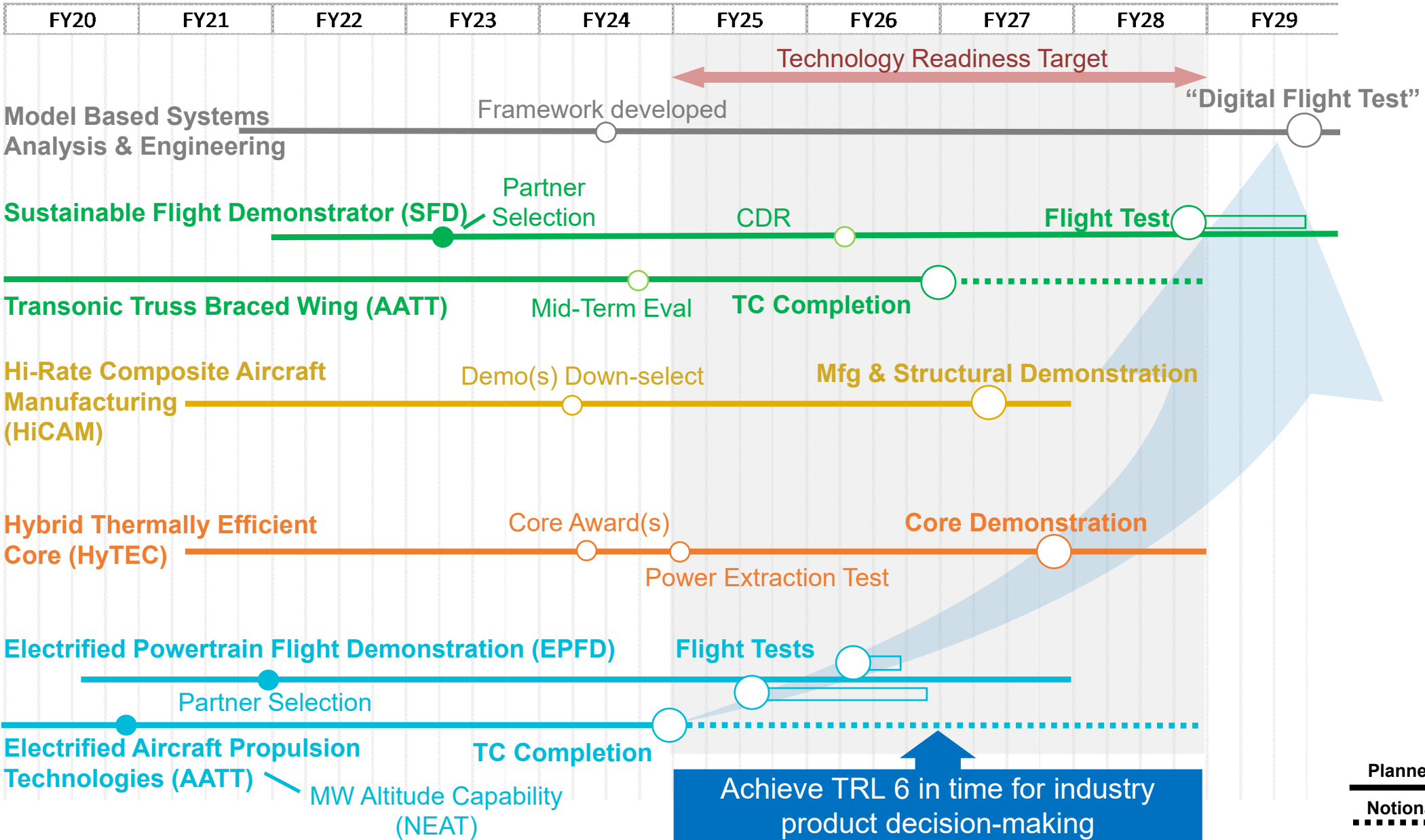
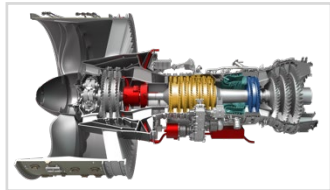
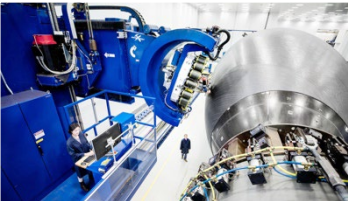


Model-Based Systems Analysis and Engineering for the Sustainable Flight National Partnership

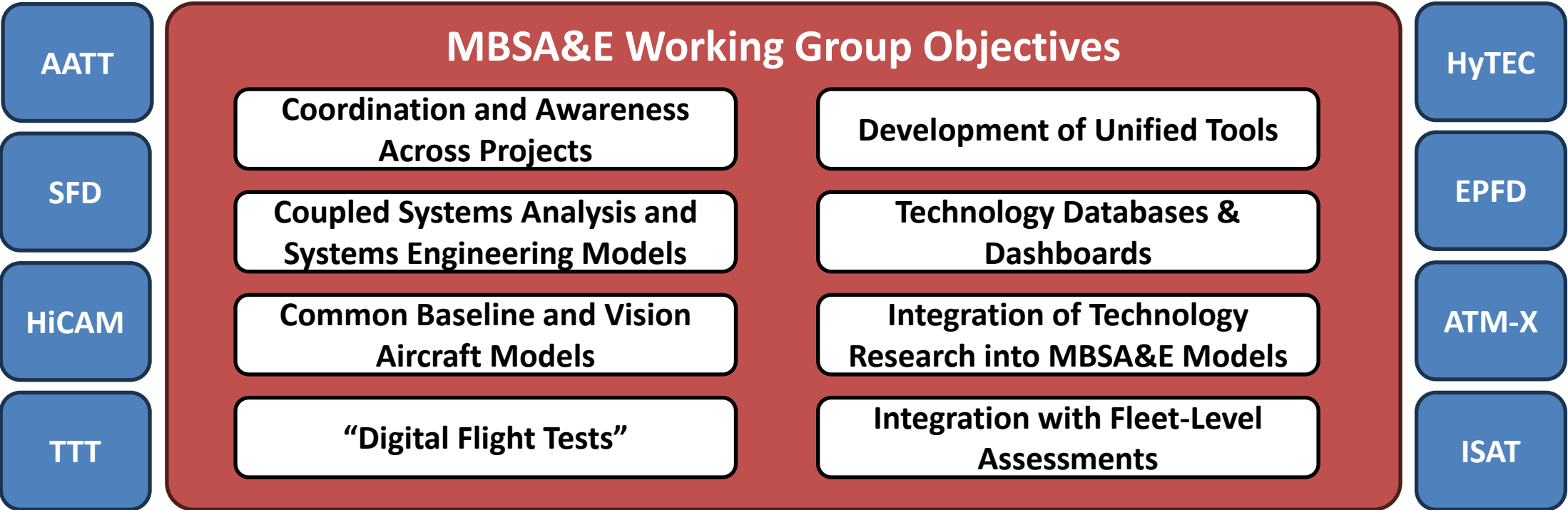
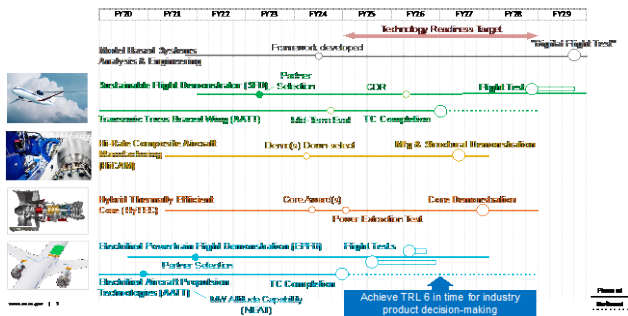
Eric Hendricks
SAE AeroTech
March 12, 2024

