National Aeronautics and Space Administration

HyTEC
Hybrid Thermally Efficient Core

HyTEC Project Overview

Tony Nerone, Project Manager

8th International Workshop on Aviation and Climate Change

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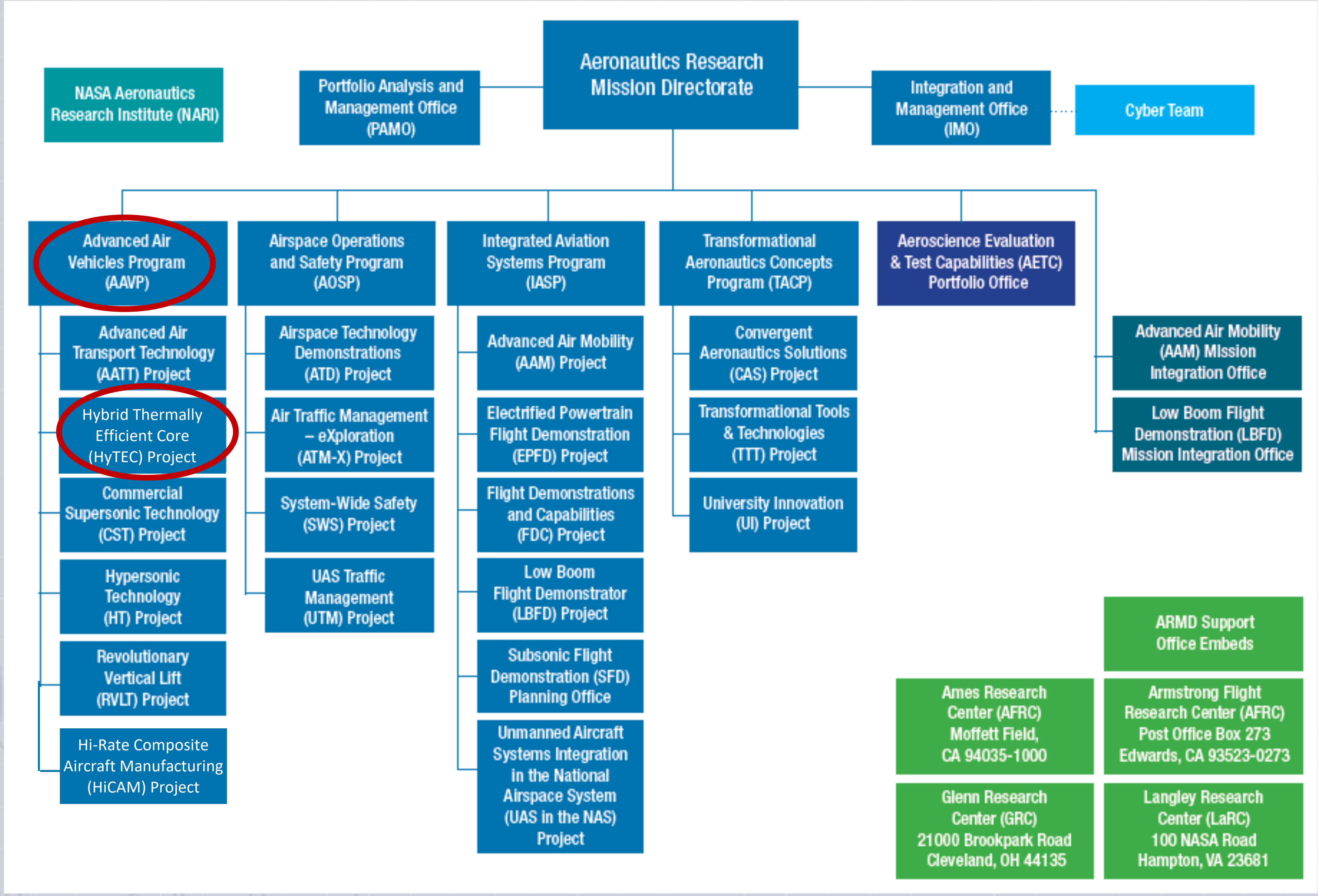
www.nasa.gov

NASA ARMD Organization



HyTEC Project Organization FY23

Hybrid Thermally Efficient Core (HyTEC) Project Structure

Project Manager
Tony Nerone

Deputy Project Manager
Leah Nakley (Acting)

Chief Engineer
Joe Haglage

Lead Systems Engineer
Bob Tornabene

Aero CSO
Scott Numbers

Technical Advisors

AATT SA&I Liaison	*Jeff Chapman*
Turbine Engine Tech	*Ken Suder*
Aeropropulsion	*Mark Turner*

Project Planning and Control Team

Resource Analyst	*Kathy Lentz*
Scheduler	*April Albert*
Risk Manager	*Kelli Peterson*
Project Coordinator	*Ashley Marshall*
Config. and Data Mgr.	*Michael Rogers*

Acquisition Team

Contracting Officers	*Ian Park*
	Linda Nabors

Hybrid, Compressor, and Combustor Technology Subproject
SPM: *Kim Pham*
SE: *Bob Tornabene/Joanne Walton*

