Emissions Research Activities

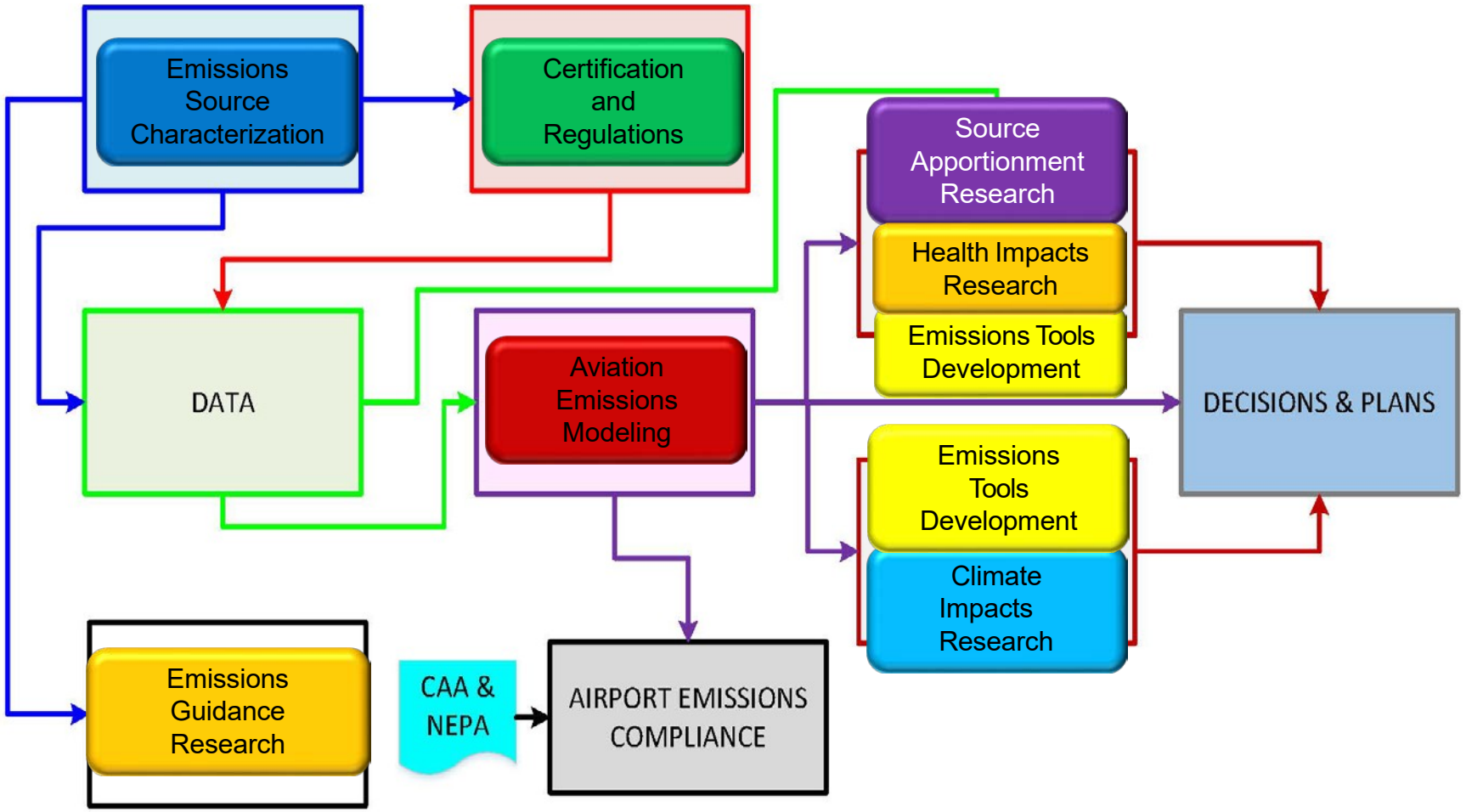
Presented To: REDAC E&E Subcommittee

By: S. Daniel Jacob & Ralph Iovinelli

Date: 16 September 2020

Federal Aviation Administration

Emissions Research Roadmap



Outreach: Aviation Emissions Characterization (AEC) Annual Meeting

Purpose:

- Communicate research findings and coordinate research among stakeholders (Domestic and International Government Agencies, Airports, Industry, Non-Governmental Organizations, etc.) interested in aviation emissions and their impacts.

