Overview of the NASA STARC-ABL (Rev. B) Advanced Concept

Jason Welstead – PI, Aeronautics Systems Analysis
Jim Felder – Propulsion Systems Analysis
Mark Guynn – Aeronautics Systems Analysis
Bill Haller – Propulsion Systems Analysis
Mike Tong – Propulsion Systems Analysis
Scott Jones – Propulsion Systems Analysis
Irian Ordaz – Aeronautics Systems Analysis
Jesse Quinlan – Aeronautics Systems Analysis
Brian Mason – Structural Mechanics

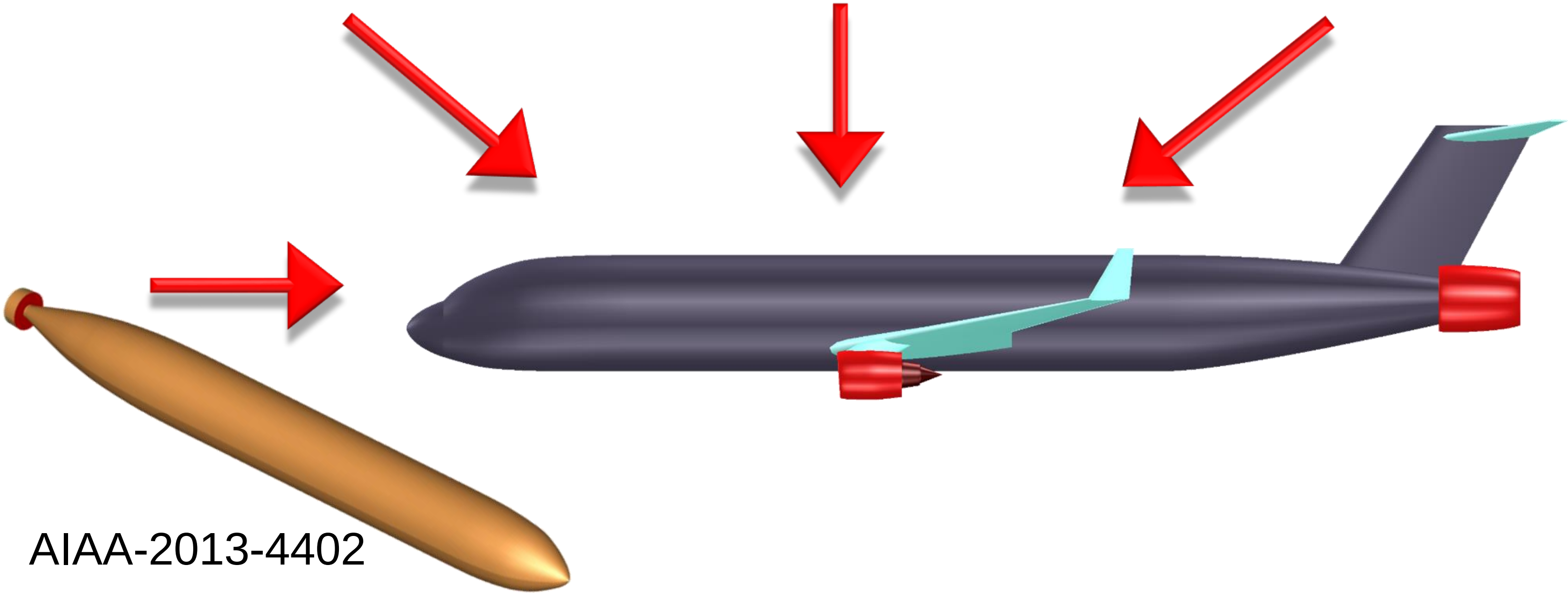
March 22, 2017

Concept Germination

SUGAR VOLT

SUGAR Freeze

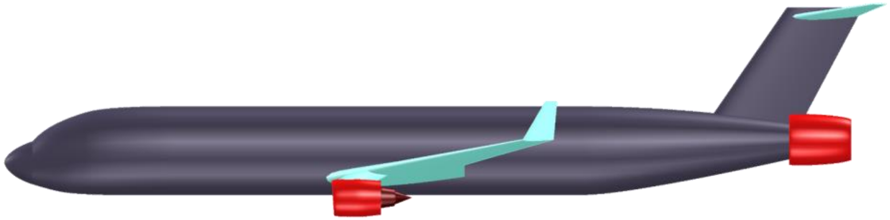
N3X



AIAA-2013-4402

STARC-ABL Rev. B* Concept Description

- STARC-ABL: **S**ingle-aisle **T**urboelectric **A**i**RC**raft with **A**ft **B**oundary **L**ayer propulsion
  - Conventional single aisle tube-and-wing configuration
  - Twin underwing mounted N+3 geared turbofan engines with attached generators on fan shaft
  - Ducted, electrically driven, boundary layer ingesting tailcone propulsor
- Summary of changes from Rev. A to Rev. B
  - Design cruise Mach number increased from 0.7 to 0.785
  - Modified wing sweep angle to accommodate increased Mach number
  - Using NASA Glenn N+3 geared turbofan model
  - Empirical estimates for propulsion weight replaced by WATE++ analysis
  - Improved weight estimates of thermal management system
  - Onboard voltage increased from 750 to 1000 volts
  - Underwing engine fan pressure ratio decreased from 1.45 to 1.3
  - Modified mission constraints to provide comparable performance to N3CC
  - All other assumptions and methods unchanged from previous analysis

