13-IAGT-101

20th SYMPOSIUM ON INDUSTRIAL APPLICATIONS OF GAS TURBINES

DEVELOPMENT OF THE RB211-Gzero AFTERMARKET POWER UP-RATE

by

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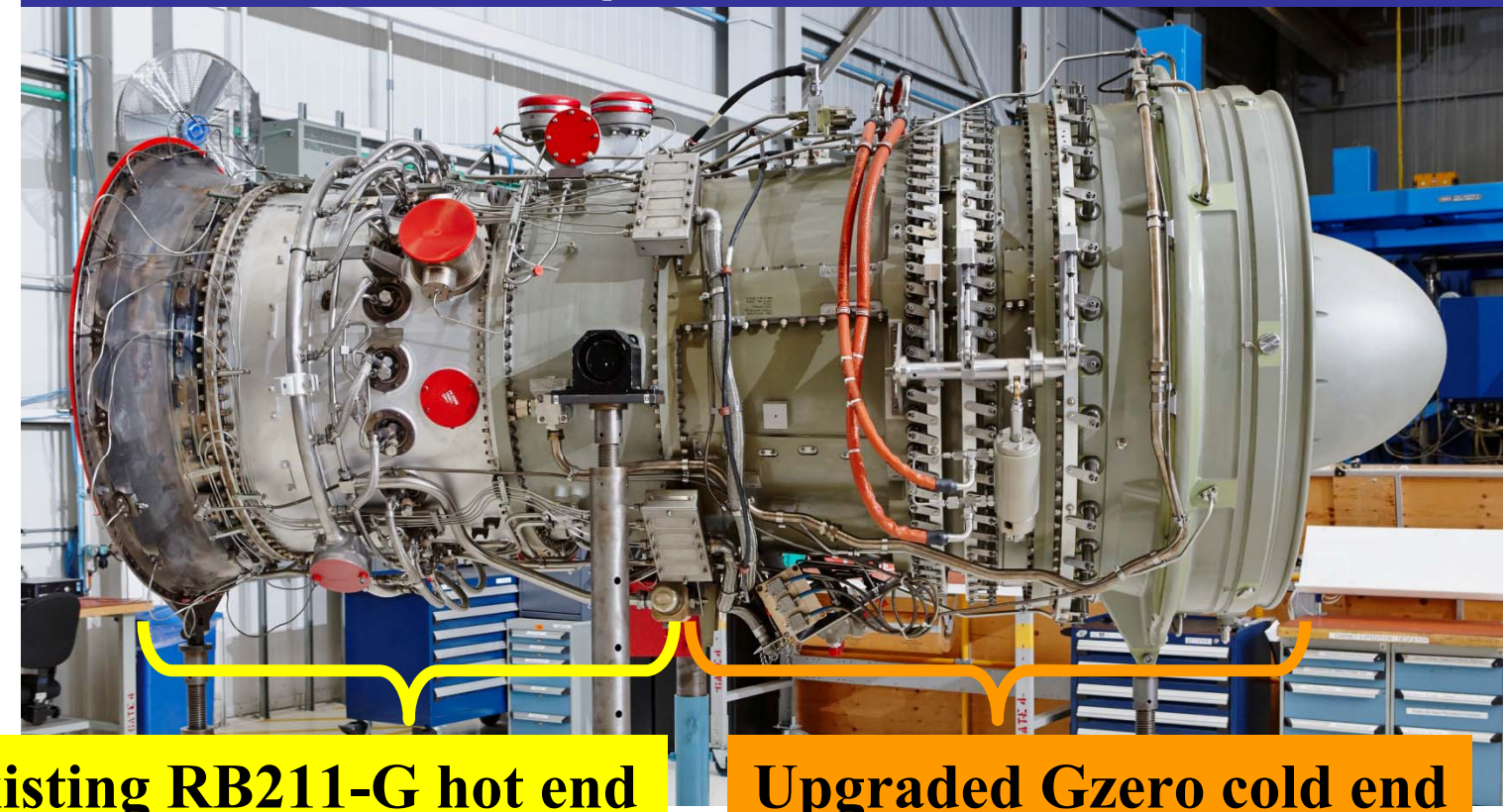
RB211-Gzero upgrade

- ✓ Retrofit for RB211 –C and –G
- ✓ +10% power, no hot end mods
- ✓ Maintained efficiency
- ✓ Applied at scheduled overhaul
- ✓ "Plug and play" engine swap
- ✓ Maintained reliability & operability

RB211-Gzero product released in 2013



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Agenda

- Product rationale
- Design features
- Engine Development Program
- Verified product attributes
- Conclusions

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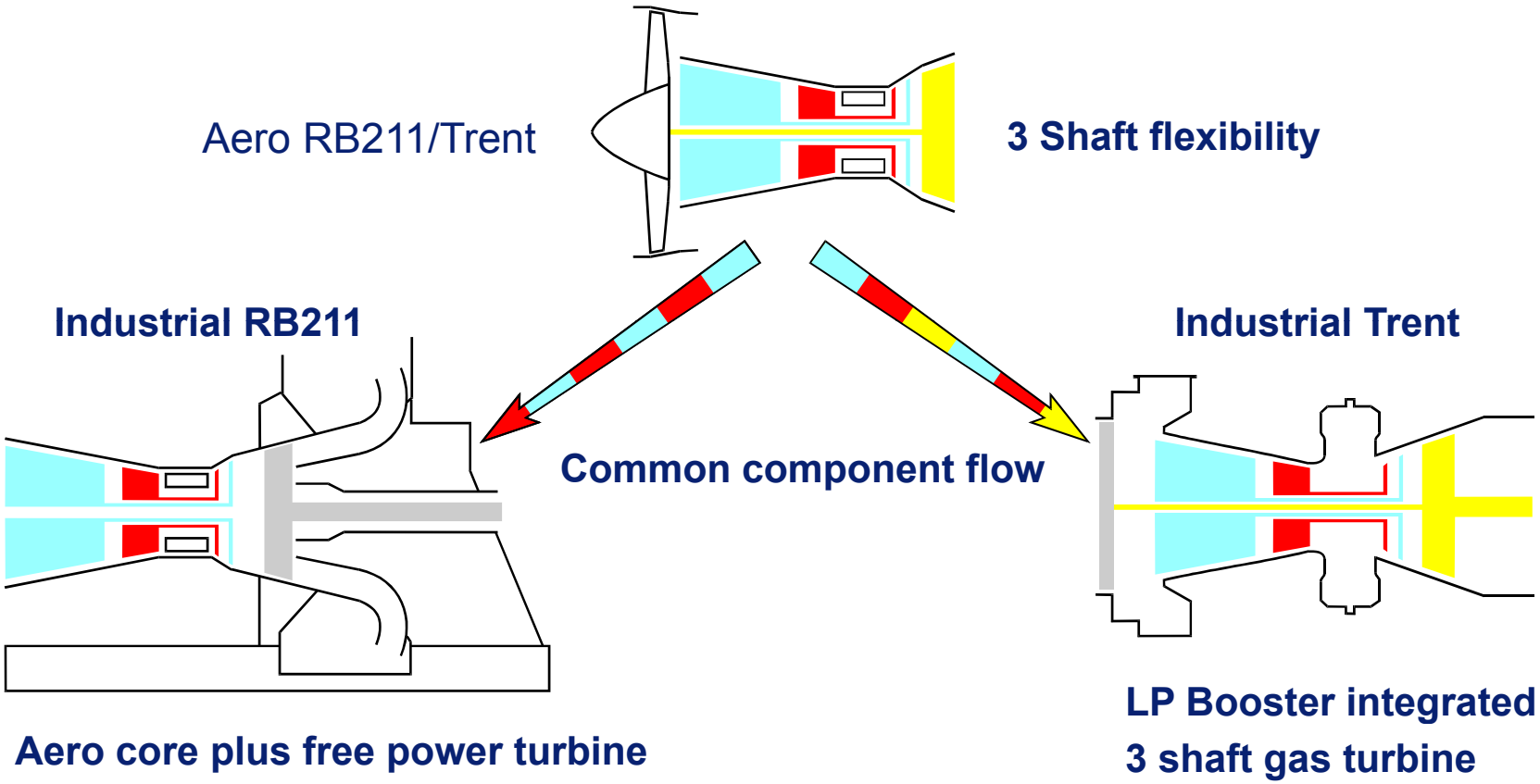
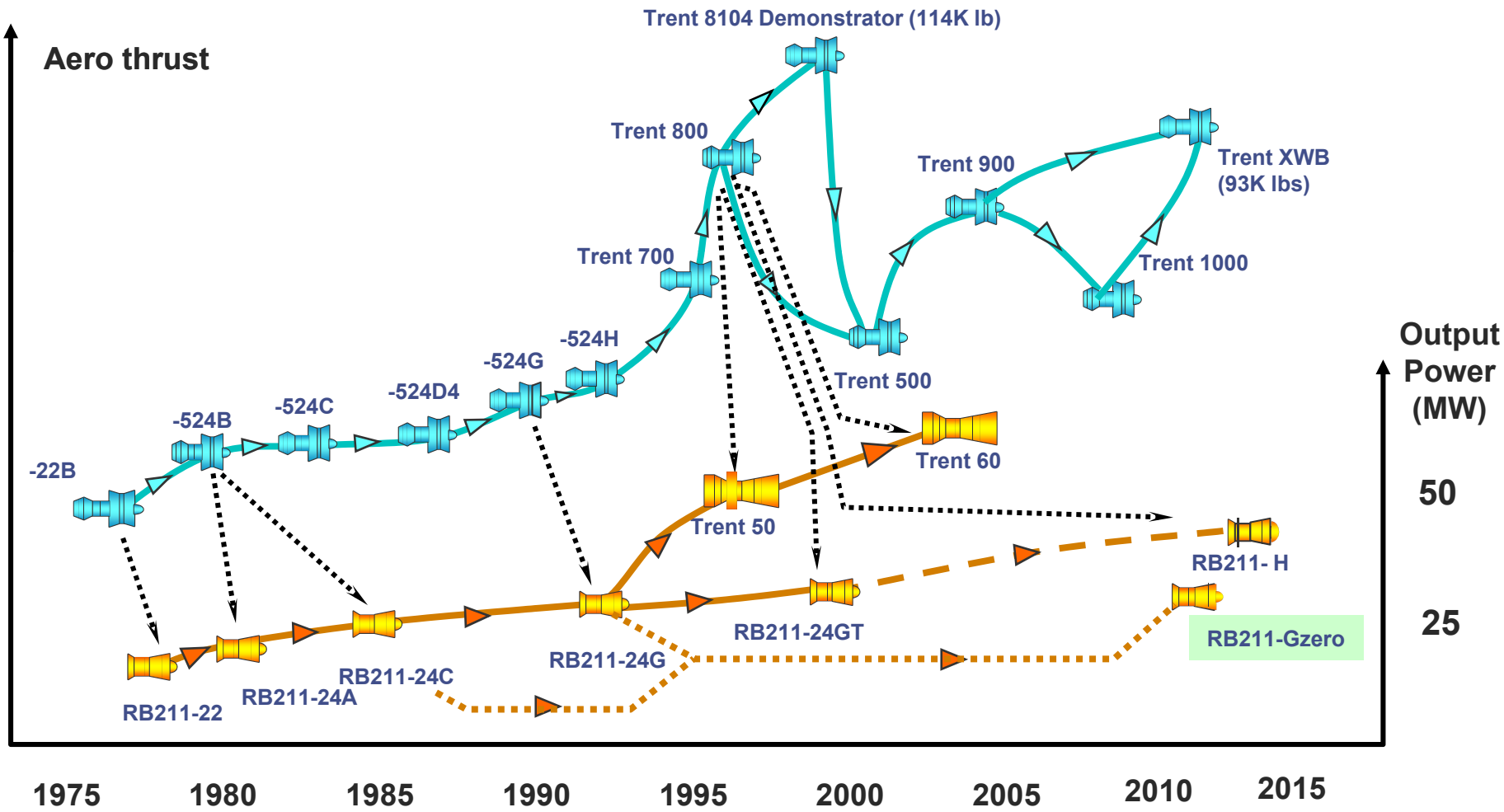
Rolls-Royce aero-derivative GT