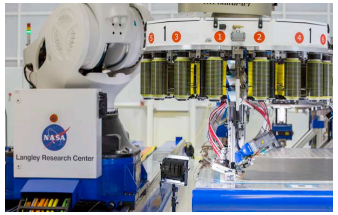
Technical Leads
High Pressure Compressor (HPC)
Sameer Kulkarni
Turbofan Power Extraction (PEx)
Joe Connolly
Combustion
Joe He

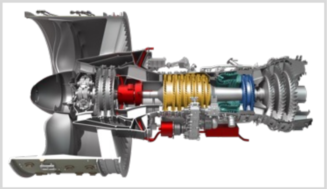
Materials and Turbine Technology Subproject
SPM: *Laura Evans (Acting)*
SE: *Amelia Wilson/Joanne Walton*

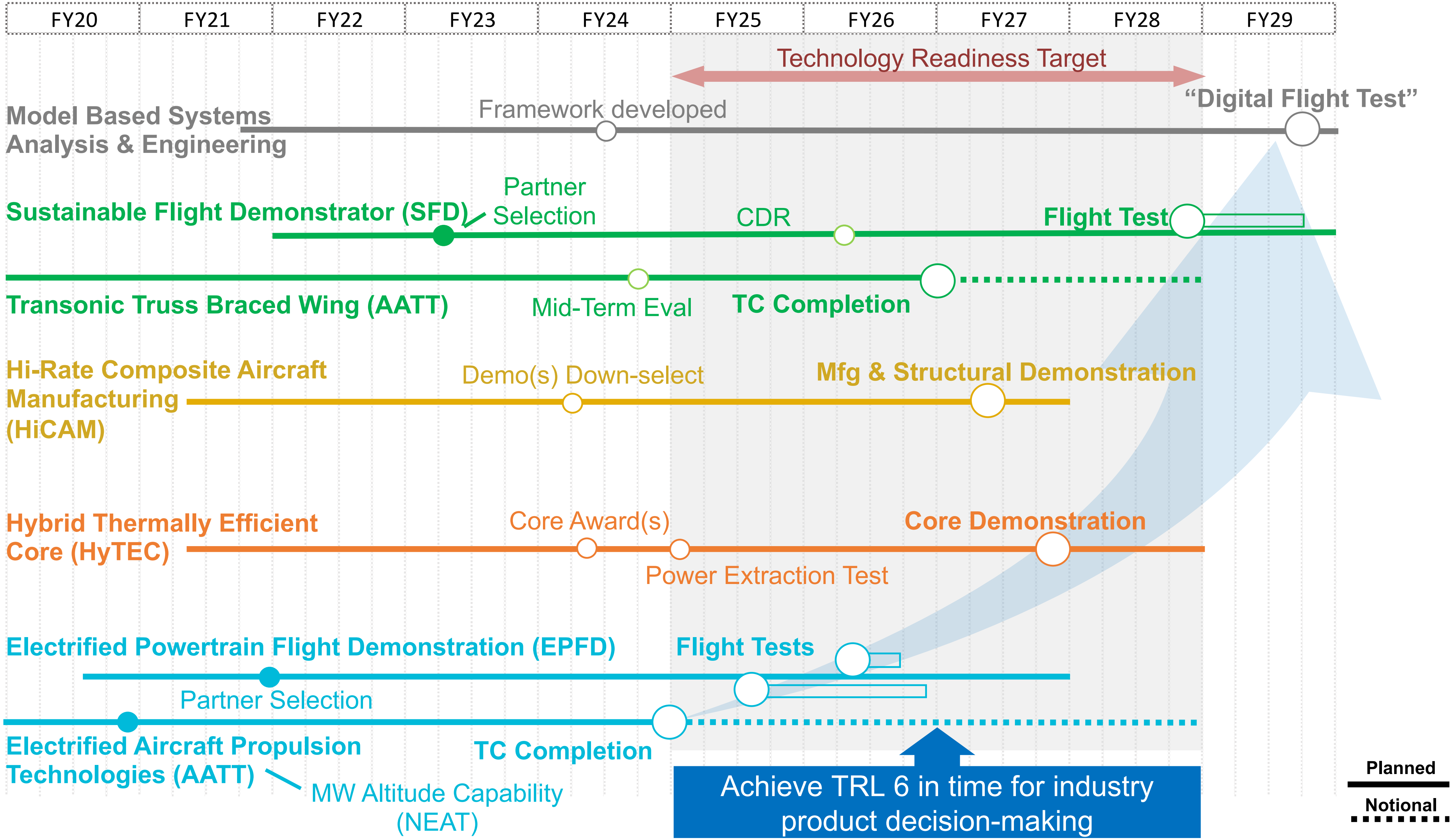
Technical Leads
High Pressure Turbine (HPT)
Doug Thurman
Advanced Materials and Coatings
Craig Smith

Advanced Core Demonstration
Execution Manager: *Joshua Campbell*

Subsonic Transports: Integrated Technology Development







Hybrid Thermally Efficient Core

Goal:

- The Hybrid Thermally Efficient Core (HyTEC) Project will accelerate the development of the next generation small-core turbofan engine technologies with improvements in efficiency, durability, performance, hybridization, and sustainability in order to meet the next Entry into Service (EIS) single aisle aircraft expected in the 2030's.

