GO BEYOND

CLEEN III: Fan Module Technologies Development &
TALON® X+ Combustor Module Enhancements
693KA9-21-T-00005

PRATT & WHITNEY – FAA CLEEN III CONSORTIUM
INDUSTRY DAY / PUBLIC SESSION -- VIRTUAL MEETING

NOVEMBER 3, 2021

Raytheon Technologies

180,000 employees worldwide

$57* billion 2020 sales

$8 billion annual customer- and company-funded R&D spend

10 Enterprise-wide development capability centers

Pratt & Whitney

$17B 2020 sales

39,000 employees

195 customer countries

*TOTAL COMPANY REVENUES FOR RAYTHEON TECHNOLOGIES EXCLUDES INTERCOMPANY SALES BETWEEN THE BUSINESSES.

Pratt & Whitney - GTF

CREATING THE NEXT GENERATION

Photo, Credit Pratt & Whitney

5 AIRCRAFT PLATFORMS > 1000 Aircraft Delivered

On Hold

16%
Reduction in Engine Fuel Consumption

75%
Reduction in Noise Footprint

50%
Reduction in Regulated Emissions

10,000+
Orders and Commitments

80+
Customers

ANNUAL OPERATOR SAVINGS >$1M PER AIRCRAFT

Much More Than The Gear

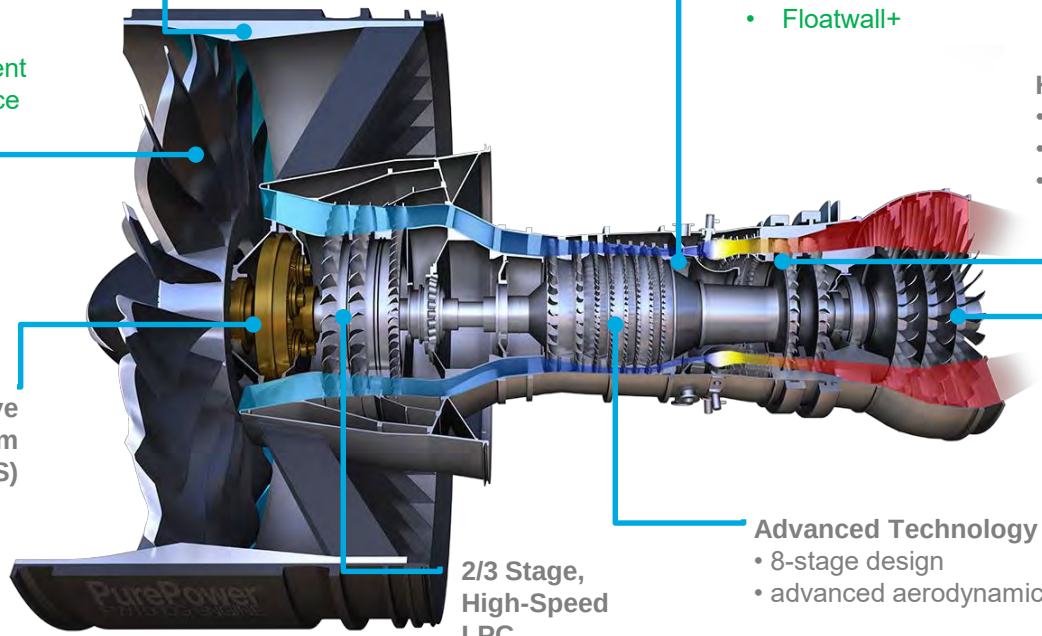
SUITE OF TECHNOLOGIES ACROSS THE ENGINE

Advanced Fan & Composite Case

CLEEN III Opportunities:
- Advanced MFG
- Acoustic Liner Development
- Improved Fan Performance

Very High Bypass, Light Weight Fan

Fan Drive Gear System (FDGS)



2/3 Stage, High-Speed LPC

TALON® X+ Combustor:

CLEEN III Opportunities:
- Noise Robust Swirler
- Low Pattern Factor
- Floatwall+

