ASCENT Project 64

Alternative Design Configurations to Meet Future Demand

Georgia Institute of Technology

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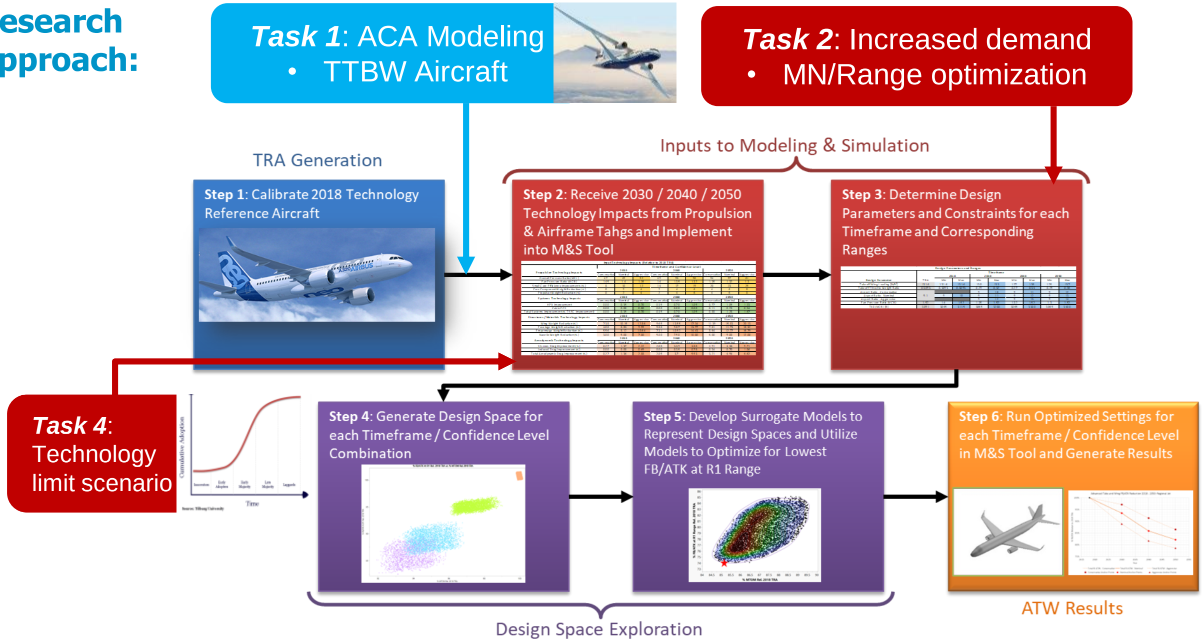
Objective:

The purpose of this ASCENT project is to address alternative means of designing aircraft besides ***business as usual*** of adopting technologies with the existing configurations, payload, range, and MN capability of the existing fleet and to capture the long term growth potential of the business as usual Approach.

Project Benefits:

- Assess potential performance impacts of new design paradigms to minimize CO2 emissions and fuel burn
- New methods developed for including such ideas in future ICAO studies and goal setting exercises.

Research Approach:



Task 1: ACA Modeling
- TTBW Aircraft

Task 2: Increased demand
- MN/Range optimization

TRA Generation

Inputs to Modeling & Simulation

Step 1: Calibrate 2018 Technology Reference Aircraft

Step 2: Receive 2030 / 2040 / 2050 Technology Impacts from Propulsion & Airframe Tahgs and Implement into M&S Tool

Step 3: Determine Design Parameters and Constraints for each Timeframe and Corresponding Ranges

Task 4: Technology limit scenario

Step 4: Generate Design Space for each Timeframe / Confidence Level Combination

Step 5: Develop Surrogate Models to Represent Design Spaces and Utilize Models to Optimize for Lowest FB/ATK at R1 Range

Step 6: Run Optimized Settings for each Timeframe / Confidence Level in M&S Tool and Generate Results

Design Space Exploration

ATW Results

Major Accomplishments:

- Task 1: TTBW aircraft design completed
- Task 2: Initial reduced Mach number design study completed
- Task 3: Reviewed and documenting prior CAEP modeling assumptions
- Task 4: Practical upper bounds for many engine parameters determined from literature review