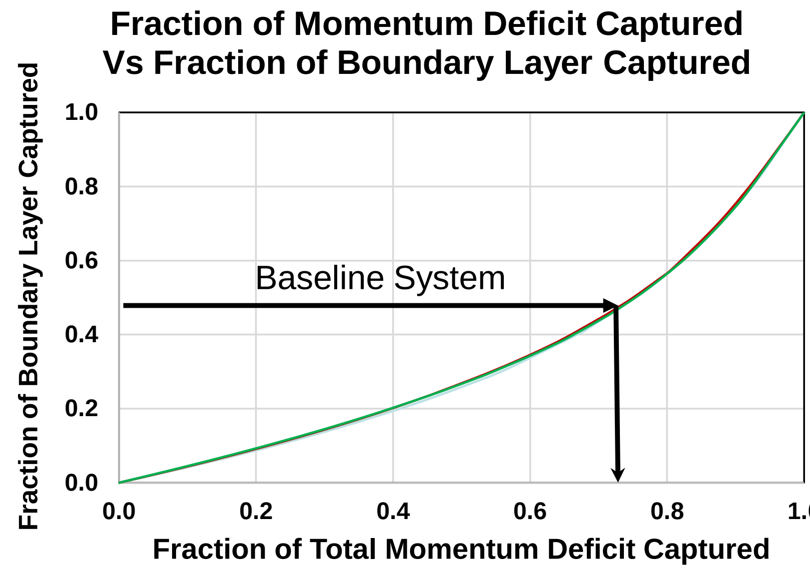


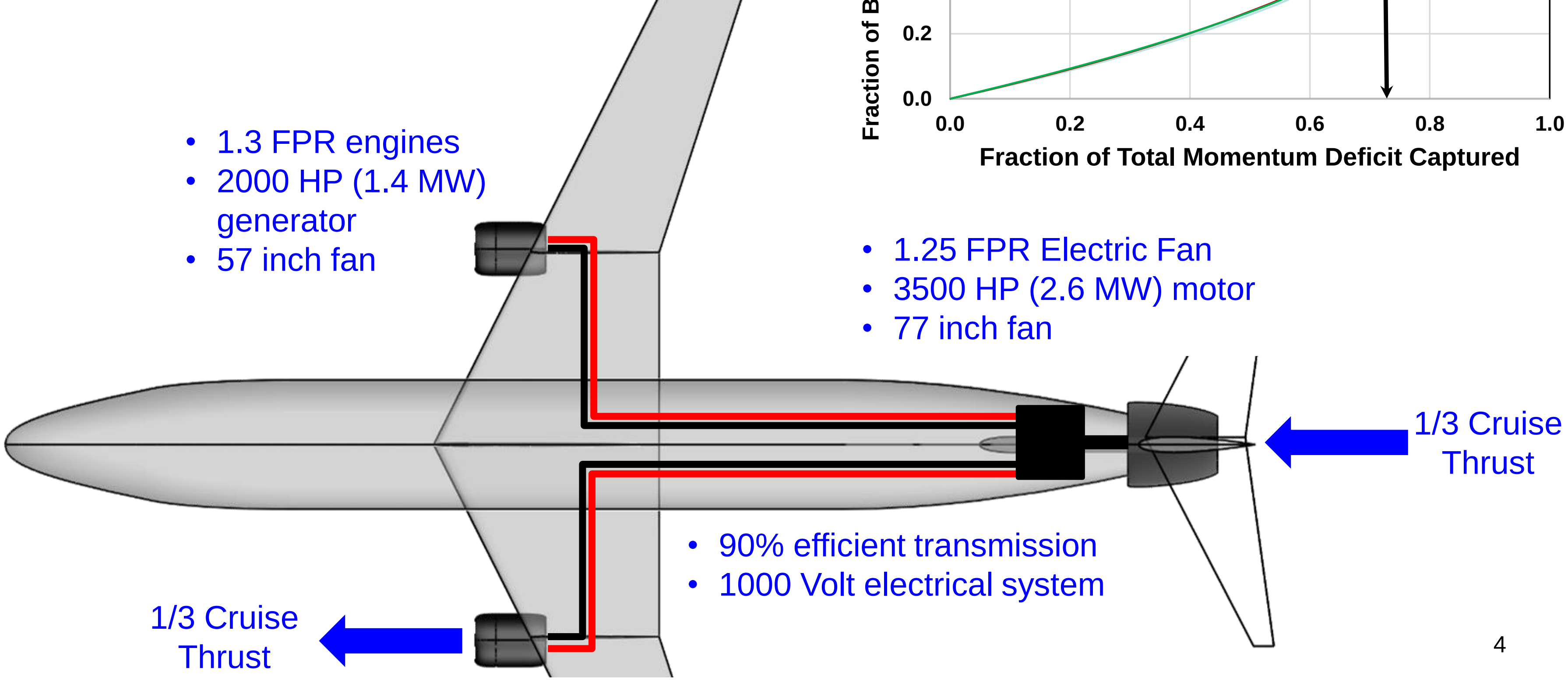
*STARC-ABL Rev. A published in AIAA SciTech 2016 paper (AIAA-2016-1027)

STARC-ABL Rev. B Power System Architecture

Electrical Component Assumptions

Component	Spec Pwr/Wt	Efficiency
Generator	8 hp/lb	96%
Motor	8 hp/lb	96%
Inverter	10 hp/lb	98%
Cable	3.9 kg/m	99.6%

