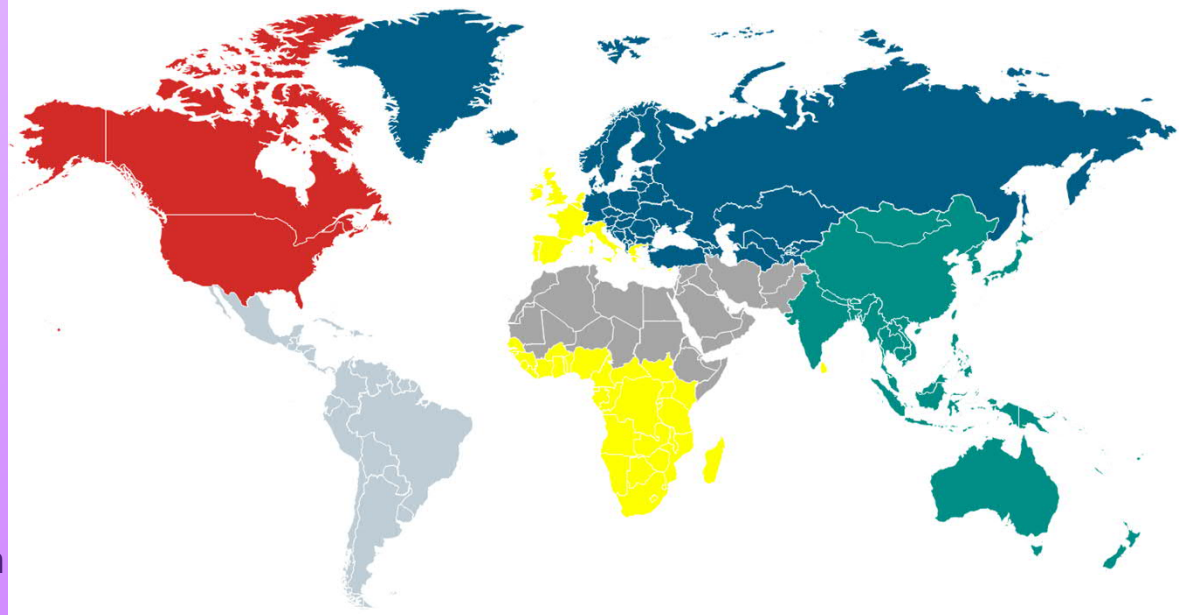
**Siemens is actively evaluating several locations globally to develop and install repair and overhaul capabilities on the Legacy RT and DR Power Turbines**

- **Evaluation of a new European location is complete and will be announced shortly.**
- **These facilities will be supported by AGT engineering, quality, and operational functions**

**Houston performs both Repair and Overhaul and New Unit production for the RT Fleet**

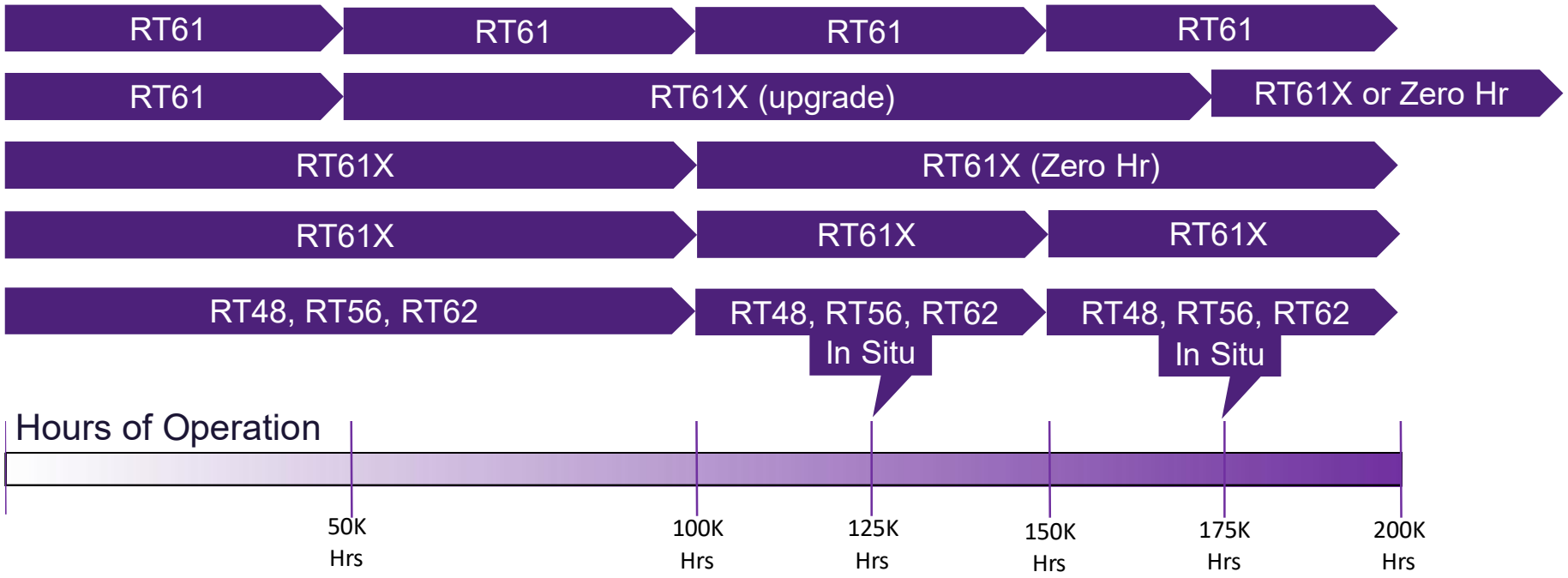
**Houston will continue to be the Center of Excellence for the Legacy RT frames, including the RT61/RT61X**

