CLEEN II Consortium
Program Update – Public Plenary
GE Aviation

Federal Aviation Administration

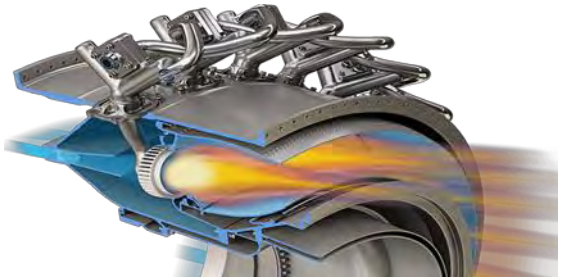
Approved for Public Use

CLEEN II Consortium Public Plenary
GE Aviation

- TAPS III Combustor & Alternative Fuels
- MESTANG - **M**ore **E**lectric **S**ystems and **T**echnologies for **A**ircraft in the **N**ext **G**eneration
- FMS Technologies

TAPS III Combustor & Alternative Fuels

TAPS III Combustor:



- Higher pressure
- Reduced cooling flow
- Advanced materials

CLEEN II:

- Improved premixer for <CAEP/12 NOx target
- Advanced modeling/design tools
- TRL6 Core Demo of emissions/performance

Benefits:

- GE9X projected SFC ~10% below GE90-115B
- LTO NOx >35% margin to CAEP/8 @ 55 OPR
- Mission cruise NOx reduction below SOA
- Low-NOx technology for application in highest OPR/largest engines; design tools/methods for scaling to future applications and engine cycles

Objectives:

Advance the development of next-generation low-NOx TAPS III combustor to TRL6

Work Statement:

- Establish baseline NOx / performance
- Develop technologies: Fuel injection, aerodynamic mixing, modeling tools
- Staged advancement to TRL6 via rigs & core engine demonstration

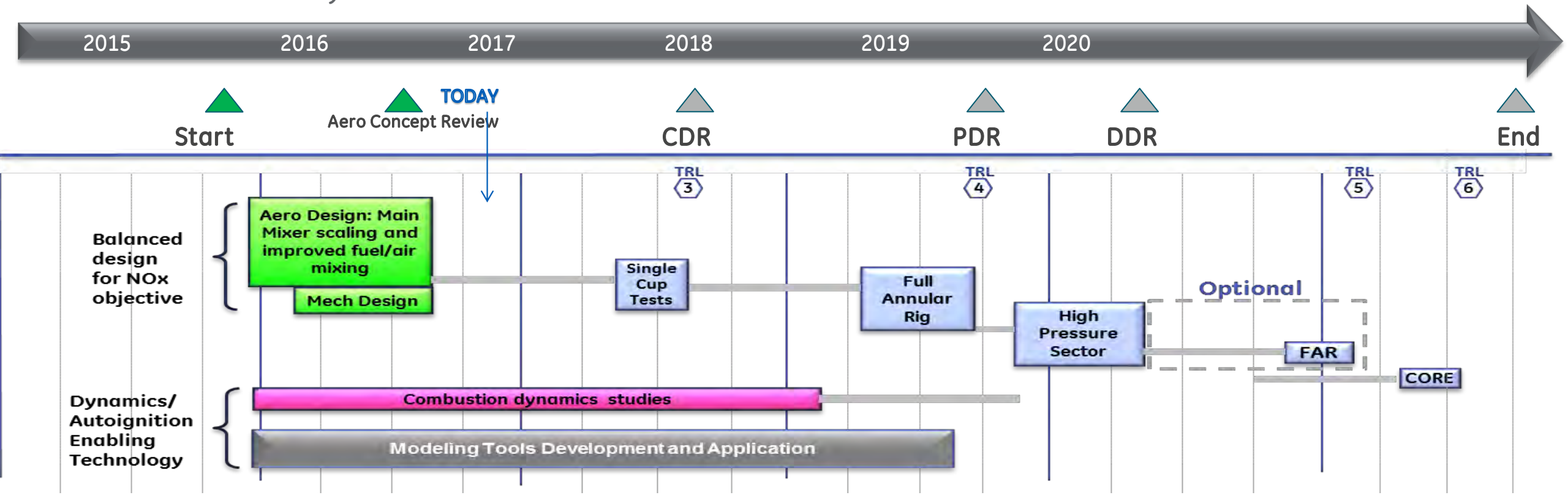
CLEEN II Progress since May 2016:

- 3 adv. premixer architectures optimized via CFD; 1 group screened in optical rig
- Concepts reviewed within GEA & FAA; down-selected to 8 configs across 2 architectures; manufacturing begun
- *Baseline:* 1-cup & 7-cup sector acoustics maps; FAR thermal profile, cruise efficiency, NOx mapping completed
- Combustion dynamics models continue validation against rig & engine data

TAPS III Combustion System Development

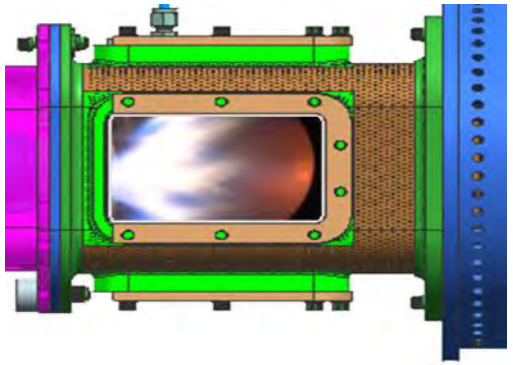
Goals and Schedule

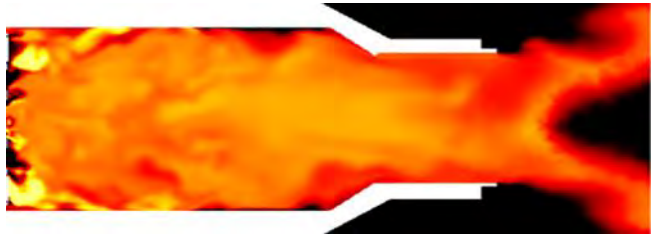
- LTO NOx emissions (FAA Goal) — 35% margin to CAEP/8 @ 55 OPR
  - Cruise NOx emissions (GE Goal) — < SOA
  - Solid Particulate Matter (GE Goal) — 60% margin to CAEP/6 (based on Smoke no.)
  - Combustor Durability (GE Goal) — Increased TOW