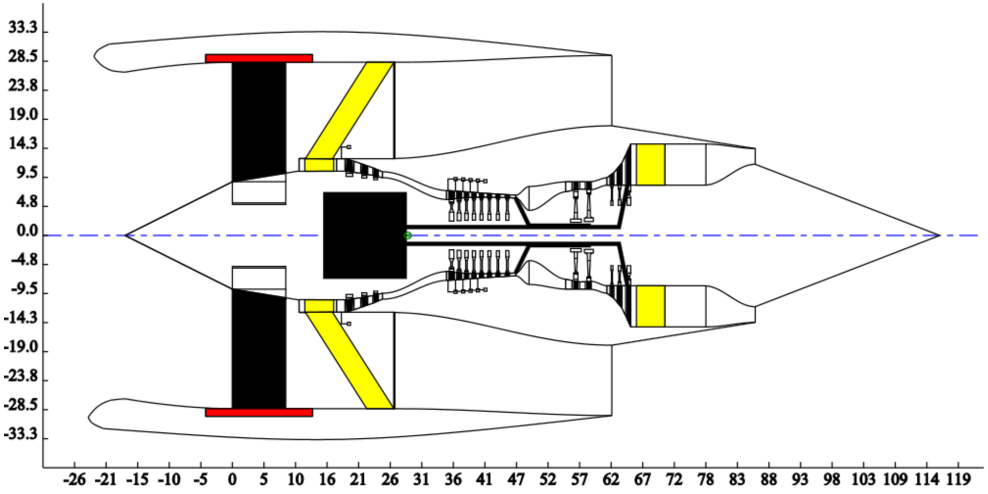




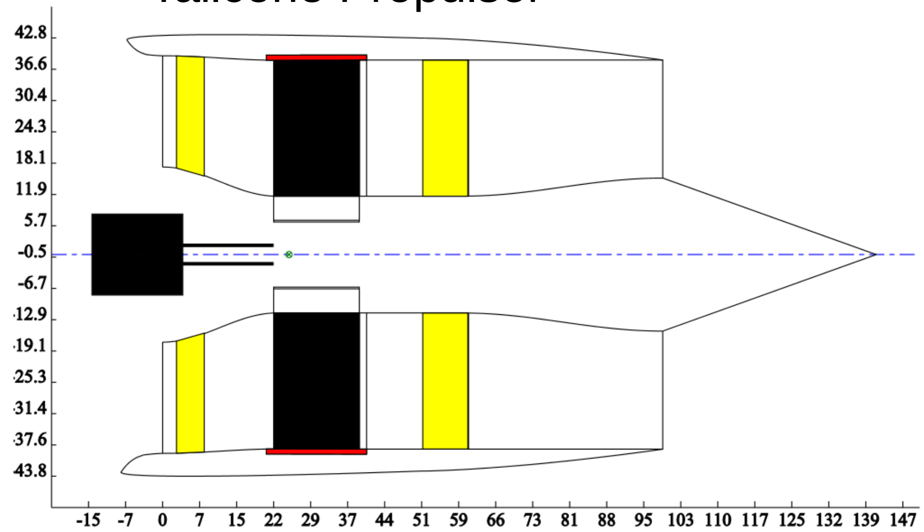
Propulsion System Concept Description

- Normal conduction (non-superconducting) electrical system
- Constant 3500 HP to BLI propulsor except at low system throttle settings
- Underwing engine fan pressure ratio of 1.30
- BLI propulsor fan pressure ratio of 1.25
- N+3 technology assumptions on propulsion architecture

Underwing GenFan



Tailcone Propulsor



System Performance Comparison

Conceptual Design of a Single-Aisle Turboelectric Commercial Transport with Fuselage Boundary Layer Ingestion

Jason R. Welstead*
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A single-aisle commercial transport concept with a turboelectric propulsion system architecture was developed assuming entry into service in 2035 and compared to a similar technology conventional configuration. The turboelectric architecture consisted of two underwing turbofans with generators extracting power from the fan shaft and sending it to a rear fuselage, axisymmetric, boundary layer ingesting fan. Results indicate that the turboelectric concept has an economic mission fuel burn reduction of 7%, and a design mission fuel burn reduction of 12% compared to the conventional configuration. An exploration of the design space was performed to better understand how the turboelectric architecture changes the design space, and system sensitivities were run to determine the sensitivity of thrust specific fuel consumption at top of climb and propulsion system weight to the motor power, fan pressure ratio, and electrical transmission efficiency of the aft boundary layer ingesting fan.

Nomenclature

C_L = lift coefficient
C_p = pressure coefficient
D = Drag
HPC = high pressure compressor
HPT = high pressure turbine
L = lift
LPC = low pressure compressor
LPT = low pressure turbine
$\bar{M}$ = mass-averaged Mach number
MN = Mach number
N+3 = third generation concept with expected entry into service near 2035
Nc = corrected fan speed
$\bar{P}_t$ = mass-averaged total pressure
P_t = total pressure
$psia$ = pounds per square inch absolute
RTO = rolling takeoff
T4 = turbine inlet total temperature
TSFC = thrust specific fuel consumption
W = mass flow rate