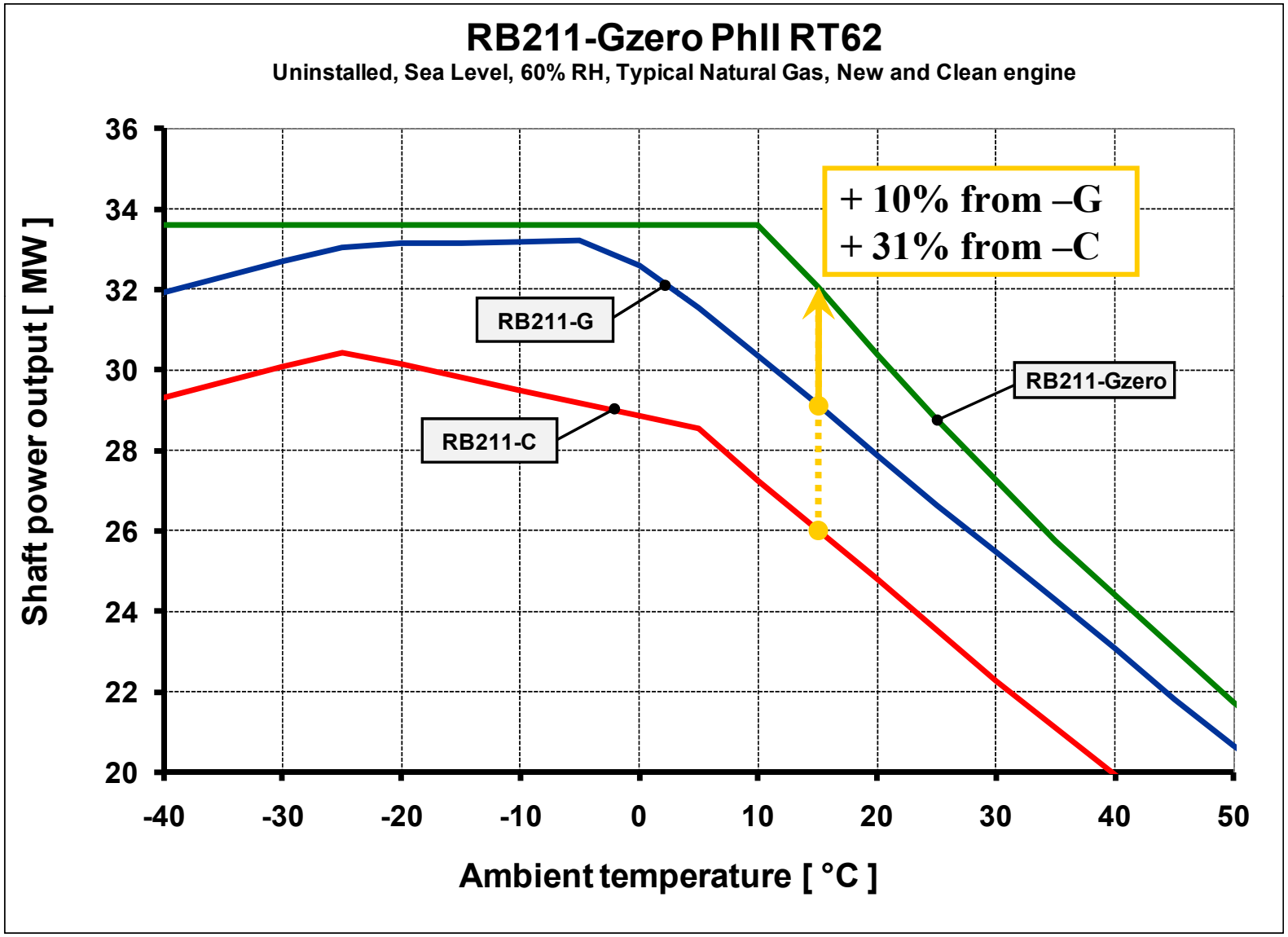
Industrial RB211

- **Over 32 Million hrs accumulated to date**
- **Many upgrades and improvements since initial introduction in 1970's**