- **All vital support functions are located in Houston providing integrated OEM support to each project**
- **All work is performed to rigorous OEM standards using 100% OEM components and processes**



# Power Turbine Maintenance Strategy
# Current PT Rotor Overhaul Intervals

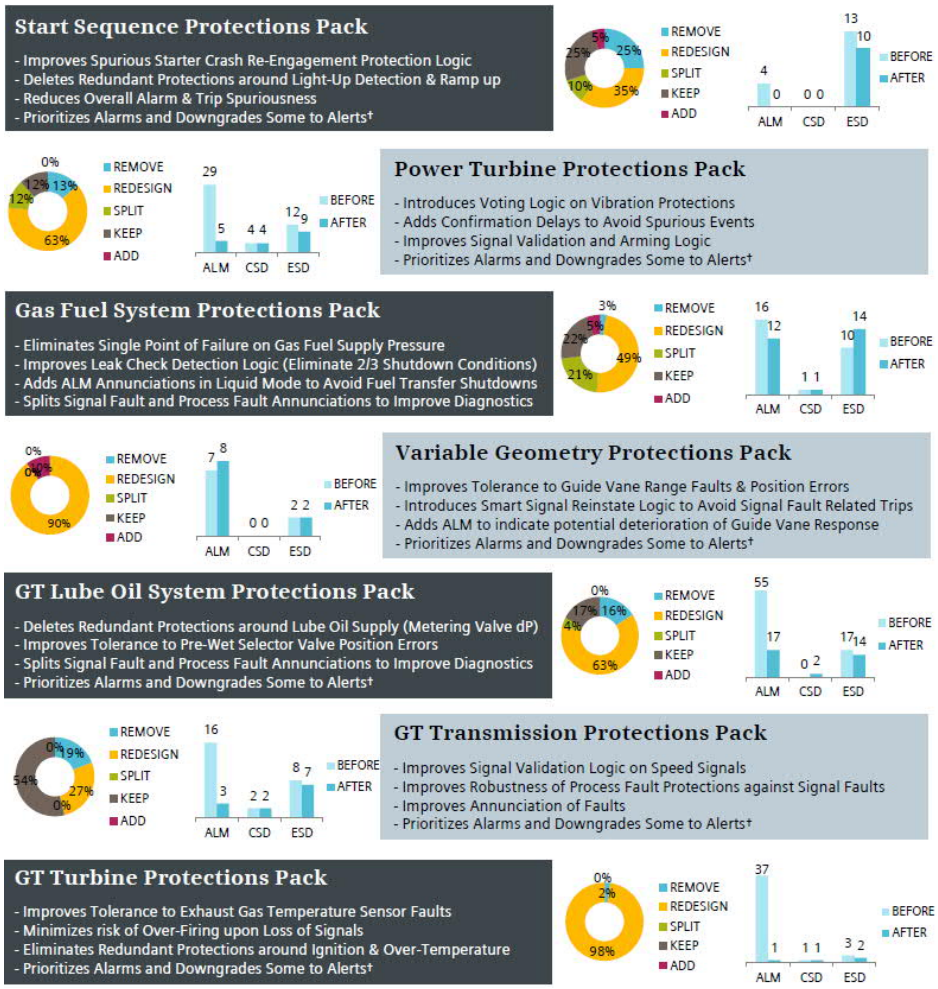
O/V intervals




Siemens Product Advisory Bulletin (PAB-01-0008-01)

# Johann Wiseman

# Alarm Trip Rationalisation




- **Comprehensive review of all Alarms and Trips**
- **70%** Total Number of Alarms & Trips Removed, Downgraded or Redesigned
- **14%** Improvement in MTBFO on test site
- Higher Availability
- Higher Reliability