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SciTech 2016 Results

Start of Cruise TSFC: **-14.6%**

Design Mission Block Fuel: **-12.2%**

Economic Block Fuel: **-6.8%**

		STARC-ABL R.B	N3CC R.B	Delta
Wing Area (trap)	ft^2	1140	1170	-2.3%
Span	ft	118	118	Fixed
Aspect Ratio	-	12.2	11.9	2.3%
Sweep (LE)	deg	29	29	Fixed
Wing Loading	lb/ft^2	116.3	118.1	-1.5%
Empty Weight	lb	72730	73920	**-1.6%**
Operating Empty Weight	lb	77350	78540	-1.5%
Zero Fuel Weight	lb	108150	109340	-1.1%
Takeoff Gross Weight	lb	132480	137670	**-3.8%**
Excess Specific Power	ft/min	650	430	51.0%
Time to Climb	min	25.8	20.7	24.6%
Thrust (Sea Level Static)	lb/eng	21470	21660	-0.9%
Altitude (Start of Cruise)	ft	37000	36340	1.8%
CL (Start of Cruise)	-	0.58	0.57	1.5%
Cruise Mach Number	-	0.785	0.785	Fixed
L/D (Start of Cruise)	-	20.9	20.1	**4.0%**
Takeoff Length	ft	8160	8200	-0.5%
Landing Length	ft	5960	6030	-1.1%
Approach Velocity	knots	146	147	-0.7%
TSFC (Start of Cruise)	lb/hr/lb	0.437	0.496	**-11.8%**
Design Mission BF	lb	21340	25170	**-15.2%**
Economic Mission BF	lb	6260	6910	**-9.4%**

Propulsion System Weights

- Each propulsion system sized to meeting rolling takeoff and climb thrust requirements
- Sized propulsion systems are similar in sea level static thrust

	STARC-ABL (41,780 lb)	N3CC (37,660 lb)
Turbofans* (2)	7250	10690
Tailcone w/ gearbox	2040	-
Electric motor	440	-
Inverter	350	-
Rectifier	390	-
Cable	450	-
Circuit breaker	120	-
Thermal management	110	-
Nominal total	11,150 lb	10,690 lb
Installation weight	5%	5%
Sized SLS thrust	42,940	43,320
Engine scale factor	+2%	+15%
Sized total	12,074 lb	13,179 lb

← SLS Thrust

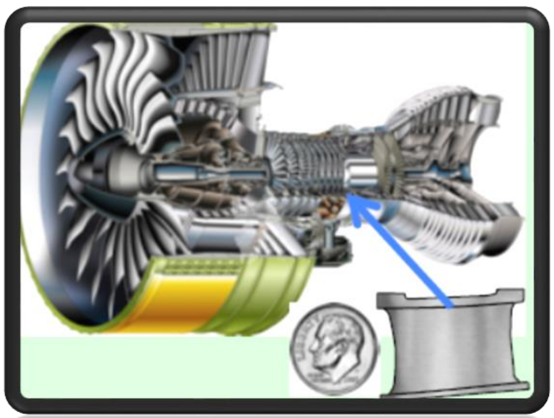
*Includes generators for STARC-ABL

Quick Summary of Rev. B Results

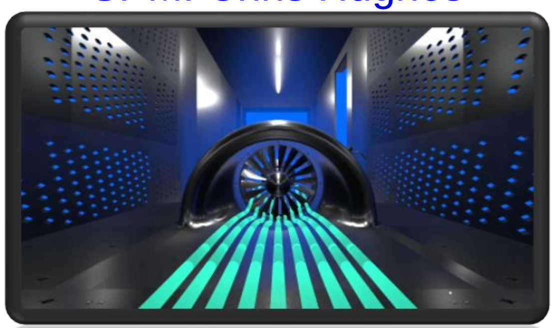
- Significant reductions in system fuel burn
  - **12%** reduction in start of cruise (SOC) TSFC
  - **9%** reduction in economic mission block fuel
  - **15%** reduction in design mission block fuel
  - Fuel burn benefits similar to Mach 0.7 STARC-ABL Rev. A results
- Fuselage propulsor details
  - Only bottom half of boundary layer ingested
  - BLI propulsor placed at most aft fuselage position
  - Driven by an all-electric motor, nominally operating at 3500 HP
  - Electrical system modeled assuming ~10% total system losses
- Partially turboelectric system is not a weight penalty
  - Downsizing of underwing engines enabled by turboelectric offsets the weight addition of electrical components and tailcone propulsor
- Cable size/weight can become prohibitive if onboard voltage too low
- Electric system specific power based upon current AATT NRA efforts

