X-57 Subproject Overview and Evolution

Heather Maliska, X-57 Subproject Manager
Sean Clarke, X-57 Subproject Principal Investigator

X-57 Subproject Need

Advance the Nation's ability to design, test, and determine airworthiness of distributed electric and aero-propulsive coupling technologies, which are a critical enabler of emerging, advanced air mobility markets.

The value of X-57 lies in advancing the Nation's ability to design, test, and certify electric aircraft, which will enable entirely new markets

Mod III/IV explores the benefits of Distributed Electric Propulsion which will revolutionize aircraft architecture and performance

Meet “Maxwell”

Mod I: Baseline performance of gasoline-powered aircraft

Mod II: High-voltage powertrain integration, impact of electric retrofit

Together:
Comprehensive impact of electric propulsion technologies on aircraft design, performance, efficiency, acoustic signature, and operations

Mod IV low-speed: High-lift propeller takeoff, landing, handling qualities

Mod III : Impact of cruise-sized wing, wingtip propellers

The X-57 Maxwell Team

NASA Team

Armstrong Flight Research Center

- Oversight and project management
- Airworthiness/design reviews
- Mission management
- Piloted simulation
- Ground and flight testing
- Power system design specification

Langley Research Center

- Wing design requirements
- Wing structural analysis
- Vehicle design /analysis
- Flight dynamics simulation
- Wind tunnel testing
- Propulsor sizing

Glenn Research Center

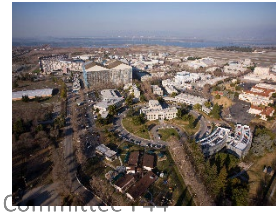
- Thermal Management analysis
- Battery Expertise
- Electrical Systems Expertise
- Cruise Motor Controller Redesign Lead
- HLMC HW/SW lead

Johnson Space Center

- Battery System Development

Ames Research Center

- Computational Fluid Dynamics



Contractor Team

Tecnam

Prime Contractor
ESAero Inc.

Motors/Controllers
Joby Aviation

Mod II Initial Integration
Scaled Composites

Software V&V
TMC

Mod III Cruise Nacelle Des/Anal/Fab
Sierra Technical Services

Battery Design & Fabrication
Electric Power Systems (EPS)

Airframe
Tecnam

Mod IV High Lift Motor Dev
Zone 5/Trust Automation

Wing Design & Manufacturing
Xperimental

X-57 Organization

Subproject Manager (SPM) & COR
Heather Maliska (AFRC)

Deputy SPM
Vince Schultz (LaRC)

Principal Investigator (PI)
Sean Clarke (AFRC)

Deputy PI
Nick Borer (LaRC)

GRC POC - Peggy Cornell
Project Management Support – Bill Cookson (AFRC)
Acquisition Office – Jenny Staggs (AFRC)
Resource Analyst – April Jungers (AFRC)
Project Coord./Doc Control – Lynnell Parker (AFRC)
Schedule Analyst – Tara Requist (AFRC)
Admin Assistant – Elena Birdwell (AFRC)

Subproject Chief Engineer
Ethan Baumann (AFRC)

Deputy CE
Claudia Sales (AFRC)

- **Vehicle IPT** – Laura Kushner (LaRC)
- **Flight Systems Lead** – Kassidy Mclaughlin(AFRC)
- **Flight Controls IPT** – James Reynolds (AFRC)
- **Performance & Sizing IPT** – Nick Borer (LaRC)
- **Wing IPT** – Jeff Viken (LaRC)
- **Systems Engineering** – Laura Kushner (LaRC)
- **Software Manager** – Cathy Davis (AFRC)
- **Power & Command IPT** – Sean Clarke (AFRC), David Avanesian (GRC)
- **Instrumentation IPT** – Joe Hernandez (AFRC)

Lead Ops Engineer
Brennan Wehr (AFRC)