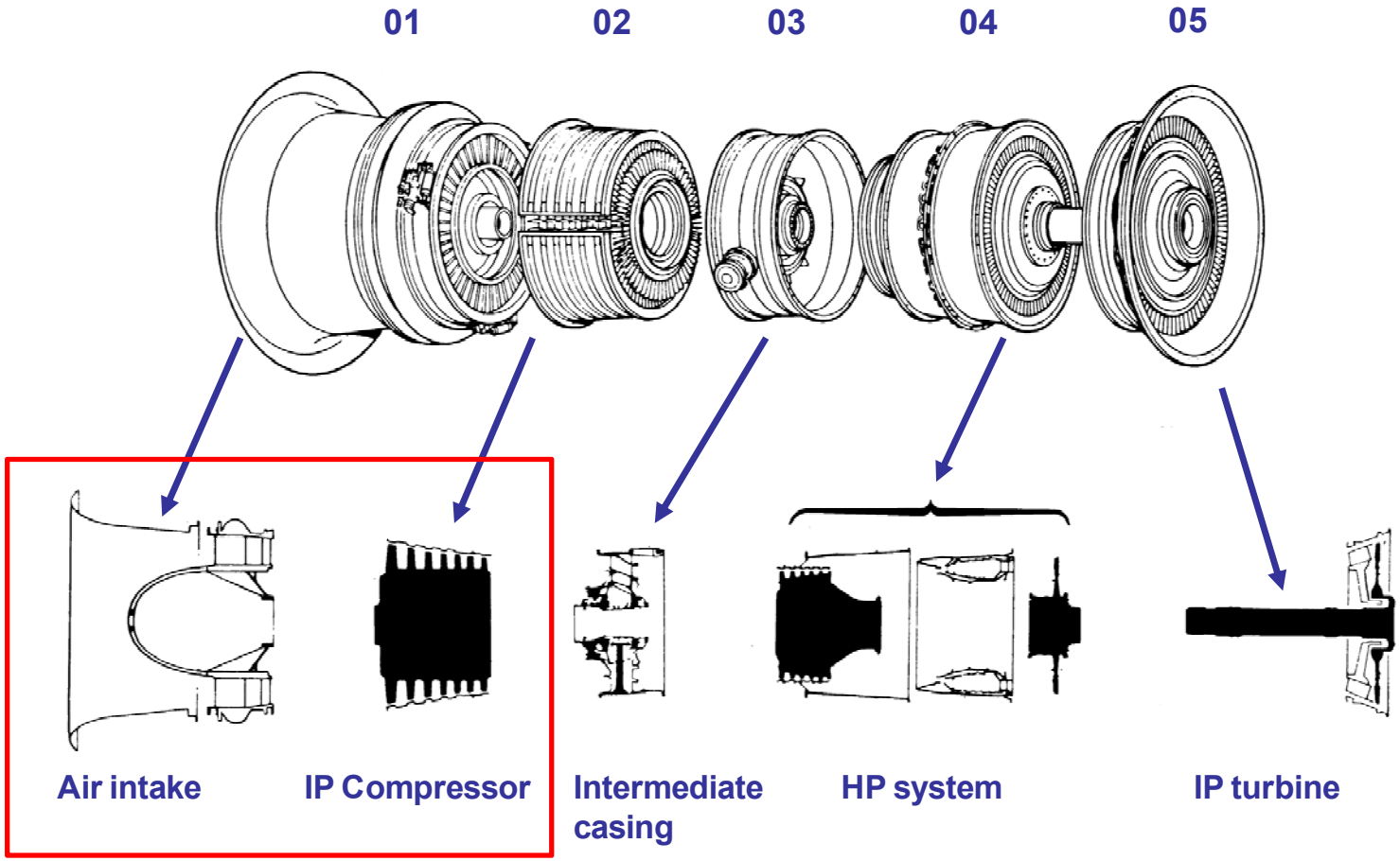
RB211 / Trent product families



Power growth



RB211 modular architecture



- **Only front-end modules modified by the Gzero upgrade**
- **Increased core flow capacity**
- **Power increase achieved without hot end modifications**

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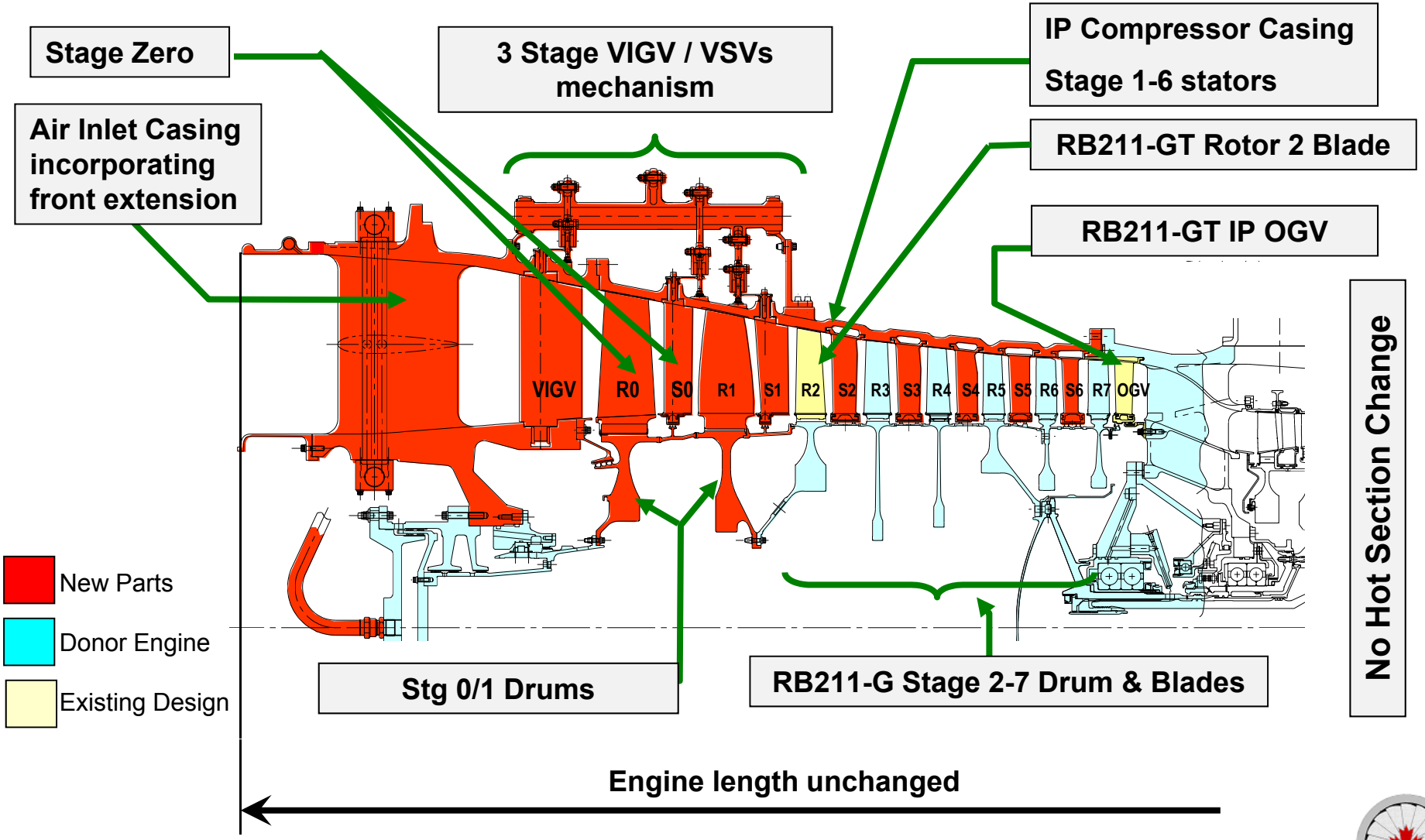
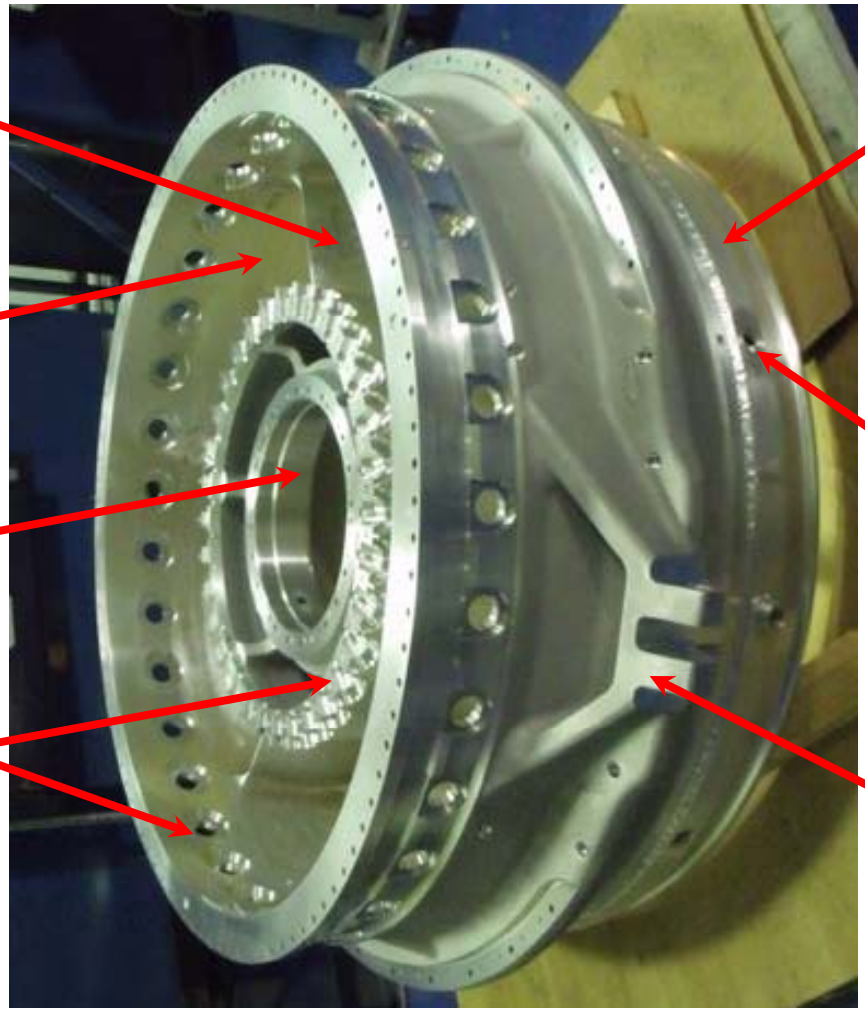
Engine cold end upgrade