Related AATT Investments on Enabling Technologies for STARC-ABL

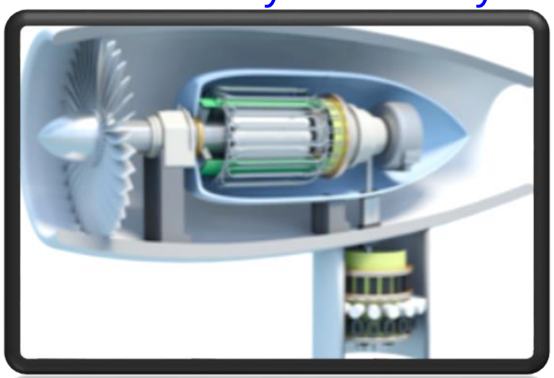
Compact High OPR Gas Generator
SPM: Jim Walker



Integrated BLI (Tailcone Thruster)
SPM: Chris Hughes



Hybrid Gas-Electric Propulsion
SPM: Amy Jankovsky

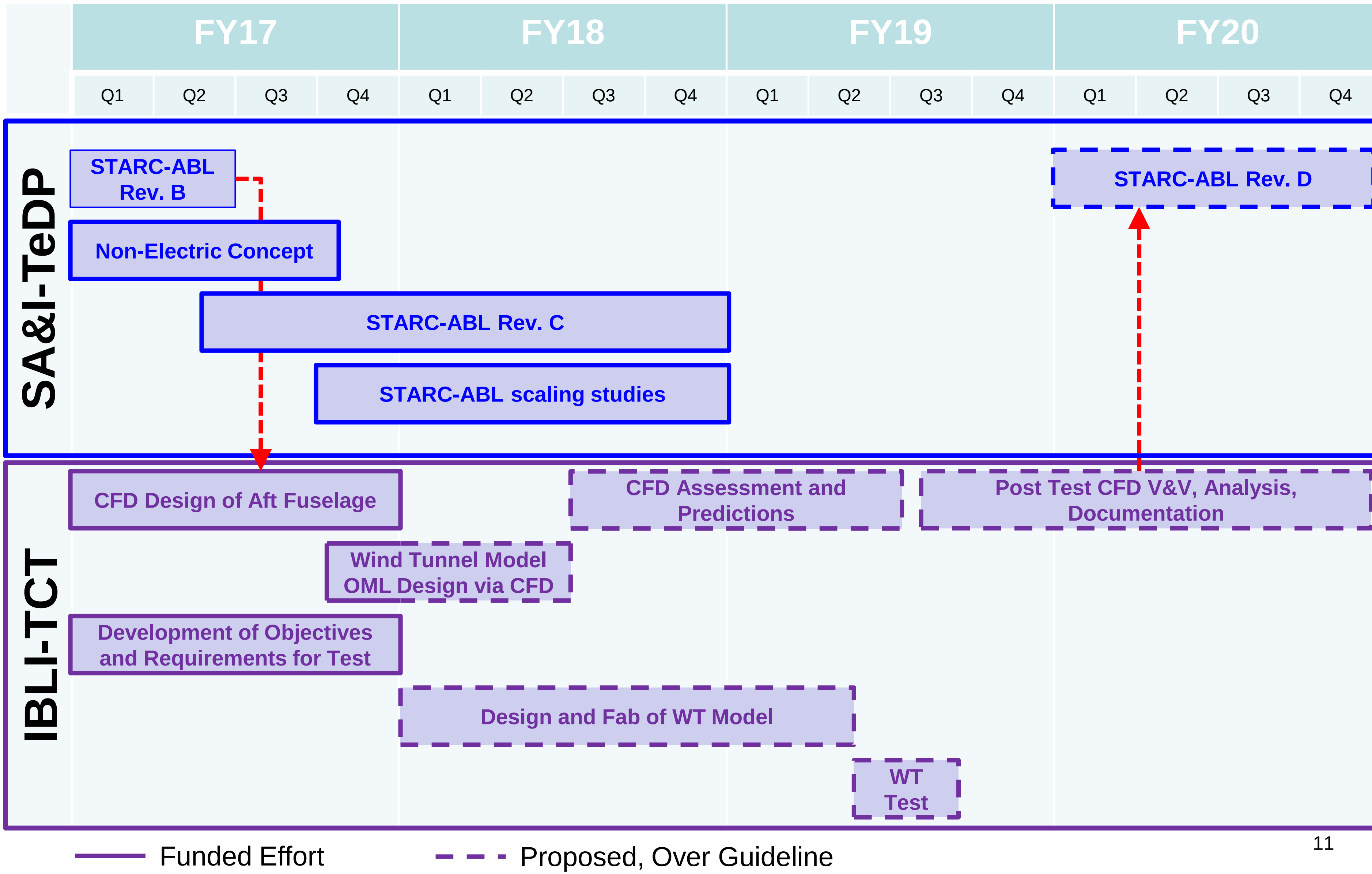


Summary of Current and Near Term AATT Research Efforts

SA&I
Concept Study and Trades
	• Continued systems analysis of STARC-ABL Concept (Rev. B)
	  ○ Improved propulsion system weight modeling
	  ○ Increased design cruise Mach to 0.785
	  ○ Better estimate of TMS requirements and weights
	  ○ Higher order analysis (Rev. C)
	
	• Analysis of a Single-aisle non-electric distributed propulsion concept
	  ○ Turbine powered tailcone thruster
	  ○ Explore the question, “What does electric give you?”

IBLI
Tailcone Thruster Task
	• CFD on objective (full) scale vehicle
	  ○ Generate a nominal design for rear aircraft shaping and nacelle that minimizes distortion and maximizes performance
	  ○ Use objective scale results to guide design at WT model scale
	
	• CFD analysis and design for potential wind tunnel model OML
	
	• Exploration of potential test facilities and wind tunnel model conceptual design

Notional Development Roadmap



Questions?


Single Aisle Turboelectric Aircraft Concept
NASA
H081YTWM

NASA

System Performance Comparison

