

Emissions Research Activities

Presented To: REDAC E&E Subcommittee

By: S. Daniel Jacob & Ralph Iovinelli

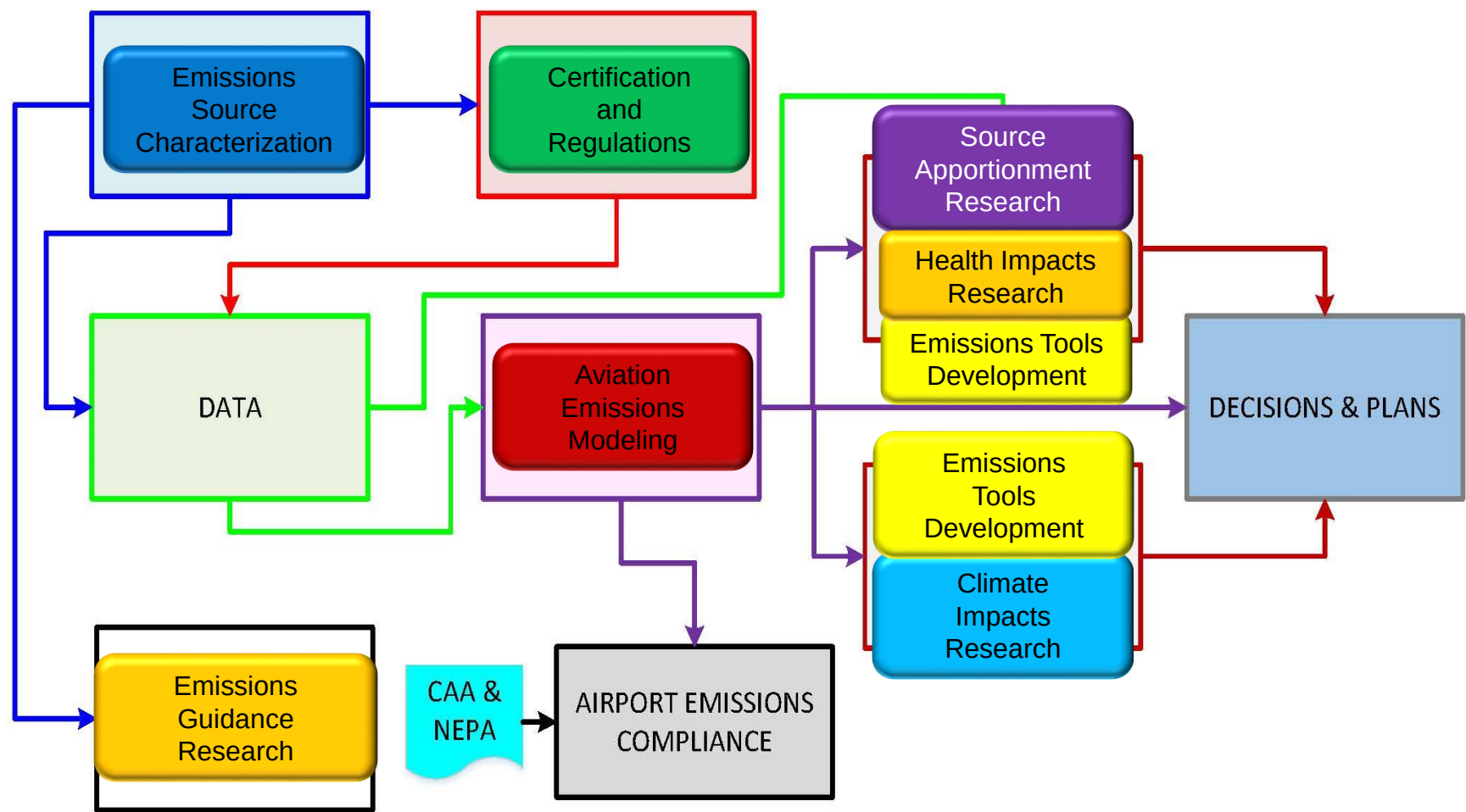
Date: 10 March 2021



**Federal Aviation
Administration**



Emissions Research Roadmap



EMISSIONS RESEACH ROADMAP ELEMENTS – CURRENT AND FUTURE				
EMISSIONS MEASUREMENT	Emissions Characterization, Corrections Development, Fuel Composition Effects, Emissions from Advanced Technology, Rig Tests, Engine Tests, Collaboration with CLEEN, NASA, Industry and International Partners			
VOLATILE PM MODELING	New methodology to model volatile particulate matter in the vicinity of airports			
NVPM MASS CALIBRATION	Maturing the charged particle mass analyzer (CPMA) methodology for in-line and in situ calibration of nvPM mass instruments			
AVIATION SPECIFIC DISPERSION MODEL	An Aviation specific dispersion model for demonstrating compliance to regulations			 
MONITORING AND SOURCE APPORTIONMENT	Comprehensive measurements in and around airports for source apportionment and validation updated or new compliance models.			 
IMPACTS OF HIGH ALTITUDE EMISSIONS	Impacts of various sources of emissions in the upper atmosphere including supersonic transport, high altitude long endurance UAVs, rocket emissions			
SUPERSONICS	Technology, Forecasts and Emissions in collaboration with Noise/ CLEEN Divisions			
CONTRAIL PHYSICS & MITIGATION	Improved understanding of contrail formation and real-time predictability of the radiative forcing of contrails as affected by technology, fuels and operations. Mitigation of Contrails through technology, fuels and operations (Avoidance)			
AVIATION CO ₂ TRENDS	Examine CO ₂ Emissions Trajectories for Domestic Aviation			
AAM LIFE CYCLE EMISSIONS	Lifecycle benefits/disbenefits of transporting people and goods via AAM			
LEGEND Source Apportionment Health Impacts Research Emissions Tools Development Emissions Source Characterization Climate Impacts Research Certification and Regulations Aviation Emissions Modeling Airport Emissions Compliance				

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LEGEND

Source Apportionment

Health Impacts Research

Emissions Tools Development

Emissions Source Characterization

Climate Impacts Research

Certification and Regulations

Aviation Emissions Modeling

Airport Emissions Compliance

Emissions Measurements

- Lack of Standard Day (i.e. Ambient Conditions) Corrections (CAEP)
- The role of Naphthalenes on nvPM Emissions (CAEP, Tools)
- Inform Cruise nvPM and NOx Emissions Modeling (CAEP, Tools)
- Collaboration: CLEEN Projects on nvPM Prediction Models (Tools)
- Collaboration: Emissions from Advanced Technology (NASA ASCR and Altitude Test – Technology, Tools, CAEP)
 - Advanced Rich Quench Lean
 - Lean Burn