Background and Activities:

- Started as National Particulate Matter Roadmap for Aviation
- 17th Annual Meeting held in 2020
- Primary forum: Annual Meeting
- Monthly Teleconferences with Coordinating Council
  - Share information on selected topics
  - Identify topics for in depth discussion for the Annual Meeting
- **18th Annual (virtual) Meeting Scheduled: May 25-27, 2021**

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
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.
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
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)

LEGEND

- Source Apportionment
- Health Impacts Research
- Emissions Tools Development
- Emissions Source Characterization
- Climate Impacts Research
- Certification and Regulations
- AIRPORT EMISSIONS COMPLIANCE

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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 Measurements

October 2019 — April 2021 — October 2021 — March 2022

ASCENT 02: HONEYWELL RIG TEST

Jet A with 29 P3 T3 Test Points

Deliverables: Ambient Conditions Corrections Methodology and Cruise nvPM Methodology Validation → **Success Criteria: Methodology applicable to all technologies Inclusion in ICAO Annex 16 Vol.II**

Reference Fuel 1

Deliverables: nvPM Emissions for Fuel 1 and Cruise nvPM Methodology Validation → **Success Criteria: Usable data for emissions prediction for different fuel composition**

Reference Fuel 2

Deliverables: nvPM Emissions for Fuel 2 and Cruise nvPM Methodology Validation → **Success Criteria: Usable data for emissions prediction for different fuel composition**

Reference Fuel 3

Deliverables: nvPM Emissions for Fuel 3 and Cruise nvPM Methodology Validation → **Success Criteria: Usable data for emissions prediction for different fuel composition**

T — T+1 — T+2

FUTURE MEASUREMENTS

Collaboration with NASA
- ASCR + Fuels
- Altitude Tests

CLEEN Collaboration

ENGINE/ RIG TEST DATA & ANALYSIS

DELIVERABLES: EMISSIONS PREDICTION MODELS FOR ADVANCED TECHNOLOGY

CLEEN ASCENT Projects on Emissions Prediction Models

Success Criteria: Methodology usable in AEDT for Emissions Prediction for Advanced Technology Engines

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

Emissions Measurements

Deliverables:

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

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

- **Challenge: EPA-mandated AEDT/AERMOD model produces artificial exceedances of 1-hour NO_2 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

Aviation Specific Dispersion Model Development

Task	Start Nov 19 – Apr 20	Apr 20 – Sep 20	Sep 20 – Apr 21	Apr 21 – Oct 21	SUCCESS CRITERIA
Develop schedules, protocols based on requirements	Model Framework & Detailed design document				Meets design implementation document, and approved by stakeholder(s)
Develop aircraft-specific prototype model		Source characterization model algorithm and testing			Updated source characterization of aircraft emissions code meets design document criteria; Demonstrate prototype model
Develop physical processes module in the model			Physical processes model algorithms and testing		Updated jet plume model, wakes, vortices source code meet design document criteria; Demonstrate prototype model
Develop chemical processes module in the model			NO2 chemistry model algorithm and testing		Improved NO_2 chemistry in 1-hr NO_2 predictions code meets design document criteria; Test and demonstrate the model
Perform model testing and evaluation			Working and validated aircraft-specific dispersion model with documentation		An improved aircraft-specific dispersion model exceeds present model AERMOD & ready for AEDT implementation