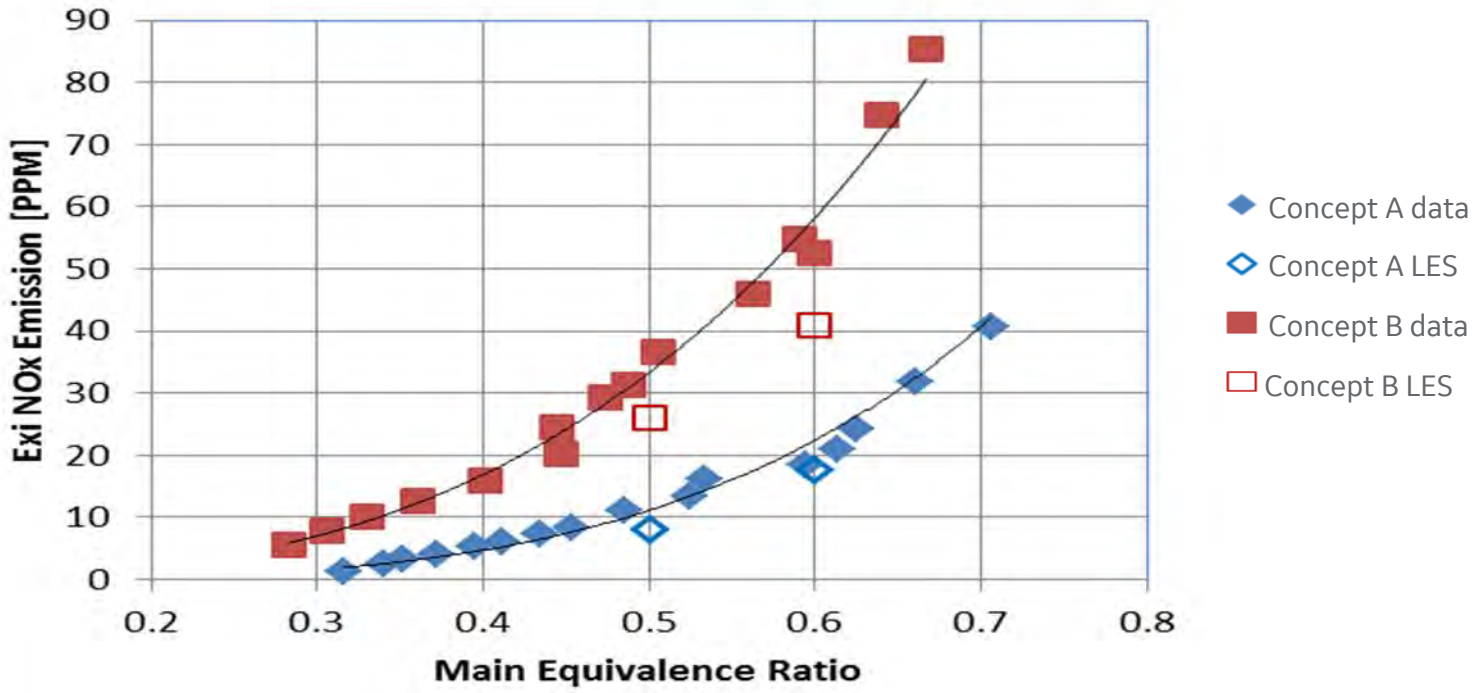
TAPS III Combustor Development – Concept Design