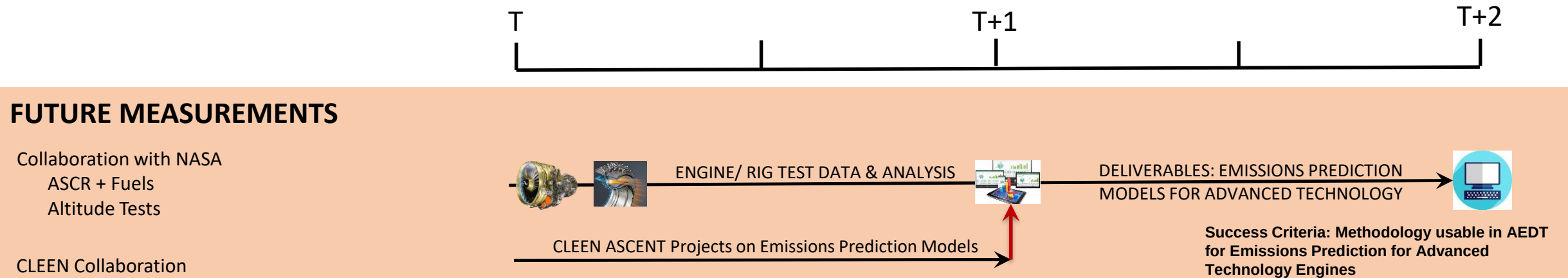
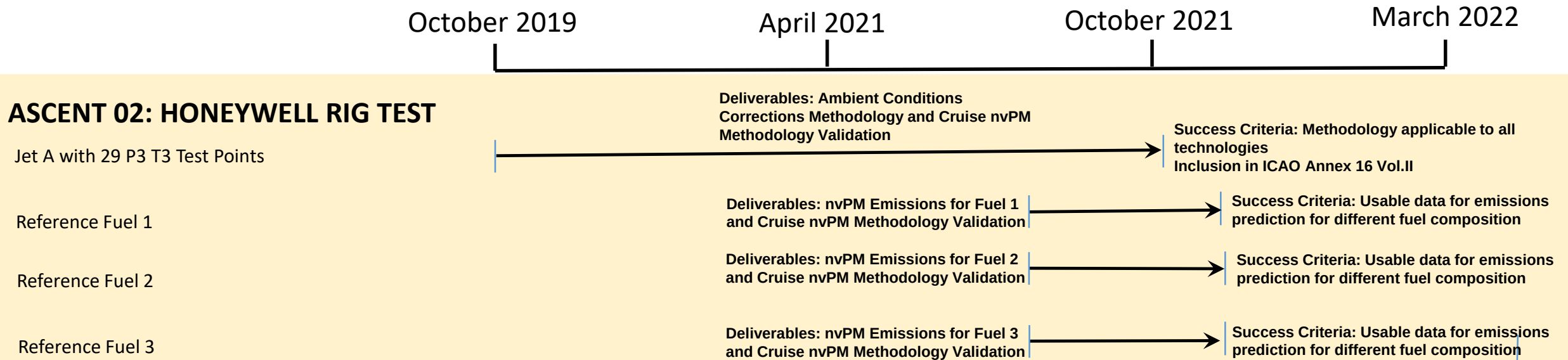
Emissions
Source
Characterization

Aviation
Emissions
Modeling

Certification
and
Regulations



Emissions Measurements



Possible Collaborators: NASA, EPA, Swiss FOCA, Transport Canada, EU/ EASA



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Emissions Measurements

Deliverables:

- Ambient Conditions Corrections Methodology and Cruise nvPM Methodology Validation
- nvPM Emissions for Different Fuel Specifications

Success Criteria:

- Methodology applicable to all technologies for inclusion in ICAO Annex 16 Vol. II
- A validated cruise nvPM Methodology
- Data for nvPM emissions prediction for different fuel compositions

Future Work:

- Additional work on Honeywell Rig Test not anticipated for ASCENT 02
- Research on Emissions Predictions for higher Overall Pressure Ratio engines needed



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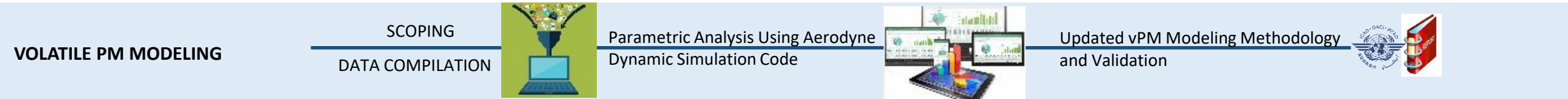
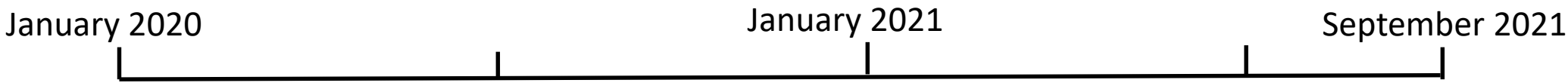
Certification and Regulations

Aviation Emissions Modeling

Airport Emissions Compliance

Microphysical Modeling of Volatile Particulate Matter (vPM) – CAEP, Tools

- The non-volatile modeling methodology that is part of the First Order Approximation 4.0 was updated during the CAEP/11 cycle. The vPM modeling methodology of FOA4 is based on a single dataset. More datasets are available now that can be used to develop a more representative vPM emissions from aircraft engines in the vicinity of airports



Possible Collaborators: NASA, EPA, EU/ EASA, Transport Canada

Available Datasets: APEX I, II and III, AAFEX I and II, ND-MAX/ ECLIF2 and future EU AVIATOR

Source Apportionment/ Health Impacts Research

Emissions Tools Development

Aviation Emissions Modeling

Microphysical Modeling of Volatile Particulate Matter (vPM)

Deliverables:

- Update to First Order Approximation 4 (FOA4) Volatile Modeling Methodology that can be included in ICAO Doc 9889 and implemented in AEDT and final reports documenting the methodology
- Contrail microphysics modeling and validation

Success Criteria:

- Demonstrated improvement over the current vPM prediction methodology
- Enhanced understanding of contrail microphysics in the near field.

Future Work:

- Methodology may need refinement as newer measurement datasets become available



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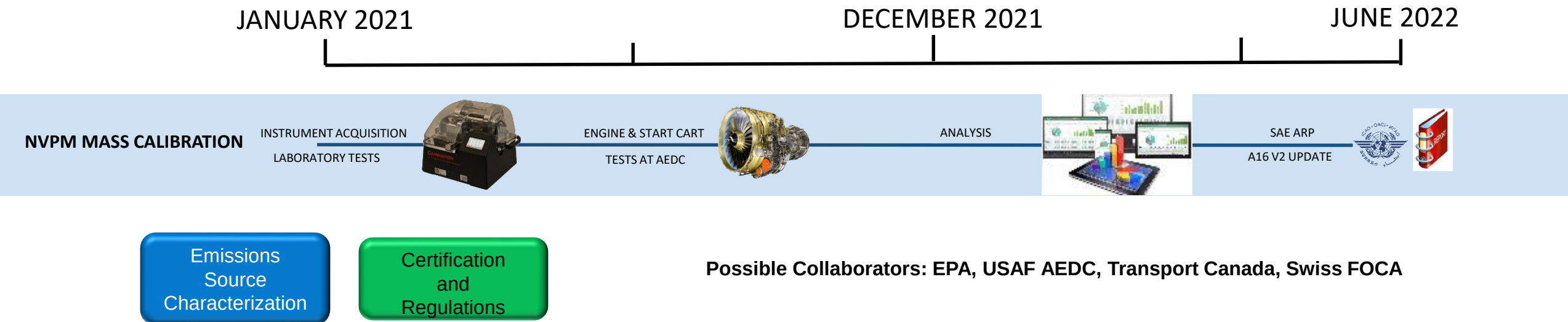
Certification and Regulations

Aviation Emissions Modeling

Airport Emissions Compliance

Transitioning a research nvPM Mass Calibration Methodology to Certification (ASCENT 69 – builds on ASCENT 02 results) - Certification

- Due to the lack of a standardized non-volatile Particulate Matter (nvPM) source, the measurement uncertainties of nvPM mass and number instruments are larger than the measurement uncertainties of gaseous instruments used in certification. The use of a Charged Particle Mass Analyzer (CPMA) has been shown to reduce uncertainties in calibration and measurement of nvPM mass in research setting. The objective of this task is to mature and transition this methodology for use in engine certification.