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Overview

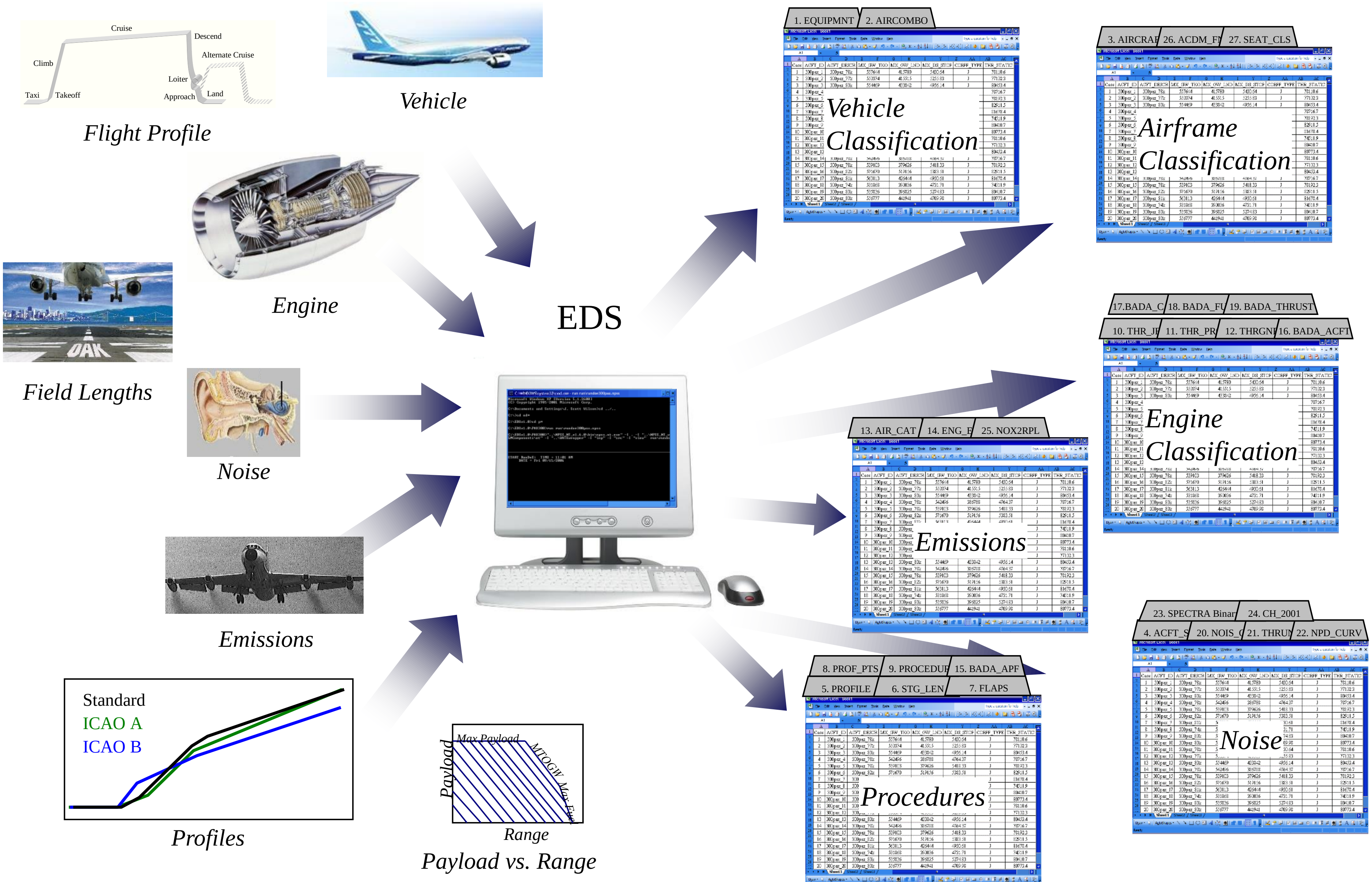
- Motivation:
  - Investigate how trends in innovative aircraft technology and design will impact fuel burn (CO2), noise and emissions
  - Goal is to forecast impacts of new technologies on fuel burn and CO_2 emissions from international aviation through and beyond 2050 under a variety of scenarios related to technology, market factors, and constraints and how these vehicles can be more realistically represented in the fleet modeling tools
- Expected outcomes
  - Provide the FAA insight into alternative means to meeting future aviation demand
- Benefits of the research
  - This project will be an improved understanding of the impacts of potential alternative design and technology choices by the aircraft manufacturers on potential aviation environmental goals of the future