CLEEN II Test Rig @ GRC
Screening Concepts
150psia / 850F





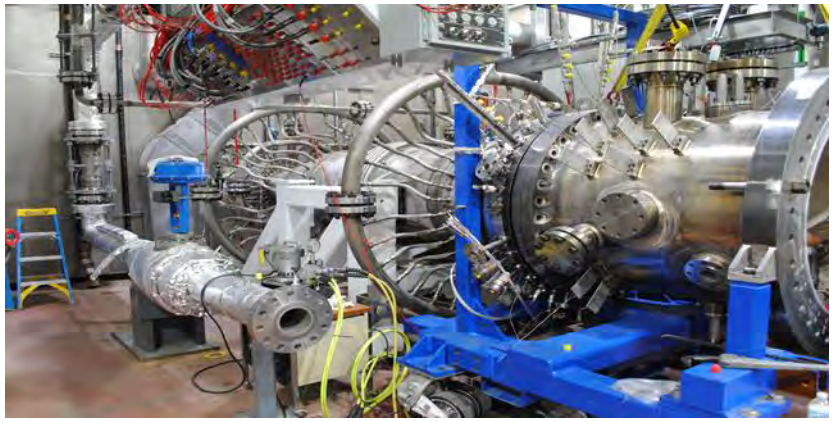
LES modeling of Adv Premixers



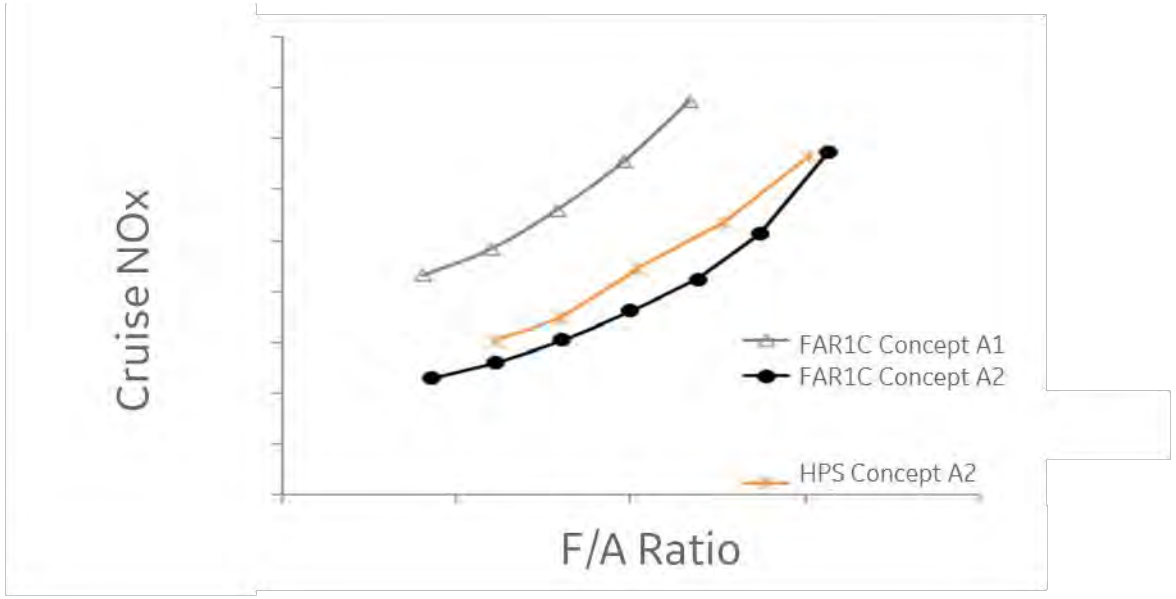
- **Concept B unfavorable for NOx; dropped**
- **Additional C, D configs designed with further NOx & performance improvements beyond Concept A**
- **Optimized for durability, up to 8 configs being built**
- **Single-cup (TRL3) tests planned mid-2017**

TAPS III Combustor Development – Test rigs

Rig tests establish reference NOx & performance



HP Sector – testing beyond GE9X cycle T3/P3



- **Concept A2 expected to meet CLEEN II objectives for NOx**
- **Concepts C, D expected to enable higher engine performance, decreased LTO NOx**

TAPS III Combustor Development – Modeling Tools

Combustion Dynamics model advancements validated against engine & rig data; applied to CLEEN II new concepts

Goal (Task B.7 Self-Excited Dynamics)

Validate and refine best practice for liquid injection SED and apply to Baseline & CLEEN II engine tests. Simulate TCA/HPS/FAR test rigs to obtain predictions and validate the SED process

Current status

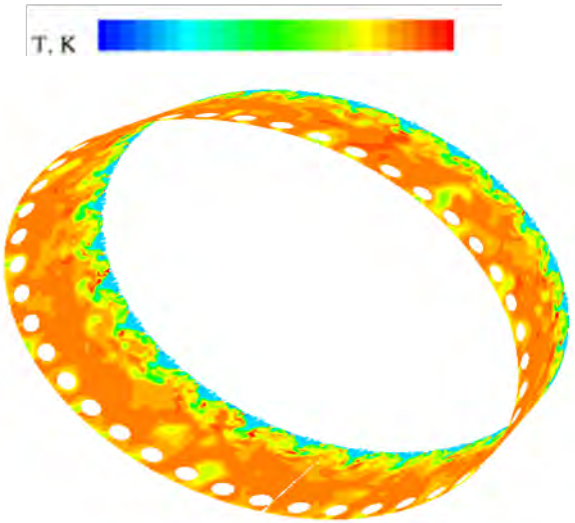
- Single-cup SED simulation for legacy configurations
- Example full annular combustor SED simulation

Next Steps

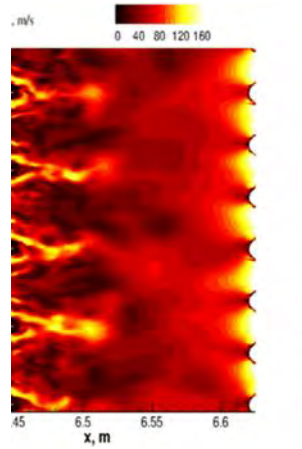
- Full annular combustor SED for legacy engine at high power condition
- CLEEN II concepts evaluation for dynamics

Example engine simulation:

Temperature profiles



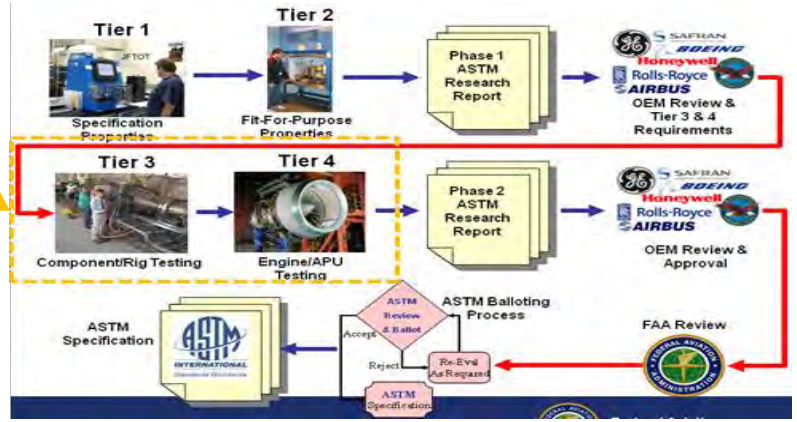
Velocity magnitude



➢ **Balanced CLEEN II design will enable improved NOx & performance while managing lean combustion dynamics**

Alternative Fuels:

Test evaluations



ASTM D4054

Benefits:

- Advance to fully synthetic fuels
- Extend further to lean combustion systems evals – synergize with TAPS III
- Determine: do sensitivities of combustion parameters observed at component level, have a significant impact at system level?