Objectives:

- Achieve **5-10% fuel burn reduction** versus 2020 best in class.
- Achieve **up to 20% power extraction** (4 times current state of the art) at altitude to optimize propulsion system performance and enable hybridization.
- Demonstrate the effective and efficient operability of high blend **(>80%) Sustainable Aviation Fuels (SAFs)** in 2030s EIS combustors.

HyTEC Metrics

- Small core technologies aligned with future single-aisle propulsion products
- Target engine thrust of 25,000 – 35,000 lb_f

Key Performance Parameter (KPP)	Full Success Single Aisle ~2035 EIS
Engine Bypass Ratio	> 15
Engine Overall Pressure Ratio	> 50
HPC Exit Corrected Flow	< 3 lbm/s

Partner with industry to mature and demonstrate promising technologies

Propulsion Efficiency through High Power Density Core

Small core:

- Low mass flow rate
- Keeping axial High Pressure Compressor (HPC)
- Enables higher bypass ratio

Enabling technologies:

- High Pressure Turbine (HPT):
  - Advanced materials (Ceramic Matrix Composites/ Environmental Barrier Coatings) to increase temp/reduce cooling
  - Aerodynamic improvements
- HPC aerodynamic and operability improvement
- Compact combustor optimization

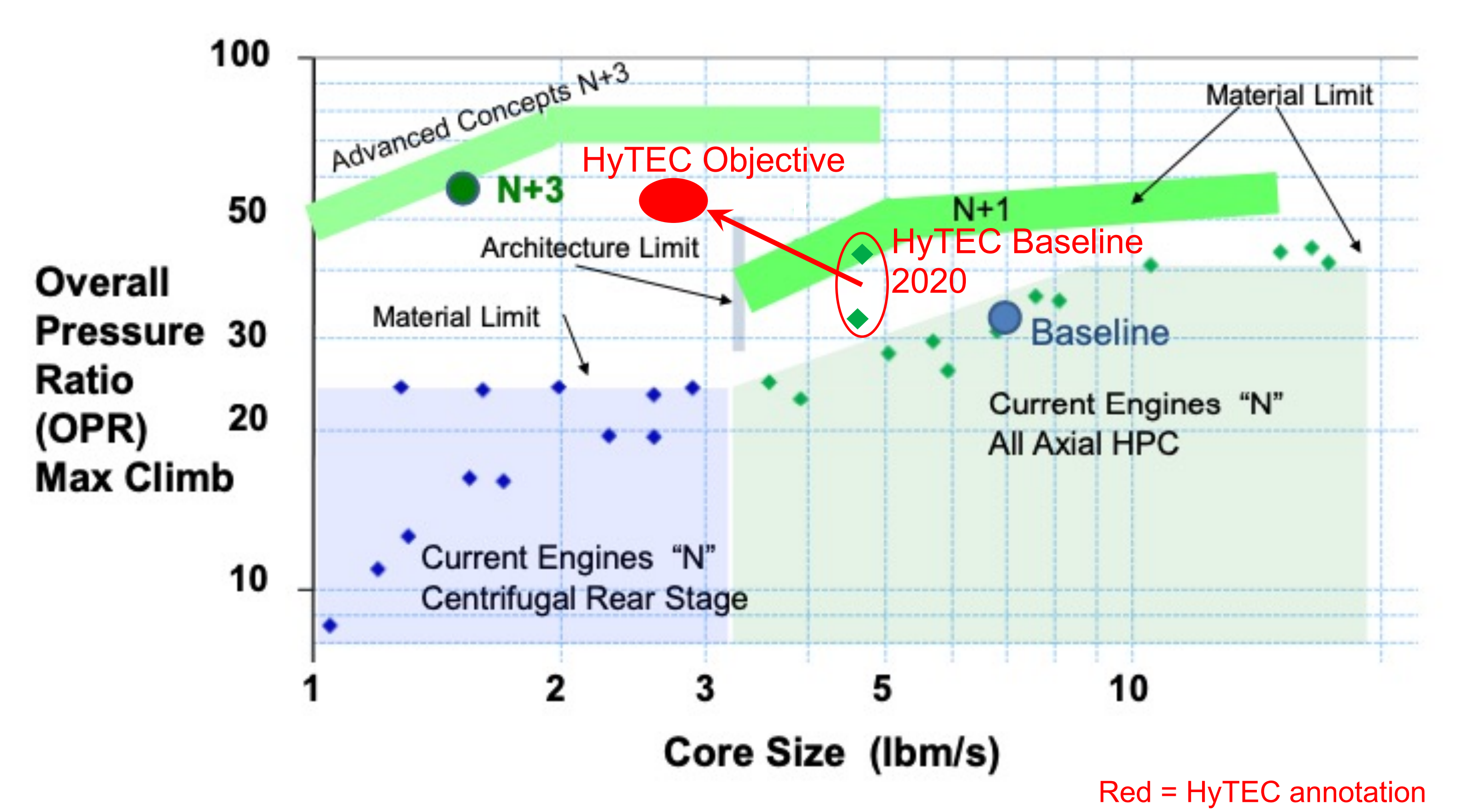


Figure 5 OPR versus Core Size for Generation N, N+1 , N+3

Ref. Lord, W.K. et al.: "Engine Architecture for High Efficiency at Small Core Size," AIAA 2015-00071. https://arc.aiaa.org/doi/10.2514/6.2015-0071

Develop technologies to overcome scaling barriers for compact core.