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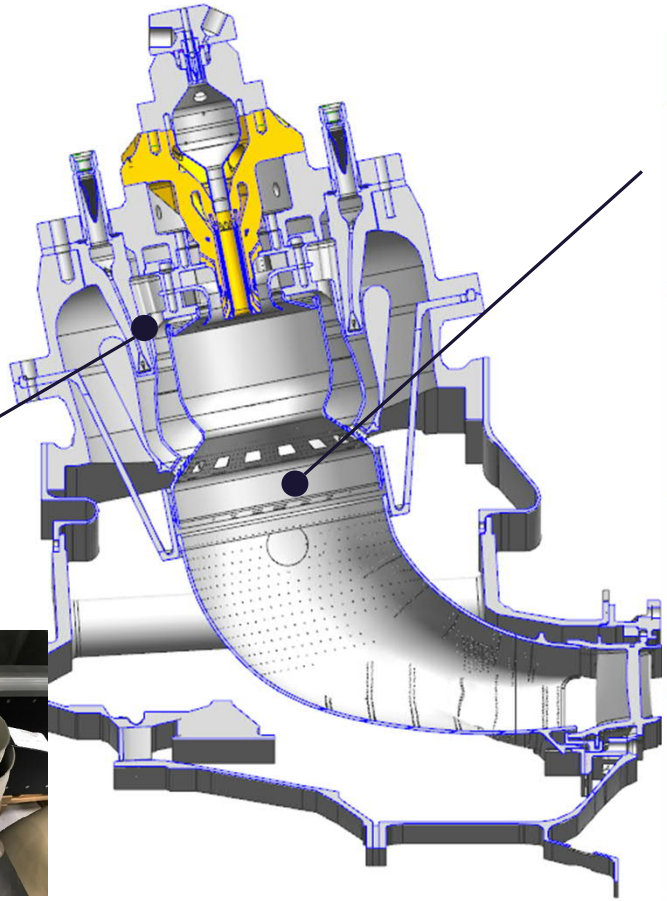
# Mark Scudamore

# SGT-A35 DLE enhancement

*Incremental improvements to a proven architecture*

| Targets |
| --- |
| Lower $NO_x$ and CO |
| Durability & service cycle |
| Easy to retrofit |



**AM Component development**

Rigorous qualification

| Key Targets | R&D status |
| --- | --- |
| 15 ppm $NO_x$ ✓ | High confidence in 15 ppm guarantee |
| 15 ppm CO + turndown ✓ | Expect 15 ppm baseload guarantee<br>"Turn Down" range extended without compressor bleed → improved part-load heat rate |
| Durability & Service Cost ✓ | Known issues specifically addressed in the design of the improved DLE |
| Easy to retrofit ✓ | Incremental improvements to existing combustor, implemented at shop visit.<br>Package upgrade scope limited to re-purposing 1x fuel line. |

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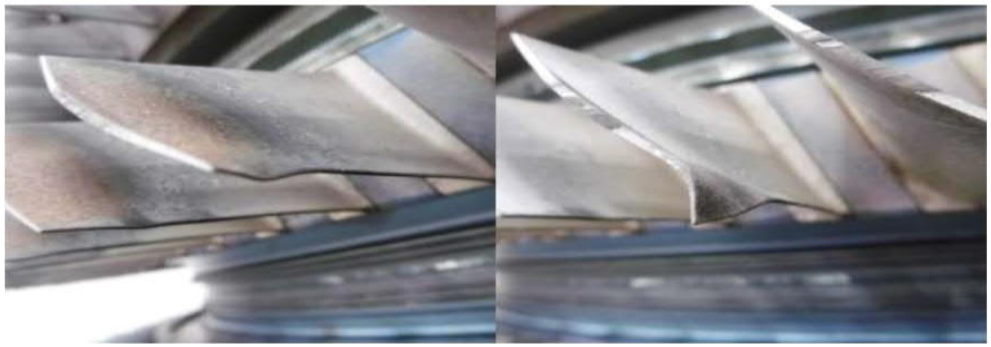
# Steve Broomfield

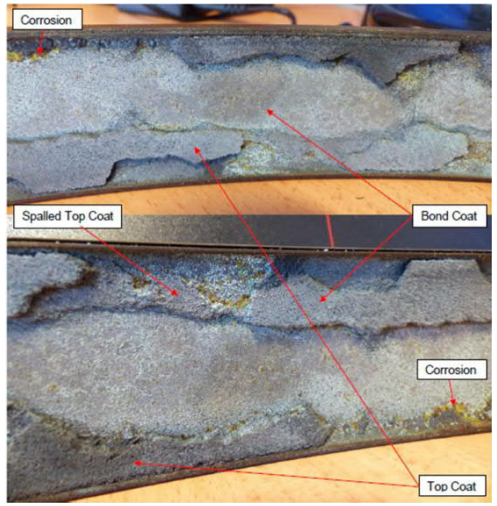
# Potential risk associated to abradable Metco coating in the HPC coming out

- No HPC compressor abradable loss noted in G-rated engines.

