ADDITIVE MANUFACTURING GAS TURBINE HIGH PRESSURE NOZZLES: DESIGN AND VALIDATION

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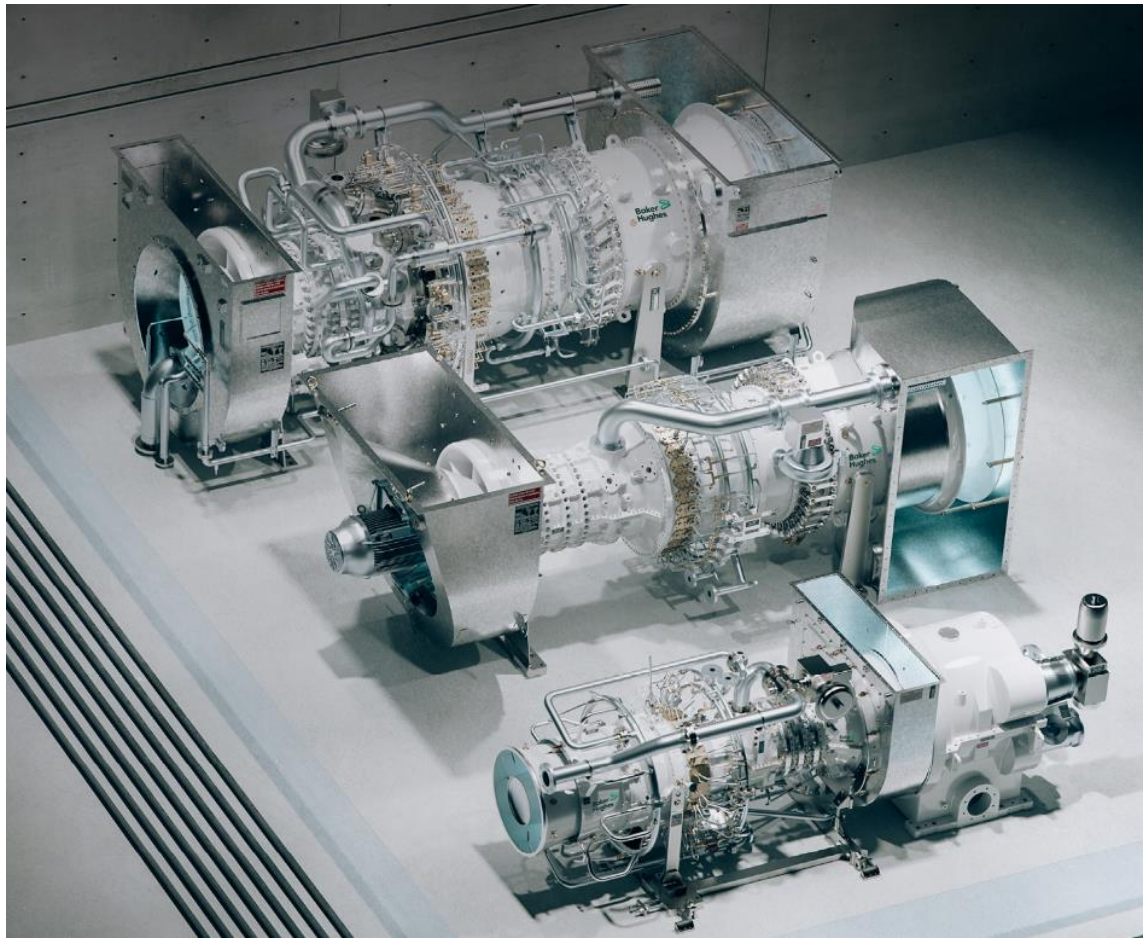
Agenda

- Additive Technologies & Applications
- NovaLT™ Family
- Design
- Validation
  - Jugular pre-Test
  - 1st Campaign on NovaLT™16
  - 2nd Campaign on NovaLT™12
  - Field Endurance Test
- Conclusion



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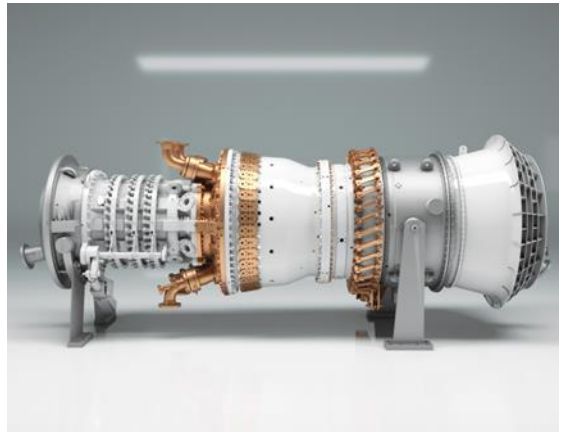
Additive Technologies & Applications