Subsonic Airlines: Integrated Technology Development





- A MBSA&E Working Group internal to NASA was established to coordinate across the SFNP projects and support the the SFNP mission manager



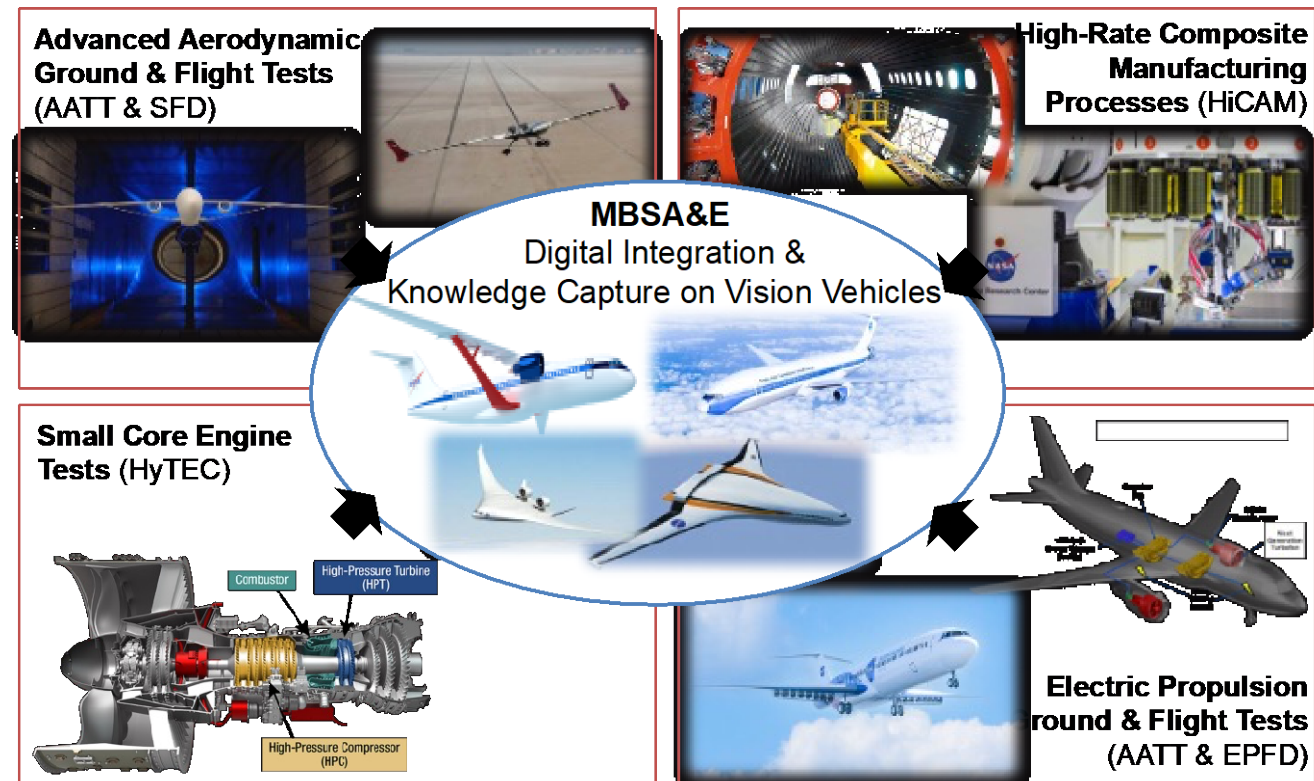
The MBSA&E Vision for the SFNP



A systems-level, digital integration across SFNP projects which will support the assessment, advancement, and adoption of sustainable technologies for 2030s EIS subsonic transport aircraft concepts

Objectives:

- Develop an open, cross-project/program/external-capable MBSA&E framework building off ARMD investments and capabilities across AAVP/IASP/TACP in support of the SFNP
- Conduct coordinated, integrated systems analysis studies in support of SFNP including:
 - Common, open, reference vehicle models
 - Common, open, vision vehicle models
 - Technology benefit assessments and sensitivity studies informed by the SFNP demos



MBSA&E: A Phased Approach

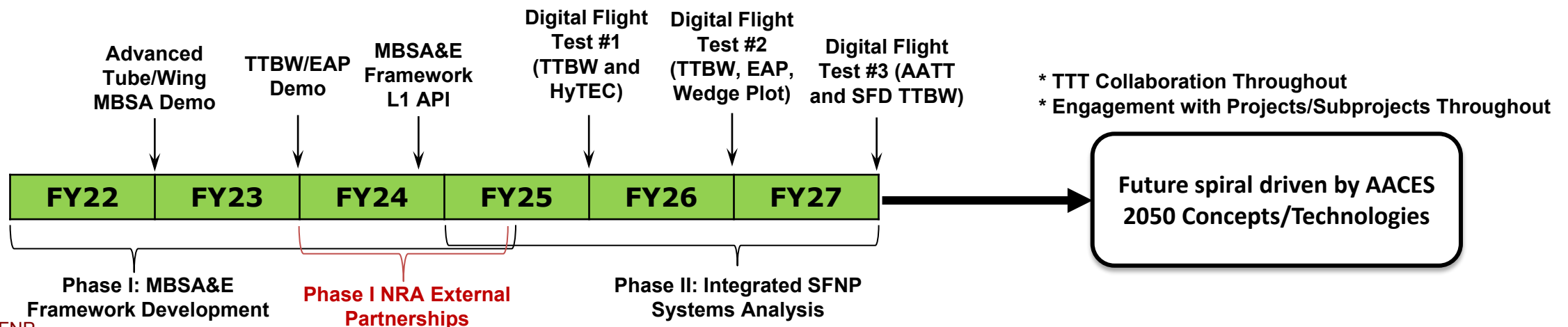


Phase I: Develop common MBSA&E Framework/Ecosystem

- Create building blocks needed for key disciplinary analyses where lacking
- Integrate building blocks to form coupled MBSA&E framework leveraging cross-project collaboration and external partnerships
- Evaluate and test the MBSA&E framework with several use cases (conventional aircraft, TTBW, EAP)
- Explore and develop integration between MBSA/MDAO environment and MBSE tools