High Efficiency Advanced HPT:
- advanced aerodynamics
- advanced sealing / cooling
- durability technologies

3-Stage, High-Speed LPT

Advanced Technology HPC:
- 8-stage design
- advanced aerodynamics – CLEEN II

Pratt & Whitney Integrating Customer Needs

LOWER ENGINE CASH OPERATING COST & ENVIRONMENTAL SUSTAINABILITY

20%

Market Drivers, Initiatives & Commitment to Action

- Fuel
- Maintenance cost
  - Noise
    - Emissions
      - Reliability
        - Sustainability
        - Product Cost
        - Capability

Domestic & International pledges

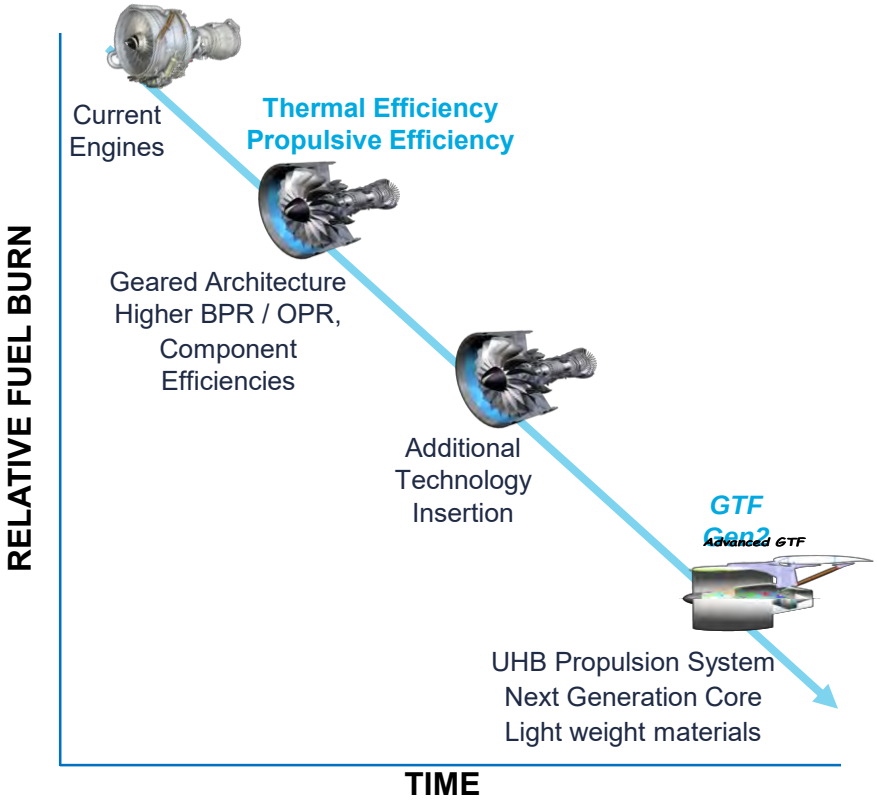
CLEEN Program Goals

Develop and demonstrate (TRL 6-7) certifiable aircraft technology

CORNERS OF THE TRADE SPACE	CLEEN (N+1) (EIS 2015-18) Ref: B737/CFM56-7B	N+2 (2020)* Ref: B777-200/GE-90	N+3 (2025)*
Noise (cum below Stage 4)	-32 dB	-42 dB	-71 dB
LTO NO_x Emissions (Below CAEP 6)	-60%	-75%	better than -75%
Aircraft Fuel Burn	-33%	-50%	better than -70%