Task 1: Improvement of ACA Representation in MDG/FESG Models

Motivation of Advanced Concept Aircraft (ACA) Modeling in AEDT

- The traditional approach to modeling future aircraft types in the MDG fleet tools has been to define a proxy aircraft that the new aircraft entering the fleet will replace and establish a change in benefit
- While this works for evolutionary aircraft of the past, this is not the case for ACAs, which could have drastically different performance behavior from conventional aircraft
- This task is focused on modeling one representative ACA, develop the necessary information to “fly” it in AEDT, and identify and short-comings in modeling in AEDT

ACA to AEDT Connectivity



Advanced Concept Aircraft (ACA) Modeling:

- ***Selected ACA***: Boeing Transonic Truss Braced Wing Design:

- Unique features relative to ACA:
  - High wing, T-Tail, Higher BPR engines
  - Truss, high aspect ratio wing, heavier wing weight / MTOW, very high L/D
  - Typically higher cruise altitudes
  - Some differences in how it might perform in AEDT, but not as different as, say, LH2 or electrification or more radical architectures

- TBW aircraft was modeled and calibrated in EDS by a separate GT team to resemble the Subsonic Ultra Green Aircraft Research (SUGAR) study performed by Boeing
- The TBW is expected to be deployed in the 2030-40 timeframe if chosen, and the modeling assumptions for the engines, composites, etc. were based on a 2035 level of technology engine
- With the output data the necessary performance, emissions, and noise coefficients needed by MDG's modeling tools were obtained
- EDS utilized the calibrated TBW model to generate Aviation Environmental Design Tool (AEDT) coefficients and to obtain noise contours
- Currently attempting setup of AEDT with these coefficients to validate modeling approach

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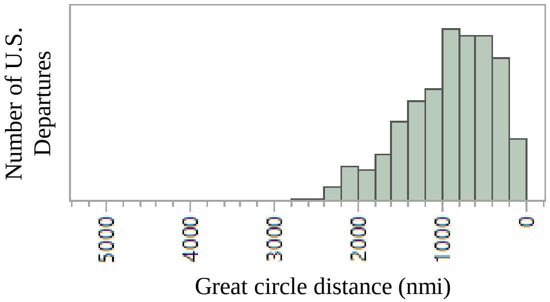
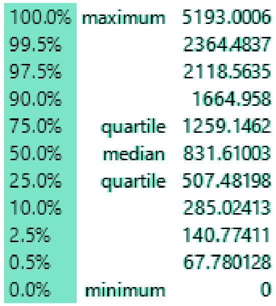
Task 2: Alternative Configurations to Meet Future Demand

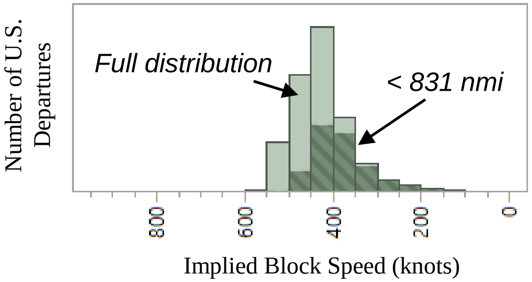
Matching Aircraft Design Requirements, Future Demand, and Zero Emissions Goals

*Plotted from BTS data (2019)





100.0%	maximum	5193.0006
99.5%		2364.4837
97.5%		2118.5635
90.0%		1664.958
75.0%	quartile	1259.1462
50.0%	median	831.61003
25.0%	quartile	507.48198
10.0%		285.02413
2.5%		140.77411
0.5%		67.780128
0.0%	minimum	0



- Current aircraft sized for long range design missions, but flown primarily at 1/4 range (median)
- What if aircraft were individually designed/optimized for particular sectors of market demand? → **Reduced CO2**
- **Why not reduce design range?**
  - Single aircraft/aircraft family capable of full range of missions within a given passenger class
  - Marginally heavier OEW required to carry larger fuel loads for longer range
  - Larger wings required for fuel volume storage, lift, etc. and larger engines

- Mach can be reduced to improve aircraft overall specific air range
- **Why not reduce MN?**
  - Technically reduces aircraft capacity and passenger delivery throughput
  - Reduces fuel burn / pax, but requires additional flights/aircraft to meet additional demand
  - Compensate by increasing ***payload***