HyTEC Phases

Project will be divided into two Phases of technology development:

Phase 1

- Address technology challenges through component or sub-system testing and mature a suite of small core technologies to TRL 4-5.
- Lays the groundwork for Phase 2 by maturing promising new technologies that meet HyTEC goals.

Phase 2

- Integrate key small core technologies into a full engine core to demonstrate a functional high power-density small core at TRL 6.
- Goal to integrate successful funded Phase 1 and potentially additional TRL 4-5 technologies into engine core demonstrations to increase TRL.
- Accelerate technologies for inclusion into the next EIS single-aisle engines earlier to increase US competitiveness in the global market.

HyTEC Phase 1—Technology Development

Accelerate through component or sub-system testing and mature a suite of small core technologies to TRL 4-5.

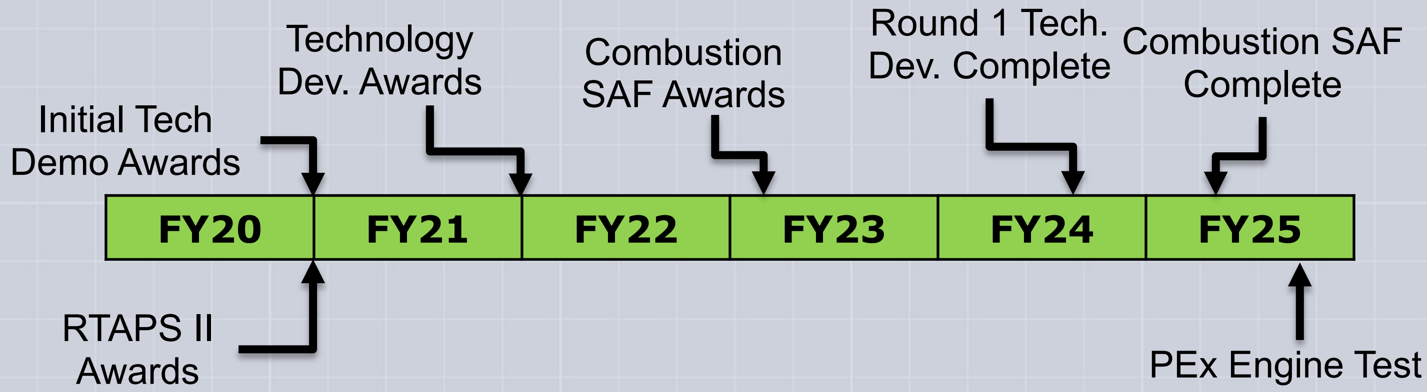
Objectives:

- Invest in aggressive, impactful small core turbofan technologies with development risk.
- Focus technologies on improvements in efficiency, durability, performance, hybridization, and sustainability.
- Assess impact of variable power extraction from low and high spools on turbofan performance, operability, and durability.

Approach:

- Partner w/ industry and Government Agencies on technology development.
- Leverage prior NASA/industry small core and hybrid engine technology advances.
- Utilize NASA expertise and facilities to develop key small core technologies.

Milestones



Phase 1 Technology Development Portfolio

NASA Research Announcement (NRA) Awards (Sept. 2021 & ‘22):

- High Pressure Compressor (HPC)/ GE Aviation
- High Pressure Turbine (HPT) Advanced Aerodynamics/ GE Aviation
- High Pressure Turbine (HPT) Advanced Aerodynamics/ Pratt & Whitney
- High Temperature Environmental Barrier Coatings (EBCs)/ GE Aviation
- Ceramic Matrix Composite (CMC) and EBCs/ Pratt & Whitney
- Ceramic Matrix Composite (CMC) Combustor Liner/ GE Aviation
- Sustainable Aviation Fuel (SAF) Combustion Technologies / Pratt & Whitney

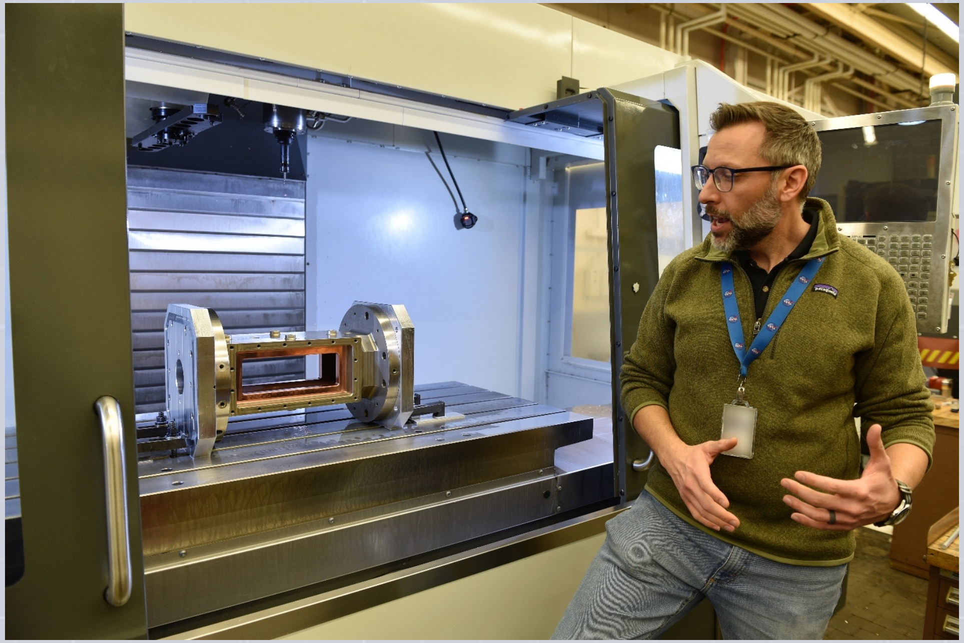
RTAPS 2 Contract Award (Sept. 2020):