Phase II: Cross-project integrated model development and coordination

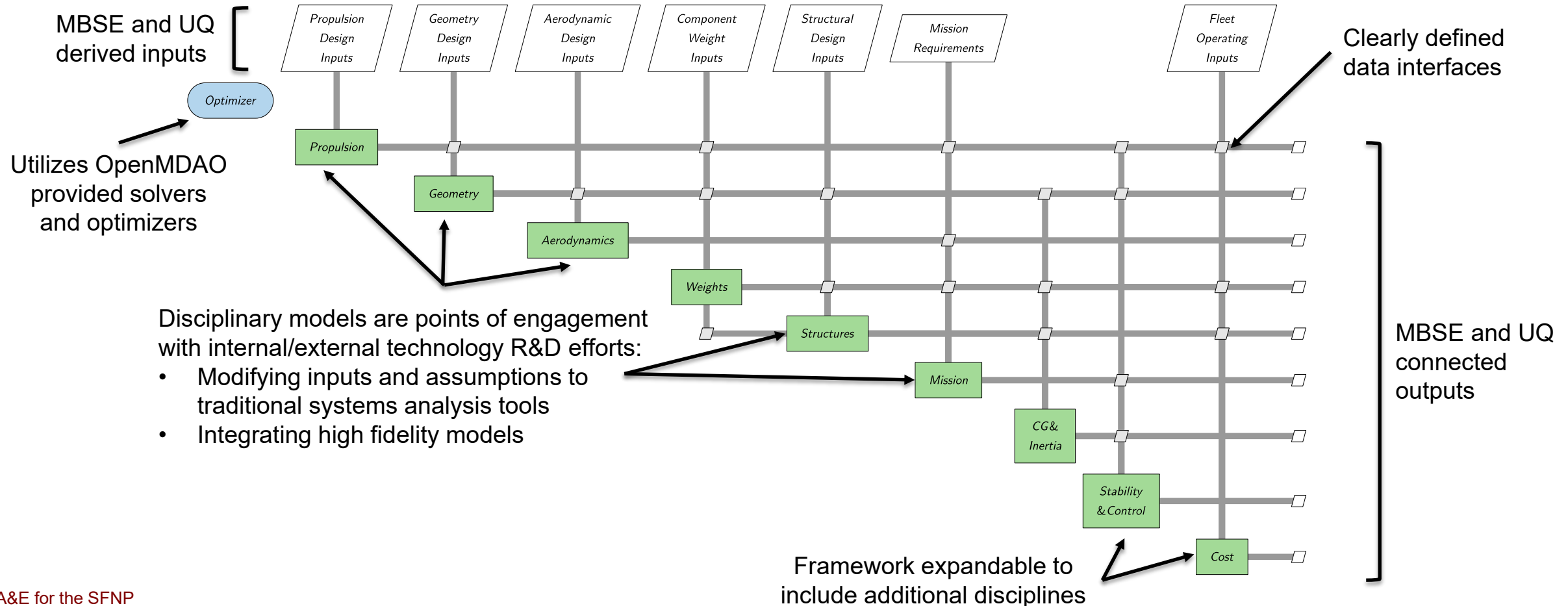
- Development of open, common SFNP reference and vision vehicle concepts and models
- Regular, frequent tech interchange meetings across SFNP systems analysis teams, including external project partners
- Integrated systems analysis studies to incrementally 'roll-up' SFNP findings into a consolidated understanding of vision vehicle benefits and trades