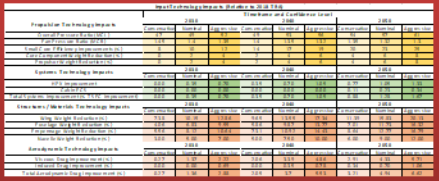
LTAG Study Technology Methodology

TRA Generation

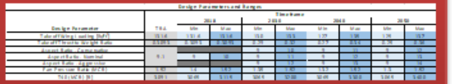
Step 1: Calibrate 2018 Technology Reference Aircraft

Inputs to Modeling & Simulation

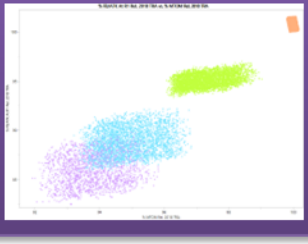
Step 2: Receive 2030 / 2040 / 2050 Technology Impacts from Propulsion & Airframe Tahgs and Implement into M&S Tool



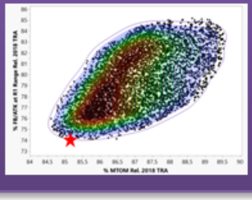
Step 3: Determine Design Parameters and Constraints for each Timeframe and Corresponding Ranges



Step 4: Generate Design Space for each Timeframe / Confidence Level Combination



Step 5: Develop Surrogate Models to Represent Design Spaces and Utilize Models to Optimize for Lowest FB/ATK at R1 Range



Step 6: Run Optimized Settings for each Timeframe / Confidence Level in M&S Tool and Generate Results

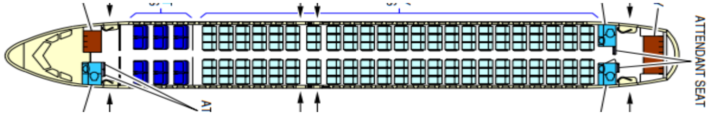
Design Space Exploration

ATW Results

- 5 aircraft categories considered:
  - WB, NB, RJ, TP, BJ
  - ***Only the narrow body*** will be considered for this effort
  - Process will be the same with some modifications

Narrowbody Tech Reference Aircraft: A320neo

- NB Technology Reference Aircraft (TRA) is based on a technology level in line with state-of-the-art of the vehicles in production today:
  - Notional Airbus A320neo
  - Assumed payload of 33,750 lbm
    - 150 pax @ 225 lbm (@ design range)
  - Design range of 3,360 nm
    - R1 range of 2,455 nmi and 42,510 lbs of payload
  - Metallic main components (wing, fuselage, empennage)
  - 2 geared fan engines (notional PW1133G) at high bypass ratio of ~11 (SLS)
    - Created notional engine model from publically available information and ICAO databank
    - Match ICAO fuel flow and thrust levels



Images from Airbus Website [http://www.aircraft.airbus.com/aircraftfamilies/passengeraircraft/a320family/a320neo/]

Modified Aircraft Fixed Parameter Set

- For LTAG, the technology impact vehicle-level results have the following design parameters **fixed** for technology infused vehicles
  - Design Range → ***Specific intervals***
  - Design Payload
  - ~~Design Cruise Mach Number~~ → ***Reformulated as opt. parameter***
  - ~~Field Length Requirements~~ → ***Reformulated as constraint***
  - ~~Sweep~~ → ***Reformulated as design variable***
  - ~~Average Thickness to Chord Ratio~~ → ***Reformulated as design variable***
- The crossed-out options above we propose to move to the design variable category
- Range will be varied from a shorter range to TRA design range (3360 nmi) in discrete intervals (propose 1360, 2360, 3360 nmi)
- The M&S tool will ***size*** the vehicle to maintain each Payload / Range capability for every point run through the simulation
- This will mean that there are 3 separate sets of optimizations to perform at the 2035 technology level for each specified design range