- Turbofan Engine Power Extraction (PEx) Demonstration/ GE Aviation

Phase 1 Technology Development Portfolio

Advanced Materials Development: Testing at NASA GRC Facilities

Dr. Michael Presby testing a NASA-developed, high-temperature EBC deposited on a CMC. The composite's environmental barrier coating surface temperature is 3,000 degrees Fahrenheit.

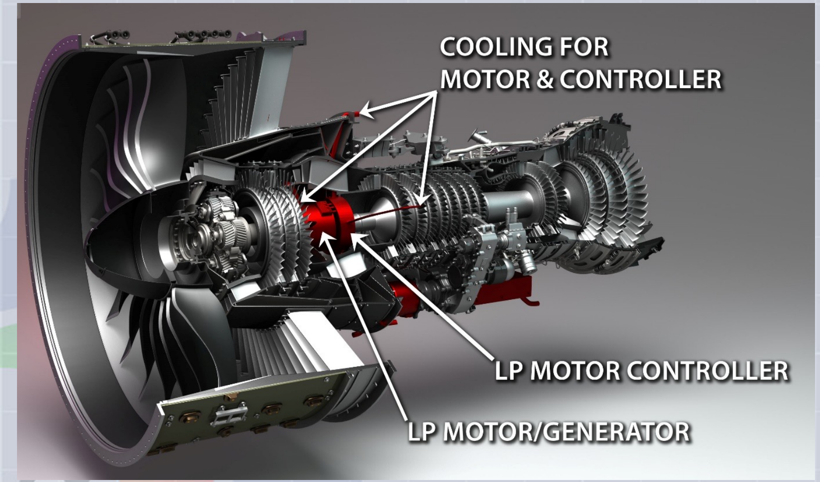


Dr. Bryan Harder describes hardware that will allow researchers to test an advanced CMC airfoil with an innovative EBC in a combustion environment. This test will be used to show the capability of these materials prior to a future engine core demonstration.

Phase 1 Technology Development Portfolio

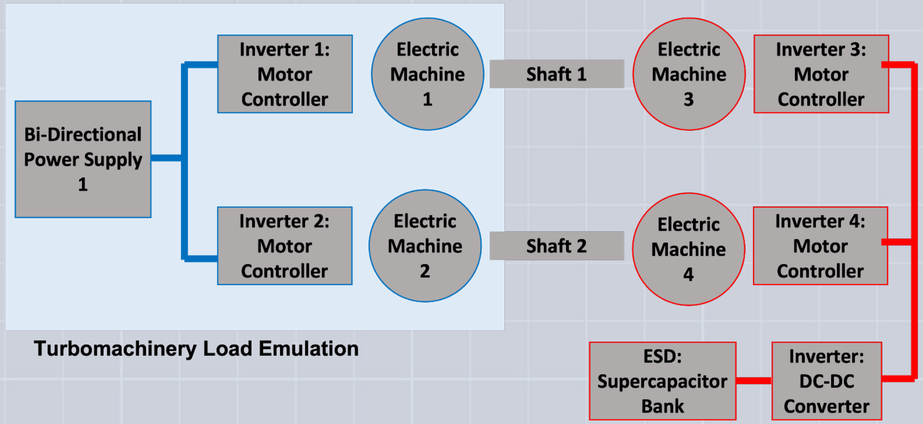
Turbofan Power Extraction (PEx): NASA and GE Aerospace are in partnership to mature a megawatt-class hybrid electric engine that advances technology for single-aisle aircraft.

NASA is conducting system analysis trade studies and controls hardware in the loop tests to advance technologies and to assess the performance impact of power extraction and insertion for commercial hybrid turbofans.



NASA Concept Hybrid Turbofan

Megawatt-Scale Controls Test



Kilowatt-Scale Controls Test with Energy Storage

HyTEC PEx Key Performance Parameter: Achieve 10% to 20% power extraction at altitude from a modern commercial turbofan engine with the thrust, efficiency, operability, and durability to enable the benefits of electrified aircraft propulsion at a vehicle level.

HyTEC Phase 2—Core Ground Demonstration

Integrate key small core technologies into a full engine core to demonstrate a functional high power-density small core at TRL 6.