Transitioning a research nvPM Mass Calibration Methodology to Certification

Deliverables:

- Charged Particle Mass Analyzer (CPMA) based calibration methodology ready for inclusion in Annex 16 Vol.II and ARP 6320 and Final Reports

Success Criterion:

- CPMA in-line calibration for nvPM mass during certification and eliminate the need for filter based calibration methods

Future Work:

- None anticipated



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Aviation Emissions Modeling

Airport Emissions Compliance

Dispersion Model Development (A19) and Monitoring Study (A18) – Compliance and Local AQ

- ❑ **Challenge: EPA-mandated AEDT/AERMOD model produces artificial exceedances of 1-hour NO₂ National Ambient Air Quality Standard**
 - Delays National Environmental Policy Act (NEPA) review, which is a critical need for new or expansion of existing infrastructure projects
 - EPA's Model, AERMOD does not represent aircraft jet exhaust emissions accurately
- ❑ **Research Solution: Develop an aircraft-specific emissions dispersion model for compliance demonstration**
- ❑ **Conducting short and long-term monitoring around airports for modeled-monitoring comparison study and new model validation**
- ❑ **Expected Outcome – A more accurate aircraft-specific model to demonstrate airport air quality compliance that is acceptable to EPA.**
 - A new model reflecting the best science and algorithms
 - Improved source treatment; and physical and chemical processes in EPA's AERMOD for aircraft emissions
 - Improved source attributions from aircraft emissions
 - Better characterization of air quality impacts on communities surrounding airports through modeling and monitoring study

Source
Apportionment

Health Impacts
Research

Emissions
Tools
Development

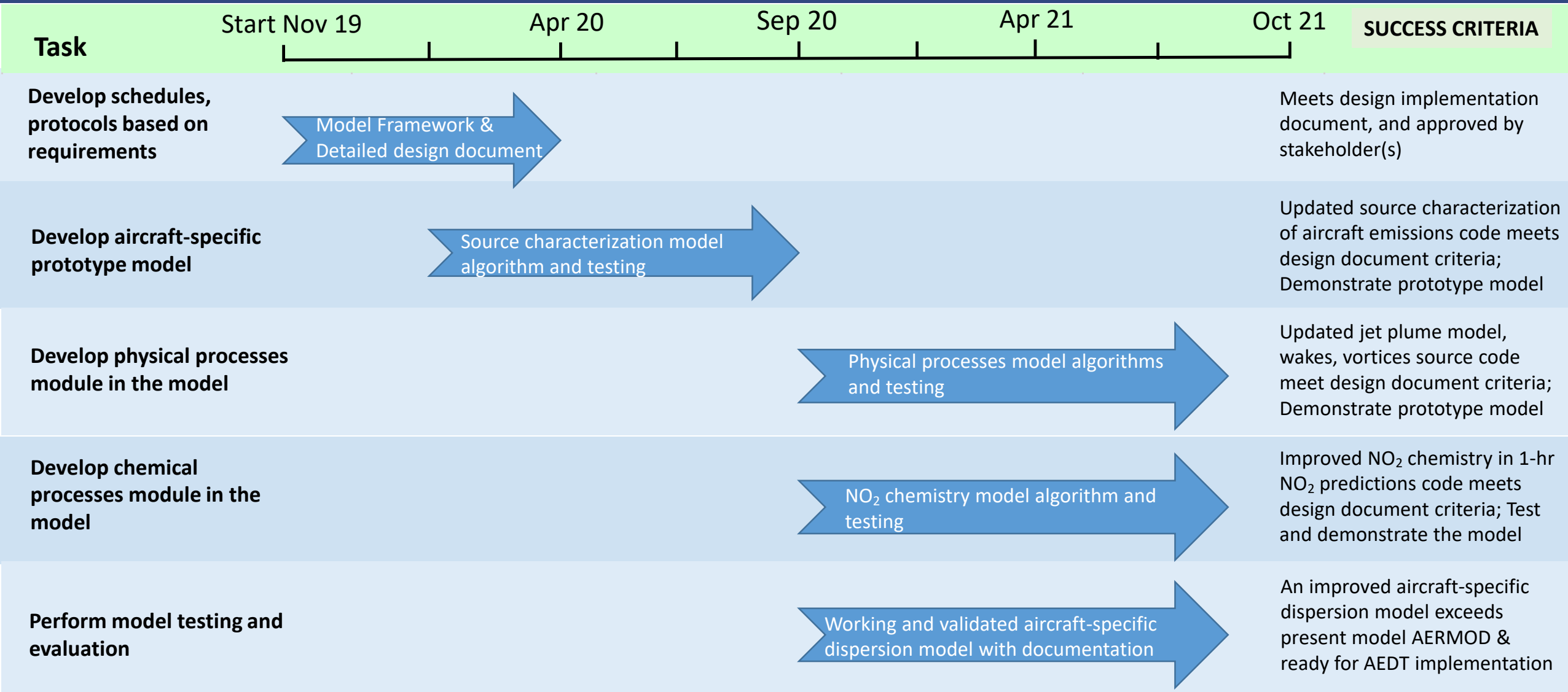


Federal Aviation
Administration

Aviation
Emissions
Modeling

AIRPORT
EMISSIONS
COMPLIANCE

Aviation Specific Dispersion Model Development



- Both dispersion models simulate lower NO_x concentrations than the monitored concentrations at four core monitors at LAX.
- For NO_x, aircraft NO_x emissions are **not** a dominant contributor to the total measured concentrations at four core monitor stations.
- Both models have simulated SO₂ dispersion
 - Aircraft SO₂ is a good tracer for model evaluation
 - Diagnostics to understand modeled exceedances late in the evenings and early mornings of SO₂ is in progress



Aviation Specific Dispersion Model Development

Deliverables:

- Improved aircraft-specific dispersion model with better source characterization
- Improved physical and chemical processes
- Fully tested new model that outperforms AERMOD and ready for AEDT implementation

Success Criteria:

- Updated source characterization of aircraft emissions code
- Updated jet plume model that takes into account wakes + vortices
- Improved NO₂ chemistry in 1-hr NO₂ predictions code meets design document criteria

Future Work:

- Airport monitoring campaigns data for model validation;
- An improved meteorological model and state-of-science algorithms; and
- Implementation of the model replacing present EPA's AERMOD in AEDT