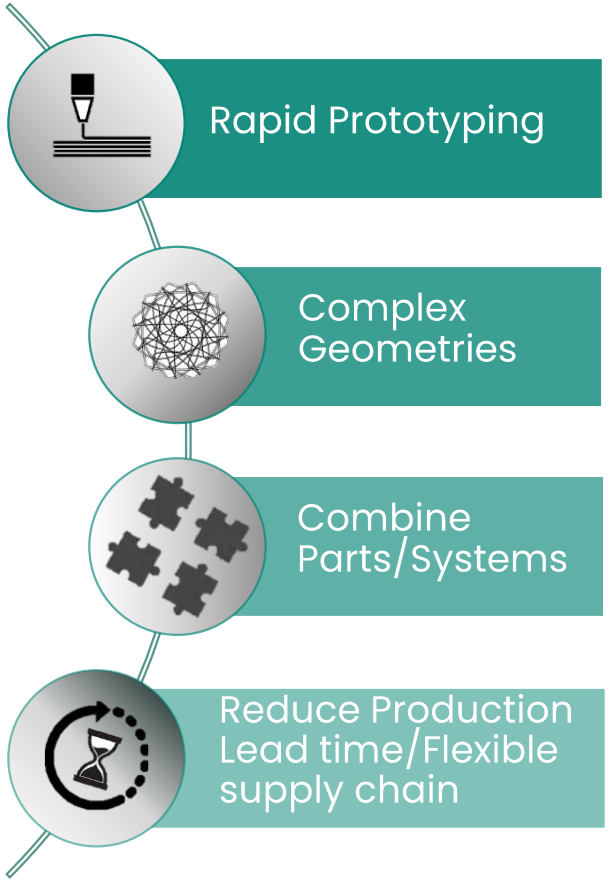
New Units

- New products development time reduction
- Performance improvement
- Economically viable for small quantities



Service – Parts

- Lead Time Reduction
- “Digital Inventory”
- Retrofit Innovative Solutions



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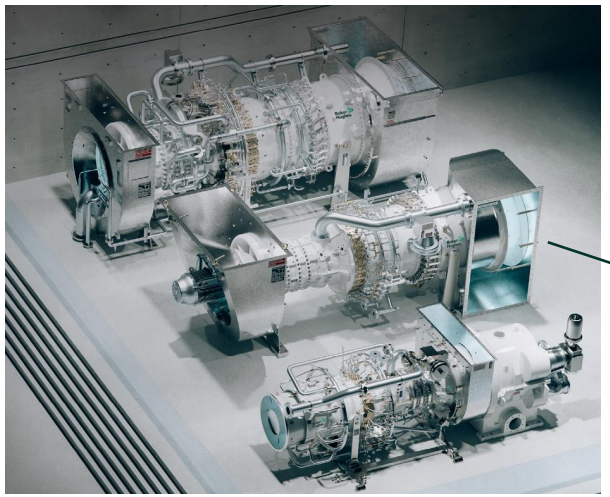
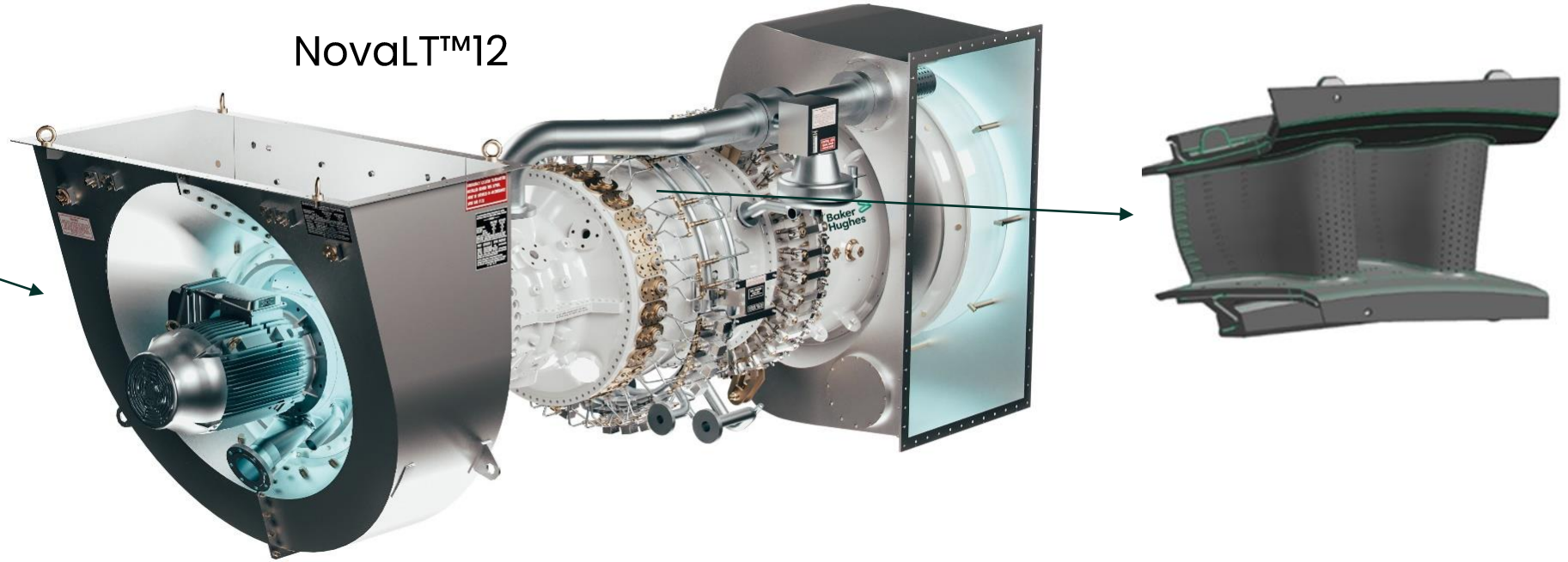
NovaLT™ Family