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 NO_2 chemistry in 1-hr NO_2 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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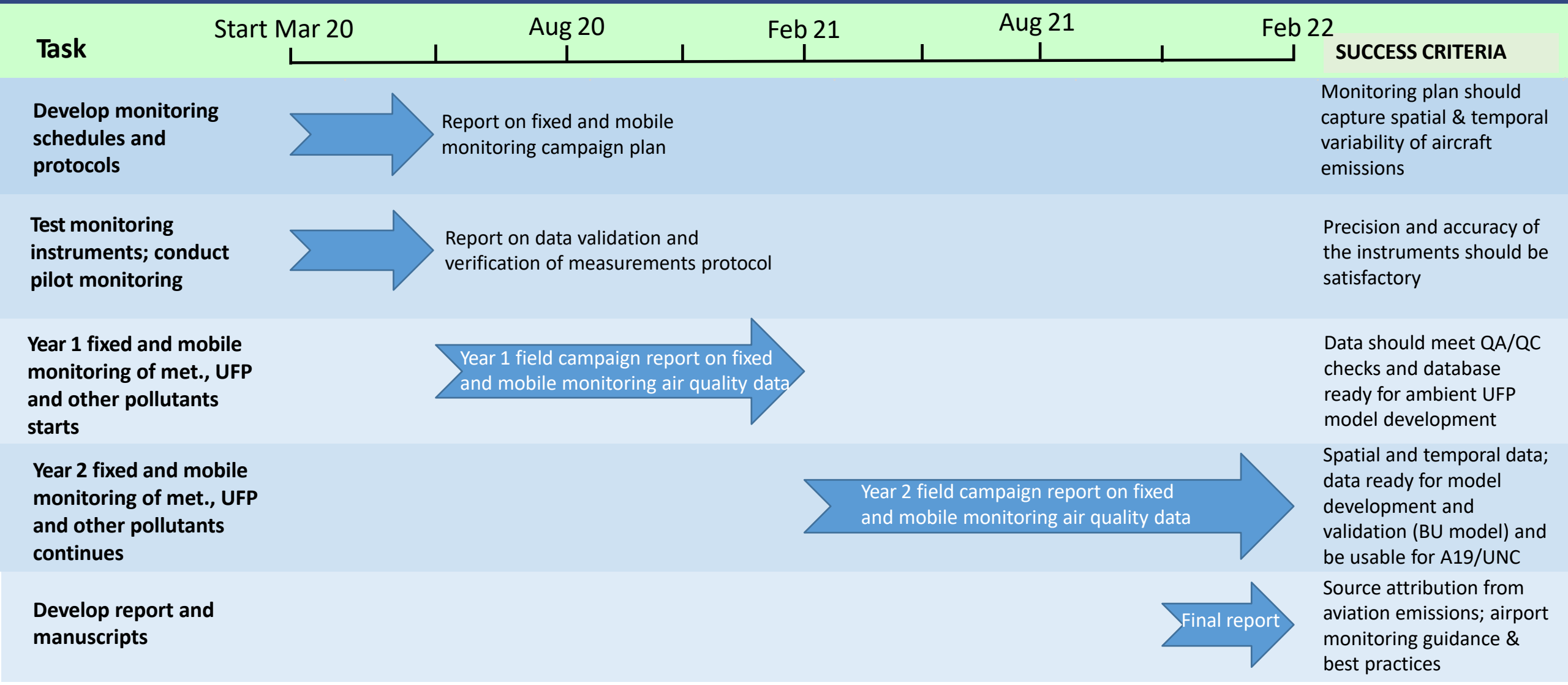
Airport Monitoring



Airport Monitoring

Deliverables:

- Demonstration of measurement concepts for long-term spatial and temporal UFP, BC and NOx 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

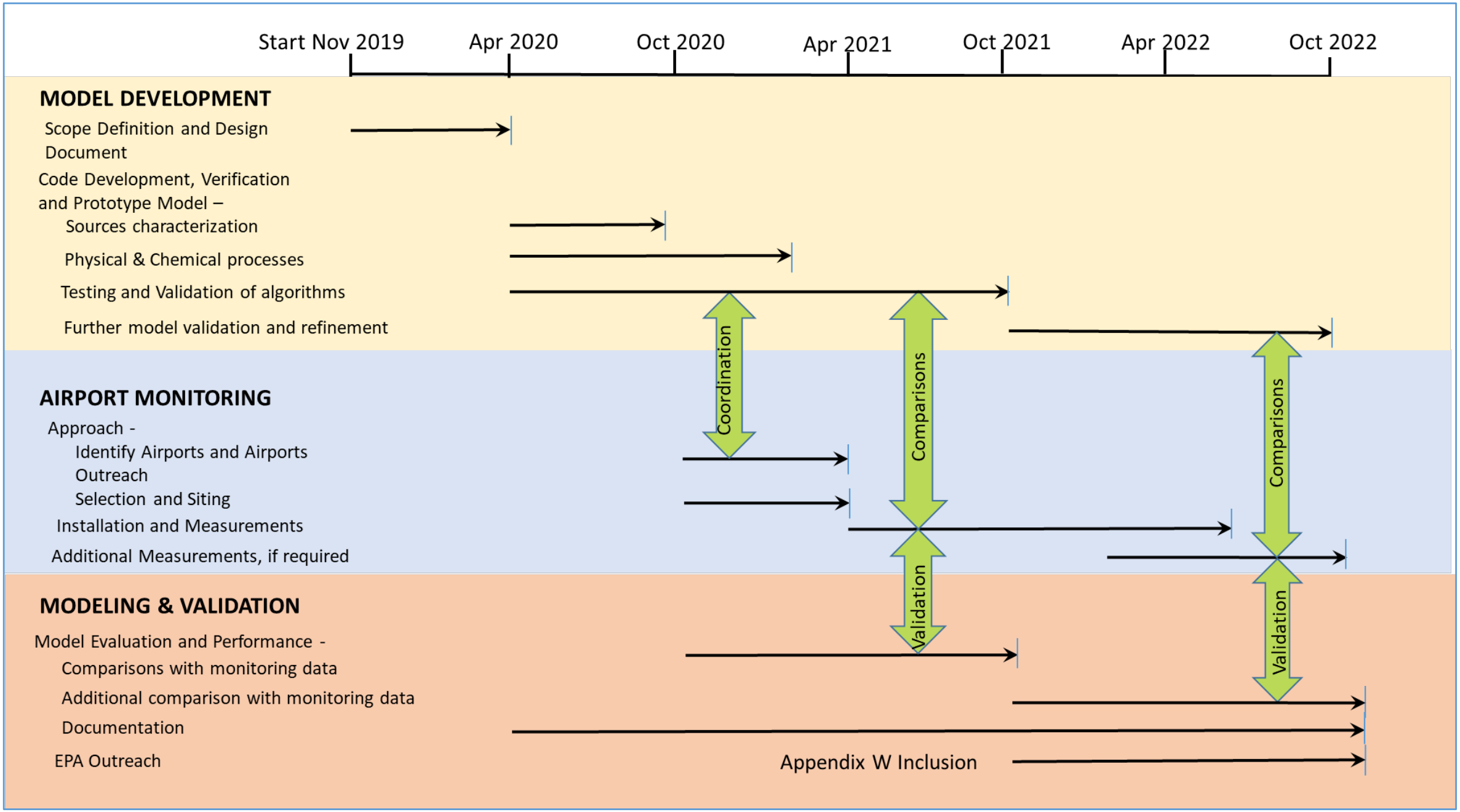
Success Criteria:

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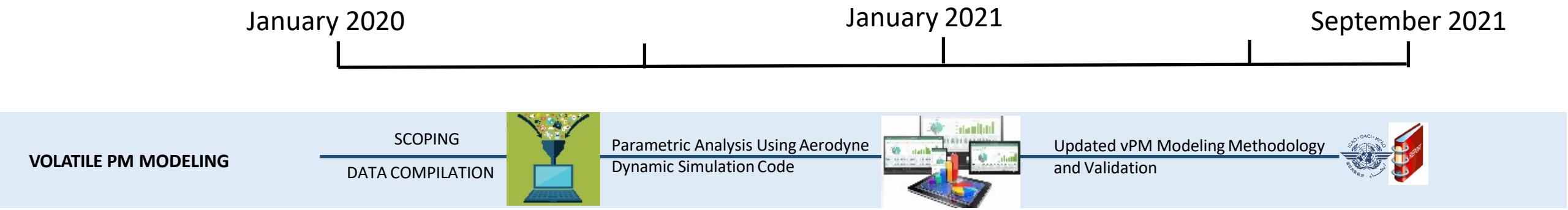
Microphysical Modeling of Volatile Particulate Matter (vPM) – CAEP, Tools

- 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



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

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

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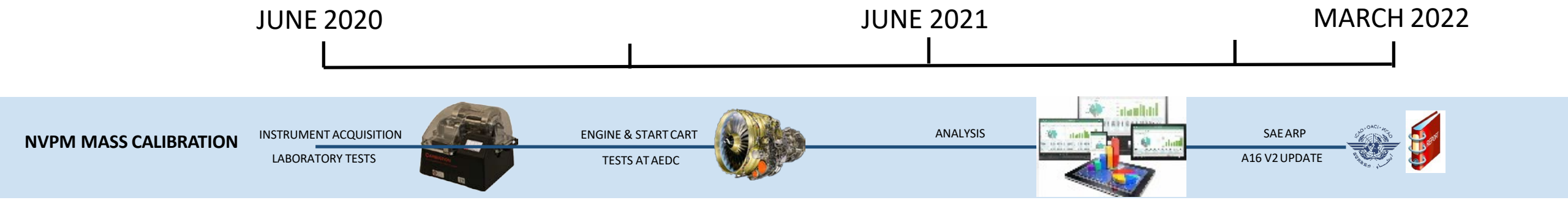
Transitioning a research nvPM Mass Calibration Methodology to Certification (ASCENT 69 – builds on ASCENT 02 results) - Certification

- 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.