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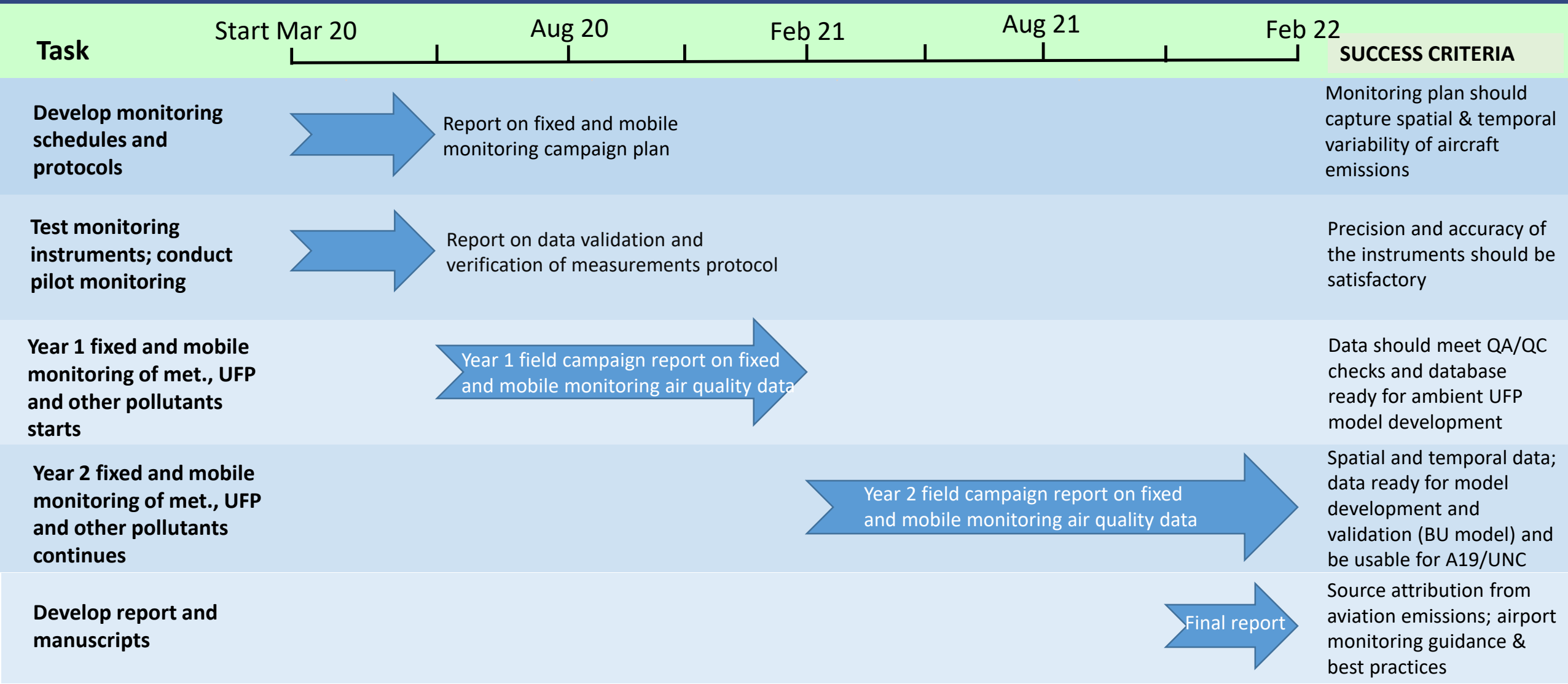
Climate Impacts Research

Certification and Regulations

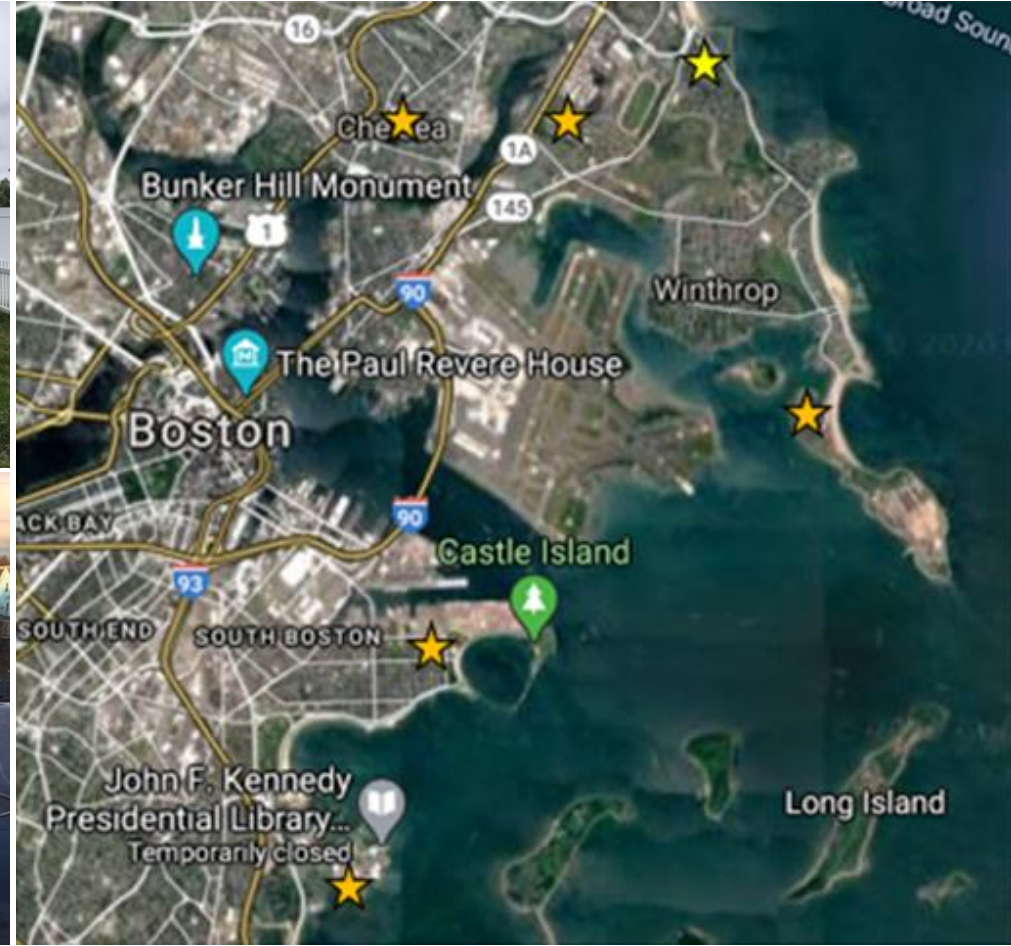
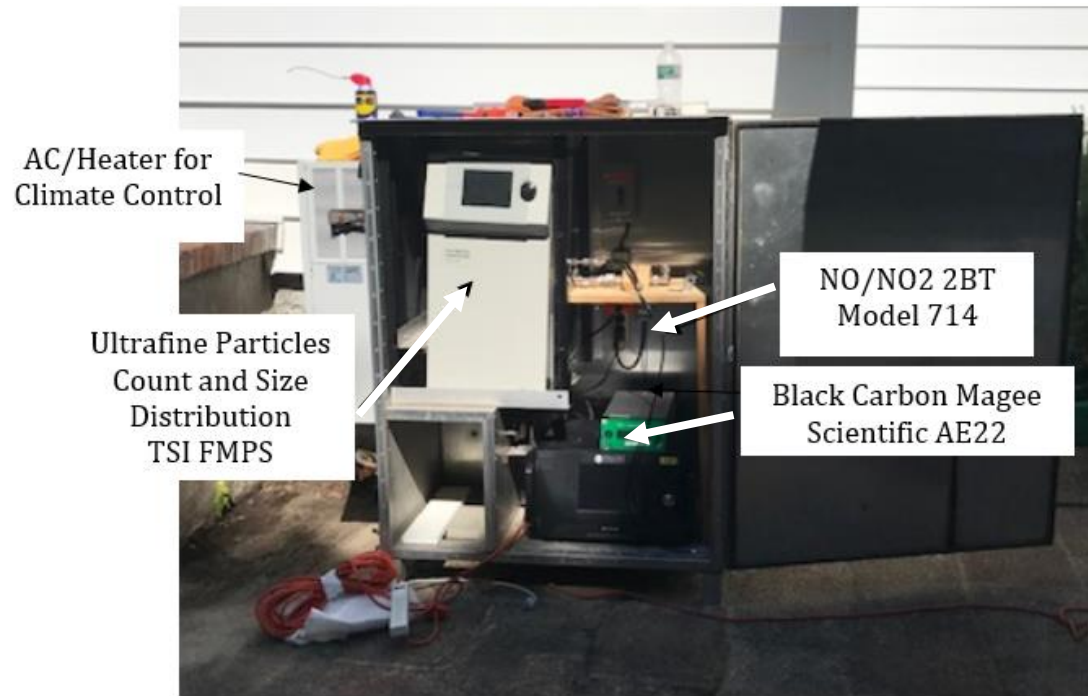
Aviation Emissions Modeling