Objectives:

Advance approval and intro of "drop in" fuels

- Support ASTM D4054 – testing/demo phase
- Conduct work complimentary to other FAA programs

Work Statement:

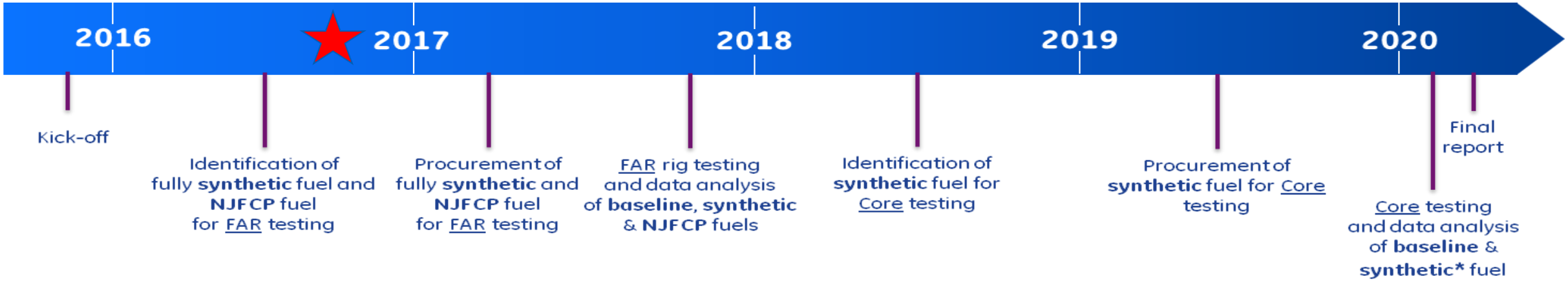
- Test one fully synthetic fuel in ASTM roadmap – (FAR and Core Test)
- Test one "reference" fuel defined by FAA's National Jet Fuel Combustion Program (NJFCP) – (FAR test)

CLEEN II Progress since May 2016:

- Identified 100% synthetic fuel and producer for FAR2 test in 2017.
  - Letter of Intent submitted
- NJFCP fuel determined w/ consensus at mid-year review in June
  - Quote received, delivery in 2017

Alternative Fuels

Schedule / Milestones / Accomplishments / Issues

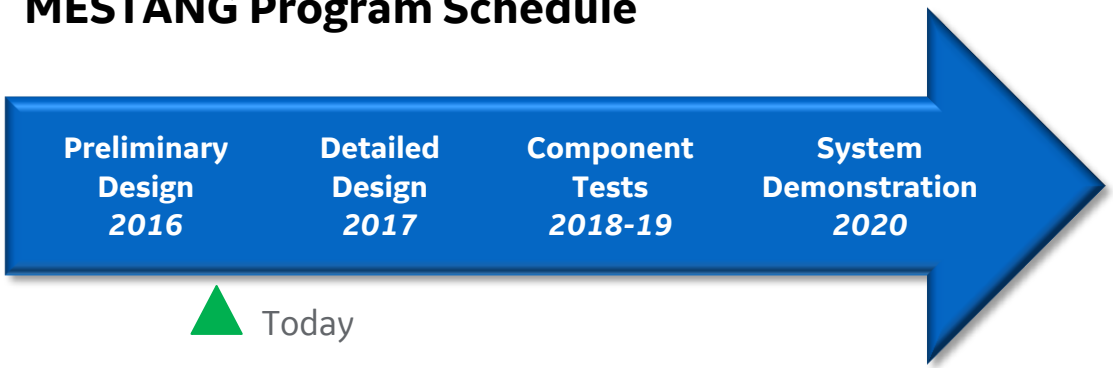


- Originally targeted fully synthetic fuel won't be available due to issues related with the producer facilities and timelines.
- In contact with another producer to procure a SPK (92%) + aromatics (8%), fully synthetic blend. Letter of Intent issued to the producer.
  - Help pave the way for 100% synthetic fuel approvals
- NJFCP fuel determined w/ consensus at mid-year review in June: C1 (100% SPK). This fuel showed the most amount of sensitivity in NJFCP tests. Official quote received from the producer, delivery 2017.
- Key figures of merit to be evaluated: Operability – L/O, LBO

More Electric Systems and Technologies for Aircraft in the Next Generation (MESTANG)

MESTANG Program Summary

MESTANG Program Schedule



Benefits:

More electric power and a light-weight power system to realize practical fuel savings and/or mission capability

- GE power system with improved performance at equivalent cost
- Fuel savings derived from reduced weight
- Subsystems certifiable for retrofits before 2026

Objectives:

Mature an integrated aircraft power system consisting of a bleedless, dual-spool engine, and a second-generation more-electric primary power system