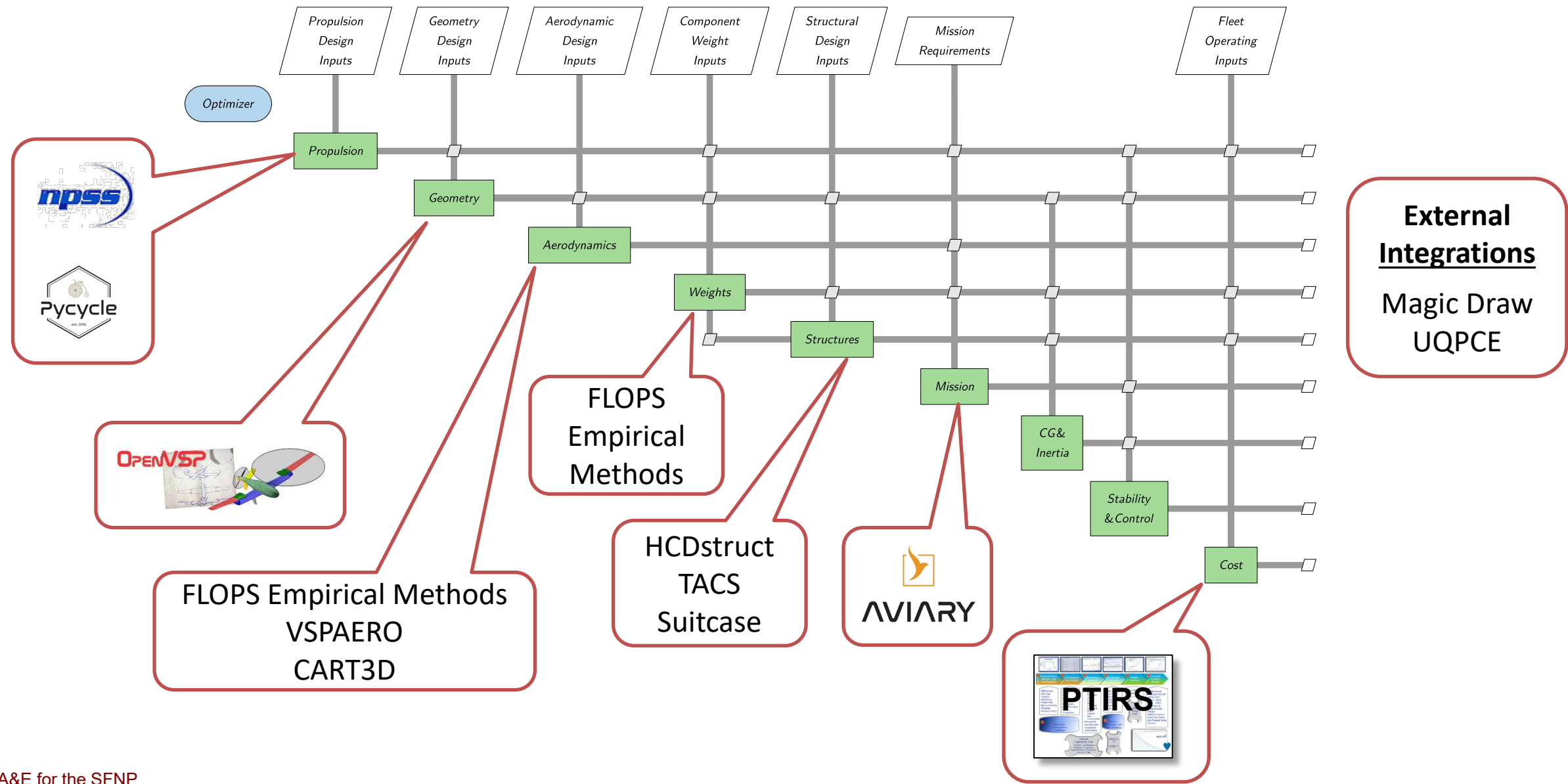
MBSA&E Framework Overview



- Goal is to provide a rigorous and traceable systems analysis approach with improved interfaces with internal/external tech R&D efforts
- Developing an OpenMDAO-based framework which will provide advanced capabilities for coupling existing tools and producing optimized, converged solutions

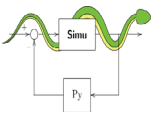


MBSA&E Framework Year 1





AVIARY NASA's next-generation aircraft design, analysis, and optimization tool

- Combines the capabilities of legacy codes (FLOPS and GASP) into a single tool which can run them both together
- Uses a modern code architecture built on , to construct modular components that can be easily modified or replaced with custom tools or methods
- Performs state-of-the-art coupled optimization with , , and 
- Provides capability to analyze advanced future aircraft concepts, including EAP
- Open-source release for maximum impact to the aerospace research community:

<https://github.com/OpenMDAO/Aviary>

Combine legacy
tools

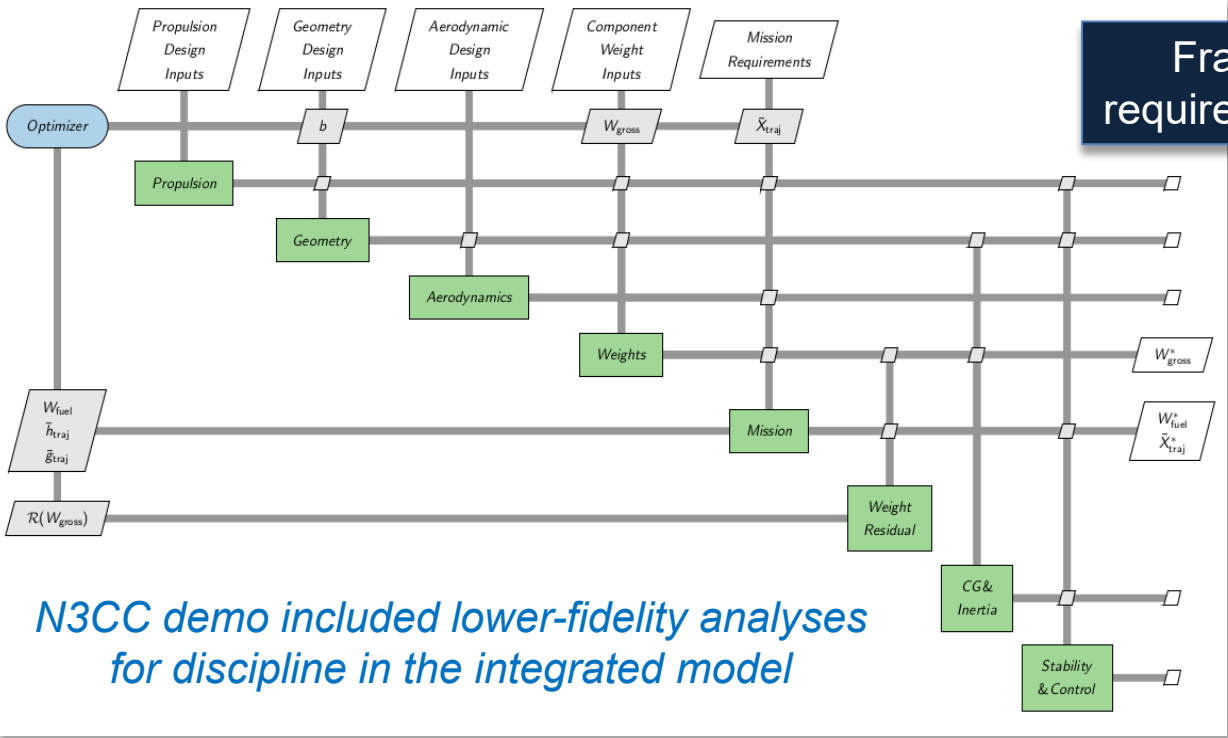
Modular for
modification and
substitution