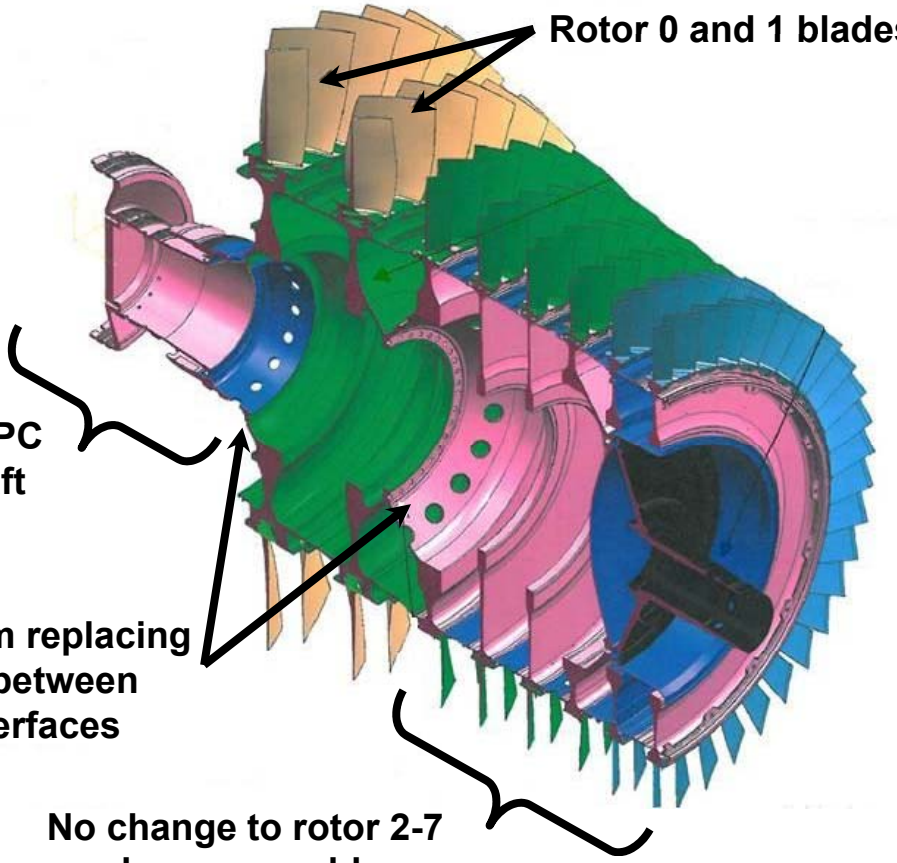


Module 01- Air Inlet Casing



Single casting incorporating all features

IP Compressor – rotor assembly



- Rotor 1 disc replaced with new 0 & 1 stage drum assembly
- Titanium discs and blades to maintain optimal rotor dynamics
- Discs and blades of rear stages (2 -7) left unchanged

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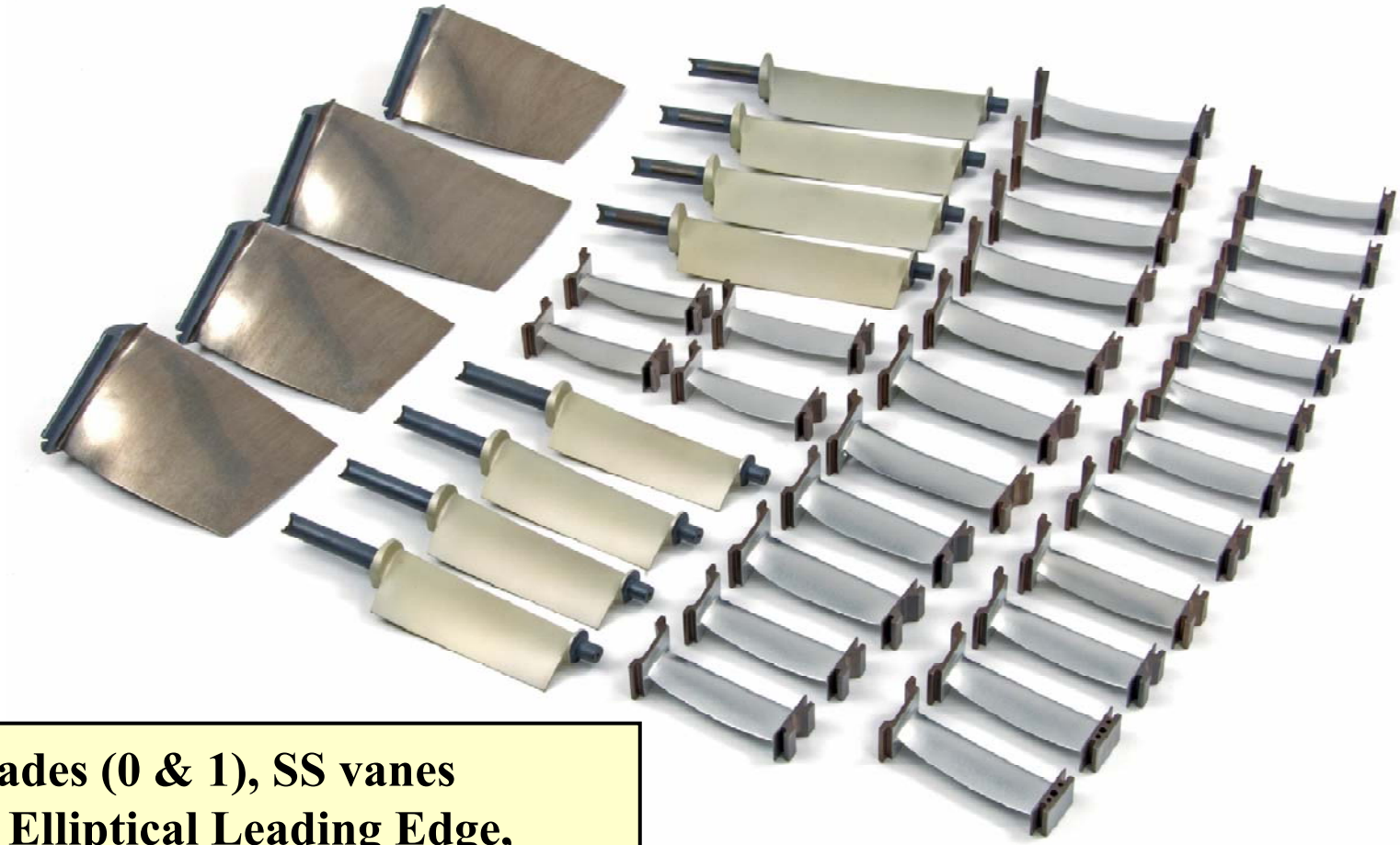
IP Compressor – blades & vanes



- **Titanium blades (0 & 1), SS vanes**
- **Blades have Elliptical Leading Edge, optimized by CFD for high efficiency**
- **Bench tested for HCF strength**
- **Three variable geometry stages**