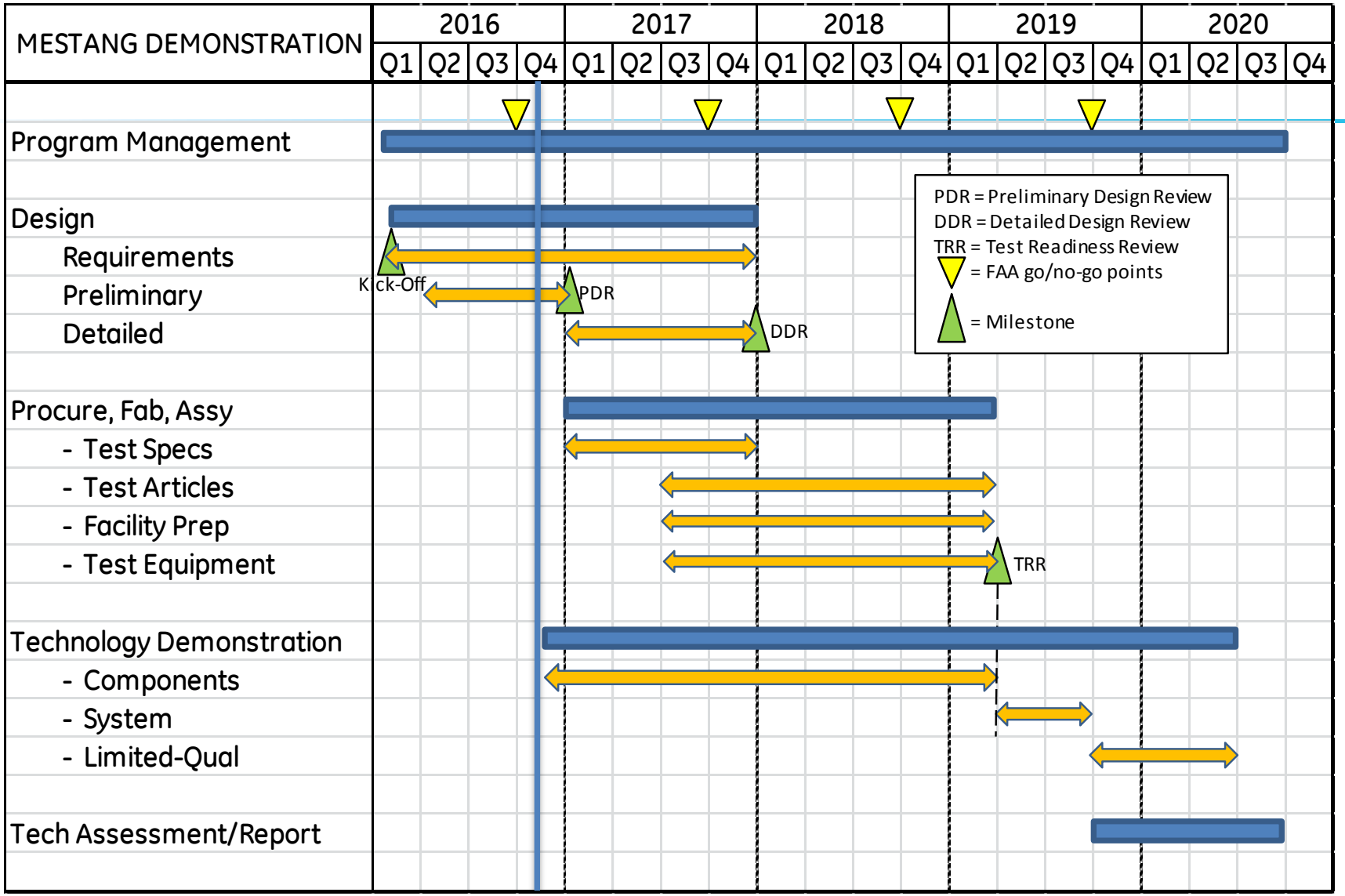
Work Statement:

- Component/subsystem validation
- Electric power system and integrated technology lab demonstration

Key CLEEN II Accomplishments:

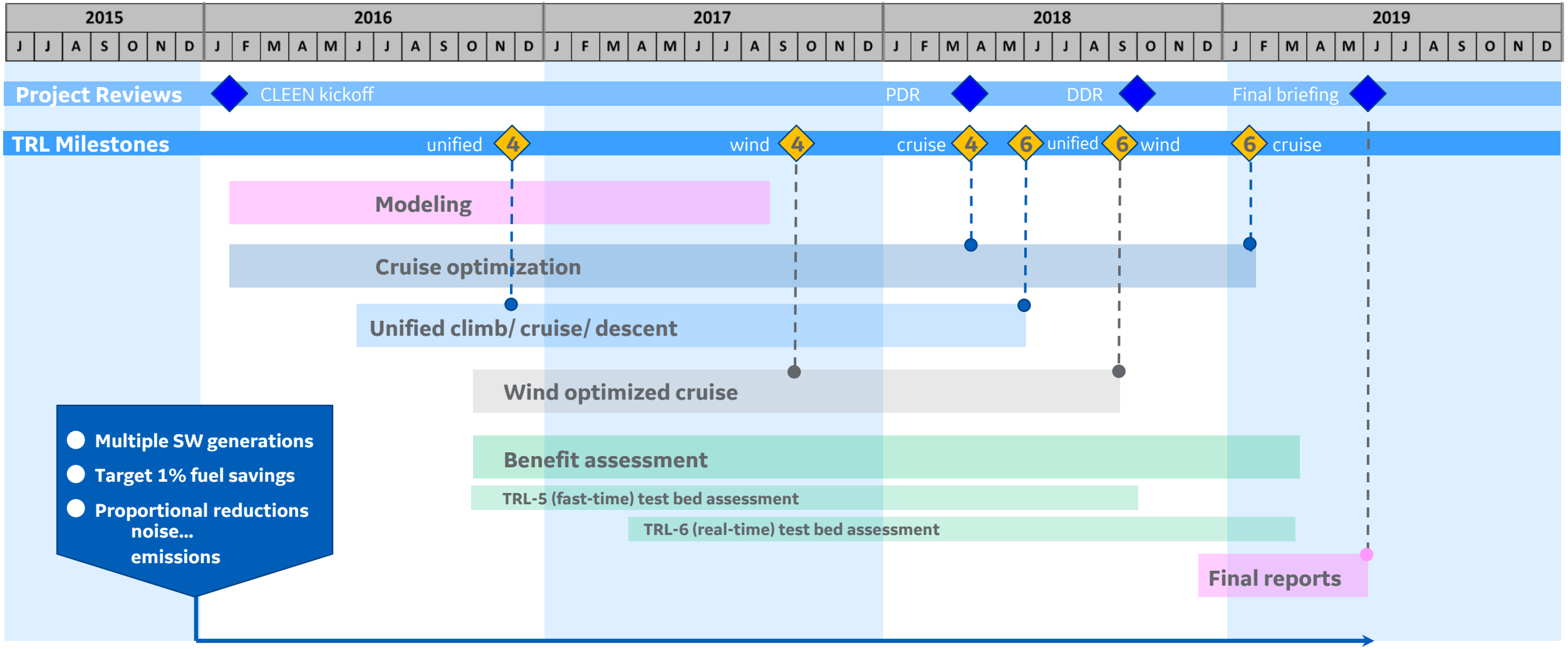
- Finalized engineering trade studies for architectural layout
- Engaged the GE Bangalore Engineering Center
- Preparing for demos of LRU's at GRC-NY
- Preparing for PDR in January