- Some loss of HPC stage 1 seen in GT engines. Typically occurs in offshore high ambient conditions indicating corrosion is contributory factor. This is confirmed by lab examination.

- Abradable lining is brittle and disintegrates on impact with the rotor blades.
- Normally lining loss results in minor tip bending and is usually only noticed during routine borescope or overhaul and does not result in any significant operational problems.



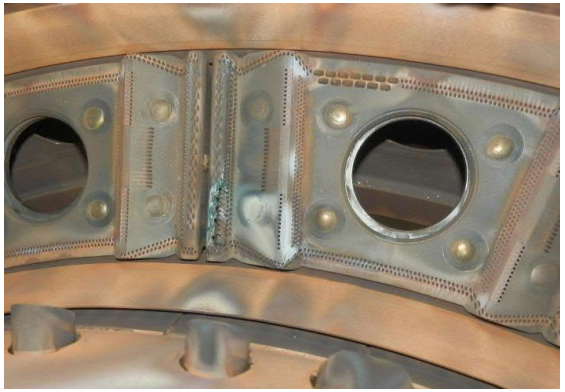


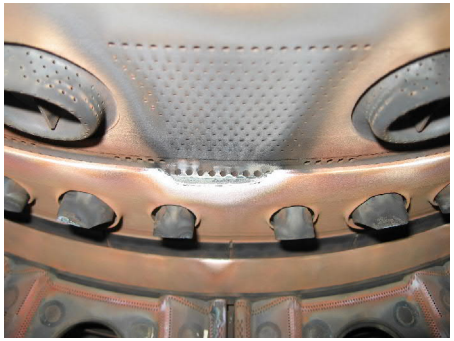

- However one engine was removed due to surge and blade damage. HPC1 lining found to be heavily corroded

- Ensure engines are fully dried after compressor washing to reduce corrosion.
- HEPA filters are recommended to reduce induction of corrosive elements which also reduces requirement for washing.
- Siemens can provide E10-E12 grade filters ref PIB01-0008.
- Intermediate impact damage can be repaired in the berth by boroblending ref PAB01-0032.

# Mitigate/reduce the effects of hot corrosion

- In normal operation with good fuel the SGT A35 Duel Fuel combustion liner does not suffer from sulphidation.
- Over 300 dual fuel engines in operation. ~12m Hours
- The only areas which normally exhibit any deterioration are:-
  - Oxidation of the heatshield corners
  - Erosion of the smoke chutes
  - Thinning of the splitters
  - Oxidation of the inner 1st cooling ring (GT only)
- These do not limit the life of the liner which routinely achieves 25K+ hours.
- These features are easily repaired as part of the normal overhaul workscope.





# Mitigate/reduce the effects of hot corrosion

- There are only 2 or 3 operators who routinely suffer from Sulphidation of the DF FCL

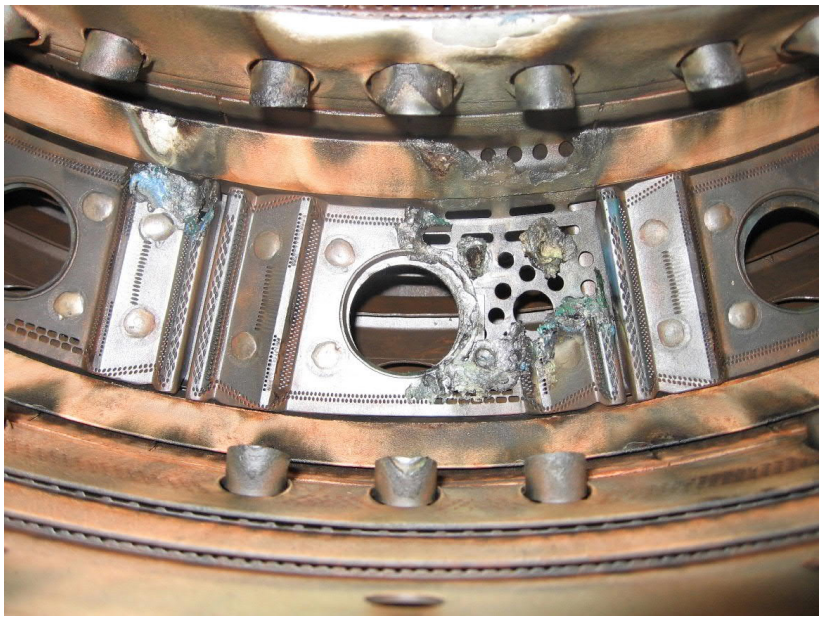
- **Operation with high Sulphur gas fuel in marine environment**
  - <2.5% H2S vs 0.0005% H2S+SO2 limit in PAB01-0020

- **Extended operation with high sulphur Diesel fuel in marine environment**
  - <3% H2S vs <0.005% Sulphur limit in PAB01-0020

- Both are in marine / coastal environments.