Coupled
Optimizations

Analyze advanced
concepts

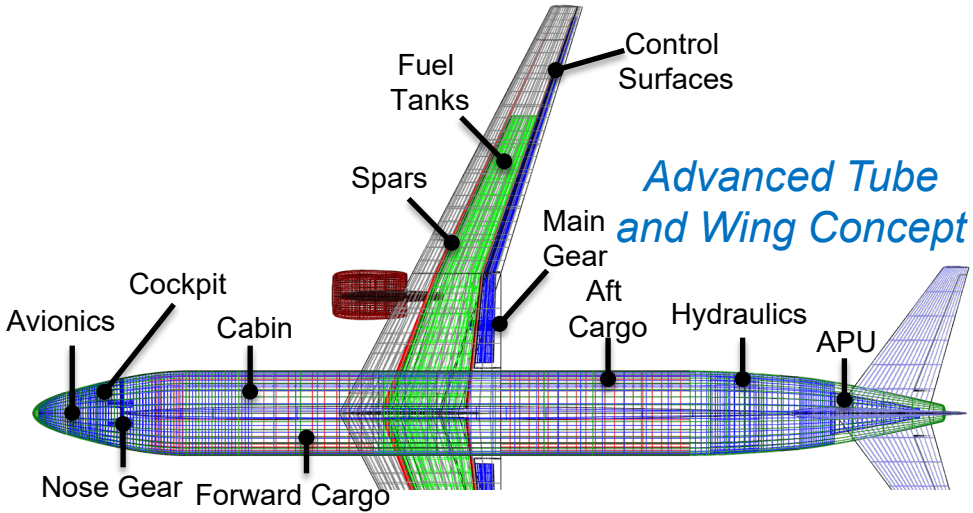
Open-source
software

MBSA&E Conventional Aircraft Demonstration

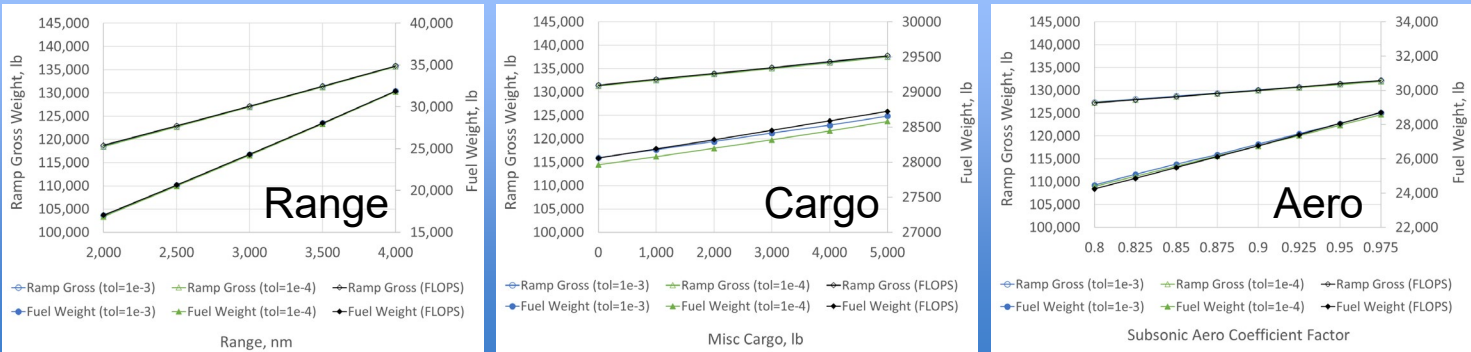


Framework will allow sizing, design, and systems studies required to verify SFNP technology objectives for vision vehicles

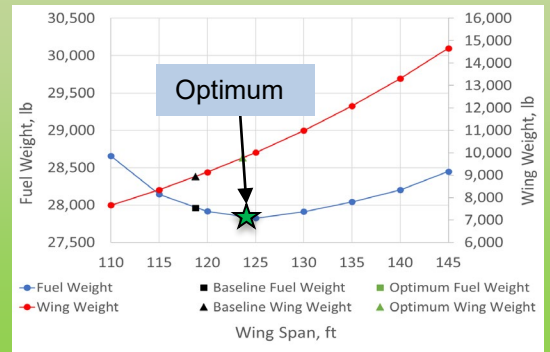
N3CC demo included lower-fidelity analyses for discipline in the integrated model



Sensitivity Analysis and Verification



Wingspan Optimization

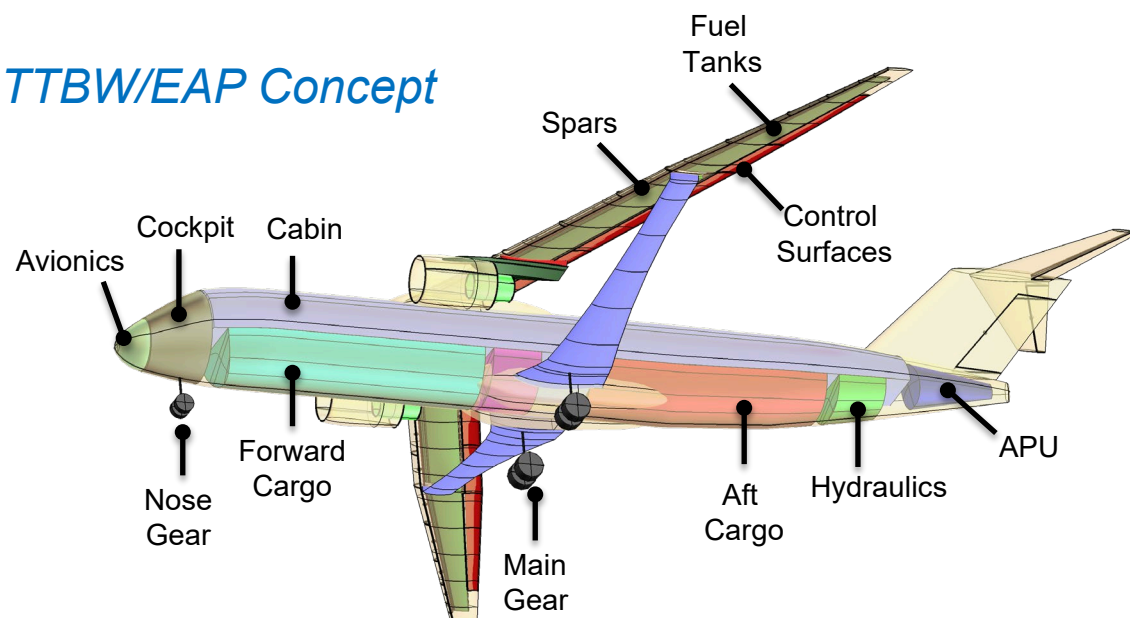


MBSA&E Framework Year 2: Continued Framework Development and TTBW/EAP Reference Model

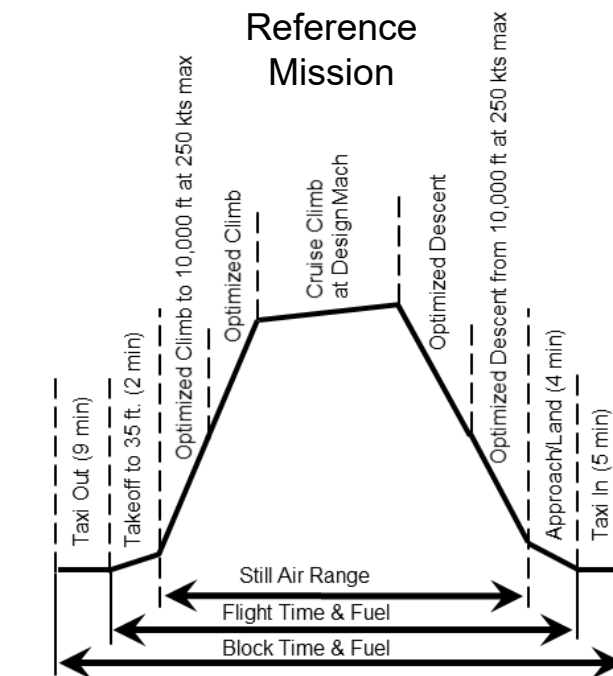


- Extended the MBSA&E Framework to include additional disciplines and analysis tools to more completely assess this configuration
- Demonstrated flexibility in tools and problem setup
- Non-proprietary *TTBW Tech Collector* developed by NASA to allow future vehicle technology studies, open publication of results, and easier collaboration with parties outside of NASA.
- EAP technology demonstration includes an electric climb assist