Airport Emissions Compliance

Airport Monitoring

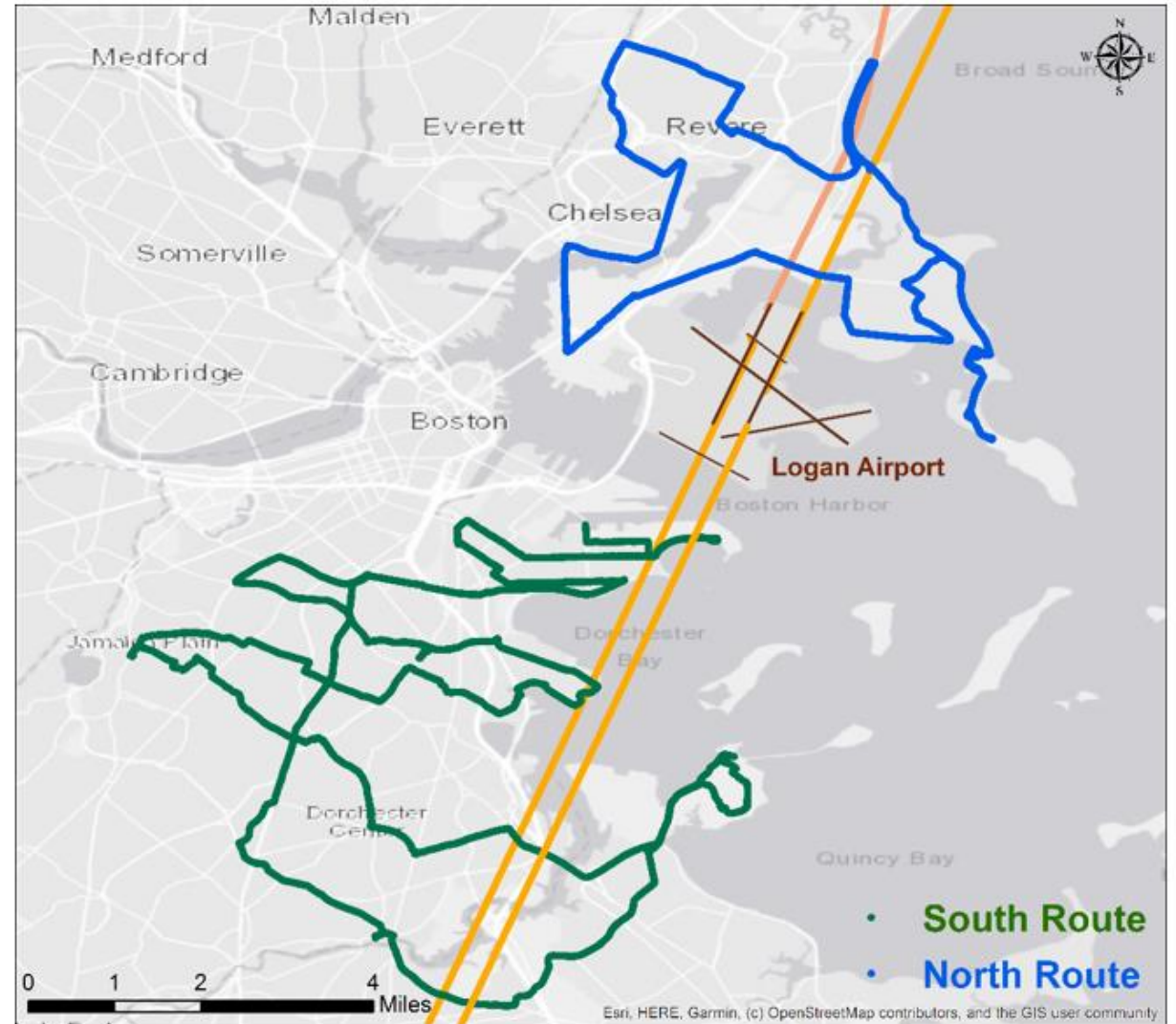
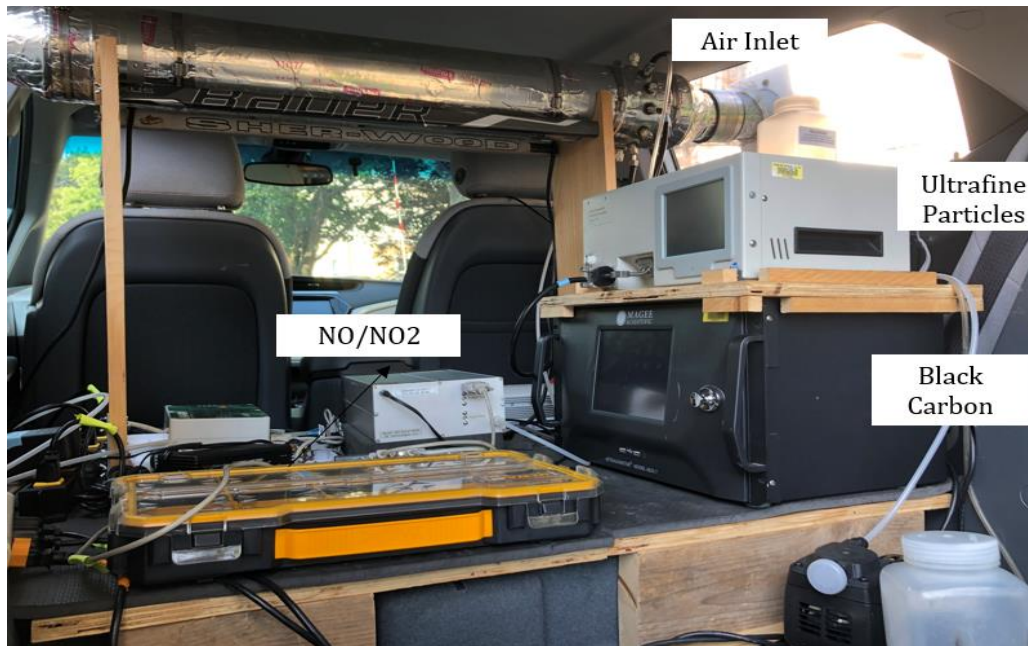


A18: Airport Monitoring: Stationary Platform



- Stations operational since April with some growing pains
- Data collected for 169 days of 2020 (100% in September and October)

A18: Airport Monitoring: Mobile Platform



Airport Monitoring

Deliverables:

- Demonstration of measurement concepts for long-term spatial and temporal UFP, BC and NO_x around BOS that can be extended to other airports
- Data for statistical and mathematical model development and validation purpose
- Data sharing protocol and platform with other ASCENT and non- ASCENT projects

Success Criteria:

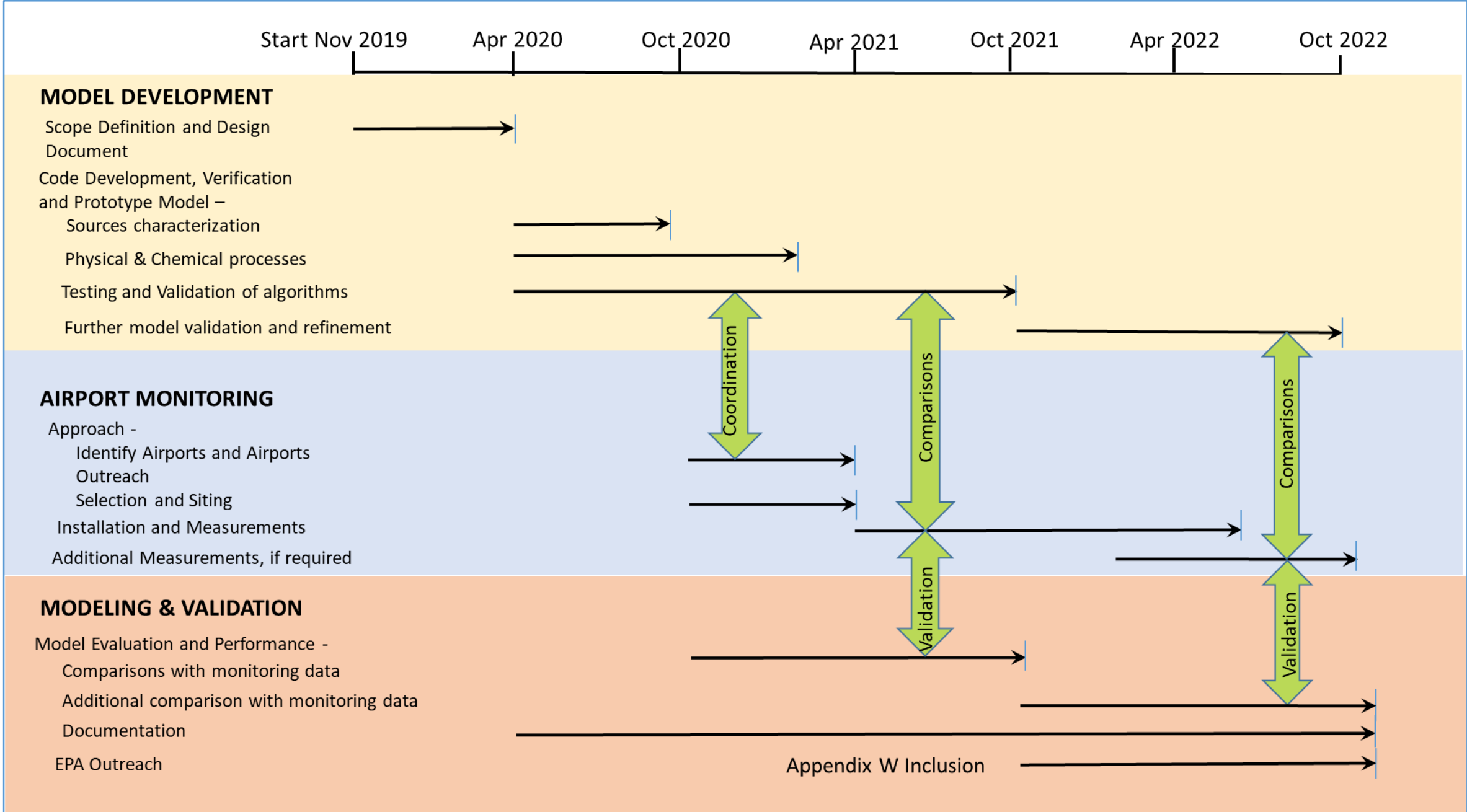
- Spatial and temporal data; data ready for model development and validation and for use by A19
- Source attribution from aviation emissions
- Airport monitoring guidance & best practices

Future Work:

- Additional airport monitoring campaigns for model validation (A19/UNC);
- Development of ambient UFP prediction model around airports;
- UFP and Health impact studies - Epidemiological model and field campaign; and
- Joint Emission and Noise study design and health studies



A19 & A18 Action Plan: Aviation-Specific Dispersion Model Development & Airport Monitoring Plan



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Supersonic Engine Emissions Research – Policy, CAEP, Tools, Impacts

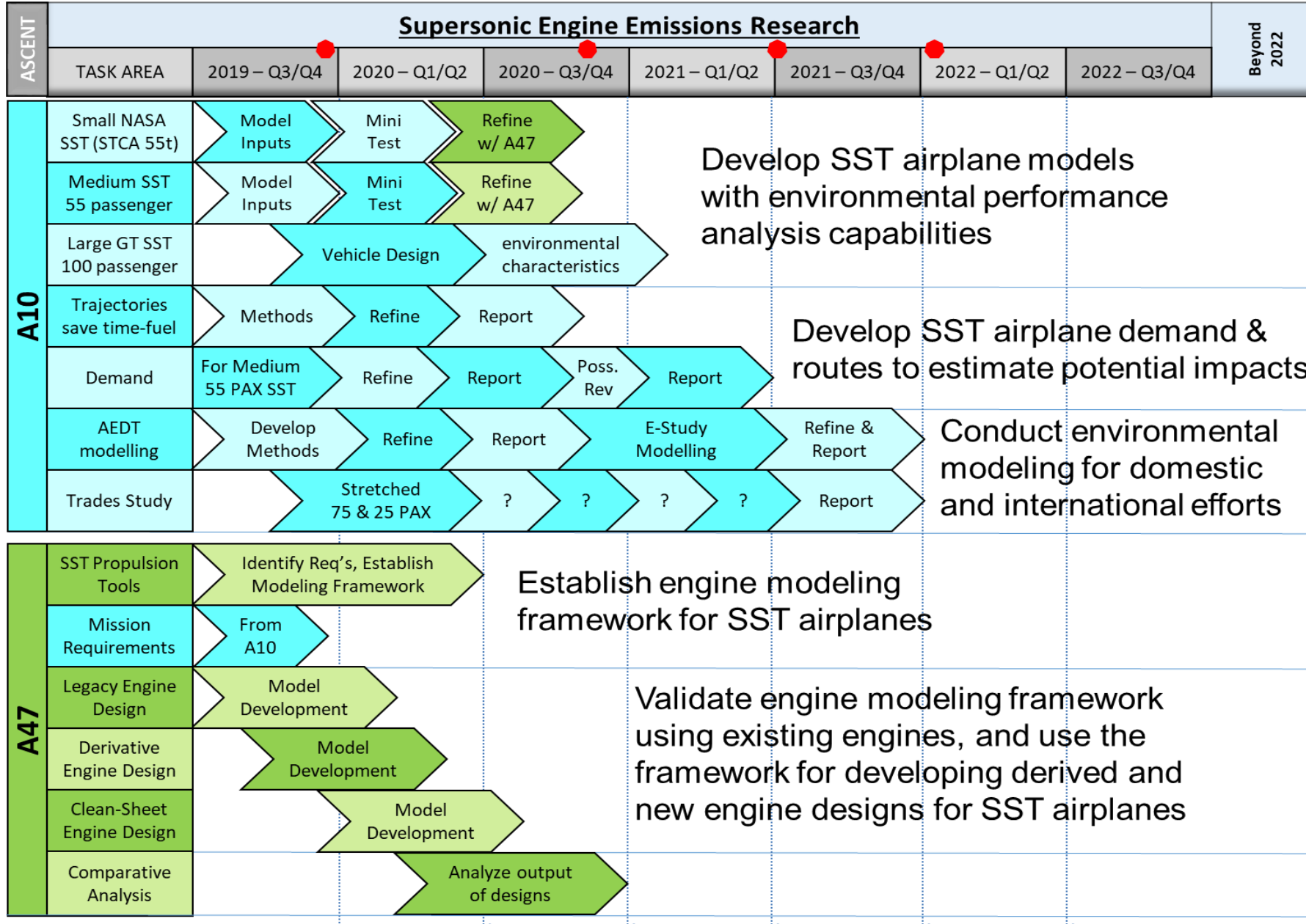
- With the proposed supersonic aircraft, development of:
 1. Airplane models with environmental performance capabilities; and
 2. Demand routes to estimate potential impacts are needed.
- Environmental modeling is needed for domestic and international efforts. ASCENT 10 addresses these needs not only for emissions but also for noise.
- Proposed engine designs for the new SST use existing cores. ASCENT 47 investigates the emissions benefits that may be realized if a clean sheet engine design is adopted from a modeling perspective.