- **Crew Chief/Lead Avionics Tech** – Nick Whitman(AFRC)
- **Avionics Technician** – Steven Evans (AFRC)
- **Operations Engineer** – Pablo Mendoza (AFRC)
- **Operations Engineer: Design** – Daniel Son (AFRC)

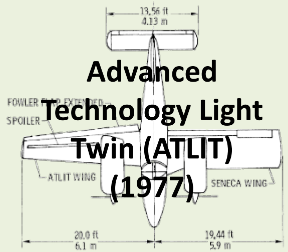
Lead Pilot
Tim Williams (AFRC)

- **Pilot** – Wayne Ringelberg (AFRC)

Subproject Support

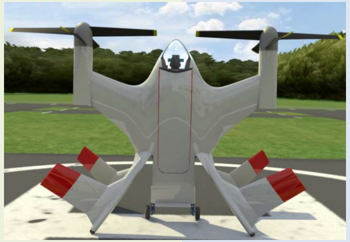
- **Flight Test Range** – Brad Butler (AFRC)
- **Quality Assurance** – Rosalio Salazar(AFRC)
- **Systems Safety** – Phil Burkhardt (AFRC)
- **Configuration Control** – Linda Soden (AFRC)
- **Public Affairs** – Sarah Mann (AFRC)
- **SQA** – Stephen Washington (AFRC)

Our Origin: A Convergence of NASA Research

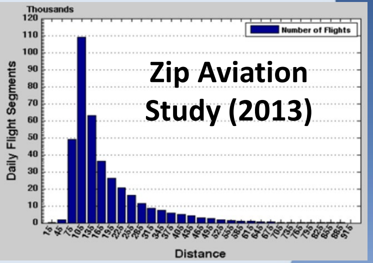


Advanced Technology Light Twin (ATLIT) (1977)

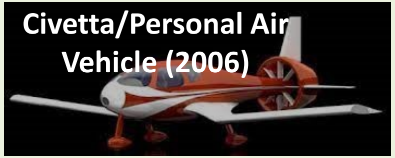
e-ATLIT (2013)



Small Aircraft Transportation Systems (SATS) (2003)



Zip Aviation Study (2013)



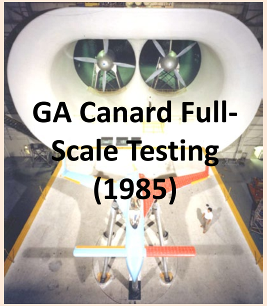
Civetta/Personal Air Vehicle (2006)

Novel General Aviation Designs for Improved Economics

New Operational Paradigms

LEAPTech (2014)

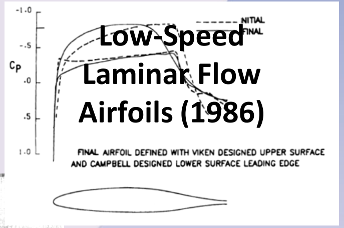
CEPT/SCEPTOR (2015)
X-57 (2016)



GA Canard Full-Scale Testing (1985)

Improved Safety and Assurance Techniques

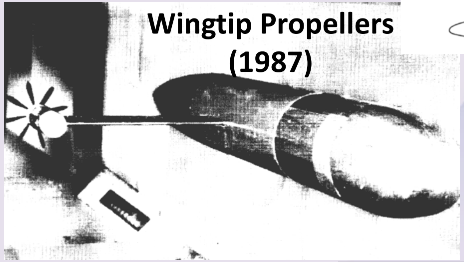
Technology Development



Low-Speed Laminar Flow Airfoils (1986)

Spin Resistant Aircraft Standards (1986)