TTBW/EAP Concept



Reference Mission



- Nominal Performance
- Standard Day

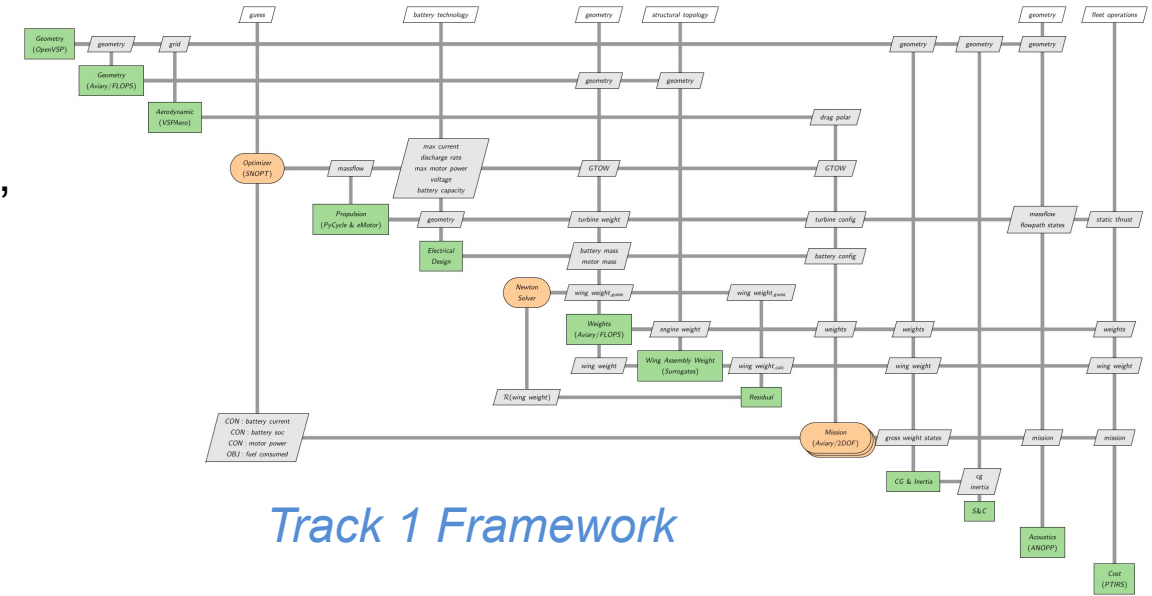
- Cruise Mach: 0.8
- Cruise altitude: 38,000 ft
- Design range: 3,205 nm

MBSA&E Framework Year 2: New Tools and Flexible Setup



- **Track 1**

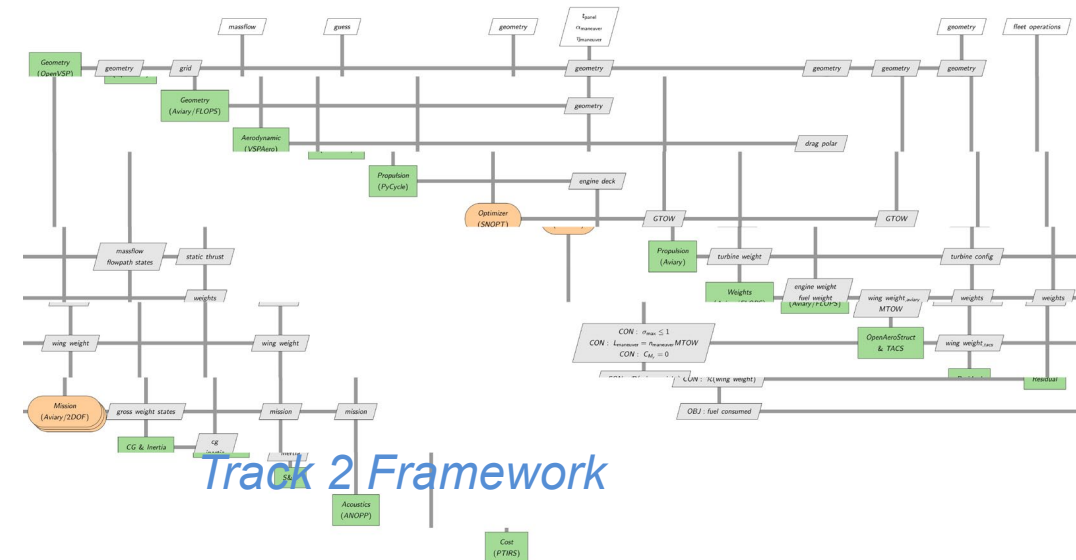
- Integrated OpenVSP, VSPAERO, PyCycle, **electrical, wing mass surrogate**, Aviary, CG, S&C, cost, and ANOPP components
- Includes PyCycle as part of optimization for propulsion design and drag polar generated with VSPAERO
- Design problem minimized fuel weight with respect to 136 design variables and 195 constraints



Track 1 Framework

- **Track 2**

- Integrated OpenVSP, VSPAERO, PyCycle, **OpenAeroStruct/TACS**, Aviary, CG, S&C, cost, and ANOPP components
- PyCycle used to generate a static engine deck offline, and this tabular data is read by the mission wing analysis for engine performance
- Design problem minimized fuel weight with respect to 351 design variables and 240 constraints

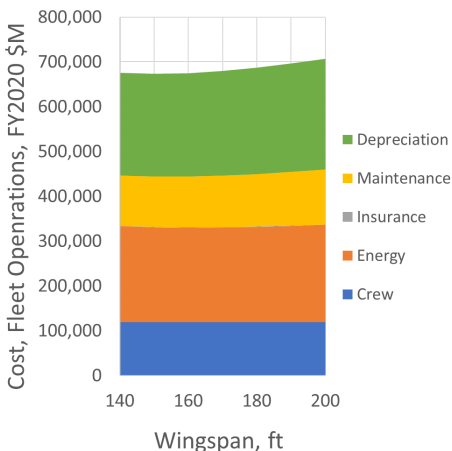
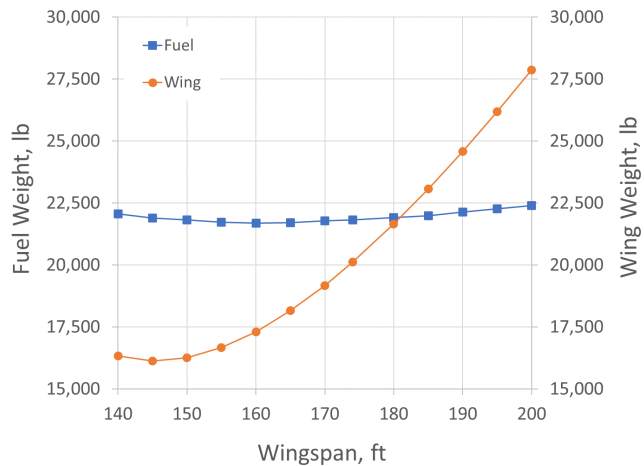