* Technology Readiness Level for key technologies = 4-6

Strategy For Future Growth

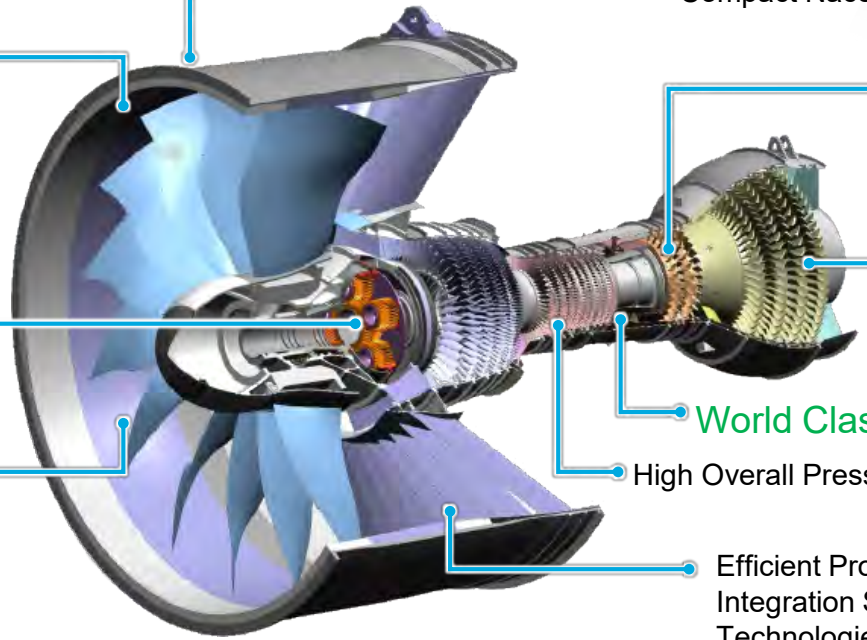


Photo, Credit Pratt & Whitney

Future Generation GTF Engine

GTF GEN2 – INSPIRED BY EXPERIENCE, SUSTAINABILITY & COLLABORATIVE INNOVATION

CLEEN III INITIATIVES HELP ENHANCE FUTURE ENVIRONMENTAL PRODUCT OFFERINGS



Advanced Fan Case & Compact Nacelle

Next Gen Advanced Fan

HPT High-Temperature Materials Advanced Cooling Technologies

High-Speed, High-Efficiency LPT

Fan Drive Gear System (FDGS)