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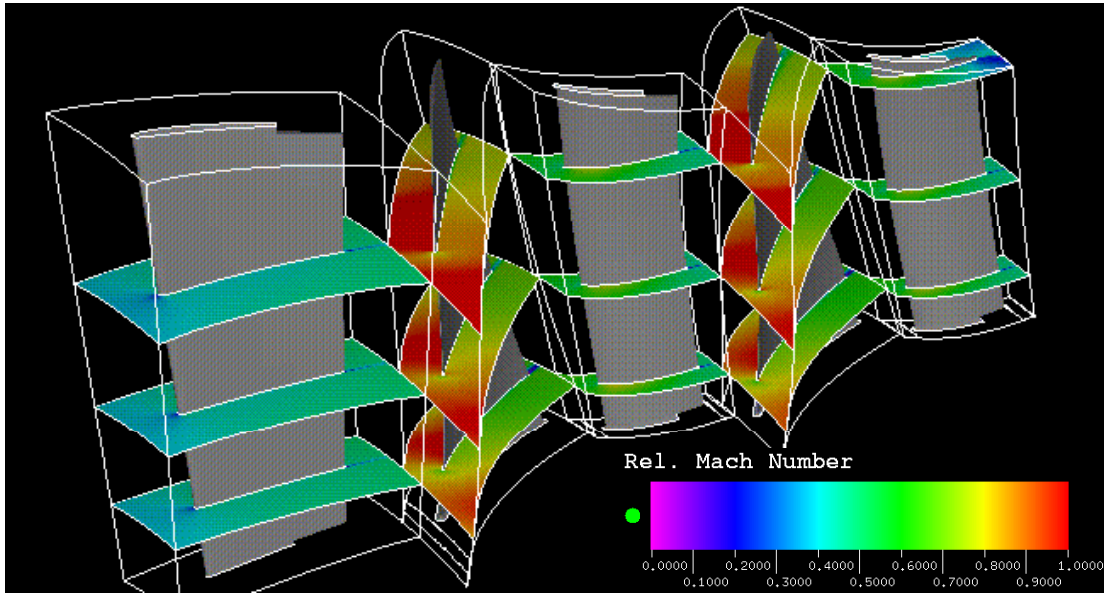
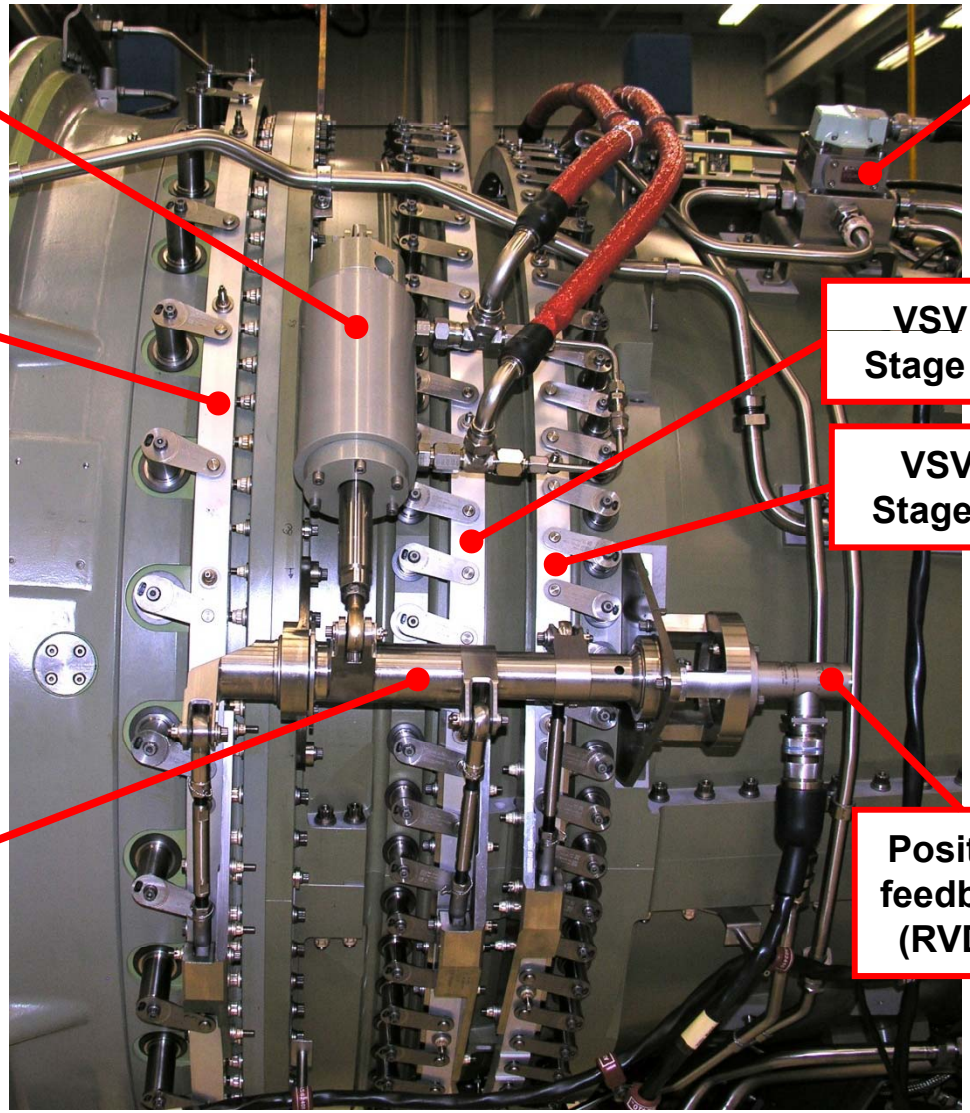
IPC design optimization

- Aerodynamics optimized by 1D, 2D and 3D CFD using latest tools for increased IPC flow and efficiency, and preserved surge margin
- Vibration response of all blades & vanes to pressure forcing from upstream & downstream stages simulated with proprietary tool
- Stator incidence angles optimized to minimize vibration response
- Stress analysis completed with 3D FEA tools
- Avoided need for complex on-engine strain gauge testing



Variable geometry actuation



- 3-stage variable geometry
- System design based on aero Trent 900
- Actuation & controls already proven in Ind. RB211 & Trent

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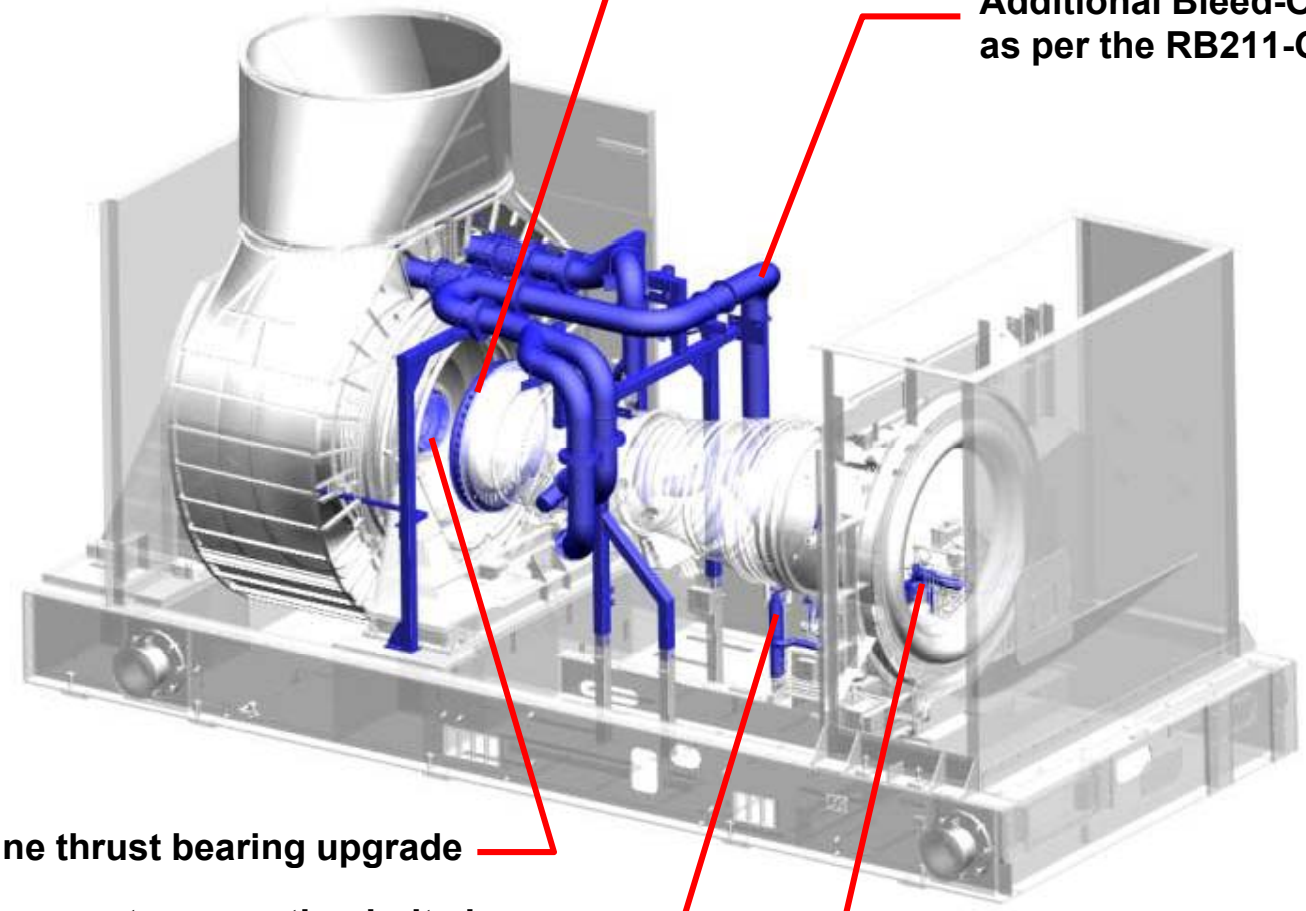
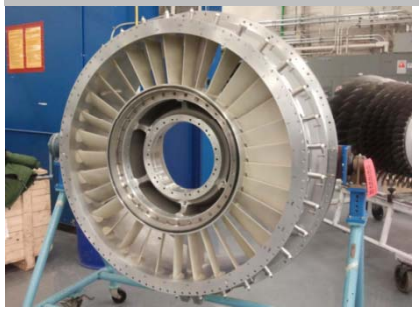
Package and Power Turbine modifications