Emissions Source Characterization

Certification and Regulations

Possible Collaborators: EPA, USAF AEDC, Transport Canada, Swiss FOCA

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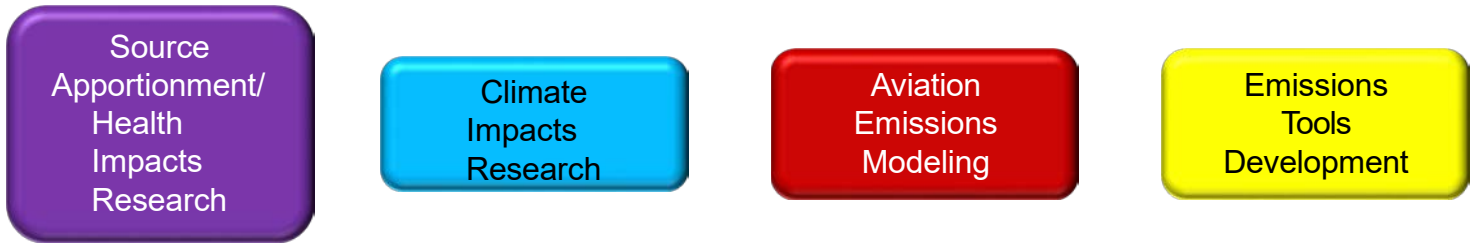
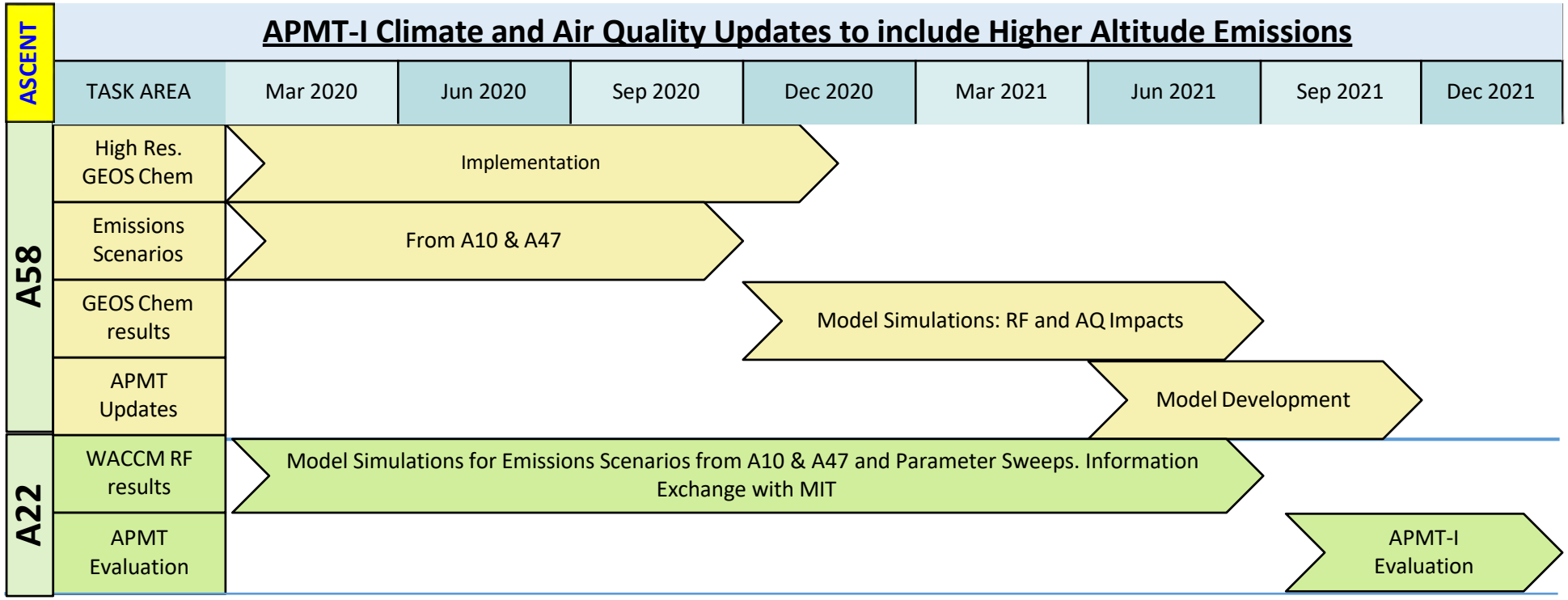
Improving Policy Analysis Tools to Evaluate Higher-Altitude Aircraft Operations – Tools, Policy, CAEP

- 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.