Narrow Body - Technology Impacts

Input Technology Impacts (Relative to 2018 TRA)			
	From TAHGs	Interpolated	From TAHGs
Propulsion Technology Impacts	**2030**	**2035**	**2040**
	Medium	Medium	Medium
Overall Pressure Ratio (MCL)	49 (Upper bound)	Optimized in range	53 (Upper bound)
Fan Pressure Ratio (MCR)	1.4 (Lower Bound)	Optimized in range	1.35 (Lower Bound)
Small Core Efficiency Improvements (%)	10	13.5	17
Core Component Weight Reduction (%)	2	3	4
Propulsor Weight Reduction (%)	2	3	4
Systems Technology Impacts			
	Medium	Medium	Medium
HPX Improvement	0.35	0.525	0.70
Cabin ECS	0.00	0.00	0.00
Total Systems Improvement (% TSFC Improvement)	0.35	0.525	0.70
Structures / Materials Technology Impacts			
	Medium	Medium	Medium
Wing Weight Reduction (%)	10.15	11.85	13.55
Fuselage Weight Reduction (%)	6.83	8.35	9.87
Empennage Weight Reduction (%)	8.12	9.52	10.92
Nacelle Weight Reduction (%)	5.00	6.25	7.50
Aerodynamic Technology Impacts			
	Medium	Medium	Medium
Viscous Drag Improvement (%)	1.37	2.38	3.39
Induced Drag Improvement (%)	0.00	0.175	0.35
Total Aerodynamic Drag Improvement (%)	1.36	2.53	3.7

Narrow Body – Design Parameter Ranges & Constraints

Design Parameters and Ranges

Design Parameter	Timeframe		
	TRA	2035	
		Min	Max
Takeoff Wing Loading [lb/ft2]	131.6	128	134
Takeoff Thrust to Weight Ratio	0.3093	0.28	0.33
Aspect Ratio	10.95	9	11.5
Overall pressure ratio at TOC	47.72	48	52 (use 51 for clouds)
Fan Pressure Ratio (MCR)	1.52	1.33	1.52
T40 (MCR) [R]	3091	3065	3250
Sweep	23.84	17	27
Cruise Mach	0.78	0.7	0.8
Average thickness-to-chord ratio	0.124	0.09	0.13

Constraints

Constraint Parameter	Timeframe	
	2018 TRA	2035
T3max Limit [R]	1649	1800
Gate Constraint [ft]	110.6	118.1
Fan Diameter Constraint [ft]	6.2	7.17
Takeoff Field Length Requirement	7900 ft	8190 ft
Fuel Capacity	> Required	> Required
Approach Speed	-	< 155 kts

- Fan Diameter constraint to ensure at least 2 ft of engine ground clearance
- For this aircraft, a folding wing tip penalty of 4.4% was applied for advanced designs with wingspan > 118.1 ft
- TRA TOFL was ~8000ft, which was too constraining for the design space
  - Expanded to be under 8,190 ft