World Class Sustainable Combustor

Digital Analytics & Advanced Manufacturing Technologies

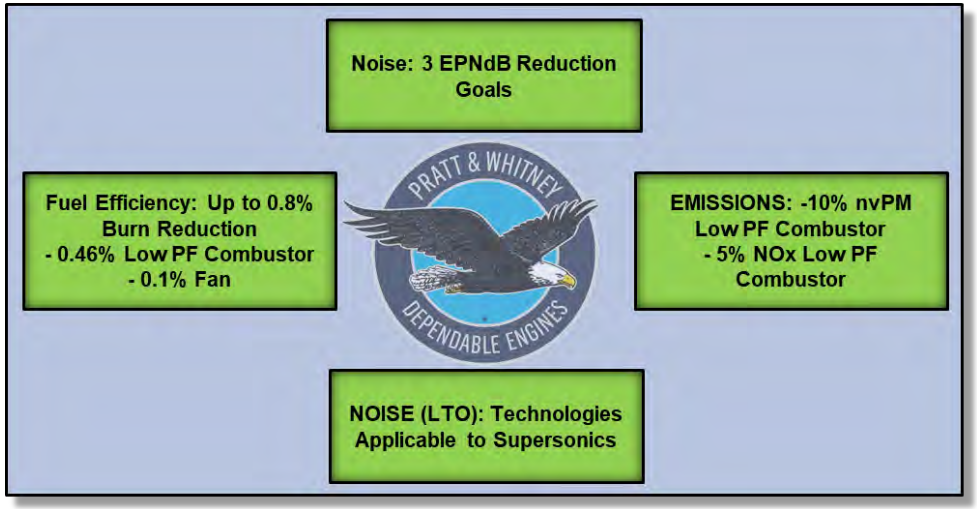
High Overall Pressure Ratio, Small Core

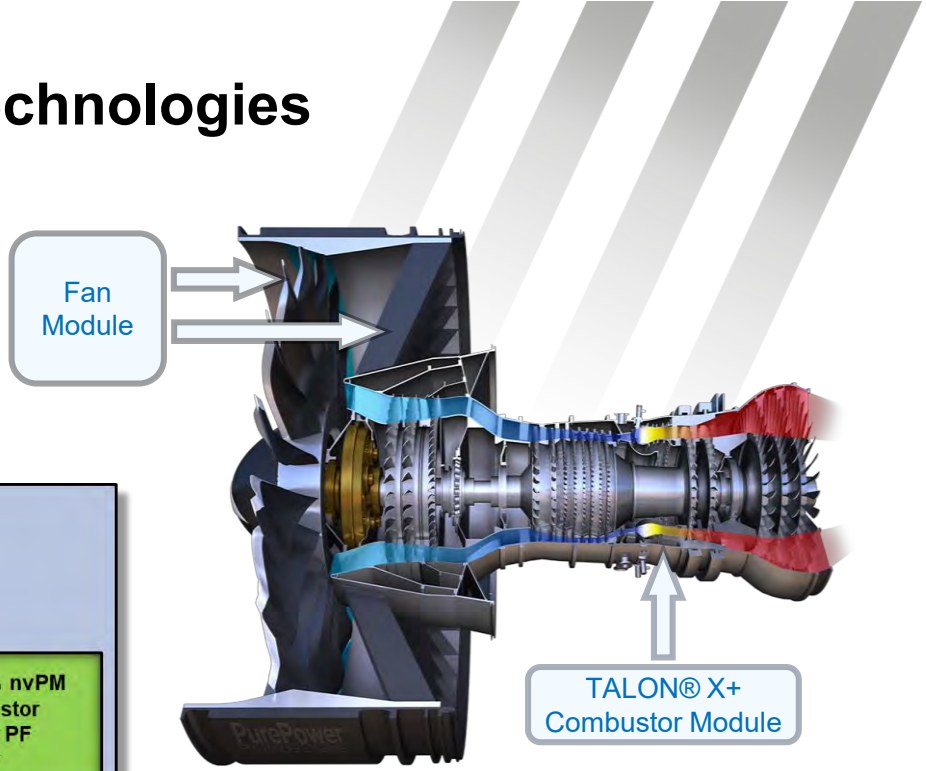
Efficient Propulsion-Airframe Integration Sub-Systems & Technologies

Pratt & Whitney's CLEEN III Technologies

OVERALL PROGRAM GOALS AND OBJECTIVES

- **Additively Manufactured Acoustic Liners**
- **Low-Loss Intra-Stage Liners**
- **Low-Count / Low-Noise Guide Vanes**