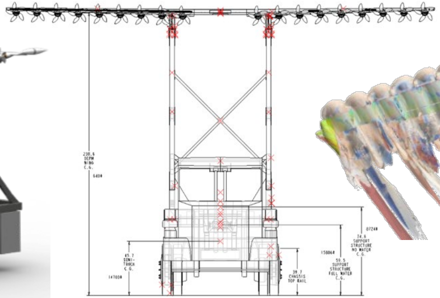
AGATE
ADVANCED GENERAL AVIATION TRANSPORT EXPERIMENTS
NASA · INDUSTRY · FAA

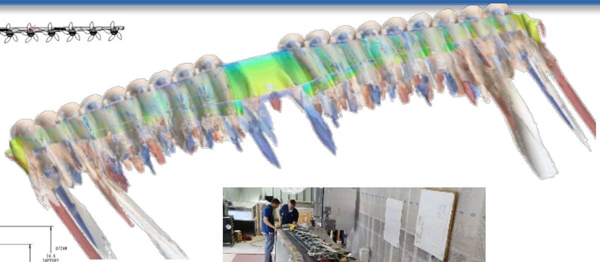


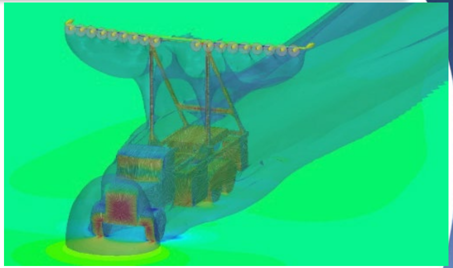
Wingtip Propellers (1987)

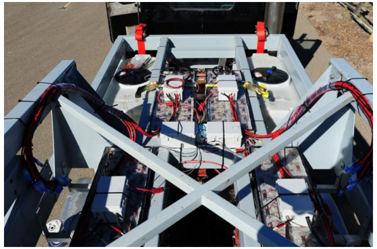
NASA MAXWELL X-57 ELECTRIC AIRPLANE

Our Origin: Leading Edge Asynchronous Propeller Tech Demo

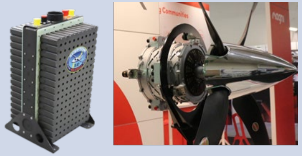








State of Industry Over X-57's Lifetime

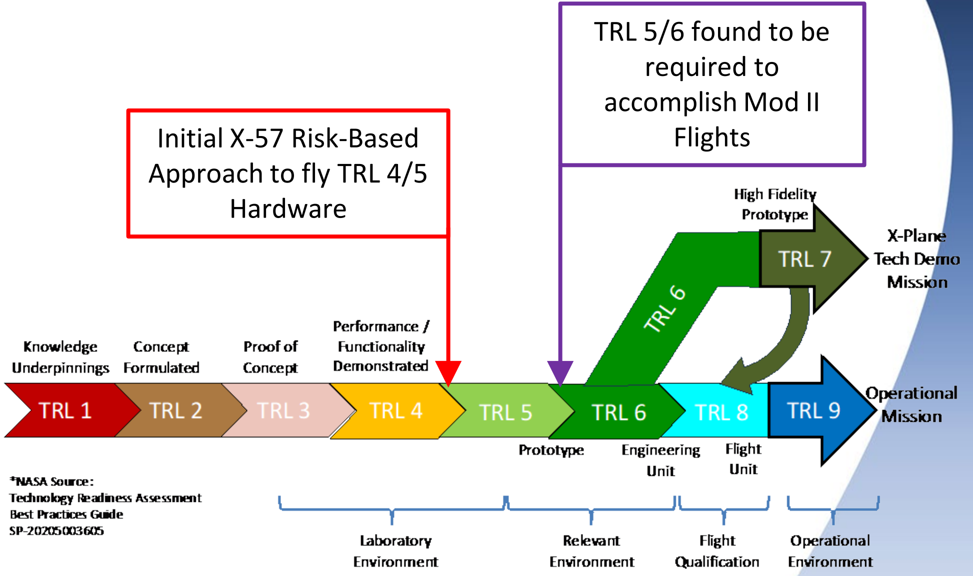
Era	Prior to CEPT (~2010-2014)	VTOL Renaissance (~2017-COVID)	Sustainability Focus (~COVID-Present)
Activity	 Numerous demonstrations & "stunts" to show possibility of electric flight  Some products on the market or (publicly) under development for specific applications	 Investment spree in a new transportation paradigm enabled by electrified propulsion  Rules, standards and products try to keep up	 Several electrified aircraft concepts in certification or product development  Increased emphasis on sustainability and accessibility of aviation
X-57 Relevance	**Show how electric flight can be a game-changer at a scale relevant for transportation**	**Develop assurance methods for EAP systems and integrations as a public pathfinder**	**Technologies and concepts for sustainable, accessible aviation transportation**