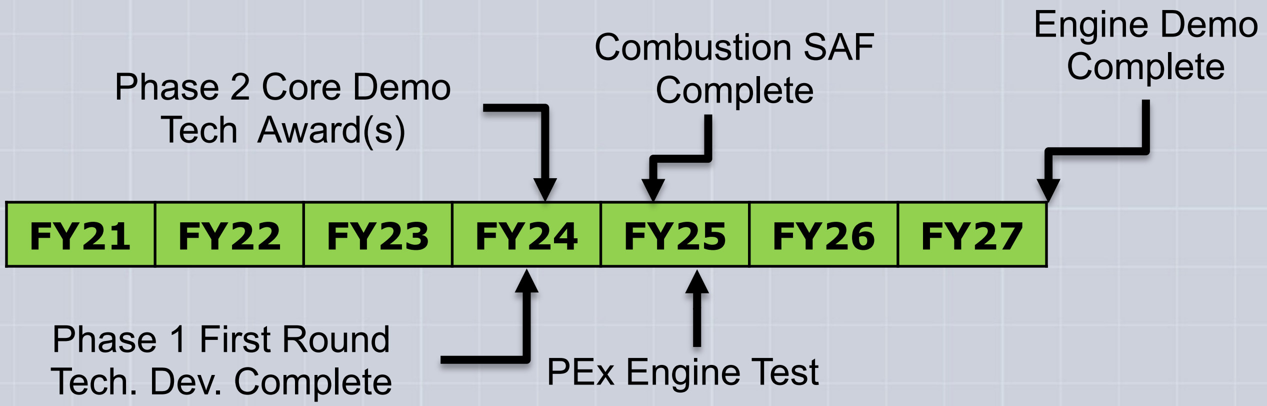
Objectives:

- Integrate technologies that enable reduced engine core size and advanced vehicle architectures.
- Integrate power extraction with small core for integrated demo if feasible.
- Demonstrate technologies achieve a 5-10% fuel burn benefit versus 2020 best in class.

Approach:

- Leverage technologies matured to TRL 4-5 from Phase 1 (not limited to HyTEC Phase 1 contracts).
- Partner w/ industry and Government Agencies for ground test of small turbine engine core technologies, with hybridization potential.

Milestones



Phase 2 Technical Strategy

Mature high impact small core technologies to a TRL 6 through an integrated core ground demonstration(s) by 2027.

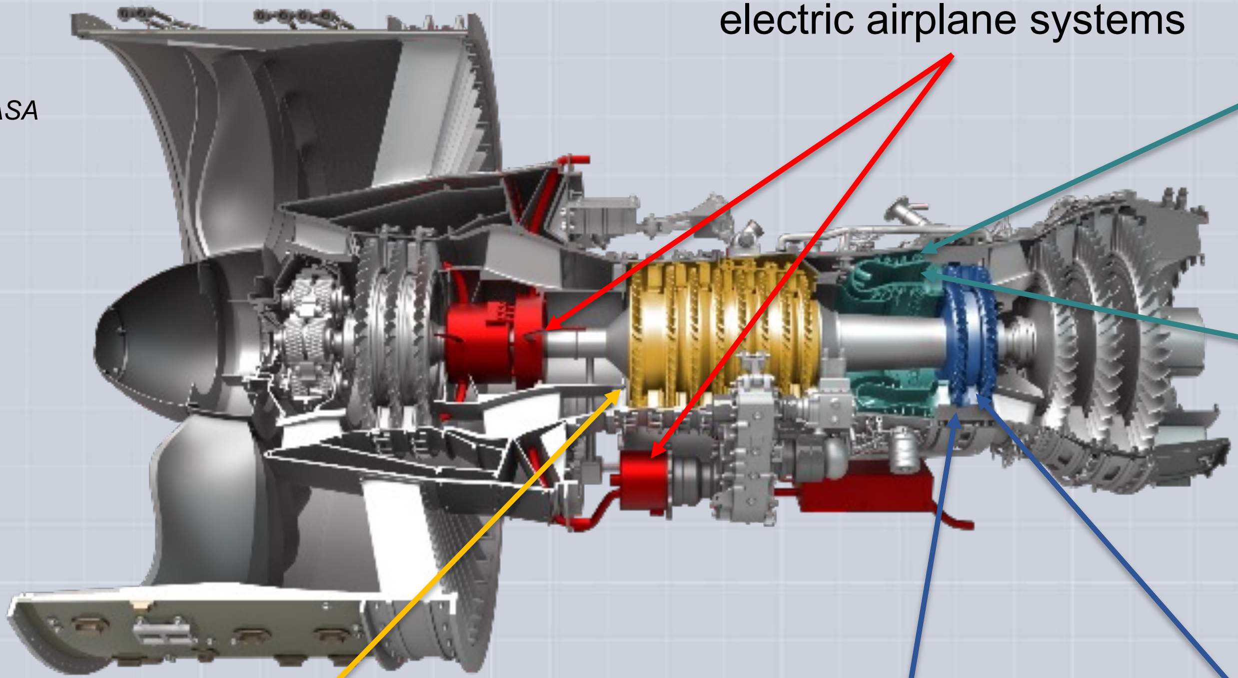
Approach:

- Fund Phase 1 technologies into an integrated core demonstration.
  - Phase 1 technologies that are on track to meet the TRL targets will be eligible for Phase 2.
  - Proposals should identify risks and mitigations since Phase 1 activities are in parallel to Phase 2 award period.
- Open competition to include TRL 4-5 technologies that were not funded under Phase 1.
- Seek improvements in efficiency, durability, performance, hybridization, and sustainability.
- Reduce technical risk.
- Enable technology transfer for the next single aisle engine architecture.