Narrow Body Data Set

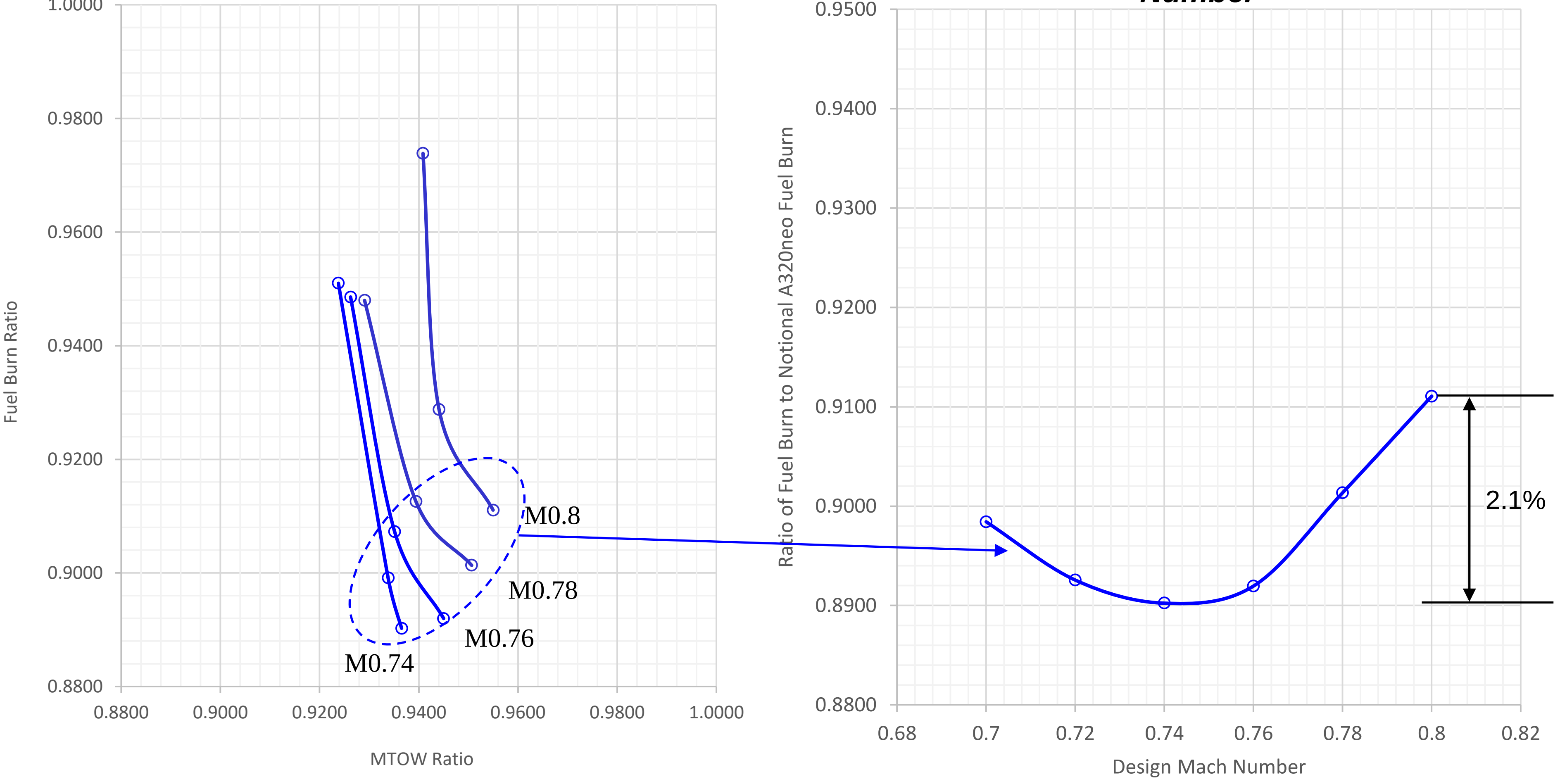
- Ran design of experiments within ranges specified in the prior chart for each design variable
- Recorded constraints and design block fuel to be used as an objective function
- 1000 cases used to form a dataset of inputs and outputs
- Low order neural nets created to best fit data set within approximately +/- 1% on block fuel burn
- Gradient based optimization used to determine best fuel burn, best MTOW, and best 50/50 split at discrete Mach numbers values

Prelminary Optimization Results

PRELIMINARY RESULTS

Fuel Burn vs. MTOW Pareto Frontier

Optimal Fuel Burn Cases vs. Mach Number



Task 2 Findings and Next Steps

Tentative Findings:

✓ Fuel burn and MTOW savings achievable by reducing Mach number

- Sensitivity on the smaller side relative to those quoted in other studies (e.g. [1])
    - Optimum Mach number of 0.74 consistent for SA class
    - In general, have found that future tech actually slightly reduces benefit
    - Exception: NLF tech likes reduced sweep

Next steps:

- Aero tech impacts held constant at various sweep angles
    - Investigate impact on aero tech by reducing sweep angle (e.g. NLF tech)
    - Potentially yield more reduction if more NLF possible
- Minor tweaks/improvements to the optimization approach
- Include cases for reduced range
- Report final optimizations and conclusions

[1] Brett, P., A Methodology for Evaluating Fleet Implications of Mission Specification Changes, Georgia Institute of Technology Dissertation, December 2014