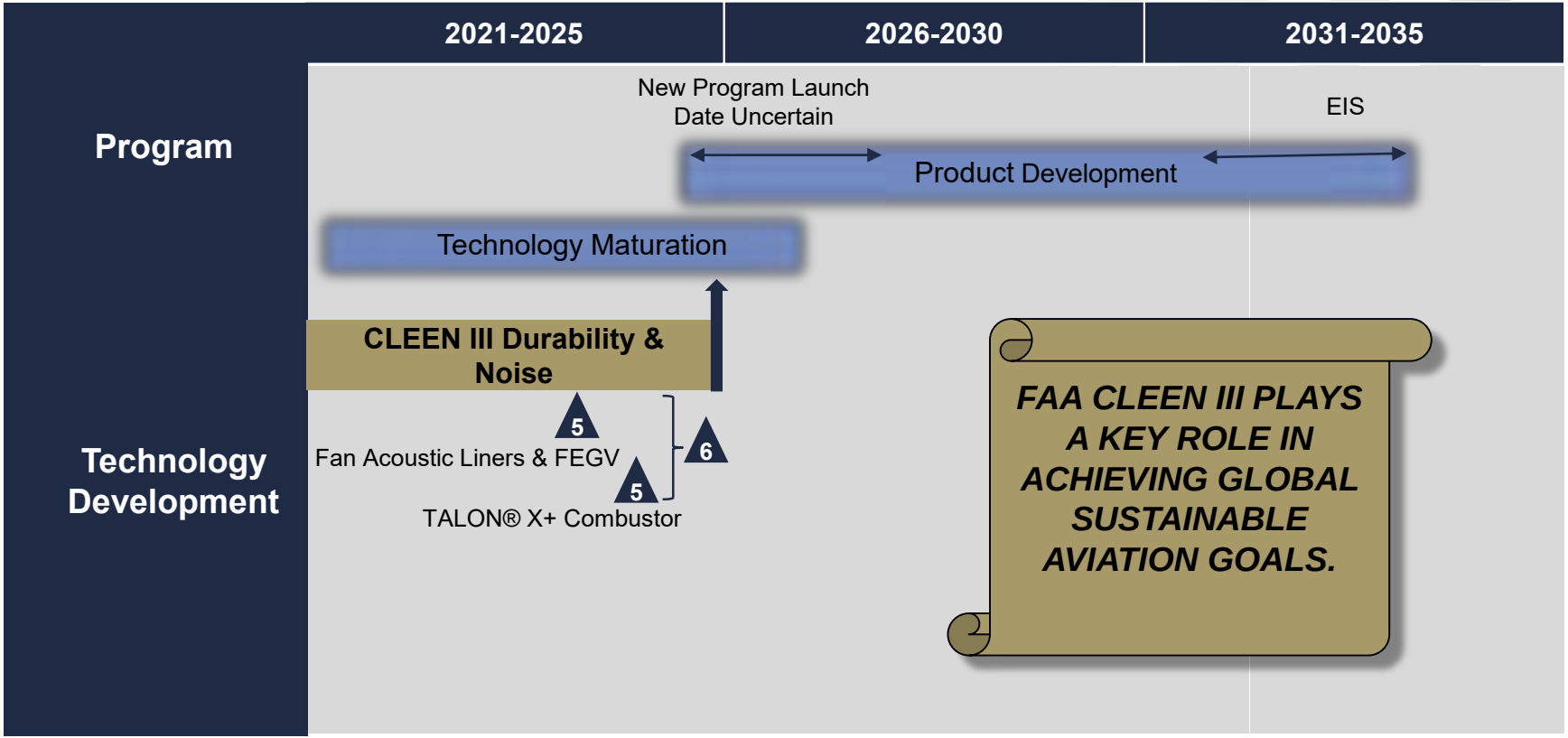




- **Noise Robust Swirler**
- **Low Pattern Factor**
- **Floatwall+**

Pratt & Whitney's CLEEN III Technologies

NEW PRODUCT ROADMAP STRATEGY CHART

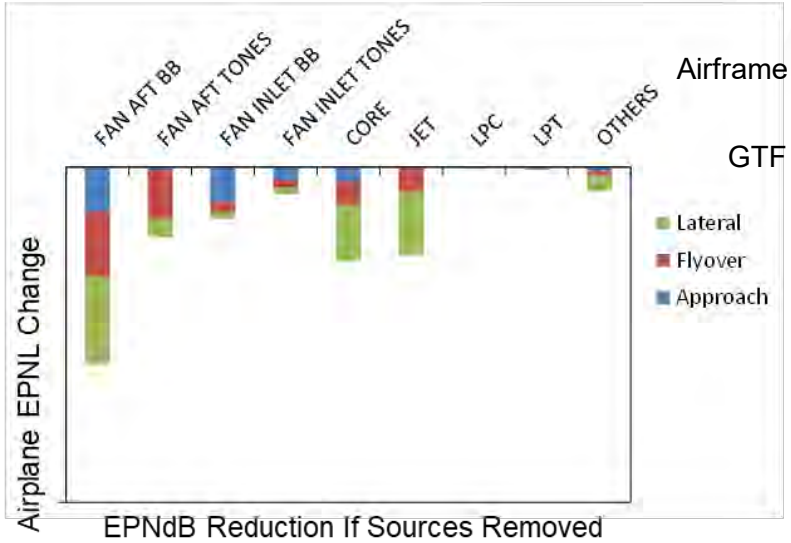


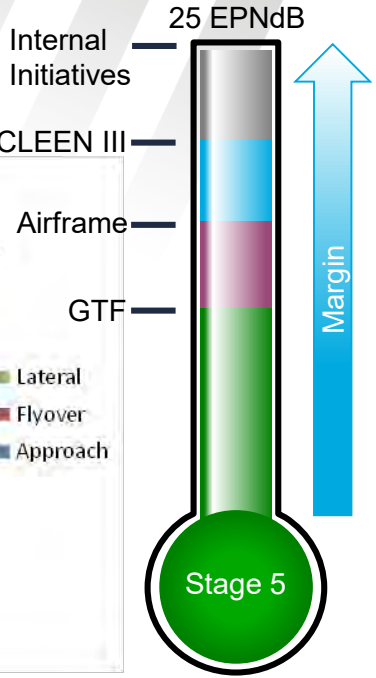
Fan & Combustor Noise Reduction Enable Noise Goals

FAA Goal:
25 EPNdB Cumulative Margin to Stage 5

- ✓ **GTF Noise 12 – 13 EPNdB Margin to Stage 5**

- FAA CLEEN III 3 EPNdB Noise Reduction Goals (WIP)
  - Focus is on fan and combustor component noise reduction





Pratt & Whitney's CLEEN III Technologies

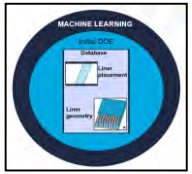
NEXT GENERATION FAN MODULE

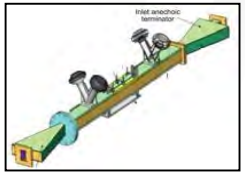
Technologies:

- Additively Manufactured Acoustic Liners
- Low-Loss Intra-Stage Liners
- Low-Count / Low-Noise Guide Vanes

Benefits:

- Improve Liner Effectivity for Noise
- Compact Liner Designs Improves Weight
- Low Loss Acoustic Liner Reduces Fuel Burn
- Acoustically Treated FEGVs Targets Source