Emissions
Tools
Development

Certification
and
Regulations

Aviation
Emissions
Modeling





Collaborator: NASA



Supersonic Engine Emissions Research

Deliverables:

- ASCENT 10: SST Modeling Tools and Demand Scenarios
- ASCENT 47: Emissions Impacts of clean sheet supersonic engine design
- ASCENT 74 (new): Emissions performance of a novel lean pre-mixed combustor for a SST engine

Success Criteria:

- Realistic aircraft and engine designs to estimate environmental impacts
- Forecast fleet comparing well with actual future fleet

Future Work:

- Inform future SST engine emissions standards
- Emissions predictions methodologies for full flight gaseous and particle emissions



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Improving Policy Analysis Tools to Evaluate Higher-Altitude Aircraft Operations – Tools, Policy, CAEP

- Commercial supersonic aircraft and high-altitude and long-endurance (HALE) unmanned aerial vehicles offer the potential to become enablers for new use cases and business models in the aviation sector.
- Combustion emissions of these vehicles will have atmospheric impacts which differ from conventional subsonic aviation due to the higher altitudes of emission. Emissions at higher altitudes are associated with a different chemical environment, longer emission lifetimes, and greater distances over which the emissions will be transported.
- The APMT-Impacts Climate and Air Quality tools need to be updated to capture the impact of such high altitude emissions.

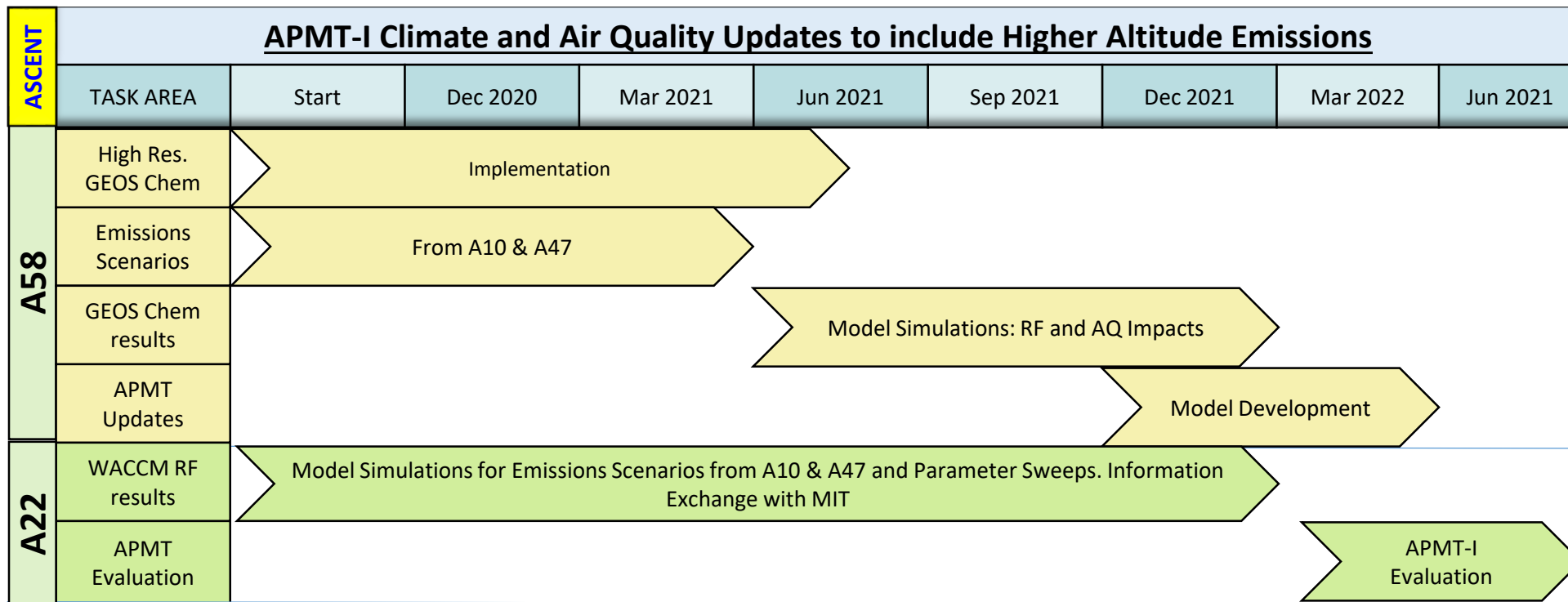
Health
Impacts
Research

Climate
Impacts
Research

Aviation
Emissions
Modeling

Emissions
Tools
Development





Collaborators: NASA



Improving Policy Analysis Tools to Evaluate Higher-Altitude Aircraft Operations

Deliverables:

- ASCENT 22 & 58: Radiative Forcing and Climate Impacts for high altitude Emissions Scenarios for APMT Implementation
- ASCENT 58: Air Quality Impacts Tool for High Altitude Emissions
- ASCENT 58: Climate Impacts Tool for High Altitude Emissions
- ASCENT 22: Evaluation of APMT-I Climate and Air Quality Tools

Success Criterion:

- APMT-I Climate and Air Quality Tools that can be used in operational Costs Benefits Analyses to include high altitude emissions

Future Work:

- Tools update and evaluation based on latest scientific knowledge



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A78: Contrail Avoidance Decision Support and Evaluation (MIT – NEW)