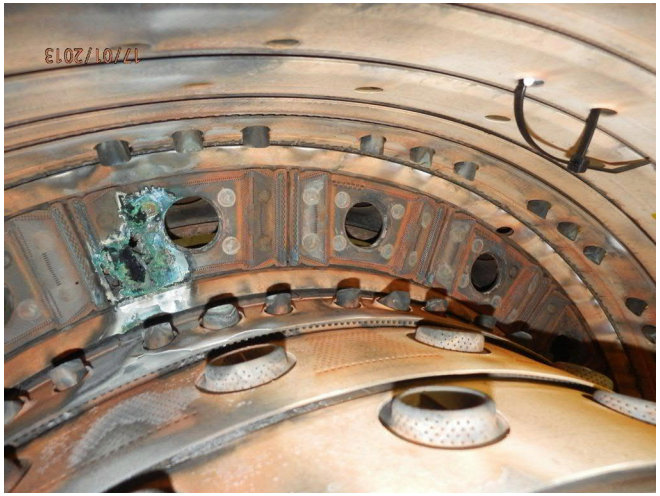
- Operation with fuel containing Sulphur above the limits in PAB01-0020 is expected to result in combustion and turbine corrosion / sulphidation.

- Therefore reductions in the recommended overhaul lives are given for these environments.



# Mitigate/reduce the effects of hot corrosion

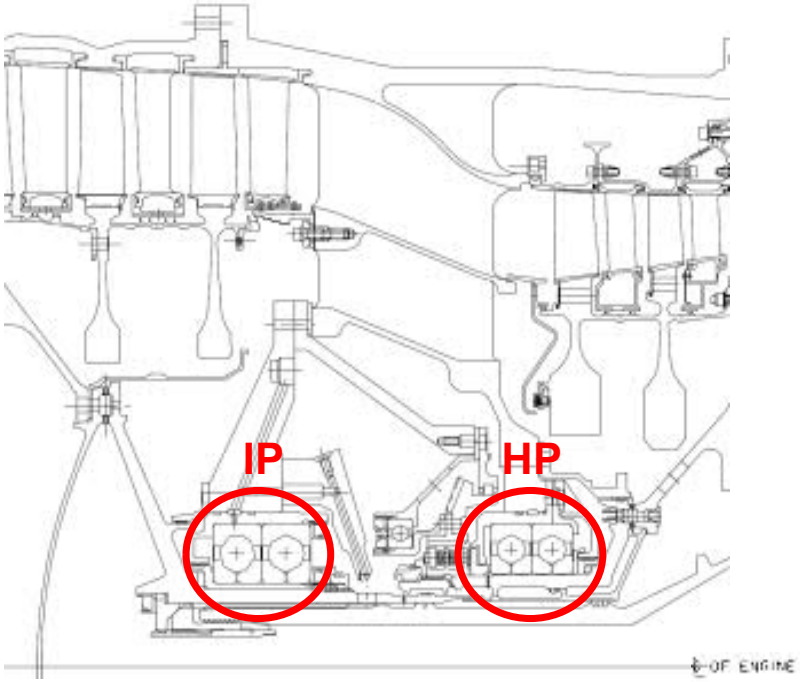
- Hot corrosion is normally caused by a combination of airborne salts and fuel borne sulphur.
- Low-moderate levels of sulphur will increase overhaul costs due to additional damage to blades, NGV's and seal segments but does not limit overhaul lives
- High levels of sulphur in gas fuel (>1.5%-2%) can significantly reduce engine life primarily as a result of hot corrosion of the combustion liner heatshields.
- Sermaloy J coating can be added to HP and IP turbine seal segments to provide additional protection.
- HEPA filters can significantly reduce the airborne salt content ref PAB01-0008.
- Mod 1578 introduces a combustion liner heatshield with Sermaloy 1515 on the front and rear surfaces and increased cooling through the metering panel.




- For the operator with high sulphur gas this, in conjunction with improved intake filtration, in has increased the life of the heatshields from <4K hours to >8K.
- Given the small occurrence of sulphidation across the fleet there is no active programme to investigate further design changes to reduce the effects of hot corrosion.

# HP Thrust Bearing Reliability & Material Update

- The current standard of HP thrust bearing was released in 2001 by Mod1368. This introduced revised material inner and outer races with improved fatigue strength.
- Mod1368 was introduced primarily to enable a satisfactory life in GT engines which have higher bearing thrust loads. The improved fatigue strength will also make the bearing less sensitive to other failure causes.
- Since 2006 the previous standard of bearing is upgraded to mod1368 at overhaul. Therefore since ~2012 most of the fleet will have Mod1368
- To date there have been 9 recorded failures of Mod1368 bearings the last of which was in 2018.
- Confirming the cause of bearing failure is difficult but causes are normally one of the following:- assembly issues, oil contamination, corrosion, shipping damage.
- Assembly improvements were introduced in 2012 by mod1624. This introduced hydraulic tooling to ensure the bearing races are clamped together. This is critical to ensure even load sharing.