- 5-20 MW Gas Turbines
- Minimizes total cost of ownership (TCO)
- Power Generation and Mechanical Drive applications
- High uptime for the entire operating lifecycle
- High efficiency (up to 85% in cogeneration configuration)
- Ideal solution in industrial and combined heat and power applications.

NovaLT™12



Specification*	**Mechanical drive**	**Power generation** (50/60 Hz)
Power [MW]	13	12.5
Efficiency [%]	36.8	35.3
NOx emissions [ppm]	15 (9ppm upon request)	
Exhaust temperature [°C/°F]	496/924.8	
Speed [rpm]	4,450-8,900	
Hot gas path inspection [h]	35,000	
Major inspection [h]	70,000	
Package dimensions LxWxH [m/ft]	8.8x2.5x3.5/28.9x8.2x11.5 driven equipment excluded	14.3x2.5x3.5/46.9x8.2x11.5 driven equipment included

*At ISO conditions with natural gas fuel, ambient temperature 15°C, no inlet or exhaust losses, sea level, 60% relative humidity.

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Design

Nozzle Design

Material full characterization mechanical & lifing curves

Design for Additive (fillets optimization, support design, printing orientation..)

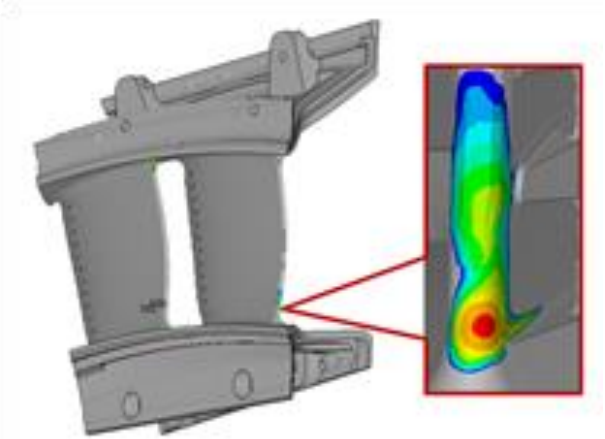
Aerodynamic ⇔ Heat Transfer & Secondary Flows

Metal Temperatures (includes transient conditions for start-up, shut-down, emergency shut down...)

Structural & Life-time calculations based on FEM modelling with in-house methods calculations to evaluate Oxidation, Low Cycle Fatigue, Creep..

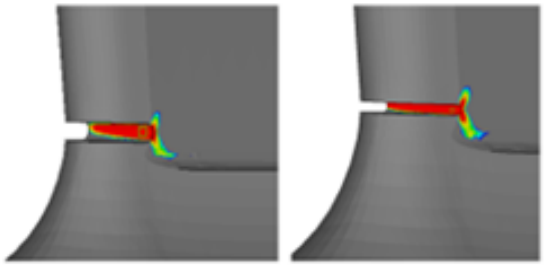
All the assessments successfully completed with enough margin with respect to proprietary design requirements before to release the part.