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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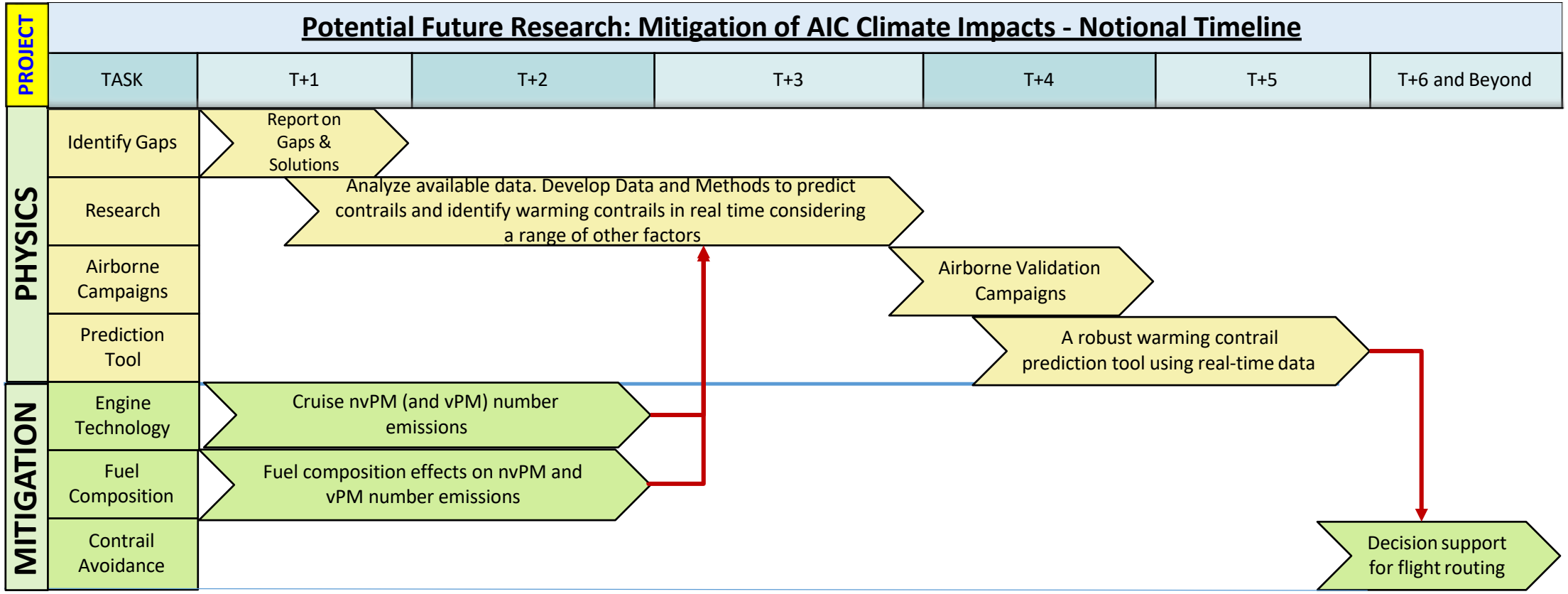
Contrail Physics and Mitigation (Tools, Impacts)

- **Understanding:** Aircraft Exhaust Contrails are the most important aviation transient effects that impact climate. The magnitude of contrails and induced-cirrus clouds global mean impact on climate is of the same order as CO_2.
- **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 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


Potential Future Research: Mitigation of AIC Climate Impacts - Notional Timeline
PROJECT
TASK
T+1
T+2
T+3
T+4
T+5
T+6 and Beyond
PHYSICS
MITIGATION
Identify Gaps
Report on Gaps & Solutions
Research
Analyze available data. Develop Data and Methods to predict contrails and identify warming contrails in real time considering a range of other factors
Airborne Campaigns
Airborne Validation Campaigns
Prediction Tool
A robust warming contrail prediction tool using real-time data
Engine Technology
Cruise nvPM (and vPM) number emissions
Fuel Composition
Fuel composition effects on nvPM and vPM number emissions
Contrail Avoidance
Decision support for flight routing

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 to inform airline flight routing that includes 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

Summary

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

Discussion

- **Are there R&D areas within the Emissions Research Plan that should be lower / higher priority?**
- **Are there emission research areas that AEE is not examining that should be added?**
- **What do you see coming on the horizon regarding aviation emissions that may require future R&D efforts?**

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