		2016			2017		
		STARC-ABL R.A	N3CC R.A	Delta	STARC-ABL R.B	N3CC R.B	Delta
Wing Area (trap)	ft^2	1270	1220	4.3%	1140	1170	-2.3%
Span	ft	118	118	Fixed	118	118	Fixed
Aspect Ratio	-	11.0	11.4	-4.1%	12.2	11.9	2.3%
Sweep	deg	20.1 (c/4)	20.1 (c/4)	Fixed	29 (LE)	29 (LE)	Fixed
Wing Loading	lb/ft^2	106.1	106	0.1%	116.3	118.1	-1.5%
Empty Weight	lb	76700	69020	11.1%	72730	73920	-1.6%
Operating Empty Weight	lb	81380	73690	10.4%	77350	78540	-1.5%
Zero Fuel Weight	lb	112180	104490	7.4%	108150	109340	-1.1%
Takeoff Gross Weight	lb	135000	129260	4.4%	132480	137670	**-3.8%**
Excess Specific Power	ft/min	980	300	222.6%	650	430	51.0%
Time to Climb	min	19.7	25.3	-22.1%	25.8	20.7	24.6%
Thrust (Sea Level Static)	lb/eng	21460	20510	4.6%	21470	21660	-0.9%
Altitude (Start of Cruise)	ft	34400	34580	-0.5%	37000	36340	1.8%
Cruise Mach Number	-	0.7	0.7	Fixed	0.785	0.785	Fixed
CL (Start of Cruise)	-	0.59	0.6	-1.7%	0.58	0.57	1.5%
L/D (Start of Cruise)	-	22.1	21.4	3.3%	20.9	20.1	**4.0%**
Takeoff Length	ft	8190	8190	0.0%	8160	8200	-0.5%
Landing Length	ft	5590	5580	0.1%	5960	6030	-1.1%
Approach Velocity	knots	140	140	0.1%	150	150	-0.7%
TSFC (Start of Cruise)	lb/hr/lb	0.377	0.437	**-13.8%**	0.437	0.496	**-11.8%**
Design Mission BF	lb	19940	22050	**-9.6%**	21340	25170	**-15.2%**
Economic Mission BF	lb	5860	6090	**-3.7%**	6260	6910	**-9.4%**