MESTANG Milestone Schedule

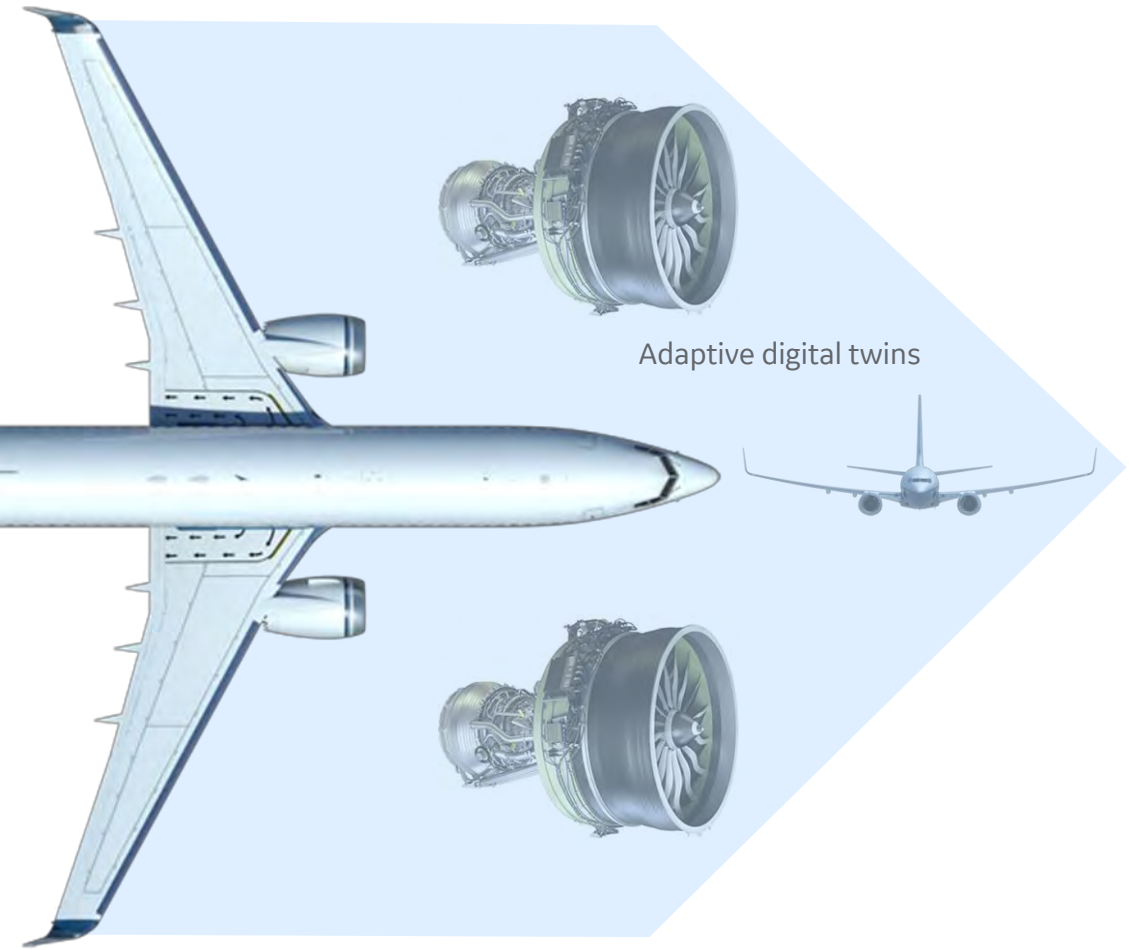


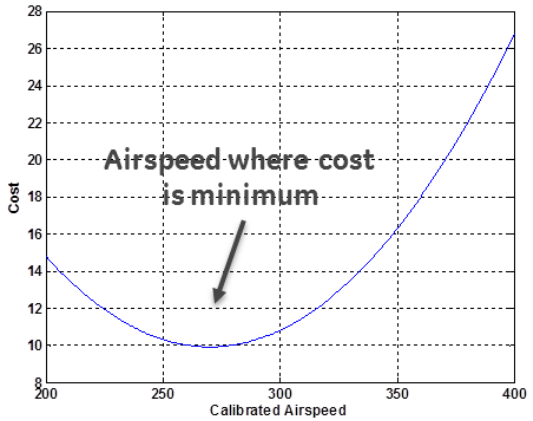
FMS Technologies

CLEEN II Project plan

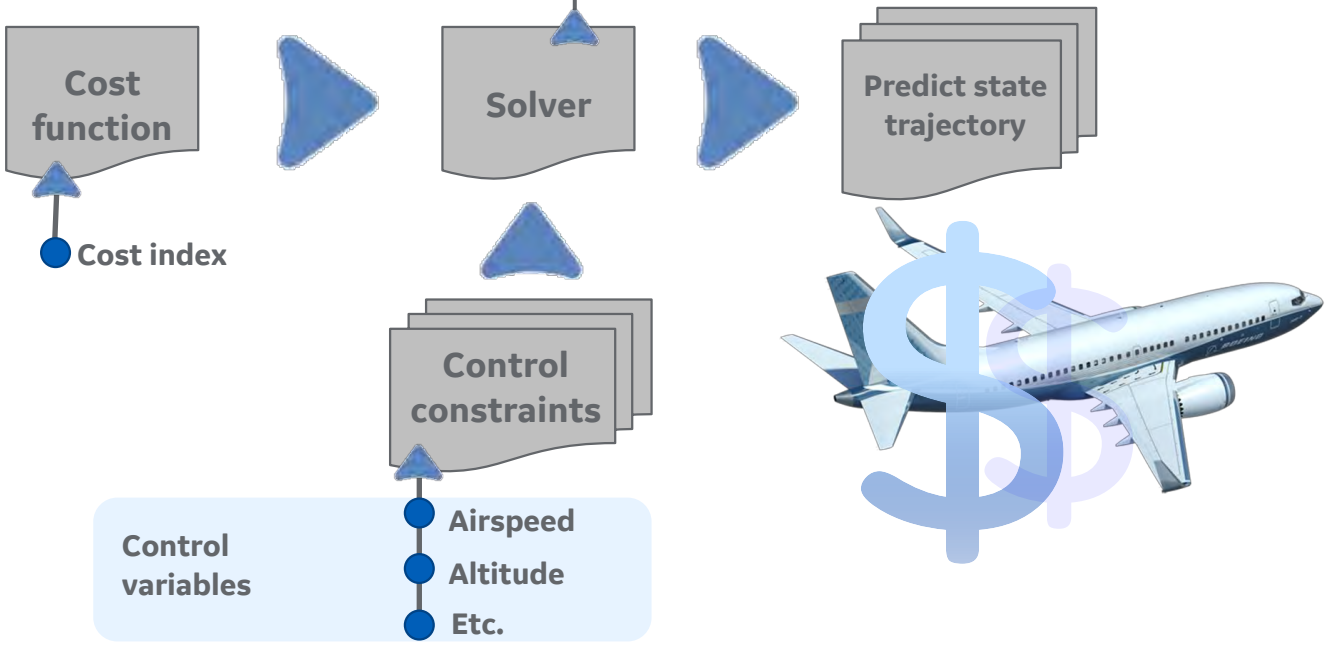


FMS Optimal Control

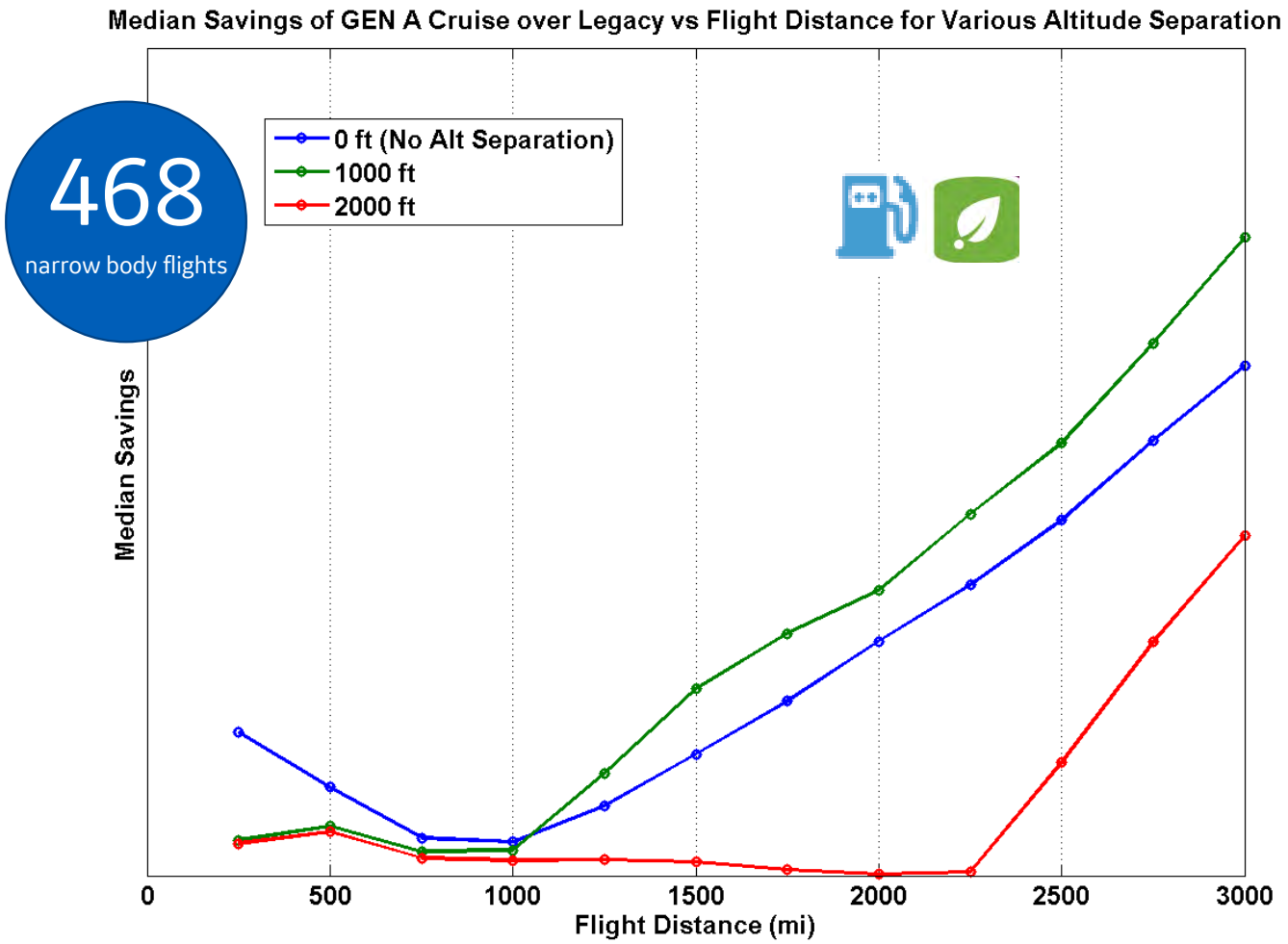




The solver determines the set of controls that minimize the cost function



Cruise Optimization

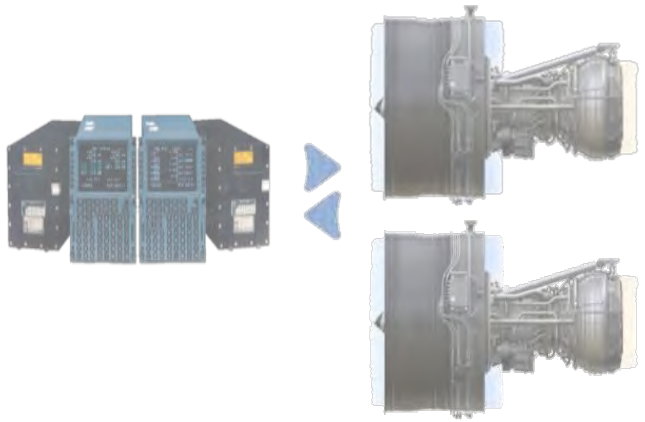