23.1, 23.2, 23.3, 125

# HP Thrust Bearing Reliability & Material Update

**Failure detection**

- ❑ Debris on MCD's / QDM's
- ❑ Debris on scavenge baskets and supply filters.
- ❑ Increased filter Dp and potentially low centre bearing Dp.
- ❑ In a small number of instances HP thrust bearing failure may result in HP speed probe reliability issues on G-rated engines. Broadband casing vibration is generally not effected.
- ❑ By monitoring vibration and debris engines can often continue to run with a failing bearing while a replacement engine is made available.

**Failure Rate.**

- ❑ To date there have been 9 recorded failures of Mod1368 bearings. The majority of the failures have been at less than 25K hours.
- ❑ Weibull analysis indicates the failure rate is falling, this may be as a result of improvements made to the build process in 2012. Weibull also indicates the failures are more wear-in than wear-out.
- ❑ Siemens recommends thrust bearings are overhauled every 50K and not disturbed at 25K.
- ❑ Siemens has reviewed the availability of different materials which may improve the tolerance to damage, contaminated oil etc. However no superior materials were identified.

There have been no failures of IP thrust bearings

# HPT blade failure event (2018), and risk for the fleet, (slide#1)

- There have been 8 HPT blade failures on the A35 GT variant all have been on engines with DLE combustors.

- Two types of failure mode have been seen:
  - Platform failures
  - Aerofoil failures

# HPT blade failure event (2018), and risk for the fleet (slide #2)

## Platform Failures

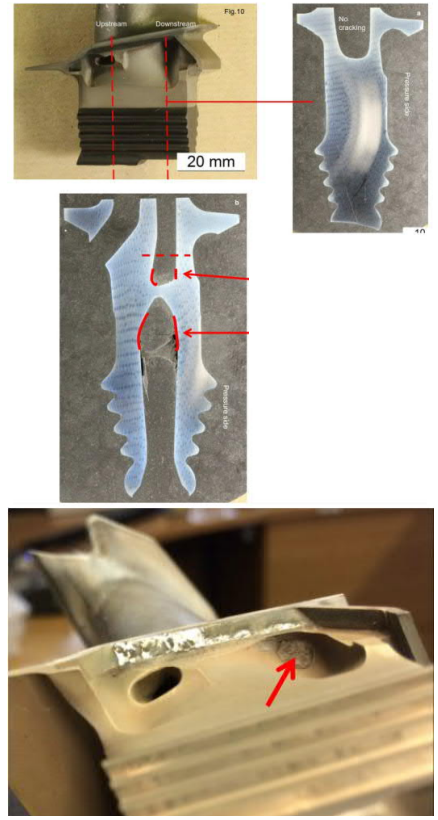
- ❑ Analysis of two failures has been carried out.
- ❑ Of the failures examined no metallurgical or dimensional defects found
- ❑ Low temperature sulphidation has been found in the failure region.

- ❑ Analysis of deposits found in the platform containing sulphur, sodium and potassium were also found

- ❑ This area is primarily compressor cooling air, therefore contaminants will have originated in the intake air

- ❑ Operators are advised to ensure airborne contamination is minimised which can be achieved by the use of HEPA filters ref PAB01-0008.

- ❑ HEPA filters also reduce contamination leading to performance loss which then reduces the downtime necessary for compressor washing.



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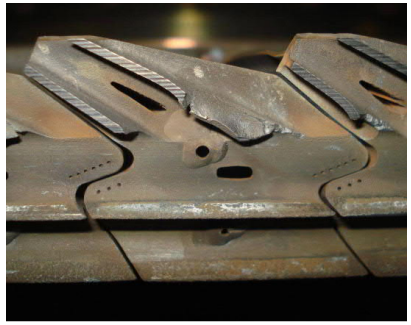
# HPT blade failure event (2018), and risk for the fleet (slide#3)

## Aerofoil Failures

- Failure is due to High Cycle fatigue initiates at the leading edge. No metallurgical or dimensional defects found.
- Cyclic operation is contributory factor as it causes wear of the shroud interlocks. This allows the blade to vibrate in cantilever modes.
- Blockage of fuel injectors as a result of fuel quality was also a factor in one failure.
- The vibration mode likely to cause mid-height aerofoil failures is primarily generated by wakes from the NGVs



- To minimise risk, Siemens recommends DLE overhaul life is limited to ~25K to maintain interlock condition.
- Siemens has initiated a programme to redesign the HPNGV aerofoils to reduce the aerofoil wake strength reducing the vibration forcing on the blade.
- The new HPNGV's will be available for retrofit onto the existing DLE combustor as well as with the new <15ppm DLE combustor design.