X-57 Subproject Goals and Objectives

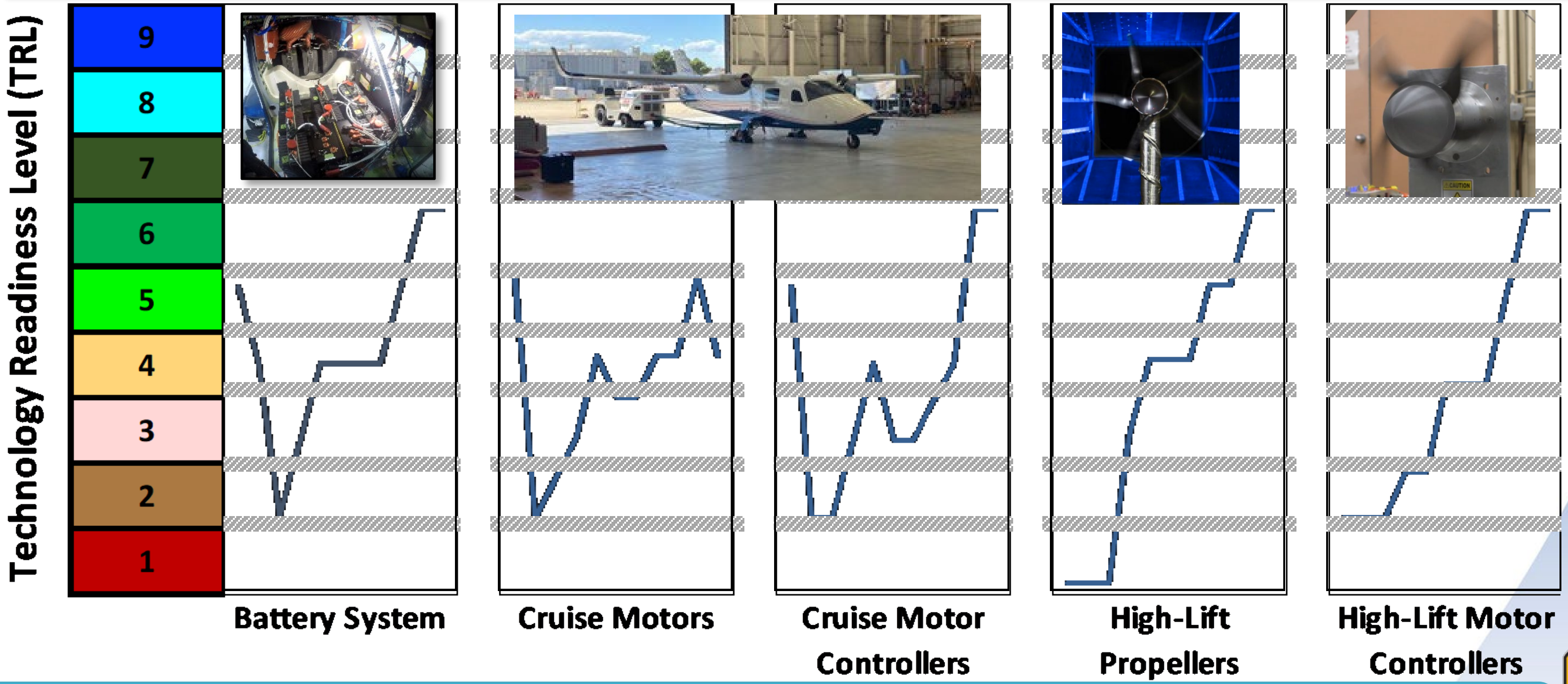
Goals	Share NASA X-57 design & airworthiness process with regulators and standards organizations to further development of distributed electric propulsion (DEP) airworthiness certification approaches and procedures.		Establish a reference platform for integrated approaches of distributed electric propulsion technologies, including best practices and lessons learned, to advance the Nation's science and industrial base.	
	Objectives	**Success Criteria**	**Objectives**	**Success Criteria**
	OBJ-1: Develop distributed electric propulsion (DEP) airworthiness standards with industry.	Actively influence civil airworthiness standards development to address the critical DEP-related gaps related to public certification rules.	OBJ-3: Share X-57 integrated DEP design & lessons learned with industry and academic stakeholders.	Conduct yearly technical progress sessions at key aviation conferences and workshops. Provide access to technical reports, major design reviews, and flight results on the X-57 technical data website.
	OBJ-2: Increase regulators' proficiency in the development of airworthy electric aircraft and distributed electric propulsion systems.	Complete a Flight Readiness Review of an aircraft with a complex, integrated DEP system. Publish X-57 "Airworthiness Validation Plan," which maps NASA FRR artifacts to FAA airworthiness documents.	OBJ-4: Provide a reference vehicle for DEP technology advancement.	Publish X-57 design artifacts such as analyses, instrumented flight data, outer mold line data file, in-flight DEP acoustic profile.