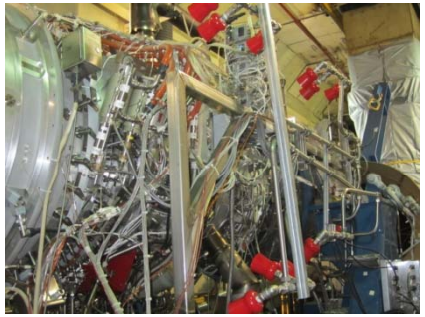
Gzero Development Engine Timeline

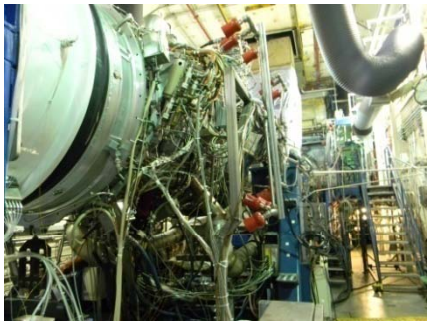
Feb 2012 – All H/W in store



May 2012 – Development Engine Build Complete

Gzero Engine in Montreal Test Bed





Jun 2012 – Sep 2012: Gzero Engine Development Program

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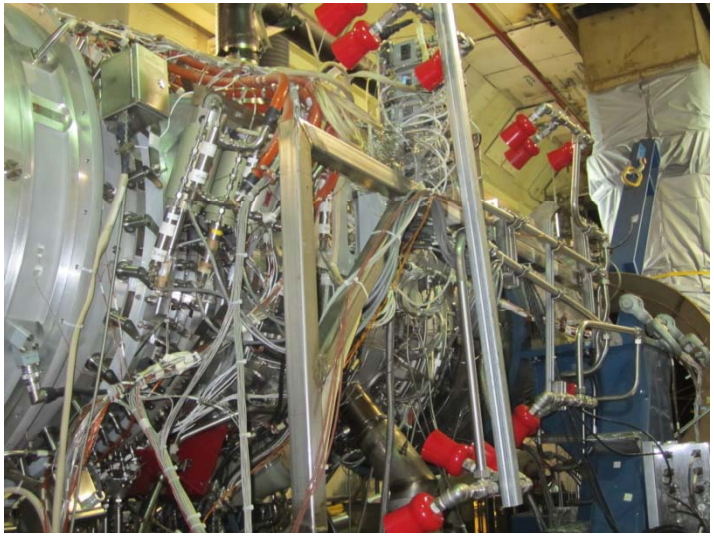
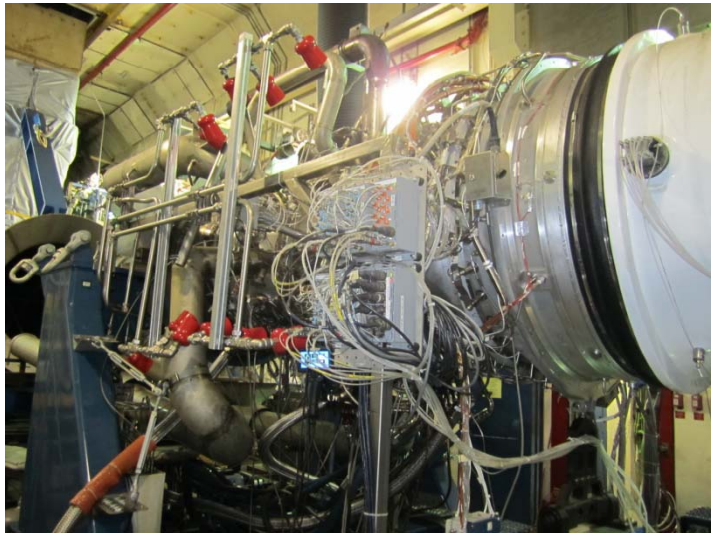
Engine Instrumentation

<u>More than 1200 parameters recorded:</u>

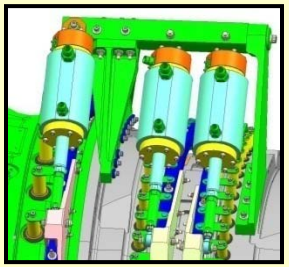
- Inter-stage instrumentation (temperature and pressure survey) in new IP Compressor for full characterization
- “Blade Tip Timing” laser probes to measure the vibration response of the new IP compressor blades while running
- Inlet air meter for accurate measurement of core flow
- Fast response dynamic pressure probes to detect the onset of compressor stall
- Capacitance probes for real-time monitoring of Compressor blade Tip Clearances
- Accurate position measurement of new variable geometry stator vanes
- Strain gauges / accelerometers
- …and more





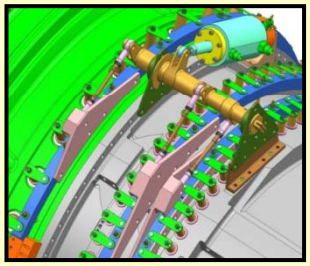
Gzero Engine Development Program

F1A Testing – 3 independent VSV stages

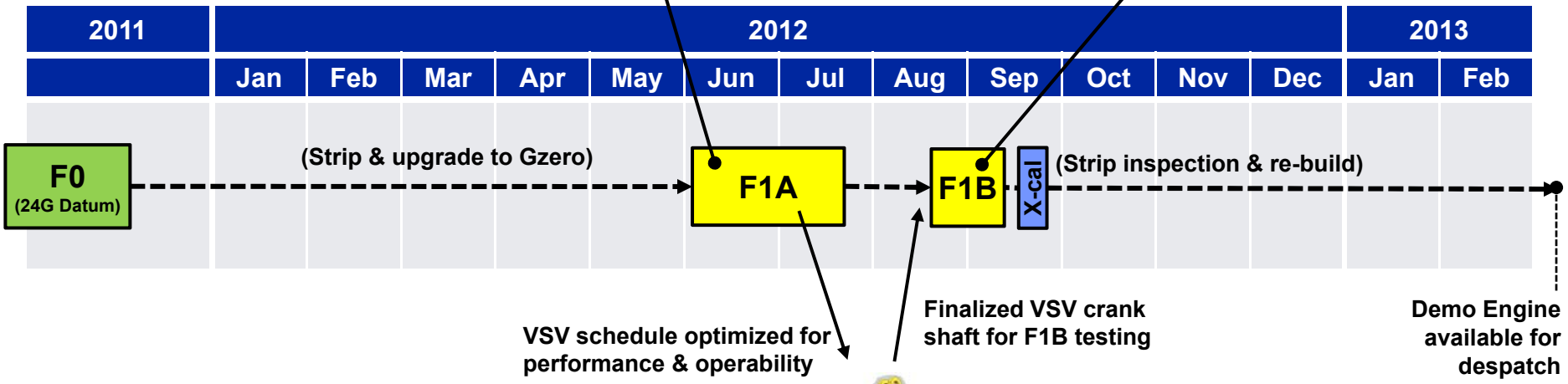


- Mapping of new IP compressor (performance, surge margin)
- Optimization of VSV schedule
- Schedule robustness