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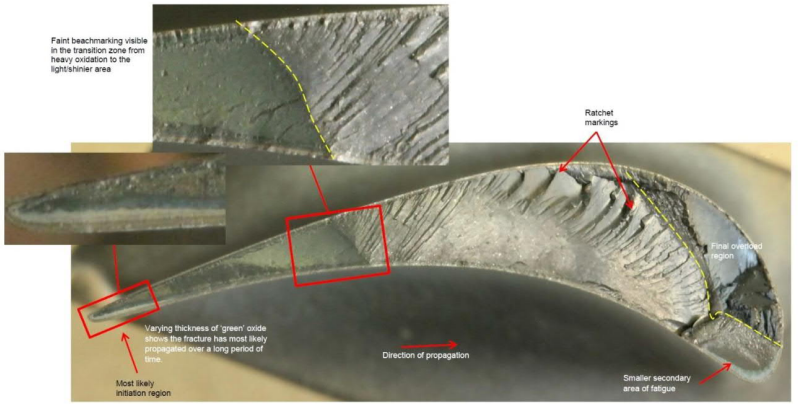
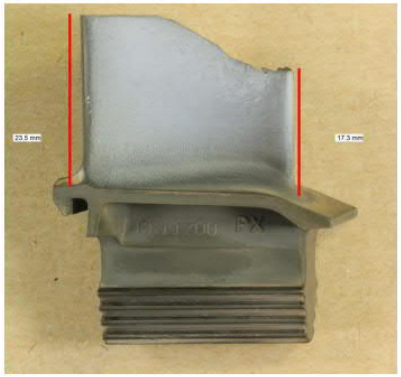
# IP turbine blade failures, and risk for the fleet

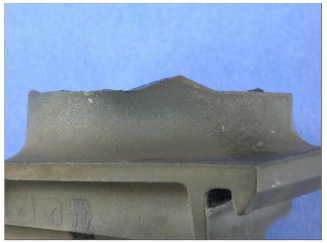
- There have been 3 IPT blade failures all on GT dual fuel engines.
- There have been no primary G rated IPT blade failures. G and GT blades are identical except for material.
- One IPT blade failure occurred at 49K hours TSN in 2018 :
- Failure had originated at the trailing edge approx. 23mm above the platform. Heavy o with the coating SRZ indicated it had been initiated very early in the life of the engine. significant time. At the mid-section more rapid HCF occurred leading to blade release
- A secondary area of fatigue was present on the leading edge.
- Other blades in the set were found to have leading edge cracks
- Analysis did not find any metallurgical or dimensional defects to explain the failure. Having excluded other possibilities it was concluded the most likely cause was an unusual operational condition early in the engine life that initiated the cracking although no data is available to identify this.
- The GT fleet is over 200 engines with over 4m hours operation
- IPT blades from a further 27+ engines have achieved over 50K hours and have been fully inspected as part of the routine 50K overhaul. No other blade cracks have been found.



# IP turbine blade failures, and risk for the fleet

- Two failures occurred at the same site on adjacent units both in early 2019. The engines had completed 88.7K and 76.6K TSN. Failure initiated at the TE ~5mm above the platform and propagated in HCF. No metallurgical defects were found.
- Investigation of these engines showed both to have suffered significant damage to the IPNGV's upstream of the IPT rotor due to high temperatures.
- The turbine damage was most likely caused by fuel quality issues although limited data was available to evaluate this.
- This resulted in excessive temperatures that resulted in loose blade shroud interlocks. This, as well the aerodynamic disturbance from the holed IPNGVs, resulted in vibration of the IPT blades causing failure.
- These failures are therefore considered to be due to operational issues and are not related to the 2018 failure.



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# Hexavalent Chrome

- Siemens recommendations for identifying and dealing with Hexavalent Chrome (Cr6) are contained in PSW01-0008-01 issued in March 2019
- This PSW is in the process of being updated to add additional Cr6 test kits.
- Cr6 forms in external locations as a result of reaction with anti-seize compounds used on bolts.
- Siemens is conducting laboratory assessments of alternative anti-seize compounds that will not react with engine materials to form Cr6.
- This is expected to be complete by end 2020 so engines built after this date should not present this risk. Engines built before this date will still need HSE precautions to be taken until they are removed and returned to the MROC where all parts will be cleaned.

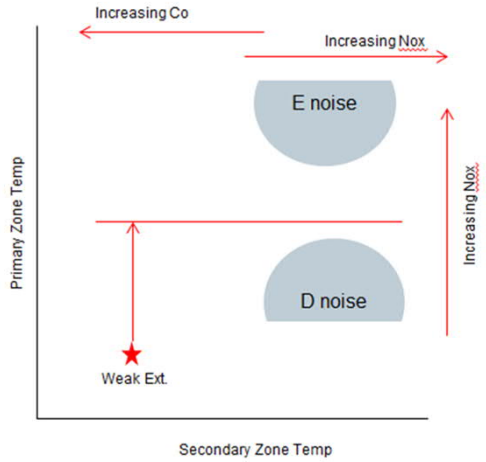
# Procedure to commission a DLE engine after overhaul FT-110/125 controls & STI187

- STI 187 is DLE combustor noise mapping procedure.