X-57 Technology Challenges

- X-planes typically advance a handful of key technologies from the 5/6 to 6/7 level
  - Subsystems not related to the technologies being demonstrated are typically at a Technology Readiness Level (TRL) of 8 or 9
- For X-57, nearly all aircraft subsystems were at a lower TRL or impacted by the new subsystems
  - Significant challenges arose while developing and integrating lower TRL hardware for a flight project
- X-57 embarked on subsystem development efforts to advance the key technologies to the TRL 5/6

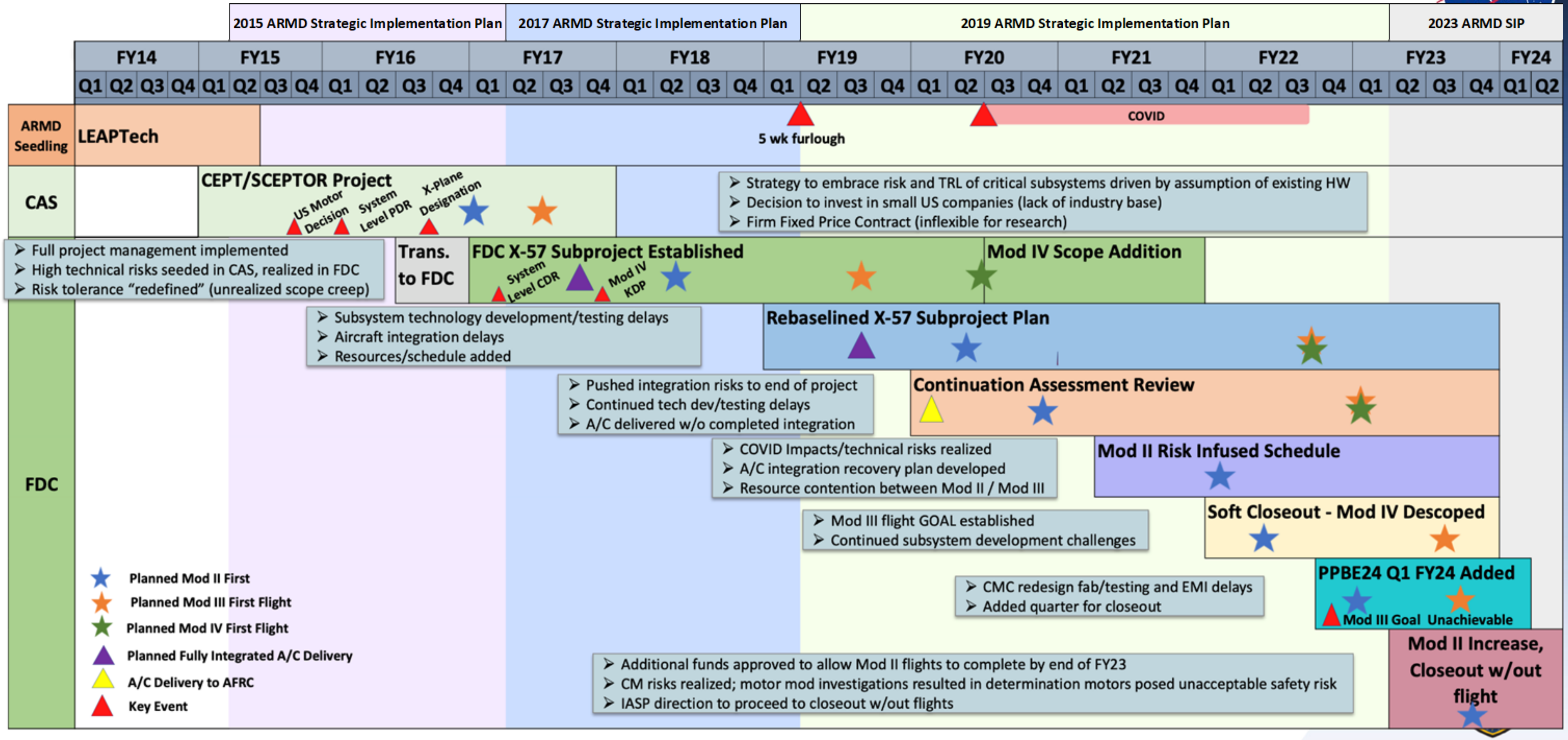


X-57 Key Technology Advancements from Kickoff to Closeout

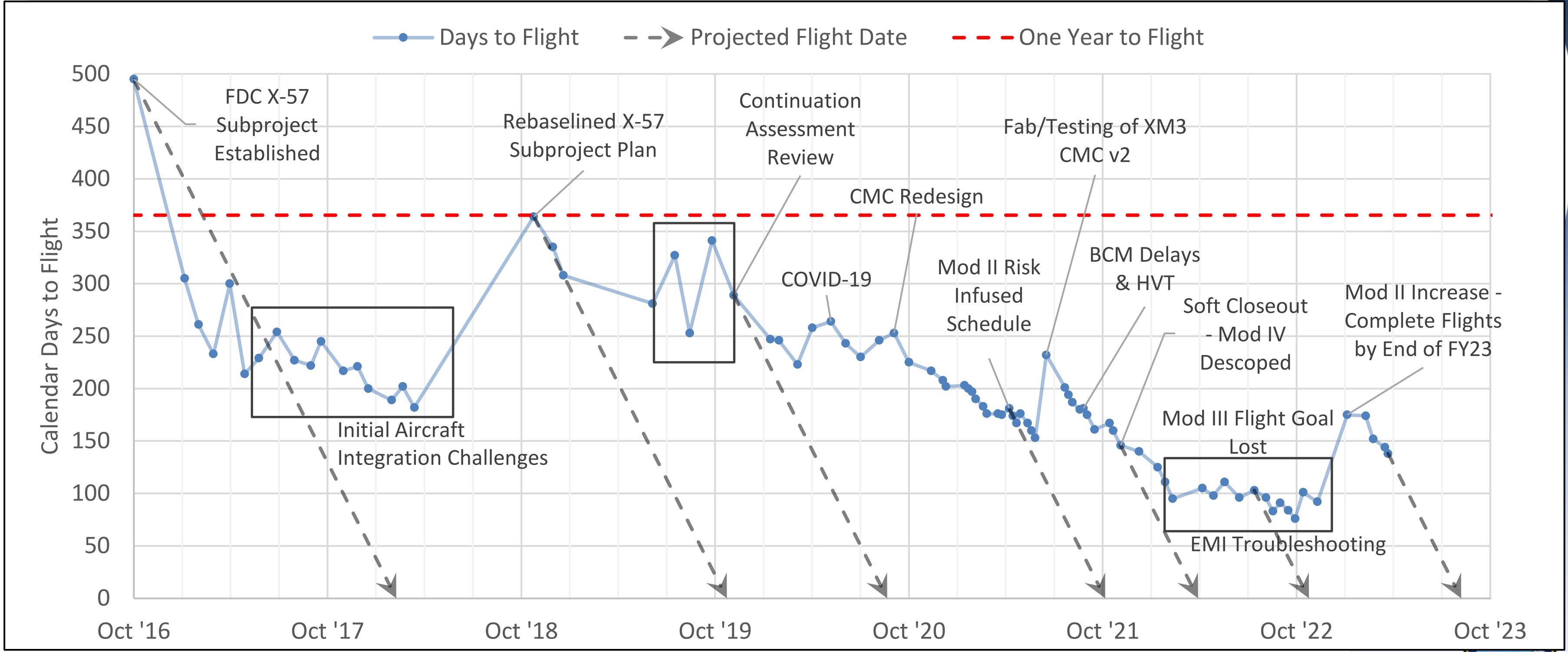


Assessed TRL dropped for many major subsystems after project initiation due to focus on domestic suppliers. Despite challenges, the X-57 made enormous headway in TRL advancement during the subproject.

