National Aeronautics and Space Administration

Hi-Rate Composite Aircraft Manufacturing (HiCAM)

Commercial Transport Needs

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NASA Aeronautics – Strategic Thrusts

6 Strategic Thrusts

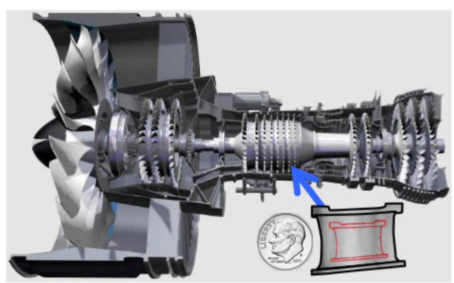
- Safe, Efficient Growth in Global Operations
- Safe, Quiet, and Affordable Vertical Lift Air Vehicles
- Innovation in Commercial Supersonic Aircraft
- In-Time System-Wide Safety Assurance
- Ultra-Efficient Subsonic Transports
- Assured Autonomy for Aviation Transformation

Thrust 3: Realize revolutionary improvements in economics and environmental performance for subsonic transports with opportunities to transition to alternative propulsion and energy

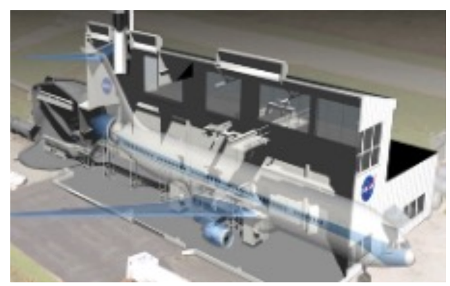
ARMD Key Subsonic Technologies:

TRL 6 by 2027 for Industry Product Decision-Making

Transonic Truss-Braced Wing



Small Core Gas Turbine



Electrified Aircraft Propulsion

High-Rate Composite Manufacturing

Transport Market Demand & Opportunity

Boeing & Airbus market outlook

- By 2040, > 43,000 deliveries
  - – replace 80% current & double fleet size
  - – Single-aisle, 2nd decade: ~150 per month
    - ➔ Industry recommends 80 per month as target production rate
- Historic aircraft production rates per month
  - – Metals (B737, A320) : 60 1.3x = 80
  - – Composites (B787, A220): 10-14 6x = 80

Increased Emphasis on <u>Sustainability</u>:

- Reduced emissions (reduced weight, drag) ➔ Composites: low weight, enables low-drag configs
- Reduced operating cost (acquisition, fuel, maintenance)

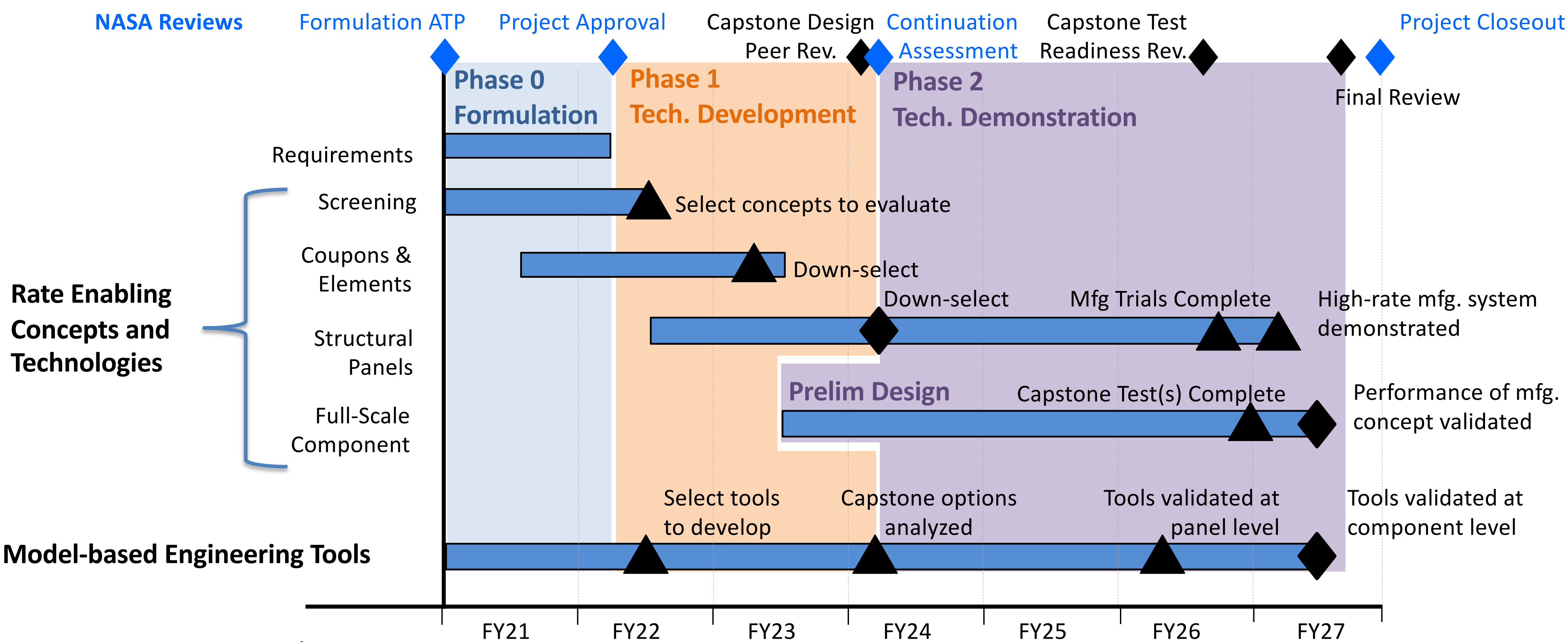
Transport Market driving: (1) High volume, earlier deliveries ➔ high-rate production
(2) cost reductions ➔ <50% of current cost
(3) performance improvements
Potential AAM market: similar drivers, vehicle rate approaching automotive (1000x)