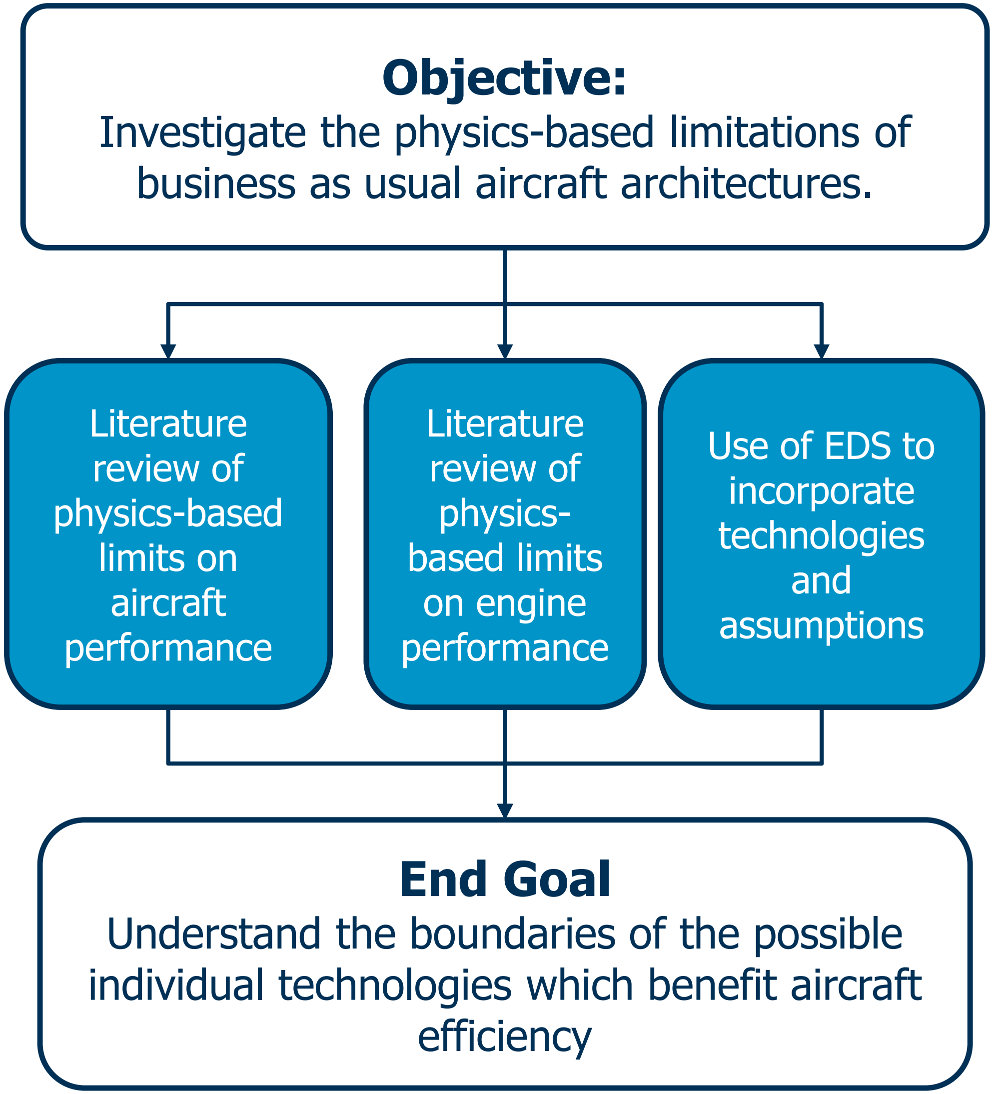
Task 3: Improved Environmental Assessment Methods

Task 3: Assessing MDG/FESG Modeling Assumptions

- This task is focused on how can the modeling of MDG/FESG be improved to provide more insight to the decision makers
- Objective: provide the FAA and Volpe insight to assumptions that could be improved to explore more analytical scenarios in a more efficient and rapid manner
- Team has gathered prior CAEP documentation on trends and stringency analysis and reviewed how it has been traditionally done
- Created a framework of the categories of assumption that will be filled out through each review beginning with LTAG and moving backwards in time
  - Costs, fleet evolution, retirements, etc.
- Next Steps: Finalize review of prior CAEP assumptions and document findings