Photos, Credit Pratt & Whitney

Advanced MFG & Machine Learning → Acoustic Tunnel & Grazing Flow → Engine 2025

Objectives:

Demonstrate Advanced Fan Acoustic Tools & Technologies that will enhance the next Generation GTF.

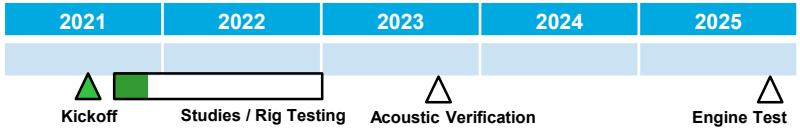
Ahead of us:

- Additive MFG Trials & Quality Sampling
- Environmental and Chemical exposure
- Automated Machine Learning Trials
- Include Flight and Broadband Analytics

Accomplishments:

- ✓ Created AM test article to establish manufacturing limits
- ✓ Machine Learning - Initial DOE Tools Integrated
- ✓ Preliminary DOE for Automated Tone Noise Assessments

Schedule & Planned Milestones:



Pratt & Whitney's CLEEN III Technologies

TALON® X+ COMBUSTOR MODULE

Technologies:

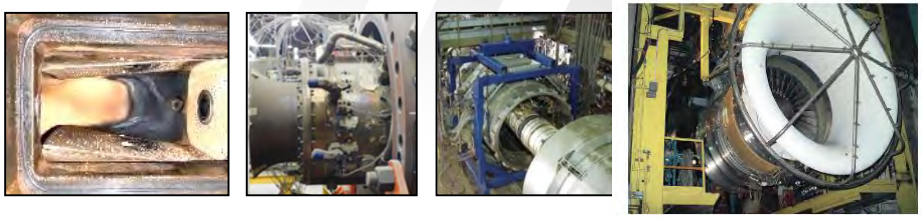
Noise Robust Swirler:
- Improves fuel/air uniformity for decreased NOx and nvPM

Floatwall+:
- Reduces Cooling air, Exit Thermals & Emissions

Low Pattern Factor Combustor:
- Improved CFD capability for complex flow and geometric variation.