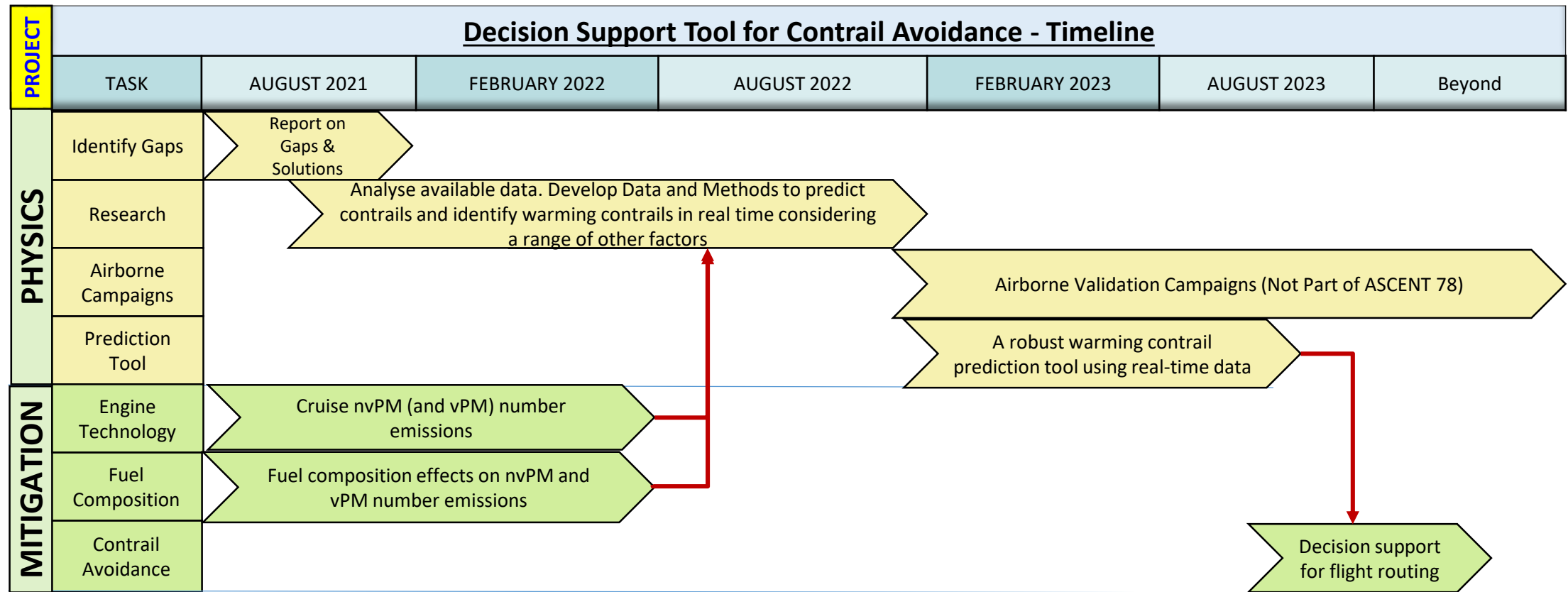
- **Understanding:** Aircraft Exhaust Contrails (Aviation Induced Cloudiness – AIC) are the most important aviation transient effects that impact climate. Contrails and induced-cirrus clouds have global mean climate impact that is of the same order as CO₂.
- **Challenge:** The effects are highly variable in space and time. It is important to be able to predict if a contrail is a warming contrail or a cooling contrail.
- **Research:** Investigate science and data gaps, develop methods to predict contrails at various spatial and temporal scale. More importantly, develop the capability to identify formation of warming contrails in real-time, along with changes in fuel burn, that will also consider engine technologies and fuel composition. Use existing datasets (e.g., ND-MAX/ ECLIF)
- **Mitigation:** Develop approaches that mitigate formation of warming contrails, through technology, fuel composition and/or operations while accounting for tradeoffs in terms of fuel burn and overall climate impact of all aviation emissions.
- **Expected Outcome:** Identify approaches and decision support tools that could be used by industry to cost effectively mitigate the overall climate impacts of aviation via contrail mitigation.

Climate
Impacts
Research

Emissions
Tools
Development



Federal Aviation
Administration



Mitigation of AIC Climate Impacts

Deliverables:

- Identification of data and science gaps and development of approaches to address gaps to predict real-time contrail formation at flight by flight resolution and impacts of potential mitigation actions to identify effective mitigation solutions – Resulting Action: Research to Address Gaps
- Development of tools to predict warming contrails and changes in fuel use using operations, technology, and fuel composition to assess the practicability of avoiding warming contrail formation. Validate using existing and future airborne data
- Real time tool with appropriate data stream that can predict formation of warming contrails
- Evaluation of optimal flight routing to minimize climate impacts of aviation

Success Criteria:

- Real time predictability of warming contrails
- Decision support tools that could be used by airlines to inform flight routing. Needs to determine means of warming contrail avoidance, increased fuel burn, and other climate impacts in real time

Future Work:

- Implement an integrated research program that would identify approaches that could be used by industry to cost effectively mitigate the overall climate impacts of aviation via contrail mitigation

EMISSIONS RESEACH ROADMAP ELEMENTS – CURRENT AND FUTURE					LEGEND Source Apportionment Health Impacts Research Emissions Tools Development Emissions Source Characterization Climate Impacts Research Certification and Regulations Aviation Emissions Modeling Airport Emissions Compliance
EMISSIONS MEASUREMENT	Emissions Characterization, Corrections Development, Fuel Composition Effects, Emissions from Advanced Technology, Rig Tests, Engine Tests, Collaboration with CLEEN, NASA, Industry and International Partners				
VOLATILE PM MODELING	New methodology to model volatile particulate matter in the vicinity of airports				
NVPM MASS CALIBRATION	Maturing the charged particle mass analyzer (CPMA) methodology for in-line and in situ calibration of nvPM mass instruments				
AVIATION SPECIFIC DISPERSION MODEL	An Aviation specific dispersion model for demonstrating compliance to regulations				
MONITORING AND SOURCE APPORTIONMENT	Comprehensive measurements in and around airports for source apportionment and validation updated or new compliance models.				
IMPACTS OF HIGH ALTITUDE EMISSIONS	Impacts of various sources of emissions in the upper atmosphere including supersonic transport, high altitude long endurance UAVs, rocket emissions				
SUPERSONICS	Technology, Forecasts and Emissions in collaboration with Noise/ CLEEN Divisions				
CONTRAIL PHYSICS & MITIGATION	Improved understanding of contrail formation and real-time predictability of the radiative forcing of contrails as affected by technology, fuels and operations. Mitigation of Contrails through technology, fuels and operations (Avoidance)				
AVIATION CO ₂ TRENDS	Examine CO ₂ Emissions Trajectories for Domestic Aviation				
AAM LIFE CYCLE EMISSIONS	Lifecycle benefits/disbenefits of transporting people and goods via AAM				

CO₂ Trajectory for Domestic Aviation – Blue Skies - NEW

This project will assess future domestic CO₂ emissions trajectories under different scenarios of aviation growth and technology introduction. The analysis is leveraging work that is ongoing by the ICAO CAEP Long Term Aspiration Goal-Task Group and will provide domestic data to complement it.

Key Deliverables:

- Evaluate future domestic aviation CO₂ emission trajectories
- Determine impact of new technologies, operational improvements, and SAF usage on domestic emissions trajectory
- Provide data to support decision-making on research investments

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					LEGEND Source Apportionment Health Impacts Research Emissions Tools Development Emissions Source Characterization Climate Impacts Research Certification and Regulations Aviation Emissions Modeling Airport Emissions Compliance	

This project will assess the lifecycle emissions impacts of Advanced Air Mobility (AAM) and drones. Recently, these vehicles have been projected to be a cleaner form of transport for people and goods. Using a combination of life cycle data and models, this project will investigate trades with other forms of transportation to understand relative benefits.

Key Deliverables:

- Lifecycle benefits/disbenefits of transporting people and goods via AAM and drones.
- Interdependencies and impacts to air quality and climate.



- **Comprehensive Emissions Research Portfolio**
- **Research needs based on:**
 - Characterizing emissions of current and future engine technologies and fuels
 - Impacts reduction
 - Tools development
 - CAEP / domestic policy needs
- **Establishing internal and external collaborations**
- **Successful outreach through Annual AEC Roadmap Meeting**