Key elements to the acquisition:

- Technologies eligible for Phase 2 consideration are NASA funded HyTEC Phase 1 and others funded by industry alone (or with other resources, partners) that meet requirements, TRL 4-5.
- NASA funds and internal expertise will make riskier, bigger payoff technologies possible to execute.

HyTEC Potential Phase 2 Technology Portfolio



Credits: NASA

Turbofan Power Extraction
Power Extraction to enable more electric airplane systems

Combustion Technologies
- Sustainable aviation fuel compatibility
- Compact design for small core engines

Enhanced Combustor Materials
Ceramic matrix composite (CMC) liners for combustors to increase performance and durability.

High Temperature Turbine (HPT) Materials
- CMCs/Environmental Barrier Coatings (EBCs) for turbine components to increase temperatures and efficiency.

High Pressure Compressor (HPC)
Casing treatments and advanced designs to enable operability with optimized efficiency and performance

Advanced HPT Aerodynamics
Enable more efficient turbine operation by developing advanced blade and cooling designs and aerodynamic features.

Phase 2 NASA Research Announcement Timeline

- ✓ January 9, 2023: Draft NRA Released
- ✓ January 31, 2023: Industry Day
- ✓ February 14, 2023: Questions/ Comments Due
- ✓ March 16, 2023: Final NRA Released
- ✓ May 3, 2023: Proposals Due

HyTEC is seeking a minimum 50/50 cost share

HyTEC plans to invest NASA share of ~$80-100M total on the NRA contract(s).

HyTEC Major Milestones

Small core technology Phase 1 assessment:

- Systems analysis in partnership with NASA Advanced Air Transport Technology (AATT) Project to determine benefits of Phase 1 technologies.
- Will be measured against HyTEC KPP's to show progress toward final goals.

Turbofan power extraction demonstration assessment:

- Systems analysis in partnership with AATT to determine the success criteria of Power Extraction KPP.

Integrated small core demonstration assessment:

- Systems analysis in partnership with AATT to determine the success criteria of all HyTEC KPP's for the final product.

> ➢ HyTEC will evaluate performance at three points via these Level 1 milestones in coordination with AATT Systems Analysis to determine success against the project performance metrics.

Summary

HyTEC is not a typical NASA research project:

- Highly focused technology development.
- Centered around contracts with industry partners supporting engine company needs for next single aisle aircraft entry into service (EIS 2030's).
- Higher TRL only—lower TRL core technology development remains in other NASA Projects.

Aggressive schedule:

- Activities are on an accelerated schedule to meet industry needs for next single aisle EIS.
- Phase 2 procurement occurs before Phase 1 is complete proceeding with calculated risk.

HyTEC's strong technical support from industry partners and internal NASA expertise will meet the aggressive schedule and technical challenges to ensure the Sustainable Flight National Partnership propulsion goals.