Task 4: Exploring Physics-based Boundaries of the Possible

Task 4:Exploring Physics-based Boundaries of the Possible : Problem definition



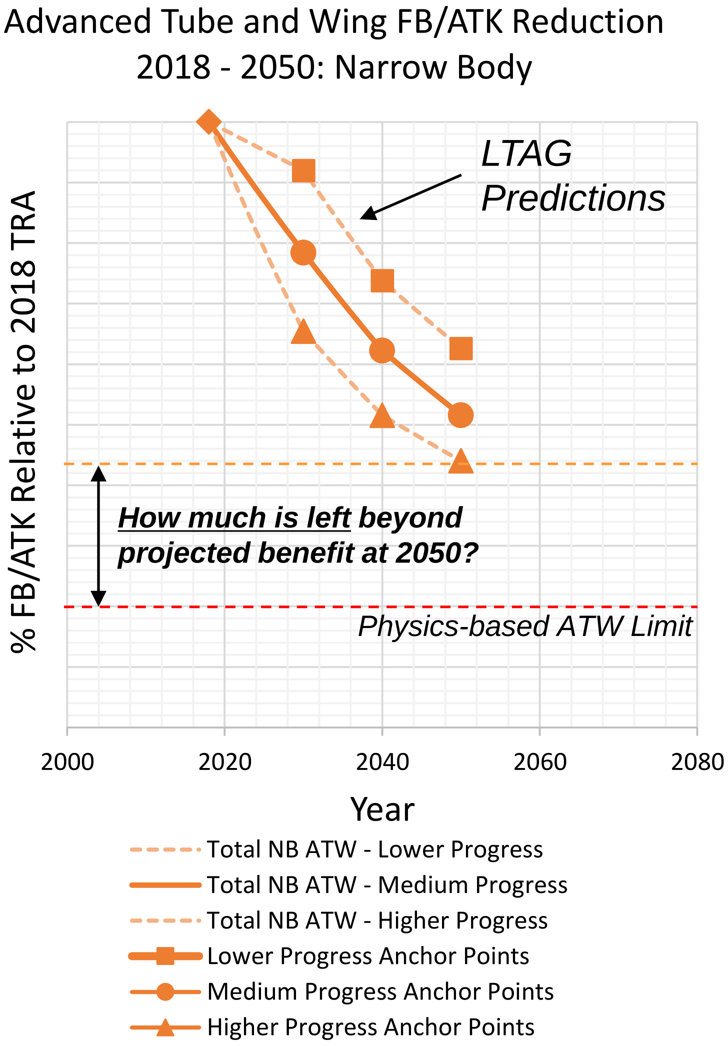
Objective:
Investigate the physics-based limitations of business as usual aircraft architectures.

Literature review of physics-based limits on aircraft performance

Literature review of physics-based limits on engine performance

Use of EDS to incorporate technologies and assumptions

End Goal
Understand the boundaries of the possible individual technologies which benefit aircraft efficiency



General Approach

- **Use case: Narrow body**
  - Use narrow body 2050 advanced T&W cases as a basis
- **Engine**:
  - Large core achievable component efficiencies
  - Small core impacts and practical achievable loss mitigation
  - Potential cycle enhancements (related to core size)
  - Fan stream losses
  - Materials/Weights (Cooling)
  - Inlets/nozzles
- **Aircraft**
  - Structures/materials
  - Aero
  - Systems (ECS, etc.)

Task 4:Exploring Physics-based Boundaries of the Possible : Core Components Literature Review

- Large core engine component efficiencies
  - Maximum practical polytropic efficiency of the fan and compressor as 95% [1,3,4]
  - Maximum polytropic efficiency of the turbine using cooling as 92% [3,4,5]
  - Predicted future operating CMC-based turbine temperature as 1200 C [6,7,8,9]
- LTAG and IEIR report [2] and literature predict a possibility of a maximum OPR of 60 for the narrow body class with small core technology advancements
- **Core Size:**
  - Losses due to fundamental Re scaling / boundary layers are inevitable
  - Other losses due to growth of tip clearances, etc.
  - Papers published recently on compressor core size impacts, ideal scaling of clearances, gives guidance on practical minimum core size loss as a function of core size[10]
  - Turbine size impacts needed
- The turbine stator and rotor is assumed to be made of CMC in order to decrease the required cooling
  - Predicted future operating CMC-based turbine temperature as 1200 C [6,7,8,9]

1. "Report on the Feasibility of a Long-Term Aspirational Goal Appendix M3 APPENDIX M3 LTAG-TG TECHNOLOGY SUB GROUP REPORT" [Online]. Available: https://www.icao.int/environmental-protection/LTAG/Documents/ICAO_LTAG_Report_AppendixM3.pdf
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10. S. Evans et al., "Clearance Sensitivity Mitigation in Small Core Compressors," Volume 10A: Turbomachinery — Axial Flow Fan and Compressor Aerodynamics, Jun. 2022.

Contact Details

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