F1b Testing – Production standard VSV system



- Final verification with production crank shaft
- Fast transient response

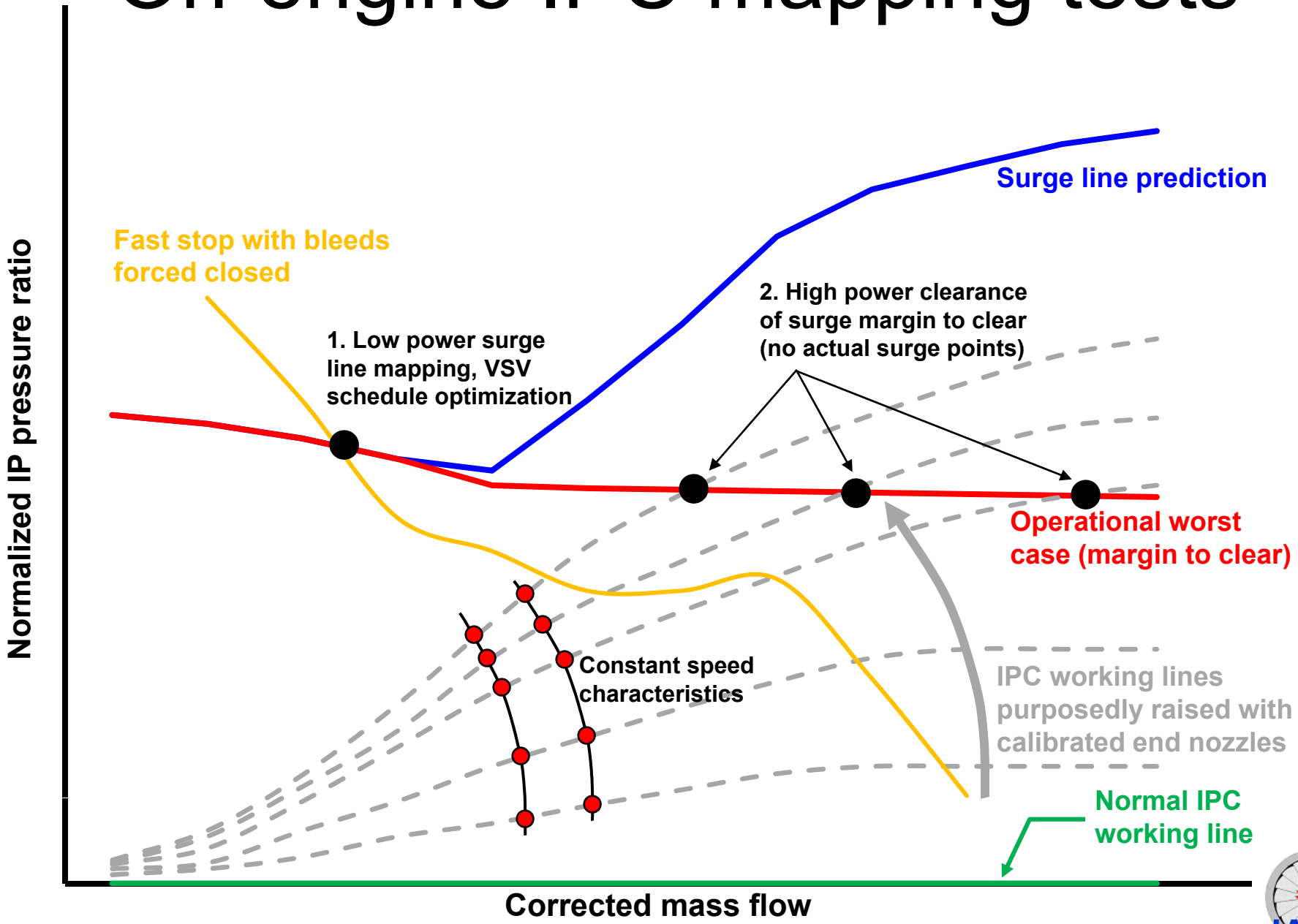


(Pre-roughed set of crank shafts for quick turnaround)

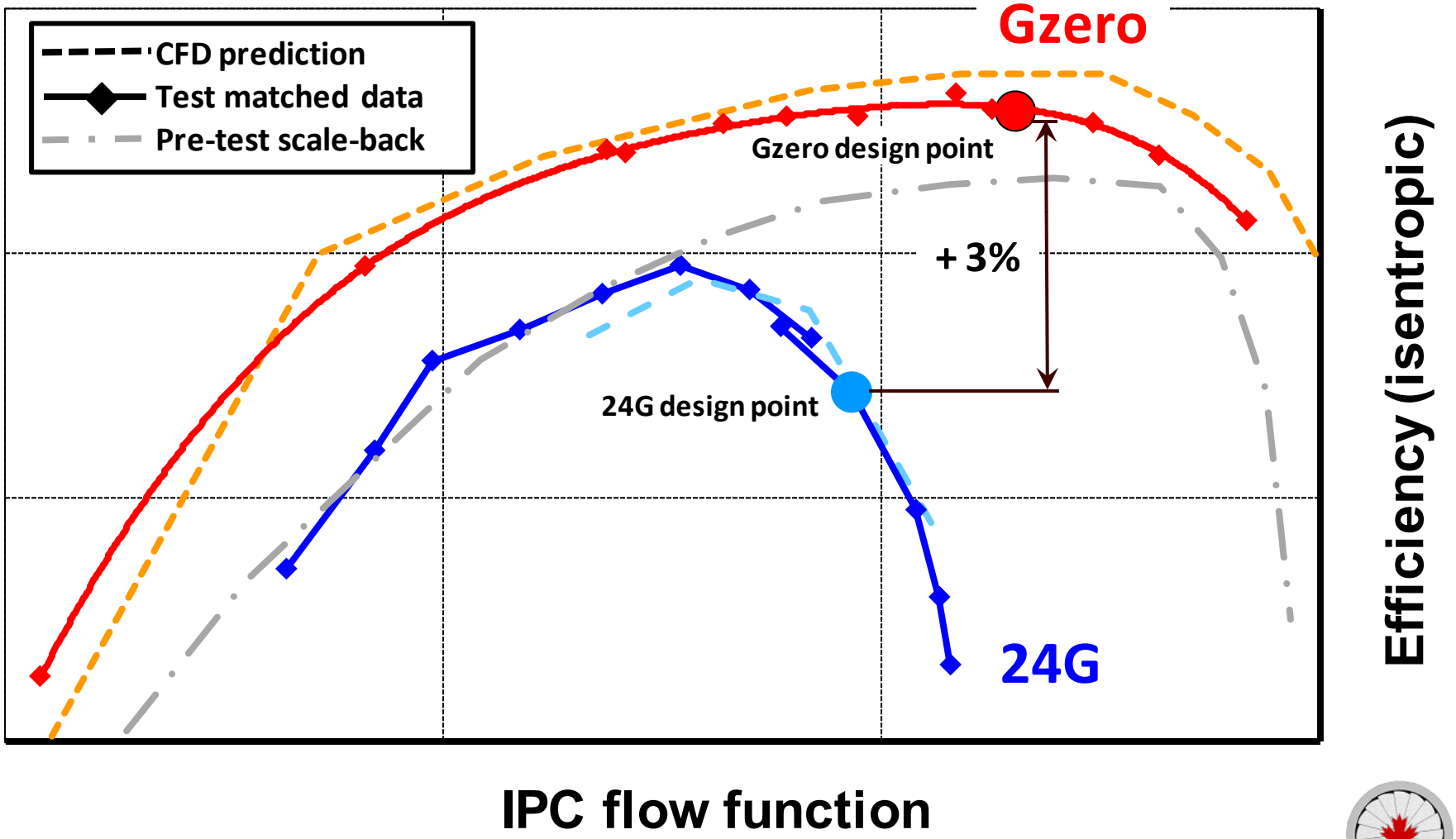
ESN424 Gzero EDP Vehicle

	24G		Gzero		
	Customer service	F0 Test	F1A Test	F1B Test	X-cal Test
Hrs	100,031	87	134	59	17
Cycles	777	113	113	48	18
	Production	Development			