NASA

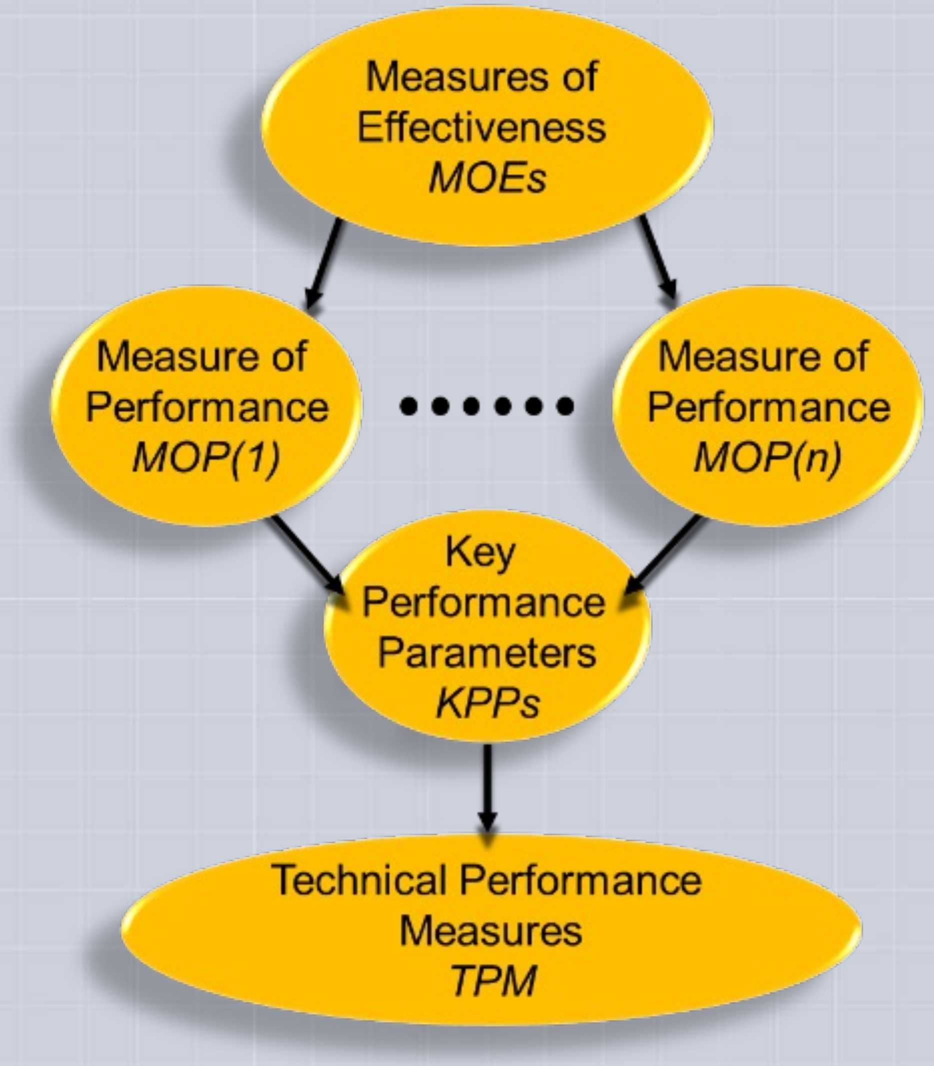
HyTEC Technical Performance Metrics

MOEs (Goals, Mission Outcomes) - used by stakeholders to judge their satisfaction with the delivered product

MOP (Objectives, System Outputs) - quantitative measure, that when met, helps ensure an MOE will be satisfied

KPP (Success Criteria)- capabilities or characteristics most essential for mission success - (High Priority)

TPM - a set of KPPs monitored (current best estimate) to confirm progress and ID deficiencies that might impact meeting a system requirement



Measures of Effectiveness (MOE)

The HyTEC MOEs will be used to establish the HyTEC stakeholder's expectations and HyTEC's goals.

MOE #	Measure of Effectiveness (MOE)
MOE-1	Define a viable path that identifies key high power density core technologies needed to accelerate U.S. Industry product that is enhanced by government participation.
MOE -2	Establish a turbofan engine with a high power density core that addresses the next generation single-aisle for EIS in the 2030s timeframe.
MOE-3	Demonstrate increased power extraction at altitude from a modern commercial turbofan engine with the thrust, efficiency, operability, and durability to enable the benefits of electrified aircraft propulsion at a vehicle level.
MOE-4	Advance small core combustor design capabilities for effective and efficient operability using high-blend SAF

Measures of Performance (MOP)

The MOPs defines the objectives HyTEC seeks to achieve through the technology development and hybrid thermally efficient core ground demonstration.

MOP #	Measure of Performance (MOP)
MOP-1	Execute dual spool power extraction on a turbofan engine via ground and altitude testing
MOP-2	Develop and demonstrate via ground test an advanced high power density core engine
MOP-3	Raise the TRL level of high-power density core technologies to TRL 4-5 through component testing by 2023
MOP-4	Raise the TRL level of high-power density core technologies to TRL 6 through ground testing by 2027
MOP-5	Raise TRL of turbofan power extraction and insertion to TRL 5 through altitude ground testing by 2025
MOP-6	Raise the TRL of a small core combustor design to TRL 4-5 that provides reliable ignition and lean blowout performance when burning > 80% blend (by volume) SAF by 2025
MOP-7	Raise TRL of turbofan power extraction and insertion to TRL 6 through integration into a core demonstration by 2027.
MOP-8	Integrate a small core combustor design at TRL 6 that provides reliable ignition and lean blowout performance when burning > 80% blend (by volume) SAF by 2027.

Key Performance Parameter (KPP)

The KPPs define the success criteria of the HyTEC technology development and core ground demonstration.

KPP#	Key Performance Parameter (KPP)	Full Success Single Aisle ~2035 EIS	Min. Success Single Aisle ~2035 EIS
KPP-1	Fuel burn reduction attributed to the high-power density core of the original equipment manufacturer's (OEM) vision turbofan engine	10%	5%
KPP-2	Engine Bypass Ratio	> 15	> 12
KPP-3	Engine Overall Pressure Ratio	> 50	> 45
KPP-4	Durability, measured in operating hours between major refurbishment	Exceed SOA by 5%	Meet SOA of baseline
KPP-5	Degree of hybridization measured by level of power extraction from the turbofan engine at altitude	20%	10%
KPP-6	HPC Exit Corrected Flow	< 3 lbm/s	< 3.5 lbm/s
KPP-7	Combustor operability using SAF is comparable to its performance using Jet-A/A-1fuel, as measured by lean blowout and ignition performance.	Combustor operability demonstrated with 100% SAF	Combustor operability demonstrated with >80% SAF
KPP-8	Degree of hybridization measured by level of power extraction/insertion from the core.	10%	5%

Technical Performance Measures

Technical Performance Measures (TPMs) are a set of performance measures that will monitor progress and identify deficiencies that may jeopardize meeting the MOPs.

Industry partners propose Technical Performance Measures (TPM's) associated with each individual technology.

- TPM's are used to assess the performance of each technology.
- Requirements were developed to verify that these TPM's were met.