Design for Testing



The airfoil Trailing Edge Hub is normally one of the most demanding locations for GT nozzles sectors

Artificial defect increase the probability of crack and propagation



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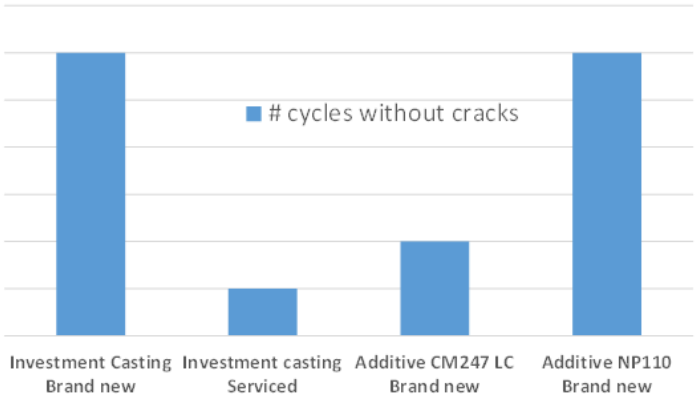
Validation

Jugular pre-Test

As the first nozzles sectors were printed by Additive, they were:

- heated in a furnace,
- rapidly cooled down by forced air convection
- FPI inspected to detect the presence of cracks.

The same was done with the sectors produced by investment casting



1st Campaign on NovaLT™16

HPT S1N arranged by mixing Investment Casting (17) & Additive Manufacturing (5) sectors

The scope of this test was to detect, under controlled conditions, unplanned or unexpected early failure mechanisms.

80+hours
50+ Start-up/shut-down cycles

Nozzles sectors disassembled after the test

- Visual inspected
- FPI executed
- Airfoils metallurgical cross section executed and analyzed

No defects highlighted by inspections after 1st Engine Test Campaign

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Validation

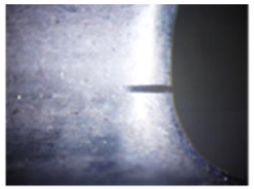
2nd Campaign on NovaLT™12

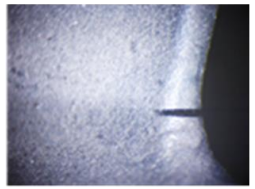
2nd Phase of the product validation campaign was focused on the testing of the machine resistance against repeated loads.

On the NovaLT™12 fully instrumented prototype test, the HPT S1N ring was equipped with:

- Standard investment casted nozzles sectors
- AM printed nozzles sectors
- Notched AM printed nozzles sectors
- Notched investment casted nozzles sectors

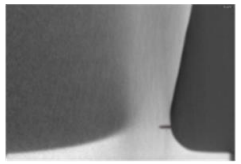
Additively manufactured nozzle FPI (after test)





Comparison between notch area of additively manufactured nozzle (on the left) and investment casted (on the right) after prototype test

Additively manufactured nozzle notch Computer Tomography



Nozzles were inspected and did not show any damages neither on the trailing edge fillets (both hub and tip) nor on the notch.

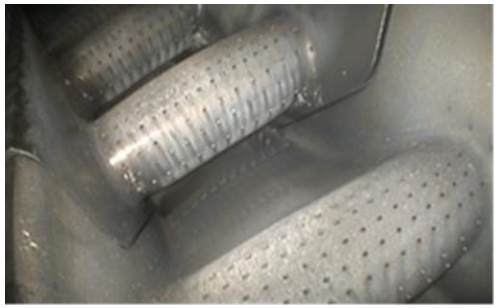
Field Endurance Test

Endurance on a commercial unit (with the agreement of the customer).

5 AM nozzles sectors.

Borescope Inspection every 8000 hours

Reached 20000+ hours



Borescope Inspection

At 20000 hours the parts were disassembled for a deeper check

The AM nozzles did not show any difference from the casting version (visual inspection, FPI, Computer Tomography).
The parts have been reassembled and engine restarted, endurance test target is the 35000 hours Hot Gas Path Inspection.

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Conclusion

- This work showcase how the design and validation of the new additive nozzle in NP110 for the NovaLT™ family was structured. Starting from the development of a new AM superalloy, the full mechanical properties characterization, trough the life assessment, to validation end the endurance test. A notched geometry of the nozzle sector was simulated and tested too.

- The simulations were followed by experimental validation on real engines, which confirmed that the additively manufactured nozzles behave in the same manner with respect to the investment casted version.

- It was a Multi-Years and Multi-Disciplines program that led to prove AM is a suitable technology to produce GT nozzle sectors, even if, requires the development of specific knowledge and consolidated experience.

- The AM technology also allows the customization of the nozzles, in fact, adjustment to the design can be introduced in a simpler way without the necessity to modify, or rebuilt, expensive tooling, saving time and decreasing cost of customization while maximizing the performance according to specific machine/site operating conditions.

- Not treated in this paper, but deserve to be highlighted, LCA (Life Cycle Assessment) was performed to assess the CO2 emission for the manufacturing of gas turbines nozzles in additive with respect to traditional investment casting. The results is that more than 15% emission reduction can be achieved by mean of additive manufacturing in place of investment casting.

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