Hi-Rate Composite Aircraft Manufacturing (HiCAM)

Goal: Demonstrate manufacturing approaches and associated technologies for large composite primary airframe structures that enable high-rate production (up to 80 aircraft per month) with reduced cost and no weight penalty versus 2020 technology for composite structures for early 2030s single-aisle aircraft production

- Mature, affordable, high-rate composite manufacturing technologies with reduced labor, equipment, and tooling costs
- Model-based engineering tools for high-rate concepts
- Large-scale demo by 2026 (TRL/MRL 6)

HiCAM Schedule & Proposed Budget



NASA Proposed Budget ($M)

	FY21	FY22	FY23	FY24	FY25	FY26	FY27	Total
Per FY22 President's Budget Request	12	18	21	25	25	20	6	**126**
Planned PPP invest = Partner match	8	11	14	17	16	11	3	**80**

= 206M

Key Partners: Advanced Composites Consortium (ACC)

Tier 1 Members

NASA
BOEING
GE Aviation
Aurora Flight Sciences
Federal Aviation Administration
LOCKHEED MARTIN
Collins Aerospace
SPIRIT AEROSYSTEMS

Tier 2 Members

NORTHROP GRUMMAN
Collier Research Corporation
ATC Advanced Thermoplastic Composites
NIAR Wichita State University National Institute for Aviation Research
UofSC South Carolina
ELECTROIMPACT
CGTECH
CONVERGENT Manufacturing Technologies - US
HEXCEL
TORAY Toray Advanced Composites
SOLVAY Progress beyond

Executive Steering Committee (ESC)

Technical Oversight Committee (TOC)

Cooperative Research Teams (CRT)

NASA – ACC relationship, NASA is:
- Founder and Member
- NASA controls 50% of the funding
- Chair ESC, TOC, alternating term with industry
- Manager, ACC business operations

Phase 0: Tasks Supporting Formulation

	System Requirements, Assessment Process		Manufacturing Technology Assessments							Model-Based Engineering Tool Assessments		
			NDE	Resin Infusion		Thermoplastic			Thermoset			
PWP / CRT Members	P0-1.1 Req. Def	P0-1.2 Tech Assess Process	P0-2.1 NDE	P0-2.2 Rapid Cure Resins	P0-2.3 Resin Infusion	P0-2.4 Thermoplastic Forming	P0-2.5 Thermoplastic Assembly	P0-2.6 Thermoplastic AFP	P0-2.7 NextGen Thermoset	P0-3.1 Process Models	P0-3.2 Structural Sizing Tools	P0-3.3 Design for Manufacturing
NASA												
ATC Mfg.												
Boeing												
CGTech												
Collier Research												
Electroimpact												
GE												
Hexcel												
Northrop (NGSC)												
Rohr (Collins/RTX)												
Solvay												
Spirit												
Toray												
U of SC												
WSU (NIAR)												