Accomplishments

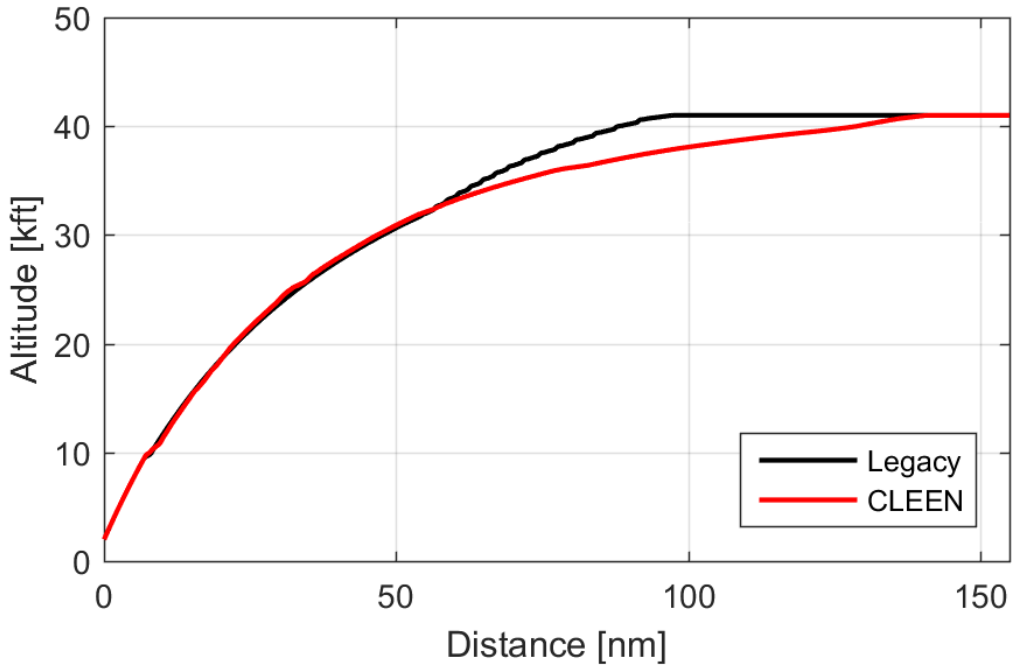
- Developed algorithm and proved concept using desktop computer simulation (TRL 5)
- Assessed benefit
- Developed software architecture for Unified Climb, Cruise, and Descent

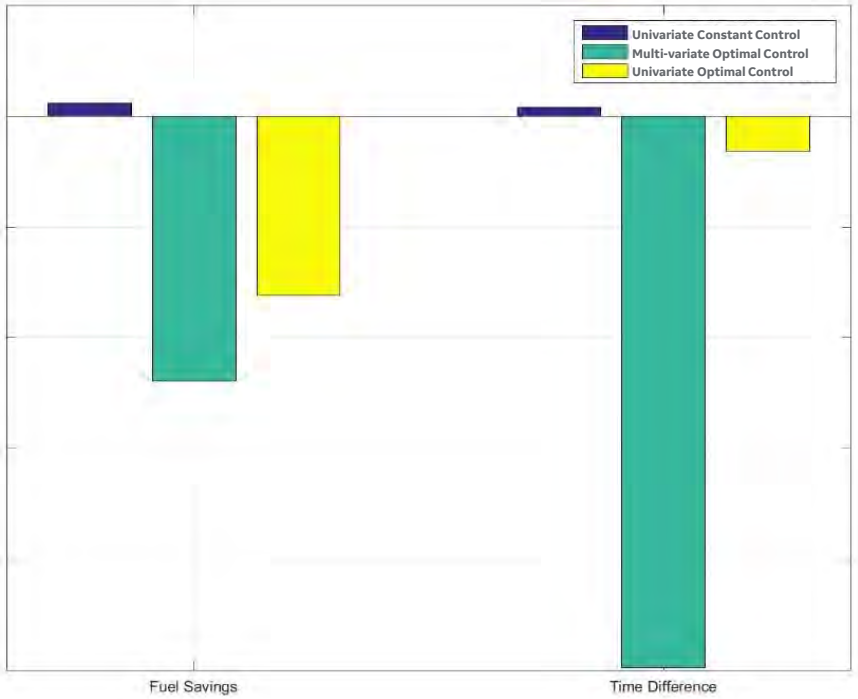
Near-Term Plan

Implement software design in TRL 6 prototype for Unified Climb, Cruise, Descent architecture (Q1 2017)



Unified Climb, Cruise, and Descent





Near-Term Plan

- Study optimal transition from climb to cruise, cruise to descent
- Iterate climb, cruise, and descent controls to account for the effect of climb and descent weight on cruise altitude
- Identify barriers to entry into service and apply corresponding constraints

TrueCourse™


Calculate an optimized flight control
and performance profile

Imagination at work