Track 2 Framework

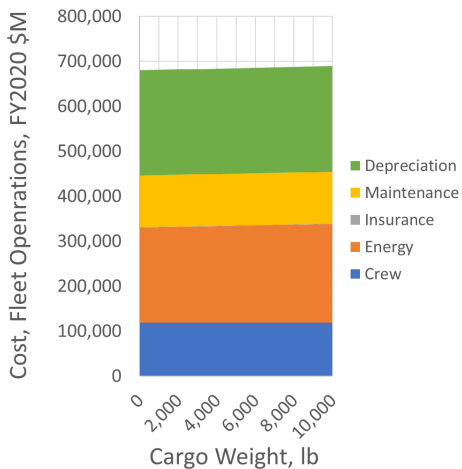
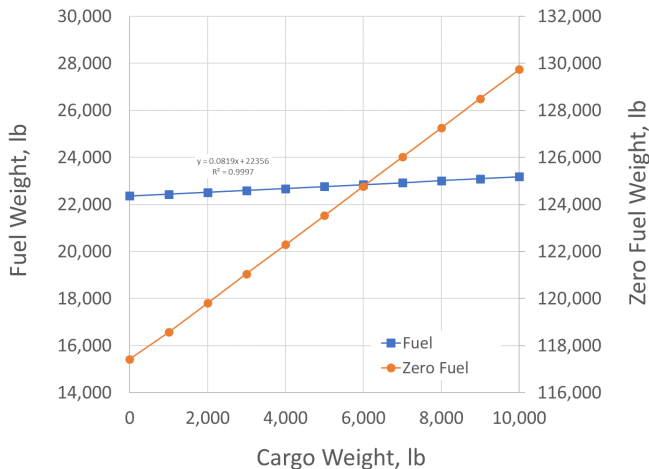
Track 1: Trade Study Results



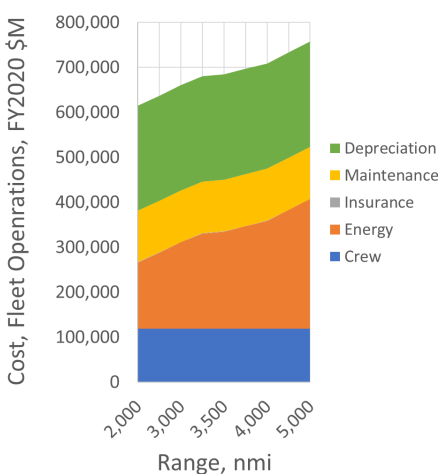
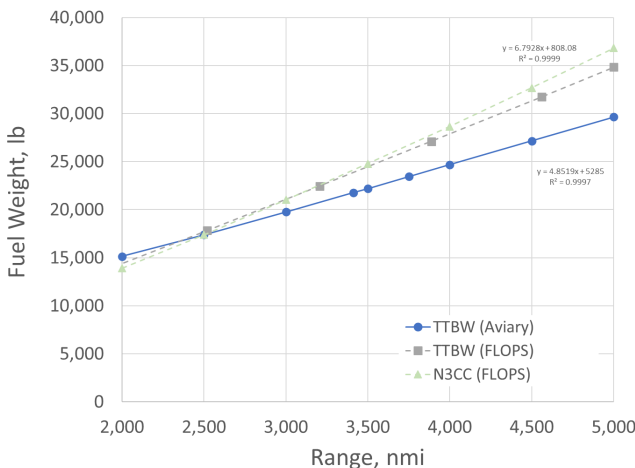
Wingspan



Cargo Weight



Range



Trade studies performed for Track 1 were used to demonstrate the successful integration of higher-fidelity disciplinary tools and verifying reasonable design trends across the design space

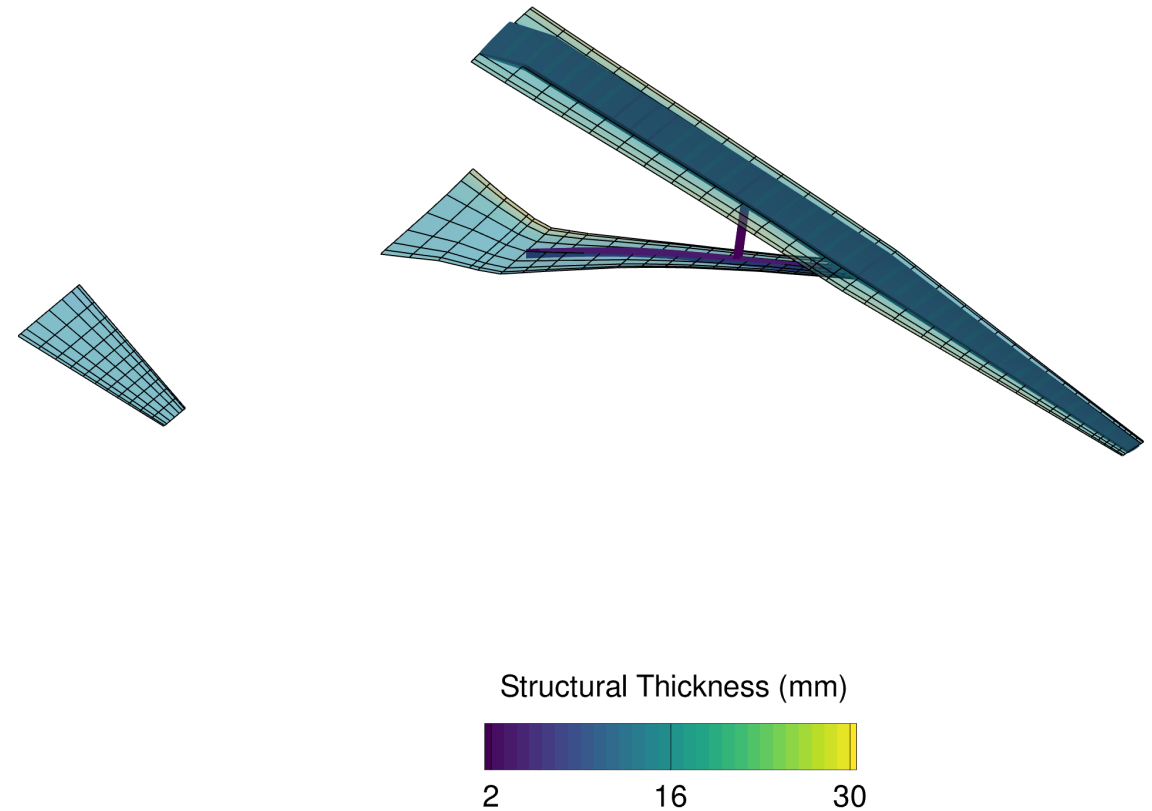
Track 2: TACS/OpenAeroStruct Results



Iteration: 000

- Optimizer reinforces root and strut junction areas of wing panels where stresses are highest
- Strut is reinforced at jury connection to account for shear load at intersection
- Structural thicknesses are reduced in low stress regions to save on weight