X-57 Programmatic History Overview



Mod II Forecasted Days to First Flight



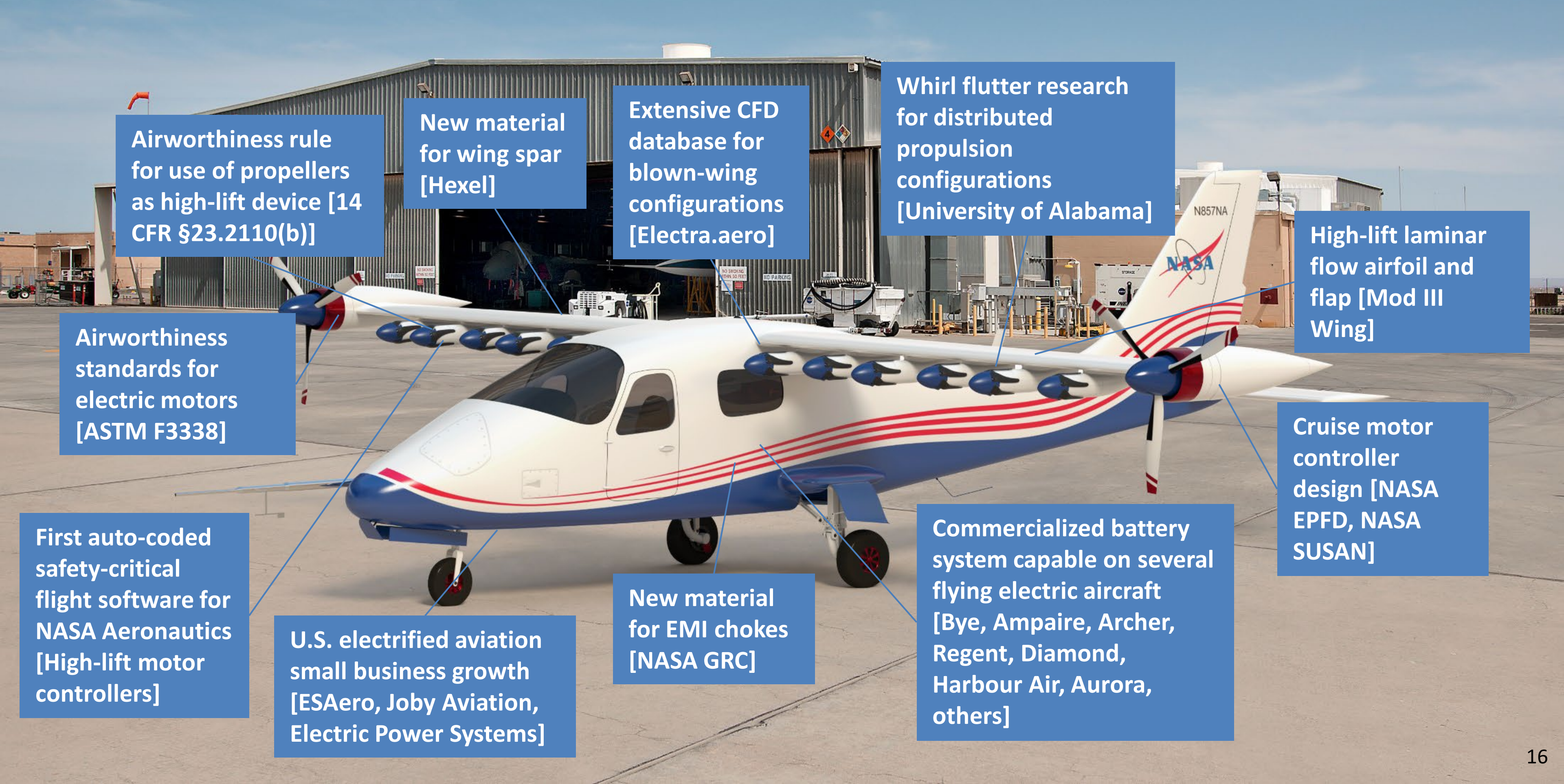
Integration and unplanned subsystem development challenges hindered ability to maintain steady progress to first flight. Mod II was a year from flight for six years of the subproject.

Lessons in the Journey to Flight

- Despite not achieving flight, the focus on achieving flight enabled the team to gather and share relevant lessons and data with industry and regulators
  - Maintaining flight as an objective drove testing and analysis rigor that leads to more discovery
- The success of the X-57 lies not in what was originally set out to achieve, but that we have identified and addressed gaps in industry that needed to be filled
  - Lessons learned were foundational to electrified propulsion
- Lessons shared early and often with industry and standards bodies
- Built up electrified aircraft US small businesses
  - Enabled commercial products
- X-57 has advanced the Nation's ability to design, test, and determine airworthiness of distributed electric and aero-propulsive coupling technologies, which are a critical enabler of emerging, advanced air mobility markets

Subproject had impact on industry and standards/regulations despite the absence of flight

X-57 Contributions



Overall Impact to Electrified Aviation

- X-57 contributions have been substantial, especially compared to level of investment
  - Elevated electric propulsion TRL of components leading to integration with flight performance specs
  - X-57 publishing approach has been "early and often," includes sharing of design tools, component and subsystem test data, and operational lessons learned with academia and industry
- Contractor/Subcontractors grew, in part, because of X-57
  - Joby Aviation – working through certification full scale flight demonstrations now
  - EP-Systems – commercialized X-57-series battery systems and continues to advance product line
  - ESAero grew substantially during execution and has integrated QA practices (AS9100 certification)
- Wider impact across the electrified aviation space (industry, regulators, academia)
  - Published architecture is a principal reference for academia and standards development
  - Design and test standards and lessons learned are being adopted
  - Impact on regulations and standards ongoing as operational constraints drive further learning

X-57 *HAS* advanced the Nation's ability to design, test, and determine airworthiness of electrified aircraft technologies


MAXWELL
X-57
ELECTRIC AIRPLANE