Benefits:

- Contributes to the 3 EPNdB Noise Reduction
- >10% nvPM reduction
- > 5% NOx reduction
- 0.46% improvement in engine efficiency
- Improved life combustor liners



Photos, Credit Pratt & Whitney

Single Sector 2021-2022 → Multi-Sector and Full Annular 2023-2024 → Engine 2025

Objectives:

Demonstrate combustor technologies address core noise, engine efficiency and emissions

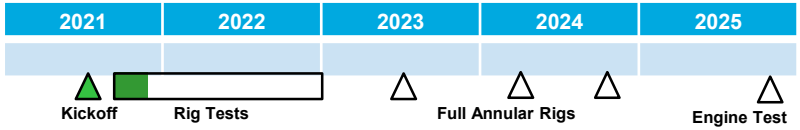
Ahead of us:

Develop the constituent combustor technologies (Noise Robust Swirler, Floatwall+, and Low Pattern Factor Combustor) with CFD and single nozzle rigs, then integrate and test in full annular rigs

Accomplishments:

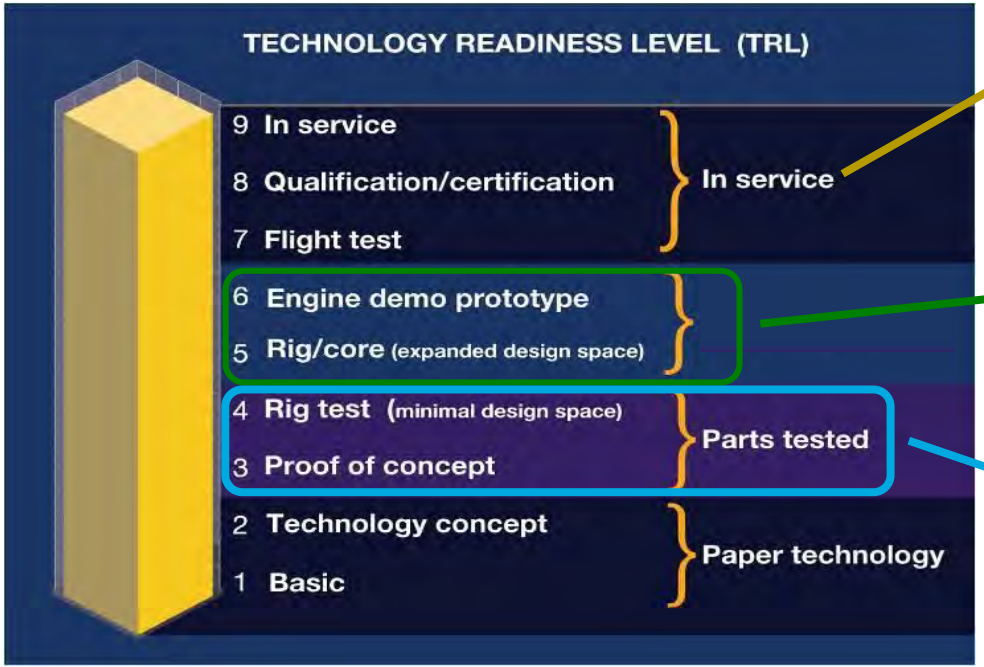
✓ Rig tests and CFD initiated

Schedule & Planned Milestones:



Technology Maturation in CLEEN

TECHNOLOGY DEMONSTRATION WILL FOLLOW PROVEN PROCESS TO VERIFICATION



Photos, Credit Pratt & Whitney

Summary

- PW1100G-JM engine ideal candidate for high bypass ratio technology demonstrator vehicle
  - Mature foundation to build upon to achieve FAA CLEEN III goals with high probability of success
  - Direct product relevance for both next generation and retrofit opportunities

- P&W progressing in maturing high bypass ratio fan and combustor technologies through analytics, component rigs, and engine demonstration
  - The Pratt & Whitney team is fully engaged
  - Initial cost, schedule, risk, and technical maturation planning complete, and execution in-process
  - CLEEN III goals remain at the forefront during these early stages of the program

GO BEYOND

THIS DOCUMENT HAS BEEN PUBLICLY RELEASED.