- 12 Cooperative Research Teams, comprised of 3 to 10 members
- Total Value $16M (including $8M partner cost share)

Results from Tasks Supporting Formulation

System Requirements and Baseline Definition

- Baseline Components:
  - HiCAM Reference Aircraft for high-rate production market
  - Today's "state of the art" composite construction processes
- Design Requirements and Objectives
  - Commercial airplane requirements
  - Standard Design Objectives, Constraints
- Structural Sizing Plan & Baseline Sizing
  - Common Methods, Commercial Tools
  - Consistent structural sizing for competing concepts

Large-scale Demo Options

- Conceptual Designs
  - Fuselage Barrel Segment, Wing Box, Precursor Articles
- Test Plans: Types and Quantities
- ROM Schedules and Cost Estimates

Calculation of Key Performance Parameters (KPP)

- Component Definition: geometry, manufacturing definition
- Structural Sizing → **Weight**
- Manufacturing Models
  - Activity Level Model; Station Definition, Precedence, Duration, Cost
  - Discrete Event Simulation; parts & tooling moving through stations; determines # lines for 80 ship-sets per month

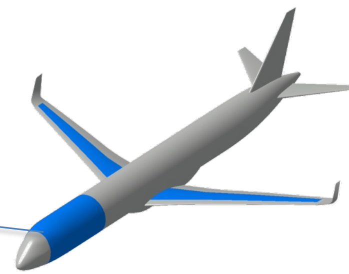
  → **Production Rate (80/mo)**; **Non-Recurring Cost ($B)**; **Recurring Cost ($M)**; **Factory Area (M sq ft)**

Quantitative Technology Assessments for Competing Manufacturing Approaches

- Compare to baseline production system (787 technology)
- Potential impact on KPPs (future state)
- Current state assessment: TRL, MRL
- Technology development roadmaps

HiCAM Scope

- Large composite primary airframe structures



Competing Manufacturing Approaches

- Next Gen Thermosets
  - Evolutionary, lower risk
  - AFP: heating, inspection
  - Automated stiffener forming
  - Shorter autoclave cycle time
  - Paint prep
- Resin Infusion
  - Out-of-autoclave
  - Rapid cure resins
  - Near net shape
  - Integrated structures
  - Unstitched and stitched
- Thermoplastics
  - AFP, out-of-autoclave
    - Tack, secondary oven
    - *In situ* consolidation
  - Stamping, cont. compression molding, stiffener forming
  - Welding, bonding, repair

Shorter Cycle Time → Less Equipment, Labor → Lower Cost

Commercial Transport: Composites Technology Needs

- **High-rate, low-cost manufacturing concepts (labor, equipment; material cost is small factor)**
  - Low processing time = less equipment, labor ➔ ‘new’ materials to enable rate
  - Consolidation choices: on the fly, secondary process, oven or autoclave (forgiving)
  - Assembly: Reduced part count (?)
    - Complex unitized versus simple parts & rapid assembly
    - Joining (co-processing, bonding, welding)
  - Inspection: *in situ*, final product, big data processing
  - Automation: quality, factory flow
  - Factory design for rate (movements, inspection, rework)
  - Design for manufacturing, inspection; machine learning
  - Flaw acceptance: fast, not perfect, but safe
- **Lighter weight**
  - always desired, but secondary importance
- **Computational methods**
  - Concepts lacking historical experience
    - Simulation for rapid development, learning
    - Sizing tools for aircraft program application
  - Many variables, simulation to predict trends
- **Collaboration**
  - Multiple company teams, supply chain: leverage expertise, resources (funds, facilities)
  - Govt, industry, university collaboration for public good
  - Integration of manufacturing, inspection and design
  - Openness external to team for broad innovation
- **Manufacturing project team focus**
  - Limited scope, defined requirements & objectives
  - Technology assessment process, quantitative key performance parameters
  - Constrained timeline to drive decisions, down-selects

Summary

- High-rate, low-cost manufacturing of composite structures is key technology in transport market
  - Meet anticipated market demand (80 aircraft/month)
  - Enables sustainability
  - Related benefit to military and Advanced Air Mobility markets
- HiCAM is focused national effort; gov't, industry, universities teaming through public-private partnership
- Considering competing manufacturing approaches
- Down-select based on KPPs for further development and large-scale demonstration
- Transition technologies at TRL / MRL 6 by Project end, 2027