Structural wing weight (w/ strut)	9,773 lb
Wing control surface weight	6,861 lb
Miscellaneous wing weight	1,981 lb
Total wing weight	18,616 lb
Zero fuel weight	118,488 lb
Fuel weight	22,177 lb



Track 2 demonstrated the capability to include high-fidelity structural optimization as part of a coupled multidisciplinary overall design optimization to minimize vehicle fuel burn

MBSA&E Partnership with Industry and Academia



- Partnership with industry and academia established to:
 - Implement industry best practices in MBSA&E into the NASA framework
 - Develop advanced MBSA&E methods for both NASA and industry
 - Facilitate the application of MBSA&E methods in the assessment of SFNP technologies which will support their inclusion on new 2030s commercial aircraft
- Primary research topic areas:
 - Develop elements of the MBSA&E framework such as the aircraft data definition, disciplinary data interfaces, and systems analysis/systems engineering coupling (3 subtopic areas)
 - Develop approaches for sharing SFNP technology models and data between industry partners and the government (2 subtopic areas)
 - Integrate additional disciplinary tools with the MBSA&E framework and develop technology models which will support the assessment of SFNP technologies (3 subtopic areas)

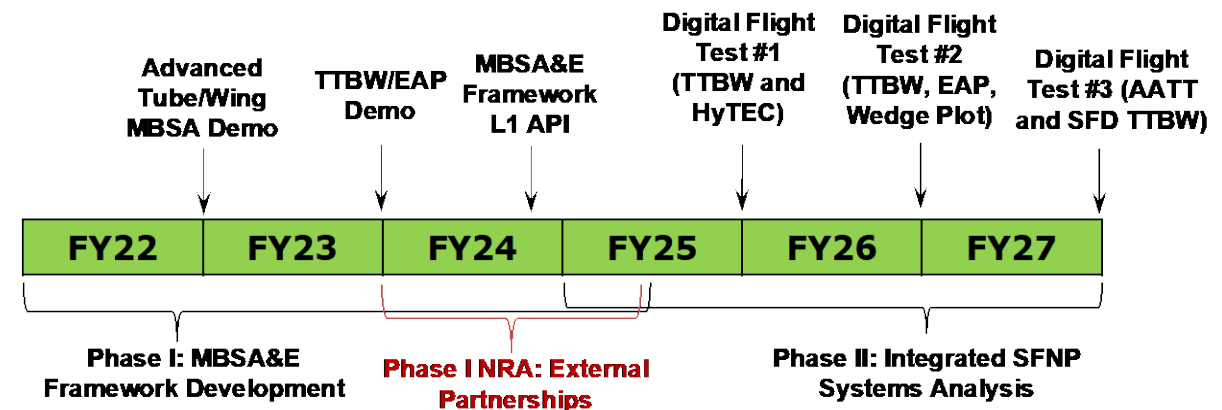
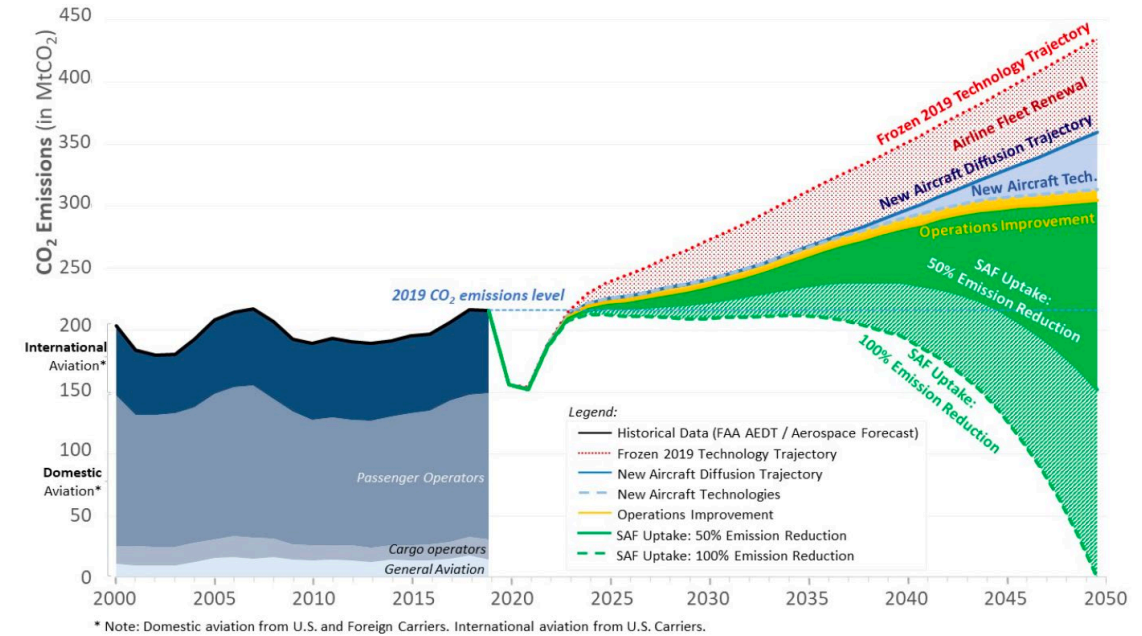
MBSA&E NRA Partners



MBSA&E Future Work



- Fleet Forecasting and Fleet-Level Emissions Modeling
 - Exploring options to develop a new module which can estimate the impact of aircraft concepts and technologies on fleet-level metrics over time to generate wedge plot
- NRA Capability Development and Integration
 - Working with NRA partners to continue development and integrate new capabilities from those awards with NASA's MBSA&E framework
- Baseline Reference Vehicle Models
 - Developing reference vehicle models which are representative of current aircraft to serve as baselines for evaluating the benefits of SFNP technologies
- First “Digital Flight Test”
 - Beginning the development of the first digital flight test example to incorporate technologies from multiple SFNP projects



A systems-level, digital integration across SFNP projects which will support the assessment, advancement, and adoption of sustainable technologies for 2030s EIS subsonic transport aircraft concepts

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- 
- Significant progress has been made over the last 2 years by NASA's AATT & TTT projects to develop this capability
 - Collaboration with SFNP projects and external partners supports framework development, ensures modeling needs are met, and supports cross-project adoption

- 
- Most work over the next 5+ years will fall in this area
 - Collaboration across SFNP projects will support development of common, consistent models for performing technology assessments
 - Planned “digital flight tests” will be critical for evaluating the overall success of the SFNP

The MBSA&E effort is an ambitious undertaking to modernize NASA's systems analysis and engineering capabilities to enable the integration of research efforts across NASA project and programs to support the objectives of the SFNP



This work is supported by NASA's Advanced Air Transport Technology Project
in the Advance Air Vehicles Program