- The mapping process is:-

1. Establish the Primary Zone temperature (TPZ) at which weak extinction occurs. This then sets the baseline minimum TPZ.

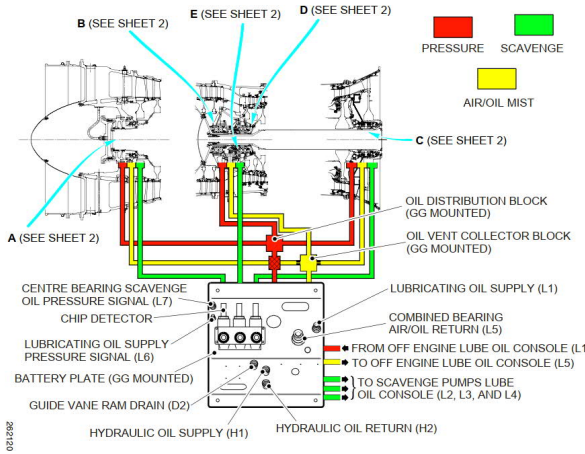
2. The engine is then mapped across the power range (TSZ) at incrementally higher TPZ settings to establish the position of the noise islands. The final fuel schedule can then be defined to achieve the emissions limits at minimum noise levels.

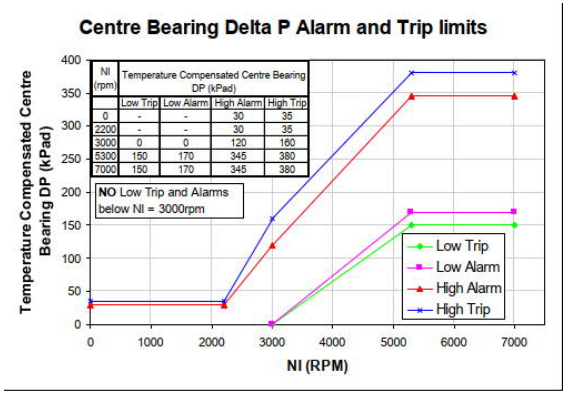



- Completing weak extinction and mapping requires access to the fuel control software and so only be done by a Siemens FSR.
  STI's are internal documents intended for use by service engineers.
  They are therefore Siemens IP and not made available to Operators.

# Tripping on Center Bearing LO dp

- Unit is tripping on high Centre bearing Dp. ‘K’ factor adjusted to enable operation
- Assuming the problem is High Dp on startup. Problem is typically high flow or cold oil.
- We would not recommend adjustment of the ‘K’ factor as this changes the flow schedule across the whole running range. (K factor is the flowmeter pulse/rev calibration).
- Potential fixes or further investigation:-
  - Reduce the prewet flow demand.
  - If a replacement flowmeter has been fitted has the new calibration been applied ?
  - Has the flowmeter been in service for a long time - it may require replacement.
  - If ambient temp is low check lines are lagged and trace heating is working.
  - Circulate oil for 10mins before attempting to start to ensure the system is warm.
  - If this is a recurring issue in cold weather the oil temperature measurement point can be relocated from the skid closer to the engine to provide a more accurate reading and therefore correct temperature compensation.
- If additional info can be provided we can investigate further.




| NI (rpm) | Temperature Compensated Centre Bearing DP (kPad) | | | |
|---|---|---|---|---|
| | Low Trip | Low Alarm | High Alarm | High Trip |
| 0 | - | - | 30 | 35 |
| 2200 | - | - | 30 | 35 |
| 3000 | 0 | 0 | 120 | 160 |
| 5300 | 150 | 170 | 345 | 380 |
| 7000 | 150 | 170 | 345 | 380 |

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# HPC Stg1 blade - high cycle fatigue crack

- A A-35 GT conventional combustor engine was rejected from service for a suspected HPC stage 1 blade failure.
- However initial findings from strip indicate this was likely to have been caused by impact damage from debris from the stage 6 IP stator vane inner shroud.
- The Stage 6 shroud is common with the G-rated A35. Failures have occurred previously in G and GT engines although the overall failure rate is very low.
- The IPC stage 6 vane and inner shroud overhaul inspection limits were tightened in late 2015 to ensure any wear was identified and worn components repaired or replaced.
- The HPC blade and the IPC stage 6 stator parts are in the process of being returned to the Siemens laboratory for detailed analysis. The RCA will be reported in due course.
- Impact damage from IPC stator failure has previously been detected by Siemens monitoring of engine performance allowing planned removal before further damage to the HPC occurred.

# Thank you for your attention


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