On-engine IPC mapping tests

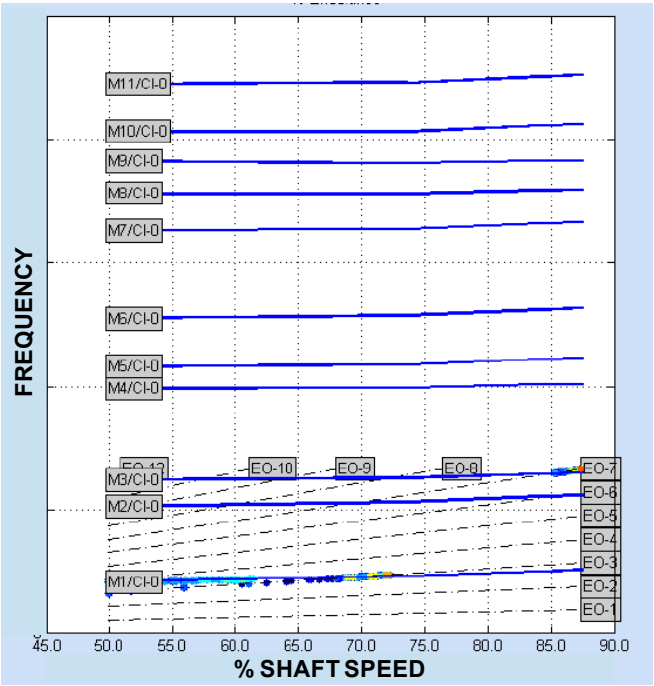


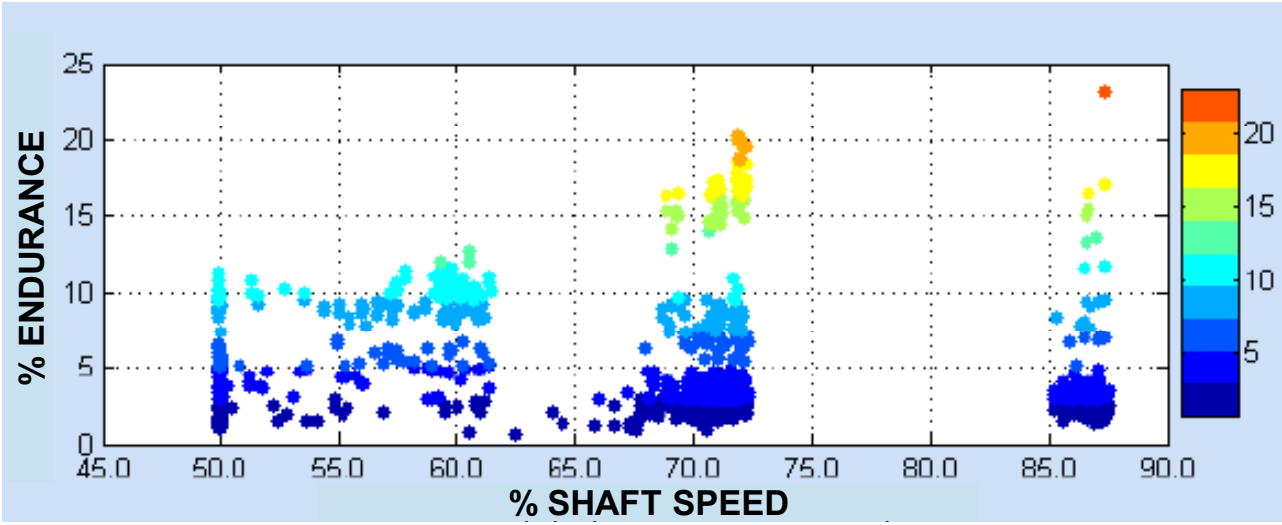
Test results – IPC performance



Compressor blade vibration

- **Blade response to engine forcing monitored real time with "tip timing" optical probes across entire range**
- **Data processed to calculate "endurance ratios" of blade response vs. HCF strength**
- **Max response less than half the HCF initiation threshold**
- **Pre-test analysis confirmed – HCF not an issue**





Verified technical attributes

Attribute	Target	Result	Data
Power growth	+ 10% or more	✓	Slightly better than expected. Opportunity to grow beyond initial 10%.
Surge margin	To clear operational worst case	✓	IPC stack-up cleared by extensive testing. HPC surge margin maintained.
Efficiency	No less than 24G	✓	Higher than 24G.
Gas Generator Exit Temperature (TGT)	No higher than 24G	✓	Lower than 24G.
Operability	No worse than 24G	✓	Fuel transfers OK, no auto-ignition. Load step capability maintained.

Conclusions

- Gzero provides 10% power increase for existing RB211 without hot end modifications
- Focused introduction of today's best technology into a proven engine core
- "Plug-and-play" aftermarket upgrade
- Product attributes verified by extensive testing
- Novel analysis & test techniques successfully utilized to reduce development risk & lead time
- Verification program complete, Demonstrator Engine available

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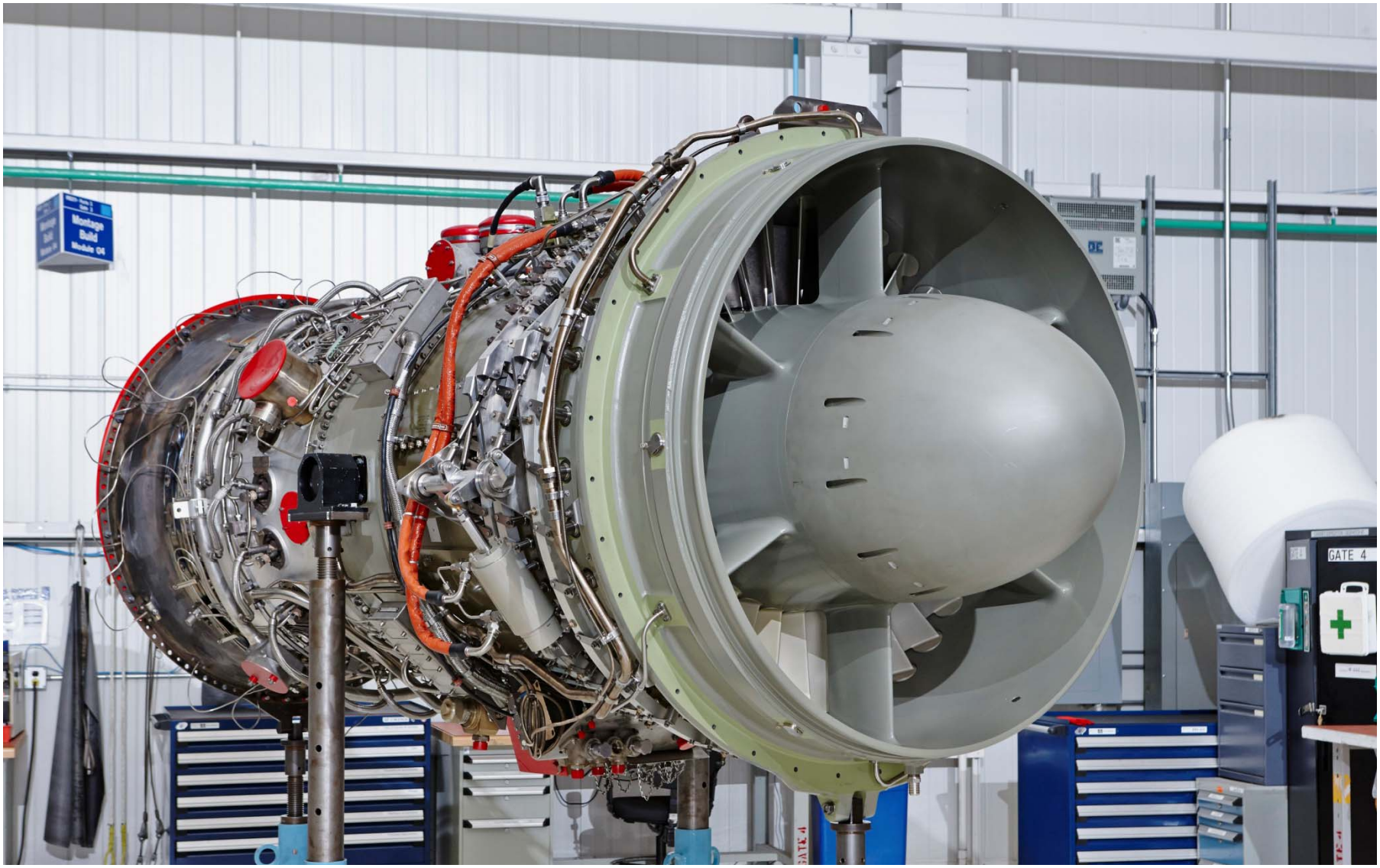

THANK YOU

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